
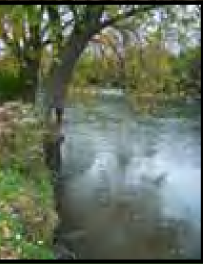

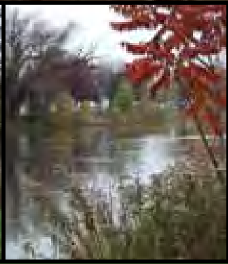

Contract Report 2010-05

Modeling Effects of FMWRD Discharges During Storm Events on Fox River Water Quality

Alena Bartosova, William Gillespie, Jory Hecht, Michal Ondrejcek

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by
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Report presented to the
Fox Metro Water Reclamation District

July 2010

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Abstract

This report summarizes the development of a water quality model for an eight-mile reach of the Fox River in Aurora, Illinois, and evaluates water quality impacts of the Fox Metro Water Reclamation District (FMWRD) discharges during storm events in the Fox River. A part of the FMWRD service area collects both wastewater and stormwater in combined sewers. A portion of the increased volume associated with rain events is released to receiving waters through combined sewer overflows (CSOs). The FMWRD owns and operates one CSO by the treatment plant; remaining CSOs in the area are owned by the City of Aurora. This project focuses on quantifying water quality impacts of modifications planned at the FMWRD facilities on the Fox River to aid in development of the FMWRD CSO long-term control plan (LTCP).

The water quality impact was evaluated from two different perspectives. First, a change in Fox River water quality from existing to proposed conditions was assessed. Second, compliance with water quality standards was evaluated for constituents with applicable ambient water quality standards (fecal coliform bacteria and ammonia nitrogen) or a value used by the Illinois Environmental Protection Agency (IEPA) to list a constituent as a potential cause of impairment (total suspended solids, nitrate nitrogen, and total phosphorus). The proposed changes at the FMWRD include a) full treatment expansion increasing the capacity of the plant; b) enhanced phosphorus removal at both new and existing full treatment facilities; and c) a new chemically enhanced primary treatment (CEPT) facility used only during larger storms when inflow exceeds the plant capacity. The CEPT capacity is designed to capture 5-year design storms, i.e., only storms larger than a 5-year storm would result in an overflow of untreated water. This study evaluates impacts that these proposed modifications have on Fox River water quality during storm inflows, focusing on the effect of the FMWRD CSO.

A computer model was developed to simulate the fate of nitrogen, phosphorus, suspended solids, and fecal coliforms in the Fox River reach from Sullivan Road Bridge in Aurora to Route 34 Bridge in Oswego using WASP software. The model was calibrated for two storm events (July and August 2008) and verified for two different storm events (September 2008 and August 2009). In addition, the calibrated model was set to simulate the full period between May and October 2008 to validate the model coefficients and any long-term trends that would not be detectable during the short-event simulations. The impact of the FMWRD discharges on biochemical oxygen demand and dissolved oxygen was estimated from discharged loads.

Monitoring data collected by Walter E. Deuchler Associates, Inc. (WEDA) during 2008 and 2009 were used to calibrate the model. It is difficult to collect monitoring data during the exact time period when a discharge from CSOs upstream passes through a monitoring location, especially when the time of CSO discharge is not known until after the monitoring is completed. Unfortunately, most monitoring data were collected before or after the peak concentration associated with CSO discharges passed through monitoring locations, catching the receding part of the pollutograph at best. Peak concentrations simulated by the model are thus unverified by field observations. The intensive sampling effort in August 2009 provided the best data, describing the rising portion of the pollutograph, although only for selected constituents. The model matched observed data during the calibration and validation periods adequately, considering the difficulties with data collection and interpretation.

The calibrated model was then set to simulate impacts from the FMWRD discharges under existing and proposed conditions. The impact of three design storms (1-year, 5-year, and 10-year) was evaluated for all constituents. The impacts on ammonia nitrogen, total phosphorus,

and dissolved oxygen were also evaluated for the more common 3-month storm. The impact of the "no action" condition (expected future inflows treated at existing FMWRD facilities) on ammonia and dissolved oxygen was evaluated for the 5-year storm.

Four scenarios were simulated for each design storm and for each FMWRD condition, existing or proposed, to evaluate a range of possible impacts as they change with the changing Fox River flow and water quality. Two selected flows represent a low flow (exceeded on 75% of days) and a median flow (exceeded on 50% of days). Two selected concentrations for each simulated constituent represent a low concentration (exceeded in 75% of samples) and a high concentration (exceeded in 25% of samples). High flow in the Fox River was not simulated at this time as the impact of FMWRD discharges on Fox River water quality is expected to diminish with increased Fox River flow.

For all constituents, maximum simulated concentrations under proposed conditions are lower than maximum simulated concentrations under existing conditions. Model simulations indicate the proposed FMWRD discharges under the normal treatment level a) do not cause an exceedance of the water quality standard for fecal coliforms for 5-year and smaller storms; b) would likely not cause exceedances of ammonia water quality standards unless pH and temperature reach high values or upstream ammonia concentrations are high; c) would likely cause exceedance of the total phosphorus listing value when no chemical treatment is applied to CEPT and large storms occur during low flows and high phosphorus concentrations in the Fox River upstream of the FMWRD; and d) would not cause exceedances of the total suspended solids and nitrate nitrogen listing values.

The goal of the CSO Control Policy is to limit the number of overflows to four to six per year. The FMWRD is providing full biological treatment for all storms of a corresponding return period (3 months) and a partial treatment, including full disinfection for all storms with a return period between 3 months and 5 years. Proposed modifications will result in a far greater positive effect on Fox River water quality than the minimum required by the CSO Control Policy.

Acknowledgements

The study was funded by the Fox Metro Water Reclamation District. The authors would like to express thanks to the staff of Walter E. Deuchler Associates, including Carrie Carter, Ryan Cramer, John Frerich, Mark Halm, Philippe Moreau, and Dan Stein, and staff of the Fox Metro Water Reclamation District, Randy Hummer and Tom Muth. The authors would also like to recognize the contribution of the City of Aurora staff, including Eric Schoeny, Jan Mangers, and Jennifer Grobe. The authors gratefully acknowledge the contribution of several ISWS staff. Amy Russel, Glenn Heistand, and Mike Machesky reviewed the report, Sara Olson provided guidance and expert advice on all illustrations, and Lisa Sheppard edited the report.

Any opinions, findings, conclusions, or recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the Fox Metro Water Reclamation District, the Illinois State Water Survey, or the University of Illinois.

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Introduction

The City of Aurora, with a population of 170,855, resides on the Fox River in Kane County[1]. The city was established as a settlement in the late 1830s and 1840s by millwrights that found the Fox River was particularly conducive to the construction of hydropower mills (J. Manger, personal communication, March 30, 2009). They impounded portions of the river with low-head dams and constructed the early lumber, grist, and wool carding mills. Starting in 1886, the municipal drainage system was installed (E. Schoeny, personal communication, March 30, 2009). This system combined stormwater, domestic wastewater, and industrial wastewater for discharge directly into the Fox River.

The combined sewer system and the growth of the city caused the quality of Fox River's water to suffer. Public health problems began to surface, and in 1928 the Fox Metro Water Reclamation District (FMWRD) wastewater treatment plant was constructed to treat the wastewater from the City of Aurora and surrounding areas (E. Schoeny, personal communication, March 30, 2009). Interceptor lines were installed to convey wastewater from the combined sewer system to the treatment plant. In order to avoid sewer backups during intense precipitation events while keeping construction costs low, interceptor lines were sized to collect wastewater flows from the combined sewer system during normal flow conditions, and overflow structures were installed to carry excess stormwater into the adjacent river. The overflow structures contain a weir, such that when the interceptor reaches a certain capacity, the weir is overtopped and the excess flow is diverted to the Fox River. In this manner, a mixture of untreated stormwater and wastewater enters the Fox River during intense precipitation events through combined sewer overflows (CSOs).

Though progress has been made to separate stormwater from wastewater, 1,813 acres of the city have stormwater draining to the combined sewer system. Currently, 15 permitted CSOs discharge into the Fox River and one permitted CSO discharges into Indian Creek. These 16 CSOs are owned by the City of Aurora. The FMWRD has one permitted CSO that is designed to limit the influent flow rate within the plant capacity during storm events.

Both the City of Aurora and the FMWRD are required to submit a CSO long-term control plan (LTCP) to the Illinois Environmental Protection Agency (IEPA). The FMWRD retained the engineering consulting company Walter E. Deuchler Associates, Inc. (WEDA) to prepare the LTCP on their behalf. This study supports the LTCP development, focusing on evaluating impacts of the FMWRD storm discharges on water quality in the Fox River using a computer model capable of simulating the loading of CSO pollutants and the fate of those pollutants within the Fox River. The FMWRD proposes an overall expansion that will address requirements of the LTCP as well as an anticipated increase in their service area. In addition to an added full-treatment facility, a chemically enhanced primary treatment facility is designed to partially treat excess flow for storms with recurrence intervals of 5-years or fewer.

The following constituents were selected for evaluation: fecal coliform bacteria, total suspended solids, ammonia nitrogen, nitrate nitrogen, total nitrogen, total phosphorus, 5-day biochemical oxygen demand (BOD_5), and dissolved oxygen. This report summarizes the model development and anticipated impacts of storm-related discharges from existing and proposed FMWRD facilities on Fox River water quality.

[1] U.S. Census Bureau, 2007 population estimate, http://www.census.gov/

Model Development

Computer Model Selection

The first step was to select the software that will be used for simulation. There are several computer models that can simulate in-stream water quality. To achieve the goals of this project, the selected model needed to simulate the dynamic nature of the Fox River system during storm events as water quality and quantity are constantly changing with varying upstream conditions and intermittent CSO discharges. The water quality parameters modeled and methods through which they are simulated are also significant. The following water quality models were considered and evaluated, taking into account cost, developer's support, the model's ability to simulate a hydrodynamic non-steady state on branching rivers with low head dams, and constituents simulated: WASP (Wool et al., 2001; Wool, 2009), QUAL2K (Chapra and Pelletier, 2003), CE-QUAL2-W2 (Cole and Buchak, 1995), EPD-RIV1 (Martin and Wool, 1995), SWMM-TRANSPORT (Rossman, 2009), and DUFLOW (2000).

WASP was selected since it is a public-domain model developed and supported by the United States Environmental Protection Agency (USEPA). WASP is also regularly updated to include current knowledge of in-stream processes. WASP includes several modules. Two of those modules, HEAT and EUTRO, were used in this study. The EUTRO module simulates nutrient cycles, including organic matter, algae, and dissolved oxygen. The HEAT module simulates temperature and a general first-order decay constituent used to simulate fecal coliform bacteria. Dissolved oxygen, algae, and temperature were not simulated in this study due to the complexity of the constituent behavior under rapidly changing conditions associated with storm runoff and a lack of observed data.

Segmentation and Model Structure

The study area includes Fox River from the Sullivan Road Bridge in Aurora to the Route 34 (Washington Street) pedestrian bridge in Oswego. This 8-mile reach of the Fox River contains 16 sizeable islands, 15 combined sewer overflows, 42 storm drains, two tributaries, an FMWRD effluent discharge and overflow, and a discharge from the Marina sanitary treatment plant (STP). The challenge for model segmentation was to select a segmentation scheme that promoted accurate representation of the river system while also accommodating the CSO inputs. The resulting segmentation consists of 51 segments, of which 32 were used to fraction flow around islands.

Each segment was selected with an emphasis on homogeneity of the channel characteristics, consistency of travel time, and location of discharges. Figure 1 shows the study reach segmentation. Waubonsie Creek joins the Fox River just a short distance upstream of Route 34, the model's downstream boundary (Segment 51). Waubonsie Creek was excluded from simulation due to lack of discharge and water quality data as well as an insufficient distance for mixing (Figure 2). Grab samples would not reflect any contribution from this tributary as those are typically collected mid-stream.

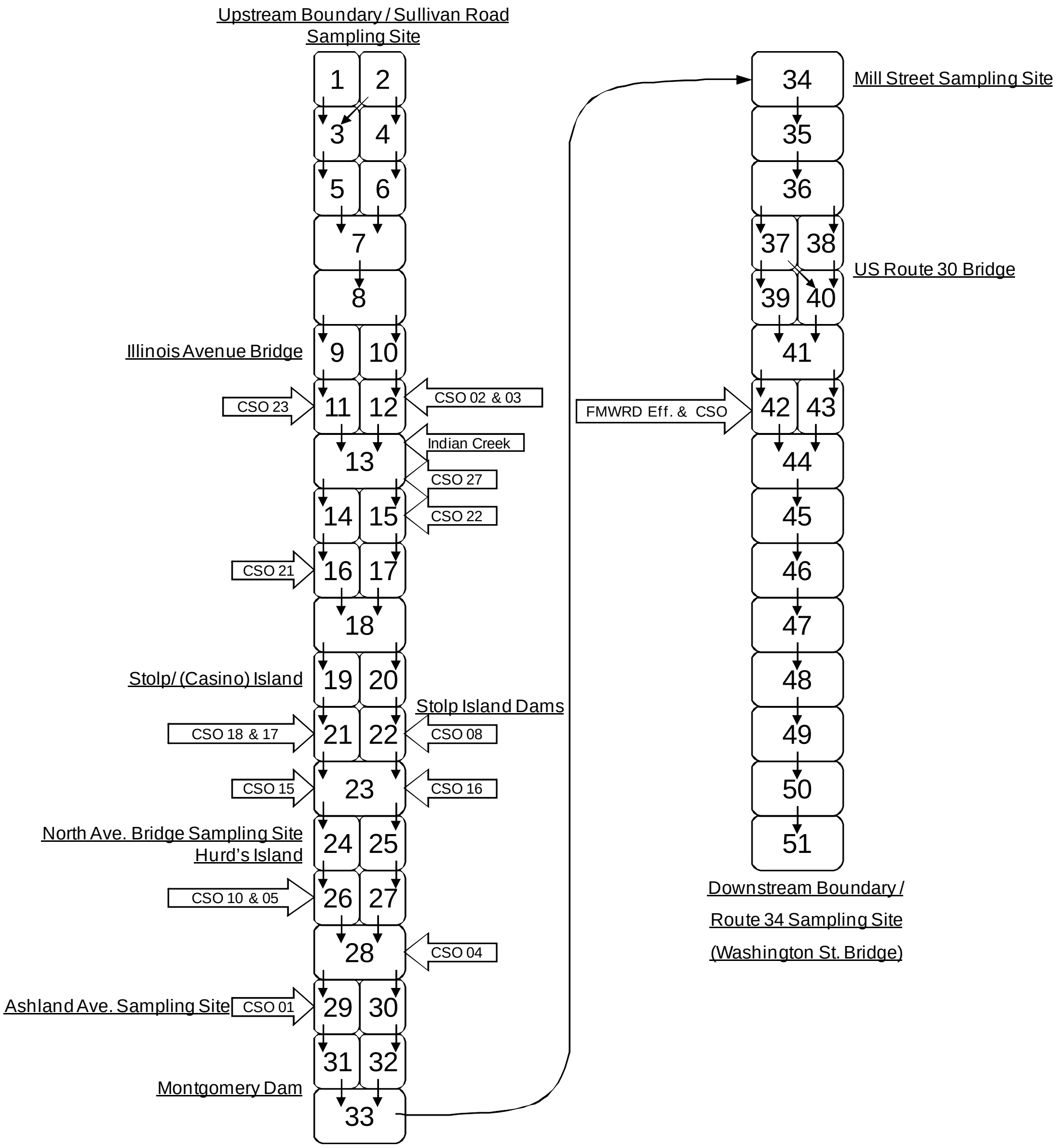


Figure 1. Model segmentation and flow branching

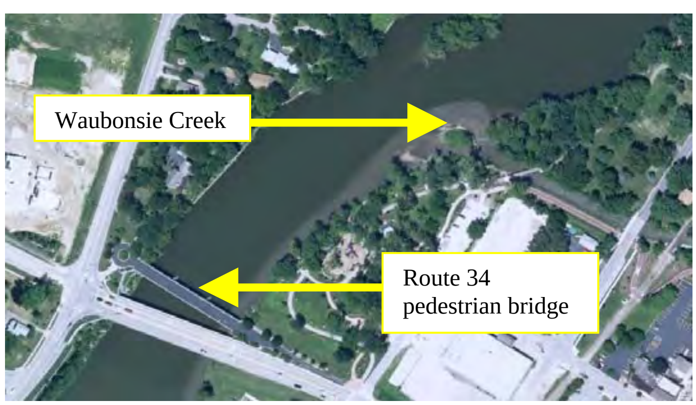


Figure 2. Aerial image, Route 34 and Waubonsie Creek (Google Earth, accessed 4/9/2009)

Modeling Approach

The computer model needs to be calibrated and validated to ensure it simulates realistic conditions in the study reach. Hydraulic coefficients were calibrated using depth and velocity measurements collected at several locations by WEDA and at Mill Street downstream of the Montgomery gage by the United States Geological Survey (USGS). Water quality coefficients were calibrated using data collected by WEDA during two storm events in 2008 and verified using data collected by WEDA during one storm event in 2008 and one in 2009. The calibrated model was also used to simulate water quality for May–October 2008 to evaluate any cumulative impacts and trends. The long-term simulation verified overall model performance under various conditions.

To simulate the impact of the CSOs on the Fox River, the computer models were set to simulate relatively short time periods, typically less than one week, during which CSOs occurred. Hydraulic simulations indicated that the overall retention time of the 8-mile study reach varied from 8 hours during high-flow periods to 24 hours during low-flow periods. Focusing the simulations on CSO discharges from a single precipitation period allowed for a short simulation time step (5 minutes) with more accurate comparison of observed values to model results. This event-calibrated model would be used later in the project to simulate the impact of CSOs under existing conditions and proposed modifications at the FMWRD facilities using a design rain of specified duration and frequency.

Initially, three time periods were chosen when CSOs occurred and water quality data were collected for CSOs and Fox River stations. July 7–12, 2008 and August 3–6, 2008 data were used to calibrate the model. The model was then verified using September 1–4, 2008 data. Figure 3–Figure 5 show flows in the Fox River at Route 34 pedestrian bridge during the simulated time periods and times when water quality samples were collected at the same location. Figure 6 then shows when CSOs stopped discharging, when the discharged flow would be expected to pass through the Route 34 sampling site, and times when water quality samples were collected at Route 34 for days when CSOs discharged during simulated periods. While travel times include only transport without additional effects of dispersion or stormwater contribution, these figures indicate most water quality samples were collected after the CSO discharge passed through the sampling site, catching the receding portion of the hydrograph at best (note the gap between the travel timelines and sample markers; they overlap only for the 8/4/2008 event and the 8/7/2009 intensive sampling event). Simulated CSO events occurred at night, making river sampling difficult to accomplish within the needed time-frame considering the relatively short travel time.

To alleviate this problem, an intensive sampling for a limited number of constituents (fecal coliform bacteria, total phosphorus, total suspended solids, and ammonia nitrogen) was conducted by WEDA on August 7, 2009. This sampling was limited to three bridges on the Fox River (Sullivan Street, Mill Street, and Route 34), but separate samples were collected from east, west, and middle portions of the channel at 15- to 20-minute intervals. Separate analyses across the channel were designed to evaluate the level of mixing as simulations of 2008 periods indicated incomplete mixing at some locations. Although samples were analyzed for ammonia nitrogen, the laboratory detection limit was too high (0.1 milligrams per liter, or mg/l) and the majority of data was reported as below the detection limit and was not used in this study. Figure 7 indicates samples at Route 34 were taken during the rising portion of the hydrograph during intensive sampling.

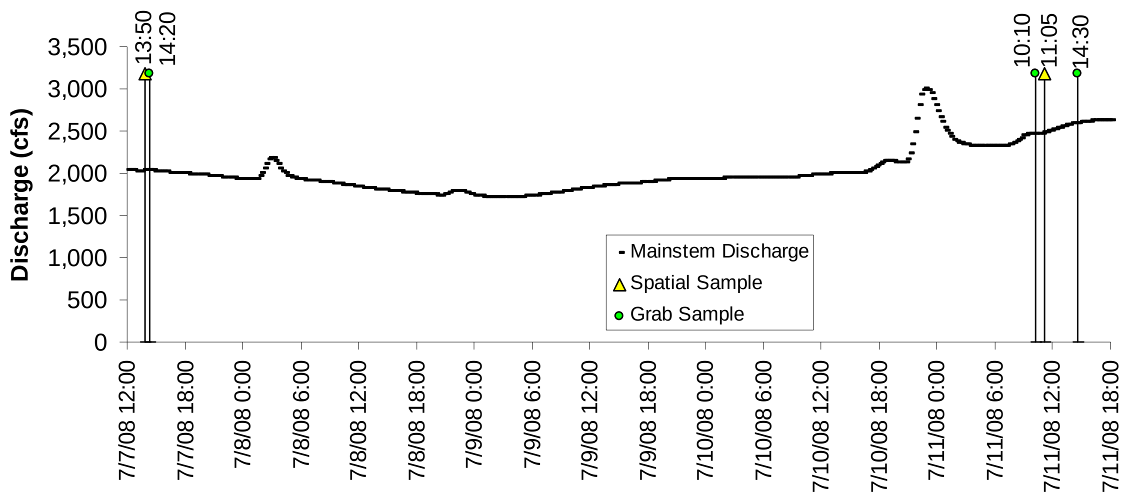


Figure 3. Sampling timeline 7/7–11/2008 at Route 34 pedestrian bridge

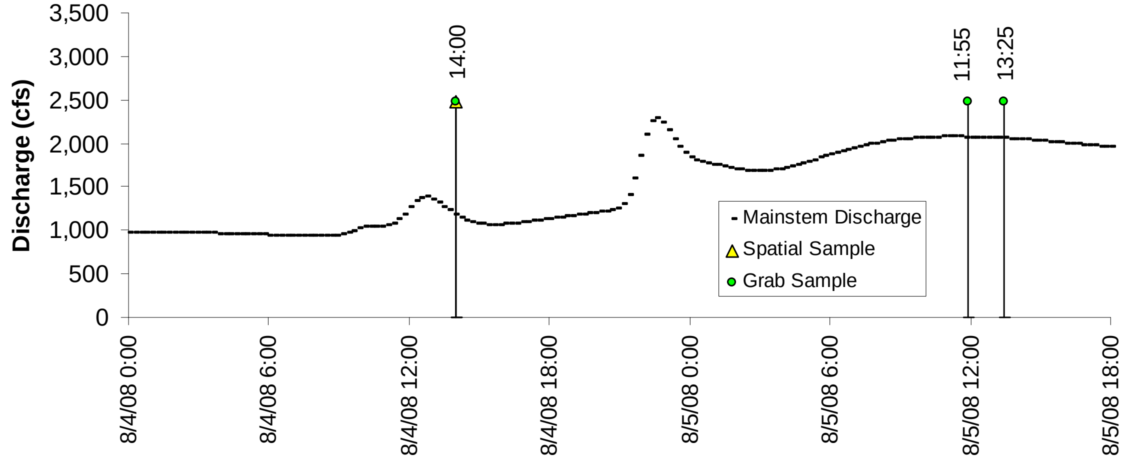


Figure 4. Sampling timeline 8/4–5/2008 at Route 34 pedestrian bridge

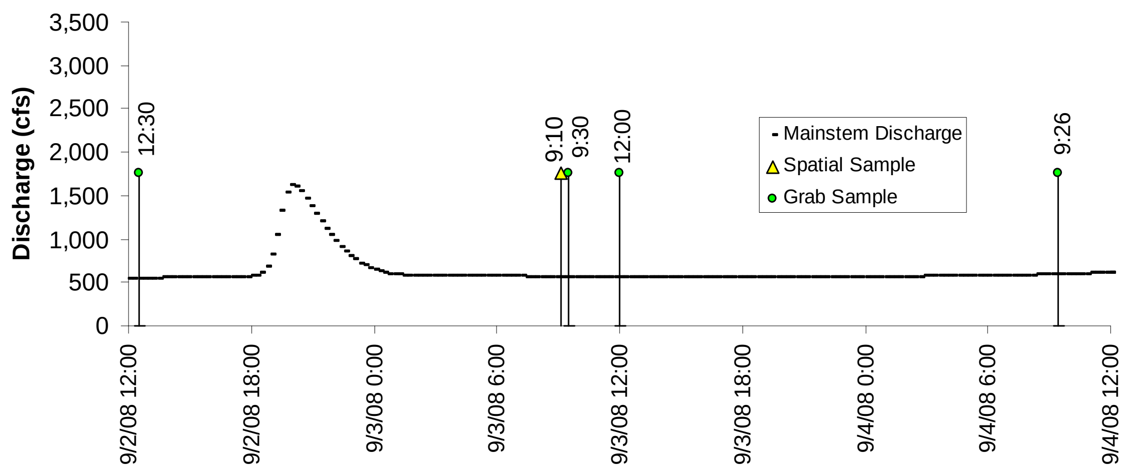


Figure 5. Sampling timeline 9/2–4/2008 at Route 34 pedestrian bridge

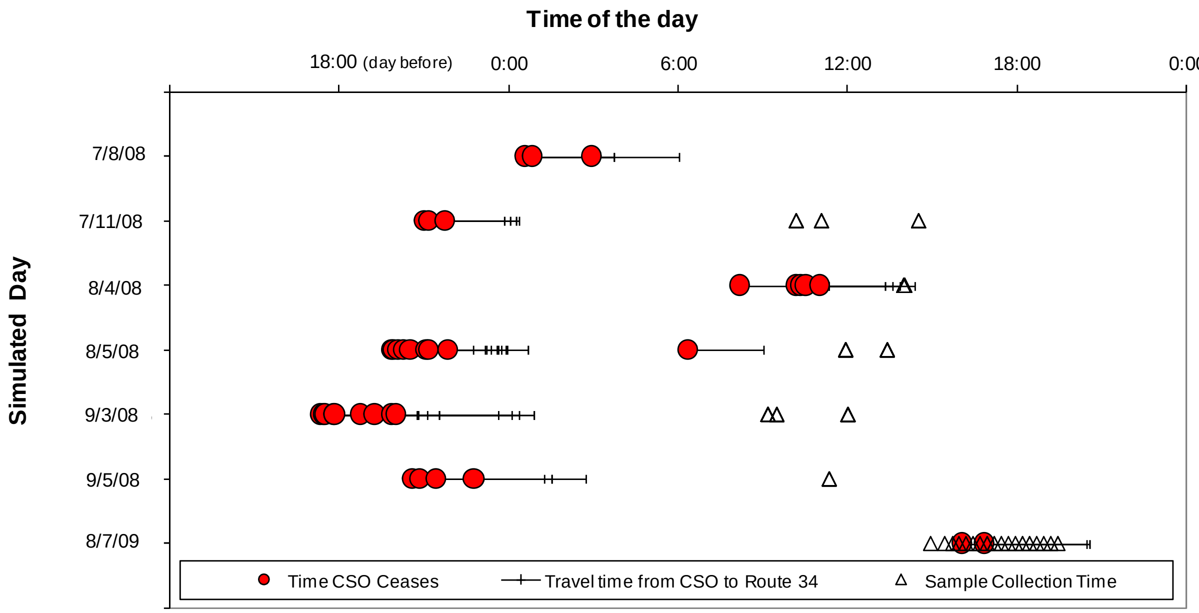


Figure 6. Timing of CSOs passing through Route 34 and sampling times

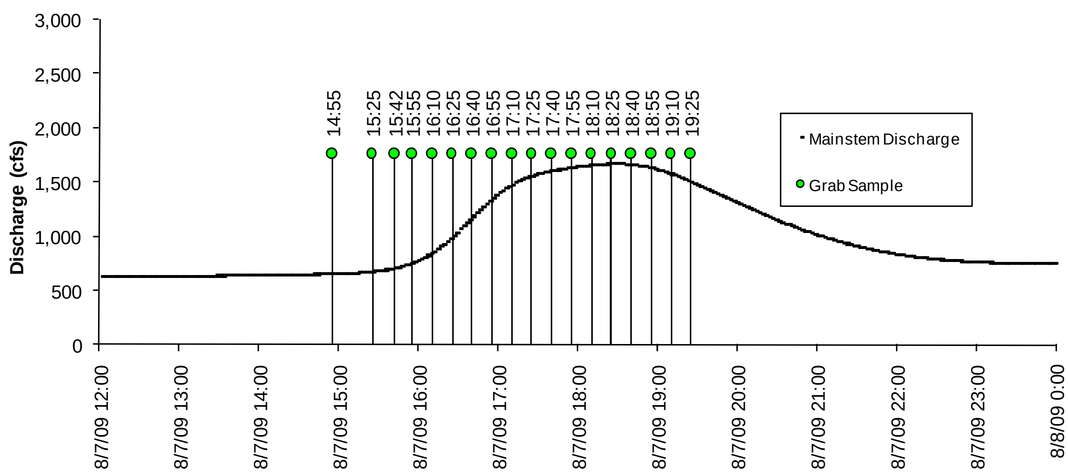


Figure 7. Sampling timeline 8/7–8/2009 at Route 34 pedestrian bridge

Data Sources

Computer simulation models are data intensive. For each simulated period, complete information on water quality and quantity is needed for the Fox River, the Indian Creek, all Aurora CSO discharges, the FMWRD effluent and CSO, the Marina STP, and storm drains. WEDA operates gages at the North Aurora Dam and an adjacent mill race on the Fox River and at an abandoned railroad bridge on Indian Creek just east of Route 25 (Broadway Street, Aurora). Since there are no significant discharges between North Aurora Dam and the study upstream boundary at Sullivan Road Bridge, the discharge at North Aurora Dam is combined with discharge from the adjacent mill race and is used directly as a model input at Sullivan Road Bridge.

