Report for 2004LA21B: Quantifying Hydrologic Impacts on Spatio-Temporal Variability of Stream Water Quality in Coastal Louisiana

- Conference Proceedings:
    - 1. Singh, V.P., Flow Routing in Open Channels: Some Recent Advances. Proceedings, River Flow 2004, held June 23-25, 2004, in Naples, Italy, 2004.
    - 2. Singh, V.P., Applications of Fluid Mechanics in Hydrology and Environmental Engineering. Recent Advances in Fluid Mechanics, Proceedings of the 4th International Conference on Fluid Mechanics, held July 20-23, 2004, in Dalian, China, edited by F. Zhuang and J.C. Li, pp. 29-40, 2004.
    - 3. Singh, V.P. and L. Zhang, Stochastic Dependence Modeling in Environmental Hydrology. Proceedings, International Conference on Hydraulic Engineering: Research and Practice, October 26-28, 2004, Indian Institute of Technology, Roorkee, India, pp. 46-59.
    - 4. Singh, V.P. and Zhang, L., Multivariate Stochastic Hydrologic Analysis. Proceedings, International Workshop on Watershed Management in Dry Areas: Challenges and Opportunities, January 4-6, 2005, Djerba, Tunisia, 2005.

Report Follows

Problem and Research Objectives

Louisiana is naturally blessed with an abundance of aquatic systems, including bayous, rivers, lakes, and aquifers, which provide Louisiana's citizens with fishing, hunting, boating, and recreational opportunities and contribute to the state's wealth and economic growth in agriculture and fisheries. While the state has more surface water available for its current use (84%) than any other state in the U.S., rapid urbanization and intensive agricultural and forest practices have increased the potential for reduction in the quality of the state's surface waters. Studies on hypoxia in the northern Gulf of Mexico have shown that an average midsummer hypoxic zone of 8,000-9,000 km^2 during 1985-1992 increased to 16,000-20,700 km^2 during 1993-2001 on the Louisiana/Texas continental shelf (Rabalais & Turner, 2001). This 3-fold increase of hypoxic zone over a relatively short period of time has been attributed to the increase of river-borne nutrients that can exacerbate coastal water eutrophication, favor harmful algal blooms, aggravate oxygen depletion, and alter marine food webs (e.g., Rabalais et al., 2002). The northern Gulf of Mexico is found to be the second largest zone of coastal hypoxia in the world (Rabalasis et al., 2002). This oxygen-depleted phenomenon is attributed to nutrient enrichment in the waters of the northern Gulf of Mexico, and it is especially profound from spring through late summer. Agriculture is considered as a major source of nutrient enrichment from the Mississippi river basin (Burkart and James, 1999; Ferber, 2001; Howarth, 2001; Winstanley, 2001; Snyder, 2001). Atmospheric deposition of nitrogen is seen as another significant source to nitrogen limited estuaries and coastal waters (Paerl et al., 2002).

In January 2001, an action plan with the major goal of reducing nitrogen discharge through Best Management Practices from the inland water into the Gulf was cleared by the state, tribal, and federal agencies and delivered to Congress (US EPA, 2001). The action plan recognizes a 30% nitrogen load reduction that is required to ensure a reduction of 5-year running average of the Gulf hypoxia zone to less than 5,000 km^2 by 2015. While this action plan called for an implementation of BMPs based on voluntary, incentive-based subbasin strategies, several key questions that will influence the success of this plan remained unanswered:

- How effective are the current BMP guidelines in protecting stream water quality from agricultural and forest activities?
- How feasibly and accurately can we provide estimates for subbasin nitrogen discharge based on the current water quality monitoring networks, especially for the areas on the lower coastal plains that have a very flat topography?
- To what extent do hydrological and hydrometeorological conditions, such as rainfall and temperature, affect the variability of coastal inland stream water quality?

These questions were addressed in this project.

A recent study by Thomson et al. (2002) reported that rainfall deficits accumulated since 1998 in Louisiana have culminated in a twofold increase in the mean annual salinity in the Lake Pontchartrain estuary. Using monthly measurements selected from 25 subbasins in Louisiana over a period of 1978–2001, Xu (2003) showed that the nutrient loads, total suspended solids, and dissolved oxygen concentrations all varied widely in the monitored streams and across seasons. However, monthly routine monitoring seems to work well for characterizing base flow conditions, but may not be appropriate to characterize rapidly changing conditions in response to storm events. An understanding of hydrologic influences on water quality indicators at the watershed scale is apparently needed, and such an understanding is especially critical for the coastal regions of Louisiana where storm weather occurs throughout the year.

This proposed project assessed the relationship of stream water quality changes with hydrological and hydrometeorological conditions in Louisiana's six major basins close to the Gulf of Mexico. The project utilized existing long-term water quality data, hydrometeorological data, and stream discharge data maintained by Louisiana Department of Environmental Quality, Southern Regional Climate Center, US Geological Survey, and US Army Corps of Engineers. Information on land use activities and timber harvesting from the watersheds was also gathered to investigate the magnitude of hydrological influences on water quality under various land use activities. Specifically, the project had the following objectives:

1. To investigate the space-time variability of water quality indicators in the major stream/rivers on Louisiana's lower coastal plain;

2. To determine the interrelationships between water quality variability and hydrometeorological regime, such as storm weather conditions, rainfall intensity, and temperature fluctuation;

3. To identify the linkage between water quality variability and hydrological regime, such as base flow, peak flow, and groundwater recharge; and

4. To assess the impacts of land use activities on water quality of the coastal streams, wetlands, and estuaries in Louisiana under various hydrologic conditions.

