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Memorandum

To:	**Michael Hahn (SEWRPC)**	**Date:**	**September 17, 2012 (FINAL)**
From:	**Kevin Kratt, J. Butcher**	**Subject:**	**Milwaukee Climate Change Risk Modeling**
cc:		**Proj. No.**	**100-CLE-T27944**

1 Introduction

The National Oceanic and Atmospheric Administration (NOAA) is sponsoring a study entitled "Evaluating Climate Change Risks and Impacts on Urban Coastal Water Resources in the Great Lakes." This project is a collaborative effort involving the University of Wisconsin-Milwaukee Great Lakes WATER Institute, the University of Wisconsin-Milwaukee Department of Civil Engineering and Mechanics, the University of Wisconsin-Madison Center for Climate Research, and the Southeastern Wisconsin Regional Planning Commission (SEWRPC). The overall objective of this project is to create a decision support tool for understanding climate impacts on water resources within the greater Milwaukee watersheds. The results of this project will be disseminated through the Wisconsin Initiative on Climate Change Impacts Milwaukee Working Group to both water resources managers for planning purposes, and the public to increase awareness of the potential consequences of climate change.

The overall analysis includes simulation of both the Greater Milwaukee watersheds draining to Lake Michigan and the receiving waters in Lake Michigan. The receiving water modeling, which requires the watershed model output as boundary conditions, is being conducted at the University of Wisconsin-Milwaukee. The watershed modeling component, documented in this memorandum, was conducted by Tetra Tech under contract to SEWRPC.

Watershed flow and water quality modeling uses the calibrated and validated continuous simulation models developed by Tetra Tech in support of the Milwaukee Metropolitan Sewerage District 2020 facilities plan and SEWRPC regional water quality management plan update for the greater Milwaukee watersheds (collectively referred to as the Water Quality Initiative or WQI). These models are documented in Milwaukee Metropolitan Sewerage District, *MMSD 2020 Facilities Plan*, June 2007 and SEWRPC Planning Report No. 50 (PR No. 50), *A Regional Water Quality Management Plan for the Greater Milwaukee Watersheds*, December 2007. These models simulate instream water quality conditions and flow in the Kinnickinnic, Menomonee, Milwaukee, and Root River watersheds, the Oak Creek watershed, the area draining directly to the Milwaukee Harbor estuary, and the Lake Michigan direct drainage area (collectively referred to as the greater Milwaukee watersheds) in the Southeastern Wisconsin Region. Models for the Kinnickinnic River, Menomonee River, Root River, and Oak Creek watersheds are built using EPA's Hydrologic Simulation Program – FORTRAN (HSPF)[1], while the Milwaukee River model (the largest individual model) uses a recompiled version of HSPF called Loading Simulation Program in C++ (LSPC), developed by Tetra Tech[2].

The original HSPF and LSPC watershed water quality model runs from the WQI were developed for the 10-year meteorological period from 1988 through 1997. The models were developed to represent both year 2000 and planned year 2020 land use conditions and management practices, assuming climate conditions characteristic of the period from 1988 through 1997, which was determined to approximate normal conditions in the absence of major climate change influences. For this study, the watershed representation (independent of climate change) is provided by the models for revised 2020 baseline population and land use and recommended regional water quality management plan conditions (the "preferred alternative") with 1988 – 1997 climate. In Tetra Tech's library of multiple model scenarios this is referred to as the "PA2" and/or the "PrefAlt2" model run.

2 Climate Scenarios

Potential climate impacts are estimated based on expected conditions at mid-century (from 2046 through 2065). The envelope of potential impacts is estimated by comparing "best case" and "worst case" climate change conditions for rainfall, air temperature, and potential evapotranspiration to current conditions, where current conditions are represented by the 1988 through 1997 meteorological time series. To provide a consistent basis for comparison, the future weather series were based on perturbations of the 1987 – 1997 time series (allowing a year for model spin-up). Specifically, the UW-Madison Center for Climate Research created downscaled versions of 1987 – 1997 precipitation and temperature representing the 10th percentile and 90th percentile of predicted climate statistics for mid-century under the A1B emissions scenario (which projects emissions for a future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology).. The underlying ensemble is derived from the suite of archived output from 14 general circulation models (GCMs) contained in the World Climate Research Programme's (WCRP's) CMIP3 multi-model dataset, statistically downscaled to the local scale using the CRU CL 2.0 20th century climate dataset. Results were provided at a 15-minute time step. Potential evapotranspiration (PET) was computed using the Penman Pan Evaporation formula along with some localized monthly adjustments.

The climate models are generally in agreement that spring rainfall will increase in the Milwaukee area. The "best case" (10th percentile) and "worst case" (90th percentile) scenarios for mid-century were defined relative to the spring rainfall thresholds associated with SSO and CSO events over the past ten years[3]. Specifically, the choice of a particular distribution for rescaling the historical precipitation and temperature records was based on interpolating the two models closest to the upper 90th percentile and the two closest to the lower 10th percentile for increases in the number of spring precipitation events larger than 1 inch in 24 hours. The 10th percentile ("best case") simulations are based on a 50/50 blend of ipsl_cm4 and csiro_mk3_0; the 90th percentile ("worst case") simulations are based on a 50/50 blend of the miub_echo_g and microc3_2_hires simulations. The future time series were created from observed data using a remapping approach in which the gridded climate output is related to the probability density function of temperature and precipitation at a point meteorological station and the time-mean cumulative

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[1] Bicknell, B.R., J.C. Imhoff, J.L. Kittle, Jr., T.H. Jobes, and A.S. Donigian, Jr. 2005. HSPF Version 12.2 User's Manual. Aqua Terra Consultants in Cooperation with the U.S. Geological Survey for the U.S. Environmental Protection Agency, National Exposure Research Laboratory, Office of Research and Development, Athens, GA.

[2] Tetra Tech. 2009. Loading Simulation Program in C++ (LSPC) Version 3.1 User's Manual. Fairfax, VA. LSPC is available at: http://www.epa.gov/athens/wwqtsc/html/lspc.html.

[3] McLellan, S., M. Hahn, D. Lorenz, G. Pinter, I. Lauko, E. Suer, D. Bennett, D. Perry, and J. McMullin. 2011. Impact of Climate Change on CSOs and SSOs in Milwaukee Watersheds. University of Wisconsin-Milwaukee and Southeastern Wisconsin Regional Planning Commission.

distribution function for the present and future conditions is used to map percentiles between present and future. This approach allows the future time series to incorporate any changes in the probability distribution that are predicted by the GCM, such as a higher frequency of intense rainfall events.

For the watershed model application, the two scenarios represent an increase of from 5.6 to 8.7 degrees Fahrenheit in annual average temperature relative to the 1988-1997 baseline (Table 1). While the two scenarios were selected to describe the potential range of frequency of large spring rainfall events, the resulting differences in annual average precipitation are small. On the other hand, PET is estimated to increase by 25 to 38 percent, with predictions for a more arid future in which average annual PET exceeds precipitation.

