Scale-dependent behavior and modeling of dissolved oxygen in coastal Louisiana rivers

Basic Information

Title:	Scale-dependent behavior and modeling of dissolved oxygen in coastal Louisiana rivers
Project Number:	2010LA73B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	6th
Research Category:	Water Quality
Focus Category:	Water Quantity, Solute Transport, Models
Descriptors:	
Principal Investigators:	Zhi-Qiang Deng

Publications

1. Deng, Z.-Q., Jung, H.-S., and Ghimire, B. (2010). "Effect of channel size on solute residence time distributions in rivers." Advances in Water Resources, 33 (9), 1118–1127, DOI: 10.1016/j.advwatres.2010.06.016.
2. Ghimire, B., and Deng, Z.-Q. (2011). "Event flow hydrograph-based method for shear velocity estimation." Journal of Hydraulic Research, 49(2), 272-275.
3. Ghimire, B., and Deng, Z.-Q. (2011). "Event Flow Hydrograph-Based Method for Modeling Sediment Transport." ASCE Journal of Hydrologic Engineering (in review).
4. Zahraeifard, V. and Deng, Z. (2011). "VART Model-Based Method for Estimation of Instream Dissolved Oxygen and Reaeration Coefficient." ASCE Journal of Environmental Engineering (in review)

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RESEARCH

Problem and Research Objectives

The dissolved oxygen variation displays a strong scale-dependent behavior. At the seasonal scale, the DO becomes low in summer and high in winter following seasonal temperature change. At event (e.g. floods) scale, DO fluctuation in coastal Louisiana rivers with fine-grained sediment is significantly affected by flood events. The seasonal variation in DO is already well known. However, the DO fluctuation in response to flood events is still poorly understood, making it impossible to quantify the uncertainty and thereby the margin of safety (MOS) involved in the DO TMDL (Total Maximum Daily Load) development. This is a critical regional and state water quality problem needing to be addressed.

The primary goal of this project is to understand the linkage between the episodic sediment resuspension and DO cycling in fine-grained coastal Louisiana rivers. The specific objective of this project is to develop an efficient and effective mathematical model for simulating scale-dependent behavior of dissolved oxygen in coastal Louisiana rivers characterized with fine-grained sediment.

Methodology

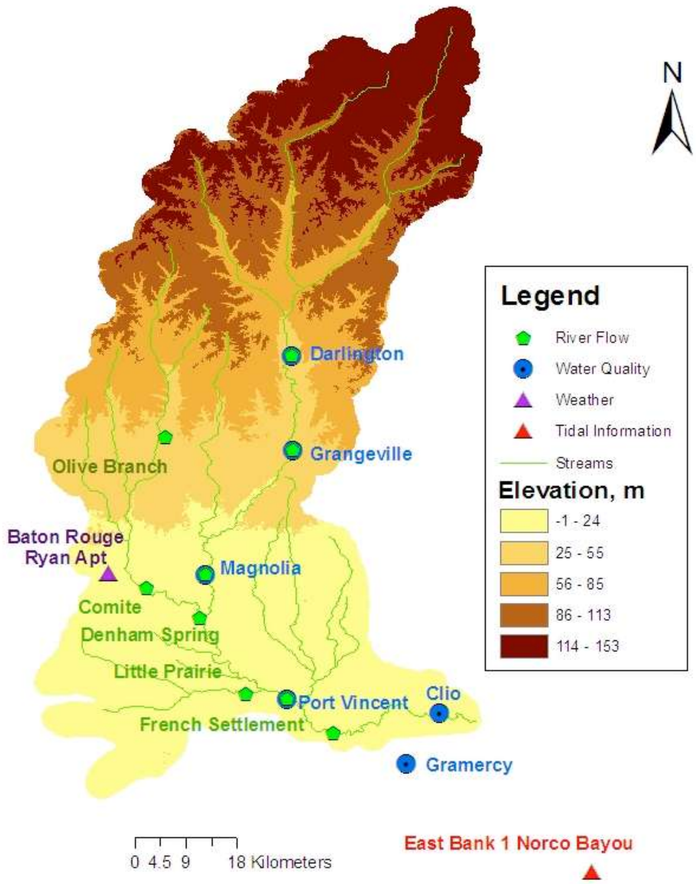

Figure 1. Map of the Amite River watershed.

