Appendix D: CE-QUAL-W2 Modeling Report

CE-QUAL W2 Hydrodynamic and Water Quality Model for the Black River, Ohio

The Black River modeling domain consists of a riverine portion (upper river - 10.19 to 4.94 miles) feeding into the navigation channel (lower river - 4.94 to 0.01 miles) at the downstream which ultimately feeds into Lake Erie. The length of the study area is approximately 10 miles. Based on past studies of the Black River and data collected for this study, the critical area of interest for the attainability of dissolved oxygen water quality standards is the dredged portion of the lower river (river miles 2.76 to 0.01).
The U.S. Army Corps of Engineers CE-QUAL-W2 (W2 version 3.2) hydrodynamic and water quality model was used to simulate eutrophication processes within the lake. The model provides a single framework model to simulate the upper river and lower river portions of the Black River. The modeling domain of the upper river was sufficiently extended to incorporate the effects of the Seiche, the effects of which can extend upstream to river mile 6.4 when upstream flow is relatively low (e.g., less than 150 cfs (LTI, 2003a)).

1.1 MODEL FRAMEWORK

The U.S. Army Corps of Engineers CE-QUAL-W2 model was used as the primary receiving water model for simulating the eutrophication processes in the Black River. The W2 model is a two-dimensional, longitudinal/vertical (laterally averaged), hydrodynamic and water quality model. The model allows application to multiple branches for geometrically complex waterbodies (dendritic/branching lakes and reservoirs) with variable grid spacing, time-variable boundary conditions, and multiple inflows and outflows from point/nonpoint sources and precipitation.

The two major components of the W2 model include hydrodynamics and water quality kinetics. Both of these components are coupled (i.e. the hydrodynamic output is used to drive the water quality transport simulation internally in the code). The hydrodynamic portion of the model predicts water surface elevations, flow velocities, and temperature. The water quality portion can simulate the complex interactions between dissolved oxygen (DO), nutrients, and phytoplankton. Any combination of constituents can be simulated. Refer to the CE-QUAL-W2 Version 3.2 Users Manual [for a more detailed discussion of simulated processes and model parameters.

1.2 HYDRODYNAMIC MODELING

1.2.1 Model Configuration

Model configuration involved setting up the model computational grid, setting initial conditions, boundary conditions, and hydrodynamic parameters for the hydrodynamic simulations. The following subsections describe the configuration and key components of the model.

1.2.1.1 Segmentation/Computational Grid Setup

The computational grid setup defines the process of representing the Black River system in the finite difference scheme. Configuration information is provided in the main control file of the W2 model while the computational grid is specified in the bathymetry file. The model requires the user to set up the bathymetry file for each branch defining the upstream and downstream segment. A bathymetry file specifies the average segment width, depth, and orientation information, along with bottom roughness and initial water surface elevation for each segment. Bathymetry for the Upper Black River (UBR) was generated using USGS quadrangle maps and City of Lorain Flood Profiles from FEMA. The USGS quad maps were used to estimate the average widths and orientation. The geometry of the Lower Black River (LBR) was based on an existing HEC-2 model from FEMA, with the orientation estimated from the USGS quadrangle maps and NHD stream coverage. The HEC-2 model provided detailed channel crossectional information of the navigation channel from Lake Erie to approximately river mile 5.

In this study, a watershed model was developed and calibrated to simulate the hydrology and water quality in all the tributaries of the Black River (see Appendix B). This allowed for representation of the spatial variable impact from tributaries in the W2 model. The W2 model was configured to include the various point sources, withdrawals and watershed inputs feeding into the Black River that were not within the domain of the watershed model.

The Black River was configured in one setup, with two waterbodies the UBR and the LBR, connected by an internal head boundary. Splitting of the Black River into two water bodies ensures stability and specification of different slopes and water body characteristics. The UBR is characterized by steep slopes along with relatively narrow widths and shallow depths. The UBR was configured with 9 longitudinal segments with lengths ranging from 330 to 1750 meters, and contains up to a maximum of eight 0.5-meter thick vertical layers. The LBR consist of the navigation channel and is relatively flat, wide and deep with characteristics similar to a lake. The LBR was configured with 18 longitudinal segments with lengths ranging from 170 to 1073 meters. The model segmentation is shown in Figure D-1 and longitudinal profiles of both the waterbodies are shown in Figures D-2 and D-3 respectively. Note that segments 1, 11, 12 and 31 are boundary cells required for the W2 computational grid setup and are not active and do not carry any water, hence are not shown in the figure.

