Uncertainty-based TMDL Calculations for Dissolved Oxygen in Amite River

Basic Information

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Project Number:	2008LA58B
Start Date:	3/1/2008
End Date:	2/28/2009
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Congressional District:	6
Research Category:	Water Quality
Focus Category:	Water Quality, Solute Transport, Models
Descriptors:	
Principal Investigators:	Zhi-Qiang Deng

Publication

1. Deng, Z. and Jung, H.-S. (2009). “Variable residence time based model for solute transport in streams.” Water Resources Research, 45, W03415.
2. Deng, Z. and Jung, H.-S. (2009). “Scaling dispersion model for pollutant transport in rivers.” Environmental Modelling & Software, 24(5), 627-631.
3. Mishra, P. K. and Deng, Z. (2009). “Sediment TMDL development for the Amite River.” Water Resources Management, 23(5), 839-852.
4. Deng, Z., de Lima, João L.M.P., and Jung, H.-S. (2008). “Sediment Transport Rate-based Model for Rainfall-induced Soil Erosion.” Catena, 76(1), 54-62.

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SYNPOSIS

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RESEARCH

Problem and Research Objectives

The U.S. Environmental Protection Agency and the states are faced with developing tens of thousands of TMDLs with a margin of safety (MOS). In almost all cases, MOS is defined arbitrarily, without consideration for the actual uncertainty in the likelihood of achieving water quality objectives. This can lead to two outcomes: (1) if MOS is too small, the TMDL has a high probability of not meeting its designated use; (2) if MOS is too large, the cost of implementing the TMDL will be much higher than necessary. Thus, a scientifically sound approach to determining MOS is required for all impaired water bodies, including the Amite River that is impaired by low dissolved oxygen (DO).

The primary goal of this project is to develop and demonstrate an effective approach to identifying uncertainty sources and to quantifying the TMDL uncertainty arising from these sources through TMDL development for dissolved oxygen in the Amite River. To achieve the goal four objectives are proposed: (1) uncertainty analysis of model input data with emphasis on temporal and spatial scale-induced uncertainties, (2) uncertainty propagation through model parameters and structure, (3) uncertainty analysis of model output-based load duration curves, (4) total uncertainty-based margin of safety, and (5) TMDL calculations for dissolved oxygen in the Amite River.

Methodology

The HSPF (Hydrologic Simulation Program Fortran) simulations were performed to obtain the time-series data of water quality parameter in the Amite River at Port Vincent, LA, as shown in Figure 1. In HSPF, key input parameters are weather and landuse data. The hourly weather time-series data for the period of 1970-1995 were collected from USEPA, that included rainfall, air temperature, wind, evapo-transpiration, humidity, dew-point temperature, solar radiation, and cloud cover. The landuse data was developed using Landsat TM imagery data (30 m resolution) for year 1992 acquired from Global Land Cover Facility (GLCF) at University of Maryland. The landuse data was classified into 25 classes by using un-supervised classification. These classes were then categorically classified using visual interpretation to re-classify it into six major classes as per HSPF requirement. This input data and methodology was used as base scenario for further simulations. The model was calibrated and validated using observed data at Port Vincent obtained from LDEQ (Louisiana Department of Environmental Quality). While calculating the sampling induced uncertainty the other parameters including the spatial and temporal data were kept similar and vice-versa. The input data uncertainty was estimated by first calculating the sampling induced uncertainty, then temporal scale and resolution induced uncertainties. The subroutine OXRX of HSPF model was used for the analysis of uncertainty propagation through model parameters and structure. Load duration curves for dissolved oxygen were produced using HSPF simulated data with different temporal scales to determine the uncertainty involved in the load duration curves. The probability distribution functions derived for input data uncertainty, model structure uncertainty, and model output uncertainty were