The Lower Amite River at the Port Vincent was selected as the study site, as shown in Figure 1. The Amite River flows generally southwestward to Lake Pontchartrain estuary that is connected to the Gulf of Mexico. Therefore, the Lower Amite River is a typical coastal river with fine-grained sediment. The Lower Amite River (Subsegment 040303) is on US EPA's 2006 Impaired Water 303(d) List because it was "not supporting" the designated use of Fish and Wildlife Propagation. The Lower Amite River is impaired for dissolved oxygen and some other nutrients such as nitrate/nitrite and total phosphorus. In order to understand the scale-dependent behavior of DO in coastal rivers, a number of mathematical models have been developed, including (1) event flow hydrograph-based method for estimation of shear velocity (see Publication 2), (2) event flow hydrograph-based method for modeling sediment resuspension (see Publication 3), (3) improved variable residence time (VART) model for simulation of instream solute transport (see Publication 1), and (4) VART-DO model for estimation of instream dissolved oxygen and reaeration coefficient (see Publication 4). The four models are then combined to form a new model for simulation of sediment resuspension-induced scale-dependent behavior of instream DO:

$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial x} = \frac{\partial}{\partial x}\left(E\frac{\partial C}{\partial x}\right) + \frac{A_{adv} + A_{diff}}{A}\frac{1}{T_V}(C_s - C) + K_2\,(C_{sat} - C) - \Lambda C$$

where x = distance, t = time variable, C = dissolved oxygen concentration in the water column, Cs = dissolved oxygen concentration in the sediment, Csat = dissolved oxygen in the saturation condition, U = flow velocity, E = dispersion coefficient, $A_{adv.}$ = advection-dominant area of storage zone, A_{diff} = diffusion-dominant area of storage zone (defined in Paper 1), A = channel cross-sectional area, T_V = actual varying residence time of solute (defined in Paper 1), K_2= reaeration coefficient, Λ = sediment resuspension coefficient. The parameter Λ was determined using the model presented in Publication 3 while parameter K_2 was determined using the model presented in Publication 4. The parameter values were calibrated using flow and DO data collected at Denham Springs (Figure 1) in 1990 by Louisiana Department of Environmental Quality (LDEQ). The calibrated model was then applied to perform continuous simulation of DO variations at the Port Vincent in January and July of 1990. The two months (January and July) represents the two extreme conditions in terms of the seasonal scale variation in DO. The modeling results are compared with observed DO data from LDEQ.

PRINCIPAL FINDINGS AND SIGNIFICANCE

1. Flow Hydrograph-based Method for Shear Velocity Estimation (Paper 2)

A simple event flow hydrograph-based method is developed for determining the shear velocity during river floods. The method is based on the Saint-Venant equations, simplified for floods in mild-sloping rivers of constant channel width. Applications of the new method using published experimental data and simulated results indicate that the method is comparable with existing more complex methods in terms of accuracy but requires less input data, especially if the channel is prismatic and the flow conditions are similar to those in typical lowland rivers.
This method is particularly applicable to natural floods in relatively straight reaches of lowland rivers where the non-inertia wave approximation to the Saint-Venant equations is theoretically appropriate.
Comparisons between the new method (Equations 9 and 10 in Figure 2) and other methods against measured data are shown in Figure 2 (a - d).

