Report as of FY2008 for 2008LA58B: "Uncertainty-based TMDL Calculations for Dissolved Oxygen in Amite River"

Publications

Project 2008LA58B has resulted in no reported publications as of FY2008.

Report Follows

12. Uncertainty-based TMDL Calculations for Dissolved Oxygen in Amite River

13. Critical Regional and State Water Quality Problems

The Total Maximum Daily Load (TMDL) is embedded in the Clean Water Act (CWA) [Section 303(d)] and the EPA's water quality regulations (40 Code of Federal Regulations 130). This regulation requires states to develop and implement pollution abatement plans for all water bodies for which the current water quality standards are not met and cannot be met by enforcing the technology-based standards for point sources. The TMDL program requires the inclusion of a margin of safety (MOS) in the allocation step; that is, the TMDL should be equal to the sum of the waste load allocation (WLA) to point sources, the load allocation to nonpoint source pollution or to natural background sources (LA), and MOS, i.e.,

$$\text{TMDL} = \sum \text{WLAs} + \sum \text{LAs} + \text{MOS} \qquad (1)$$

The most common unit for TMDL, WLA, and LA is mass per time, where the time should be in days, however, other expressions may also be possible (U.S. EPA 1991) such as percent reduction of the loads.

Scientific uncertainty is a reality within all water quality programs, including the TMDL program that cannot be entirely eliminated (Committee 2001). The TMDL program currently accounts for the uncertainty embedded in the modeling exercise by applying a simple implicit or explicit approach to estimate the MOS. The implicit approach is to incorporate the MOS using conservative model assumptions to develop allocations while the explicit approach is to reserve a portion of the total TMDL for the MOS (U.S. EPA 2002). Due to the usual tight schedules and limited budgets for TMDL development projects, the selection of MOS has typically been made by subjective decisions without explicitly taking into account uncertainty sources and directly estimating their impacts on overall uncertainty in the TMDL calculations. Based on a recent national survey supported by the Water Environmental Research Foundation (WERF) (Dilks 2004), among a total of 172 TMDLs being reviewed, there are 12 TMDLs that have no MOS estimates at all. Of the remaining 160 TMDLs, 119 of them employed the subjective EPA simple explicit MOS method while 40 applied implicit MOS or conservative assumptions. Only one TMDL explicitly calculated the uncertainty through a parallel research study and reflected this uncertainty into MOS. None used uncertainty analysis tools to calculate the MOS during TMDL development (Zhang and Xu 2004). 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. Therefore the Committee (2001) TMDL report calls for ending the practice of arbitrary selection of the MOS and instead requiring uncertainty analysis as the basis for MOS determination. Uncertainty must be explicitly addressed both in the models selected for developing the TMDLs and in the results generated by the models. However, currently the rigorous MOS determination in any TMDL development remains a challenging and sometimes cost prohibitive task, especially when technical guidance is still not yet available to provide assistance in implementing uncertainty analysis. Theoretically, the application of uncertainty analysis is not entirely free of arbitrariness, which is especially true for a water quality-based program such as TMDL. There are significant uncertainties associated with many aspects of TMDL estimation, such as using constant flow discharges, constant rates of sediment oxygen demand and other lumped parameters. This introduces a significant amount of uncertainty into the predictions of safe loads into water bodies. Coastal Louisiana rivers and bayous are often subject to backwater flooding events and other hydrologic events unique to the region that are not considered in the simulation models. This introduces additional uncertainty in the model output. The stochastic nature of meteorological events is a major driving force that causes uncertainties in nonpoint source pollution generation. Because of the complexity of watershed and water quality modeling, current EPA's simple explicit and implicit methods for calculating MOS cannot evaluate the relative significance of the contributing sources of uncertainty. A strategy on how to reduce uncertainty cannot be formulated due to the fact that the sources of uncertainty have not been determined. Consequently, it can be noted that knowing the key sources of uncertainty in TMDL estimation will be very important for the long-term success of the TMDL program.