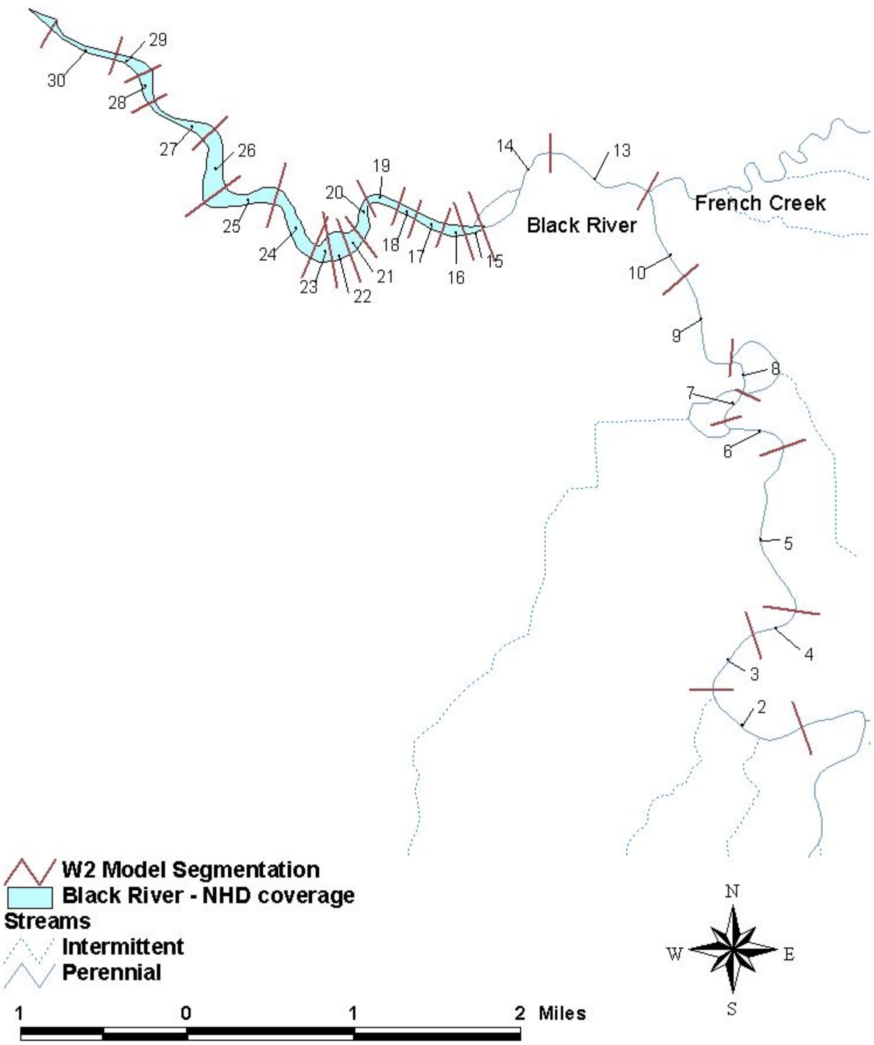


Figure D-1. Black River W2 segmentation

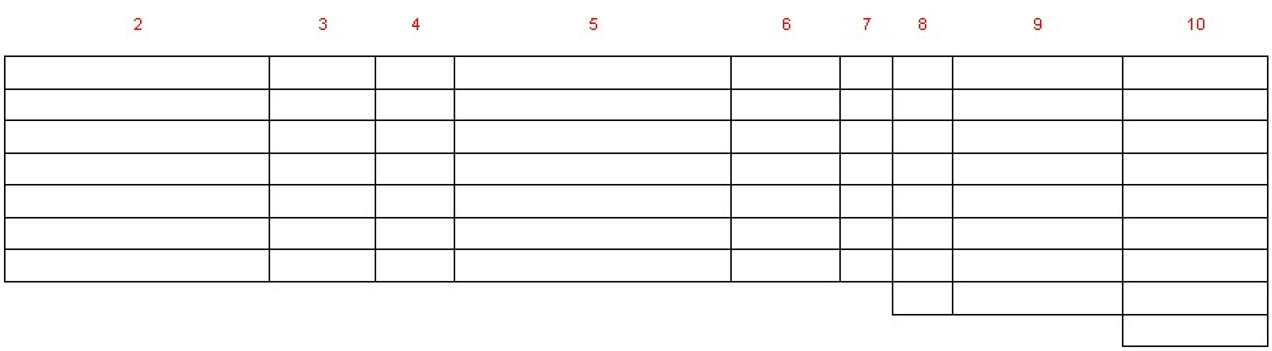


Figure D-2. Longitudinal profile/Computational Grid of Lower Black River (Waterbody 1)

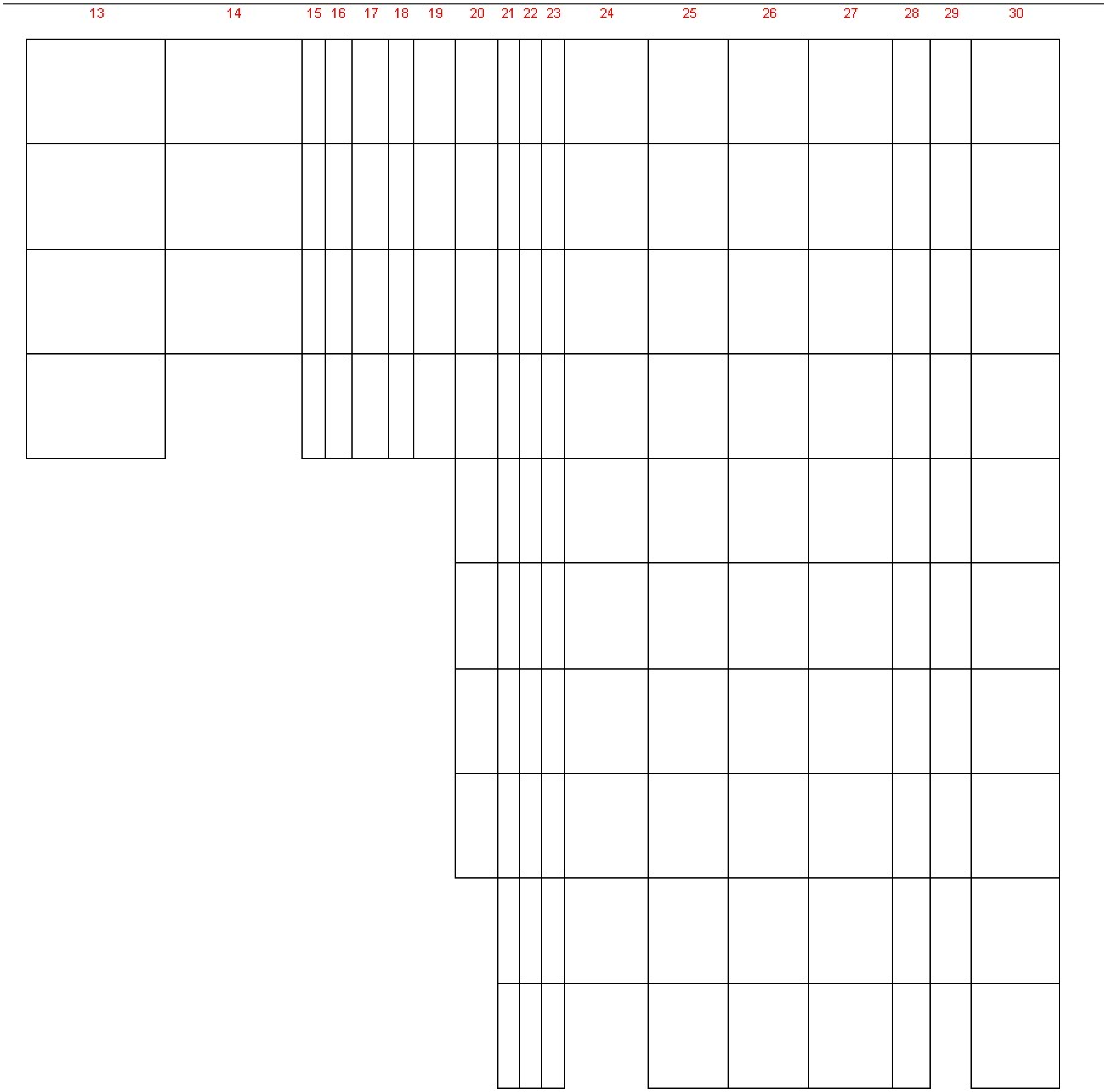


Figure D-3. **Longitudinal profile/Computational Grid of Lower Black River (Waterbody 2)**

1.2.1.2 Initial Conditions

The W2 model requires specifying initial conditions in the control and bathymetry input files. The control file specifies the initial temperature and constituents. An initial temperature of 20 deg C was specified for the waterbodies along the entire length and depth. All the initial conditions values were estimated based on observed in-stream monitoring data at the start of the calibration period. The number and location of inflow/outflows are also provided in the control file as part of initial conditions. In addition to the geometric data in the bathymetry file, an initial water surface elevation was specified in the bathymetry file.