Table 1. Comparison of 2050 Climate Scenarios to 1988 – 1997 Baseline

	Baseline (1988 – 1997)	10^{th} Percentile (“Best Case”)	90^{th} Percentile (“Worst Case”)
Precipitation (in/yr)	32.5	33.2	33.4
Average Temperature (°F)	47.7	53.3	56.4
Potential Evapotranspiration (in/yr)	30.4	37.5	42.1

The existing watershed models were built using multiple weather stations to capture local variability in precipitation amounts, temperature, and other meteorological variables. In contrast, the future climate scenarios provide output for only one station in Milwaukee – General Mitchell International Airport. Therefore, it was first necessary to re-run the existing condition models using a single meteorological station. This means that the baseline results will not exactly match (and indeed should be less accurate) than those presented under the WQI based on model calibration to multiple meteorological stations. In addition, using a single meteorological station is equivalent to an assumption that rain events occur everywhere in the watershed at exactly the same time, which can lead to an artificial increase in the predicted intensity of extreme events, particularly high flow events. Nevertheless, the results should provide a reasonable basis for *relative* comparison of the potential range of impacts of climate change.

The model uses additional meteorological variables, including wind travel, solar radiation, dew point temperature, and cloud cover. Wind, solar radiation, and dew point temperature are used in the upland simulation only in the estimation of snow melt and snow sublimation. All four variables are used in the stream reach simulation, where they affect water temperature and algal growth. All four variables are also inputs to the calculation of Penman Pan PET. The statistical approach used for downscaling the climate results did not produce estimates of these meteorological time series. Therefore, they are represented by the existing condition time series from General Mitchell International Airport in all scenarios. As a result, the PET time series differs between climate scenarios only as a function of air temperature and does not reflect any potential changes in wind, changes in incident solar radiation as a result of changes in cloudiness, or changes in dew point temperature. For the reach simulation, water temperature in shallow streams is most strongly controlled by air temperature, so holding the other meteorological variables that affect sensible and evaporative heat exchange should have only a small impact. Finally, simulations of algal growth do not reflect any changes in light availability due to changes in cloudiness.

Another important, but sometimes ignored, aspect of climate change is the predicted increase in ground level CO_2 concentrations. IPCC predictions of CO_2 concentrations in the atmosphere under the A1B emissions scenario call for an increase from 369 ppmv in 2000 to about 532 ppmv (using the ISAM model reference run) or 522 ppmv (using the Bern-CC model reference run) in 2050[4]. Plants require CO_2 from the atmosphere for photosynthesis. An important effect of CO_2 fertilization is increased stomatal closure, as plants do not need to transpire as much water to obtain the CO_2 they need for growth. This effect can potentially counterbalance predicted increases in temperature and potential evapotranspiration. It may also reduce water stress on plants, resulting in greater biomass and litter production, which in turn will influence pollutant loads. Recent research, particularly the FACE experiments summary[5], seems to confirm that significant evapotranspiration reductions do occur at the ecosystem level under CO_2 fertilization. Although there are differences in responses among plant species, with lesser effects with C_4 photosynthesis, the magnitude of the response to CO_2 levels predicted by the mid-21st century appears to be on the order of a 10 percent reduction in evapotranspiration response[6].

This feedback effect from increased CO_2 may in part offset the predicted increase in PET. Unfortunately, a limitation of the HSPF model is that it does not include an integrated plant growth model and therefore cannot directly simulate this feedback effect on actual evapotranspiration. The major impact of this shortcoming is to introduce a potential bias in which summer low flows may be underestimated. To a lesser extent, peak flows from summer convective storms may also be underestimated if antecedent soil moisture is underestimated.

3 Simulation Results

The WQI recommended plan simulations were run three times for each watershed: once using existing climate (restricted to General Mitchell International Airport time series), and once each using the 10 percent and 90 percent mid-century climate scenarios. These runs include seasonal disinfection, which is represented in HSPF by combining the results of simulations with and without the disinfection units in place.[7] The disinfection units have a major impact on fecal coliform loads, and also slightly alter hydrology by delaying some storm flows.

3.1 LOAD AND CONCENTRATION SUMMARIES

Annual average loads delivered from each watershed over the ten-year simulation period are summarized in Table 2. Table 3 summarizes the average annual flow and concentrations at the watershed outlets for

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[4] Appendix II *in* IPCC (Intergovernmental Panel on Climate Change). 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, UK.

[5] Leakey, A.D.B., E.A. Ainsworth, C.J. Bernacchi, A. Rogers, S.P. Long, and D.R. Ort. 2009. Elevated CO_2 effects on plant carbon, nitrogen, and water relations: six important lessons from FACE. *Journal of Experimental Botany*, 60(10): 2859-2876.

[6] See, for instance, Bernacchi, C.J., B.A. Kimball, D.R. Quarles, S.P. Long, and D.R. Ort. 2007. Decreases in stomatal conductance of soybean under open-air elevation of [CO_2] are closely coupled with decreases in ecosystem evapotranspiration. *Plant Physiology*, 143: 134-144.

[7] Within the water quality models for the recommended plan and extreme measures condition, the detection and elimination of illicit discharges to storm sewer systems and control of urban sourced pathogens, including those in stormwater runoff, are represented using stormwater disinfection units. Such units were initially considered as a recommended approach to treatment of runoff under the SEWRPC regional water quality management plan update, but were eliminated from consideration based on comments from the Technical Advisory Committee that guided preparation of the plan. However, the use of such units is considered to be appropriate as a surrogate representation of the varied and as yet undetermined means that would be applied to implement the plan recommendation to detect and eliminate illicit discharges and to control pathogens in urban stormwater runoff. Those units explicitly address the control of bacteria in stormwater runoff, and, based on the way that bacteria loads are represented in the calibrated model, they also implicitly provide some control of bacteria that may reach streams through illicit connections that contribute to baseflow.

pollutants of interest. Concentration results are not provided for the Lake Michigan direct drainages as these consist of multiple small drainages that are not represented by a single output concentration.

Significant decreases in annual flow are predicted for both the "best" and "worst" case climate scenarios for 2050. This occurs because PET is predicted to increase at a much faster rate than precipitation. In many, but not all cases, annual pollutant load is also predicted to decrease due to lower total volumes of storm runoff. This is offset by the observation that both the "best" and "worst" case scenarios predict an increase in the frequency of large spring rainfall events – resulting in less total storm runoff but more high runoff events. The predicted effects on total suspended solids (TSS) loads reflect the complex interplay between upland loading rates and channel scour/resuspension events. In the Menomonee and Kinnickinnic watersheds the TSS load is greater than the recommended plan under both climate scenarios, whereas net reductions are predicted under both climate scenarios for the Milwaukee River, Oak Creek, and Root River watersheds.