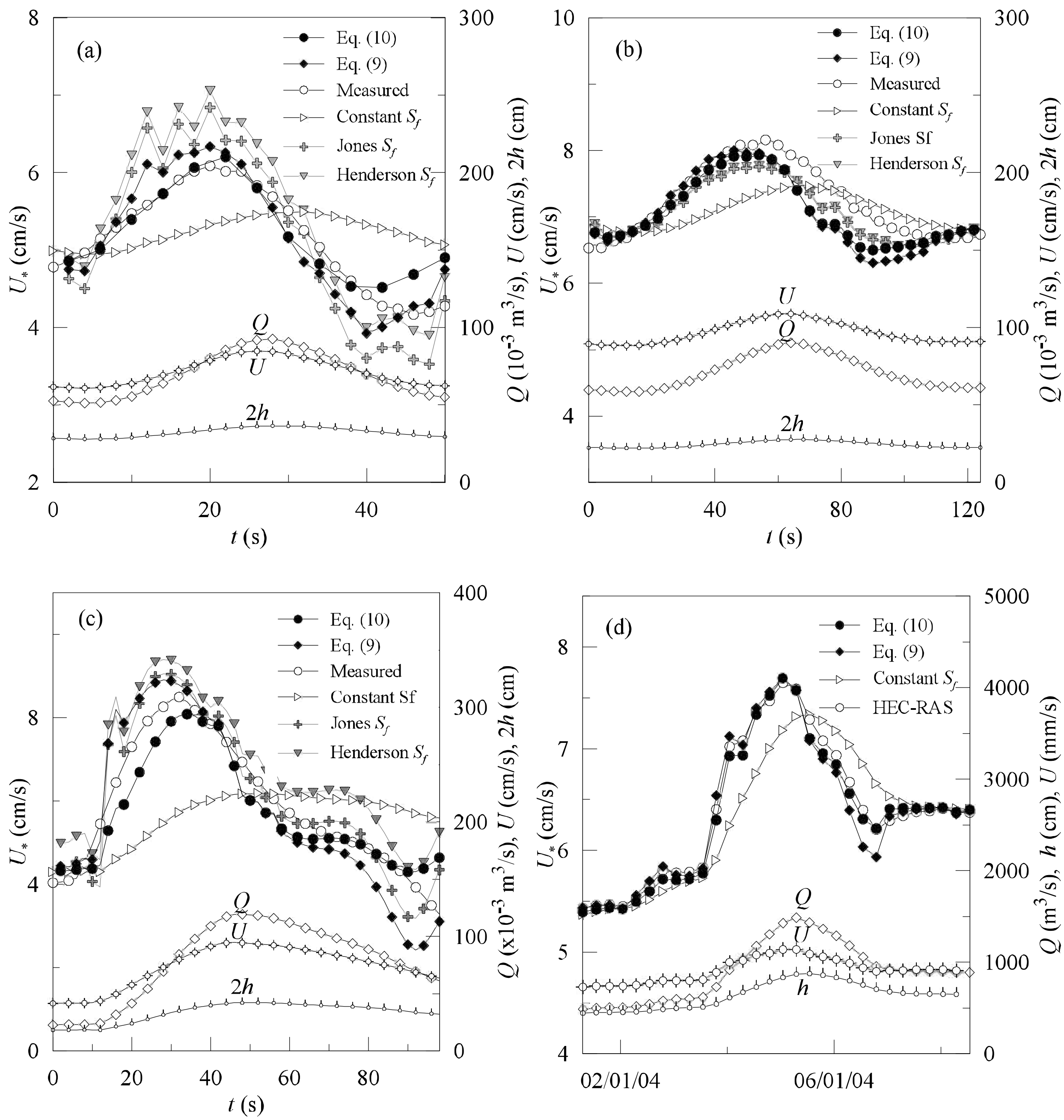

Figure 2. Comparison of shear velocities U_* for (a) Exp. S-15-936, (b) Exp. S30-931, (c) Exp. NS1(1), (d) HEC-RAS results for January 2004 flood of Muskingum River at McConnelsville OH. Measured values for Q, U and h (or $2h$) are also shown.

2. Flow Hydrograph-based Method for Modeling Sediment Resuspension (Paper 3)

(1) Under the assumptions of equilibrium transport, uniform sediment and prismatic channel, the application of the proposed hydrograph-based method indicates that this method is comparable with more advanced numerical model such as HEC-RAS in terms of overall accuracy and gives relatively better results during rising as well as falling phases of large flood events (Figure 3). This is an encouraging result, especially as the proposed method is much simpler, less data intensive and does not require numerical computation.

(2) This method is able to reproduce clockwise hysteresis of sediment concentration frequently observed in natural rivers (Figure 4). Obviously, this method assumes that the trends in shear stress explain the trend in sediment transport. When the sediment supply is limited or the trend in the sediment transport is independent of channel hydraulics, this method is not directly applicable.