Louisiana's 2006 Water Quality Integrated Report (http://www.deq.louisiana.gov/portal/tabid/2692/Default.aspx) shows that 69% of Louisiana rivers (including bayous and streams) does not support for fish and wildlife propagation (fishing). The most frequently identified suspected impairment found in Louisiana rivers is low dissolved oxygen (3,263 miles). The Amite River is one of the 59 water bodies impaired by low dissolved oxygen. Therefore, a TMDL calculation for dissolved oxygen in the Amite River is required to be completed by 2011 (Boydstun 2007). The primary difficulty in the DO TMDL development lies, to a large extent, in the uncertainty of loading calculations, especially the nonpoint source loading LA in Eq. (1).

14. Results and Benefits

(1) This project leads to the development of an uncertainty-based methodology for estimation of MOS and thereby TMDL. The new method will be demonstrated through the TMDL development for dissolved oxygen in the Amite River. The method involves the determination of uncertainties in flow discharge and in contaminant concentration.

(2) The proposed study identifies two primary sources of TMDL uncertainty: (i) uncertainty in flow discharge and (ii) uncertainty in contaminant concentration, that can be further linked to uncertainties in model parameters.

(3) For the first time this study includes the second-order uncertainty or error in uncertainty analysis and provides an efficient method for determination of two-dimensional uncertainty.

(4) This project will improve understanding of uncertainty propagation in loading calculations, which will further the development of scientifically defensible load allocations for impaired rivers. Owing to the quantification of TMDL uncertainty the results of this study will help lower the risk of inadequately characterizing the margin of safety.

(5) The uncertainty-based TMDL calculations will also help with the development of stream restoration priorities and thereby loading reduction strategies as well as the selection of sources in which to target reduction efforts.

(6) The results of this project will also be presented at professional conferences and serve as the basis for one or more professional journal articles.

(7) Although this study focuses on dissolved oxygen TMDL in the Amite River, the methods presented in this study will be generally applicable to TMDL calculations of other contaminants and nutrients as well.

The results of this project are therefore of great benefits and practical use in environmental restoration of impaired watercourses and watershed in Louisiana in an efficient and cost-effective fashion.

15. Nature, Scope, and Objectives of the Research

Nonpoint source pollution (LA) has been recognized as the major contributor of the impairment of the nation's waters (Committee 2001). Therefore, this study focuses on the uncertainty analysis of nonpoint source loading (LA). In terms of mass per time, LA is commonly calculated as the product of a specified flow discharge *Q* and pollutant concentration *C*. If the uncertainties involved in *Q* and *C* are ΔQ and ΔC, respectively, the load allocation LA can be determined as

$$\begin{aligned} LA &= Q \times C \\ &= (\overline{Q} + \Delta Q)(\overline{C} + \Delta C) \\ &= \overline{Q} \times \overline{C} + \overline{Q} \times \Delta C + \overline{C} \times \Delta Q + \Delta Q \times \Delta C \end{aligned} \tag{2}$$

Comparing Eqs. (1) and (2) gives

$$\mathrm{MOS} = \overline{Q} \times \Delta C + \overline{C} \times \Delta Q + \Delta Q \times \Delta C \tag{3}$$

where $\overline{\mathrm{Q}}$ = daily mean discharge, and $\overline{\mathrm{C}}$ = mean or event mean concentration, ΔQ = uncertainty in the calculated or measured discharge, ΔC = uncertainty in the calculated or measured concentration. The last term in Eq. (3) represents the second order uncertainty or error that is conventionally neglected based on the assumption of small ΔQ and ΔC. Eqs. (2) and (3) show that uncertainty involved in TMDL calculation is mainly caused by the uncertainties in flow discharge Q and contaminant concentration C. Existing methods for TMDL uncertainty analysis mainly focuses on the uncertainty in contaminant concentrations. Uncertainty in flow and the correlation between the flow and the concentration are rarely included in the TMDL uncertainty analysis. Consequently, the primary goal of this research is to provide efficient methods for estimation of ΔQ and ΔC involved in Eqs (2) and (3) and thereby to quantify the TMDL uncertainty (MOS).