Methodology

This project utilized existing long-term datasets collected from six coastal basins in Louisiana. Despite a large number of studies conducted on water quality in Louisiana's shore of the Gulf of Mexico during the past 2 to 3 decades, little knowledge has been actually gained about the impacts of hydrological and hydrometeorological variability on the dynamics of water quality indicators, even though it is inarguable about the ultimate role of hydrology on water quality. Many studies have been conducted, and many are being conducted on various aspects ranging from restoration of bottomland forests to microbiology of the coastal estuaries, inland streams and bayous; There exists a large amount of data that has not yet been fully analyzed, whereas USGS and LDEQ continue collecting water quality and streamflow data in Real-Time across the state's rivers and bayous.

To achieve its objectives described above, this project accomplished the following tasks:

1. Gathered existing water quality, stream discharge, and climatic data from all monitoring stations within the Atchafalaya, Barataria, Calcasieu, Mermentau, Terrebonne, and Vermillion-Teche river basins;

2. Identified spatial and temporal characteristics in water quality and hydrological and hydrometeorological conditions in the drainage basins;

3. Assessed the variability of annual nutrient loads and sediment runoff in relation to the variability of hydrological and hydrometeorological conditions; and

4. Utilized GIS and geostatistical techniques to determine land use impacts on water quality changes under hydrometeorological conditions across the landscapes.

Thus, the project involved the development of statistical analyses of hydrometeorologic, hydrologic and water quality data. Specifically, these included (1) analysis of variance, (2) identification of probability distributions, (3) determination of trends, and (4) development of prediction models relating hydrologic and hydrometeorologic conditions to space-time variability of stream water quality under a variety of land use changes. These models determined critical areas of water quality deterioration and the causes-land use and anthropogenic, and industrial. This information will be pivotal to defining BMPs.

Principal Findings and Significance

This research provided critical insights into the interrelationships between hydrological conditions, land use and the water quality of inland streams, wetlands, and coastal estuaries in Louisiana. The knowledge gained from this research contributes to developing site-specific TMDLs and applicable water quality standards, facilitating the assessment of the BMP effectiveness in protecting water quality in Louisiana's coastal watersheds, and helping improve the water quality monitoring strategies, all of which contribute to supporting the state's economic wealth and health of its citizens. Furthermore, the project and its results will be introduced in several Hydrology and Water Quality courses at LSU, immediately benefiting both graduate and undergraduate students in learning how science applications solve real world problems.

References

Alexander, R.B., R.A. Smith and G.E. Schwarz, 2000. Effect of stream channel size on the Delivery of nitrogen to the Gulf of Mexico. Nature 403 (6771): 758-761.

Burkart, M.R. and D.E. James, 1999. Agricultural-nitrogen contributions to hypoxia in the Gulf of Mexico. Journal of Environmental Quality 28 (3): 850-859.

Ferber, D., 2001. Hypoxia, fertilizer, and the Gulf of Mexico - Response. Science 292 (5521): 1486-1486.

Howarth, R.W., 2001. Hypoxia, fertilizer, and the Gulf of Mexico. Science 292 (5521): 1485-1486.

Paerl, H.W., R.L. Dennis and D.R. Whitall, 2002. Atmospheric deposition of nitrogen: Implications for nutrient over-enrichment of coastal waters. Estuaries 25 (4B): 677-693.

Rabalais, N.N. and R.E. Turner (eds.), 2001. Coastal Hypoxia: Consequences for Living Resources and Ecosystems. Coastal and Estuarine Studies 58, American Geophysical Union, Washington DC.

Rabalais, N.N., R.E. Turner and D. Scavia, 2002. Beyond science into policy: Gulf of Mexico hypoxia and the Mississippi river. BioScience 52: 129-142.

Rabalais, N.N., R.E. Turner and W.J. Wiseman, 2002. Gulf of Mexico hypoxia, aka "The dead zone". Annual Review of Ecology and Systematics 33: 235-263.

Snyder, C.S., 2001. Hypoxia, fertilizer, and the Gulf of Mexico. Science 292 (5521): 1485-1485.

Thomson, D.M., G.P. Shaffer, J.A. McCorquodale, 2001. A potential interaction between sea-level rise and global warming: implications for coastal stability on the Mississippi River Deltaic Plain. Global and Planetary Change 32 (1): 49-59.

US EPA, 2001. Action Plan to Reduce the Size of the “Dead Zone” in the Gulf of Mexico. USEPA, EPA841-F-01-001, Washington DC.

USEPA, 2001. Better Assessment Science Integrating Point and Nonpoint Sources. BASINS Version 3.0 (EPA-823-B-01-001). Washington DC.

Winstanley, D., 2001. Hypoxia, fertilizer, and the Gulf of Mexico. Science 292 (5521): 1486-1486.

Xu, Y.J., 2003. Spatiotemporal Assessment of Long-Term Stream Water Chemistry across Louisiana. *In Proceedings* of The 1st Interagency Conference on Research in the Watersheds, Benson, AZ, October 28-30 2003.