Water quality sampled by WEDA at Sullivan Road Bridge and at the abandoned railroad bridge on Indian Creek is also entered directly as model inputs at these locations. While discharge is available at 5-minute intervals, water quality data are collected at much more infrequent and irregular intervals. For event-based simulated periods, a simple interpolation routine is used by WASP to provide concentration information for time periods without observed values. For the summer 2008 simulation, water quality data were analyzed for any flow and seasonal variations, and where appropriate, relationships were developed to provide missing concentrations at critical points in time (e.g., significant change in flow).

The FMWRD provided average daily discharge information for the treated effluent and the start time, duration, and total volume for discharges through its CSO. Self-reported average monthly discharge data from the Discharge Monitoring Report (DMR) were downloaded from EnviroFacts (USEPA, 2009) to provide water quantity and quality information for the Marina STP.

CSO Inputs

All Aurora's active CSOs are equipped with a flow meter recording data in 5-minute intervals. Automated samplers were installed at the seven largest or most active CSOs, collecting water quality data at pre-determined time intervals during a CSO discharge. When a CSO without automated sampler discharged during the simulated period, the discharged load was estimated using the "CSO Load Estimator" tool developed for this study. This tool uses build-up and wash-off equations (Novotny and Olem, 1994) to develop a relationship between a load discharged from a CSO and CSO discharge characteristics such as peak discharge, duration of discharge, and time from a previous discharge:

$$P_t = \{(I/\xi)(1 - \exp(-\xi D)) + P(0)\exp(-\xi D)\}(1 - \exp(-Krt))$$

where P_t is the amount of pollutants washed out of the system after time *t*, *I* is the sum of all inputs, is the removal coefficient, *D* is the time since the last CSO event, *P(0)* is the initial amount of pollutants in storage at first discharge, *r* is the maximum discharge intensity, and *K* is the wash-off coefficient. Assuming that *P*(0) is zero and that all CSO outlets have the same characteristics, the constants *I*, and *K* were found for all simulated constituents using data from fully monitored CSOs (Table 1). Figure 8 compares actual loads calculated from observed concentrations and loads estimated using the build-up and wash-off equations above for two selected constituents, ammonia nitrogen and fecal coliforms, as an example. Each individual CSO discharge is represented by a point, colored by a corresponding CSO pipe. The points are evenly scattered along the 1:1 line, indicating a good fit and no bias with respect to total load. The full equation was then applied to CSOs where only discharge is recorded.

The total load for each unmonitored CSO calculated using the build-up and wash-off equation was then distributed over the duration of the CSO discharge using fractional volume and load relationships. Cumulative load and volume were calculated for the monitored CSOs and divided by total load and volume for each CSO discharge, respectively, to determine fractional loads and volumes. Figure 9 shows the fractional relationships for ammonia nitrogen with a best fit line. A sharp increase from the (0,0) point would indicate that a higher proportion of the load was discharged at the beginning of the CSO (first flush).

Table 1. Optimized coefficients for total CSO load calculations

Constituent	*I [kg/day]*	*1/day*	*K [s/day/m3]*
BOD_5	813610	43.948	0.30018
Fecal coliform	8.49E+09	55.15	0.434
Total suspended solids	2.73E+06	47.061	0.38306
Organic nitrogen	49384	39.493	0.61969
Ammonia nitrogen	2084.9	15.724	1.0459
Nitrite nitrogen	901.34	11.871	0.094968
Nitrate nitrogen	43.852	4.5656	10.712
Kjeldahl nitrogen	57204	38.649	0.60588
Total phosphorus	18604	42.894	0.34839
Dissolved phosphorus	313.22	73.558	8.583

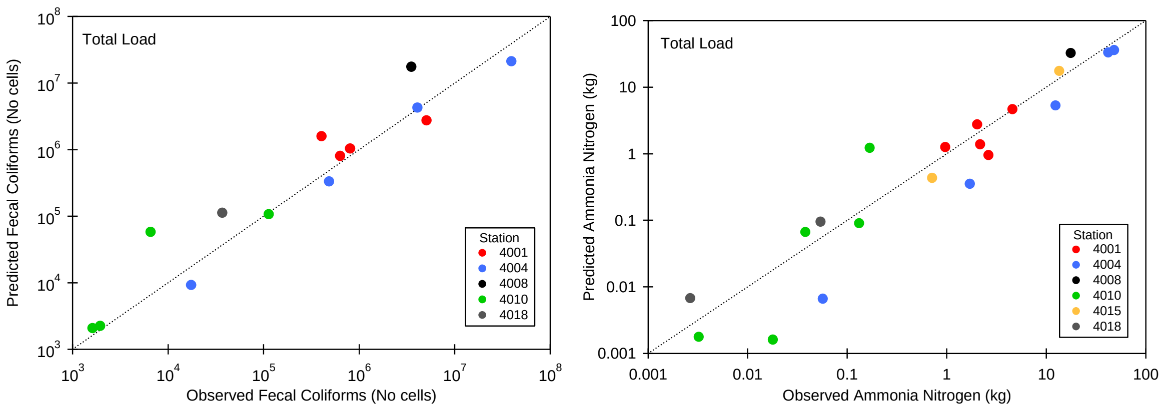


Figure 8. Predicted versus observed total load (P) of fecal coliforms and ammonia nitrogen

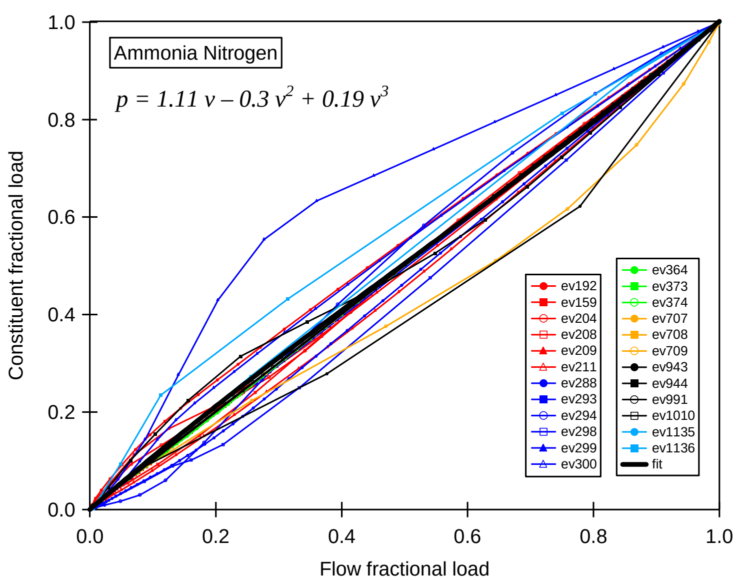


Figure 9. Fractional load (*p*) of ammonia nitrogen as a function of fractional volume (*v*) discharged.
Lines represent individual storm events (ev.) colored by a location.
Equation corresponds to the best fit line.

Stormwater Contribution

The study reach also contains 43 stormwater drainage outfalls that contribute water and pollutant loadings to the Fox River. Total contributions from storm drains during simulated periods had to be estimated to properly calibrate the model. In 2008, WEDA collected several water quality samples from three storm drains in different areas near their outfalls to Fox River. In 2009, this monitoring was enhanced by installing a gage that provides stage and discharge information during runoff events. These data enabled site-specific estimation of loads and volumes released to the Fox River in the study area.

Precipitation data were obtained from the rain gage located at and operated by WEDA. The WEDA office is centrally located within the project area. The data for each simulated time period were divided into intervals of consistent intensities. The intensity for each time interval was used to estimate the peak discharge using the rational equation. Although the rational equation is not recommended for watersheds over 200 acres in size, it provides an acceptable method for purposes of this study since the contributing area (9,735 acres) is divided into 43 discharge points. In-depth hydrologic analysis for this highly urbanized area would be beyond the scope of this project.

The peak runoff rates used to create the runoff hydrographs were calculated by the rational formula:

$$Q = CC_f IA,$$

where Q is the peak runoff in cubic feet per second (cfs), C is the runoff coefficient, C_f is the frequency factor, I is the intensity in inch/hour, and A is the watershed area in acres (Debo and Reese, 2003). The widely accepted runoff coefficients were developed for storms with intensities in the 5-year to 10-year return interval range. Storms during the simulated time periods include those with return intervals of much less than five years. The frequency factor allowed for a more accurate prediction of the actual peak runoff. A water balance and hydrologic analysis validated the stormwater volume and peak runoff approximated using the rational method. The best match was obtained for the study watershed when the time of concentration was calculated with the Federal Aviation Administration (FAA) formula:

$$t_c = \frac{0.39(1.1 - C)L^{\frac{1}{2}}}{S^{1/3}}$$

where C is the runoff coefficient, L is the length of flow path in feet, and S is the average slope (FAA, 1970). Peak runoff values and the resulting hydrograph were adjusted for storms shorter than time of concentration. The calculated stormwater volume for each time interval was distributed proportionally across individual storm drain outfalls based on the contributing area, or, when unknown, on pipe cross-sectional areas assuming pipes are sized properly to carry runoff from their respective contributing areas.

Water quality data collected by WEDA at the stormwater outfalls were analyzed for any patterns with respect to storm duration (first flush effect). Data for any distinct periods of high, medium, or low concentrations were then processed to determine 25th, 50th, and 75th percentiles to represent widely variable stormwater quality. All three values were used in simulations representing low, medium, and high concentrations, respectively. The results from these simulations were compared in the same chart to evaluate variability due to varying stormwater quality.

Model Calibration and Verification

Both graphical and statistical measures were used during calibration to evaluate how well the model simulates water quality in the Fox River. For each water quality sample, percent error was calculated as *(Simulated – Observed) / (Observed) *100%* using a simulation with 50th percentile concentrations for stormwater quality. Average and median percent errors for each station are given in Table 2 for calibration and Table 3 and Table 4 for verification. Ideally, the error would be zero. A negative number shows underestimation, while positive numbers show an overestimation. The median error is not affected by a presence of a large value, positive or negative, while the mean error can be, especially for small sample sizes. For fecal coliform bacteria, the percent error was also calculated for logarithms of simulated and observed values. Fecal coliform values can vary significantly even between two samples taken at the same location and time (duplicate samples). Bartosova et al. (2010) showed that variation between duplicate samples can often be 40%. Calculating the percent error from logarithmically transformed values evaluates error in the order of magnitude.

The limited number of observed data during most simulated periods was unfortunately collected outside the time period when Fox River water quality was affected by combined sewer overflow (CSO) discharges. It is extremely difficult to time a sample collection in a system with relatively short travel times, especially when exact times of CSO discharges are not known before sampling is initiated. The data on the FMWRD treated effluent are only available as daily averages that do not describe diurnal or storm-related changes in discharged volume and loads during the event. Stormwater discharges were estimated from a single precipitation station and under simplifying assumptions. All these factors contribute to the final accuracy of simulation.

For illustration, graphical comparisons of simulated and observed data for fecal coliform bacteria are shown in Figure 10 through Figure 12. Four simulation results are shown for each simulated period: 25th, 50th, and 75th percentile for concentrations of pollutants in stormwater, and a hypothetical case with no stormwater discharge to isolate the effects of CSOs. While observed values at the receding portion of the pollutograph on July 11, 2008 (Figure 10a) follow simulations rather well, the increased concentration at that time was caused by stormwater contributions as indicated by the “no stormwater” simulation. Also note the second peak in Figure 10b for the “no stormwater” simulation; the sustained increase in fecal coliform bacteria was mostly due to the FMWRD CSO that was actively discharging on August 5, 2008. Direct comparison of observed and simulated values is presented for summer 2008 using the 50th percentiles for stormwater concentrations (Figure 12).

The “no stormwater” simulations indicate that water quality samples collected during the calibration events represent conditions before any CSO discharge occurred and after it has passed through the monitoring location, reflecting upstream conditions or effects of stormwater. Sampling during validation events was more successful. The lack of data collected during the peak of the pollutograph make it impossible to verify peak simulated values by field observations. However, they are the best estimates determined by the model and are mostly affected by mixing as travel time through the study reach is quite short.

During the intensive sampling event, samples were taken and analyzed separately at three different locations for each sampling site characterizing concentration at the east, middle, and west sections of Fox River. The lowest and the highest observed values are plotted together with a geometric mean of all three values to show the variation of fecal coliform bacteria within a cross-section (Figure 11b). While there is a lot of variation in the highest observed values (order of magnitude), simulated values follow the observed mean rather well.

Table 2. Average percent error at Route 34 – Calibration

Constituent	*Simulated Period*	*Number of Samples*	*Statistic*	*Station*			
				North Ave.	*Ashland Ave.*	*Mill St.*	*Route 34*
BOD_5	7/8/2008	3	Mean	-3%	-4%	-11%	-18%
			Median	-1%	-1%	-11%	-21%
	8/4/2008	3	Mean	8%	-13%	-4%	-2%
			Median	3%	-19%	4%	7%
TSS	7/8/2008	3	Mean	-10%	-6%	-18%	-30%
			Median	-17%	-10%	-22%	-29%
	8/4/2008	3	Mean	13%	-1%	-5%	-2%
			Median	3%	1%	-5%	-4%
NH3,4	7/8/2008	4	Mean	20%	26%	44%	84%
			Median	47%	40%	50%	83%
	8/4/2008	3	Mean	-5%	-15%	-9%	17%
			Median	-10%	-17%	-12%	14%
NO3	7/8/2008	4	Mean	7%	-2%	-5%	87%
			Median	-3%	-10%	-4%	65%
	8/4/2008	3	Mean	-30%	-25%	-15%	3%
			Median	-30%	-24%	-22%	6%
TN	7/8/2008	3	Mean	13%	3%	4%	18%
			Median	8%	-8%	-2%	11%
	8/4/2008	3	Mean	-12%	-10%	-5%	-5%
			Median	-12%	-10%	-9%	0%
TP	7/8/2008	4	Mean	7%	2%	3%	61%
			Median	5%	3%	4%	63%
	8/4/2008	3	Mean	4%	-1%	-2%	2%
			Median	5%	-2%	-3%	17%
FC	7/8/2008	3	Mean	-32%	-8%	3%	38%
			Median	-32%	-13%	3%	27%
	8/4/2008	3	Mean	56%	-15%	-13%	-19%
			Median	25%	0%	0%	-22%
	On logarithmic scale						
	7/8/2008	3	Mean	-6%	-2%	0%	3%
			Median	-6%	-3%	0%	4%
	8/4/2008	3	Mean	5%	-3%	-3%	-3%
			Median	3%	0%	0%	-4%

Table 3. Average percent error at Route 34 – Validation

Constituent	*Simulated Period*	*Number of Samples*	*Statistic*	*Station* *North Ave.*	*Ashland Ave.*	*Mill St.*	*Route 34*
BOD_5	Summer 08	51	Mean	20%	7%	10%	12%
			Median	1%	-2%	1%	8%
	9/2/2008	3	Mean	-17%	-18%	-18%	-21%
			Median	-20%	-23%	-26%	-24%
TSS	Summer 08	51	Mean	2%	0%	-2%	-5%
			Median	3%	1%	-3%	-7%
	9/2/2008	3	Mean	13%	8%	21%	24%
			Median	8%	4%	28%	34%
NH3,4	Summer 08	46	Mean	40%	24%	62%	133%
			Median	26%	10%	45%	99%
	9/2/2008		Mean	32%	54%	110%	260%
			Median	27%	7%	103%	299%
NO3	Summer 08	48	Mean	33%	-1%	1%	51%
			Median	-1%	0%	1%	32%
	9/2/2008		Mean	17%	21%	23%	268%
			Median	16%	21%	25%	280%
TN	Summer 08	45	Mean	4%	0%	-1%	21%
			Median	0%	-1%	-1%	15%
	9/2/2008		Mean	12%	13%	13%	88%
			Median	15%	15%	16%	88%
TP	Summer 08	47	Mean	13%	14%	11%	25%
			Median	3%	4%	4%	16%
	9/2/2008		Mean	16%	22%	25%	48%
			Median	7%	9%	14%	55%
FC	Summer 08	46	Mean	125%	29%	54%	56%
			Median	-22%	-17%	-15%	-15%
	9/2/2008	5	Mean	-53%	-46%	-2%	87%
			Median	-50%	-50%	-20%	30%
	On logarithmic scale						
	Summer 08	46	Mean	1%	-1%	1%	0%
			Median	-5%	-3%	-3%	-3%
	9/2/2008	5	Mean	-15%	-12%	-4%	4%
			Median	-12%	-12%	-5%	7%

Table 4. Average percent error – Intensive sampling event on 8/7/2009

Constituent	*Number of Samples*	*Statistic*	*Mill Street*			*Route 34*		
			West	*Middle*	*East*	*West*	*Middle*	*East*
BOD_5	18	Mean	-0.4%	2.4%	-5.9%	14.1%	-1.5%	-7.4%
		Median	-2.4%	2.6%	-6.1%	12.1%	-0.3%	-5.9%
TSS	18	Mean	7%	2%	-4%	0%	-11%	-21%
		Median	8%	4%	-3%	1%	-14%	-19%
TP	18	Mean	5%	16%	8%	-43%	80%	98%
		Median	3%	4%	4%	-44%	83%	94%
FC	18	Mean	103%	113%	35%	-1%	106%	115%
		Median	1%	-7%	-12%	-20%	-47%	-10%
	On logarithmic scale							
	18	Mean	2%	5%	0%	-4%	-2%	-1%
		Median	0%	-1%	-2%	-3%	-8%	-2%

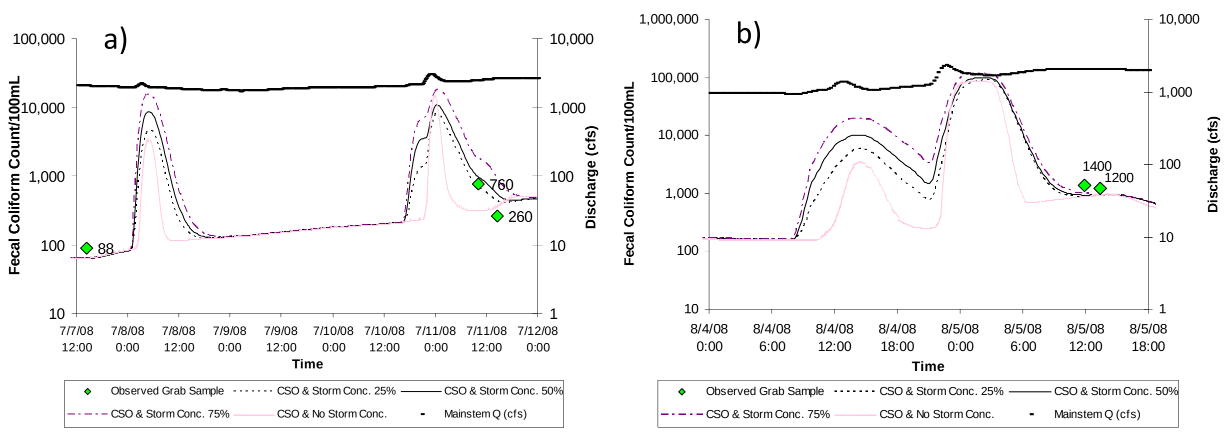


Figure 10. Fecal coliform calibration a) 7/8/2008–7/10/2008 and b) 8/4–5/2008 at Route 34 Bridge

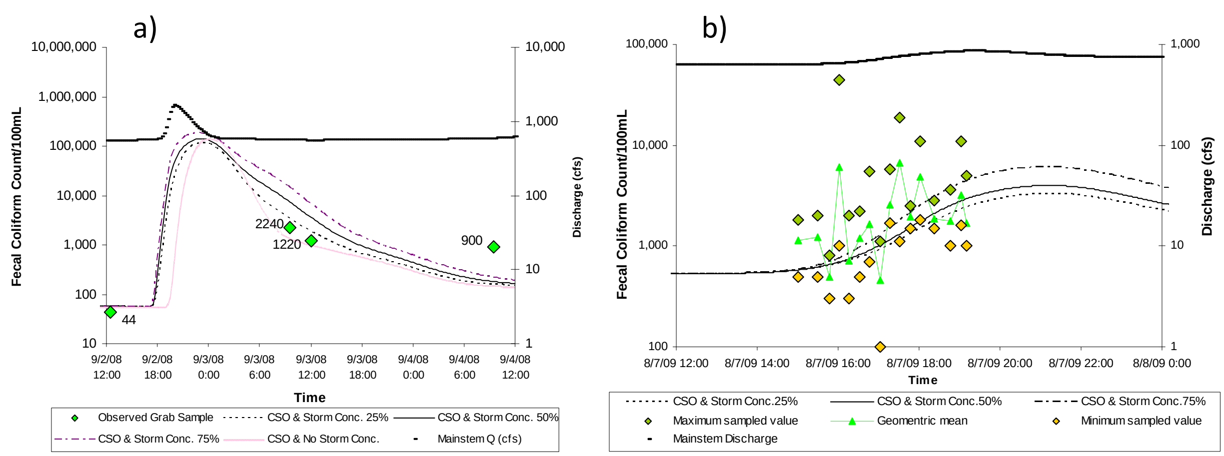


Figure 11. Fecal coliform validation a) 9/2–4/2008 and b) 8/7–8/2009 at Route 34 Bridge

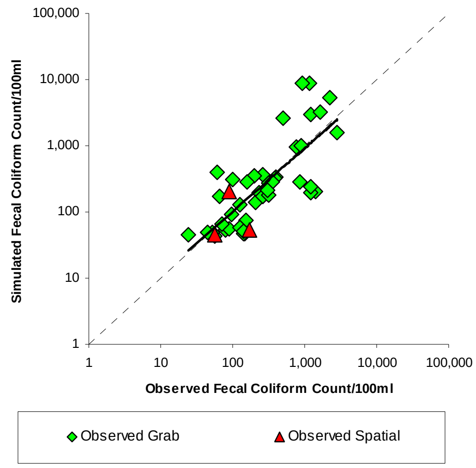


Figure 12. Fecal coliform validation for summer 2008 at Route 34 Bridge

Figure 13 presents the mean and median errors graphically for each constituent and monitoring location separately. Overall, about half of the errors are within ±10% and most of the errors are within ±30%. Ammonia nitrogen consistently shows the largest departure from observed data for all locations. Route 34 also shows errors for nitrate nitrogen and total phosphorus are larger than for other locations. Fox River at the Route 34 location exhibits strong cross-sectional variation for some constituents caused by incomplete mixing of FMWRD discharges as confirmed by intensive sampling conducted by WEDA. Since only the first sample collected during a storm was a spatial composite, all additional (grab) samples do not necessarily reflect the average water quality in the cross section simulated by the model. The incomplete mixing then results in a large error at Route 34. The model is expected to simulate higher concentrations of ammonia nitrogen, nitrate nitrogen, and total phosphorus than indicated by observed values when used for design storm simulations.

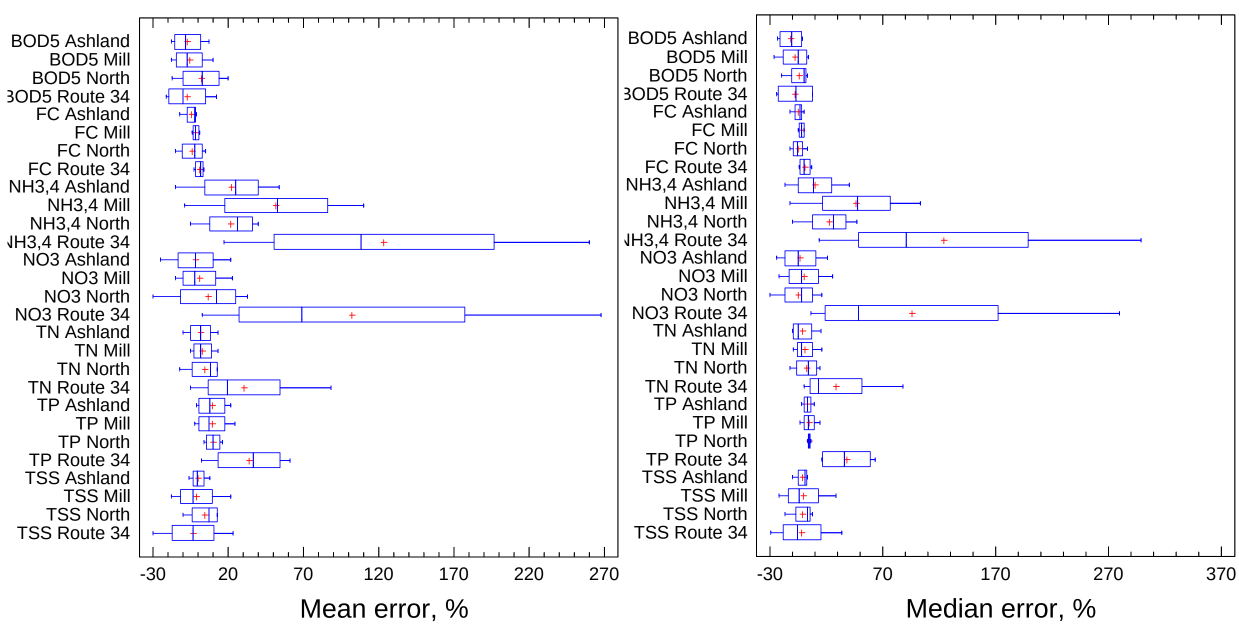


Figure 13. Range of mean and median errors by constituent and monitoring location

Evaluating Impact

FMWRD Plan for 2025

Under existing conditions, influent waste and stormwater are treated at the FMWRD facility until its capacity is reached. When the inflow is higher than the design peak hourly flow (85 million gallons per day [mgd] or 3.72 cubic meters per second [m^3/s]), the excess flows directly to the Fox River through the FMWRD CSO. The FMWRD 2025 plan proposes to build a) a full treatment expansion with a design peak hourly flow of 46 mgd (2.02 m^3/s), and b) a new chemically enhanced primary treatment (CEPT) facility with a design peak hourly flow of 44 mgd (1.93 m^3/s) that would begin to operate when inflow exceeds capacity of the full treatment facilities. The proposed full treatment expansion assumes the same removal efficiencies as at the existing facility for all constituents other than phosphorus. Phosphorus removal will be chemically enhanced, greatly reducing the discharged load.