To achieve the goal of the project, the research is split into five specific objectives/tasks:

(1) Uncertainty analysis for flow
(2) Uncertainty analysis for DO concentration.
(3) Two dimensional simulation of variability and uncertainty.
(4) TMDL calculations for dissolved oxygen in the Amite River.

The objectives will be addressed through the combination of a statistical analysis and a deterministic model. The uncertainty involved in the flow will be estimated by means of probability distributions of discharge. The uncertainty involved in the concentration will be determined using a 1D mass transport equation and the first order error analysis method.

Timeline for Project Completion:

March 1 – April 30:	Object 1
May 1– August 31	Object 2
September 1 – November 30:	Object 3
December 1– January 31:	Object 4
February 1 – February 29:	Complete and submit the final report of the project

16. Methods, Procedures, and Facilities

Each objective constitutes a task. The discussion that follows briefly outlines how each task and in turn each objective will be accomplished.

Task 1: Uncertainty Analysis for flow

In order to determine the uncertainty in flow discharge, probability distributions of daily mean flow will be plotted. To that end, daily mean flow data of the Amite River will be collected from USGS websites. It is expected that the probability of daily mean flow may follow a lognormal or Weibull or other types of distributions, as shown in Figure 1**.**

Daily mean flow discharge

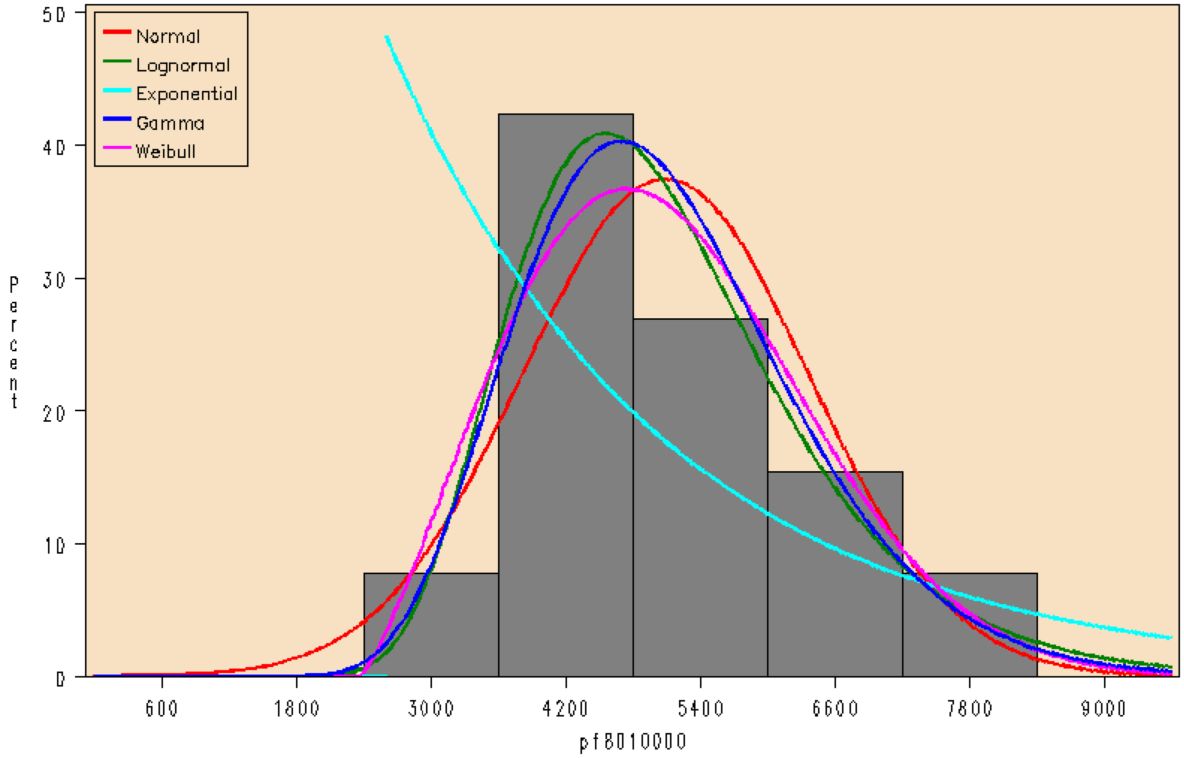

Figure.1. Expected probability distributions of daily mean flow in the Amite River

