Water Quality Monitoring and Modeling for Pollution Assessment and Control in Estuarine Waters: An Overview

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Abstract

Under the provisions of the Clean Water Act, water quality modeling plays a central role in development of control strategies for both point and nonpoint pollutants. These pollutants include oxygen demanding substances, toxic chemicals, whole effluent toxicity, nutrients, and pathogens or surrogate organisms. The Act broadly defines procedures for the determination of the "Total Maximum Daily Load" (TMDL) of pollutants and the allocation of the load between the various natural, nonpoint, and point sources. Federal guidance and Louisiana policies further specify procedures to be followed in water quality management.

Water quality models are utilized in the assessment of pollutant sources, pollutant transport, and environmental transformation, as well as in the determination of appropriate load limitations and management practices. Many water bodies in Louisiana have been modeled for these purposes, including the Calcasieu Estuary, the Vermilion River, and Bayou Grand Caillou. Additionally, at the present time, several areas are in some stage of field study or model development.

Model selection depends on a variety of factors. At times, steady state models are adequate for the purpose of TMDL development. However, in complex estuarine environments, a dynamic model may most often be required. Special studies are generally required to collect the data necessary to calibrate these models. Studies performed in support of development of these water quality models are termed intensive, or synoptic, surveys. Under estuarine conditions, certain aspects of the design of these studies must be modified and often may gain additional significance. For example, use of a tracer dye can facilitate the assessment of estuarine transport and pollutant transformation. The application of the emerging technology of satellite global positioning systems (GPS) also has been found to provide a needed utility in estuarine locales. For model development, the utilization of a geographic information system (GIS) for site mapping, database support, and spatial segmentation has provided increased efficiency and flexibility.

Efforts to develop water quality models, TMDLs, and wasteload allocations for Louisiana estuaries continue. These efforts will not only assist the State in point and nonpoint source pollutant management, but will also provide a basis for better understanding the special characteristics of Louisiana's estuarine water resources.

Introduction

The Louisiana Department of Environmental Quality (LDEQ) has responsibility for the development of the Louisiana Water Quality Standards and the development of a Water Quality Management Plan, which provides for the attainment of these standards in the State's surface waters. Several Louisiana universities have provided technical assistance to the LDEQ in support of the development of this plan. Among these, the University of Southwestern Louisiana's Center for Louisiana Inland Water Studies (CLIWS) has provided part of the technical assistance, especially in the area of water quality modeling. This paper summarizes the water quality modeling procedures and experience of the CLIWS and the LDEQ, with an emphasis on the activities in the Barataria and Terrebonne basins. Additionally, data needs within these basins are discussed.

Pollutant Modeling And Load Allocation

The Clean Water Act (CWA) and regulations which implemented the provisions of the Act place specific requirements on state and federal regulators (USEPA 1985). The State of Louisiana and Region VI of the USEPA have been collaborating for several years to develop a joint memorandum of understanding (MOU) concerning the technical procedures to be applied in implementing procedures related to water quality modeling and management. A draft revision of the MOU (Waldon 1991a) is currently under review by the USEPA Region VI. This section summarizes some of the definitions and provisions of the CWA and the draft MOU.

A load is the amount of matter or thermal energy that is introduced into a receiving water. A load may be caused by man (a pollutant load) or by nature (a natural background load). For oxygen demanding material, load may be expressed separately for separate components (e.g. CBOD, NH_3-N) or may be expressed as a total oxygen demand. Numerical criteria for maximum and/or minimum water quality parameters have been defined by the LDEQ through the publication of Water Quality Standards (LDEQ 1989). The load capacity of a stream is the greatest amount of loading that a water can receive without violating these criteria. If seasonality and flow are not considered in the determination of the load capacity, annual critical conditions are used as a basis. Load capacity may also be determined on a seasonal or flow and temperature variable basis.

The load allocation (LA) is the portion of a receiving water's load capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading which may range from reasonably accurate estimates to gross allotments, depending on availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be separately estimated. For calibrated modeling studies, the LA may often be estimated from the headwater flow, incremental flow loads, and nonpoint loads required for calibration.

The total maximum daily load (TMDL) establishes the allowable loadings or other quantifiable parameters for a waterbody and thereby provides the basis for water-quality based controls. The TMDL for a substance is the sum of the individual waste load allocations for point sources, safety, and reserve and the LAs for nonpoint sources and for natural background. The allocable TMDL is the loading capacity minus the LAs for a waterbody.