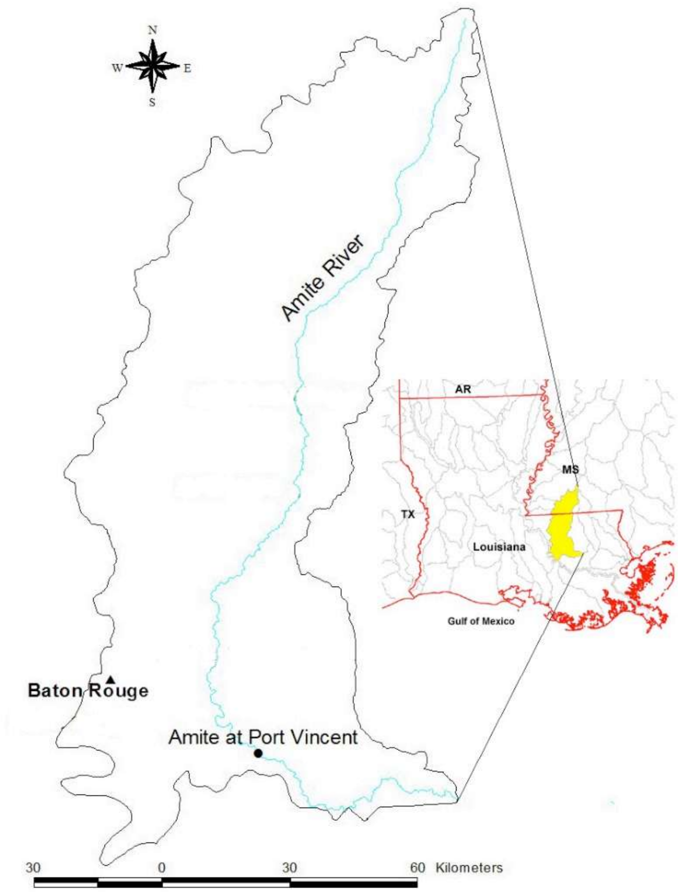


Figure 1. Map of the Amite River Basin.

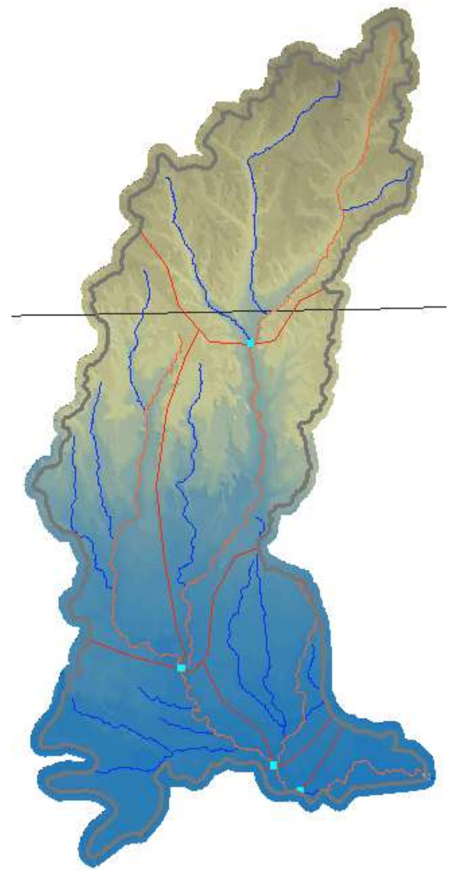


Figure 2. Sub-watersheds used in HSPF model.

utilized in a Bayesian analysis to determine the total uncertainty and the margin of safety for DO TMDL. Application of HSPF involves the segmentation of the Amite River watershed, preparation of input data, and model calibration. The sub-watersheds were generated using the delineation tool in BASINS. Sub-watershed delineation and creation of river-reach segments utilized the NED (national elevation dataset) digital elevation model (DEM) and national land cover data (NLCD) representing land use type in 1992 for computing watershed boundaries, overland flow-path length and slopes, stream segment slopes, and pervious and impervious surface areas and forested areas in each delineated sub-watershed, as shown in Figure 2.

PRINCIPAL FINDINGS AND SIGNIFICANCE

1. Temporal Scale Induced Uncertainty in Temperature and Rainfall Input Data

The temporal scale analysis was conducted using the coefficient of variation (CV = standard deviation/mean). Figures 3a and 3b show that the coefficients of variation (CV) in both temperature (3a) and rainfall (3b) decrease with increasing temporal scale varying from hourly scale to monthly scale.