Different probability distributions showing in Figure 1 will be tested and the best fit will be selected and utilized in the determination of ΔQ that will be discussed in Task-3.

Task 2: Uncertainty Analysis for DO concentration

The in-stream dissolved oxygen (*D*) is a function of nitrification, re-aeration, sediment oxygen demand (SOD), biochemical oxygen demand (BOD) and benthal and phytoplankton activities. A 1D model for DO in rivers can be expressed as:

$$\frac{\partial D(x,t)}{\partial t} = \underset{\boxed{\text{Reaeration}}}{-U\frac{\partial D(x,t)}{\partial x} - K_a D(x,t)} + \underset{\boxed{\text{CBO}}}{K_d L(x)} + \underset{\boxed{\text{NBOD}}}{K_n N(x)} + \underset{\boxed{\text{Benthal}}}{S(x)} + \underset{\boxed{\text{Algal DO}}}{R(x) - P(x,t)} \qquad (4)$$

where, U = Q/A is the stream velocity of daily mean flow,

L(x) = carbonaceous BOD at distance ‘x’,

N(x) = nitrogenous BOD at distance ‘x’,

K_d = deoxygenation rate coefficient of carbonaceous BOD,

K_n = deoxygenation rate coefficient of nitrogenous BOD, which reflects both removal of ammonia and oxygen consumption,

K_a = reaeration rate coefficient,

S(x) = benthic respiration rate,

R(x) = algal respiration rate,
P(x,t) = algal photosynthetic oxygen production rate.

An analytical solution of equation (4) is given by,

$$D(x,t) = D_0\left(t-\frac{x}{U}\right)\exp(-j_a x) + F_{d,r}[exp(-j_r x) - exp(-j_a x)]$$
$$+F_{n,r}[exp(-j_n x) - exp(-j_a x)] + \left(\frac{S}{K}\right)[1-exp(-j_a x)]$$
$$+\left(\frac{R}{K}\right)[1-exp(-j_a x)] - P_m\left\{\left(\frac{2p}{\pi K_a}\right)[1-exp(-j_a x)] + f(x,t)\right\} \quad (5)$$

where,

$$j_a = \frac{K_a}{U}, \qquad j_r = \frac{K_r}{U}, \qquad j_n = \frac{K_n}{U}$$

$$F_{d,r} = \frac{K_d L_0\left(t-\frac{x}{U}\right)}{K_a - K_r}, \qquad F_{n,r} = \frac{K_n N_0\left(t-\frac{x}{U}\right)}{K_a - K_r}$$

$$f(x,t) = \sum_{n=1}^{\infty}\frac{b_n}{[K_a^2+(2\pi n)^2]^{1/2}} cos\left[2\pi n\left(t-t_s-\frac{p}{2}\right) - \tan^{-1}\frac{2\pi n}{K_a}\right]$$
$$-\exp(-j_a x)\sum_{n=1}^{\infty}\frac{b_n}{[K_a^2+(2\pi n)^2]^{1/2}} cos\left[2\pi n\left(t-t_s-\frac{p}{2}-\frac{x}{U}\right) - tan^{-1}\frac{2\pi n}{K_a}\right]$$

The model can be further improved based on the specific conditions of the Amite River. It can be seen from Eqs. (4) and (5) that the uncertainty involved in the DO concentration D may be caused by uncertainties (ΔX_i) in the model parameters (X_i). The uncertainty ΔC can be determined using the first order error (FOE) analysis, also called mean value first order second moment method. In this method, the Taylor's series expansion of the performance function is truncated after the first order term (Zhang and Yu 2004). According to the FOE analysis the uncertainty ΔC is given as:

$$\Delta C = \sum_{i=1}^{N}\left(\frac{\partial D}{\partial X_i}\right)_{X_e}\Delta X_i \quad (6)$$

where, N = number of basic parameter or variable X_i (K_d, K_n, K_a, U, N, L, S, R, and P), X_e = mean value of parameter X_i.