A wasteload allocation (WLA) is the portion of a receiving stream's loading capacity that is allocated to one of its existing or future point sources of pollution. The WLA constitutes a type of water-quality-based effluent limitation. Under the MOU, every waterbody for which one or more WLAs are developed also has a designated WLA for future growth and safety. Typically, the LDEQ reserves twenty percent (20%) of the allocable TMDL for this WLA. This allocation for growth and safety is also referred to in EPA guidance as a margin of safety (MOS). The relationship between these TMDL components is diagrammed in Figure 1.

Nonpoint source tradeoffs are provided for in the allocation process described here. If best management practices (BMPs) or other nonpoint source pollution controls make more stringent LAs practicable, then wasteload allocations can be less stringent. Note, however, that because of the 20% reserve WLA, a reduction in the LA of 1.25 pounds would be required to increase the point source WLAs to point sources by 1 pound.

Allocation of loads between the various point source dischargers is a difficult management decision. Within the constraints of the TMDL requirements, the selection of allocation methodology to be applied is a responsibility of the State.

Various load allocation schemes have been proposed, and each may be most appropriate in particular circumstances. A wasteload allocation strategy should

- o be protective of the environment and reduce the risk of exceedance of water quality standards,
- o be equitable to all regulated parties, and
- o provide a reasonable distribution of costs of load reductions, and attempt to minimize overall costs of meeting TMDL requirements.

If all dischargers are of similar size, it will usually be most equitable to set equal concentration limits for each discharger. Where both small and large dischargers are involved, the Louisiana "Statewide Sanitary Effluent Limitations Policy" (LDEQ not dated) should be followed, so far as possible, in setting limitations on smaller sanitary dischargers.

If dischargers are not similar, for example, if industries and municipalities are involved, it may be more appropriate to require an equal percent removal, or equal reductions from technology-based limits (e.g., secondary or BAT guidelines), rather than simply requiring equal concentration limits. Note, however, that for some industries, such as food processors, LDEQ has determined that the character of the waste and waste treatment methods are sufficiently similar to sanitary waste to be included in an overall allocation without consideration of wastewater source or specific industry category.

If multiple dischargers are owned by a single entity, a city for example, it may be appropriate to consult with the permittee to determine the most cost-effective allocation. This consultation is at the discretion of LDEQ. If such an allocation strategy is pursued, contact with the regulated municipalities or industries should be initiated as early as practical during the TMDL development process, and final TMDL determination should not be delayed because of lack or inadequacy of response from the regulated dischargers.

In cases involving nonpoint sources, the tradeoff between point and nonpoint load must be considered. Because of the uncertainty which is usually associated with nonpoint source loading estimation and BMP reductions, a phased TMDL is likely to be required when such trades are proposed.

When developed according to a phased approach, the phased TMDL can be used to establish load reductions where there is impairment due to nonpoint sources or where there is lack of data or adequate modeling. Lack of information about certain types of pollution problems (for example, those associated with nonpoint sources or with certain toxic pollutants) may not be used as a reason for delay of implementation of water quality-based controls (USEPA 1991).

The phased TMDL will normally include a monitoring plan. This plan should include a description and assessment of existing data and the design of additional monitoring or special studies which will be required. The objectives of the monitoring plan should include

- o assessment of water quality standards attainment,
- o verification of pollutant source allocations,
- o model calibration or modification,
- o measurement of stream discharge, dilution, and development of mass balances, and
- o evaluation of effectiveness of point and nonpoint source controls.

The monitoring plan must include a provision for appropriate QA/QC. Data from discharge monitoring reports (DMRs) and data collected by other agencies and organizations should also be considered. A proposed schedule for data collection and evaluation must also be included in the plan.

TMDLs and WLAs for toxic substances and toxicity may be developed using one or more of three technical approaches:

- o Chemical specific,
- o Whole effluent toxicity, and
- o Biocriteria/bioassessment.