The CEPT capacity is designed to capture excess inflow water for storms with recurrence interval of 5-years or less, i.e., only storms larger than a 5-year storm would result in an overflow of untreated water. The CEPT is used to disinfect and partially treat the excess flow before discharging it into the Fox River when inflow exceeds the full-treatment design peak hourly flow of 131 mgd (5.74 m^3/s). While phosphorus will be removed using chemical treatment, the removal efficiency was not defined at the time of model development to simulate the worst-case scenario for CEPT without phosphorus removal.

Design Storm Approach

The calibrated and verified model was set to simulate the effects of design storms on Fox River water quality under existing and proposed conditions at the FMWRD. While the model was calibrated using all sources discharging into the study reach, only the FMWRD discharges were included in the design rain simulations, focusing evaluation of any impacts only on the evaluated source. The study reach was adjusted for impact simulation. Mill Street, located upstream of the FMWRD and just downstream of Montgomery Dam, was considered an upstream boundary instead of Sullivan Road. Changes in water quality caused by the FMWRD discharges and compliance with water quality standards were evaluated at Route 34 (Washington Street Bridge), located downstream from the FMWRD discharges. Three design storms were simulated for all constituents: 1-year, 5-year, and 10-year. An additional storm (3-month) was simulated for ammonia and total phosphorus. The input data to the model representing quantity and quality of discharge from the FMWRD for all outfalls were provided by WEDA as a time series for each design storm. The total outflow from the FMWRD facilities is shown in Figure 14. The model simulates eight days (5/9–5/16/2002) with the first day excluded from evaluation to allow the model to achieve a stable state and to minimize effects from initial conditions. The storm was starting to affect the FMWRD discharge at 10 a.m. on May 11. The impact from increased dry weather flow under proposed conditions reflecting anticipated increased service area was not evaluated as it is not relevant for the LTCP.

The selected dates have no relevance for the impact evaluation, as a range of temperatures or other conditions was considered in interpreting simulated concentrations. Any dates discussed with respect to simulations are to be understood as modeling dates.

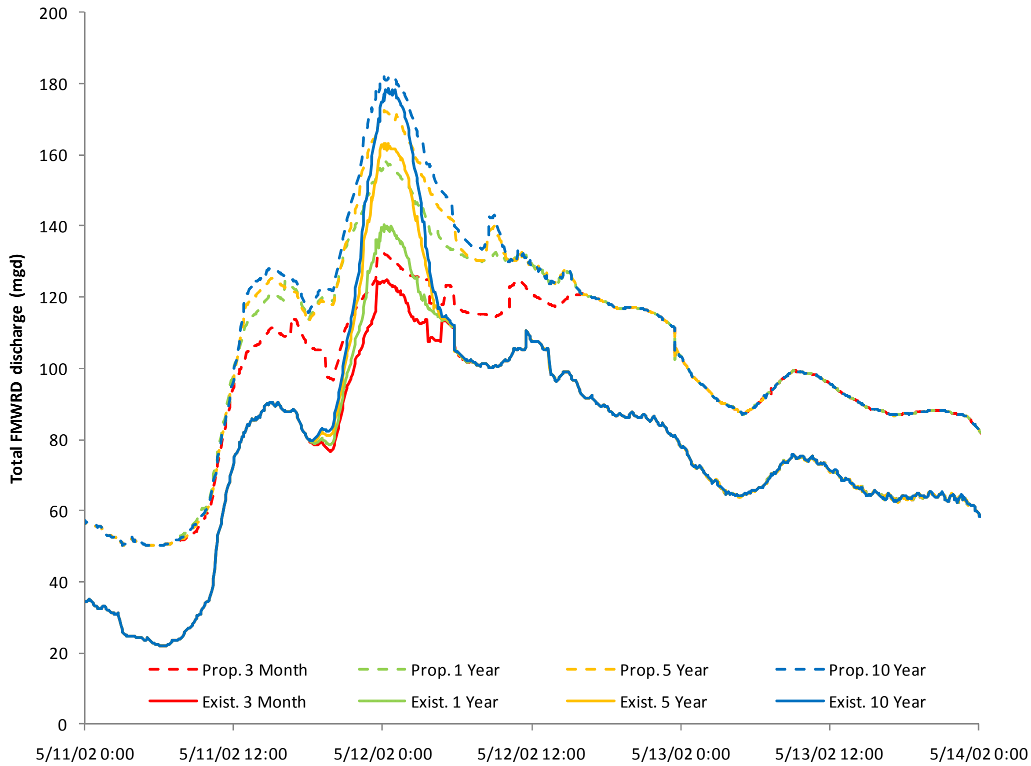


Figure 14. Existing and proposed discharges from the FMWRD facilities

The design storm model uses a constant temperature during simulations (16°C). Sensitivity analysis was conducted for 10 additional temperatures varying from 1.5°C to 32°C. The maximum difference was for the biochemical oxygen demand (BOD): 6 % for the lowest temperature and -10% for the highest temperature. Ammonia nitrogen simulations showed 4% for the lowest temperature and -2% for the highest temperature. All other evaluated constituents stayed within 1%. Such variation is acceptable and makes it unnecessary to evaluate simulations at other temperatures.

Figure 15 shows a portion of the discharge that does not receive the full treatment (i.e., discharge above 131 mgd). Figure 16 shows a portion of the discharge that is completely untreated (i.e., CSO discharge). A "no action" condition was evaluated for selected constituents using the 5-year design storm, showing the impact of future discharges under existing treatment conditions. A portion of the discharge that does not receive the full treatment (i.e., discharge above 85 mgd) for the "no action" condition using a 5-year storm is shown in Figure 17. A portion of the discharge that is completely untreated (i.e., CSO discharge) is then shown in Figure 18.

Table 5 lists peak hourly discharges through individual FMWRD facilities under existing and proposed conditions for all four design storms. Table 6 lists total volumes discharged through individual FMWRD facilities for the duration of the storm (4 days and 18 hours). The storm discharge occurred between 10 a.m. on 5/11/2002 and 4 a.m. on 5/16/2002. There is a significant discharge through the FMWRD CSO under existing conditions and even more under the "no action" condition for future discharges. Under proposed conditions, both peak rate and total volume discharged through the FMWRD CSO are significantly reduced because proposed modifications at the FMWRD are designed to process all inflow for up to a 5-year storm. For a 10-year storm, 3% of total incoming volume does not receive full treatment and only 0.1% of incoming volume is discharged untreated through the CSO under the proposed conditions.

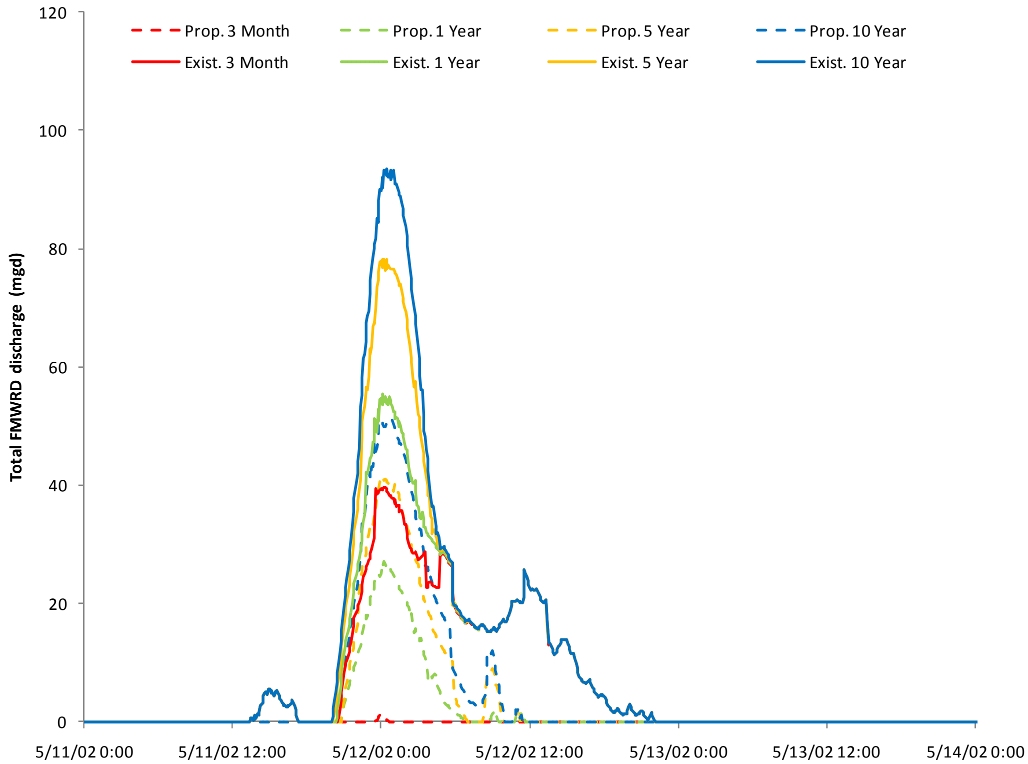


Figure 15. Existing and proposed discharges above the full treatment FMWRD design hourly peak flow

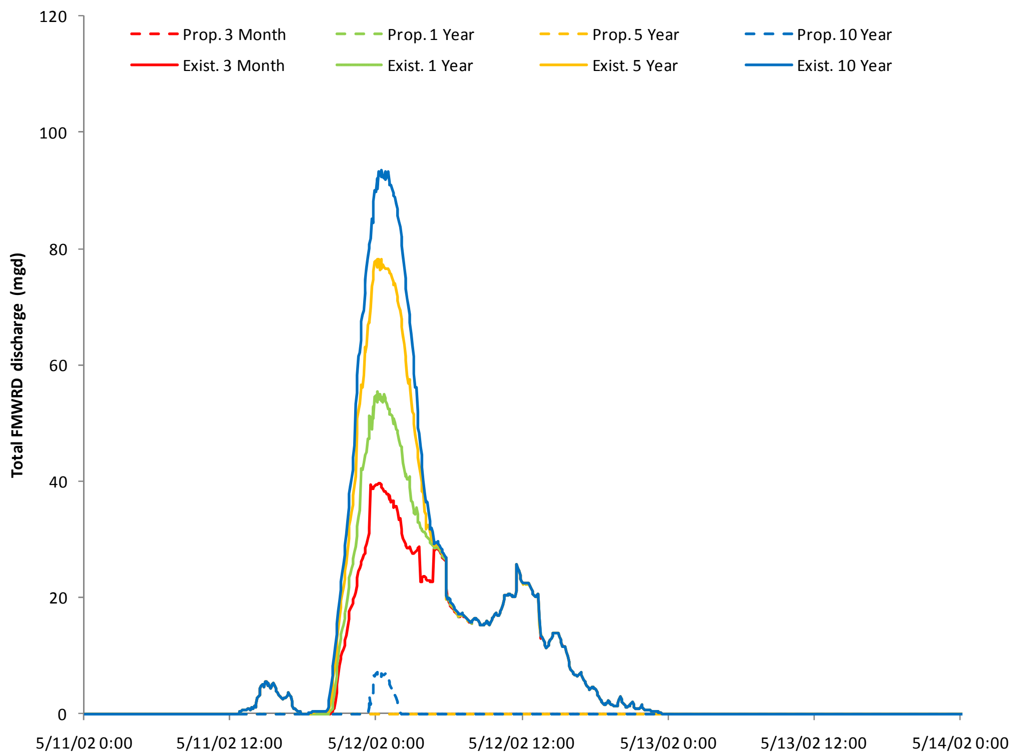


Figure 16. Existing and proposed discharges through the FMWRD CSO

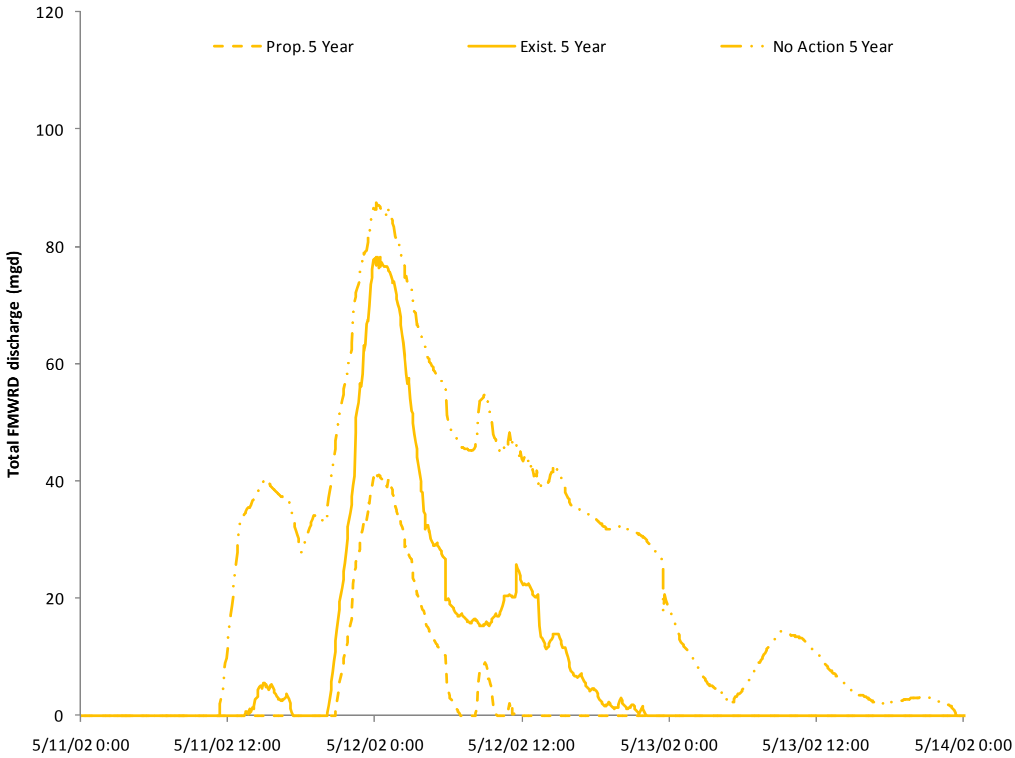


Figure 17. Existing, proposed, and “no action” discharges above the full treatment FMWRD capacity for 5-year storm

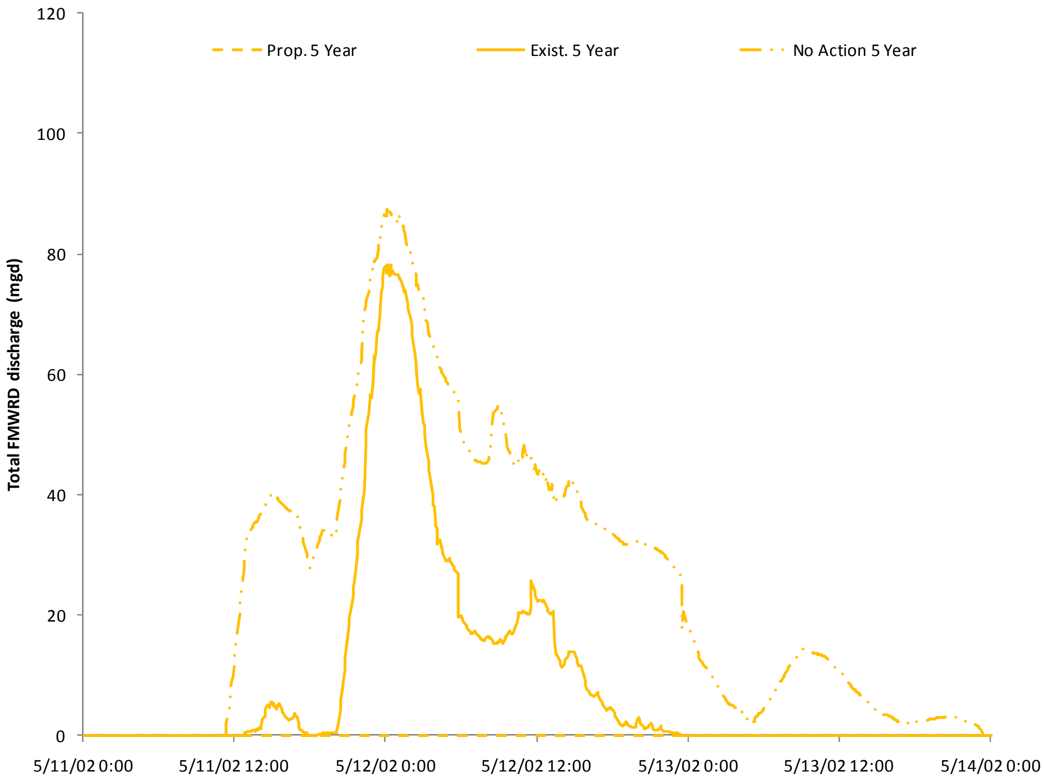


Figure 18. Existing, proposed, and “no action” discharges through the FMWRD CSO for 5-year storm

Table 5. Peak discharges through individual FMWRD facilities, mgd (m3/s)

Design storm	*Total*	*Treated effluent*	*CEPT*	*CSO*
Existing Condition				
Design peak hourly flow		85 (3.72)	N/A	
3-month	125 (5.47)	85 (3.72)	N/A	40 (1.74)
1-year	140 (6.15)	85 (3.72)	N/A	55 (2.43)
5-year	163 (7.15)	85 (3.72)	N/A	78 (3.43)
10-year	179 (7.83)	85 (3.72)	N/A	94 (4.10)
Proposed Condition				
Design peak hourly flow		131 (5.74)	44 (1.93)	
3-month	132 (5.80)	131 (5.74)	1 (0.06)*	-
1-year	158 (6.93)	131 (5.74)	27 (1.19)	-
5-year	172 (7.55)	131 (5.74)	41 (1.91)	-
10-year	182 (7.98)	131 (5.74)	44 (1.93)	7 (0.31)
No-action on proposed condition				
Design peak hourly flow		85 (3.72)	N/A	
3-month	132 (5.80)	85 (3.72)	N/A	47 (2.08)
1-year	158 (6.93)	85 (3.72)	N/A	73 (3.21)
5-year	172 (7.55)	85 (3.72)	N/A	87 (3.83)
10-year	182 (7.98)	85 (3.72)	N/A	97 (4.25)

Note: * This volume will be temporarily stored in CEPT and later rerouted through the full treatment.

Table 6. Total volumes discharged through individual FMWRD facilities, mil. gallons (mil. m^3)

Design storm	*Total*	*Treated effluent*	*CEPT*	*CSO*
Existing condition				
3-month	325 (1.23)	306 (1.16)	N/A	18.9 (0.07)
1-year	329 (1.25)	306 (1.16)	N/A	22.5 (0.09)
5-year	334 (1.27)	306 (1.16)	N/A	27.7 (0.10)
10-year	338 (1.28)	306 (1.16)	N/A	31.0 (0.12)
Proposed condition				
3-month	431 (1.63)	429 (1.62)	0.03 (<.01)*	-
1-year	449 (1.70)	441 (1.67)	5.52 (0.02)	-
5-year	453 (1.72)	441 (1.67)	9.84 (0.04)	-
10-year	458 (1.73)	442 (1.67)	12.7 (0.05)	0.5 (<.01)
No-action on proposed condition				
3-month	431 (1.63)	376 (1.42)	N/A	53.3 (0.20)
1-year	449 (1.70)	376 (1.42)	N/A	70.6 (0.27)
5-year	453 (1.72)	376 (1.42)	N/A	75.3 (0.29)
10-year	458 (1.73)	376 (1.42)	N/A	79.9 (0.30)

Note: Volume discharged during the storm only (10 a.m. on 5/11/2002–4 a.m. on 5/16/2002)
* This volume will be temporarily stored in CEPT and later rerouted through the full treatment.

Several scenarios were simulated for each condition (Table 7). Although CSOs occur under wet weather conditions, they do not necessarily coincide with high flows in the Fox River, as the storm(s) causing CSOs may be local. Two flows in the Fox River were selected: a low flow, Q-25 (statistically, 25% of days the Fox River flow is less than or equal to Q-25), representing conditions when the FMWRD discharges would have a larger impact, and a medium flow, Q-50 (statistically, 50% of days the Fox River flow is lower or equal to Q-50), representing more common conditions. For each flow, low and high water quality concentrations were assumed in the river calculated as the 25th and 75th percentile of observed values at Mill Street in Aurora. Numerical values for 25th, 50th, and 75th percentiles used in simulations are shown in Table 8. These four combinations represent a most probable range of impacts for each design storm. High flow was not simulated as the impact of the FMWRD discharge decreases with increasing flow in the Fox River due to the dilution effect.

Table 7. List of scenarios

Scenario	*Constituents*	*FMWRD Concentration*	*FMWRD Condition*	*Storm*	*Flow*	*Fox Concentration*
1	All	MID	Existing	1yr	LOW	HI
2						LOW
3					MID	HI
4						LOW
5				5yr	LOW	HI
6						LOW
7					MID	HI
8						LOW
9				10yr	LOW	HI
10						LOW
11					MID	HI
12						LOW
13					HI	HI
14			Proposed	1yr	LOW	HI
15						LOW
16					MID	HI
17						LOW
18				5yr	LOW	HI
19						LOW
20					MID	HI
21						LOW
22				10yr	LOW	HI
23						LOW
24					MID	HI
25						LOW
26					HI	HI
27			No_Action	5yr	LOW	HI
28						LOW
29					MID	HI
30						LOW
31				10yr	LOW	HI
32						LOW
33					MID	HI
34						LOW

Table 7. Concluded

Scenario	*Constituents*	*FMWRD Concentration*	*FMWRD Condition*	*Storm*	*Flow*	*Fox Concentration*
35	Fecal coliform	HI	Existing	1yr	LOW	HI
36						LOW
37					MID	HI
38						LOW
39				5yr	LOW	HI
40						LOW
41					MID	HI
42						LOW
43				10yr	LOW	HI
44						LOW
45					MID	HI
46						LOW
47			Proposed	1yr	LOW	HI
48						LOW
49					MID	HI
50						LOW
51				5yr	LOW	HI
52						LOW
53					MID	HI
54						LOW
55				10yr	LOW	HI
56						LOW
57					MID	HI
58						LOW
61	Ammonia and total phosphorus	MID	Existing	3 month	LOW	HI
62						LOW
63					MID	HI
64						LOW
65			Proposed	3 month	LOW	HI
66						LOW
67					MID	HI
68						LOW

Notes: MID = average value or 50th percentile, HI = high value or 75th percentile, and LOW = low value or 25th percentile
Scenarios 13, 26, and 31–34 were not simulated at this time.

Table 8. Upstream conditions considered for Fox River at Mill Street, Aurora

Constituent	*Unit*	*Low* 25th percentile	*Medium* 50th percentile	*High* 75th percentile
Flow+	cfs	491	865	1,570*
Fecal coliforms	cfu/100 ml	113	236*	488
BOD_5	mg/l	1	3*	4
Total suspended solids	mg/l	24	31*	42
Nitrate nitrogen	mg/l	0.76	1.04*	1.38
Ammonia nitrogen	mg/l	0.02	0.04*	0.10
Organic nitrogen	mg/l	1.32	1.47*	1.75
Total nitrogen**	mg/l	2.10	2.55*	3.23
Total phosphorus	mg/l	0.26	0.30*	0.35

Notes: + Source: ISWS, 2009
* not used in simulations at this time
** calculated as a sum of nitrogen forms

Methods to Evaluate Impact on Water Quality

The impact of proposed expansions at the FMWRD on water quality in the Fox River is evaluated in two different ways. First, a change between existing and proposed conditions is quantified to ensure no degradation will result from the expansion during storm events. The following measures were considered: maximum simulated value and duration of concentrations above those simulated under dry weather conditions (i.e, length of the time period when simulated values were consistently above 110% of maximum concentrations simulated during dry weather conditions 24 hours prior to the storm). A higher threshold (120%) was used for fecal coliform analyses to account for larger natural variations in fecal coliform observations.

Second, compliance with existing water quality standards is evaluated. The Illinois Pollution Control Board publishes water quality standards in Illinois. Two sections of Title 35 of the Illinois Administrative Code (IAC), Section 302, *Water Quality Standards* and Section 303, *Water Use Designations and Site Specific Water Quality Standards*, contain the standards applicable to lakes and streams in Illinois.

The *Water Quality Standards* define threshold concentrations and methods of determining the threshold concentration or conditions for pH, phosphorus, dissolved oxygen, radioactivity, chemical constituents, including heavy metals and hydrocarbons, fecal coliform, toxic substances, temperature, and ammonia. The study reach falls under general water quality standards and the reach from Indian Creek to Route 34 falls under enhanced dissolved oxygen standards. Numerical values are discussed for evaluated constituents in their respective sections.

Not all simulated water quality constituents have water quality standards applicable to the study reach. The IEPA uses numerical values that list the constituent as a cause of impairment for constituents without a specific water quality standard, e.g., total suspended solids and total phosphorus (IEPA, 2006a, 2008).

Comparisons to water quality standards were carried out as required by *Water Quality Standards* with mandatory averaging periods where necessary. The listing values for constituents without Illinois water quality standards were used as maximum allowable concentrations. Any simulated value exceeding the listing values would be considered a violation. This is consistent with the IEPA's use of the listing values.

Fecal Coliforms

Fecal Coliform Water Quality Standards

Fecal coliform standards are applicable between May and October. A minimum of five samples collected over 30 days or less should be used to calculate the geometric mean and a concentration exceeded in 10% of the samples (90th percentile). The *Water Quality Standards* state that "*fecal coliform shall not exceed a geometric mean of 200 per 100 ml, nor shall more than 10% of the samples during any 30 day period exceed 400 per 100 ml.*"

It is important to note the length of the averaging period and the number of samples needed to interpret compliance with water quality standards. On one hand, regular monthly sampling does not satisfy the data requirements for evaluation, while on the other hand, intensive storm event sampling may produce a sufficient number of samples, but samples are biased toward the conditions affected by the sampled storm event. The interpretation of the standard as it applies to event or design storm simulations is not clearly specified in the Water Quality Standards.

Impact of Proposed Modifications

Proposed conditions include disinfection for both fully and partially treated water. The FMWRD NPDES permit allows for discharge of concentrations at or below 400 colony forming units per 100 mililiters (cfu/100 ml). However, the facilities are designed to disinfect to lower levels. Table 9 shows the probability of fecal coliform concentrations at the existing FMWRD outfall falling at or below selected concentrations based on 2007–2009 Discharge Monitoring Report (DNR) data (392 data points). More than 55% of the time, the effluent fecal coliform concentration is 1 cfu/100ml. About 95% of values reported for the FMWRD outfall are 50 cfu/100 ml or below. Two concentrations were selected to evaluate the change in fecal coliform concentrations in Fox River with proposed modifications at the FMWRD: the maximum permitted concentration (400 cfu/100 ml) to evaluate the worst possible impact under minimal treatment levels and the median concentration (1 cfu/100 ml) to evaluate the impact under normal treatment levels. Fecal coliform concentrations in CSOs also varied. Data collected by WEDA indicate median concentrations of 900,000 cfu/100 ml (used with normal-level treatment scenarios) and high concentrations of 2,840,000 cfu/100 ml (used with minimal-level treatment scenarios) for the FMWRD CSO.