Effects on pollutant concentration reflect the combined impact of changes in flow and load. If both flow and load decrease, average concentration can go up or down depending on which component changes more. For TSS, there is a tendency in the more urban parts of the Menomonee River, Kinnickinnic River, and Oak Creek watersheds for average concentrations to increase while the median concentration decreases (see Appendix A). This reflects a situation in which concentrations are generally predicted to decrease in the future, but the averages are higher due to a small number of large, scouring events.

Table 2. Average Annual Flow Volume and Pollutant Load by Watershed

Watershed	Parameter	Recommended Plan based on GMIA Weather Inputs	Recommended Plan under Best-Case (10%) Climate Change Scenario	Recommended Plan under Worst-Case (90%) Climate Scenario
Milwaukee River	Flow (AF/yr)	451,927	379,457	348,428
	Fecal Coliform Bacteria (#/yr)	4.13E+15	3.41E+15	3.01E+15
	Total Phosphorus (MT/yr)	95.05	83.68	84.72
	Total Nitrogen (MT/yr)	878.8	706.1	686.7
	Total Suspended Solids (MT/yr)	14,270	12,611	13,236
	Copper (kg/yr)	4,395	4,002	3,811
Menomonee River	Flow (AF/yr)	97,117	85,877	81,391
	Fecal Coliform Bacteria (#/yr)	7.21E+15	6.59E+15	6.12E+15
	Total Phosphorus (MT/yr)	15.65	14.36	14.23
	Total Nitrogen (MT/yr)	124.8	110.4	107.5
	Total Suspended Solids (MT/yr)	5,251	5,338	5,544
	Copper (kg/yr)	825	768	733
Kinnickinnic River	Flow (AF/yr)	18,766	17,244	16,614
	Fecal Coliform Bacteria (#/yr)	2.18E+15	2.10E+15	2.01E+15
	Total Phosphorus (MT/yr)	4.52	4.13	4.01
	Total Nitrogen (MT/yr)	27.0	24.2	23.2
	Total Suspended Solids (MT/yr)	1,779	1,814	1,892
	Copper (kg/yr)	209	197	187

Watershed	Parameter	Recommended Plan based on GMIA Weather Inputs	Recommended Plan under Best-Case (10%) Climate Change Scenario	Recommended Plan under Worst-Case (90%) Climate Scenario
Oak Creek	Flow (AF/yr)	20,581	18,128	17,202
	Fecal Coliform Bacteria (#/yr)	1.52E+15	1.46E+15	1.42E+15
	Total Phosphorus (MT/yr)	3.10	2.88	2.80
	Total Nitrogen (MT/yr)	25.8	24.0	23.3
	Total Suspended Solids (MT/yr)	1,122	1,086	1,093
	Copper (kg/yr)	188	179	174
Root River	Flow (AF/yr)	119,550	92,897	83,781
	Fecal Coliform Bacteria (#/yr)	3.28E+15	2.94E+15	2.64E+15
	Total Phosphorus (MT/yr)	21.93	16.63	15.84
	Total Nitrogen (MT/yr)	262.5	190.5	179.3
	Total Suspended Solids (MT/yr)	11,502	8,882	8,960
	Copper (kg/yr)	148	128	118
Lake Michigan Direct Drainage	Flow (AF/yr)	31,596	27,479	25,757
	Fecal Coliform Bacteria (#/yr)	2.69E+15	2.57E+15	2.44E+15
	Total Phosphorus (MT/yr)	7.030	6.016	5.767
	Total Nitrogen (MT/yr)	57.18	48.28	45.92
	Total Suspended Solids (MT/yr)	2617	2591	2705
	Copper (kg/yr)	286.2	259.5	245.1

Table 3 Average Annual Flow Rate and Downstream Pollutant Concentration by Watershed

Watershed	Parameter	Recommended Plan based on GMIA Weather Inputs	Recommended Plan under Best-Case (10%) Climate Change Scenario	Recommended Plan under Worst-Case (90%) Climate Scenario
Milwaukee River	Flow (cfs)	623.7	523.7	480.9
	Fecal Coliform Bacteria (#/100 ml)	460	420	373
	Dissolved Oxygen (mg/L)	9.915	9.215	8.756
	Total Phosphorus (mg/L)	0.109	0.109	0.114
	Total Nitrogen (mg/L)	1.384	1.328	1.312
	Total Suspended Solids (mg/L)	55.67	43.11	44.19
	Copper (mg/L)	0.040	0.045	0.048
Menomonee River	Flow (cfs)	134.0	118.5	112.3
	Fecal Coliform Bacteria (#/100 ml)	3,835	3,437	3,209
	Dissolved Oxygen (mg/L)	11.13	10.79	10.59
	Total Phosphorus (mg/L)	0.136	0.149	0.160
	Total Nitrogen (mg/L)	1.150	1.191	1.243
	Total Suspended Solids (mg/L)	13.09	13.55	13.54
	Copper (mg/L)	0.045	0.044	0.043

Watershed	Parameter	Recommended Plan based on GMIA Weather Inputs	Recommended Plan under Best-Case (10%) Climate Change Scenario	Recommended Plan under Worst-Case (90%) Climate Scenario
Kinnickinnic River	Flow (cfs)	25.90	23.80	22.93
	Fecal Coliform Bacteria (#/100 ml)	2,928	2,571	2,263
	Dissolved Oxygen (mg/L)	11.05	10.66	10.43
	Total Phosphorus (mg/L)	0.180	0.188	0.200
	Total Nitrogen (mg/L)	1.398	1.401	1.442
	Total Suspended Solids (mg/L)	10.41	10.63	10.70
	Copper (mg/L)	0.038	0.035	0.033
Oak Creek	Flow (cfs)	28.41	25.02	23.74
	Fecal Coliform Bacteria (#/100 ml)	3,696	3,181	2,918
	Dissolved Oxygen (mg/L)	11.22	10.91	10.74
	Total Phosphorus (mg/L)	0.070	0.068	0.068
	Total Nitrogen (mg/L)	0.811	0.803	0.810
	Total Suspended Solids (mg/L)	13.19	14.29	14.94
	Copper (mg/L)	0.047	0.046	0.048

Watershed	Parameter	Recommended Plan based on GMIA Weather Inputs	Recommended Plan under Best-Case (10%) Climate Change Scenario	Recommended Plan under Worst-Case (90%) Climate Scenario
Root River	Flow (cfs)	165.0	128.2	115.6
	Fecal Coliform Bacteria (#/100 ml)	2,836	3,280	3,373
	Dissolved Oxygen (mg/L)	11.11	10.90	10.75
	Total Phosphorus (mg/L)	0.100	0.105	0.114
	Total Nitrogen (mg/L)	1.191	1.158	1.183
	Total Suspended Solids (mg/L)	22.08	19.69	19.37
	Copper (mg/L)	0.012	0.014	0.014

3.2 WATER QUALITY CONDITION COMPARISON

Consistent with the WQI, instream water quality summary statistic condition comparison tables were developed for multiple water quality indicators at each assessment point in the five watersheds. The full set of tables is included as an appendix to this report. In general, the changes associated with future climate are small, as is the difference between the best case (10th percentile) and worst case (90th percentile) climate scenarios.