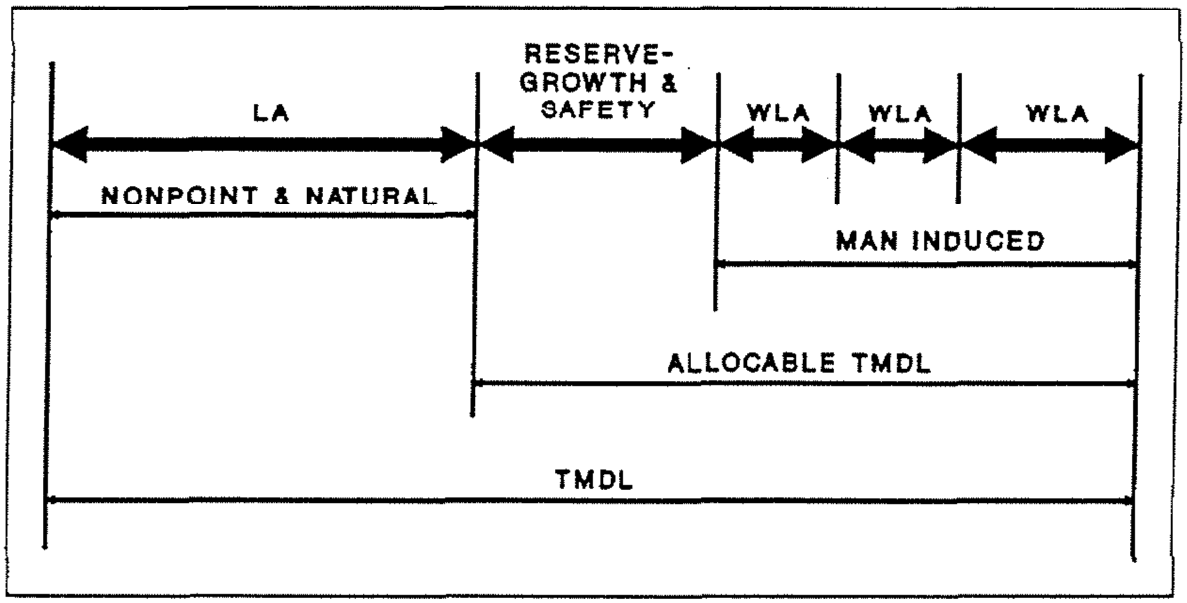
In each situation, selection of the approach for protecting receiving water quality is dependent on the specific environmental conditions and regulatory resources available. The chemical specific approach is likely to be most commonly applied. Whole effluent toxicity has recently become a common test used in NPDES permitting and is therefore likely to be more commonly utilized in toxic TMDLs. Application of the biocriteria/bioassessment approach is more difficult and currently less practical because methodologies are not fully developed and resources are not as readily available.

Special attention is required to assure that discharges of persistent and/or highly bioaccumulative toxic pollutants do not result in a loss of use or standards exceedance. The numerical criteria for these substances have been selected to be protective of water quality for typical point source discharges. Additional analysis and modeling may be required in cases of diffuse sources or multiple discharges to a waterbody. LDEQ is currently studying the development of additional criteria for application to sediment concentrations and fish tissue levels. Until such criteria have been developed, TMDLs for persistent and bioaccumulative substances must be based on a case-by-case determination of appropriate sediment or fish tissue concentrations.

Although chemical contaminant based loads and load reductions form the major thrust of all past, as well as most future, TMDLs, the State and EPA recognize that in some situations water quality standards can only be attained if non-chemical factors, such as hydrology, channel morphology, and habitat, are addressed. In such cases it is appropriate to use the TMDL process to establish control measures for quantifiable non-chemical parameters that are preventing the attainment of water quality standards. Control measures in this case would be developed and implemented to meet a TMDL that addresses these parameters in a manner similar to chemical loads (USEPA 1991). The phased TMDL approach may be particularly appropriate for development of non-chemical factor TMDL requirements.

Figure 1

Components of Total Maximum Daily Load (from Waldon, 1991a).



Assessment Of Point/Nonpoint Source Pollution Impacts

In the Barataria and Terrebonne basins, both point and nonpoint pollution have significant impacts on water quality. These basins have not been extensively studied or modeled. However, experience in other basins and watersheds suggest that while point sources are likely to have substantial impact in the vicinity of the point source discharge locations, total pollutant loads from nonpoint sources are likely to account for the larger part of the total pollutant load to the basin. The Barataria and Terrebonne basins are impacted by nonpoint source pollution from urban drainage, sugar cane fields, and pasture lands. Significant loads of organic materials are also likely to originate from natural mash grass production. Point sources include municipal treatment plants, small sanitary treatment "package" plants, commercial and recreational vessel discharges, oil and gas related discharges, seafood processors, and other industrial discharges.

At this time, the most appropriate analogous point/nonpoint source pollutant assessment and modeling study which has been completed in Louisiana is the phased TMDL developed for Crowley discharging into Bayou Plaquemine Brule in the Mermentau Basin (Waldon 1990). Under low flow conditions, Bayou Plaquemine Brule is a slightly tidal waterway with little or no net advective flow. Land use in this drainage basin is also more intensely agricultural than most other areas of Louisiana. In the eighteen mile bayou segment considered in the Crowley study, it was estimated that nonpoint source loading is 3,690 lb/day of ultimate CBOD, and 4014 lb/day of ultimate NBOD. This is a total load of 7704 lb/day. These estimates are derived from a single intensive water quality survey and were developed through model calibration. In comparison, the ultimate CBOD TMDL allocated to the Crowley treatment plant (including the 20% safety factor which is not allocated) is 209 and 417 lb/day under the summer and winter limitations, respectively. The corresponding NBOD loading is 359 and 898 lb/day. Total ultimate point source contribution is therefore 568 and 1315 lb/day for summer and winter limitations, respectively. Although agricultural land use may not be as intense as that found in the Mermentau Basin, it would, nevertheless, be anticipated that a large part of the organic loading in the Barataria-Terrebonne drainage basin is also associated with nonpoint pollutant sources.