Table 9. Probability of fecal coliform concentrations in the FMWRD treated effluent

Fecal coliform concentration, cfu/100 ml	*Probability the concentration in FMWRD effluent is at or below stated value*
1	55.6%
10	85.5%
50	95.7%
100	97.7%
150	98.2%
200	98.2%
300	99.0%
400	99.2%

Figure 19 shows simulated fecal coliform bacteria at Route 34 under both existing and proposed conditions for three design rains assuming a normal treatment level. Proposed conditions result in no impact for design storms of a 5-year or smaller return interval. The impact is also significantly reduced for the 10-year storm. The highest simulated concentrations under existing conditions are 95,300 cfu/100 ml, 131,000 cfu/100 ml, and 152,000 for the 1-year, 5-year, and 10-year design storm, respectively (Table 10). Note that the expression "simulated concentrations" within this report signify Fox River ambient concentrations simulated at Route 34 as cross-sectional average concentrations. The highest simulated concentrations under proposed conditions are 423 cfu/100 ml, 423 cfu/100 ml, and 7,990 cfu/100 ml for the 1-year, 5-year, and 10-year design storm, respectively (Table 10). The FMWRD effluent treated to normal levels lowers Fox River fecal coliform concentrations by dilution. The CSO during the 10-year storm causes a significant increase in ambient concentrations above normal concentrations. However, the duration of the concentration increase caused by the 10-year storm was reduced from 1.4 or 1.5 days to 0.2 days, or by 84 to 88%.

Figure 20 shows simulated fecal coliform bacteria at Route 34 under both existing and proposed conditions for three design rains, assuming a minimal treatment level. Proposed conditions result in no impact for design storms of the 5-year or smaller return interval. The impact is also significantly reduced for the 10-year storm. The highest simulated concentrations under existing conditions are 300,000 cfu/100 ml, 413,000 cfu/100 ml, and 480,000 for the 1-year, 5-year, and 10-year design storm, respectively (Table 11).

Under the minimal treatment level for proposed conditions, ambient concentrations simulated during the storm increase above ambient concentrations simulated during the dry weather discharge even for 1-year and 5-year storms, assuming a low upstream concentration in Fox River. The simulated increases of 31–52 cfu/100 ml result in peak concentrations of 166–191 cfu/100 ml. These highest simulated concentrations are close to the standard numerical value (200 cfu/100 ml), and measured concentrations in actual samples collected during these events may exceed 200 cfu/100 ml due to a large natural variation exhibited by fecal coliform bacteria in streams. Duplicate samples (samples collected at the same location at the same time) often vary by 20 to 40% in the Fox River (Bartosova et al., 2010; data collected by the Fox River Study Group, Inc.) However, fecal coliform concentration in treated effluent simulated under the minimal treatment level occurs only on less than 1% of days (Table 9).

The CSO discharge during the 10-year storm causes a significant increase in ambient concentrations above normal concentrations. However, the duration of the concentration increase caused by the 10-year storm was reduced from 1.5 days (existing conditions) to 0.2 to 0.3 days (proposed conditions), or by 83 to 86%, for scenarios with high upstream boundary concentrations. For scenarios with low upstream boundary concentrations, the duration of the increase was reduced by 12 to 74%, depending on the Fox River flow. For low upstream concentrations, the FMWRD effluent treated to a minimal level will result in an increase above 20% when compared to dry weather discharge, impacting the reported duration. The increase caused by the CSO itself is limited to 0.3–0.4 days only. Proposed conditions result in 94 to 100% reduction of maximum concentrations for both normal and minimal treatment levels (Table 12 and Table 13).

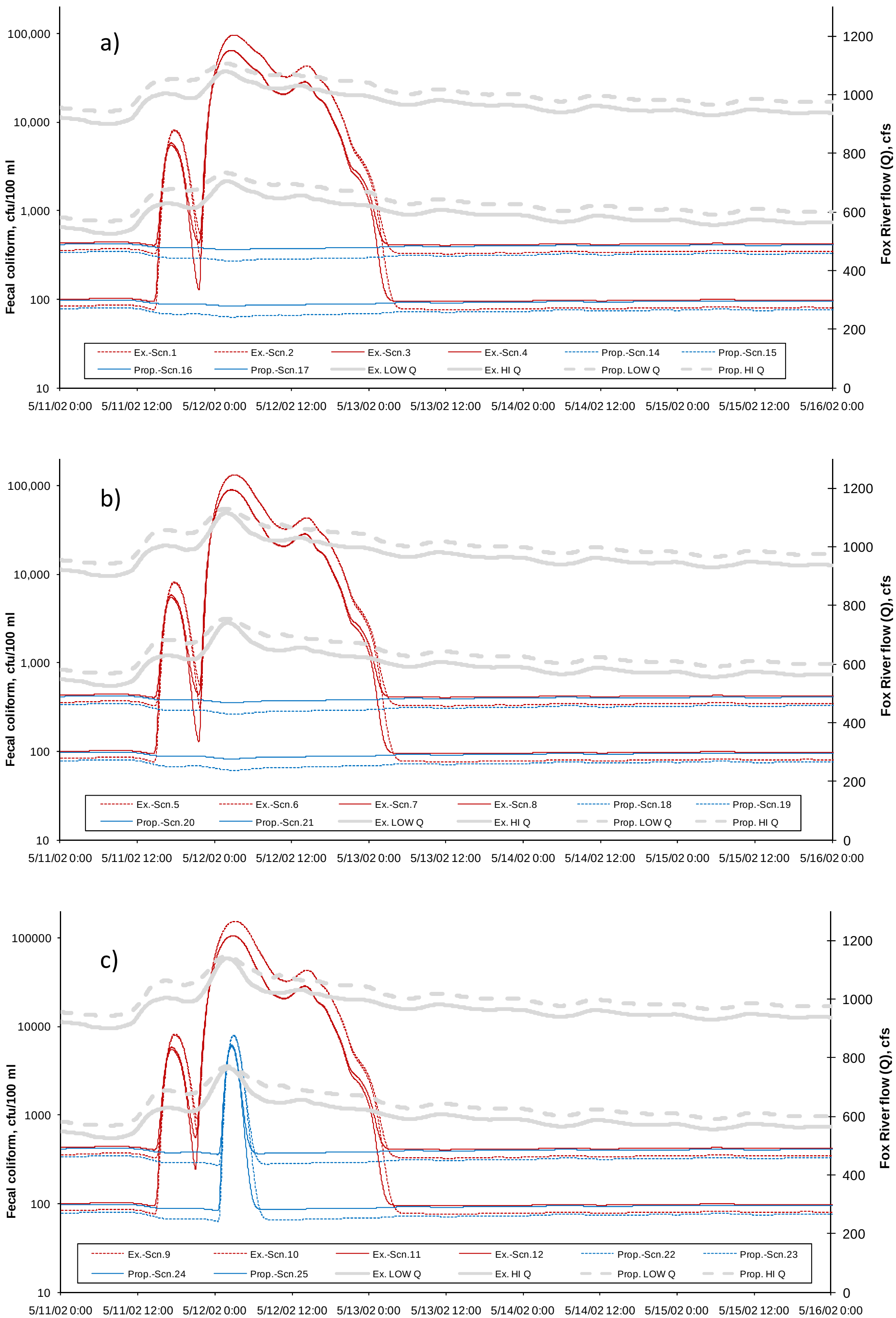


Figure 19. Fecal coliform at Route 34 under existing and proposed conditions (normal treatment level): a) 1-year storm, b) 5-year storm, and c) 10-year storm

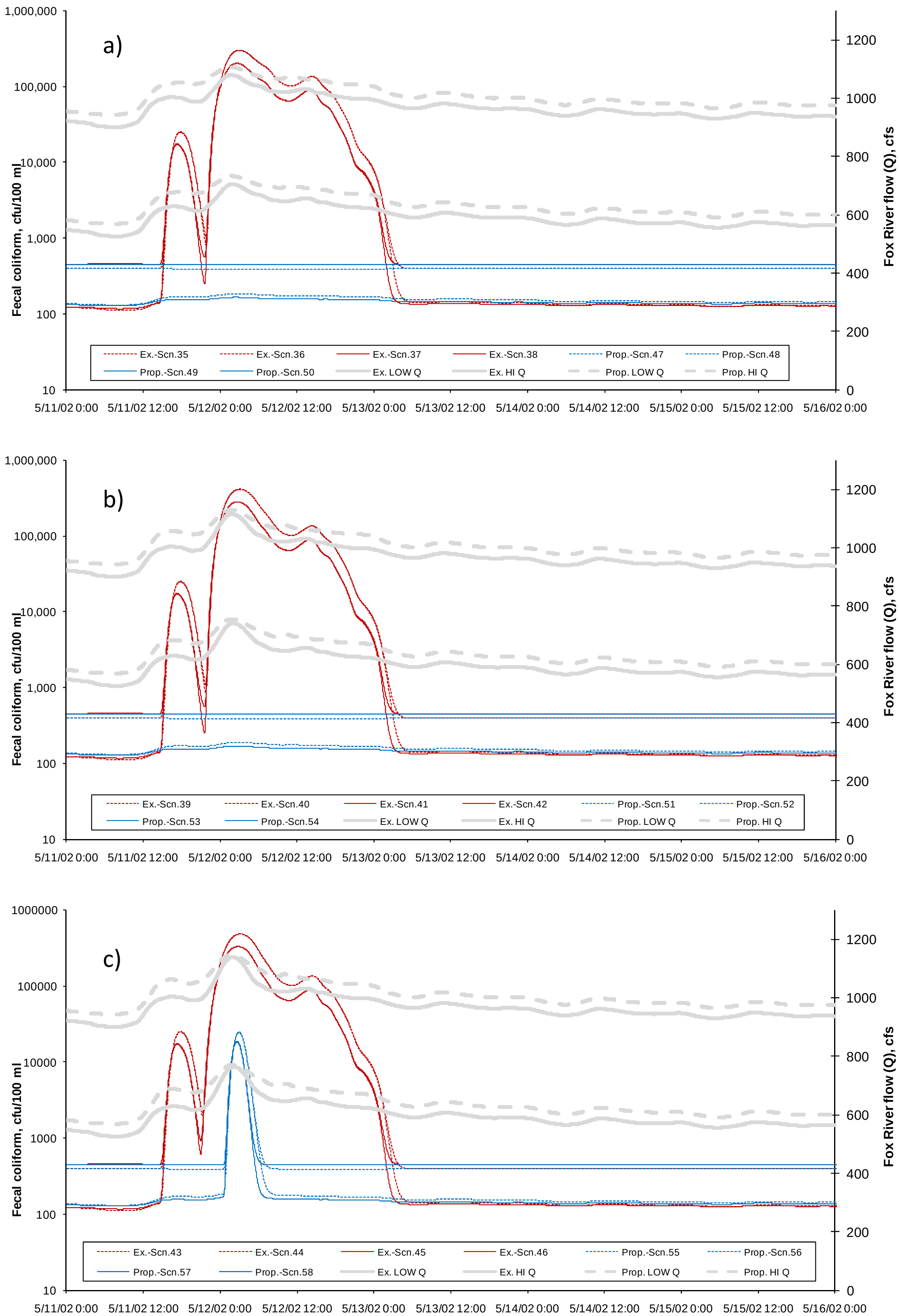


Figure 20. Fecal coliform at Route 34 under existing and proposed conditions (minimal treatment level): a) 1-year storm, b) 5-year storm, and c) 10-year storm

Table 10. Simulated fecal coliform maximum, maximum increase, and duration of increase above dry weather conditions during design storms (normal treatment level)

Storm	Existing				Proposed			
	Scenario	*Max cfu/100ml*	*Increase cfu/100ml*	*Duration days*	*Scenario*	*Max cfu/100ml*	*Increase cfu/100ml*	*Duration days*
1 year	1	95,300	94,900	1.5	14	346	*	*
	2	95,100	95,000	1.5	15	81	*	*
	3	64,100	63,700	1.4	16	423	*	*
	4	63,800	63,700	1.5	17	98	*	*
5 year	5	131,000	131,000	1.5	18	346	*	*
	6	131,000	131,000	1.5	19	81	*	*
	7	89,100	88,700	1.4	20	423	*	*
	8	88,800	88,700	1.5	21	98	*	*
10 year	9	152,000	152,000	1.5	22	7,990	7,640	0.2
	10	152,000	152,000	1.5	23	7,790	7,710	0.2
	11	105,000	105,000	1.4	24	6,130	5,710	0.2
	12	104,000	105,000	1.5	25	5,870	5,770	0.2

Note: Values rounded to three significant digits
* No increase above 20% of dry weather concentrations during design storm. Corresponding maximum concentration may occur outside the storm impact.

Table 11. Simulated fecal coliform maximum, maximum increase, and duration of increase above dry weather conditions during design storms (minimal-treatment level)

Storm	Existing				Proposed			
	Scenario	*Max cfu/100ml*	*Increase cfu/100ml*	*Duration days*	*Scenario*	*Max cfu/100ml*	*Increase cfu/100ml*	*Duration days*
1 year	35	300,000	300,000	1.5	47	396	*	*
	36	300,000	300,000	1.6	48	185	46	1.4
	37	201,000	201,000	1.5	49	454	*	*
	38	201,000	201,000	1.5	50	166	31	0.2
5 year	39	413,000	413,000	1.5	51	396	*	*
	40	413,000	413,000	1.6	52	191	52	1.4
	41	280,000	280,000	1.5	53	454	*	*
	42	280,000	280,000	1.5	54	170	35	0.3
10 year	43	480,000	480,000	1.5	55	24,800	24,400	0.3
	44	480,000	480,000	1.6	56	24,600	24,500	1.4
	45	329,000	329,000	1.5	57	18,700	18,200	0.2
	46	329,000	329,000	1.5	58	18,400	18,300	0.4

Note: Values rounded to three significant digits
* No increase above 20% of dry weather concentrations during design storm. Corresponding maximum concentration may occur outside the storm impact.

Table 12. Percent reduction in simulated fecal coliform maximum, maximum increase, and duration of increase above dry weather conditions during design storms (median treatment level)

Scenarios	*Max*	*Increase*	*Duration*	*Scenarios*	*Max*	*Increase*	*Duration*
	1 year				*10 year*		
1-14	100%	100%	100%	9-22	95%	95%	86%
2-15	100%	100%	100%	10-23	95%	95%	84%
3-16	100%	100%	100%	11-24	94%	95%	88%
4-17	100%	100%	100%	12-25	94%	95%	86%
	5 year						
5-18	100%	100%	100%				
6-19	100%	100%	100%				
7-20	100%	100%	100%				
8-21	100%	100%	100%				

Table 13. Percent reduction in simulated fecal coliform maximum, maximum increase, and duration of increase above dry weather conditions during design storms (minimal treatment level)

Scenarios	*Max*	*Increase*	*Duration*	*Scenarios*	*Max*	*Increase*	*Duration*
	1 year				*10 year*		
35-47	100%	100%	100%	43-55	95%	95%	83%
36-48	100%	100%	14%	44-56	95%	95%	12%
37-49	100%	100%	100%	45-57	94%	94%	86%
38-50	100%	100%	85%	46-58	94%	94%	74%
	5 year						
39-51	100%	100%	100%				
40-52	100%	100%	13%				
41-53	100%	100%	100%				
42-54	100%	100%	79%				

Effluent fecal coliform concentrations assuming a normal treatment level are significantly lower than numerical values specified for the water quality standard. Under normal treatment levels, the FMWRD discharges from up to the 5-year storm do not cause any exceedance of water quality standards. In fact, the discharge lowers fecal coliform concentrations in the Fox River by dilution. Note that the highest concentrations discharged under proposed conditions for 1-year and 5-year storms are affected by concentrations upstream of the FMWRD and are lower than the upstream concentration (488 cfu/100ml, Table 8).

Under the minimal treatment level, the FMWRD effluent is at or above numerical values for both standards. Simulated concentrations would not cause an exceedance for 1-year and 5-year storms when other samples collected during the same 30-day period would be below 160 cfu/100 ml (Table 14). Again, fecal coliform concentration in treated effluent simulated under the minimal treatment level occurs only on less than 1% of days (Table 9).

Storms larger than the 5-year storm result in CSO, which in turn results in high peak concentrations in the Fox River. To achieve compliance with water quality standards, the other four samples collected during the same 30-day period as a sample during maximum concentration after the 10-year storm would need to be below 80 cfu/100 ml for a normal treatment level and below 60 cfu/100 ml for a minimal treatment level (Table 14).

Table 14. Maximum concentrations allowed for four supplemental water quality samples collected during the same 30-day period as maximum simulated concentrations to achieve compliance with water quality standards (geometric mean less than 200 cfu/100 ml)

Storm	*Scenario*	*Normal treatment*		*Minimal treatment*	
		Max simulated cfu/100ml	*Max allowed cfu/100ml*	*Max simulated cfu/100ml*	*Max allowed cfu/100ml*
1 year	47	346	174	396	169
	48	81	251	185	204
	49	423	166	454	163
	50	98	239	166	210
5 year	51	346	174	396	169
	52	81	251	191	202
	53	423	166	454	163
	54	98	239	170	208
10 year	55	7,990	80	24,800	60
	56	7,790	80	24,600	60
	57	6,130	85	18,700	64
	58	5,870	86	18,400	65

Total Suspended Solids

Total Suspended Solids Water Quality Standards

The Illinois Pollution Control Board does not define a standard for total suspended solids. The Illinois Environmental Protection Agency uses a value of 116 mg/l as a threshold to identify total suspended solids as a potential cause for impaired waters (IEPA, 2008). A single exceedance is sufficient to list total suspended solids as a potential cause of impairment.

Impact of Proposed Modifications

Figure 21 shows simulated total suspended solid concentrations at Route 34 under both existing and proposed conditions for three design rains. The FMWRD storm discharges cause only a small variation of total suspended solid concentrations (mostly within ±5 mg/l) as simulated during dry weather. Note that for scenarios with a high concentration of total suspended solids in the Fox River at Mill Street (odd-number scenarios), the fully treated storm discharges from the FMWRD actually lower the simulated concentrations at first (Figure 21).

The highest simulated concentrations during the storms are 38.9 mg/l and 36.3 mg/l for existing and proposed conditions, both significantly below the listing value of 116 mg/l (Table 15). The FMWRD discharges do not trigger exceedances of the listing value and would not cause the reach to be listed with total suspended solids as a cause of impairment. Proposed conditions result in slightly lower ambient concentrations than existing conditions, less than 10% for any scenario (Table 15).

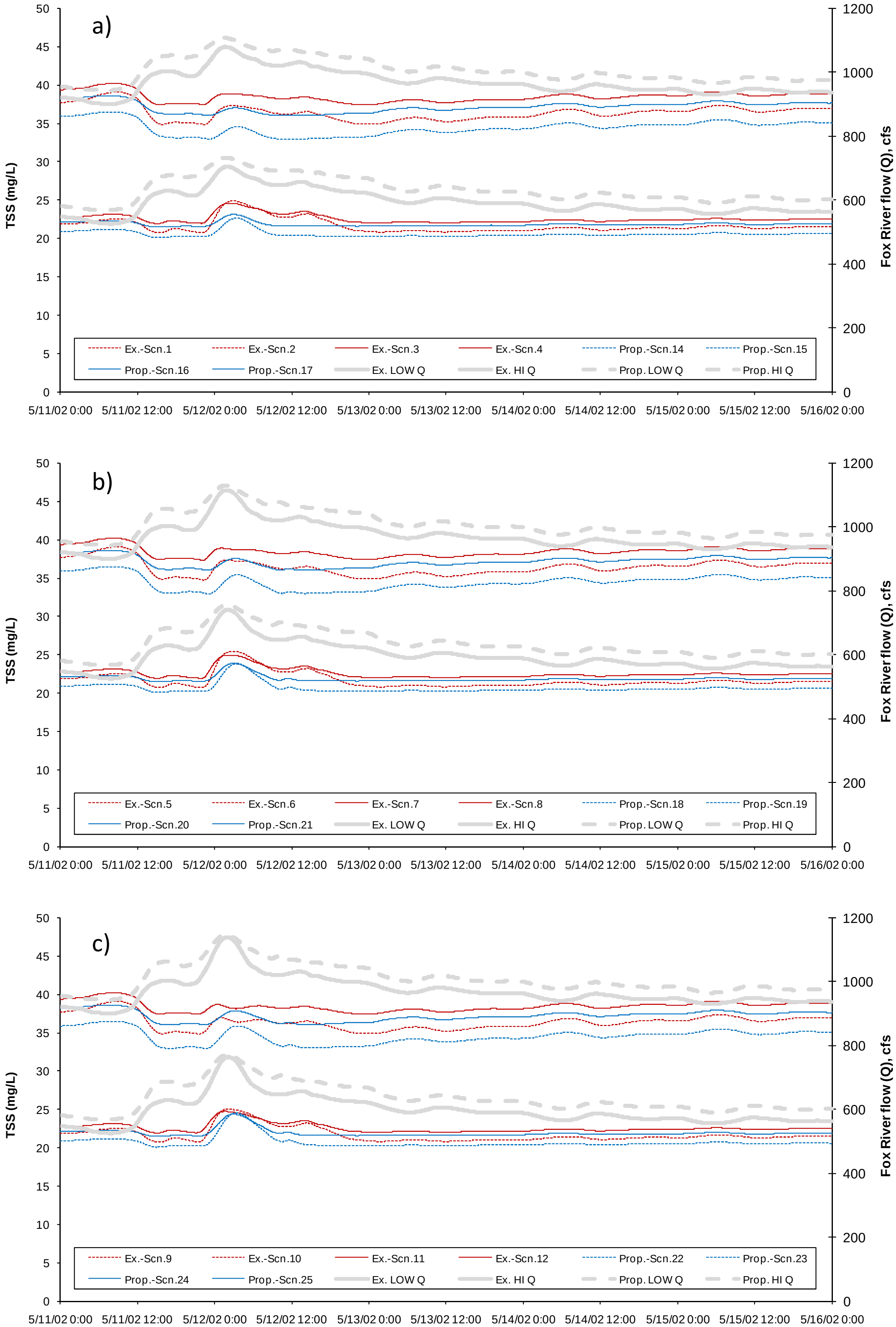


Figure 21. Total suspended solids (TSS) at Route 34 under existing and proposed conditions: a) 1-year storm, b) 5-year storm, and c) 10-year storm

Table 15. Simulated total suspended solids maximum concentrations (mg/l) and percent reduction

Storm	Existing Scenario	Existing Max mg/l	Proposed Scenario	Proposed Max mg/l	Reduction Max %
1 year	1	38.9	14	36.3	7
	2	24.9	15	22.6	9
	3	40.0	16	38.4	4
	4	24.6	17	23.1	6
5 year	5	38.9	18	36.3	7
	6	25.4	19	23.8	6
	7	40.0	20	38.4	4
	8	25.0	21	23.9	4
10 year	9	38.9	22	36.3	7
	10	25.6	23	24.5	4
	11	40.0	24	38.4	4
	12	25.1	25	24.4	3

Ammonia Nitrogen

Total Ammonia Nitrogen Water Quality Standards

There are four standards for total ammonia nitrogen: the maximum value, which is not to be exceeded at any time (15 mg/l), and the acute, chronic, and subchronic standards that vary with pH and/or temperature. Additionally, the chronic and subchronic standards are defined separately for Early Life Stage Present (March 1 to October 31) and Early Life Stage Absent (ELSA) (November 1 to February 28/29) seasons. The acute standard is considered violated if at any time a sample has a concentration higher than the calculated acute standard. The acute standard (AS) varies with water pH:

$$AS = \frac{0.411}{1+10^{7.204-pH}} + \frac{58.4}{1+10^{pH-7.204}}$$

The chronic standard is designed to protect aquatic organisms from long-term effects of increased concentration. As the chronic standard varies with water temperature and pH, these two measurements must be taken at the time of collecting ammonia samples. The ammonia nitrogen concentration is divided by the chronic standard calculated for conditions observed when a sample is collected to determine a quotient. The chronic standard is attained when a 30-day average quotient calculated from at least four samples collected to statistically represent the sampling period is less than or equal to one. During the Early Life Stage Present (ELSP) period the chronic standard (CS) is:

When water temperature T (°C) ≤14.51°C: $CS = \left\{ \frac{0.0577}{1+10^{7.688-pH}} + \frac{2.487}{1+10^{pH-7.688}} \right\} (2.85)$

T(°C)>14.51°C: $CS = \left\{ \frac{0.0577}{1+10^{7.688-pH}} + \frac{2.487}{1+10^{pH-7.688}} \right\} \left(1.45 * 10^{0.028*(25-T)}\right)$

During the Early Life Stage Absent (ELSA) period the chronic standard is:

When water temperature T (°C) ≤ 7°C: $CS = \left\{ \frac{0.0577}{1+10^{7.688-pH}} + \frac{2.487}{1+10^{pH-7.688}} \right\} \left(1.45 * 10^{0.504}\right)$

T (°C) > 7°C: $CS = \left\{ \frac{0.0577}{1+10^{7.688-pH}} + \frac{2.487}{1+10^{pH-7.688}} \right\} \left(1.45 * 10^{0.028*(25-T)}\right)$

The subchronic standard is calculated by multiplying the chronic standard by 2.5. The subchronic standard is attained when an average quotient calculated for samples collected on four consecutive days is less than or equal to one.

Impact of Proposed Modification

Figure 22 shows simulated total ammonia concentrations at Route 34 under both existing and proposed conditions for three design storms. Figure 23 shows simulated total ammonia concentrations at Route 34 under both existing and proposed conditions for the 3-month design storm to illustrate the effect of discharges when CEPT is not used. Total ammonia concentrations were also simulated for the 5-year design storm assuming "no action" conditions, i.e., future discharges treated using existing facilities only (Figure 24).

Proposed conditions result in lower maximum concentrations than existing conditions. The highest simulated concentrations under existing conditions are 0.62 mg/l, 0.71 mg/l, 0.81 mg/l, and 0.85 mg/l for the 3-month, 1-year, 5-year, and 10-year design storms, respectively (Table 16). The highest simulated concentrations under proposed conditions are 0.30 mg/l, 0.58 mg/l, 0.70 mg/l, and 0.78 mg/l for 3-month, 1-year, 5-year, and 10-year design storms, respectively (Table 16). Proposed conditions result in a 48–58%, 17–20%, 12–14%, and 9–10% reduction of maximum concentration for 3-month, 1-year, 5-year, and 10-year storms, respectively (Table 17). The highest simulated concentration under "no action" conditions for the 5-year storm is 1.11 mg/l. Proposed conditions also represent a 35–39% reduction when compared to "no action" conditions (Table 18).

Interpretation of the compliance with water quality standards is not trivial for design rain simulations. First, chronic and subchronic standards are defined for 30-day and 4-day averages, respectively. At least four samples are required for chronic standard evaluation. One of these samples was assumed to be taken at the peak of the pollutograph, i.e., the value corresponds to the maximum concentration during the storm-discharge affected increase. The remaining three samples were assumed to be equal to 50th and 95th percentiles of existing concentrations observed at Route 34. The 50th percentile (0.028 mg/l during ELSP and 0.057 mg/l during ELSA) is used to evaluate compliance with water quality standards under normal ambient conditions. The 95th percentile (0.143 mg/l during ELSP and 0.556 mg/l during ELSA) is used to evaluate compliance with water quality standards under critical, worst-case ambient conditions.