1.2.1.3 Boundary Conditions/Linkages

Boundary conditions are a set of input files required to drive the W2 model. They represent external contributions of water and heat sources to the waterbody. The hydrodynamic component of the W2 model, including temperature predictions, was forced by inflows and temperature from the watershed, point source flows and temperatures, lateral withdrawals, along with hourly surface airways meteorological data.

Watershed Linkage

The simulated daily average flows from the watershed model were used as boundary conditions that are input into the W2 model. The flows from each sub-basin were split based on the ratio of the length of the segment receiving the flow to the length of the overall length of the stream falling within a subbasin. Temperatures were specified based on observed in-stream temperatures in the Black River upstream of the Elyria WWTP. Table D-1 shows the sub-basins that were assigned to the segments in the W2 model. Figure D-4 shows the linkage between the inputs from the various sub-basins in the watershed to the lake.

Table D-1. Mapping between subbasin and W2 segments

W2 Segment	Subbasin ID
2	43
3	43
4	43
5	43
6	43
7	43
8	43
9	43
10	7, 43
13	42 & 6
14	49
15	49
16	49
17	47
18	47
19	47
20	47
21	47 & 48
22	47
23	47
24	41
25	41
26	41
27	41 & 5
28	5
29	5
30	5

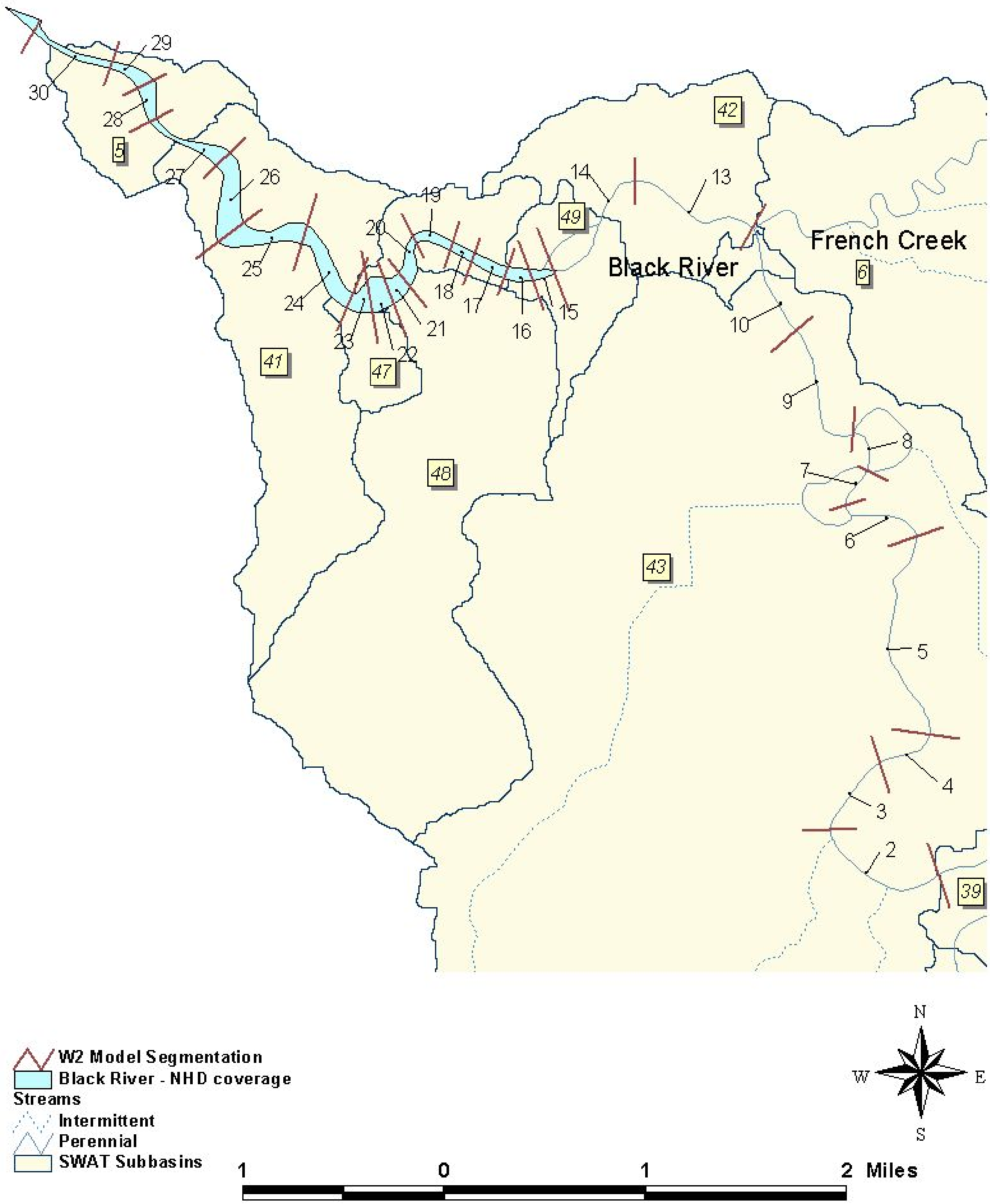


Figure D-4. Watershed Linkage Between W2 Segments and Subbasins

Downstream Boundary Condition

The UBR was connected to the LBR using an internal head boundary condition with the boundary surface elevation and temperatures calculated internally in the model. The downstream boundary condition for the LBR was specified as an external head, with time varying elevation, temperature specified at the most downstream segment. The downstream head boundary was specified using hourly gage height data from the USGS for Lake Erie (Black River) at Lorain Harbor. Data for 2001 at Lorain Harbor were available from 4/13/2001 to 11/6/2001. Days where there were no observed gage data were patched with data from the Marblehead station which was the next closest station (Figure 5). The data were patched based on an observed linear relationship ($r^2 = 0.92$) between data for Lorain and Marblehead collected simultaneously.