Both the best case and worst case climate scenarios can result in prediction of a slight improvement or slight degradation of conditions relative to the existing baseline. The result depends on the balance between changes in load and flow, especially the tradeoff between more intense events (which increase load) and lower frequency of events (which decreases load and concentration).

As an example of the complexities of the relationships in the model output, consider the downstream station on the Kinnickinnic. At this station, both total flow volume and total phosphorus load are predicted to decrease under both future scenarios, while total phosphorus concentration increases. Despite the overall decrease in flow and load, the highest flows increase under the future scenarios, as do the highest phosphorus concentrations. For TSS, both loads and concentrations increase under the future scenarios.

Figure 1 shows the flows for April – May 1990 under the baseline and 90th percentile scenarios. The flow peaks are higher under the 90th percentile scenario, while the intervening dry weather flows are lower (due primarily to increased ET). For TSS, which is loaded only by surface pathways, the higher flow peaks result in higher TSS concentrations, as the transport capacity for solids in overland flow is a nonlinear function of flow depth (Figure 2). The pattern differs from that of flow, however, as the amount of solids available for transport depends on the time since the last event. Thus, the May 10 event shows a smaller increase in TSS than might be expected from the magnitude of the flow because it occurred soon after another storm event on May 4, resulting in a reduced amount of stored sediment available for transport. In contrast, the TSS concentrations associated with events of May 16 and May 19 are relatively large because they mobilized sediment from the May 10 event that had been temporarily stored in the channel. Total phosphorus (Figure 3) shows yet another pattern, with small increases in large event concentrations accompanied by more significant increases in concentrations during dry weather conditions, when less flow is available to dilute point source loads (which are assumed to remain equal to baseline conditions.)