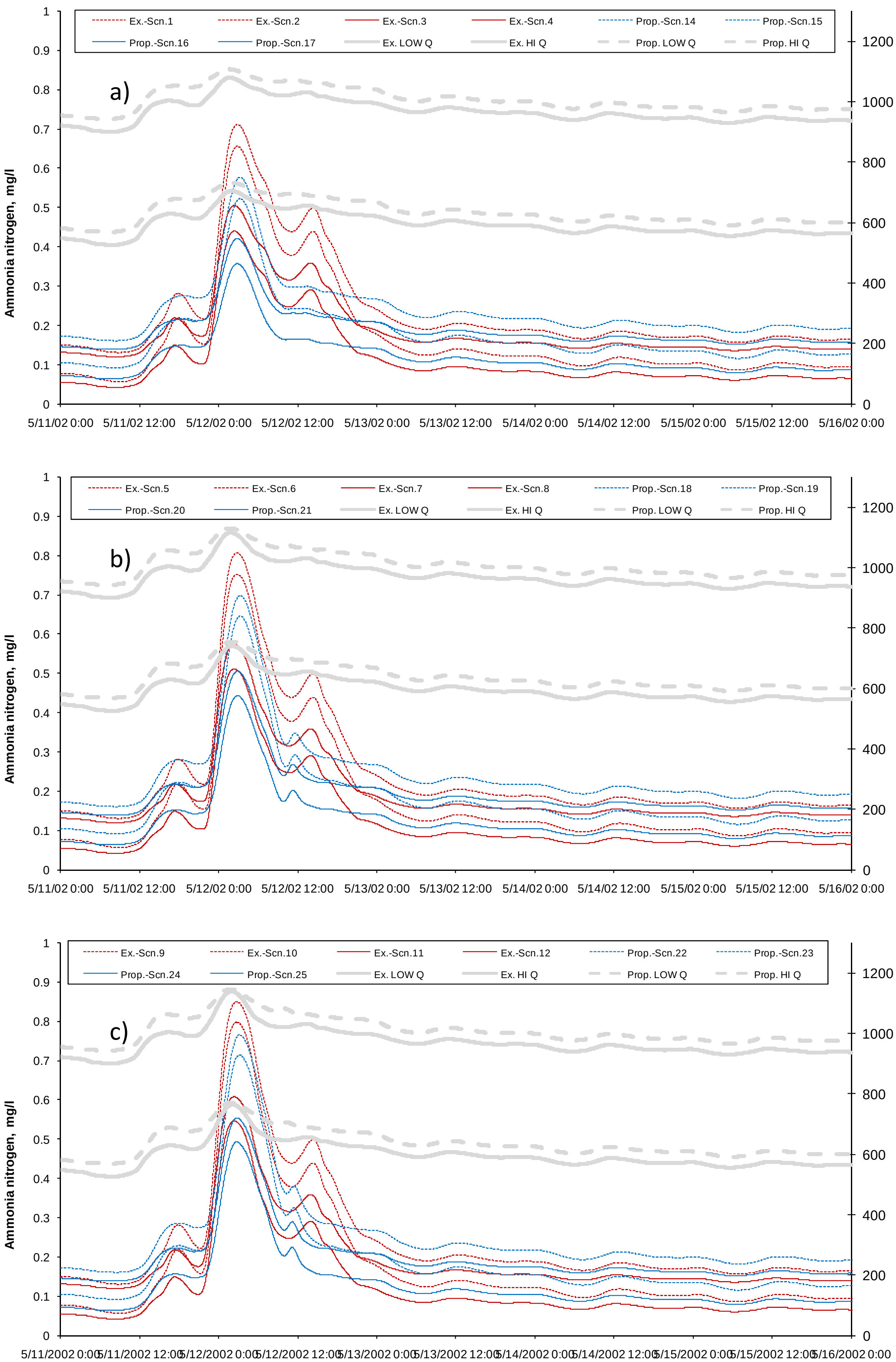


Figure 22. Ammonia nitrogen at Route 34 under existing and proposed conditions: a) 1-year storm, b) 5-year storm, and c) 10-year storm

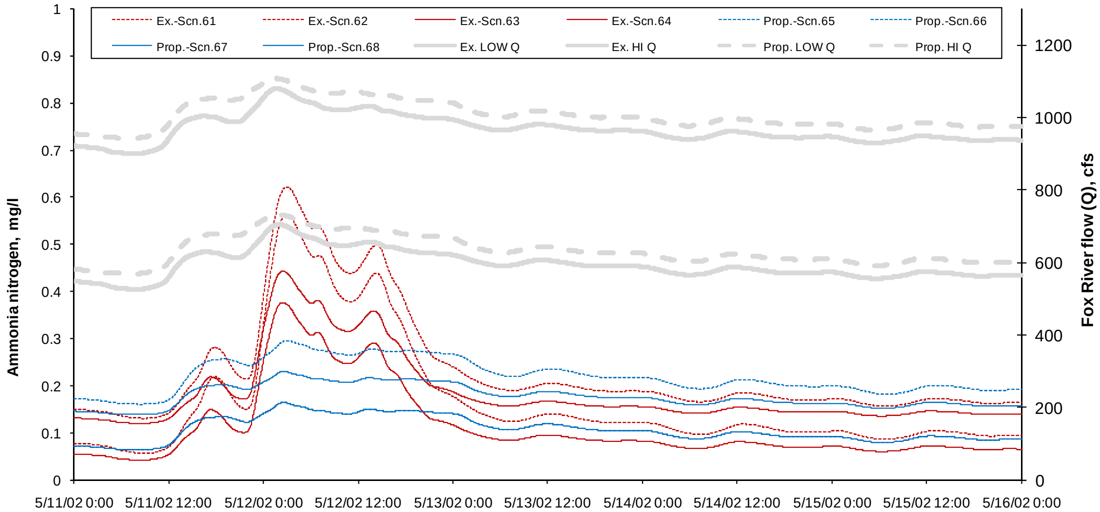


Figure 23. Ammonia nitrogen at Route 34 under existing and proposed conditions: 3-month storm

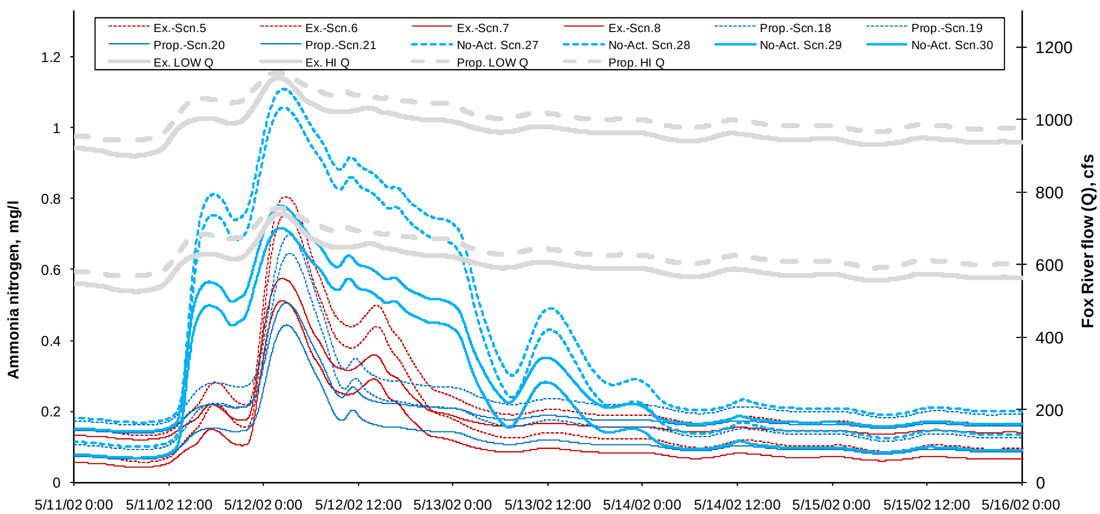


Figure 24. Ammonia nitrogen at Route 34 under existing, proposed,
and no-action conditions: 5-year storm

Table 16. Simulated ammonia nitrogen maximum, maximum increase, and duration of increase above dry weather conditions during design storms

Storm	*Existing*				*Proposed*			
	Scenario	*Max mg/l*	*Increase mg/l*	*Duration days*	*Scenario*	*Max mg/l*	*Increase mg/l*	*Duration days*
1 year	1	0.71	0.56	3.6	14	0.58	0.40	3.6
	2	0.66	0.57	4.3	15	0.52	0.41	4.3
	3	0.51	0.37	2.9	16	0.42	0.27	2.9
	4	0.44	0.38	4.3	17	0.36	0.28	4.1
5 year	5	0.81	0.65	3.6	18	0.70	0.52	3.6
	6	0.75	0.67	4.3	19	0.65	0.53	4.3
	7	0.57	0.44	2.9	20	0.51	0.35	2.9
	8	0.51	0.45	4.3	21	0.44	0.37	4.1
10 year	9	0.85	0.70	3.6	22	0.77	0.59	3.6
	10	0.80	0.71	4.3	23	0.71	0.60	4.3
	11	0.61	0.47	2.9	24	0.55	0.40	2.9
	12	0.55	0.49	4.3	25	0.49	0.41	4.1
3 month	61	0.62	0.47	3.6	65	0.30	0.12	3.5
	62	0.56	0.48	4.3	66	0.24	0.13	4.3
	63	0.44	0.31	2.9	67	0.23	0.08	2.9
	64	0.38	0.32	4.3	68	0.16	0.09	4.1

Table 17. Percent reduction in simulated ammonia nitrogen maximum, maximum increase, and duration of increase above dry weather conditions during design storms

Scenarios	*Max*	*Increase*	*Duration*	*Scenarios*	*Max*	*Increase*	*Duration*
	1 year				*10 year*		
1-14	19%	29%	2%	9-22	10%	16%	2%
2-15	20%	28%	1%	10-23	10%	16%	1%
3-16	17%	27%	-1%	11-24	9%	15%	-1%
4-17	19%	27%	3%	12-25	10%	15%	4%
	5 year				*3 month*		
5-18	13%	20%	2%	61-65	52%	75%	2%
6-19	14%	20%	1%	62-66	58%	74%	1%
7-20	12%	19%	0%	63-67	48%	74%	0%
8-21	13%	19%	4%	64-68	56%	73%	4%

Table 18. Maximum ammonia nitrogen for "no-action" conditions and percent reduction for proposed conditions when compared to "no-action" conditions (5-year storm only)

Scenario	*Max mg/l*	*Increase mg/l*	*Duration days*	*Scenarios*	*Max %*	*Increase %*	*Duration %*
27	1.11	0.92	3.5	27-18	37%	44%	0%
28	1.06	0.93	4.2	28-19	39%	43%	-2%
29	0.78	0.62	2.9	29-20	35%	43%	0%
30	0.72	0.63	4.1	30-21	38%	42%	-1%

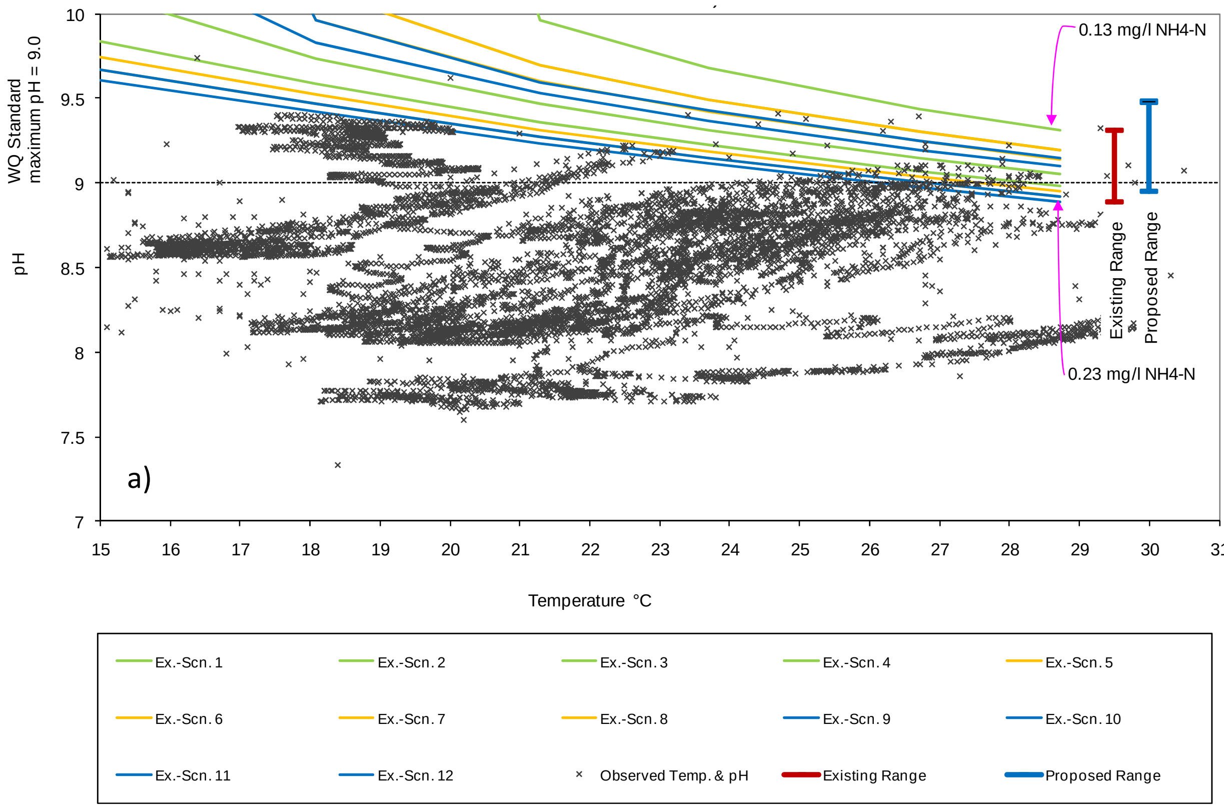
For subchronic standards, the 4-day average was calculated in two different ways: a) normal ambient conditions are represented by an average of all values simulated during 5/11–14, and b) critical ambient conditions are represented by an average of maximum daily values simulated during 5/11–14. Table 19 shows the calculated averages for each scenario assuming normal ambient conditions.

Second, the numerical values of the chronic, subchronic, and acute standards vary with pH and/or temperature. Chronic and subchronic standards are also defined differently for ELSP and ELSA periods. Theoretically, pH and temperature can vary significantly for each sample used to evaluate compliance with water quality standards. However, pH and temperatures during design storms cannot be determined without i) specifying their value in upstream boundary and all inputs for duration of the simulation, ii) simulating additional stream processes in detail (e.g., algal activity), and iii) determining exact timing of the storm. The extent of natural variation in pH and temperature that is observed at Route 34 represents a major obstacle to simulating all conditions or selecting representative conditions for water quality standards evaluation.

The following methodology was developed to evaluate compliance with chronic and subchronic ammonia water quality standards. All observed temperatures and pH combinations were plotted: temperature on the x-axis and pH observed at the same time on the y-axis (Figure 25). Each combination can be used to calculate a corresponding standard and create isolines by combining points with equal ammonia standard concentrations. To simplify the evaluation, isolines were created for 30-day and 4-day averages calculated for each scenario using the procedure described previously (Figure 25). These isolines represent a water quality standard valid for temperature and pH combinations that are situated on the isoline. Thus, any observations situated above the line represent observed conditions that would result in violation

Table 19. Approximated 30-day (chronic standard) and 4-day (subchronic standard) concentrations (50th)

Storm		*Existing*					*Proposed*			
		Chronic		*Subchronic*			*Chronic*		*Subchronic*	
	Scenario	*ELSP mg/l*	*ELSA mg/l*	*ELSP mg/l*	*ELSA mg/l*	*Scenario*	*ELSP mg/l*	*ELSA mg/l*	*ELSP mg/l*	*ELSA mg/l*
1 year	1	0.20	0.22	0.26	0.26	14	0.17	0.19	0.25	0.25
	2	0.18	0.21	0.19	0.19	15	0.15	0.17	0.19	0.19
	3	0.15	0.17	0.20	0.20	16	0.13	0.15	0.20	0.20
	4	0.13	0.15	0.13	0.13	17	0.11	0.13	0.21	0.21
5 year	5	0.22	0.24	0.26	0.26	18	0.20	0.22	0.26	0.26
	6	0.21	0.23	0.20	0.20	19	0.18	0.20	0.20	0.20
	7	0.16	0.19	0.21	0.21	20	0.15	0.17	0.21	0.21
	8	0.15	0.17	0.13	0.13	21	0.13	0.15	0.14	0.14
10 year	9	0.23	0.26	0.27	0.27	22	0.21	0.23	0.27	0.27
	10	0.22	0.24	0.20	0.20	23	0.20	0.22	0.21	0.21
	11	0.17	0.19	0.21	0.21	24	0.16	0.18	0.21	0.21
	12	0.16	0.18	0.14	0.14	25	0.14	0.17	0.14	0.14
							No Action			
5 year						27	0.30	0.32	0.48	0.48
						28	0.29	0.31	0.42	0.42
						29	0.22	0.24	0.35	0.35
						30	0.20	0.22	0.28	0.28



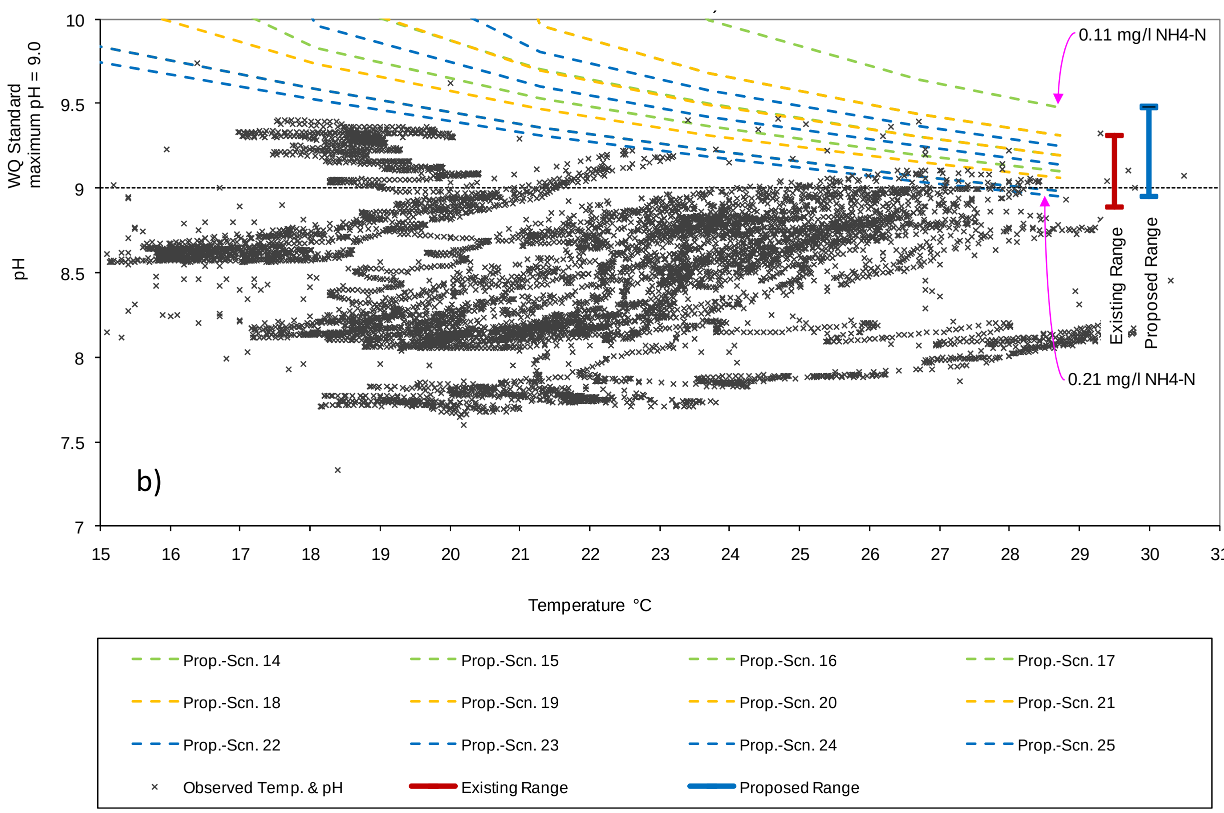


Figure 25. Chronic water quality standards (ELSP) for a) existing and b) proposed conditions (50th)

if the concentration corresponding to the isoline was observed at the same time as the observation. Since the isolines represent averages over respective periods as required by the water quality standard document, the underlying assumption is that the same pH and temperature was present for all samples used to calculate these averages. This assumption was necessary to simplify the complex requirements of ammonia water quality standards under the varying stream conditions as they apply to design storm simulations and to create a practical assessment tool.

Figure 25 and Figure 26 show isolines created for chronic water quality standards during ELSP for normal (50^{th} percentile) and critical (95^{th} percentile) ambient conditions, respectively. As explained previously, each simulated scenario is represented by an isoline. The points at or above the isolines for respective scenarios represent observed pH and temperature values in the Fox River under which water quality standards would not be met under the stated assumptions. For proposed conditions, possible violations assuming normal ambient conditions are mostly limited to observations of very high pH and/or very high temperatures. Violations for critical ambient conditions are more likely than for normal conditions but are still mostly limited to observations of high pH and/or high temperatures under proposed conditions.

The horizontal lines at the right side of the charts compare the range of isolines for existing and proposed conditions at a high temperature (29ºC for ELSP and 12ºC for ELSA), providing a frame of reference between the two charts. The upward shift of the line for proposed conditions versus existing conditions indicates an improvement in Fox River water quality and consequentially, a lower probability of violating the ammonia water quality standard. Note that the horizontal lines are plotted at higher temperatures than at which they are determined to allow better visibility of isolines.

Figure 27 and Figure 28 show isolines created for chronic water quality standards during ELSA for normal (50^{th} percentile) and critical (95^{th} percentile) ambient conditions, respectively. All isolines are located well above the pH=9 line. There are less observations recorded during the ELSA period (datasondes are often removed during winter to prevent damage), but all observations fall safely below the isolines for normal ambient conditions and no violation is expected. Under critical ambient conditions, an occasional violation may occur for very high pH or temperature values (above 11ºC; note the ELSA period is between November and February).

Figure 29 and Figure 30 show isolines created for subchronic water quality standards during ELSP for normal (50^{th} percentile) and critical (95^{th} percentile) ambient conditions, respectively. All isolines are located well above the pH=9 line. All observations fall safely below the isolines for normal ambient conditions and no violation is expected. Under critical ambient conditions, an occasional violation may occur for very high pH values.

Subchronic water quality standards during ELSA will not be violated. The highest 4-day average simulated for proposed conditions is 0.28 mg/l. The lowest applicable standard value calculated from pH=14 and temperature 12ºC is 0.48 mg/l, almost twice as high. Thus the isolines could not be created and corresponding figures are not presented.

Figure 31 illustrates a potential impact of future FMWRD discharges on chronic and subchronic water quality standards for normal ambient conditions during the more stringent ELSP period if no action was taken to expand its facilities. Possible violations of chronic standards would occur at much lower pH and temperature values when compared to limited possible cases for proposed conditions. Subchronic standard isolines for the “no action” condition are also much lower on the chart than for proposed conditions, allowing possible standard exceedances at very high pH values. Proposed modifications greatly reduce future risk of non-compliance with ammonia water quality standards.

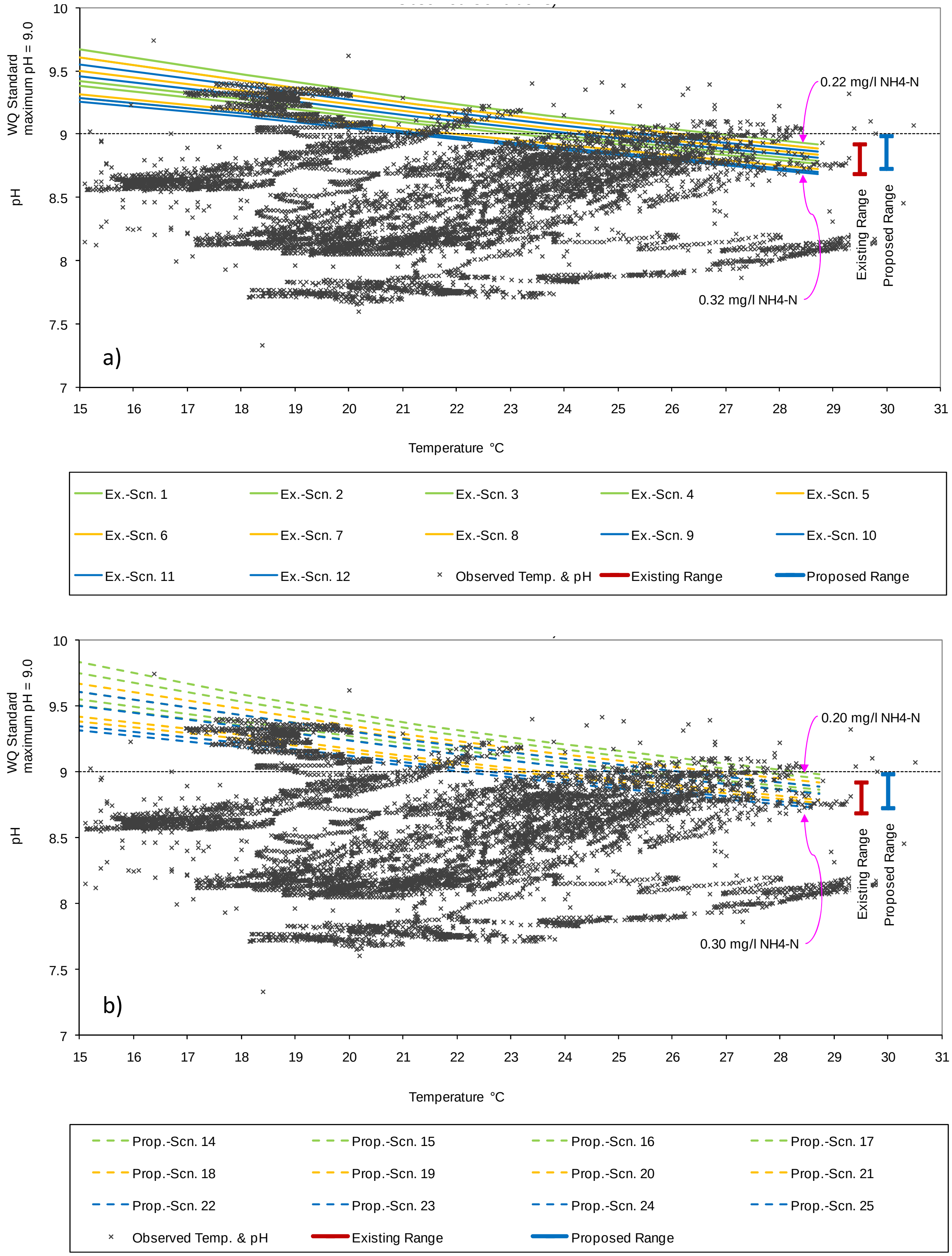


Figure 26. Chronic water quality standards (ELSP) for a) existing and b) proposed conditions (95^{th})