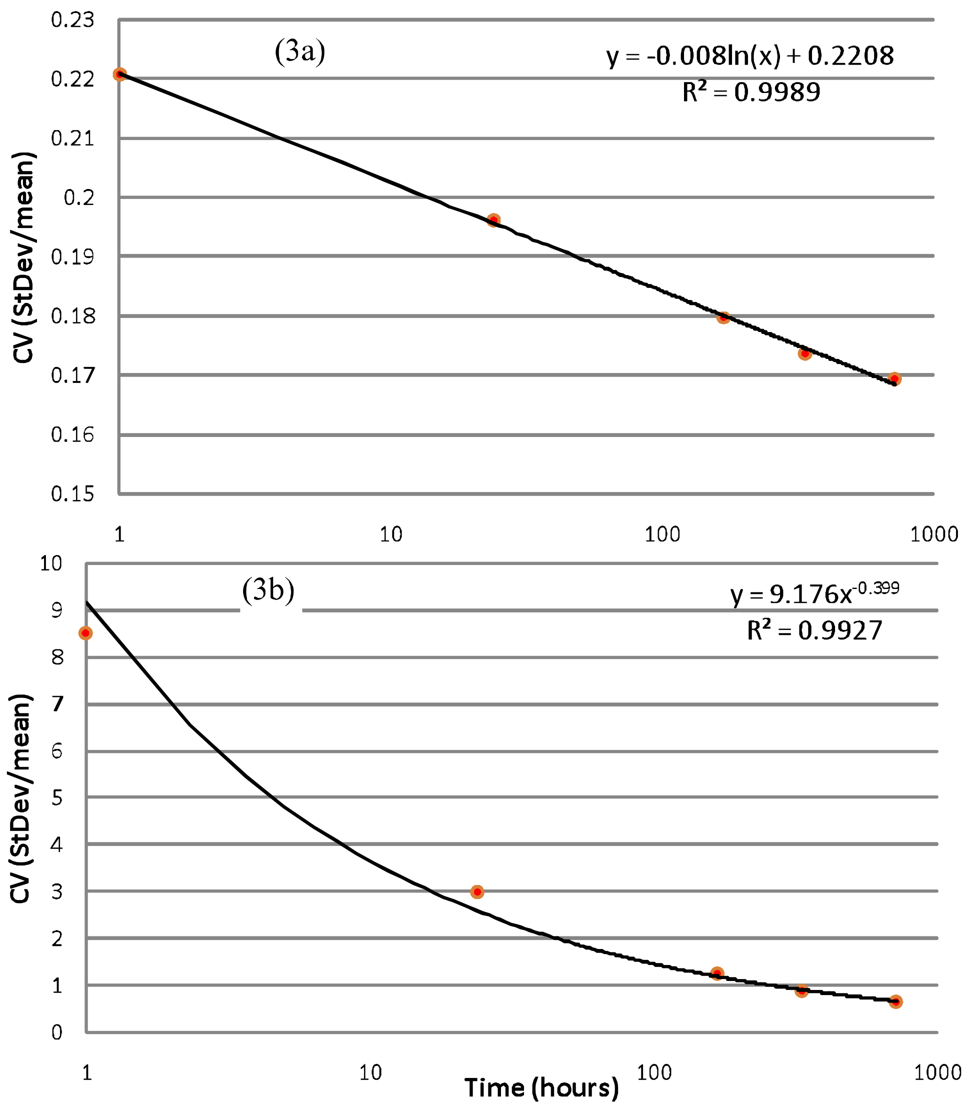


Figure 3. Temporal scale induced error in input data of (a) temperature and (b) rainfall.

The temporal uncertainty in the temperature data followed a non-symmetric, general extreme value distribution while the temporal scale-induced uncertainty in rainfall followed a power law distribution.