(3) Since the better simulation of sediment transport is achieved with improved estimates of hydrodynamic parameters such as bed shear stress or friction slopes, this method may be useful for studying the performance of sediment entrainment relations during flood events when observed data are available.

(4) The proposed method appears to be a more practical alternative to advanced numerical models that are included in the contaminant transport modelling framework but are costly in terms of input data. With this simple yet effective tool, the need to compromise with the accuracy by resorting to uniform flow formula for simplicity during unsteady flow events is largely eliminated.

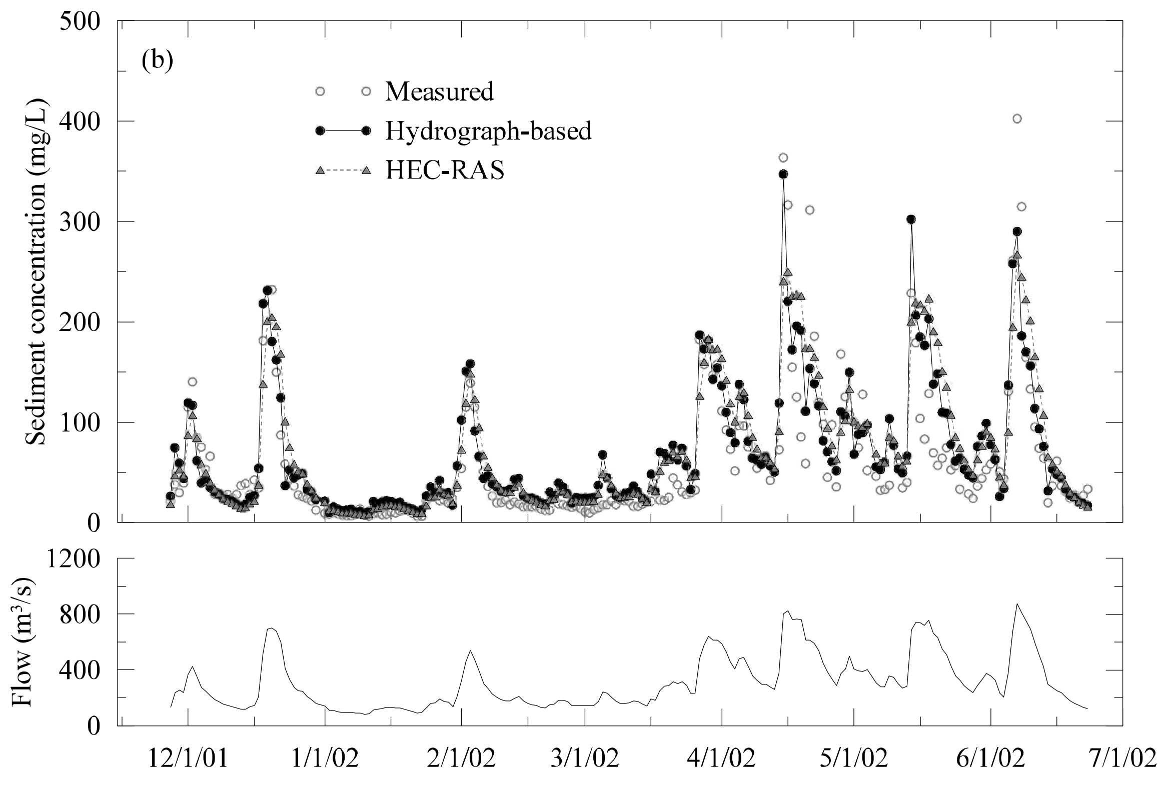

Figure 3. Comparison of measured and computed sediment concentrations using hydrograph-based method and HEC-RAS model at McConnelsville, OH during high flow seasons in 2002.