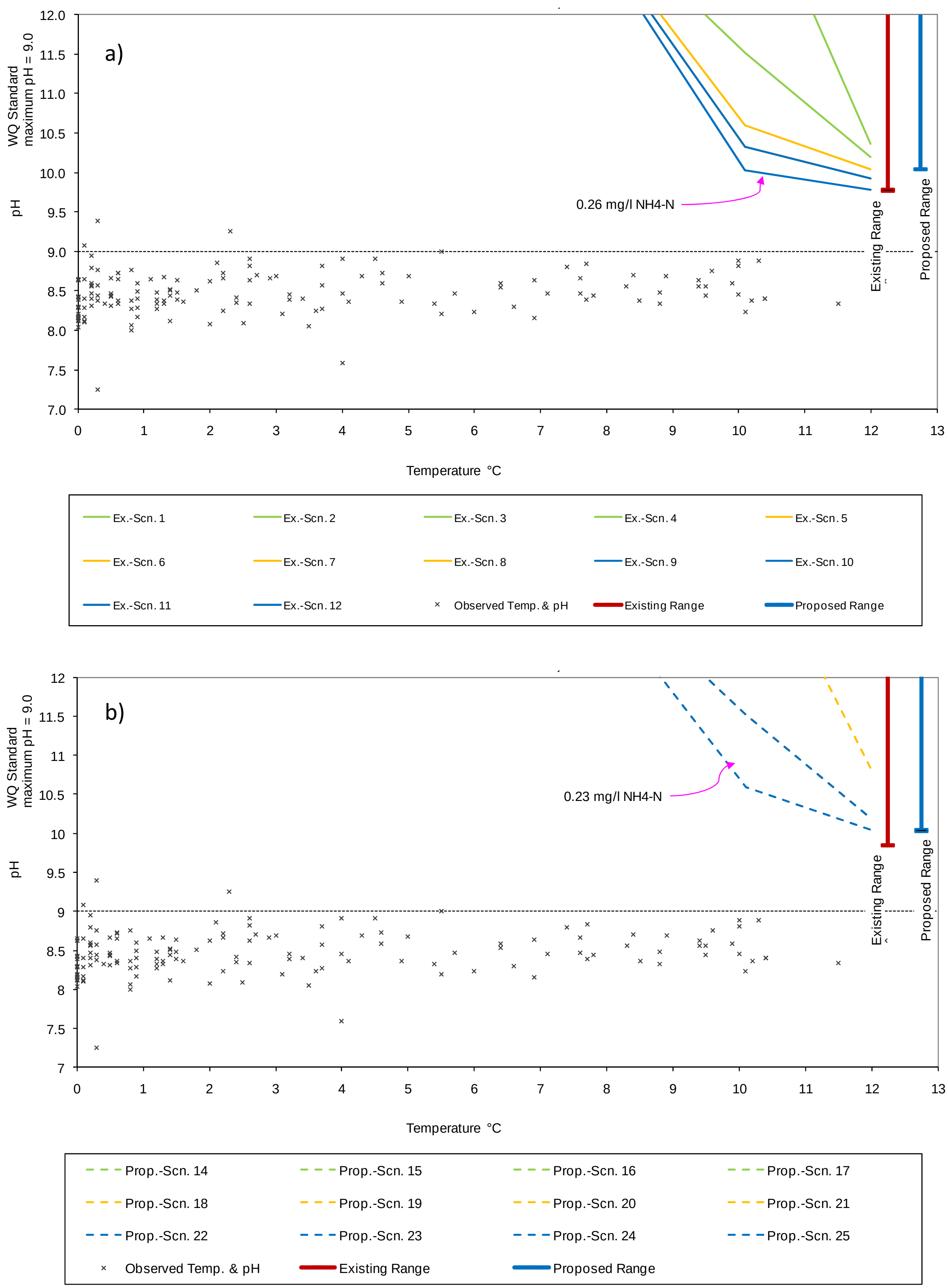


Figure 27. Chronic water quality standards (ELSA) for a) existing and b) proposed conditions (50^{th})

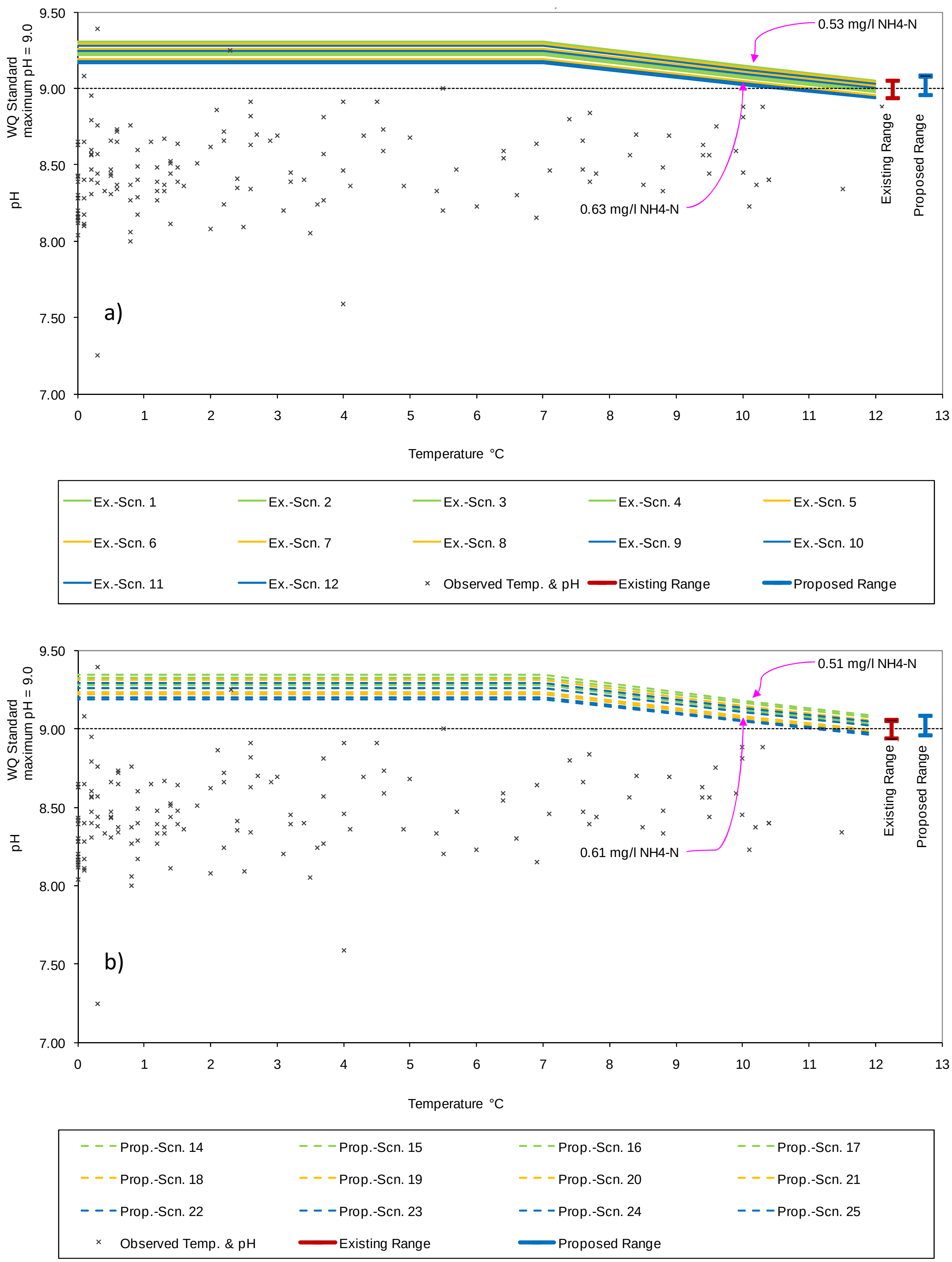
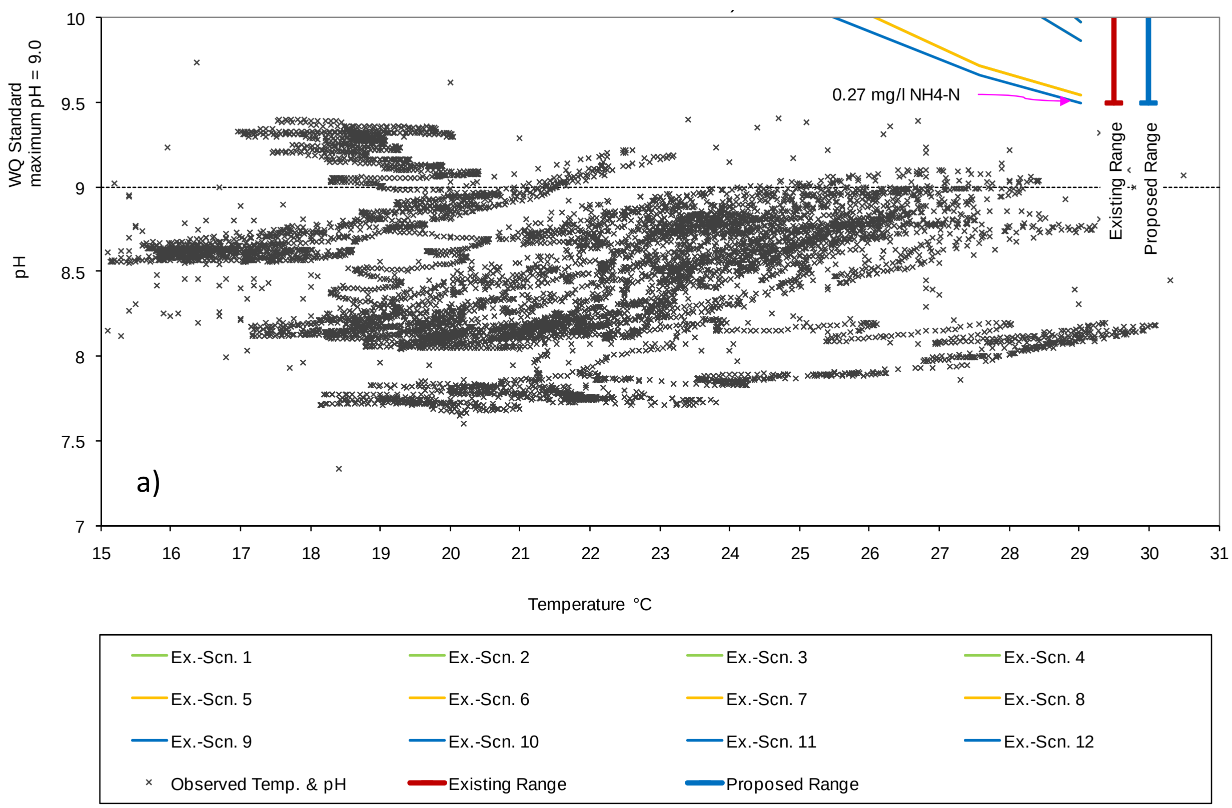


Figure 28. Chronic water quality standards (ELSA) for a) existing and b) proposed conditions (95th)



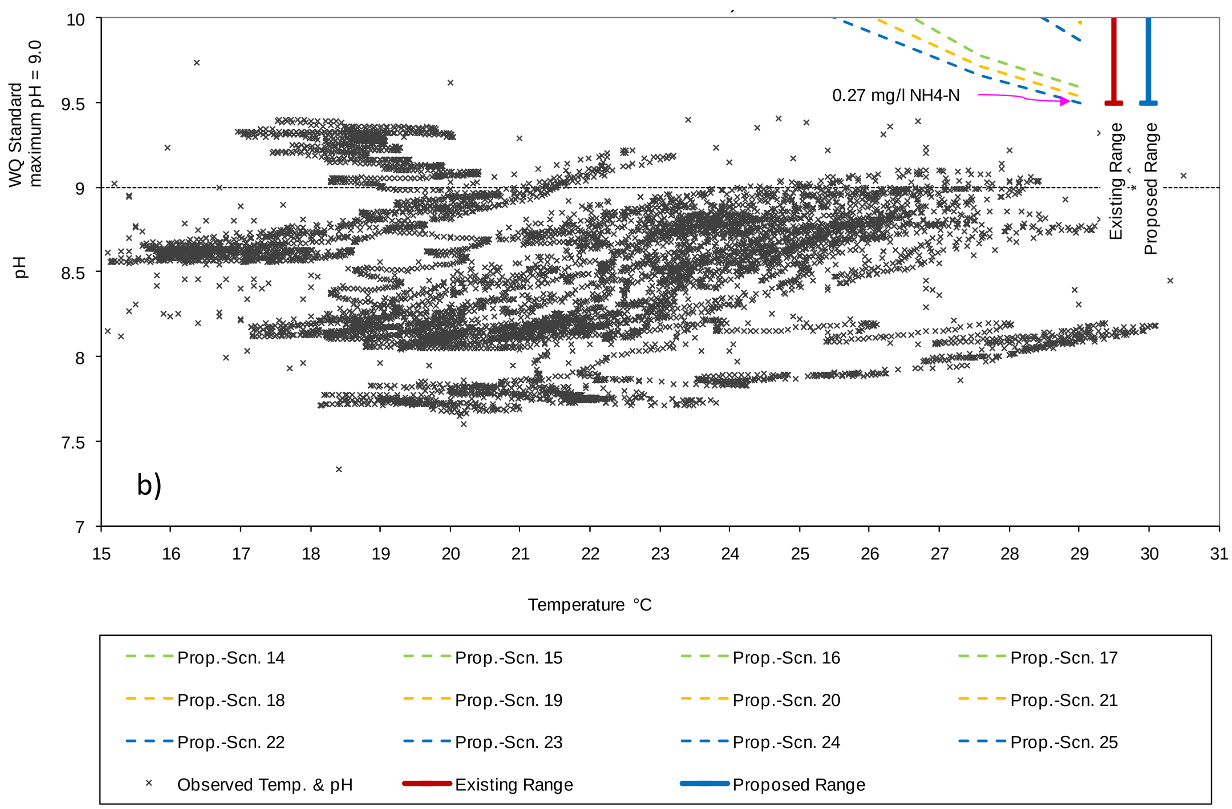
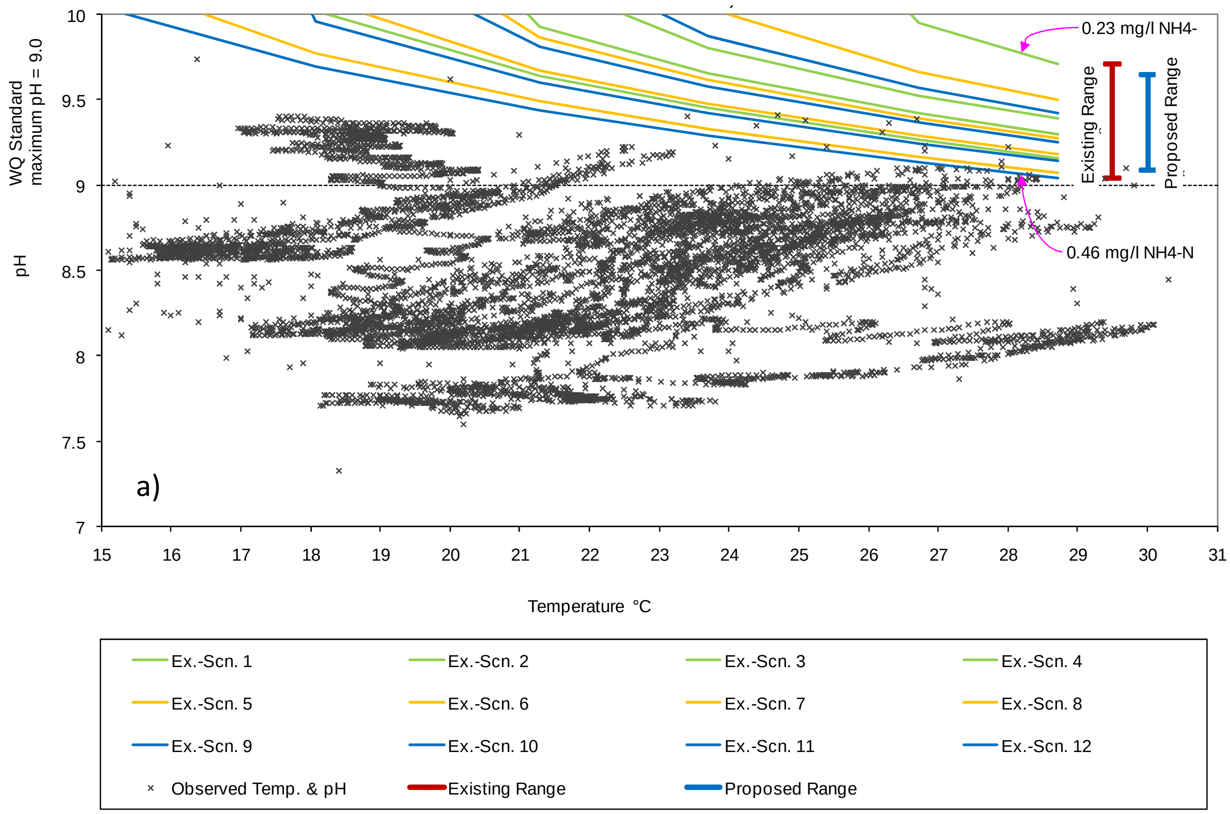


Figure 29. Subchronic water quality standards (ELSP) for a) existing and b) proposed conditions (50th)



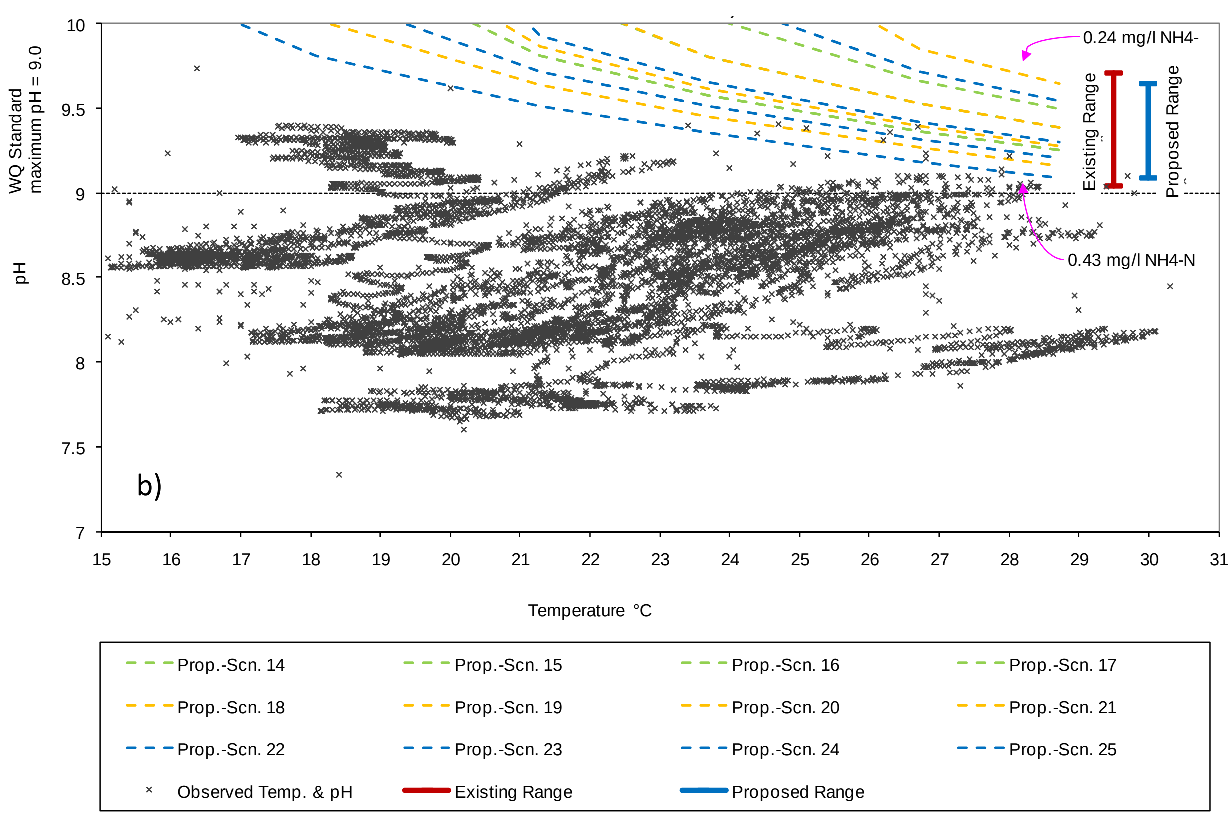


Figure 30. Subchronic water quality standards (ELSP) for a) existing and b) proposed conditions (95^{th})

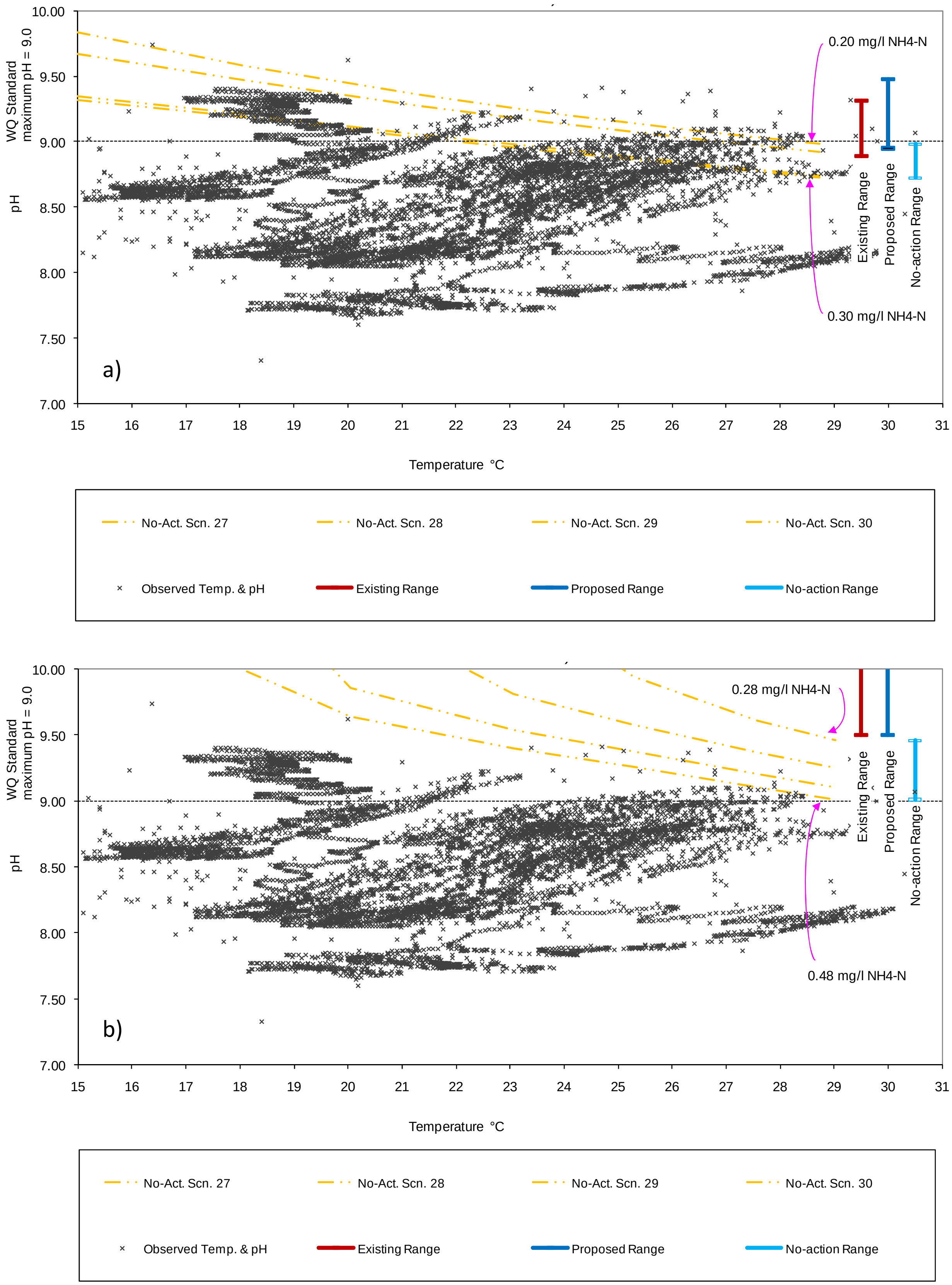


Figure 31. Chronic (a) and subchronic (b) water quality standards (ELSP) for “no action” conditions (50th)

Acute toxicity standards do not vary with temperature, only with pH. Table 20 shows pH thresholds calculated for maximum simulated concentrations. When observed pH exceeds this threshold, the concentration would be in violation of the acute toxicity standard. All pH thresholds for proposed conditions are above 9.4 and above thresholds for existing conditions. Any possible violation would occur only at very high pH levels in the Fox River.

Water quality standards also require pH values to be "*within the range of 6.5 to 9.0.*" Any violation of ammonia standards discussed previously when pH values are above 9.0 would not be a violation if pH values were within the pH standard requirements. Table 21 shows temperatures at which the isolines cross the pH standard line, i.e., a temperature threshold above which the ammonia water quality standards would be violated when pH was 9. It also means that for temperatures below this threshold, violations can occur only when the pH standard is violated. For example, the chronic ammonia standard during ESLP assuming normal ambient conditions will not be violated for the proposed conditions during the 5-year storm when Fox River temperature is below 29°C and pH is in compliance with water quality standards.

Table 20. Acute toxicity evaluation: pH thresholds indicating the lowest value leading to non-compliance

	1 year		*5 year*		*10 year*	
Condition	*Scenario*	*pH*	*Scenario*	*pH*	*Scenario*	*pH*
Existing	1	9.49	5	9.36	9	9.34
	2	9.57	6	9.43	10	9.40
	3	9.97	7	9.76	11	9.69
	4	10.5	8	9.97	12	9.86
Proposed	14	9.74	18	9.51	22	9.41
	15	9.93	19	9.59	23	9.49
	16	11.0	20	9.97	24	9.82
	17	14.0	21	10.5	25	10.1
No action			27	9.12		
			28	9.15		
			29	9.40		
			30	9.48		

Table 21. Temperatures (°C) at which isolines cross pH=9 for the 5-year storm

FMWRD	*Normal ambient conditions*				*Critical ambient conditions*			
conditions	*Chronic*		*Subchronic*		*Chronic*		*Subchronic*	
	ELSP	*ELSA*	*ELSP*	*ELSA*	*ELSP*	*ELSA*	*ELSP*	*ELSA*
Existing	27-33	25-31	38-49	38-49	22-26	11-13	30-38	30-38
Proposed	29-35	27-32	38-48	38-48	23-27	11-13	32-40	32-40
No action	22-28	21-27	29-37	29-37	18-23	9-11	21-29	21-29

Nitrate Nitrogen

Nitrate Nitrogen Water Quality Standards

The Illinois Pollution Control Board does not define a standard for nitrate nitrogen in streams except when used for public water supply or food processing. The Illinois Environmental Protection Agency also discontinued using a threshold to identify nitrogen as a potential cause for impaired waters (IEPA, 2008). A value of 7.8 mg/l was used to identify nitrogen impairment when compared to combined nitrate and nitrite nitrogen (IEPA, 2006a). A single exceedance is sufficient to list nitrogen as a potential cause of impairment.

Impact of Proposed Modifications

Figure 32 shows simulated nitrate nitrogen concentrations at Route 34 under both existing and proposed conditions for three design rains. The nitrate nitrogen load and concentration discharged by the FMWRD facilities during design storms are lower than the load and concentrations discharged during dry weather flow. The FMWRD full treatment facility is designed to convert ammonia to nitrate (nitrification). The nitrification process becomes less efficient with increasing flow to the treatment plant, converting a smaller portion to nitrate, and thus less nitrate is discharged during design storms. This leads to a decrease in ambient nitrate nitrogen concentrations during design storms as seen in Figure 32. Minimum and maximum simulated values are listed in Table 22. Note that all maximum concentrations remain the same within each simulated condition, existing (2.49 mg/l) or proposed (2.10 mg/l). This is because maximum concentrations are simulated during the dry weather as described previously. All simulated values are well below the IEPA listing value.

Total Nitrogen

Total Nitrogen Water Quality Standards

The Illinois Pollution Control Board does not define a standard for total nitrogen. The Illinois Environmental Protection Agency also discontinued using a threshold to identify nitrogen as a potential cause for impaired waters (IEPA, 2008). A value of 7.8 mg/l was used to identify nitrogen impairment when compared to combined nitrate and nitrite nitrogen (IEPA, 2006a). A single exceedance is sufficient to list nitrogen as a potential cause of impairment. No listing value is available for total nitrogen. Compliance with nitrate nitrogen standards is evaluated separately.