2. Spatial-resolution of Landuse Data Induced Uncertainty in Dissolved Oxygen

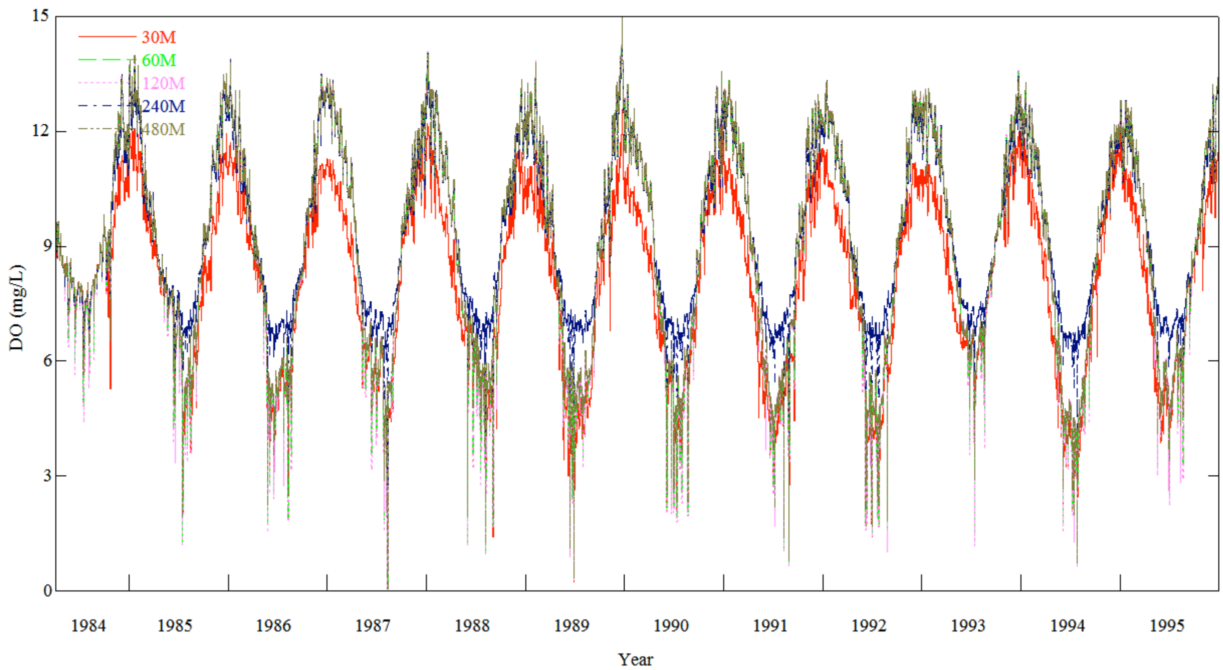


Figure 4. Effect of resolution induced error on dissolved oxygen.

The spatial-resolution-induced uncertainty in dissolved oxygen simulation was observed to follow a general extreme value distribution.

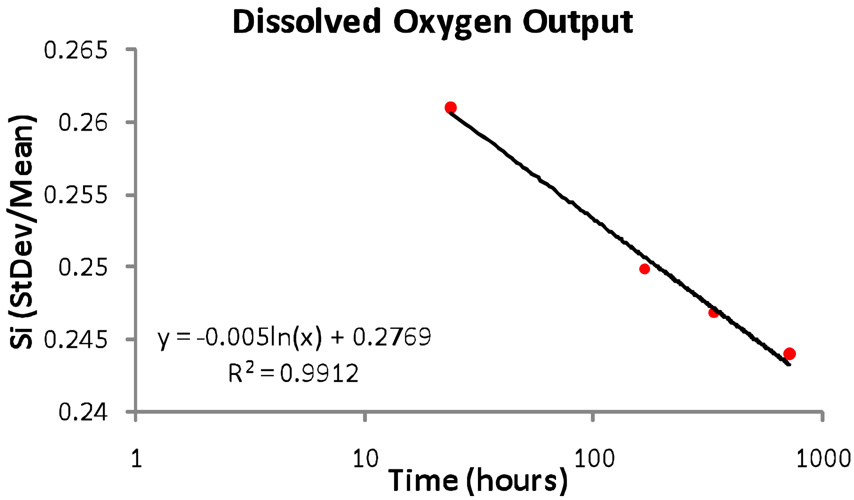
3. Uncertainty Propagation through Model Parameters and Structure

The uncertainty propagation in the model structure of dissolved oxygen follows a normal distribution:

$$f(M_{errorprop}) = \frac{\exp\left[-\frac{1}{2}\left(\frac{x-8.08}{0.427}\right)^2\right]}{0.427\sqrt{2\pi}} \tag{1}$$

This equation can be used in the estimation of the total uncertainty using Bayesian analysis.

4. Uncertainty-Involved in Model Output-Based Load Duration Curves



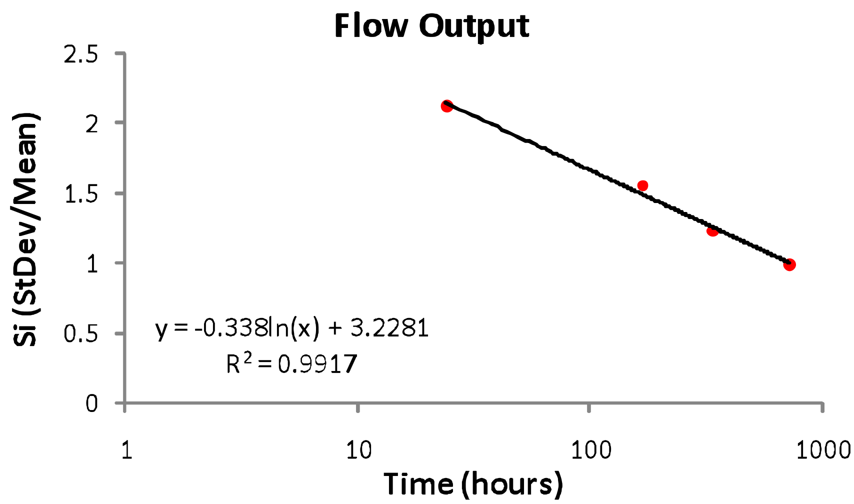


Figure 5. Temporal scale-induced uncertainty in output data computation for (A) dissolved oxygen and (B) flow data.