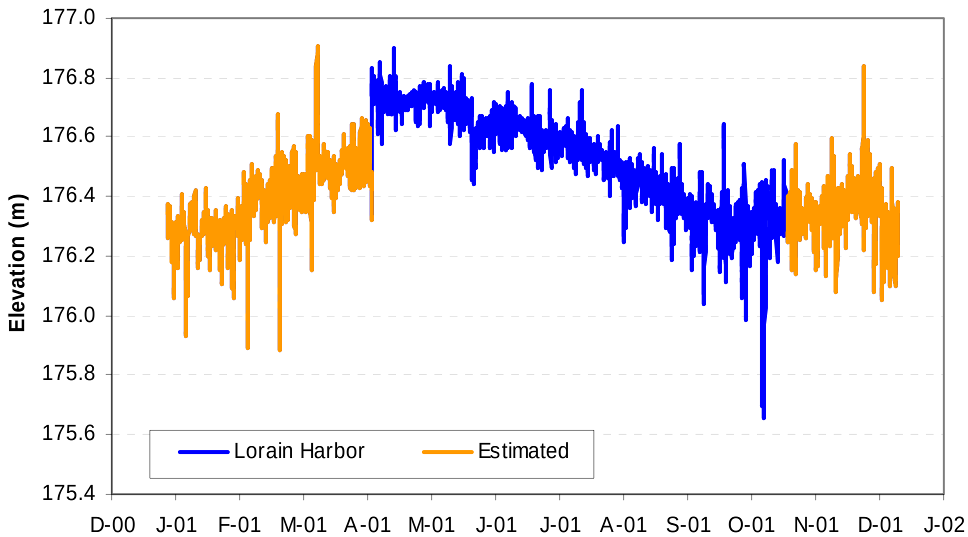


Figure D-5. Water Surface Elevation specified in the W2 model (USGS Lake Erie (Black River) at Lorain Harbor)

Point Sources

Point sources in the LBR domain include five discharges from Republic Engineered Products, Inc. (REP) and the contributions from the Lorain WWTP. The REP contributions include discharges from REP1, REP5, REP2, REP4, and REP3 at segments 13, 15, 18, 22, and 23 and the Lorain WWTP which was applied at segment 30.

Lateral Withdrawal Outflows

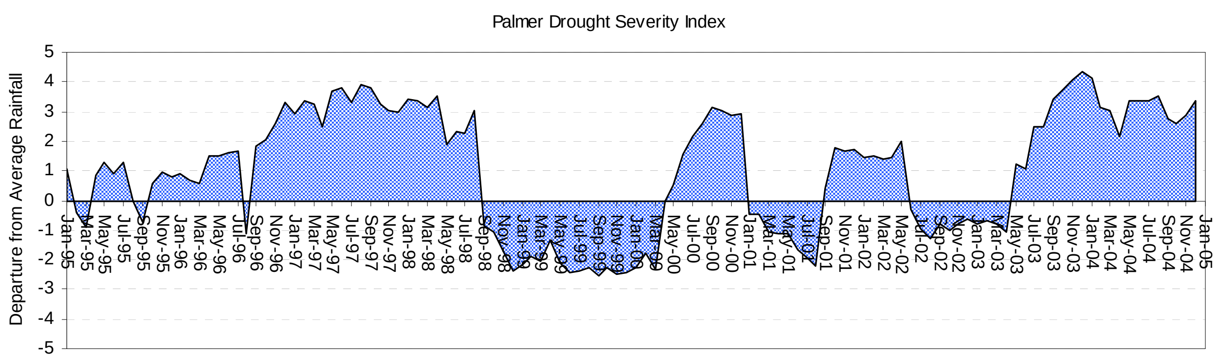
Two REP cooling water withdrawals – 901 and 902, located at river miles 2.9 and 3.9 were included in the navigation channel model. Weekly flow data from REP were available during the 2001 monitoring period. Lateral withdrawal outflows were specified at segments 16 and 20 of the W2 model at an elevation of 174 meters.

Meteorological Data

Meteorological data are an important component of the W2 model since they determine the surface boundary conditions. The meteorological data required by the W2 model are air temperature, dew point temperature, wind speed, wind direction, and cloud cover. Hourly surface airways meteorological data from the Lorain County Regional Airport (WBAN-04849) was downloaded from the National Climatic Data Centre (NCDC). The station is located approximately 19 miles south of the Black River W2 model domain. This station was chosen since it was the closest surface airways station and had the most complete coverage of data.

1.2.1.4 Simulation Time Period

The simulation time period selected for calibration was 2001. This year was selected for calibration because it had the most comprehensive dataset. Data for 2001 consisted of water-column profile data for two 5-day intensive surveys and bi-weekly monitoring from April through September. The year 2001 also included both wet and dry periods providing a range of flow and water quality conditions in the waterbody. The Palmer Drought Severity Index (PDSI) is a useful resource for evaluating hydrologic variability. The PDSI is calculated based on precipitation and temperature data, as well as the local available water content (AWC) of the soil. It shows departure from average monthly rainfall, with positive values denoting more than and negative values showing less than normally observed rainfall amounts by month. Figure D-6 shows the PDSI for the Ohio North Central Region. It can be seen that 2001 has a mix of dry and wet conditions.



4.00 or more Extremely wet; 3.00 to 3.99 Very wet; 2.00 to 2.99 Moderately wet; 1.00 to 1.99 Slightly wet; 0.50 to 0.99 Incipient wet spell; 0.49 to -0.49 Near normal; -0.50 to -0.99 Incipient dry spell; -1.00 to -1.99 Mild drought; -2.00 to -2.99 Moderate drought; -3.00 to -3.99 Severe drought; -4.00 or less Extreme drought

Figure D-6. Ohio North Central Region (Monthly Averages). Source: NOAA-Climate Division Drought Data

1.2.2 Hydrodynamic Calibration

Hydrodynamic calibration was done for the year 2001. The hydrodynamic calibration involved calibration of the temperatures to observed data to ensure that the model represented the mixing in the water column and reproduced the heat dynamics and thermal structure within the water-column profile.

Temperature data were available at eight locations for the calibration period along the lower river domain. The eight locations were located at river miles 0.01, 0.38, 1.10, 1.75, 2.38, 2.77, 3.52, and 4.5. Temperature monitoring profile data (at a 1 meter vertical resolution) were available for the calibration periods from April through September at these locations. Figure D-7 shows the monitoring station locations used for calibration.