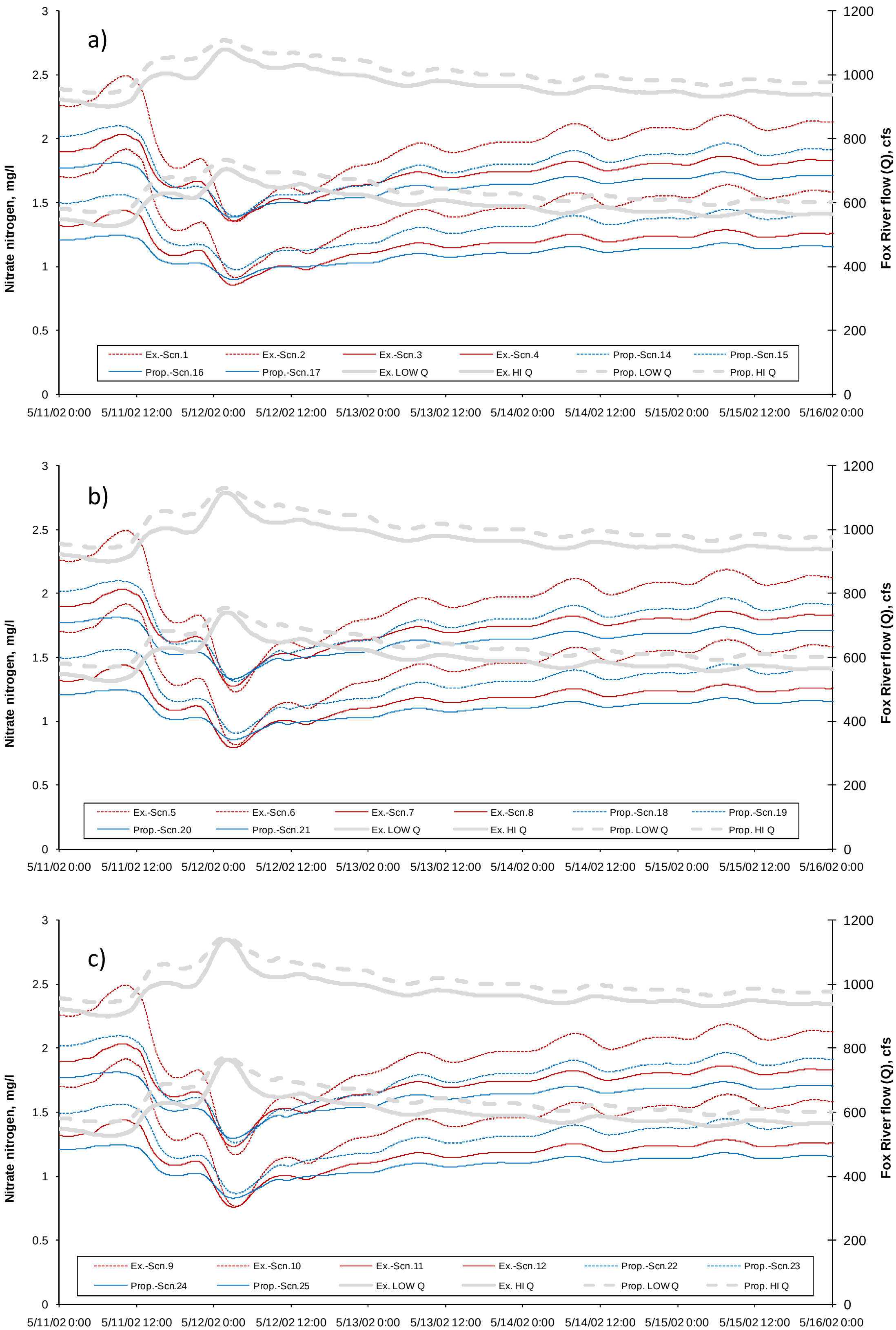


Figure 32. Nitrate nitrogen at Route 34 under existing and proposed conditions:
a) 1-year storm, b) 5-year storm, and c) 10-year storm

Table 22. Simulated nitrate nitrogen maximum and minimum concentrations and percent reduction

Storm	*Existing*			*Proposed*			*Reduction*
	Scenario	*Max mg/l*	*Min mg/l*	*Scenario*	*Max mg/l*	*Min mg/l*	*Max %*
1 year	1	2.49	1.35	14	2.10	1.39	16%
	2	1.92	0.91	15	1.56	0.97	18%
	3	2.03	1.35	16	1.81	1.38	11%
	4	1.44	0.86	17	1.24	0.90	14%
5 year	5	2.49	1.23	18	2.10	1.31	16%
	6	1.92	0.81	19	1.56	0.91	19%
	7	2.03	1.27	20	1.81	1.33	11%
	8	1.44	0.79	21	1.24	0.85	14%
10 year	9	2.49	1.17	22	2.10	1.26	16%
	10	1.92	0.76	23	1.56	0.86	19%
	11	2.03	1.23	24	1.81	1.30	11%
	12	1.44	0.76	25	1.24	0.83	14%

Impact of Proposed Modifications

Figure 33 shows simulated total nitrogen concentrations at Route 34 under both existing and proposed conditions for three design rains. The highest simulated concentrations under existing conditions occur during dry weather flow and are 4.33 mg/l for all simulated design storms (Table 23). The highest simulated concentrations under proposed conditions are 3.96 mg/l, 3.96 mg/l, and 4.04 mg/l for 1-year, 5-year, and 10-year design storms, respectively (Table 23). This represents a reduction of 4–9%, 3–9%, and 0–7% for 1-year, 5-year, and 10-year design storms, respectively (Table 23). The increase and its duration were not evaluated for total nitrogen as concentrations do not vary more than 10% from simulated dry weather values.

Total Phosphorus

Phosphorus Water Quality Standards

The Illinois Pollution Control Board defines phosphorus standards only for lakes and reservoirs with a surface area greater than 8.1 hectares (20 acres), where total phosphorus should not exceed 0.05 mg/l. Impoundments behind low head dams constructed on free-flowing streams are not considered lakes or reservoirs, regardless of the surface area and thus, this standard does not apply. The Illinois Environmental Protection Agency uses a value of 0.61 mg/l as a threshold to identify phosphorus as a potential cause for impaired waters (IEPA, 2008). A single exceedance is sufficient to list phosphorus as a potential cause of impairment.

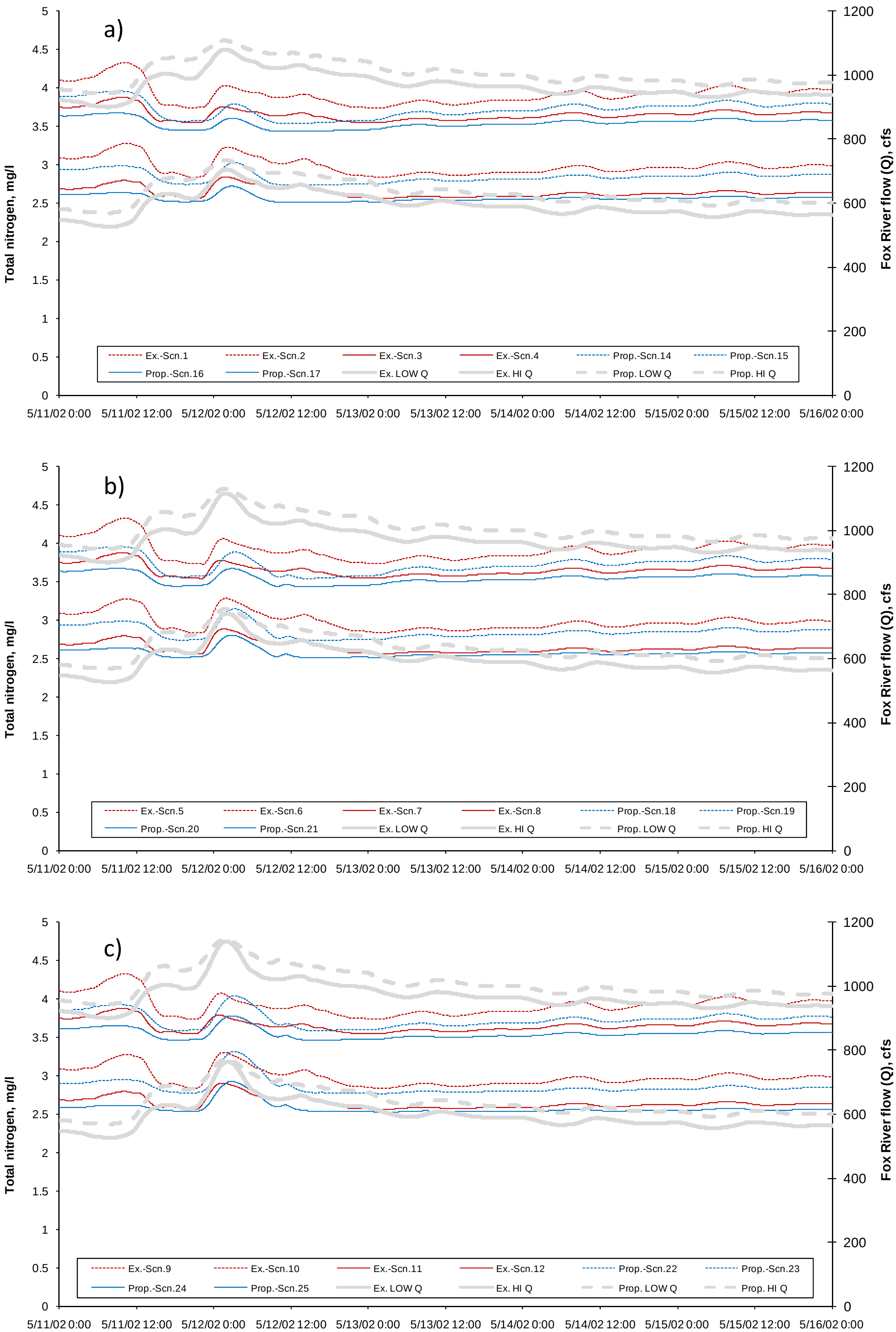


Figure 33. Total nitrogen at Route 34 under existing and proposed conditions:
a) 1-year storm, b) 5-year storm, and c) 10-year storm

Table 23. Maximum total nitrogen simulated during the storm impact (mg/l) and percent reduction

Storm	*Existing*		*Proposed*		*Reduction*
	Scenario	*Max mg/l*	*Scenario*	*Max mg/l*	*Max %*
1 year	1	4.33	14	3.96	9
	2	3.28	15	3.03	8
	3	3.88	16	3.67	5
	4	2.84	17	2.72	4
5 year	5	4.33	18	3.96	9
	6	3.28	19	3.15	4
	7	3.88	20	3.67	5
	8	2.89	21	2.80	3
10 year	9	4.33	22	4.04	7
	10	3.30	23	3.32	<1
	11	3.88	24	3.78	3
	12	2.90	25	2.92	-1

Impact of Proposed Modifications

Figure 34 shows simulated total phosphorus concentrations at Route 34 under both existing and proposed conditions for three design rains. Figure 35 shows simulated total phosphorus concentrations at Route 34 under both existing and proposed conditions for the 3-month storm. The highest simulated concentrations under existing conditions are 0.71 mg/l, 0.72 mg/l, 0.73 mg/l, and 0.75 mg/l for 3-month, 1-year, 5-year, and 10-year design storms, respectively (Table 24). The highest simulated concentrations under proposed conditions are 0.62 mg/l, 0.67 mg/l, 0.70 mg/l, and 0.73 mg/l for 3-month, 1-year, 5-year, and 10-year design storms, respectively (Table 24). This represents a reduction of 10–15%, 5–8%, 2–4%, and 1–3% for 3-month, 1-year, 5-year, and 10-year design storms, respectively (Table 25). Note that proposed conditions include higher phosphorus treatment than existing conditions, resulting in lower ambient concentrations overall.

Table 26 shows a maximum increase above the listing value and its duration. Existing conditions cause an exceedance of listing values during low flows in the Fox River for all simulated design storms. The duration of this exceedance can range from 0.7 to 1.9 days (16–45 hours), depending on the upstream concentration (longer for higher concentrations). Both magnitude and duration of exceedances are greatly reduced under proposed conditions. The increase above the listing value during the 3-month storm under proposed conditions is negligible (method detection limit is typically 0.01 mg/l). The increase above the listing value during the 1-year storm under proposed conditions is limited to the most critical scenario (low flow and high phosphorus concentrations in the Fox River). The increase above the listing value during 5-year and 10-year storms under proposed conditions occurs for scenarios simulating an impact during low flows in the Fox River. The listing value is exceeded under proposed conditions for 0.2–0.7 days (4–17 hours).

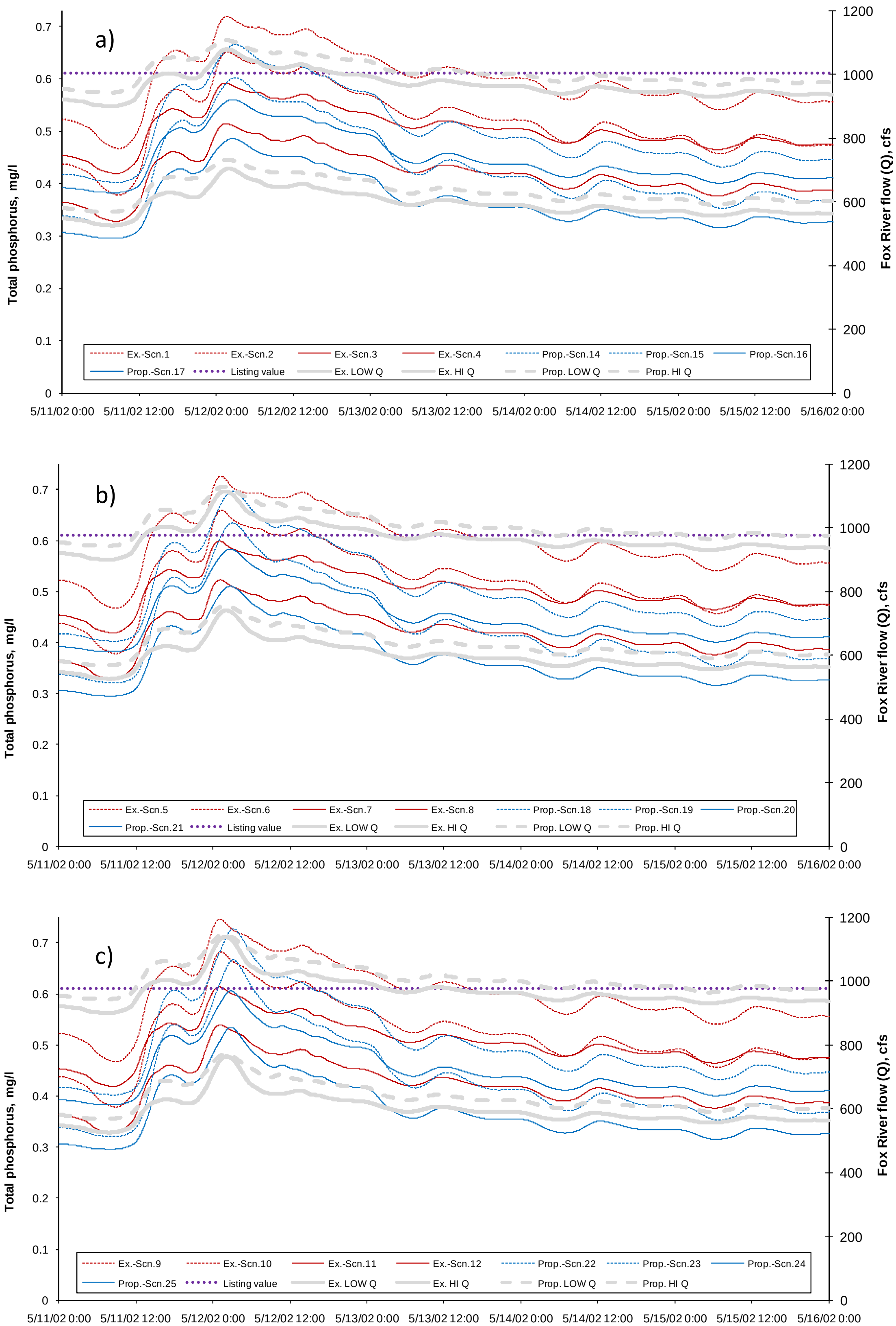


Figure 34. Total phosphorus at Route 34 under existing and proposed conditions: a) 1-year storm, b) 5-year storm, and c) 10-year storm

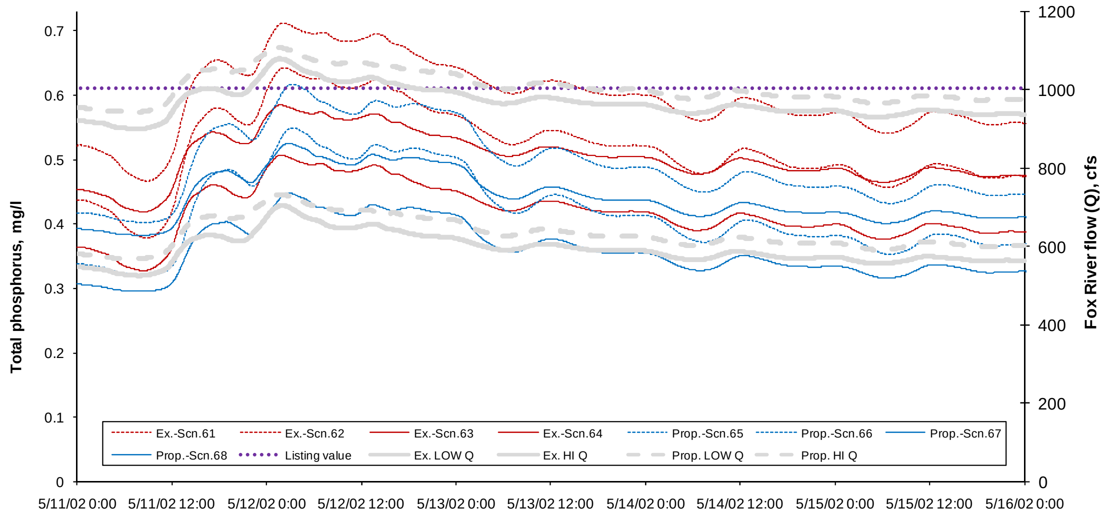


Figure 35. Total phosphorus at Route 34 under existing and proposed conditions for 3-month storm

Table 24. Simulated total phosphorus maximum, maximum increase, and duration of increase above dry weather conditions during design storms

Storm	*Existing*				*Proposed*			
	Scenario	*Max mg/l*	*Increase mg/l*	*Duration days*	*Scenario*	*Max mg/l*	*Increase mg/l*	*Duration days*
1 year	1	0.72	0.19	2.7	14	0.67	0.24	2.8
	2	0.65	0.20	2.9	15	0.60	0.25	3.0
	3	0.59	0.13	2.1	16	0.56	0.16	2.1
	4	0.51	0.14	2.7	17	0.49	0.17	2.7
5 year	5	0.73	0.19	2.7	18	0.70	0.27	2.8
	6	0.66	0.21	2.9	19	0.63	0.29	3.0
	7	0.60	0.14	2.1	20	0.58	0.18	2.1
	8	0.52	0.15	2.7	21	0.51	0.20	2.7
10 year	9	0.75	0.21	2.7	22	0.73	0.30	2.8
	10	0.68	0.23	2.9	23	0.67	0.32	3.0
	11	0.61	0.15	2.1	24	0.61	0.21	2.1
	12	0.54	0.17	2.7	25	0.53	0.22	2.7
3 month	61	0.71	0.18	2.7	65	0.62	0.19	2.8
	62	0.64	0.19	2.9	66	0.55	0.20	3.0
	63	0.59	0.12	2.1	67	0.53	0.13	2.1
	64	0.51	0.13	2.7	68	0.45	0.13	2.7

Table 25. Percent reduction in maximum simulated total phosphorus value during design storms

Scenario	*Max*	*Increase*	*Duration*	*Scenario*	*Max*	*Increase*	*Duration*
	1 year				10 year		
1-14	7%	-28%	-1%	9-22	3%	-40%	-1%
2-15	8%	-25%	-3%	10-23	2%	-36%	-3%
3-16	5%	-23%	-4%	11-24	1%	-35%	-4%
4-17	6%	-21%	0%	12-25	1%	-32%	0%
	5 year				3 month		
5-18	4%	-39%	-1%	61-65	13%	-6%	-1%
6-19	4%	-35%	-3%	62-66	15%	-3%	-3%
7-20	3%	-33%	-4%	63-67	10%	-1%	-3%
8-21	2%	-30%	0%	64-68	12%	0%	1%

Note: Negative values mean values increased from existing to proposed conditions due to higher phosphorus removal at the FMWRD facility, resulting in lower dry weather ambient concentrations.

Table 26. Increase above total phosphorus listing value (0.61 mg/l) and its duration during design storms

Storm		*Existing*			*Proposed*		*Percent reduction*	
		Increase	*Duration*		*Increase*	*Duration*	*Increase*	*Duration*
	Scenario	*mg/l*	*days*	*Scenario*	*mg/l*	*days*	*mg/l*	*days*
1 year	1	0.11	1.9	14	0.06	0.7	49%	64%
	2	0.04	0.7	15	*	*	100%	100%
	3	*	*	16	*	*	*	*
	4	*	*	17	*	*	*	*
5 year	5	0.12	1.9	18	0.09	0.7	26%	64%
	6	0.05	0.7	19	0.02	0.2	51%	76%
	7	*	*	20	*	*	*	*
	8	*	*	21	*	*	*	*
10 year	9	0.14	1.9	22	0.12	0.7	14%	63%
	10	0.07	0.7	23	0.06	0.2	21%	67%
	11	<0.01	0.1	24	*	*	100%	100%
	12	*	*	25	*	*	*	*
3 month	61	0.10	1.9	65	<0.01	0.1	93%	95%
	62	0.03	0.7	66	*	*	100%	100%
	63	*	*	67	*	*	*	*
	64	*	*	68	*	*	*	*

Note: * Maximum value is at or below listing value, no exceedance detected.

The duration of exceedance above the listing value is a theoretical value calculated under the assumption of constant flow and concentrations in the Fox River at Mill Street in Aurora, i.e., downstream of Aurora's storm sewers and CSOs that might be discharging during or after the design rains, causing flows and concentrations in the Fox River at Mill Street to increase or vary. The combined effect of all discharges in the study reach would give a more complete picture of concentrations at Route 34 during and after storms. It would also help to evaluate relative contributions of individual sources and possible improvements in concentrations at Mill Street as a result of proposed modifications to the City of Aurora's CSOs. Unfortunately, discharge and concentration data on the City of Aurora's CSO existing and proposed discharges during design storms were not provided.

Note that no phosphorus removal was assumed for CEPT at this stage of evaluation as removal efficiencies were not provided. Chemical additions planned for CEPT will further reduce phosphorus load and concentrations discharged to the Fox River during design storms. The load and concentrations considered in this study represent the worst possible case when CEPT is not utilized for phosphorus removal.

BOD_5

BOD_5 Water Quality Standards

The Illinois Pollution Control Board does not define a standard for BOD_5 outside of standards for dissolved oxygen. The Illinois Environmental Protection Agency also does not define a value for listing BOD_5 as a cause of impairment.

Impact of Proposed Modifications

Figure 36 shows simulated BOD_5 concentrations at Route 34 under both existing and proposed conditions for three design rains. The highest simulated concentrations under existing conditions are 10.4 mg/l, 11.5 mg/l, and 12.0 mg/l for 1-year, 5-year, and 10-year design storms, respectively (Table 27). The highest simulated concentrations under proposed conditions are 6.6 mg/l, 7.9 mg/l, and 8.7 mg/l for 1-year, 5-year, and 10-year design storms, respectively (Table 24). This represents a reduction of 30–43%, 26–37%, and 23–32% for 1-year, 5-year, and 10-year design storms, respectively (Table 28). There is also a significant reduction in both magnitude and duration of an increase above ambient concentrations simulated during the dry weather.

Dissolved Oxygen

Dissolved Oxygen Water Quality Standards

Dissolved oxygen standards offer different levels of protection for general use waters and waters with enhanced dissolved oxygen regime. Different seasonal standard values apply to a minimum value at any time, a daily minimum averaged over 7 days, and a daily mean averaged over 30 days (Table 29). Continuous data collected by datasondes are required to calculate averages for evaluating compliance with dissolved oxygen standards.

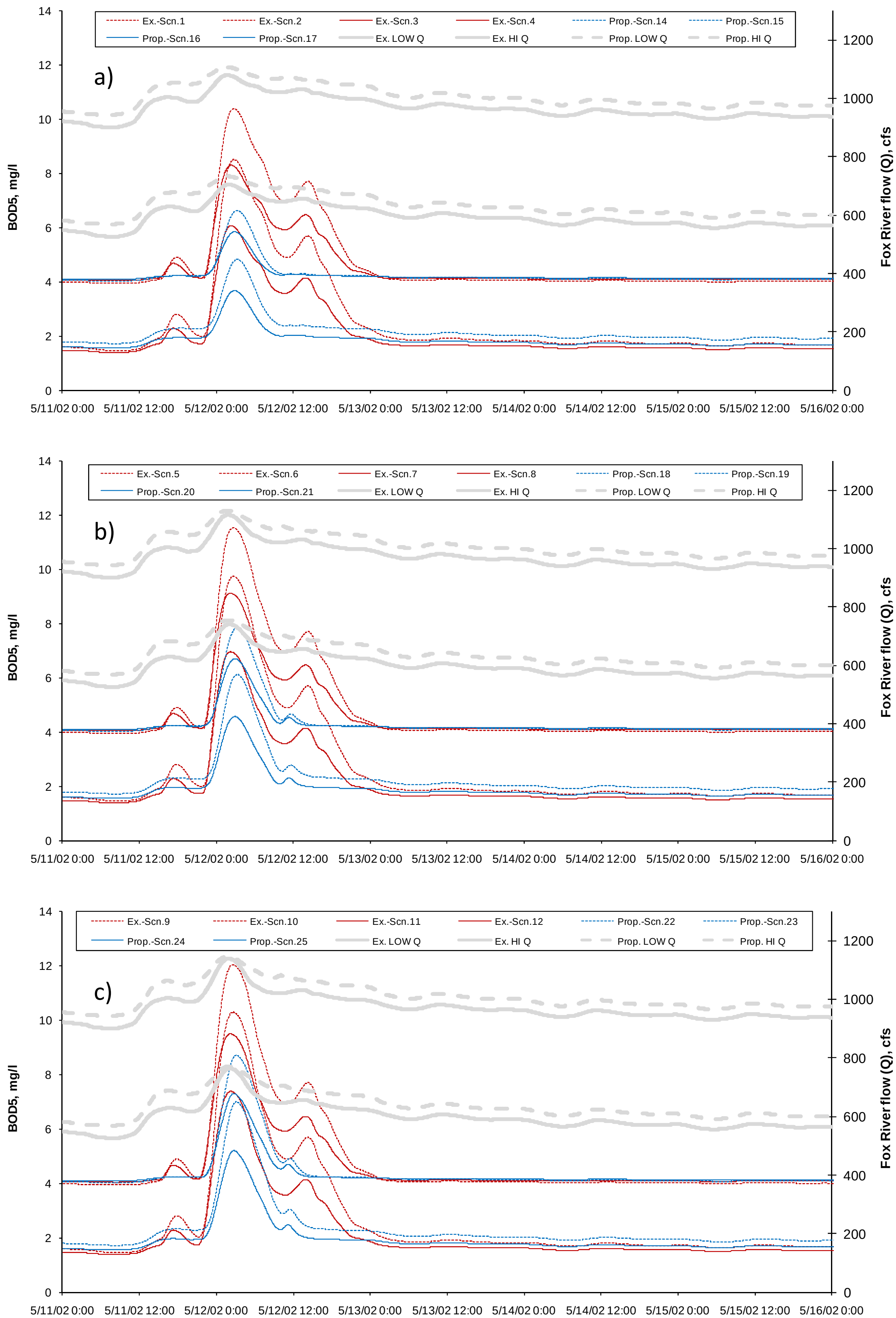


Figure 36. BOD_5 at Route 34 under existing and proposed conditions:
a) 1-year storm, b) 5-year storm, and c) 10-year storm

Table 27. Simulated BOD_5 maximum, maximum increase, and duration of increase above dry weather conditions during design storms

Storm	Existing				Proposed			
	Scenario	*Max mg/l*	*Increase mg/l*	*Duration days*	*Scenario*	*Max mg/l*	*Increase mg/l*	*Duration days*
1 year	1	10.4	6.4	1.2	14	6.6	2.6	0.4
	2	8.5	6.9	2.7	15	4.8	3.0	2.5
	3	8.3	4.2	1.0	16	5.8	1.7	0.3
	4	6.1	4.6	2.0	17	3.7	2.0	1.8
5 year	5	11.5	7.5	1.2	18	7.9	3.8	0.5
	6	9.7	8.1	2.7	19	6.1	4.3	2.5
	7	9.1	5.0	1.0	20	6.7	2.6	0.4
	8	7.0	5.5	2.0	21	4.6	2.9	1.8
10 year	9	12.0	8.0	1.2	22	8.7	4.6	0.6
	10	10.3	8.7	2.7	23	7.0	5.2	2.5
	11	9.5	5.4	1.1	24	7.3	3.2	0.5
	12	7.4	5.9	2.0	25	5.2	3.6	1.8

Table 28. Percent reduction in maximum simulated BOD_5 value during design storms

Scenarios	*Max*	*Increase*	*Duration*	*Scenarios*	*Max*	*Increase*	*Duration*
	1 year				*10 year*		
1-14	36%	60%	67%	9-22	28%	42%	51%
2-15	43%	57%	8%	10-23	32%	41%	8%
3-16	30%	59%	68%	11-24	23%	41%	49%
4-17	39%	55%	7%	12-25	29%	39%	6%
	5 year						
5-18	32%	49%	56%				
6-19	37%	47%	8%				
7-20	26%	49%	60%				
8-21	34%	46%	7%				

Table 29. Overview of Dissolved Oxygen Standards (mg/l)

Statistic	*All waters*		*Enhanced dissolved oxygen regime waters*	
	March-July	*August-February*	*March-July*	*August-February*
Any time	5.0	3.5	5.0	4.0
Daily minimum averaged over 7 days	6.0	4.0	6.25	4.5
Daily mean averaged over 30 days	N/A	5.5		6.0

Impact of Proposed Modifications

Simulating the impact of storm discharges on dissolved oxygen is not trivial. Dissolved oxygen exhibits a strong variation in temperature changes during a year and even during a day. Algal communities and their photosynthetic activities further impact oxygen concentrations and variations during a day. Storms completely change the dynamics of a dissolved oxygen cycle. Storm runoff brings a high volume of water with a relatively constant dissolved oxygen concentration. Even during summer when algal activity is high, the diurnal variation disappears or at least is dampened during a storm. Simulating this dynamic response calls for highly detailed data describing all inputs into the study reach and internal processes within the reach collected during a significant CSO event.