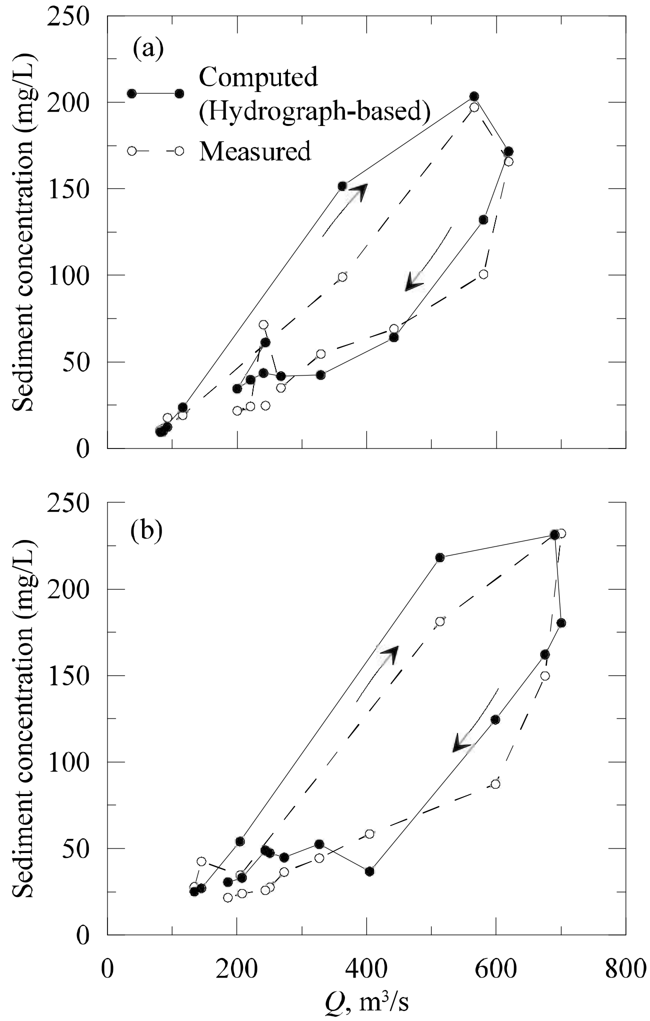

Figure 4. Hysteresis of sediment concentration at McConnelsville during two single peak flood events: (a) January 2001 and (b) December 2001.

3. **VART Model-Based Method for Estimation of Instream Dissolved Oxygen (Papers 1 and 4)**

(1) The transient storage effect may significantly affect the reaeration coefficient K_2 values. Storage zones can reduce K_2 and RMSE (root mean squared error) values by about 30 percent. Therefore, it is important to include their effects in the DO modeling.

(2) The dispersion mechanism is also important to DO exchange. The study showed that strong longitudinal dispersion can increase K_2 values significantly. According to a sensitivity analysis, the dispersion coefficient may increase K_2 value by about 50 percent and decreases RMSE by about 48 percent.

(3) The K_2 value computed using the VART-DO model may be up to 6 times greater than those obtained from existing empirical equations. The combined effects of storage zones and dispersion coefficient should be considered in the estimation of the reaeration coefficient.