Model Selection

Model selection must be primarily based on the project goals and objectives, and on the constraints of the user. As an aid to model selection, models can be categorized according to various characteristics. Four important categories (USEPA 1991) should be considered in model selection:

- Temporal characteristics,
- Spatial characteristics,
- Specific constituents and processes simulated, and
- Transport processes.

The selection of a water quality model depends on a number of factors. A model should be selected based on its adequacy for the intended use, for the specific waterbody hydrology and dischargers, and for the critical conditions applied to that waterbody. Typical TMDL/WLA studies which primarily consider point source impacts in non-tidal streams may require little justification for model selection. However, in estuarine situations more extensive justification of model selection based on study site characteristics, model characteristics, and study objectives is required.

In general, the least sophisticated model capable of addressing all relevant receiving stream characteristics should be selected. Less sophisticated models usually require fewer resources and less data and, in some cases, may produce more robust and defensible results.

When available and appropriate, models supported by the USEPA Center for Exposure Assessment Modeling (CEAM) are preferred over other models of similar applicability. These models include:

- o *QUAL2E* This model evolved from older versions of the U.S. EPA QUAL and QUAL-II models. QUAL2E is distributed in an executable form for the IBM-PC, as well as in source code. QUAL2E is a steady state one-dimensional model which allows for complex branching. The QUAL2E input is relatively complex and is not easily modified. The Program is written in FORTRAN and is available on the LDEQ VAX computer, as well as in executable PC format.

- o *WASP4* This is a dynamic node and channel model. WASP4 is capable of simulating stratification, sedimentation and sediment processes, and complex flows. Although the user may develop or customize the dynamic subroutine (WASPB), two versions are distributed and supported. EUTRO4 is suitable for simulating complex transport and transformation of oxygen demanding substances, nutrients, algae, and pathogenic bacteria. TOXI4 is suitable for modeling the transport and transformation of toxic pollutants. WASP4 is also distributed with a compatible hydrodynamic simulation program, DYNHYD.

- o *CORMIX* This family of models is suitable for modeling the near-field zone of initial dilution (ZID) and mixing zone (MZ) dilution for point source dischargers. CORMIX is capable of simulating both positively and negatively buoyant discharge plumes and may be applicable to the analysis of some oilfield discharges.

Use of a limited number of models greatly increases the efficiency of model application and review. However, the models listed above may not be adequate or appropriate in many situations. Selection of additional models will depend on the system to be simulated and on computer hardware and software availability. However, in order to facilitate public and professional review, as well as future applications and extensions, public domain models with extensive documentation and support should be given preference in model selection for management planning applications.

Model Implementation

Traditionally, water quality modeling for pollution management and TMDL development uses a defined "critical condition." The critical condition definition can have a significant influence on model selection. Critical conditions are also referred to in EPA guidance as design conditions but are generally referred to here as critical conditions to avoid confusion with treatment facility design flows. Critical conditions are the reasonable "worst case" conditions for the waterbody. The State Water Quality Standards and MOU provide definitions which are typically used for modeling environmental impacts under critical conditions. Often, point sources with continuous discharges present the greatest impact on the waterbody during low-flow (drought) and high-temperature conditions. Under some conditions, such as flow-related discharges or waterbodies heavily impacted by nonpoint source pollutants, more appropriate critical conditions may be technically justified.

There are several types of water bodies for which dissolved oxygen water quality models are not generally reliable predictive tools. Swamps, wetlands, and some lakes fall into this category. For these waterbodies, alternative methods for determining TMDLs and WLAs may be required.

Dissolved oxygen, nutrient enrichment and eutrophication of lakes present particular difficulties in model analysis. Except in rare circumstances, large computerized, ecological models of lakes are not recommended for nutrient TMDLs. Large data requirements, lack of scientific consensus, as well as professional resource requirements make these models impractical for most applications. From the standpoint of dissolved oxygen, if there are data which show that under current conditions water quality standards are being met and there are no nuisance problems associated with present discharges, then current effluent limitations and management practices should be adequate. For some impoundments and "stretch" lakes, standard stream models may provide an adequate and appropriate management model. In this case dispersion and photosynthesis should be taken into account.

