Gulf of Mexico Alliance

Nutrient Criteria Research Framework

Draft for Comments

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For more information: http://www2.nos.noaa.gov/gomex/nutrients/welcome.html

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DRAFT

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EXECUTIVE SUMMARY

A common problem in the Gulf of Mexico region is excessive nutrients in coastal waters. The States participating in the Gulf of Mexico Alliance (GOMA) are each charged by the U.S. Environmental Protection Agency with establishing nutrient criteria for coastal waters and estuaries to address this problem. The GOMA is developing a Nutrients Criteria Research Framework to provide states with the information needed to understand the transport, fate, and effects of nutrients and inform the process of developing nutrient criteria. The following goals guided the development of the monitoring framework:

- Standardize a regional approach that can be used at locations around the Gulf of Mexico, in a range of conditions and types of coastal waters. This design should be able to accommodate modifications that address local conditions and local program needs;
- Provide improved understanding and identify the core monitoring needed to characterize and understand nutrient sources, fate, transport, and effects;
- Provide sufficient understanding of the relationships between nutrients, water quality, physical processes, and biological communities to develop protective nutrient criteria for coastal ecosystems;
- Optimize the study design to the minimum necessary to determine nutrient effects and guide establishing appropriate long-term monitoring sites, parameters, and methods.

The Nutrients Criteria Research Framework addresses four major ecosystem compartments that form sources or sinks of the nutrients and the fluxes of nutrients between them. These compartments are: atmosphere, biomass, water column, and sediment. Nutrients will be assessed through monitoring and modeling techniques to assess nutrient inputs, loading, transport, fate, and biological responses. In addition, the framework will incorporate monitoring data needed to setup, calibrate, and validate models and remotely sensed data that will be used to inform the monitoring approach, optimize the sampling design, and quantify the relationships between nutrients, water quality, physical processes, and biological responses.

Meaningful regulation of nutrients requires an understanding of the effects of different nutrient concentrations and loadings on biological communities in the waters being managed. Identifying key ecological endpoints allows assessment efforts to be focused on a subset of the community, thereby minimizing the cost of collecting information while being protective of the full community. Ecological endpoints that are tightly coupled with ecosystem responses to nutrients are identified for the Nutrients Criteria Research Framework.

A general sampling design is provided to assess nutrient related water quality conditions, trends, and effects on biota in Gulf of Mexico coastal waters, estuaries, and their tributaries. Resource components included in the design are estuaries, near shore marine waters (out to about 3 nautical miles), and adjacent offshore waters beyond the influence of coastal input where background conditions exist (out to approximately the 30-m isobath). The design also monitors rivers that flow directly into estuaries, coastal marine waters, and rivers draining upland watersheds that are tributary to these waters, because fluxes of nutrients from these rivers are typically the dominant source of nutrients to coastal waters. Atmospheric deposition near the coasts will be included as will ground water in those areas where aquifers discharge directly to

coastal waters. Data from the proposed design will make a significant contribution to local evaluation of the effectiveness of management actions, identification of problems, and other objectives. In combination with studies in other locations around the Gulf that follow the same core design, data will also provide information toward a Gulf-wide evaluation of the minimum necessary monitoring essential for developing coastal nutrient criteria.

A Quality Assurance Project Plan (QAPP) will be developed to document planning, implementation, and assessment procedures and how specific quality assurance and quality control activities will be applied during a particular project. The QAPP will be composed of standardized, recognizable elements covering the entire project from planning, through implementation, to assessment.

I. INTRODUCTION

States in the Gulf of Mexico region have identified excess nutrients, from manmade sources such as wastewater treatment plants, urban and agricultural runoff, and atmospheric deposition, as one of the primary problems facing Gulf estuaries and open waters. Excessive nutrients in coastal waters can result in eutrophication, a progression of symptoms, beginning with excessive growth of phytoplankton and macroalgae to the point where grazers cannot control growth. In addition, changes in ratios of nutrients may also affect which species dominate, potentially leading to nuisance/toxic algal blooms. Blooms may last for an extended time period and lead to low dissolved oxygen and loss of submerged aquatic vegetation. Once water column nutrients have been depleted and blooms die, the bacteria decomposing the algae then consume oxygen, leading to hypoxia and anoxia.

The National Estuarine Eutrophication Assessment Update found that Gulf estuaries are impacted by excess nutrients from coastal watersheds (Bricker et al. 2007). The most commonly noted use impairments to Gulf estuaries were to shellfish, fishing, swimming, and aesthetics. The 2007 update also found that most Gulf estuaries have either a moderate or high susceptibility to nutrient loading due to shallow depths and small tidal ranges, leading to low dilution and flushing rates (Bricker et al. 2007).

Hypoxic (low dissolved oxygen) and anoxic (no oxygen) waters have existed through geologic time, but the frequency of their occurrence in shallow coastal and estuarine areas is increasing, largely attributed to anthropogenic nutrient pollution. The largest zone of oxygen-depleted coastal waters in the United States, and the second largest for the world's coastal oceans, is in the northern Gulf of Mexico on the Texas-Louisiana continental shelf. The areal extent of the hypoxic zone, monitored in mid-summer since 1985, has increased from an average of 6,900 km^2 from 1985-1992 to 15,930 km^2 from 1993-2007, with a peak of 22,000 km2 in 2002 (Rabalais et al. 1999, Rabalais and Turner 2006, unpub. data). Hypoxia is also a recurring problem in several other estuarine areas along the Gulf of Mexico coast, including Mobile Bay, Corpus Christi, Pensacola Bay, and Apalachicola Bay. In addition, Brazos River discharge during wet years can lead to hypoxia along the Texas coast; for example, record setting rainfall in spring 2007 led to a hypoxic zone that extended from the Brazos River mouth to Matagorda Bay, Texas, and persisted through mid-September.