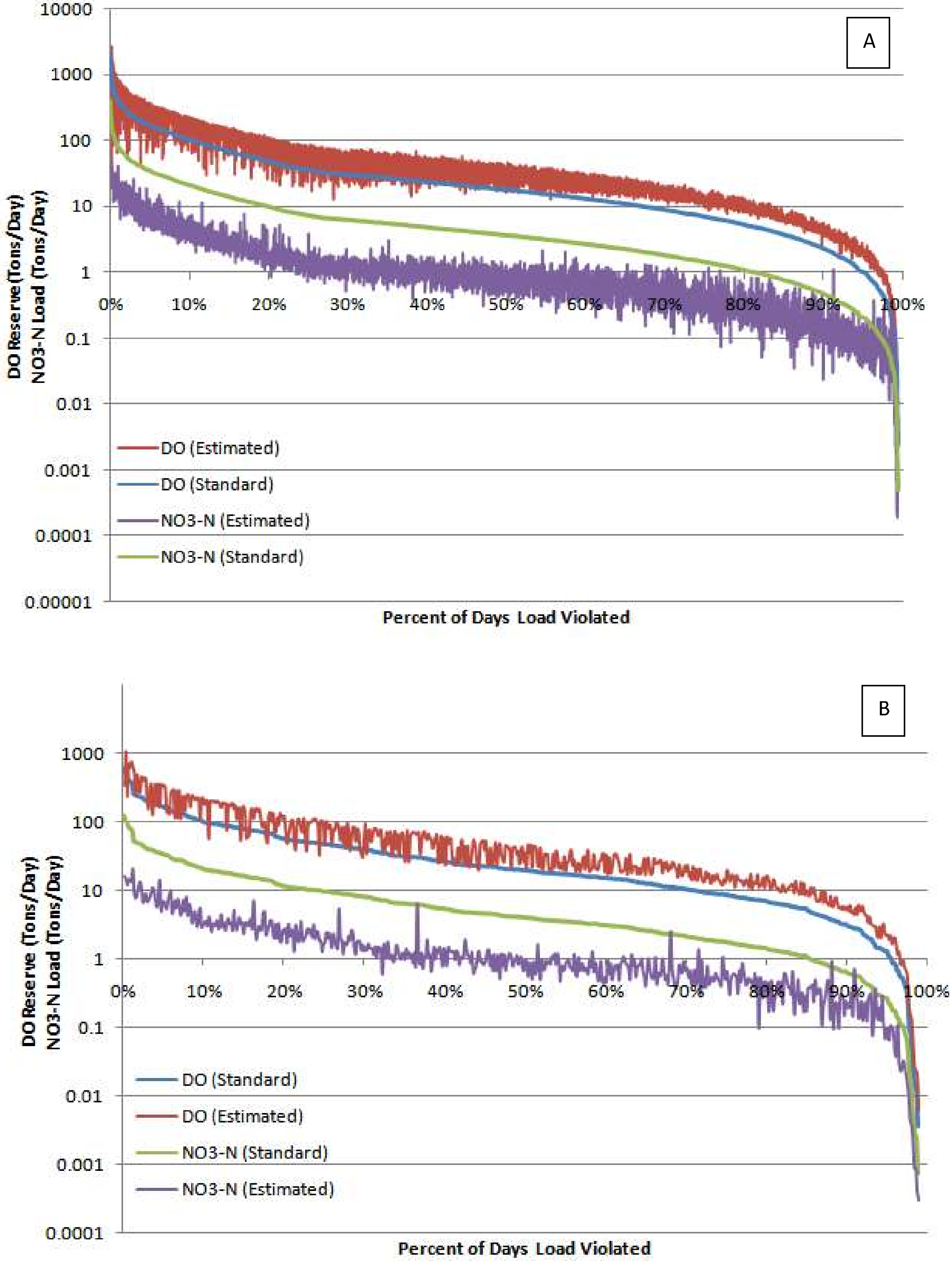