For lake or estuary nutrient loading, nutrient budget models may be used to determine if nutrient reductions should be considered and what degree of reduction is required. If nutrient loading is determined to be a problem, reduction of point source loading should be considered. The relative magnitude of nonpoint sources and their abatement possibilities should also be considered. Relocation of discharges or diffusers may be recommended to eliminate some localized or nuisance problems in lakes.

Swamps and wetlands present another situation in which presently available, complex, computer models may not be appropriate for water quality management decisions. In some situations, uses may be enhanced through such discharges, while in other cases uses may be degraded or completely lost because of wastewater or nonpoint pollutant discharges to these water bodies. For current dischargers to swamps, wetlands, etc., the current impact can be evaluated in terms of its impact on uses and the physical, chemical, and biological impacts. A comparison should be made between upstream and downstream sites. For those waterbodies not sufficiently defined by a channel, sites near the discharge may be compared to control or reference sites which are not as heavily impacted. Where the discharger is having a detrimental impact in terms of water quality standards and/or reduced quality and diversity of species, reduced effluent limitations should be imposed, or an alternative treatment system and effluent discharge system may be considered. Swamps and wetlands may be able to receive and assimilate the wastewater with proper diffusion of the effluent.

If upstream or control site data for swamps and wetlands show contravention of standards, then the standards should also be reviewed. To prevent delays, the TMDL/WLA should concurrently be developed, and if necessary, the phased TMDL procedures applied. Comparisons to existing discharges can be utilized to estimate the impact of a proposed discharge.

Modeling of bacterial contamination and development of model-based bacterial management strategies are not as well understood as modeling and management of oxygen demanding pollutants. At present, it is simply assumed that bacterial limitations or disinfection is necessary to protect human health uses for all significant sanitary dischargers. Future experience, modeling developments, and EPA guidance may demonstrate the needs for additional routine controls and TMDL procedures.

Model Calibration - Data Needs

Water quality modeling is central to the development of water quality management plans, TMDLs, and WLAs. Data requirements for model development are dependent on specific environmental and pollutant loading conditions, on the level of model accuracy, and on uncertainty of credibility required as a basis for management decision making. In all cases the primary consideration which should be given in defining data requirements is that the resultant model must provide a reasonable scientific basis and allow for a confident and defensible water quality decision.

Four levels of water quality analysis may be defined: (1) mass balance (or budget) and dilution analysis, (2) uncalibrated modeling, (3) calibrated modeling, and (4) calibrated and verified modeling. These four levels of model analysis are listed in order of increasing data requirements.

A simple mass balance and dilution analysis may, in some situations, adequately support management decisions. Extremely conservative assumptions may be applied to provide estimates of limits of pollutant or other levels which might result under specific management scenarios. In this case very limited data may be adequate for supporting management decisions.

Uncalibrated models use more realistic transport and transformation relationships but are based on little or no site specific data. Uncalibrated model inputs should typically be based upon field observations of stream width, depth, and velocity at or near low flow conditions. However, no water quality data are required, and model kinetics are estimated.

Calibrated models analyses are developed using model hydraulic and kinetic rates which are estimated from data collected during one or more field studies. A model is said to be calibrated if these hydraulic and kinetic rates cause the model to adequately reproduce the data. Development of a calibrated model requires extensive measurement of water quality, stream geometry and hydrology on one occasion. Procedures for performing such a study or intensive survey may be found in the LDEQ QA/QC document (LDEQ 1991).

Calibrated and verified models utilize data from two separate water quality surveys. One survey is used to calibrate the model as described above. The calibrated model is adjusted to account for changes in stream loads and temperature during the second survey and is then used to predict water quality observations during the second survey. Any additional model parameters which are altered during verification from their calibration settings must be documented and a detailed rationale provided for the appropriateness of such a variation. The model is considered verified when it adequately reproduces this second set of water quality data. Verified models provide a higher level of credibility for other model projections made in support of management and planning.

Special Aspects Of Estuarine Intensive Studies

There are many special aspects which need to be considered in development of research and management planning in Louisiana estuaries, and particularly in the Barataria and Terrebonne estuaries. These special considerations arise from the unusual hydrological conditions, logistical requirements, and ecological complexities which are present.

Low velocities and highly transient flow conditions make estimation of flow within Louisiana estuaries more difficult. In many coastal Louisiana streams traditional current velocity meters have been found to have very limited value in projecting net advective water movement. Dye tracers have been satisfactorily utilized to measure water movements in low-velocity water bodies (e.g., Everett 1991). The use of dye tracers not only can provide an integrated determination of water movement but also provides a basis for estimating tidally-influenced dispersion (Smart and Laidlaw 1977). An understanding of these processes is a fundamental part of any water quality modeling effort. Such modeling can also support contaminant spill tracking, projection, and investigation.