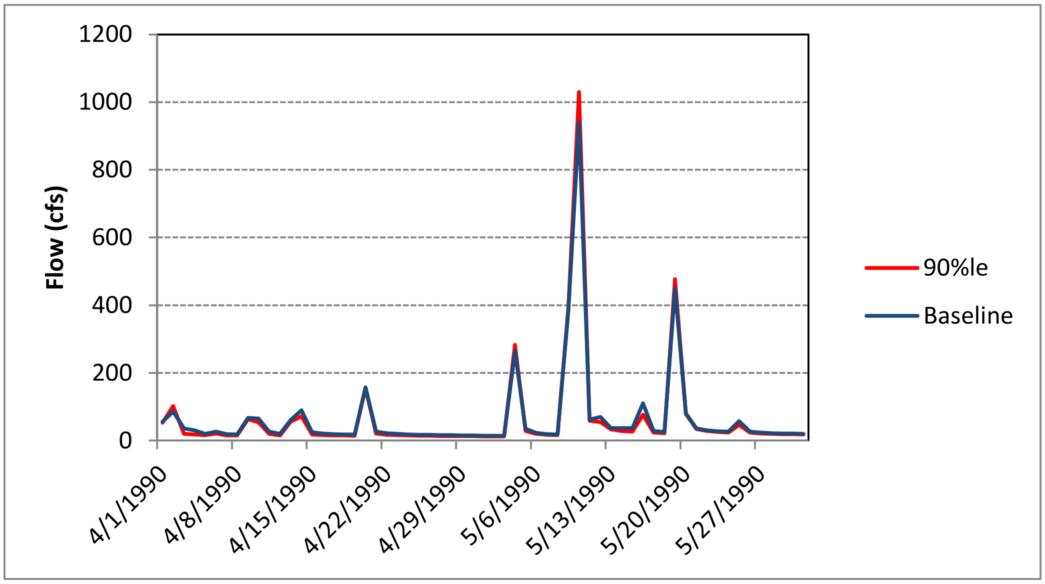

Figure 1. **Flow in Kinnickinnic River, April – May 1990**

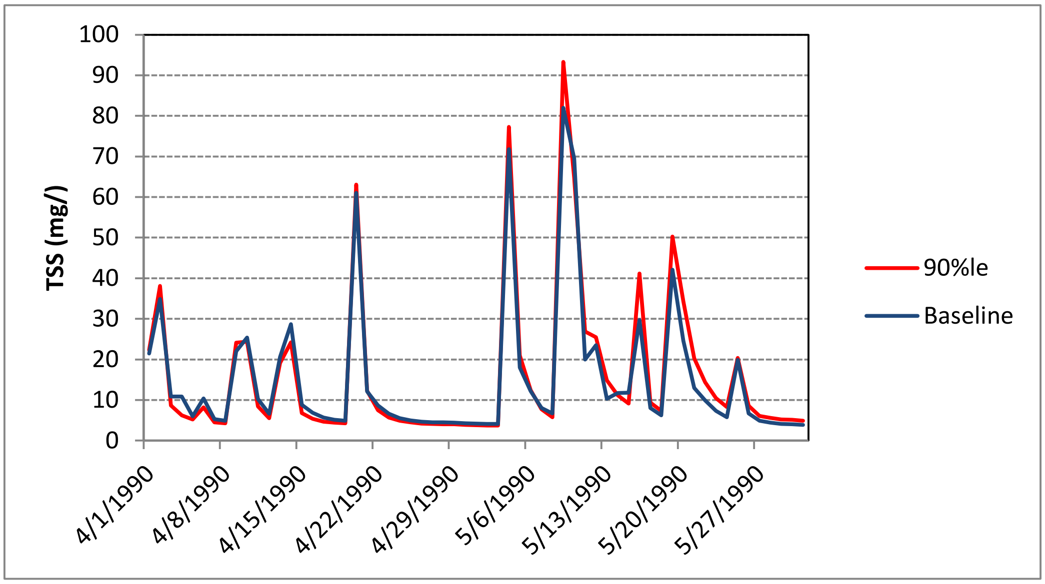

Figure 2. **TSS Concentrations in Kinnickinnic River, April – May 1990**

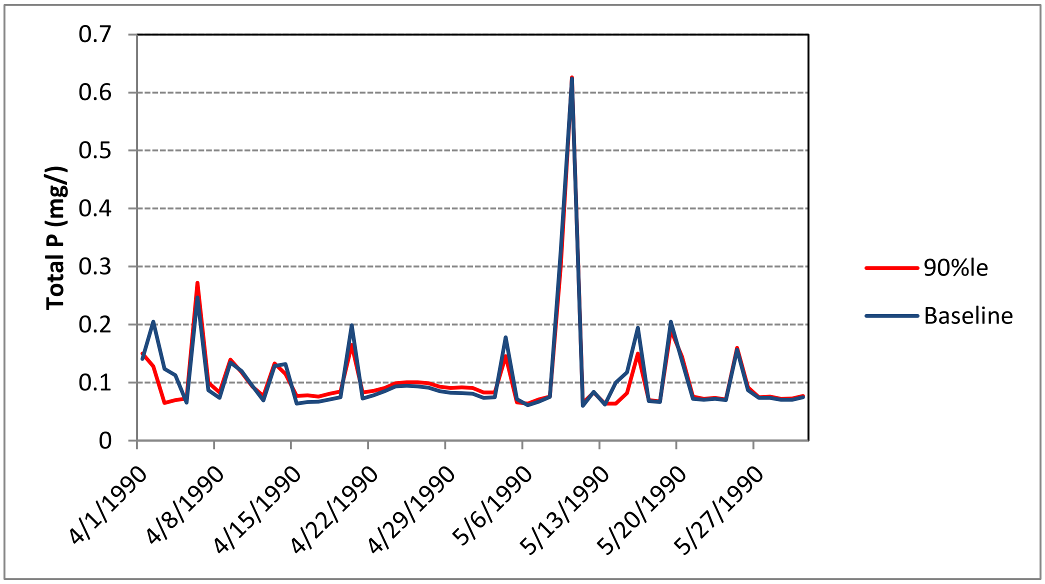

Figure 3. **Total Phosphorus Concentrations in Kinnickinnic River, April – May 1990**

3.3 IMPACTS ON TEMPORAL DISTRIBUTION OF LOAD

Future climate may result in changes in the timing as well as the magnitude of flows and pollutant loads. These potential impacts are summarized graphically in Figure 5 through Figure 9, which display results at the outlet of each major watershed. In each of these figures the left hand column shows the average flow and loading by month over the 10-year simulation period (1988 – 1997 for the baseline), while the right hand side shows duration or exceedance curves.

Seasonal results for flow are striking as average flow is predicted to decline in all months except for the winter, with the largest reduction in spring flows. There does not appear to be a pronounced shift in the timing of flows in response to climate scenarios; however, there is a systematic difference between watersheds as a result of impervious area cover, with the more urban watersheds exhibiting relatively higher summer runoff.

Monthly patterns of nutrient loads generally follow flow volume. In contrast, the TSS loads are more closely related to the frequency of intense events. Figure 4 shows the distribution of rainfall intensities greater than 0.1 in/15-min during 1987-1997 under the 90th percentile distribution (crosses) along with the number of 15-minute intervals with intensity greater than 0.15 in/15-min. The highest intensities are found in May through August, while June and August have the greatest frequency of intense rainfall as well as the largest sediment loads – even though the total flow volume for August is relatively low compared to the spring.

Nutrient loads tend to decline more than TSS loads under future climate because the nutrient loads are focused more toward the early part of the year when the flow reductions are greater. The seasonal patterns for fecal coliform loads reflect the fact that the Preferred Alternative simulation includes a representation of recreation-season disinfection at selected locations. Because only a limited number of disinfection units were included in the Kinnickinnic River model, the seasonal pattern of fecal coliform loads is less affected by disinfection than in the other waterbodies.

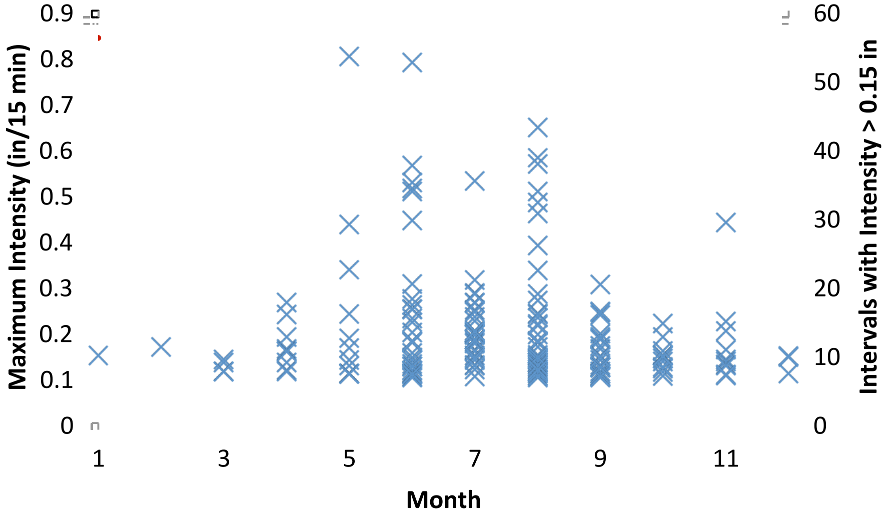

Figure 4. Seasonal Distribution of Intense Rainfall under the 90th Percentile Scenario