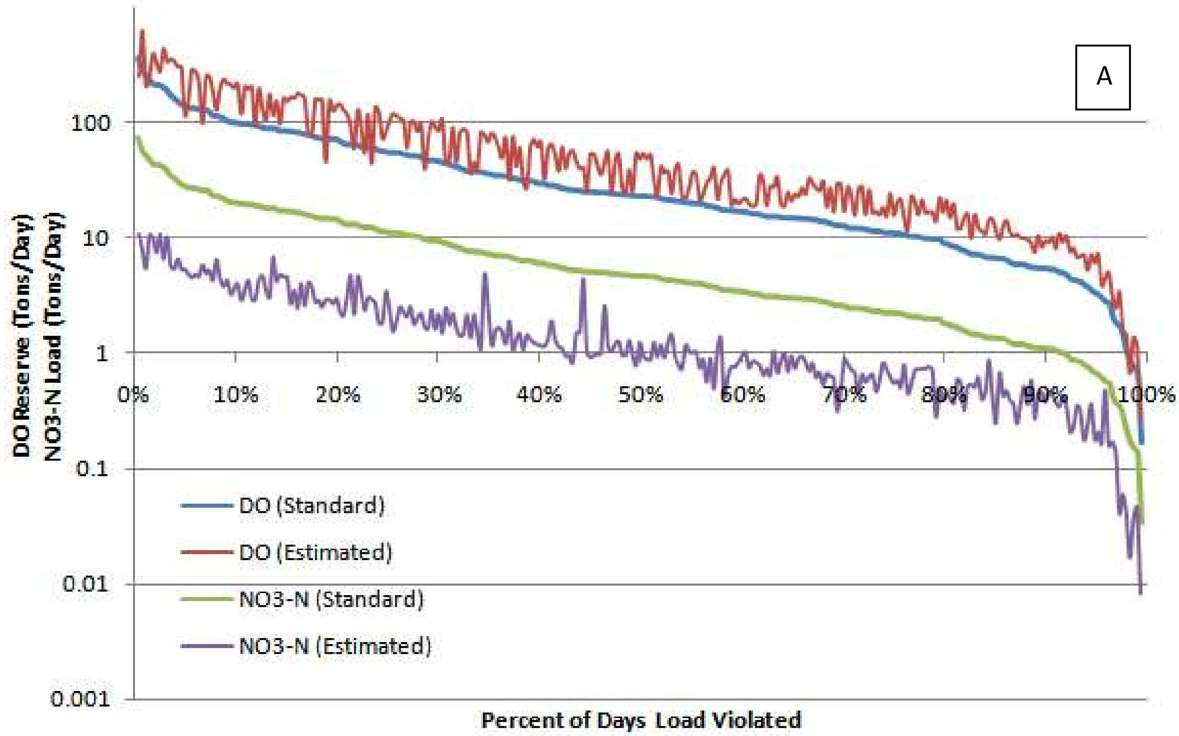