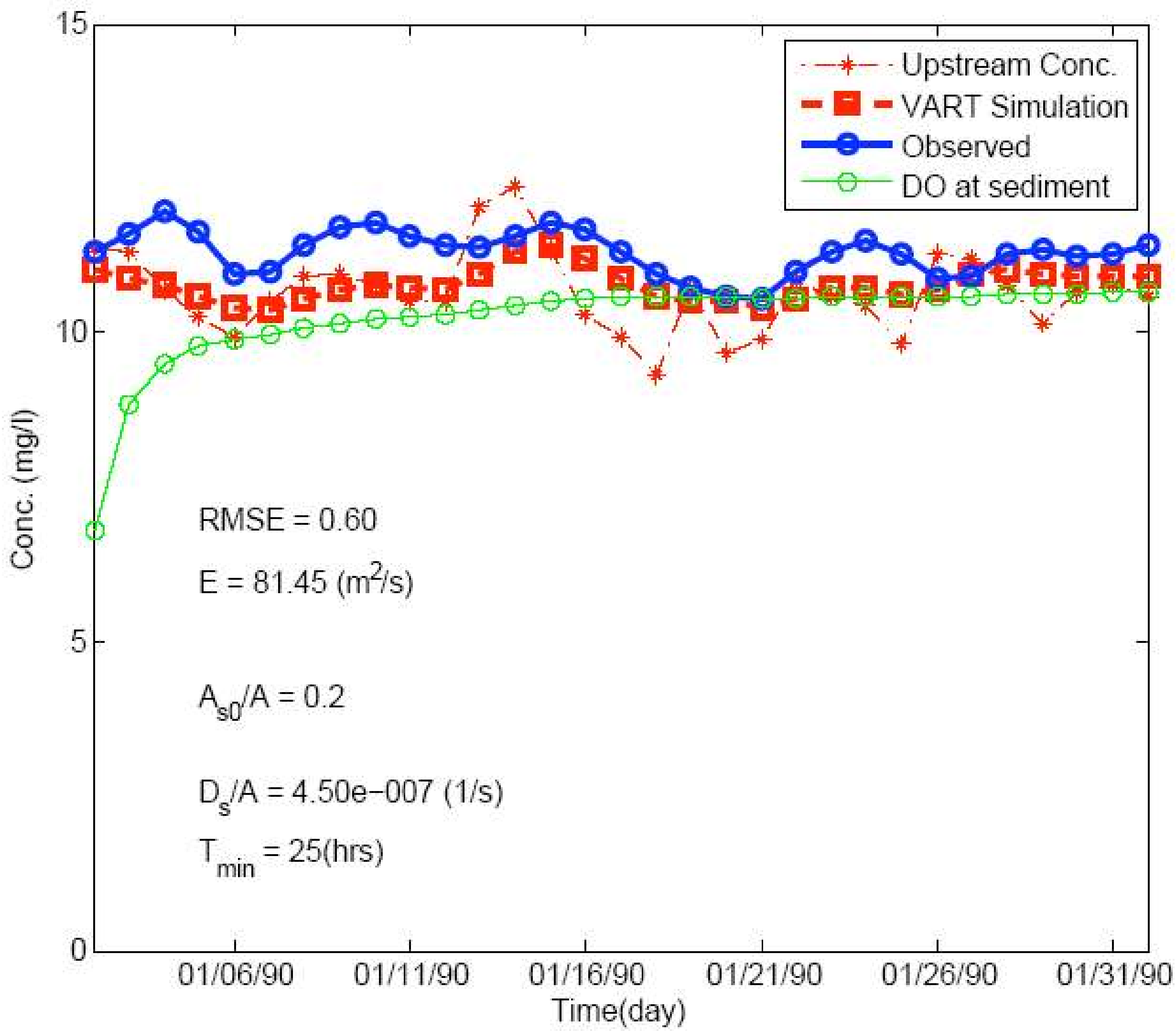

Figure 5. Comparison between observed and simulated DO levels in January 1990 at Port Vincent. The simulated DO concentration in bottom sediment at Port Vincent is also shown (the green line). Also included in the figure is the observed DO level at Denham Springs.

(4) The VART-DO model is capable of simulating DO variations in both water column and bottom sediment, as shown in Figures 5 and 6. This feature is particularly appealing for understanding the scale-dependent behavior of dissolved oxygen in fine-grained coastal Louisiana rivers.