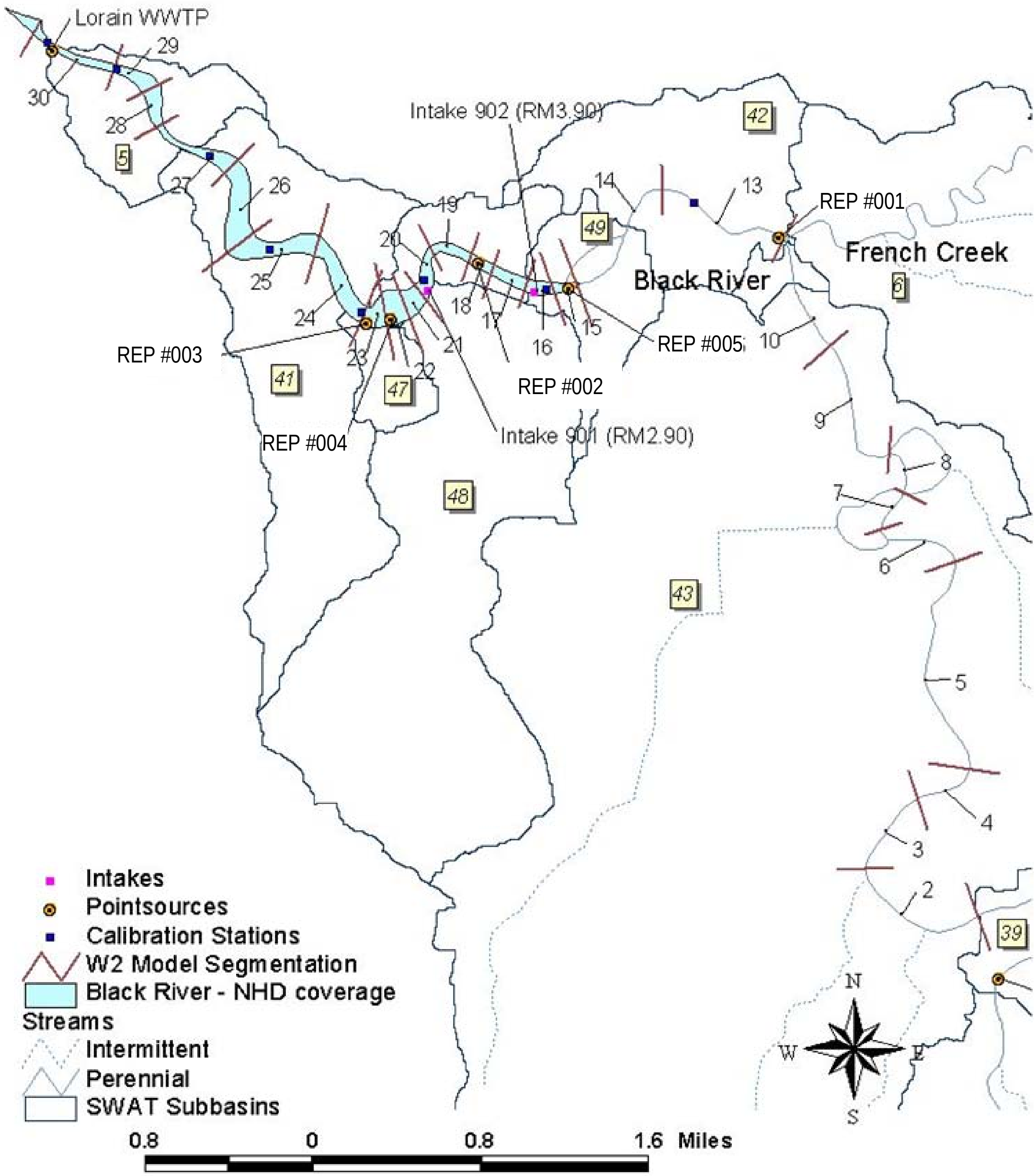


Figure D-7. Monitoring Stations Used For Calibration

The model calibration for temperature involved an iterative process of adjusting major model parameters in order to achieve a reasonable match between the simulated vertical temperature profiles and the observed data. The major parameters that can impact temperature simulation include bottom friction coefficient in terms of either Manning's n or Chezy Number, surface wind sheltering coefficient (WSC), sediment temperature (TSED), sediment-water temperature exchange coefficient (CBHE), and light extinction coefficient. Initial estimates of these parameters were obtained from CE-QUAL-W2 default values as described in W2 User's Manual (Cole, 2005). Default values were sufficient for the model to reasonably predict the observed temperature data.

Wind is always a major factor governing hydrodynamic simulation. In this study, wind speed and direction were based on the meteorological data at Lorain County Regional Airport that is located approximately 19 miles south from the Black River modeling domain. Several sensitivity analyses were implemented to check the sensitivity of the simulated temperature profile to the WSC value, and it was found that the simulated vertical temperature profile was sensitive to the wind. It was found that when the WSC was set to the default 1.0, the model was able to best capture the vertical mixing.

Solar radiation provide significant heat source to the water column. The major parameter controlling the vertical distribution of light is the light extinction coefficient. In W2, the light extinction coefficient is composed of several component: the light extinction coefficient of pure water (EXH2O), the light extinction coefficient induced by suspended solid (EXSS), the light extinction coefficient induced by organic matters (EXOM), and the light extinction coefficient induced by phytoplankton (EXA). In the pure hydrodynamic model, only EXH2O is used. Therefore, the EXH2O needs to be adjusted to represent the lumped light extinction coefficient rather than only for pure water. Initial estimate of EXH2O was 0.25/m based on W2 manual, and it was found that this value provided reasonable results. Another parameter that can change the vertical distribution of solar radiation heat is BETA, which represents the fraction of radiation heat retained in the surface layer. In this study, the value of this parameter was set to the default value of 0.45.

In the existing W2 model, the sediment temperature used to compute the heat exchange at the ground-water interface was set (TSED). The W2 manual suggests a value of 11.5 ^{o}C and states that the sediment temperature can be estimated from average annual temperature at the site. The average annual temperature was estimated to be 23.3 ^{o}C. The lower the value, the model tends to predict lower temperature at the bottom of the deep-water regions of the waterbody and compares well with the observed data. In the existing model a value of 12 ^{o}C was found to provide reasonable results. Table D-2 shows the calibrated parameters.

Table D-2. Hydraulic Coefficients used in the calibration of Black River

Parameter	Description	Units	Value	Default Value
WSC	Wind-sheltering coefficient		1.0	N/A
CBHE	Coefficient of sediment-water heat exchange	$Wm^{-2}\,^{o}C^{-1}$	0.3	0.3
TSED	Temperature of sediment	^{o}C	12.0	N/A
EXH2O	Extinction coefficient of pure water		0.25	0.25 or 0.45
BETA	Solar radiation absorbed in the surface layer		0.45	0.45

The temperature calibration results at each of the monitoring locations are included at the end of this appendix. Simulated water temperatures agreed well with the seasonal variations in the water temperatures measured in Lower Black River system. The model is able to capture the thermal profile during stratification in the deeper portions of the lake for the calibration period.

To quantify the degree to which the model fits measured data, cumulative probability of occurrence for all model results are shown for temperature in Figure D-8. These paired comparisons between the model results and data were based on all the sampling that was conducted for the year 2001. Data collected at all sampling locations and at various depths were used for conducting this analysis.