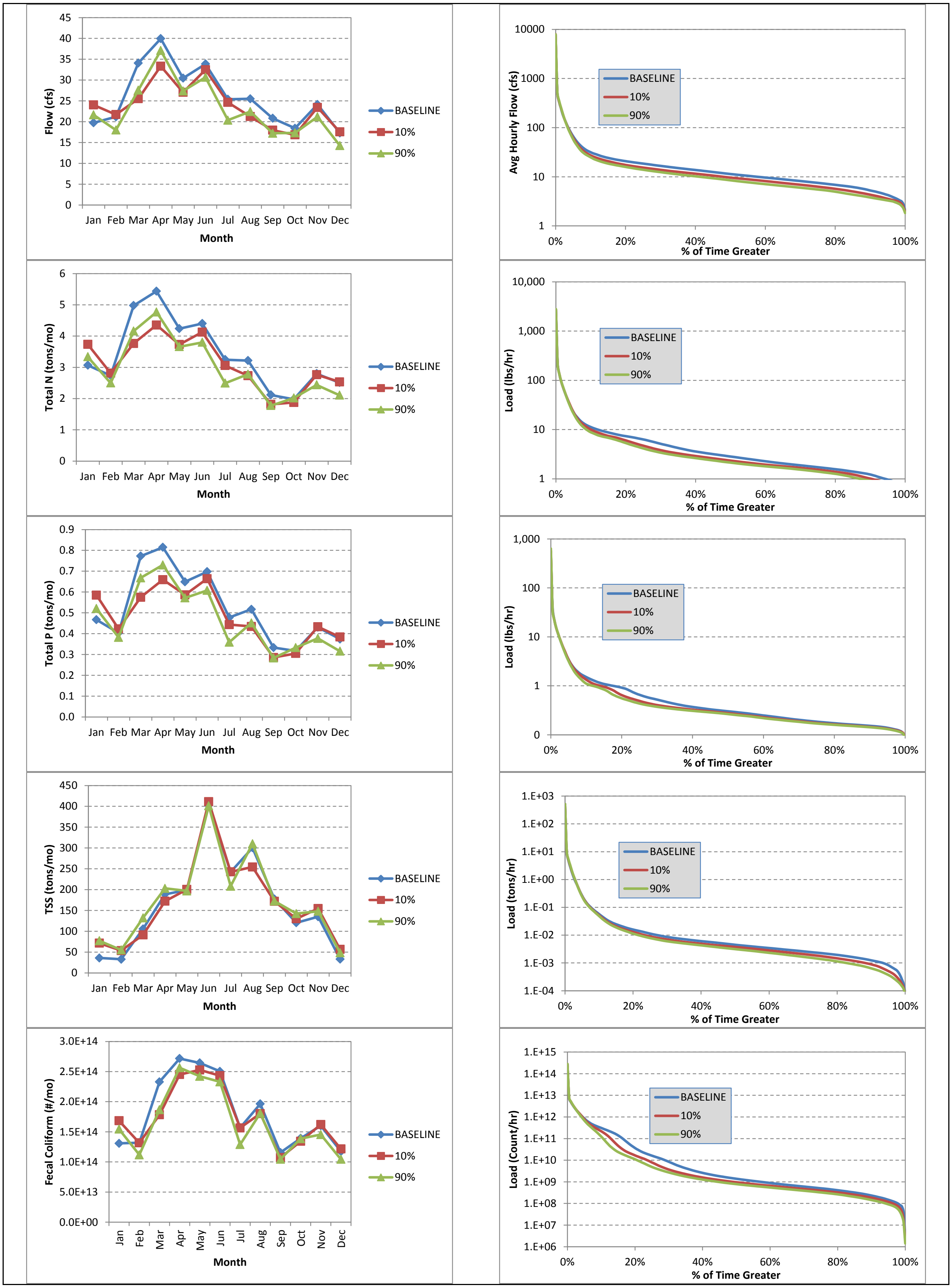

Figure 5. Monthly Loading and Duration Curves for Kinnickinnic River

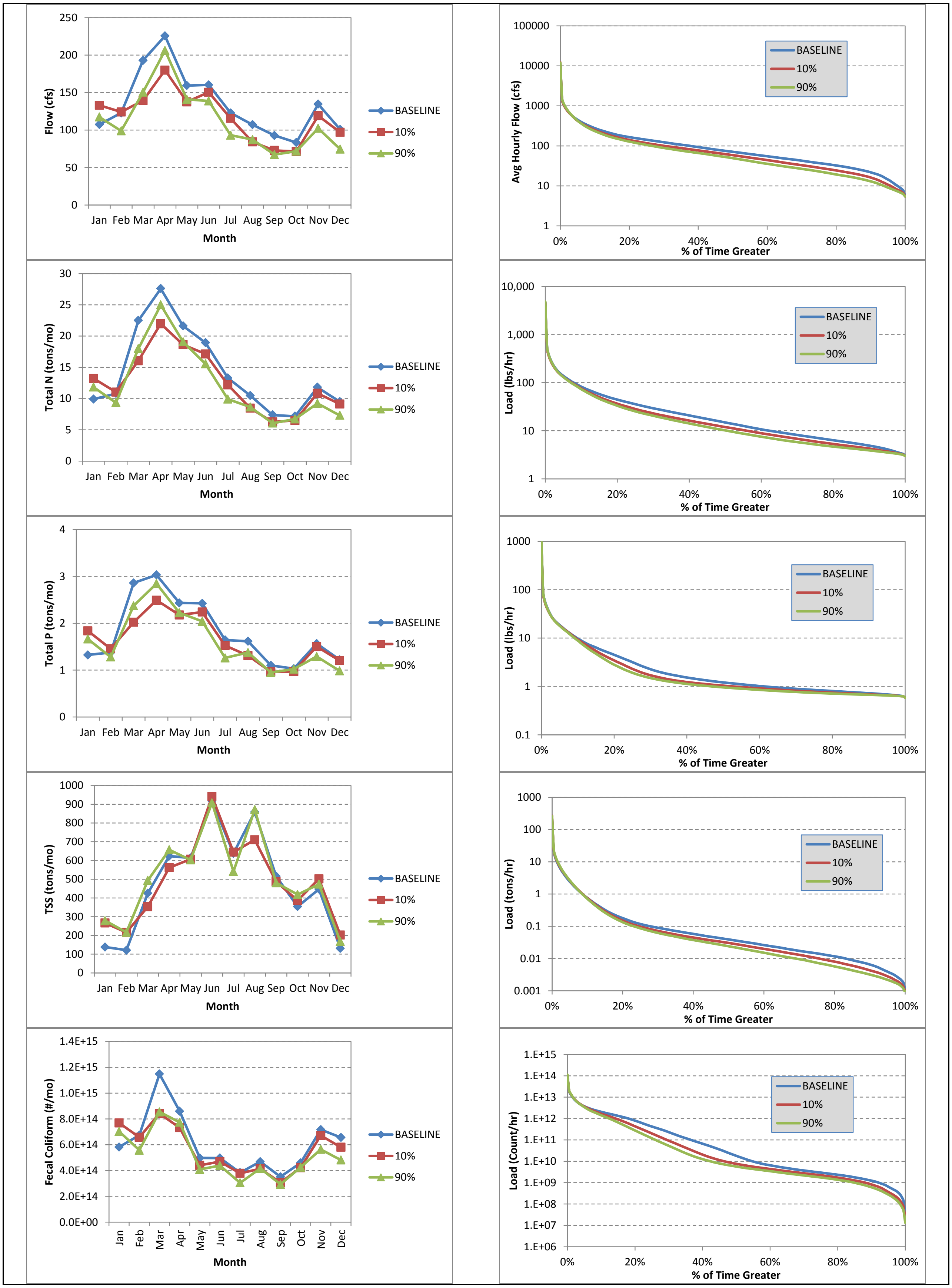

Figure 6. Monthly Loading and Duration Curves for Menomonee River

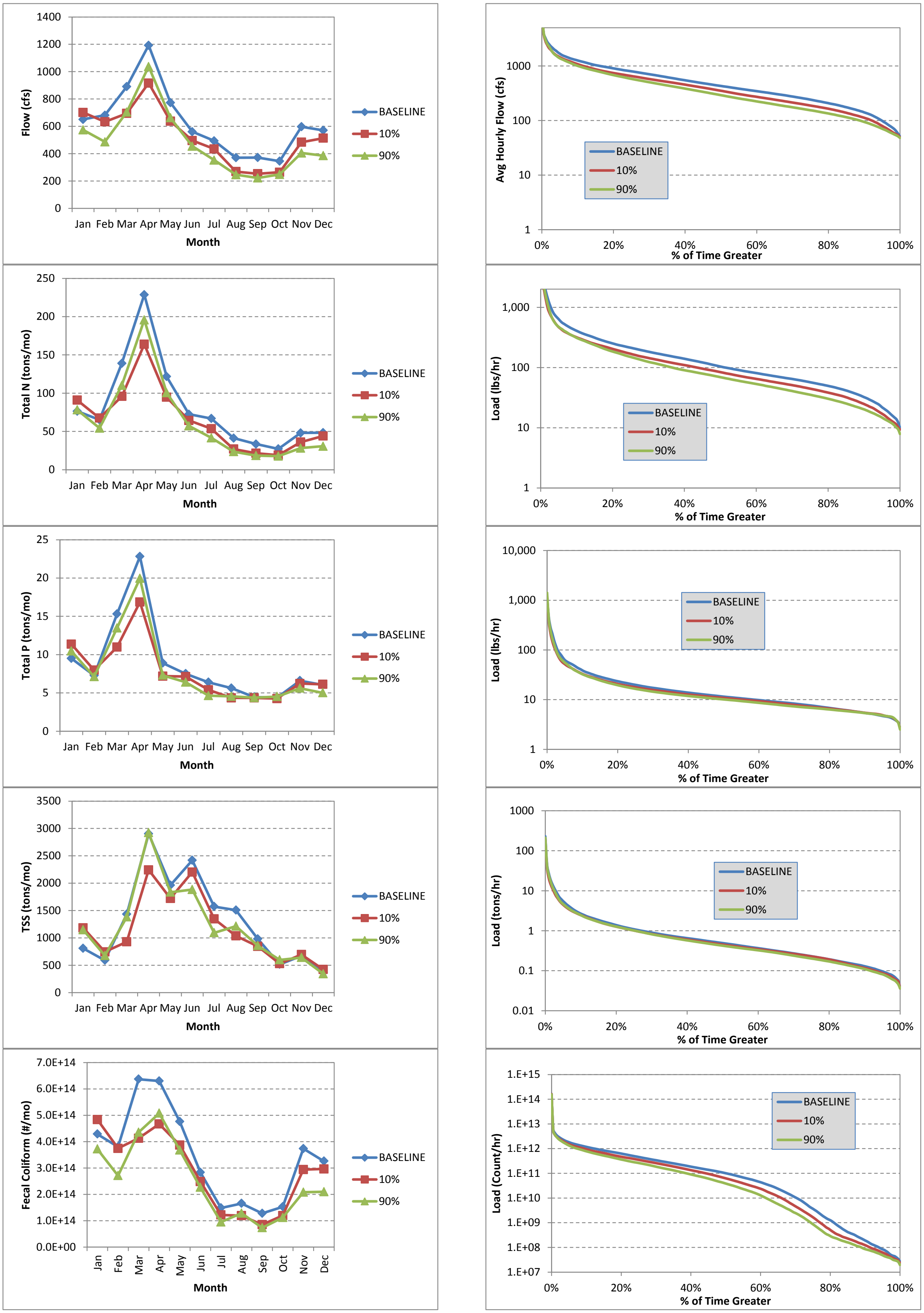

Figure 7. Monthly Loading and Duration Curves for Milwaukee River

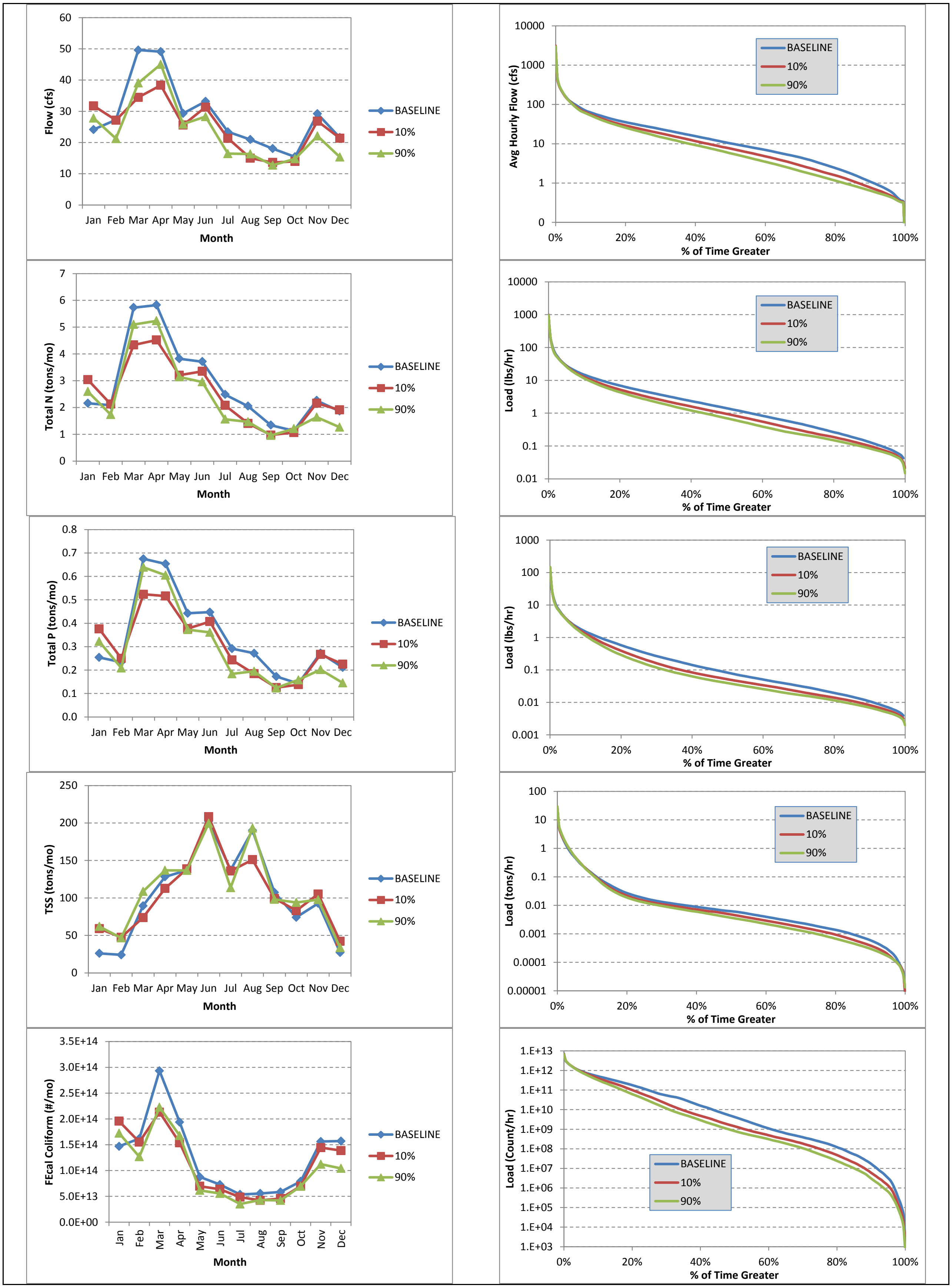

Figure 8. Monthly Loading and Duration Curves for Oak Creek

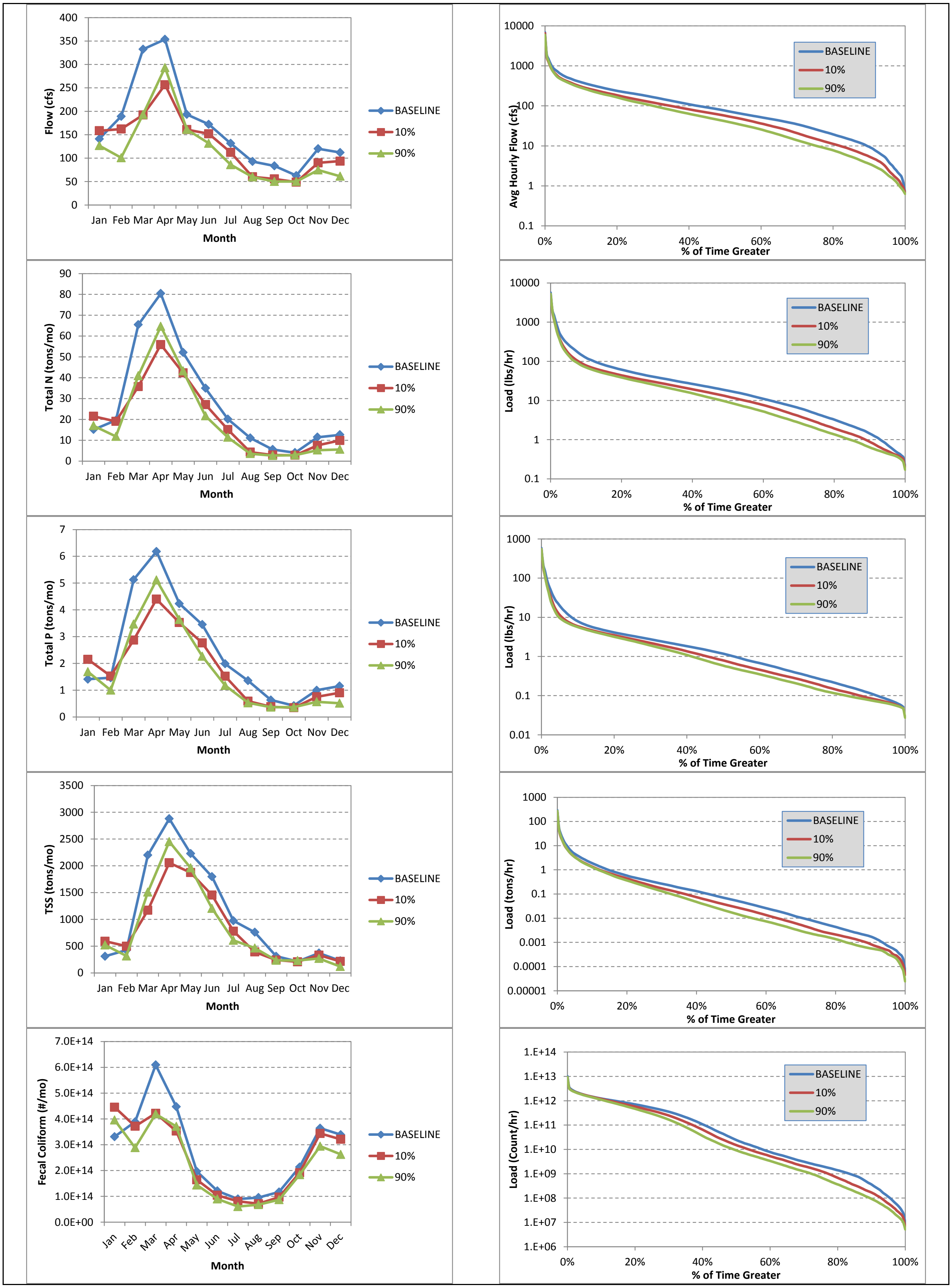

Figure 9. Monthly Loading and Duration Curves for Root River