Nine dye studies have been conducted on the lower Mississippi River by the USGS and LDEQ. These studies have provided the basis for a time-of-travel computer model for the lower Mississippi River (Waldon 1991b, 1991c). An example of model tracking of a carbon tetrachloride spill in the Mississippi River at Port Allen, Louisiana, is shown in Figure 2. This Mississippi River time-of-travel information may be of value in control of diversion structures along the River. Similar studies within the Barataria-Terrebonne basins could provide similar capabilities for estimation of transport and dispersion.

Low velocities and transient flows also profoundly affect the design of water quality intensive surveys which support water quality model development. One classification of these intensive surveys is based on the method of sampling site selection. Surveys termed as Eulerian studies sample fixed locations at predetermined times. Alternatively, in surveys termed Lagrangian studies, sampling is based on observed or calculated water movement. Typically, in a Lagrangian survey, a dye tracer is used to "tag" a volume of water. Samples are then taken at the location of the dye peak at preselected time intervals. Lagrangian water quality studies appear to be the most appropriate design for the estuarine environment of the Barataria and Terrebonne basins.

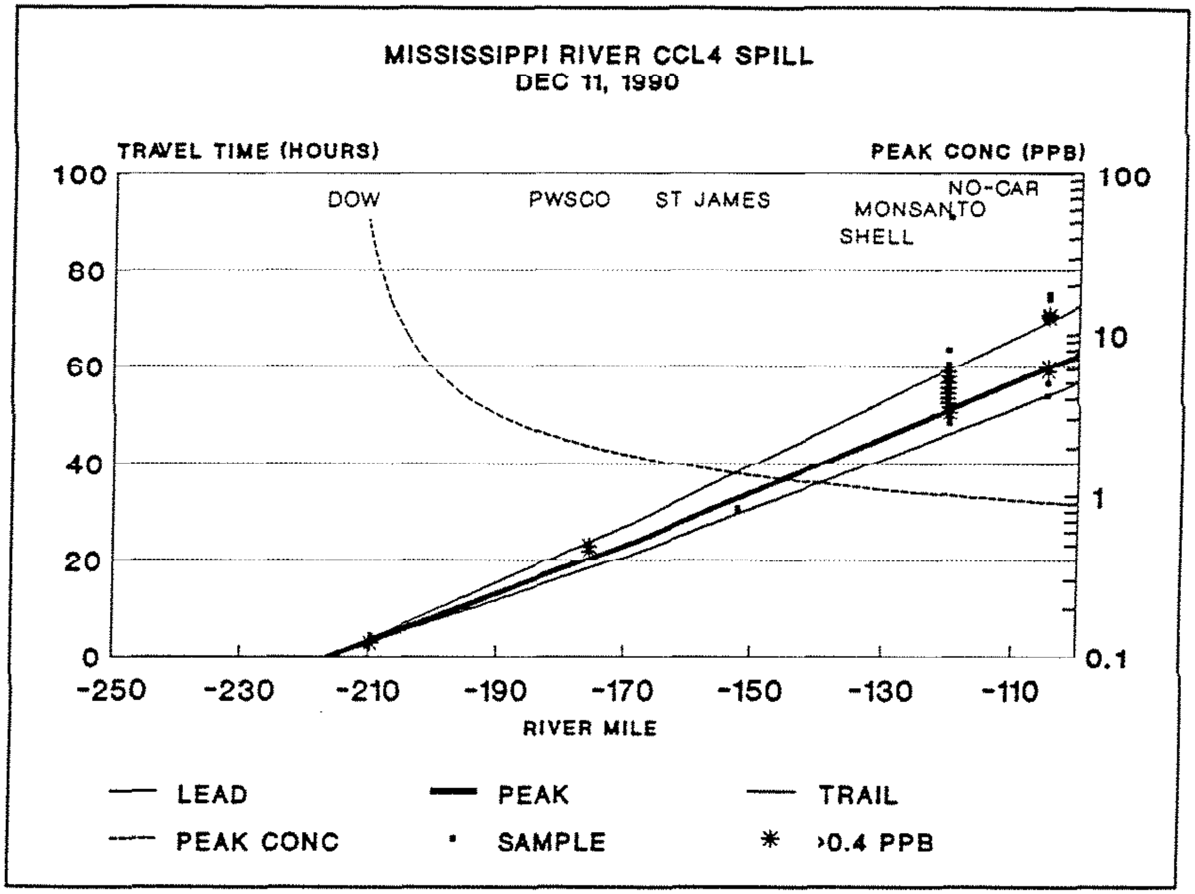
Reaeration rate and volatilization rates for organic contaminants are another class of processes which are less well understood in slow moving and tidal waterbodies. In moving streams empirical formulas are available which provide estimates of these rates. Relatively little research into these processes has been done in slow moving and tidal streams. In such streams, measurement of reaeration and volatilization may be performed through the use of propane as a volatile tracer, and dye as a pseudo-conservative tracer.