The FOE analysis requires the knowledge of only first two statistical moments (mean and variance) of the basic variable X_i. It involves the linear approximation of a model with error terms represented by the variance. Determining the prediction error can be considered as two sub-problems. First the mean value X_e of the basic variables must be computed, and then an assessment of the effects of different sources (ΔX_i) of uncertainty on the uncertainty of the mean output value is obtained based on the variation range of variable or parameter. FOE analysis provides a very clear approach to uncertainty analysis by decomposing the variance of each output into the sum of contributions from each input.

Due to the wide variation range of the parameters involved Eq. (5) different ΔC may be calculated. Then, a cumulative probability distribution versus contaminant concentration, as shown in Figure 2, can be obtained and a fixed value of ΔC can be determined based on water quality criterion.

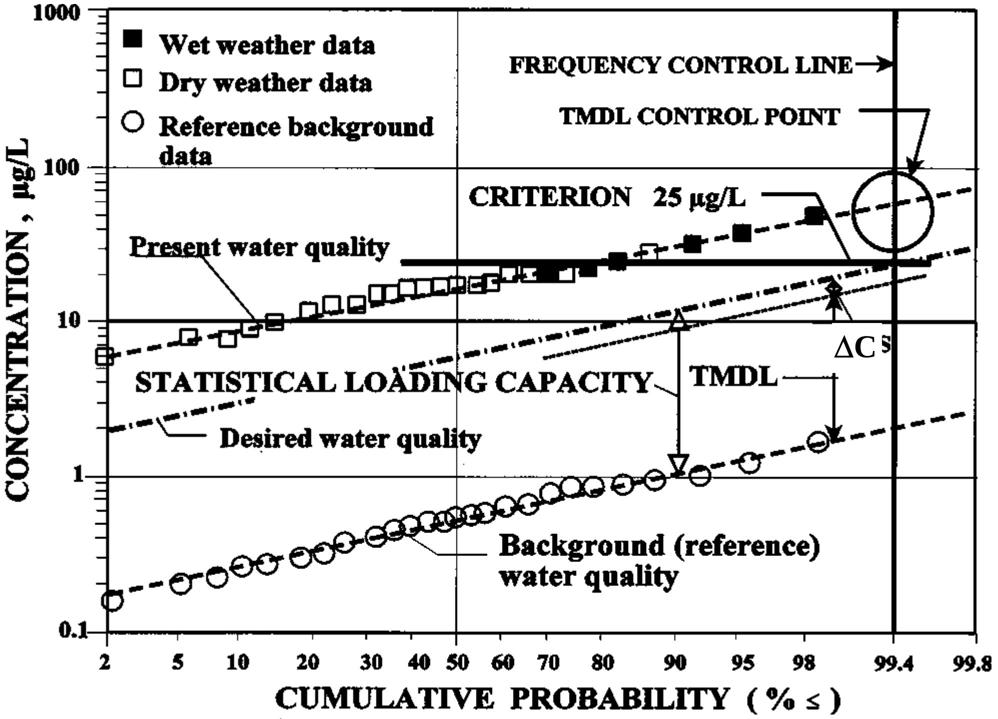

Figure 2. Estimation of uncertainty involved in contaminant concentration

Task 3: Two-Dimensional Simulation of Variability and Uncertainty

Eq. (4) clearly indicates that DO concentration depends on the mean flow Q. It means that flow discharge Q and concentration C are not independent. In order to determine the uncertainty ΔQ in flow, a Copula method will be employed to determine the joint probability density distribution of contaminant concentration *C* and flow discharge *Q*, as shown in Figure 3. Based on the cumulative probability and its corresponding density of concentration determined in Task-2, a probability density for flow discharge Q can be found from Figure 3.