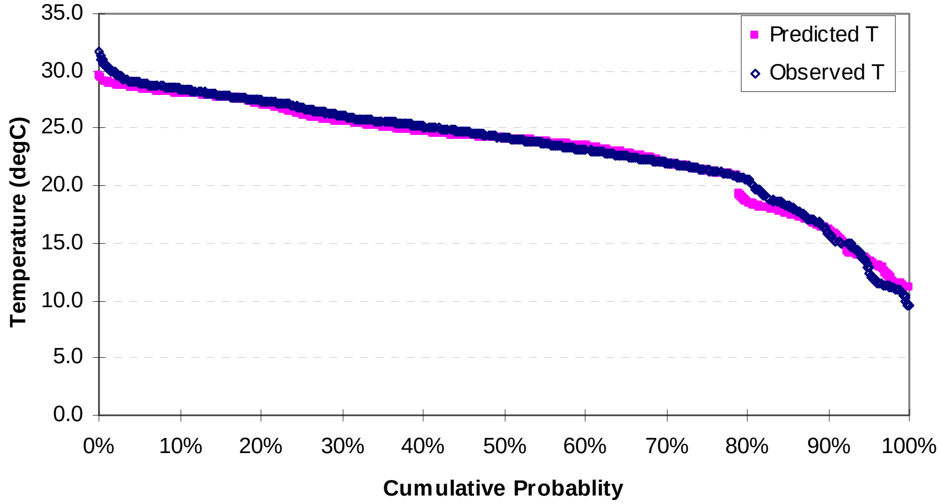


Figure D-8. Cumulative frequency distribution plot showing the comparison between the model-simulated and measured temperature at all sampling locations monitored

As presented in Figure D-8, the model results compare well with measured data. However, the model under predicted slightly at higher temperatures and overpredicted at some lower temperatures.

1.3 WATER QUALITY MODELING

1.3.1 Model Configuration

The Black River water quality model was configured using the same spatial segmentation as in the hydrodynamic model. Simulation of water quality involved the additional steps of setting water quality initial conditions, boundary conditions, and kinetic parameters for the water quality simulations. The following subsections describe the configuration and key components of the model.

1.3.1.1 State Variables

State variables are used to represent the major components in the water quality system. In this study, 10 state variables were configured as active system constituents that are used to simulate the nutrient-algae-DO (dissolved oxygen) dynamics. These active state variables are:

1. Inorganic Suspended Solid (ISS)
2. Orthophosphate (PO4)
3. Total Ammonium (NH4)
4. Nitrite/Nitrate (NO2/NO3)
5. Labile Dissolved Organic Matters (LDOM)
6. Refractory Dissolved Organic Matters (RDOM)
7. Labile Particulate Organic Matters (LPOM)
8. Refractory Particulate Organic Matters (RPOM)
9. Phytoplankton (Algae)

10. Dissolved Oxygen (DO)

1.3.1.2 Initial Conditions

The W2 model requires specifying initial conditions for all of the water quality state variables in the control file. Since the modeling period spans an entire year and the simulation starts at the well mixed winter period, it is justifiable to set uniform initial condition throughout the entire domain. The initial concentration of each active state variable was estimated based on the general magnitude of the in-stream monitoring data. It was found that the model simulated water quality is not sensitive to the specification of the initial conditions.

1.3.1.3 Boundary Conditions/Linkages

Water quality boundary conditions are configured in a set of input files, where each file represents the water quality in each of the inflows. The locations of the inflows were the same as those described in the hydrodynamic model sections. For these flows, the water quality concentrations simulated by the calibrated SWAT watershed model were converted to the format required by the W2 model to form the boundary conditions. Since SWAT does not explicitly simulate the four components of organic matters (i.e., LDOM, RDOM, LPOM, and RPOM), the SWAT output needed to be converted. The total organic matter concentration (OM) was calculated based on stochiometric equivalents using the simulated organic nitrogen (ON) concentration from the SWAT model as OM = ON/0.074 (assuming OM is 49 percent organic carbon (OC) and the ratio of OC to ON is 6.62) (Chapra, 1997). Based on the estimated OM, the labile and refractory portions of the organic matter were split as 75 percent labile and 25 percent refractory.

The labile and refractory portions of the organic matter were further partitioned into dissolved and particulate portion. The final partition ratio was obtained through the model calibration process. In this study, it was assumed that 65 percent of the LOM was LPOM and 10 percent of the LOM was LDOM. The refractory portions of the organic matter (i.e., 25 percent ROM) was split equally into the RPOM and RDOM.

1.3.2 Water Quality Model Calibration

Water quality calibration was done for the same period as the hydrodynamic calibration. The water quality calibration involved an iterative process of adjusting key model kinetic parameters to achieve a reasonable match between the model prediction and the observed concentrations. The water quality calibration was implemented for different constituents. Ammonia, nitrate/nitrite, total phosphorus, and DO were calibrated for vertical profiles at the eight monitoring stations (Figure 7). Table 3 presents the calibrated values of the kinetic coefficients in the Black River Model.

Table D-3. Calibrated Values of the Kinetic Coefficients in the Black River Model

Parameter	Description	Units	Value	Default Value
AG	Maximum phytoplankton growth rate	day^{-1}	1.1	0.07-11.0
AR	Phytoplankton base respiration rate	day^{-1}	0.04	0.014-0.92
AE	Phytoplankton excretion rate	day^{-1}	0.04	0.04*
AM	Phytoplankton mortality rate	day^{-1}	0.05	0.03-0.3
AS	Phytoplankton settling velocity	m/day	0.10	0.0 to 0.20
ASAT	Saturating light intensity	W/m^2	75.0	75-150
SSS	Suspended solid settling velocity	m/day	1.2	1.0*
AT1	Lowest algal growth temperature	^oC	5.0	N/A
AT2	Lowest optimal algal temperature	^oC	15.0	N/A
AT3	Highest optimal algal temperature	^oC	23.0	N/A
AT4	Highest algal growth temperature	^oC	32.0	N/A
LDOMDK	Labile dissolved OM decay rate	day^{-1}	0.10	0.08*
RDOMDK	Refractory dissolved OM decay rate	day^{-1}	0.001	0.001*
LPOMDK	Labile particulate OM decay rate	day-1	0.08	0.08*
RPOMDK	Refractory particulate OM decay rate	day^{-1}	0.001	0.001*
PO4R	Benthic PO4 release as fraction of SOD	N/A	0.001	0.0-0.3
NH4R	Benthic NH4 release as fraction of SOD	N/A	0.005	0.0-0.4
NH4DK	Nitrification rate	day^{-1}	0.08	0.001-1.3
NO3DK	Nitrate decay rate in water column	day^{-1}	0.05	0.05-0.15
NO3S	Denitrification rate from sediment	day^{-1}	0.00	1.0*
SOD	Sediment oxygen demand	$g/m^2/day$	Spatially varying 0.35 to 3.37	N/A