Figure 6. Duration curves developed using (A) daily data and (B) weekly data.



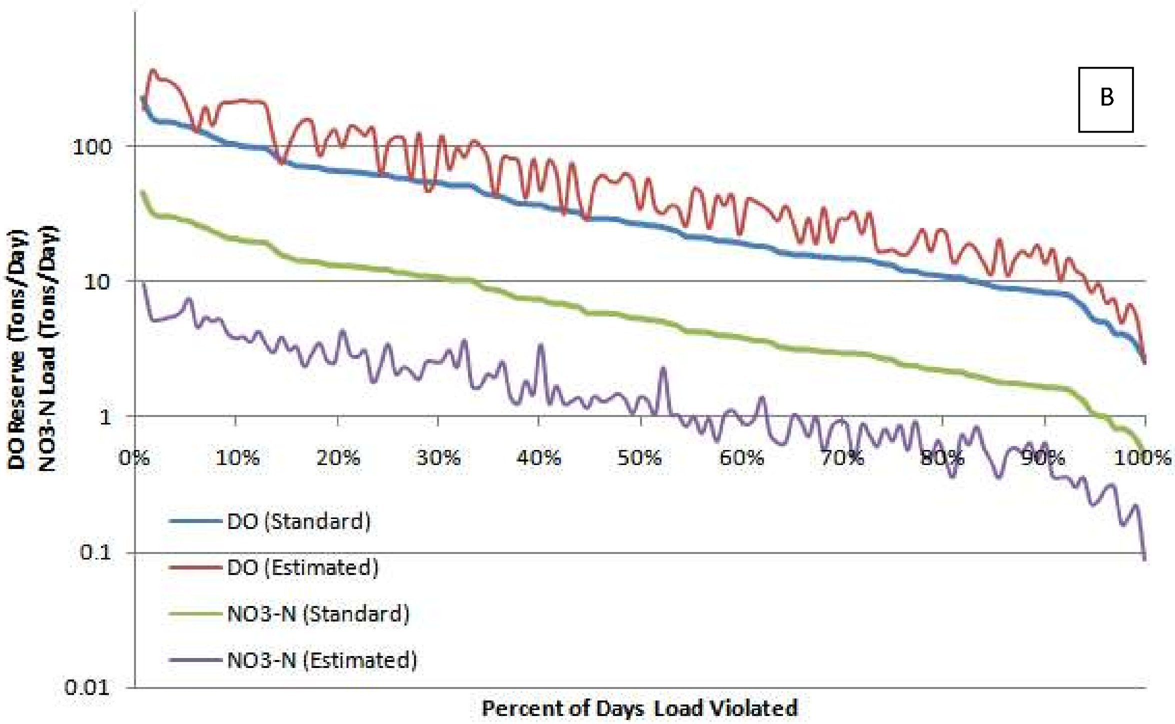


Figure 7. Duration curves developed using (A) bi-weekly data and (B) monthly data.

It is found from Figures 5 – 7 that:

1) Temporal scale of flow and water quality data controls the uncertainty in estimated loads of water quality parameters. While DO reserve (load) meets water quality standard under any flow conditions when monthly mean data is utilized, DO impairment occurs frequently during moderate-to-high flow conditions if daily mean data is employed, indicating the necessity of using near real time data in TMDL development.
2) The coefficient of variation (Si = CV = ratio of the standard deviation to the mean) is introduced to describe the temporal scale-induced uncertainty in load calculations and thus TMDL development. It is found that the parameter CV is linearly and inversely correlated with the logarithm of the time scale. Regression equations are developed to describe the correlations between the time scale and the parameter CV for DO and flow discharge. The regression equations can be employed to extrapolate near real time flow and water quality data, greatly simplifying flow and water quality monitoring and reducing the cost involved in the monitoring.
3) The standard deviation of dissolved oxygen follows a general extreme value distribution while the standard deviation of flow exhibits a normal distribution.
4) The correlation between the dissolved oxygen reserve and river flow can be better described using a power law relationship with a RMS of 0.679.

5. Estimation of Total Uncertainty Using Bayesian Analysis and DO TMDL

The probability distribution function for the natural variability in the dissolved oxygen is given by,

$$f(DO_{natural}) = \frac{\exp\left[-\frac{1}{2}\left(\frac{x-6.42}{1.88}\right)^2\right]}{1.88\sqrt{2\pi}} \tag{2}$$

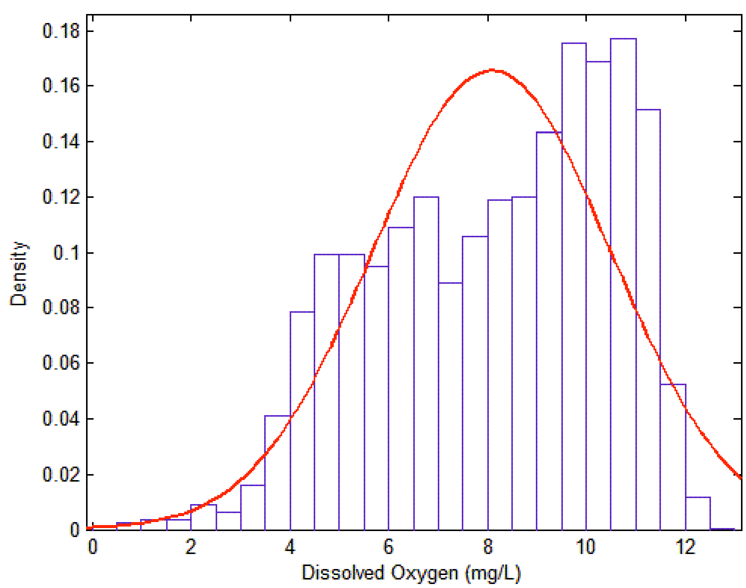


Figure 8. Daily average dissolved oxygen distribution in summer.