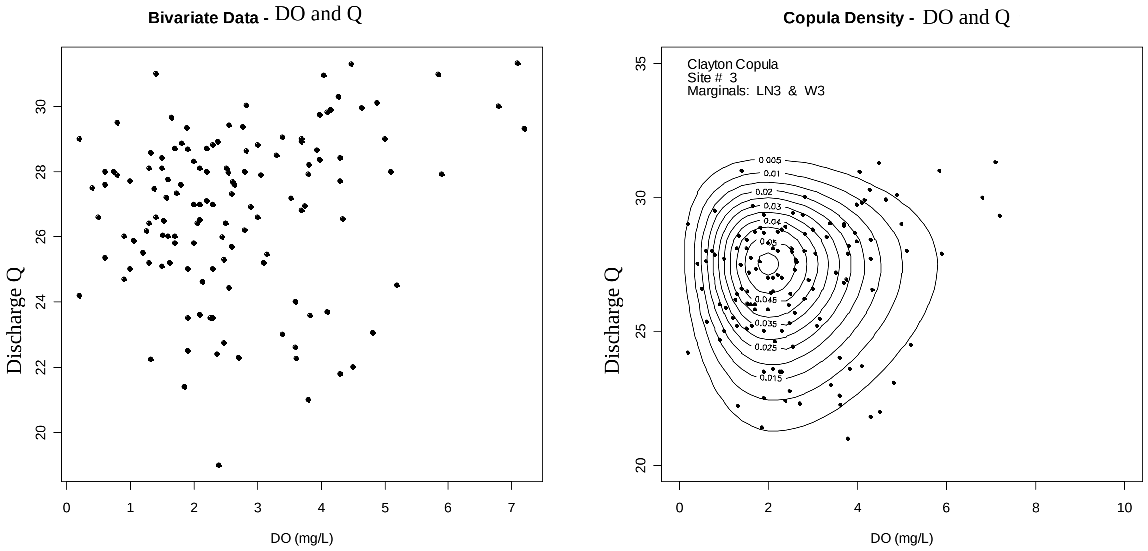

Figure 3. Joint probability density of flow discharge and contaminant concentration

Using the probability density of flow determined from Figure 3 and the cumulative probability of flow, which can be determined from Figure 1, the uncertainty in flow discharge ΔQ can be determined. Computer programs for performing the Copula analysis will be provided so that Figure 3 can be easily obtained.

Task 4: TMDL calculations for dissolved oxygen in the Amite River

Based on the uncertainties in flow (ΔQ) and in concentration (ΔC) determined in Tasks 1 – 3 the MOS can be calculated using Eq. (3). The loading capacity (LC) will be calculated using the DO water quality criterion required by LDEQ and the daily mean flow discharge. The DO TMDL will be calculated using the following equation:

$$\text{TMDL} = \text{LC} - \text{MOS} \tag{7}$$

Then, the load allocation (LA) and the waste load allocation (WLA) will be determined using point source data to be collected for the Amite River. Finally, BMPs (Best Management Practices) for achiving the DO TMDL will be recommended for the Amite River.

17. Related Research

There are plenty of researches related to the project. Probabilistic modeling-based uncertainty analysis has been widely used in environmental systems (Ayyub1998). Benaman and Shoemaker (2004) introduced methodology for analyzing ranges of uncertain model parameters and their impact on TMDL process. Zhang and Yu (2004) used the first-order error analysis in determining the margin of safety for TMDL computations. Novotney (2004) assumed that the contaminant concentrations generally follow lognormal distribution and presented a tiered probabilistic TMDL approach based on the lognormal probability distribution. Reckhow (2003) emphasized that regardless of time frame, the TMDL program will be better served with complete estimates of uncertainty than with arbitrary hedging factors that simply fulfill an administrative requirement. EPRI (2004) also provided theoretical and practical guidelines for establishing approaches to estimate the margin of safety (MOS) in a total maximum daily load (TMDL) calculation. Although extensive efforts have been made to reduce TMDL uncertainty, no existing methods include the uncertainties involved in both the flow and contaminant concentration and the effect of their correlation on MOS.