The estimation of the reaeration rate in a water body is critical in development of dissolved oxygen concentration (DO) models, as well as in modeling volatile contaminants. Although numerous studies have been performed measuring reaeration rate, relatively few of these studies have been performed in tidal or very slow moving streams. Indeed, Bowie et al. (1985) state that there has been a "lack of estuarine reaeration research." This lack of research is particularly important because pollution problems are often most extreme near the mouths of streams and rivers. Tidal streams and estuaries provide recreation, transportation, and a habitat for aquatic biota and naturally attract urban and industrial development.

Propane studies for reaeration measurement are a significant advance over indirect methods and empirical formulas (Rathbun et al. 1975; Kilpatrick et al. 1987). Propane methods typically follow an approach in which the tracer and dye are injected into a flowing stream, and the respective peaks are measured at sites downstream. Gulf Coast streams are often influenced by low energy tides, and some have been termed "stretch lakes" due to their sluggish, depositional environments. Measurement of reaeration in these environments by the traditional tracer methods is impractical because there is little or no net water movement (Waldon et al. 1991).

Figure 2

Time-of-travel model tracking of Mississippi River spill (from Bostock and Waldon, 1991).



Determining the location of sampling sites can be particularly difficult in coastal Louisiana because of the lack of landmarks and the rapid changes in shoreline configurations. The global positioning system (GPS) provides a solution to the problem of determining study site locations (Hurn 1989). The GPS is based on a constellation of 21 satellites orbiting at high altitude. The satellites avoid the problems associated with land based systems like LORAN and may be used in any location. Presently, the complete constellation of satellites has not been implemented, and therefore during some periods there are not a sufficient number of satellites available for positioning. This problem, however, should be corrected when the final satellites are launched.

Geographic information systems (GIS) applications are another emerging technology which can provide added efficiency and productivity in estuarine research. GIS integrates digital mapping with computer databases and graphical user interfaces. An example of a digital map which was used in the development of an uncalibrated model of Bayou Grand Caillou (Waldon 1991d) is shown in Figure 3. In this figure, Bayou Grand Caillou and the Houma Navigation Canal have been marked with "rivermile" notations and one tenth mile tick marks. These tick marks facilitate model implementation by identifying locations of dischargers, hydrological features, and sampling sites. Other GIS-related applications which have recently been completed include a project to assist in the protection of water supplies on the Mississippi River (Bostock et al. 1991), a GIS of produced water dischargers (Rogers and Hebel 1991), and a proposed Louisiana ecoregion map (Rogers et al. 1991). A GIS project which is currently in progress is a statewide discharger location database.

Conclusions - Special Needs In The Barataria-Terrebonne Basin

Models can be of value as a basis for management decisions for control of point source and nonpoint source pollution. Additionally, models can provide an improved understanding of the relative importance of the various mechanisms interacting within and maintaining the aquatic environment.

Within the Barataria-Terrebonne basins, there are specific data needs. An inventory of both point source and nonpoint sources within the basins needs to be completed. Major point sources and representative minor point sources should be assessed in terms of flow and load. Seasonal aspects of loading should be addressed where appropriate. Conventional oxygen-demanding pollutants, nutrients, bacteria, and toxics should be assessed. This assessment should also include an estimate of the loads entering these basins from other basins (Atchafalaya and Mississippi) and from the watersheds within the basins which are above the estuaries. This load assessment should be integrated into a GIS map and database covering the area of interest.

Additional water quality and hydrological surveys should also be performed, where required, to form a basis for water quality modeling. Determination of appropriate water quality criteria should also be addressed. These studies can provide a sound scientific basis for development of a part of the *Comprehensive Conservation and Management Plan* proposed for the Barataria-Terrebonne basins.

Figure 3

Section of GIS map, near Houma, Louisiana (from Waldon, 1991d).