The likelihood function for dissolved oxygen is given as,

$$P(I|DO) = \frac{1}{\sqrt{2\pi}0.753} exp\left[-\frac{1}{2}\sum_{i=1}^{n}\left(\frac{e_i}{0.753}\right)^2\right] \quad (3)$$

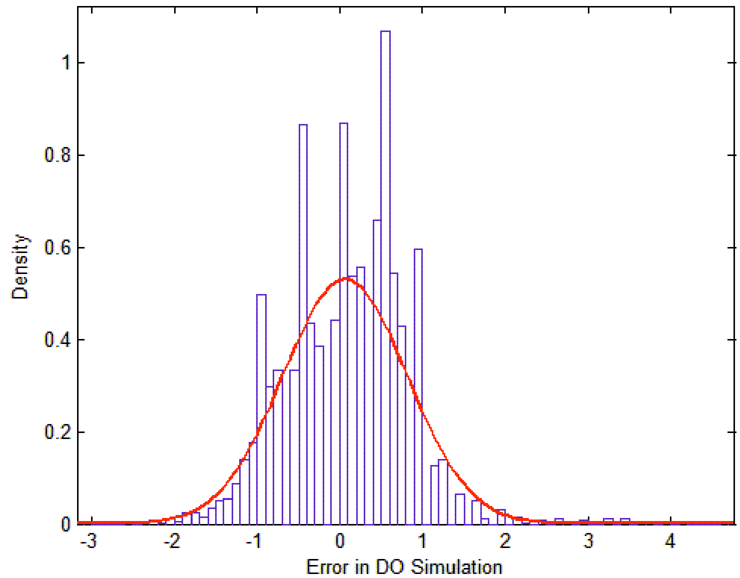


Figure 9. Error distribution for dissolved oxygen

The posterior (modified probability density function) for the dissolved oxygen can be represented by following equation:

$$P(DO|M,T,R,E,C) = \frac{\frac{1}{\sqrt{2\pi}0.753} exp\left[-\frac{1}{2}\prod_{i=1}^{n}\left(\frac{e_i}{0.753}\right)^2\right] \cdot \frac{1}{1.88\sqrt{2\pi}} exp\left[-\frac{1}{2}\prod_{i=1}^{n}\left(\frac{x-6.42}{1.88}\right)^2\right]}{3.874} \quad (4)$$

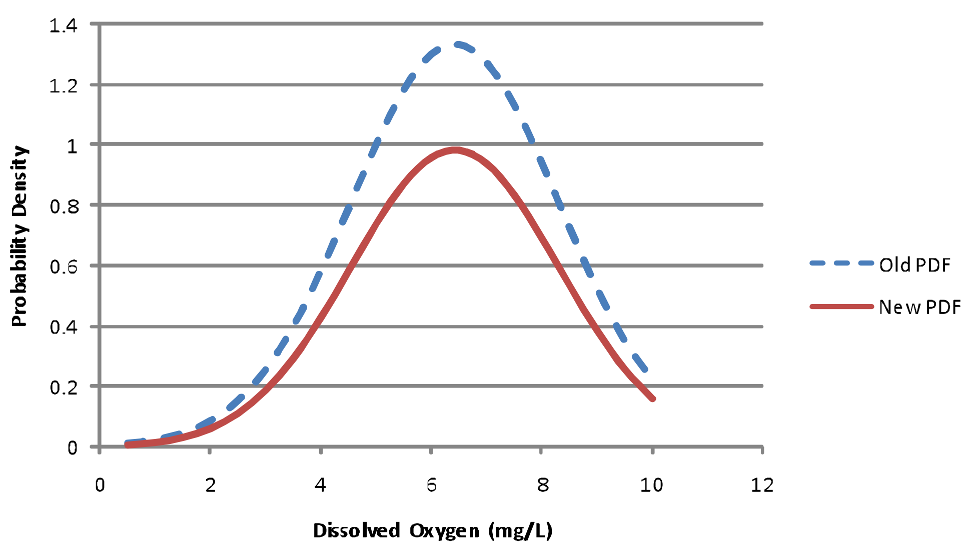


Figure 10. Prior and Posterior distributions of dissolved oxygen in the Amite River.

According to the newly developed method, the dissolved oxygen load in the Amite River is estimated to be 399.262 T/Day. Based on LDEQ standards, the dissolved oxygen load in the Amite River needs to be maintained above 440.210 T/Day. Therefore, a 40.948 T/Day of dissolved oxygen load needs to be restored to maintain a healthy aquatic system.

INFORMATION TRANSFER

The findings and methods for uncertainty-based TMDL development will be transferred to the Louisiana Department of Environmental Quality (LDEQ) for applications in TMDL developments and stream restoration.