This project is unique in that (1) it includes uncertainties involved in both the flow and the contaminant concentration as well as the second order uncertainty for the first time. Application of the approach presented in this study will greatly reduce the uncertainty in TMDL development; (2) this is the first TMDL development in Louisiana in terms of identification of uncertainty sources and quantification of the sources; and (3) Use of the Copula method for determining the joint probability density of flow discharge and contaminant concentration, providing an efficient method for determining the effect of the uncertainty related to the correlation between flow and contaminant concentration.

18. Training Potential

The Ph.D. student to work on this project is Abhijit Patil. Mr. Patil received his MS degree from the Asian Institute of Technology, Bangkok, Thailand. Mr. Patil has coauthored two books on GIS applications and published six conference papers and two peer-reviewed journal papers on shrimp waste dispersion in coastal waters. Mr. Patil will work on the tasks under the supervision of the PI.

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Novotny, Vladimir (2004). “Simplified Databased Total Maximum Daily Loads or the World is Log-Normal”. *Journal of Environmental Engineering*, Vol. 130, No. 6. June, pp. 674-683.

Reckhow, K. H. (2003). On the Need for Uncertainty Assessment in TMDL Modeling and Implementation, *ASCE Journal of Water Resources Planning and Management, 129(4), 245-246.*

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Zhang, H. X. and Yu, S. L., 2004. Applying the First-Order Error Analysis in Determining the Margin of Safety for Total Maximum Daily Load Computations, *ASCE Journal of Environmental Engineering*, 130(6): 664-673.

19. Zhi-Qiang Deng's Qualifications (Resume)

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1. EDUCATION

- **Ph.D.** in Water Resources Engineering, Lund Institute of Technology, Lund University, Sweden, 2002.
- **M.S.** in Civil Engineering with concentration in river hydraulics, Wuhan University of Hydraulic and Electrical Engineering, China, 1988.
- **B.S.** in Hydraulic Engineering (First Class Honors), Shihezi University, China, 1984.

2. HONORS AND AWARDS

(1) Hundreds-Talent Program (Century Program) Award received from the Chinese Academy of Sciences in 2003.

(2) Innovation Award in Science and Technology, Leading Faculty Award, and two Best Paper Prizes received in the years of 1997, 1997, 1996, and 2000 in China.

3. EMPLOYMENT EXPERIENCE

08/2003 - present: Assistant Professor in the Department of Civil and Environmental Engineering (CEE), LSU.
08/2000-08/2001: Visiting Scholar in the CEE Department, LSU
01/1996-08/2000: Associate Professor at Shihezi University, China.
12/1994-12/1995: Visiting Scholar in the Division of Hydrology and Hydraulics, CEMAGREF of Lyon, France.
08/1988-11/1994: Lecturer at Shihezi University, China.

4. SELECTED JOURNAL PUBLICATIONS IN THE LAST FIVE YEARS

(1) Deng, Z.-Q., Bengtsson, L., and Singh, V. P. (2006). "Parameter estimation for fractional dispersion model for rivers." *Environmental Fluid Mechanics*, 6(5), DOI: 10.1007/s10652-006-9004-5, 451-475.

(2) Deng, Z., J. L. M. P. de Lima, M. I. P. de Lima, and Singh, V. P. (2006). "A fractional dispersion model for overland solute transport." *Water Resources Research*, 42(3), W03416, doi:10.1029/2005WR004146.

(3) Deng, Z., de Lima, João L.M.P., and Singh, V. P. (2005). "Transport rate-based model for overland flow and solute transport: Parameter estimation and process simulation." *Journal of Hydrology*, 315(1-4), 220-235.