*W2 default value

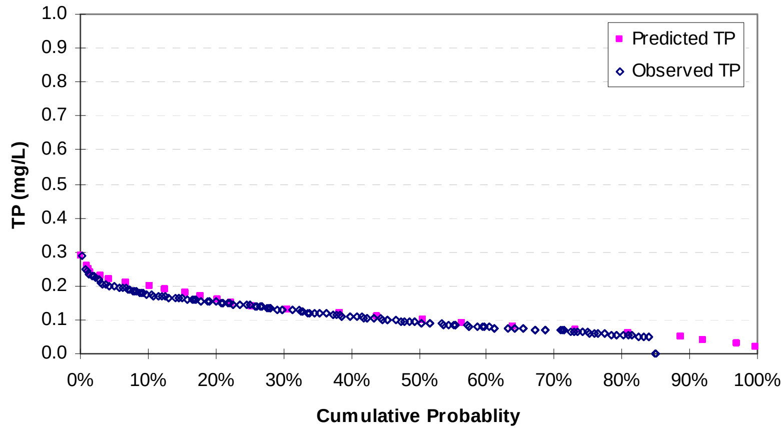
The same kinetic coefficient values were applied to the UBR (waterbody 1) and LBR (waterbody 2). All kinetic coefficients were set either in the range of the values observed in literature or based on default values prescribed in the W2 manual. The zero-order SOD values were assigned based on the SOD values calculated from available sediment data which were available as spatially varying SOD values along the entire stretch of the navigation channel (LTI, 2003b). No adjustments were made to the SOD values, except for locations were multiple observed values fell into a particular W2 model segment. In these cases the average value of the observed SOD was assigned. The UBR domain was assigned a SOD value of 1 g/m2/day. Re-aeration rates are calculated internally inside the W2 model. For the riverine portion of the UBR the Melching and Flores equation (equation #7) was used, while for the lake portion in the LBR, the Cole and Buchak (equation #6) formulation was used. Details of the reaeration formulations can be found in the W2 manual (Cole, 2005).

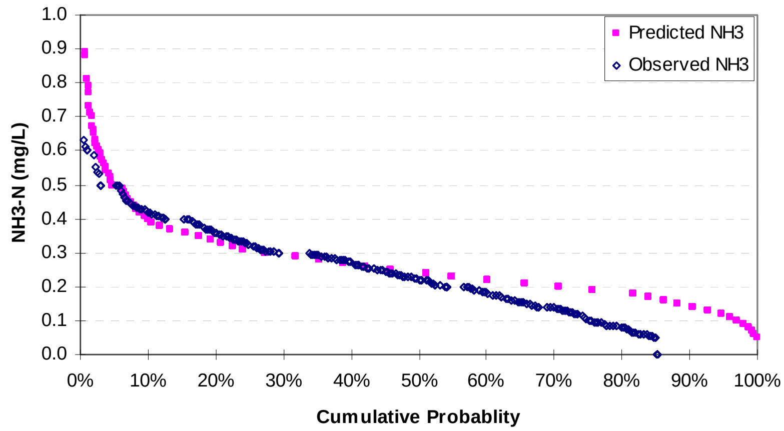
The model calibration was implemented first for nutrients, then algae, and finally dissolved oxygen. The nutrient and algae interaction was particularly difficult to calibrate because the magnitude of the maximum algae varies spatially from upstream (higher) to downstream (lower). For periods during the growing season nutrients (phosphorus) can become significant limiting factors that would control the algal dynamics. Therefore, if prediction of nutrient concentration and timing is unreasonably off, algae dynamics cannot be correctly predicted. On the other hand, algae dynamics impact the nutrient concentration at a significant level, indicating that without a reasonable simulation of algae dynamics, nutrient prediction cannot be well represented. The intertwined relationship between nutrient and algae in this lake necessitated adjusting the algal temperature multipliers to simulate timing and magnitude of the algae in the system. Other key parameters that impact both nutrient and algae dynamics were the algal growth rate, nitrification rate and nitrate decay rate.

The model simulates a clear seasonal pattern in phytoplankton biomass in that algae is in general more abundant during the warm period. There is also a spatial trend in the algae data, with higher concentrations observed in the upstream shallower regions and lower concentrations observed downstream. Algae vertical profile data were not collected and therefore the dynamics of these constituents were calibrated through a time series type of calibration (at the surface layer where the algae data were collected). The model was able to capture this spatial trend fairly well; however, the model underpredicted one peak value that occurs during the end of July in the shallower portions of the Black River. This might be due a combination of poorly specified boundary conditions or localized impacts that could be occurring. The chlorophyll a calibration results are presented at the end of this appendix.

The modeling achieved a reasonable accuracy in reproducing the observed nutrient concentrations (see figures at end of appendix). In general, the simulated nutrients are low throughout the years, which match the trend shown in the data well (with the exceptions of nitrates which are quite high). The model has simulated Total Phosphorus (TP), NH3-N and nitrate/nitrite vertical stratification at the deep segments during the summer period, where the concentrations are higher at the bottom than at the surface. The major source of P and N during the summer period is possibly from the sediment release during anoxic period.

To quantify the degree to which the model fits measured data, cumulative probability of occurrence for all model results are shown for TP, NH3-N, and NO3/NO2 respectively in Figure D-9. These paired comparisons between the model results and data were based on all the sampling that was conducted for the year 2001. Data collected at all sampling locations and at various depths were used for conducting this analysis.





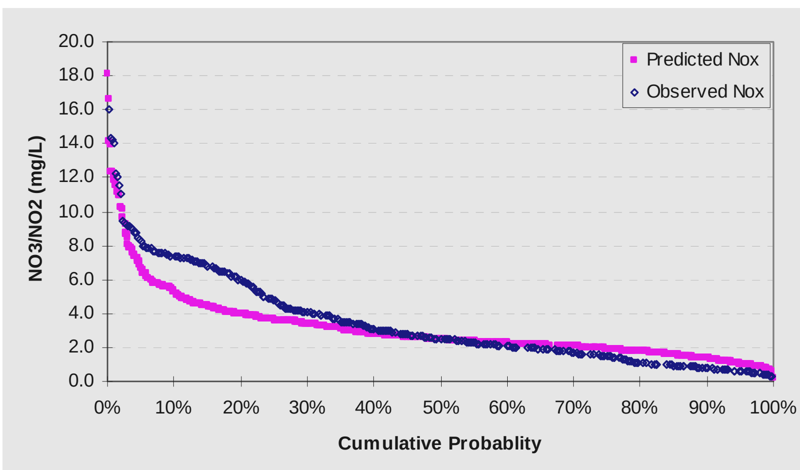


Figure D-9. Cumulative frequency distribution plot showing the comparison between the model-simulated and measured TP, NH3-N and NO3/NO2 at all sampling locations monitored