Furthermore, any impact will greatly vary with upstream conditions and timing of the storm. Selecting a constant concentration for upstream conditions would not be appropriate considering the diurnal and seasonal variation. The design storm discharge would have a different impact on dissolved oxygen, depending on the time of day when the storm occurred. A discharge during early morning hours when dissolved oxygen is typically very low would have a much higher impact than the same discharge during afternoon hours when algal productivity is high and dissolved oxygen can reach values above saturation.

A simpler approach to evaluate the impact is adopted at this stage until such data become available. BOD_5 and ammonia are the dominant oxygen-demanding substances discharged by the FMWRD. BOD_5 represents an actual oxygen demand by mostly organic material consumed within 5 days. BOD_5 was converted to ultimate BOD (BOD_u) using a multiplier of 1.8. Ammonia needs oxygen during nitrification, a conversion of ammonia to nitrate. Theoretically, 1 mg/l ammonia nitrogen requires 4.57 mg/l oxygen for full conversion. Total oxygen demand is thus approximated as:

$$TOD = 1.8\ BOD_5 + 4.57\ (NH_4\text{-}N)$$

The amount and rate of oxygen-demanding substances discharged during storms to the Fox River are calculated and compared. Figure 37 and Figure 38 show the loading rate and the cumulative load discharged during design storms from the FMRWD (all discharges combined). The storm-influenced discharges begin at 10 a.m. on 5/11/2002 and end at 4 a.m. on 5/16/2002. Total load is also converted to an average loading rate by dividing it by the length of the storm period (four days and 18 hours). The effect of dry weather discharges on dissolved oxygen is not evaluated in this study.

Table 30 lists total load and maximum rates for discharges of total oxygen demands during the design storms. Total loads and maximum loading rates discharged during design storms are also compared in Figure 39 and Figure 40, respectively. All total oxygen demand loads as well as maximum loading rates discharged under proposed conditions are lower than loads discharged under existing conditions because the design peak hourly flow for proposed conditions is about 1.5 times higher than existing design peak hourly flow. The total load discharged under existing conditions varies from 47,200 to 54,800 lbs (21,300-24,800 kg or 23.6-27.4 tons). The total load discharged under proposed conditions varies from 37,800 to 50,400 lbs (17,200-22,800 kg or 18.9-25.2 tons).

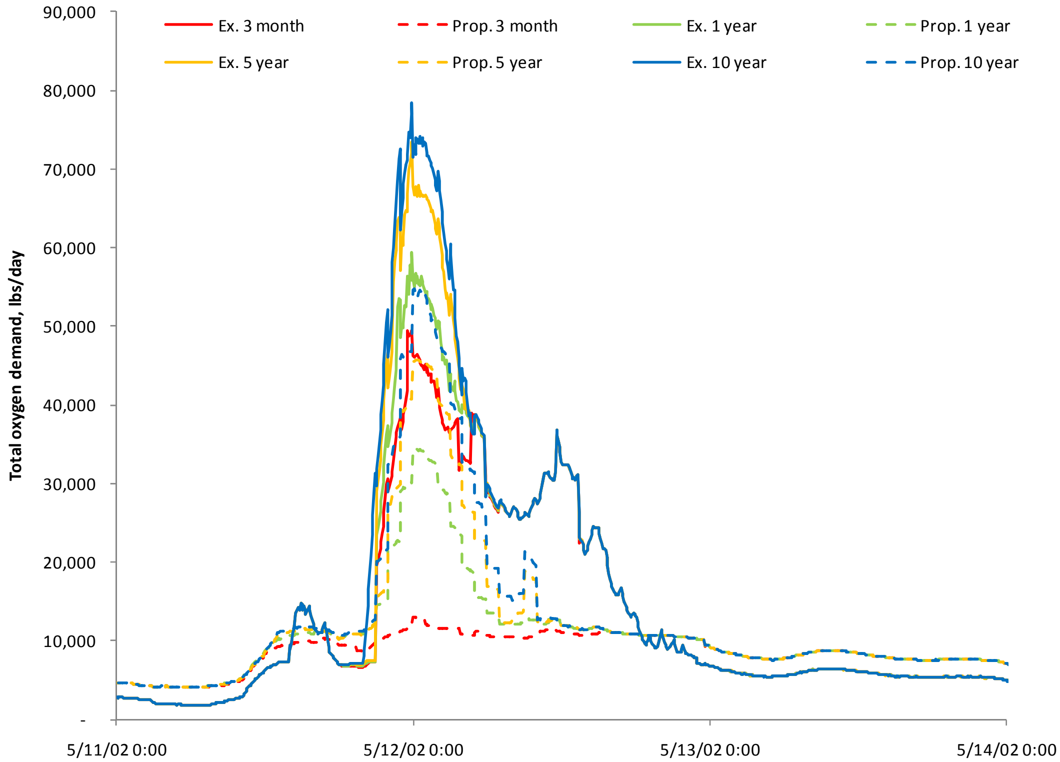


Figure 37. Total oxygen demand discharged by the FMWRD facilities

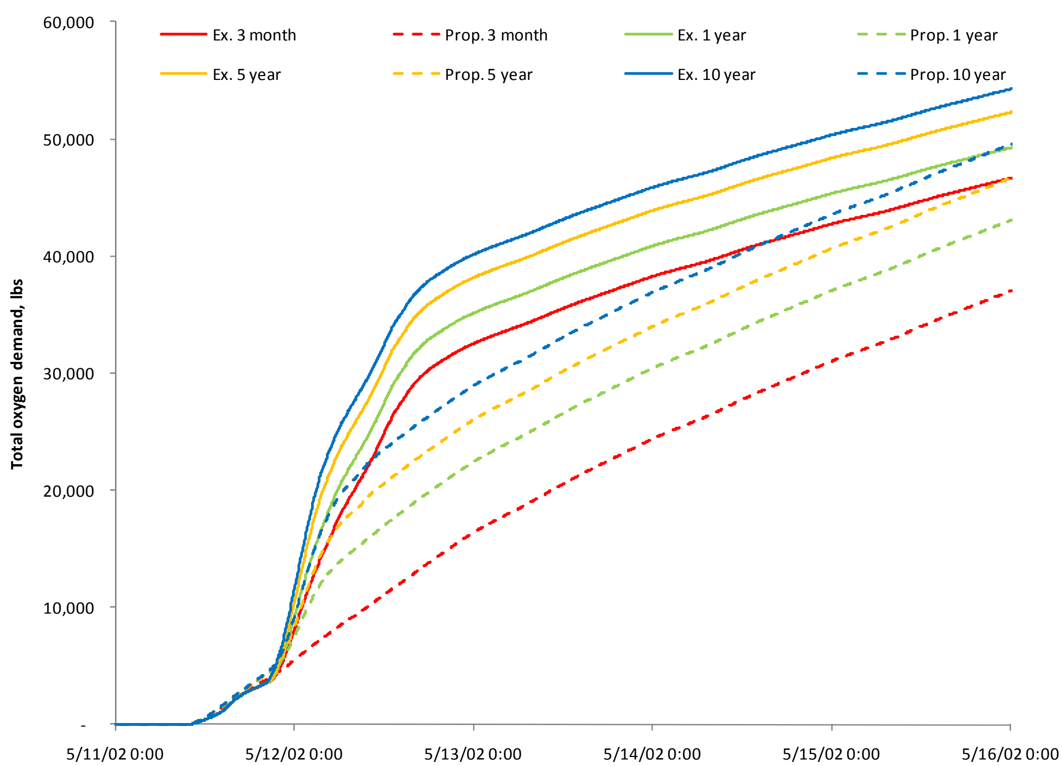


Figure 38. Cumulative total oxygen demand discharged by the FMWRD facilities during design storms

Table 30. Total oxygen demand discharged by the FMWRD facilities

Storm	*Condition*	*Total load*		*Maximum rate*		*Average rate*	
		lbs	*kg*	*lbs/day*	*kg/day*	*lbs/day*	*kg/day*
3 month	Existing	47,200	21,400	49,500	22,500	9,900	4,500
	Proposed	37,800	17,200	12,900	5,900	8,000	3,600
1 year	Existing	49,800	22,600	59,300	26,900	10,500	4,700
	Proposed	43,900	19,900	34,400	15,600	9,200	4,200
5 year	Existing	52,800	23,900	73,400	33,300	11,100	5,000
	Proposed	47,500	21,500	45,800	20,800	10,000	4,500
	No Action	137,400	62,300	105,400	47,800	28,900	13,100
10 year	Existing	54,800	24,800	78,400	35,500	11,500	5,200
	Proposed	50,400	22,800	54,800	24,900	10,600	4,800
	No Action	140,900	63,900	111,600	50,600	29,600	13,400

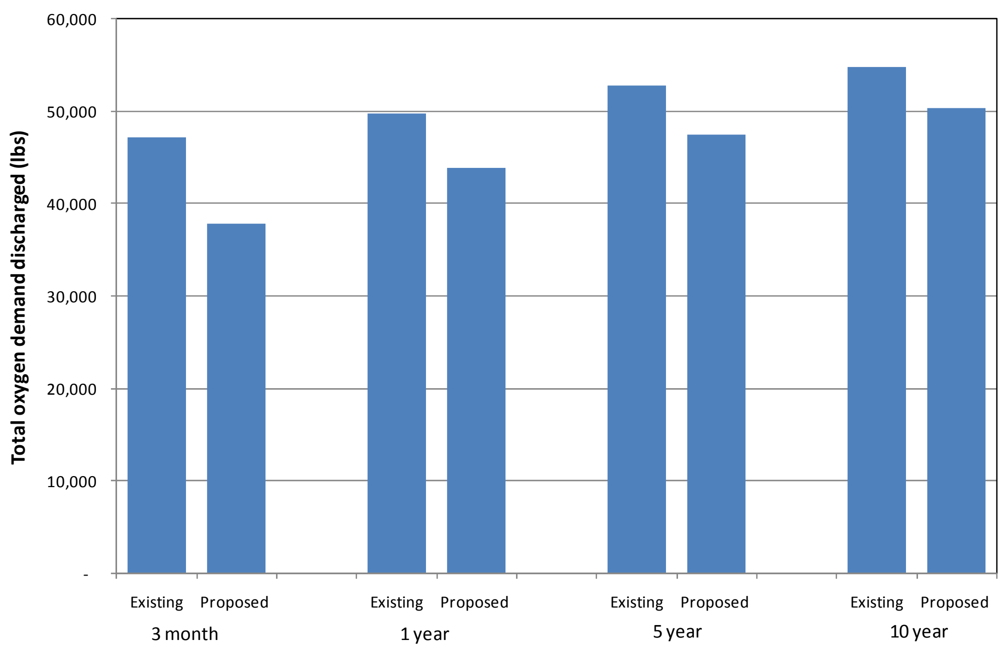


Figure 39. Total oxygen demand discharged from FMWRD facilities during design storms

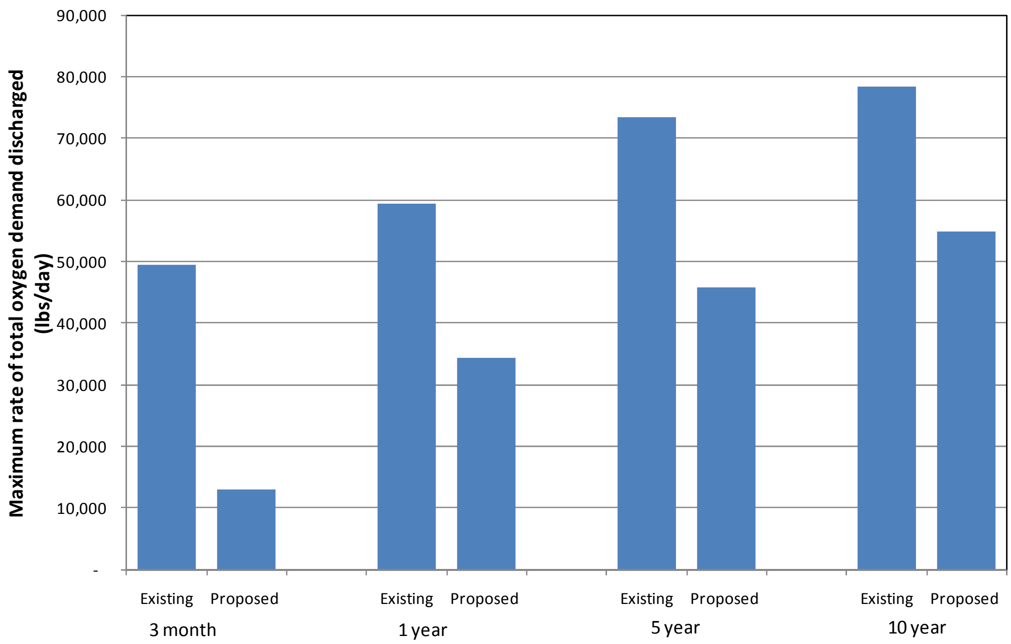


Figure 40. Maximum rate total oxygen demand discharged from FMWRD facilities during design storms

While the loads and loading rates are not directly comparable to the dissolved oxygen standard, the values clearly show the proposed condition will bring a significant reduction of total load and the maximum loading rate compared to the loads discharged under current conditions (Table 31). Total load is reduced by 8 to 20% and a maximum rate by 30 to 74% with the percentage of reduction increasing with smaller return periods, i.e., the benefits are larger for the smaller, more common rainfalls. Proposed conditions are expected to improve dissolved oxygen levels during storms when compared to existing conditions by reducing the loads of oxygen-demanding substances discharged to the Fox River. The rate of biochemical processes in receiving waters will determine the spatial extent of this positive impact.

Table 31. Percent reduction of total oxygen demand discharged by the FMWRD facilities

Storm	*Total load*	*Maximum rate*
3 month	20%	74%
1 year	12%	42%
5 year	10%	38%
10 year	8%	30%

Summary and Conclusions

The goal of this project was to evaluate impacts from the FMWRD CSO discharge on Fox River water quality using a computer simulation model. Achieving the end result required intensive cooperation with the staff of WEDA and the FMWRD, due to the model's reliance upon monitoring and design data defining discharges to the Fox River reach between Sullivan Road in Aurora and Route 34 in Oswego and water quality in the Fox River. Water quality constituents typically found in CSO discharges and those listed as potential causes of impairment were selected for evaluation: fecal coliforms, total suspended solids, ammonia nitrogen, nitrate nitrogen, total nitrogen, total phosphorus, BOD_5, and dissolved oxygen. Simulating the effects of CSO discharges requires a detailed, hydrodynamic model capable of replicating changes in ambient water quality over a short time. Changes in dissolved oxygen during storm discharges were not simulated due to a lack of data to fully describe the complexities of in-stream processes under changing flow conditions. The impact on dissolved oxygen is estimated from discharged loads.

The model developed using WASP software was calibrated using two events (July and August 2008) and validated using two events (September 2008 and August 2009). In addition, a long-term simulation of May–October 2008 was used to validate the overall model performance and identify any model trends that would not be noticeable within a short time period when simulating individual events. It is difficult to collect monitoring data during the exact time period when a discharge from CSOs upstream passes through a monitoring location, especially when the time of CSO discharge is not known until after the monitoring is completed. Unfortunately, most monitoring data were collected before or after the peak concentration associated with CSO discharges passed through monitoring locations, catching the receding part of the pollutograph at best. The peak concentrations simulated by the model are thus unverified by field observations. The intensive sampling effort in August 2009 provided the best data, describing the rising portion of the pollutograph, although only for selected constituents. The model matched observed data during the calibration and validation periods adequately, considering the difficulties with data collection and interpretation.

The calibrated and validated model was set to simulate impacts from the FMWRD discharges on the Fox River water quality under existing and proposed conditions at the FMWRD plant. A full treatment expansion is planned to treat an additional 46 mgd (design peak hourly flow), and a chemically enhanced primary treatment (CEPT) facility with design peak hourly flow of 44 mgd will disinfect and partially treat all excess flow above the full treatment capacity for storms up to and including the 5-year storm. The FMWRD CSO will be active only during storms larger than the 5-year storm. The untreated volume discharged through the FMWRD CSO during the 10-year storm represents 0.1% of total volume discharged during the storm. The evaluation focused on water quality impacts during storm-affected discharges. The effects of the FMWRD dry weather discharges were not evaluated in this study.

The impact of three design storms (1-year, 5-year, and 10-year) is evaluated for all constituents. Ammonia nitrogen, total phosphorus, and dissolved oxygen are critical constituents for which it was important to evaluate the range of impacts on water quality standards. The impacts on ammonia nitrogen, total phosphorus, and dissolved oxygen were also evaluated for the 3-month storm when all storm volume will be fully treated by the FMWRD facilities under the proposed conditions (i.e., no flow through CEPT or CSO). The impact of the "no action" condition on ammonia nitrogen and dissolved oxygen was also evaluated for the 5-year storm.

Four scenarios were simulated for each design storm and for each FMWRD condition, existing or proposed, to evaluate a range of possible impacts as they change with the changing Fox River flow and water quality. Two selected flows represent a low flow (exceeded on 75% of days) and a median flow (exceeded on 50% of days). Two selected concentrations for each simulated constituent represent a low concentration (exceeded in 75% of samples) and a high concentration (exceeded in 25% of samples). High flow in the Fox River was not simulated at this time as the impact of FMWRD discharges on the Fox River water quality is expected to diminish with increased Fox River flow.

The impact was evaluated from two different perspectives. First, a change from existing to proposed conditions was assessed. For all constituents, maximum simulated concentrations under proposed conditions are lower than the maximum simulated concentrations under existing conditions. The actual reduction varies for individual constituents, design storms, and scenarios (Table 32). Also, durations of the increase above dry weather concentrations under proposed conditions are lower than under existing conditions except for total phosphorus, where more stringent treatment for proposed conditions also results in significantly lower concentrations simulated during dry weather. Several constituents do not show a significant increase in simulated concentrations after design storm discharges from the FMWRD facilities: total suspended solids, nitrate nitrogen, and total nitrogen.

Second, compliance with water quality standards was evaluated for simulated constituents with applicable ambient water quality standards: fecal coliform bacteria and ammonia nitrogen. The IEPA adopted a threshold for some constituents with no water quality standard that is used during the stream impairment evaluation. The IEPA’s listing values were used similarly to standards when available (total suspended solids, nitrate nitrogen, and total phosphorus). No standard or listing value is available for total nitrogen and BOD_5. Since dissolved oxygen concentrations in the Fox River were not simulated, the impact was evaluated by comparing total loads and loading rates of oxygen-demanding substances discharged under existing and proposed conditions from the FMWRD facilities.

Table 32. Percent reduction of maximum simulated value for evaluated constituents

Constituent	*Design storm*		*Constituent*	*Design storm*	
	1-10 year	*3 month*		*1-10 year*	*3 month*
Fecal coliforms	94-100%	94-100%	Total nitrogen	1-10%	-
Total suspended solids	1-9%	-	Total phosphorus	1-8%	10-15%
Ammonia nitrogen	9-20%	48-58%	BOD_5	23-43%	-
Nitrate nitrogen	11-18%	-	Dissolved oxygen* - total load	8-12%	20%
			- maximum loading rate	30-42%	74%

Note: * Dissolved oxygen was not simulated. Percent reduction was calculated for total load and maximum loading rate discharged by the FMWRD during design storms.
- Not simulated for 3-month design storm.

The interpretation of fecal coliform standards as they apply to a design rain simulation is not specified in the standard documents. Fecal coliform standards are defined for five or more samples collected during a 30-day period: a geometric mean should not exceed 200 cfu/100 ml and only 10% of samples can exceed 400 cfu/100 ml. Compliance with these standards will thus largely depend on upstream concentrations and conditions sampled during this 30-day period outside the storm. Observations collected at the Mill Street Bridge in Aurora vary significantly as shown in the 25^{th} and 75^{th} percentiles used for the upstream boundary (113 cfu/100 ml and 488 cfu/100 ml, respectively).

All effluent from the FMWRD facilities will be disinfected for 5-year and smaller storms. Under the normal treatment level (1 cfu/100 ml in treated effluent and CEPT), any non-compliance simulated during the 5-year and smaller storms is strictly due to high upstream concentrations. Storms larger than the 5-year storm result in a CSO, which in turn causes high peak concentrations in the Fox River. However, storms of this magnitude have a relatively small probability of occurrence (statistically, once in 5 years). Compliance with water quality standards during the 10-year storm can be achieved if the other four samples collected during the same 30-day period were below 80 cfu/100 ml.

The effect of effluent treated only to the permitted level (400 cfu/100 ml) was also evaluated. This minimal treatment level is at or above numerical values for both standards, resulting in a possible exceedance even for 1-year and 5-year storms if other samples collected during the same 30-day period were above 160 cfu/100 ml. Fortunately, fecal coliform concentrations in the treated effluent exceed the water quality standard values of 200 and 400 only on less than 2% and less than 1% of days, respectively.

Four ammonia standards are applicable to the study reach: absolute maximum, acute toxicity standard determined by pH at a time of observation, and chronic and subchronic toxicity standards determined by pH and temperature for ELSP and ELSA periods. The chronic standard applies to a 30-day average calculated from at least four samples. The subchronic standard applies to a 4-day average calculated from at least four samples. A graphical method was developed to evaluate the likelihood of ammonia standards being exceeded given the variability in observed pH and temperature values that determine the standard value. Chronic standards during ELSP and ELSA can be possibly exceeded when observed pH and temperature values in the Fox River are very high: pH above 9 and temperatures above 27ºC and 29ºC for ELSP and ELSA, respectively. Subchronic standards during ELSP and ELSA and the acute standard will not be exceeded due to proposed FMWRD discharges. Extremely high pH (above 9.4) and temperatures (above 38ºC) or high ammonia concentration at the upstream boundary may lead to possible exceedances, although observed data do not show such pH and temperature values.

Simulated values for total suspended solids and nitrate nitrogen are all significantly below the listing values of 116 mg/l for total suspended solids and 7.8 mg/l for nitrate nitrogen. The maximum simulated total suspended solid concentrations are 40 mg/l and 38.4 mg/l for existing and proposed conditions, respectively. The maximum simulated nitrate nitrogen concentrations are 2.49 mg/l and 2.10 mg/l for existing and proposed conditions, respectively.

The listing value for phosphorus is 0.61 mg/l. Maximum simulated values exceed the listing value for at least one scenario for each design storm under both existing and proposed conditions. Under proposed conditions, the exceedance is limited to scenarios with low flow and high upstream concentrations for storms smaller than 5-year and scenarios with low flow, regardless of the upstream concentrations for 5-year and larger storms. Proposed conditions lead to a significant reduction in both the maximum increase above the listing value (14–100%) and the duration of increase (64–100%) when compared to existing conditions. Model simulations indicate the total phosphorus listing value is likely to be exceeded for 4 to17 hours when large storms occur during low flow in the Fox River and the upstream phosphorus concentration is high.

Simulated ambient concentrations for ammonia nitrogen, nitrate nitrogen, and total phosphorus during the storm-affected discharge are at or above a high range of values observed at Route 34. As FMWRD discharge is not completely mixed at this location, it is difficult to ascertain whether the model overestimates ambient concentrations or whether this difference is caused solely by the incomplete mixing. This is most pronounced for ammonia nitrogen for which simulated concentrations during design storms are within 0.2–0.85 mg/l. Although ammonia nitrogen concentrations above 0.2 mg/l are observed rarely (13 out of 252 observations collected between January 2005 and September 2009), the three highest reported concentrations are 1.15 mg/l, 0.99 mg/l, and 0.70 mg/l. The values are in the same range as simulated maximum concentrations for design storms.

Overall, simulations showed that the proposed modification to FMWRD facilities will result in an improvement of water quality when compared to water quality resulting from existing conditions for storms of the same return interval. Model simulations indicate that proposed FMWRD discharges under the normal treatment level a) do not cause an exceedance of the water quality standard for fecal coliforms during 5-year and smaller storms; b) would likely not cause exceedances of ammonia water quality standards unless pH and temperature reach high values or upstream ammonia concentrations are high; c) would likely cause an exceedance of the total phosphorus listing value when no chemical treatment is applied to CEPT and large storms occur during low flows and high phosphorus concentrations in the Fox River upstream of the FMWRD; and d) would not cause exceedances of the total suspended solids and nitrate nitrogen listing values.

The goal of the CSO Control Policy is to limit the number of overflows to four to six per year. The FMWRD is providing full biological treatment for all storms of a corresponding return period (3 months) and a partial treatment, including full disinfection for all storms with a return period between 3 months and 5 years. Proposed modifications will result in a far greater positive effect on Fox River water quality than the minimum required by the CSO Control Policy.

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