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(5) Deng, Z.-Q., Singh, V. P., and Bengtsson, L. "Numerical solution of fractional advection-dispersion equation." *Journal of Hydraulic Engineering*, ASCE, 130(5), 422-431, 2004.

(6) Singh, V. P., Yang, C. T., and Deng, Z.-Q. "Downstream hydraulic geometry relations: 1. Theoretical development." Water Resour. Res., 39(12), 1337, 2003.

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(8) Singh, V. P. and Deng, Z.-Q. "Entropy-based parameter estimation for Kappa distribution." Journal of Hydrologic Engineering, ASCE, 8(2), 81-92, 2003.

(9) Deng, Z.-Q., Bengtsson, L., Singh, V. P., and Adrian, D. D. "Longitudinal dispersion coefficient in single-channel streams." *J. Hydraul. Eng.*, ASCE, 128(10), 901-916, 2002.

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(12) Deng, Z.-Q. and Chu, J. D. "Research advances in sediment pollution in water environment." *Advances in Science and Technology of Water Resources*, 22(1), 56-59, 2002.

(13) Deng, Z.-Q., Singh, V. P., and Bengtsson, L., "Longitudinal dispersion coefficient in straight rivers." *Journal of Hydraulic Engineering*, ASCE, 127(11), 919-927, 2001.

(14) Deng, Z.-Q. and Singh, V. P. "Mechanism and conditions for change in channel pattern." *Journal of Hydraulic Research*, IAHR, 37(4), 1999, 465-478.

5. SERVICE

(1) **Paper Reviewer**: Serve as a paper reviewer for the following internationally circulated journals: (i) Geophysical Research Letters, (ii) Water Resources Research, (iii) Hydrological Sciences Journal, (iv) Journal of Hydrology, (v) ASCE Journal of Hydrological Engineering, (vi) ASCE Journal of Environmental Engineering, (vii) Journal of Fluids Engineering, (viii) Journal of Applied Mechanics, (ix) Boundary-Layer Meteorology, (x) Water Resources Management, (xi) International Journal of Ecology & Development, (xii) Environmental Modeling and Assessment.

(2) **Book Reviewer**: Serve as a reviewer for the new textbook: Fluid Mechanics – Fundamentals and Applications, published by the McGraw-Hill Education, 2005.

(3) **Proposal Reviewer:** Serve as a reviewer for funding proposals submitted to the National Science Foundation – Division of Earth Science.

(4) **Scientific/Technical Committee**: Serve on the Scientific/Technical Committee of the International Conference on Environmental Science and Technology (ICEST 05) held in New Orleans, LA, January 23-26, 2005. Baton Rouge/East Baton Rouge Zoning Advisory Committee meetings for discussing proposed changes to the development ordinance including Stormwater Management Plan.

(5) **Session Organizer and Chair:** (i) Serve as the organizer and chair of the Session H50: Modeling Persistence in Solute Transport in Streams and Rivers at the 2004 AGU Fall Meeting held in San Francisco from 13–17 December, 2004; (ii) Serve as the chair of the Session 11-2: Water Quality Modeling at the 05 International Conference on Environmental Science and Technology (EST) in New Orleans, LA on January 23-26, 2005; Serve as the co-chair of Session 6C: Coastal Water Quality – Sediment and Contamination at the International Conference on Challenges in Coastal Hydrology and Water Quality held in Baton Rouge, LA, May 21-24, 2006.

(6) **Invited Speaker:** The PI was invited as one of four speakers to give a talk on Environmental Modeling at the First Joint Meeting of CAIMS and SIAM (2003 Annual Meeting of the Society of Industrial and Applied Mathematics and the 24th Annual Meeting of the Canadian Applied and Industrial Mathematics Society) held in Montreal, Canada, June 15 – 20, 2003. The basic requirements for the invited speakers are "speakers should be selected primarily for their current contributions to the topic area; Speakers should be as representative of researchers in the area as is practical."