In general the predicted TP concentration results compare well with the observed data with minor overestimation near the higher values (around 10 percent probability). The predicted NH3 concentration results compare fairly well with the observed data with over prediction by approximately 0.1 mg/L when the concentration are lower than 0.2 mg/L (in the 70 to 80 percent range) and overprediction in the higher concentration percentile range. At higher concentration when the concentration are greater than 0.6 mg/L the concentration can be around 0.3 mg/L higher (less than 5 percent range). The NO3/NO2 concentration also compare fairly well with the observed data with some underestimation, by about 1.5 mg/L when the concentrations are higher than 4 mg/L (in the 10 – 20 percent range). Initially, it was thought that there was less denitrification occurring, but since the model slightly overestimates the observed data at lower concentration the denitrification rates were not further refined.

The model calibration for DO is presented at the end of this appendix. The simulated vertical profiles match the observed profiles well in terms of magnitude and vertical variation for most of the stations. However, the model performance cannot match the trends well at some of the shallow water area and locations where the DO profile stratifies twice. The observed DO profiles at the shallowest station show a very strong vertical gradient along the depth. For example at station BR4.5 the model is unable to capture the supersaturated conditions except in August. Different re-aeration schemes available within W2 were tested to see if the model could capture there trends, but did not result in any significant improvement to the results.

The DO profiles show an even stronger stratification pattern than the temperature profiles at the deeper portions of the LBR. The DO often shows a minimum at intermediate depths (4 to 6 meters) thus stratifying twice along the depth. As shown, the model reproduces the observed DO profile fairly well, mimicking the trend that high DO occurs for the entire water column during non-stratification seasons, and anoxic DO at the hypoliminion during the summer and early fall stratification season. However, the model is unable to capture the DO profiles timing and magnitude at intermediate depths at some location and times. One possible reason for this would be that the model is not well representing the vertical mixing. However, this is unlikely since the temperature is calibrated quite well, indicating that the mixing is represented fairly well by the hydrodynamic model. Observed EC and TDS were also checked and did not show any evidence of stronger stratification profiles like that seen in the DO. Since chlorophyll-a data are only available at the surface, the profile distribution of the algal data is unknown and uncalibrated. Overall, the model has mimicked both the spatial and temporal patterns of the observed DO.

To quantify the degree to which the model fits measured data, cumulative probability of occurrence for all model results are shown for DO in Figure D-10. These paired comparisons between the model results and data were based on all the sampling that was conducted for the year 2001. Data collected at all sampling locations and at various depths were used for conducting this analysis. In general the model under-predicts the DO by about 1 to 1.5 mg/L and is unable to capture the high supersaturated DO values that can go as high as 22 mg/L (in the 0 to 10 percent range). One possible reason is the model's inability to capture the peak chlorophyll-a concentration value in the shallower portions of the Black River. Although the model underpredicts the observed data the underestimation is only severe in the 0 to 10 percent range where the conditions are supersaturated and the DO is extremely high. This is not considered a significant error since the focus of the modeling application is primarily on periods of low dissolved oxygen. Figure D-10 illustrates that the model performs best when DO is in the range of 4 to 6 mg/L, which is the most important period for a comparison to water quality standards.

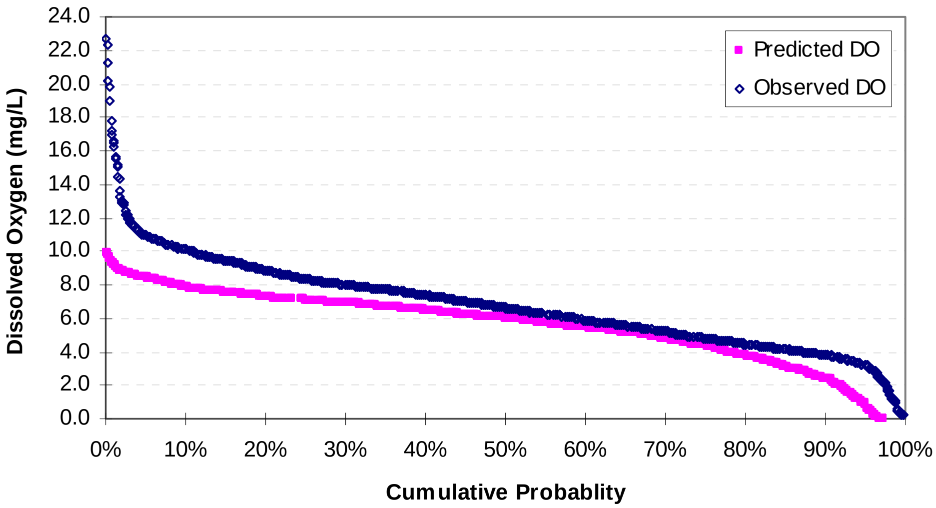


Figure D-10. Cumulative frequency distribution plot showing the comparison between the model-simulated and measured DO at all sampling locations monitored.

1.3.3 Assumptions and Limitations

The following section provides the major assumptions and limitations that were used in the development of the Black River model:

1.3.3.1 Assumptions

The major underlying assumptions associated with the Black River model development are as follows:

- The initial conditions do not have a significant impact on the simulated water quality during the critical summer and early fall periods.
- One phytoplankton species is assumed to be sufficient for representing the overall primary production and nutrient interactions in the system.
- All the organic matter in the water column (and that from other sources) has the same stochiometric ratio.
- The impact of zooplankton does not have a significant impact on the algal dynamics and nutrient recycling.

1.3.3.2 Limitations

Potential limitations that have currently been identified include

- The model does not simulate multiple species for phytoplankton. Therefore, this model is currently not suitable for evaluating competition among multiple species or evolution of the aquatic algal communities and their interaction with nutrients.
- Due to the lack of a direct linkage between organic matter loading and SOD and benthic nutrient flux, the model in its present stage is not suitable for predicatively evaluating the long-term impact of load reductions on SOD. However, a linear assumption can be employed to evaluate the change in SOD based on load reduction through using the 1st order sediment module in W2.

- No zooplankton is simulated in the model, hence, there may be some uncertainty in the simulation of algal dynamics and nutrient cycling.
- The water quality model is built based on a laterally averaged 2-D framework, therefore, the model is not capable of simulating the possible localized water quality change resulted from development activities in the watershed. However, it can be used to evaluate the overall consequence of watershed development or several "what if" scenarios.

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