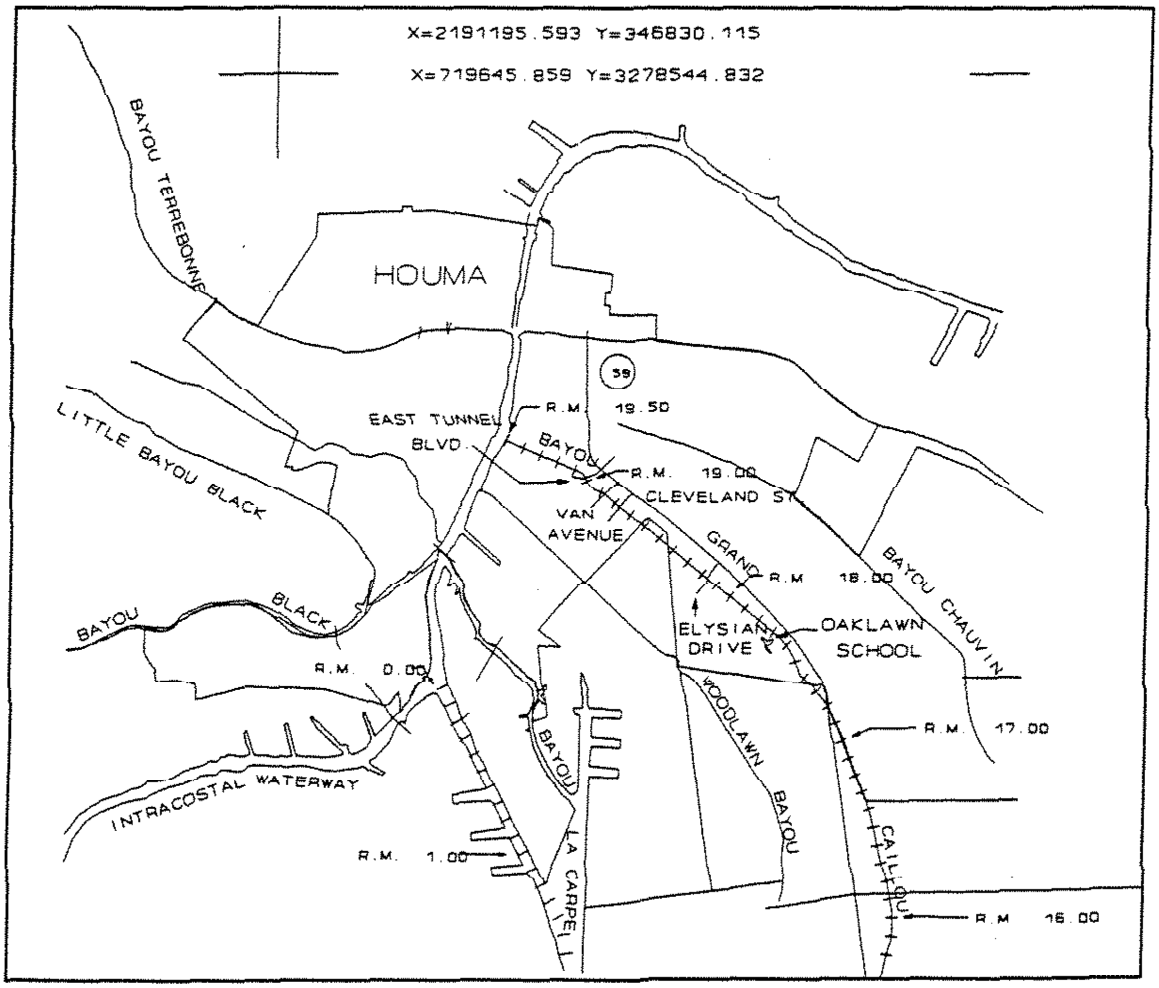


Table 1

Barataria-Terrebonne National Estuary Program Research Needs in Support of Development of a COMPREHENSIVE CONSERVATION AND MANAGEMENT PLAN
(M. Waldon - December 1991)

* Point source inventory and assessment - An inventory of all pollutant point sources within the basins needs to be completed. Major point sources, and representative minor point sources, should be assessed in terms of flow and load. Seasonal aspects of oxygen-demanding pollutants, nutrients, bacteria, and toxics should be assessed.

* Nonpoint source pollution assessment - An assessment of loading from nonpoint sources should be completed. This should also include assessment of water entering these basins from other basins (Atchafalaya and Mississippi).

* GIS map and database - A GIS map and database need to be developed, in association with the point source and nonpoint source assessments. This GIS should include land use, census information, sewerage district service areas, and other relevant information.

* Water quality and hydrology studies of selected subsegments - Representative areas should be targeted for intensive studies.

* Water quality modeling - This modeling should be utilized to determine the impacts of current pollutant sources, and the anticipated water quality improvements for specific management practices and source controls which may be proposed in the *Management Plan*. Oxygen, nutrients, algae, bacteria, and specific toxic substances could be considered.

* Use attainability analysis studies - Development of UAA studies are an essential element in the determination of appropriate water quality standards. Appropriate water quality standards play a central role in development of water quality management plans under the Clean Water Act.

* Dispersion studies - Mixing of effluents in coastal waters is not well understood. This is particularly true of oilfield brine discharges in coastal areas. The applicability of state-of-the-art computer mixing models to our Louisiana coastal environment can also be evaluated in this study.

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