4 Electronic Deliverables

Electronic deliverables are contained on the accompanying DVD.

4.1 ESTUARY INPUT FILES

A major purpose of the watershed simulations was to provide hourly time series input of flow and fecal coliform bacteria loads to the Lake Michigan model to be run by UW-Milwaukee. The Lake model is specified to run for one year, to be selected as the year with the largest fecal coliform bacteria loading under current conditions. For each individual watershed and for the sum across all watersheds, the largest total load is predicted to have occurred in 1990 (Figure 10).

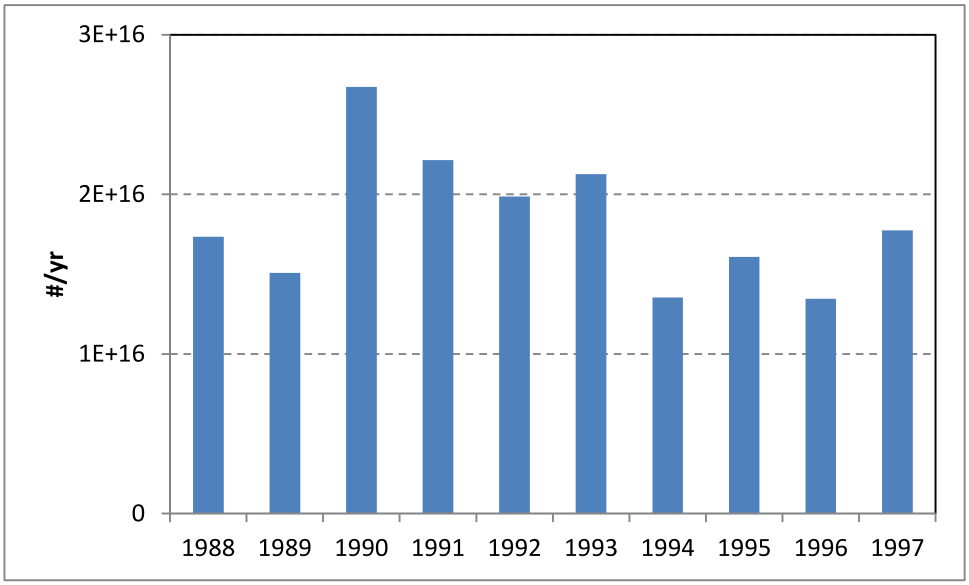

Figure 10. Total Fecal Coliform Load by Year (all Watersheds)

Time series for 1990 meteorology were created with the addition of a spin-up period consisting of the last three months of 1989. These files were transmitted electronically to SEWRPC for use in the Lake Michigan model.

4.2 MODEL FILES

Final model input files for each watershed are provided electronically.

Appendix A. Water Quality Summary Statistics

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