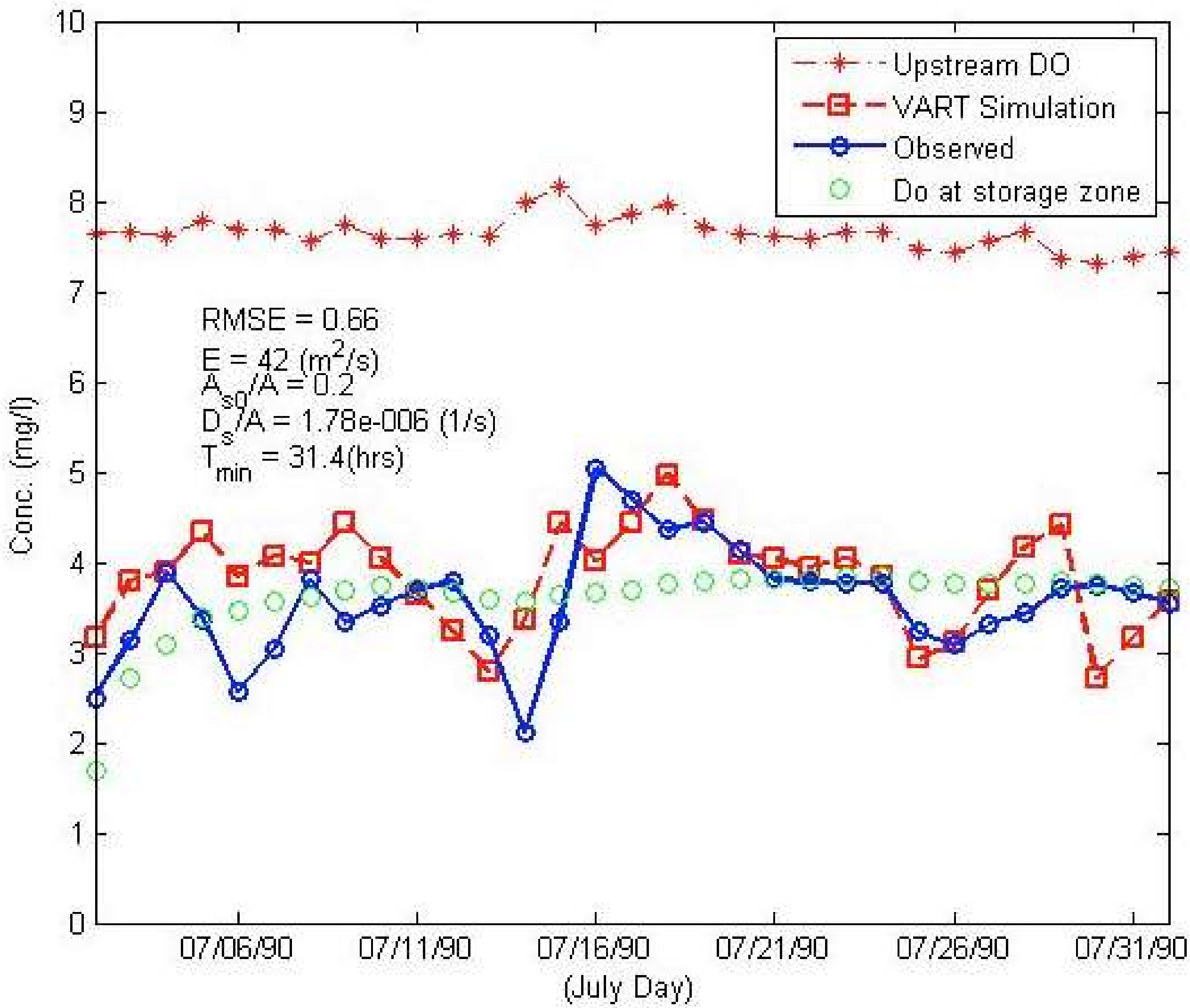

Figure 6. Comparison between observed and simulated DO levels in July 1990 at Port Vincent. The simulated DO concentration in bottom sediment at Port Vincent is also shown (the green circle line). Also included in the figure is the observed DO level at Denham Springs.

INFORMATION TRANSFER

The findings and methods for modeling sediment resuspension-induced DO variation will be transferred to the Louisiana Department of Environmental Quality (LDEQ) for applications in TMDL developments and stream restoration.

STUDENT SUPPORT

Name of supported graduate student: Bhuban Ghimire (Male)
Degree Program: Ph.D. in Water Resources
Dissertation Title: Characterization of Cycling-Induced Sediment-Water Interface and Exchange of Solutes in Fine-Grained Streams
Anticipated Graduation Date: December, 2011

FOLLOW-ON FUNDING

Title: **Remote Sensing Detection of Water Quality Indicators for Oyster Norovirus Outbreaks**
PI: Zhi-Qiang Deng
Funding Agency: NASA (National Aeronautics and Space Administration) and LaSPACE (Louisiana Space Consortium)
Duration: 10/01/2010 – 09/30/2011
Amount: $74,998