Although much progress has been made in the management of water quality, several concerns remain. Nutrient pollution in coastal areas of the Gulf of Mexico is affecting ecosystem functions, public health, living marine resources, and economic benefits from tourism, fisheries, and other coastal dependent uses. As part of its efforts to protect the nation’s waters, the U.S. Environmental Protections agency has identified the establishment of numeric criteria for nutrients and related water quality indicators (e.g., chlorophyll-a) as an important step toward reducing nutrient impacts. Numeric standards for nutrients and nutrient related water quality indicators provide a management tool for states that would strengthen regulatory programs under the Clean Water Act and potentially be used to reverse current trends in nutrient pollution to coastal waters and estuaries (Hagy et al. 2008).

The Gulf of Mexico Alliance (GOMA) developed the Nutrients Criteria Research Framework discussed in this paper to provide the information needed to understand the transport, fate, and effects of nutrients and, ultimately, to establish protective nutrient criteria for coastal waters and estuaries. The framework will be used to assess nutrients and associated water quality factors as they are transported from coastal drainages through estuaries and nearshore waters into the offshore of the Gulf of Mexico.

The following goals guided the development of the Nutrients Criteria Research Framework:

- Standardize a regional approach that can be used at locations around the Gulf of Mexico, in a range of conditions and types of coastal waters. This design should be able to accommodate modifications that address local conditions and local program needs;
- Provide improved understanding and identify the core monitoring needed to characterize and understand nutrient sources, fate, transport, and effects;
- Provide sufficient understanding of the relationships between nutrients, water quality, physical processes, and biological communities to develop protective nutrient criteria for coastal ecosystems;
- Optimize the monitoring design to the minimum necessary to determine nutrient effects and establish long-term monitoring sites, parameters, and methodology, with a consideration of reducing uncertainty or quantifying variation with increased monitoring for sensitive waterbodies.

II. RESEARCH QUESTIONS AND CONCEPTUAL MODELS

A. Research Questions

The following research questions will be addressed through application, analysis, and optimization of the Nutrients Criteria Research Framework through regional studies:

- What is the maximum amount (loads or concentrations) of nutrients that are protective of aquatic life as designated in state water quality standards under the Clean Water Act?
- What are the quantitative relationships between nutrients and biological effects?
- What are protective targets associated with ecological change thresholds?
- What are the dominant nutrient pathways, nutrient fluxes, and what influences them?

The design of individual studies and regional implementation of the framework will consider the following questions:

- What is the optimal way to capture the spatial and temporal variation critical to nutrient dynamics in coastal systems?
- What sentinel species or indicators in each system are most sensitive to nutrients and provide early detection of ecosystem change?
- How can quantitative models and quantified uncertainties be used by managers to give reasonable assurance of meeting healthy ecosystem targets?

B. Conceptual Models

The Nutrients Criteria Research Framework will be guided through on-going efforts to better capture the ecosystem processes and responses to nutrients for Gulf of Mexico coastal ecosystems. An ecosystem approach requires focus on processes such as primary production, carbon cycling, trophic level respiration, and nutrient cycling at various trophic levels. Ecosystem process information can be integrated into budgets, flow diagrams, process models, and conceptual models.

III. NUTRIENTS CRITERIA RESEARCH FRAMEWORK

A. Overview

The Nutrients Criteria Research Framework was developed as a regionally standardized approach to collecting the information necessary for the states in the Gulf of Mexico region to establish nutrient criteria that protect estuaries and coastal waters from nutrient impairment. Deciding what degree of effect constitutes legal impairment is not a goal of this effort; that responsibility remains with each state. However, studies that apply the Nutrients Criteria Research Framework are intended to establish links between nutrient concentrations or load and the resulting effects on key parts of the ecosystem; thereby providing a scientific basis on which the states can set nutrient criteria and manage nutrient inputs to coastal waters and estuaries. The Nutrients Criteria Research Framework will also be used to define an optimal or core monitoring design to minimize monitoring necessary to set nutrient criteria as well as recommend a sampling design for establishing long-term monitoring sites, parameters, and methodology. The core monitoring design will be evaluated to ascertain uncertainties in estimated results that result from the monitoring and the effects of unanticipated variation in inputs and environmental conditions that can lead to harmful effects when worst-case conditions coincide in ways that may not be captured by the minimal core monitoring condition, and recommendations will be made regarding the extent to which those uncertainties may be reduced by reasonable increases in monitoring efforts for the test case systems.

Comparative analyses to synthesize data from site-specific studies using the Nutrients Criteria Research Framework will be conducted to provide a comprehensive understanding of how excessive nutrients lead to ecosystem changes in coastal waters and estuaries, to identify how ecosystem responses are modulated by system-specific attributes, to characterize the uncertainty in quantitative analyses and the variations in inputs and environmental parameters that can lead to critical conditions in the systems, and to develop tools and strategies for management actions based on scientific understanding.

B. Components of the Nutrients Criteria Research Framework

To accomplish the goals discussed above the following components have been incorporated into the Nutrients Criteria Research Framework:

1. Nutrient sources and form
2. Nutrient loading

3. Nutrient pathways
4. Nutrient transport
5. Nutrient fate
6. Nutrient parameters

The Nutrients Criteria Research Framework will address four ecosystem compartments that form sources or sinks for nutrients as well as the fluxes of nutrients between them. These compartments are: atmosphere, biomass, water column, and sediment (Figure 2). The water column compartment includes interactions of the estuary, bay, or other water body of concern with the oceanic Gulf waters, surface water from rivers, streams and other land runoff, and rainwater. The sediment compartment consists of the porewater and includes interactions with groundwater. Below are conceptual models of the compartments to which the Nutrients Criteria Research Framework will be applied.

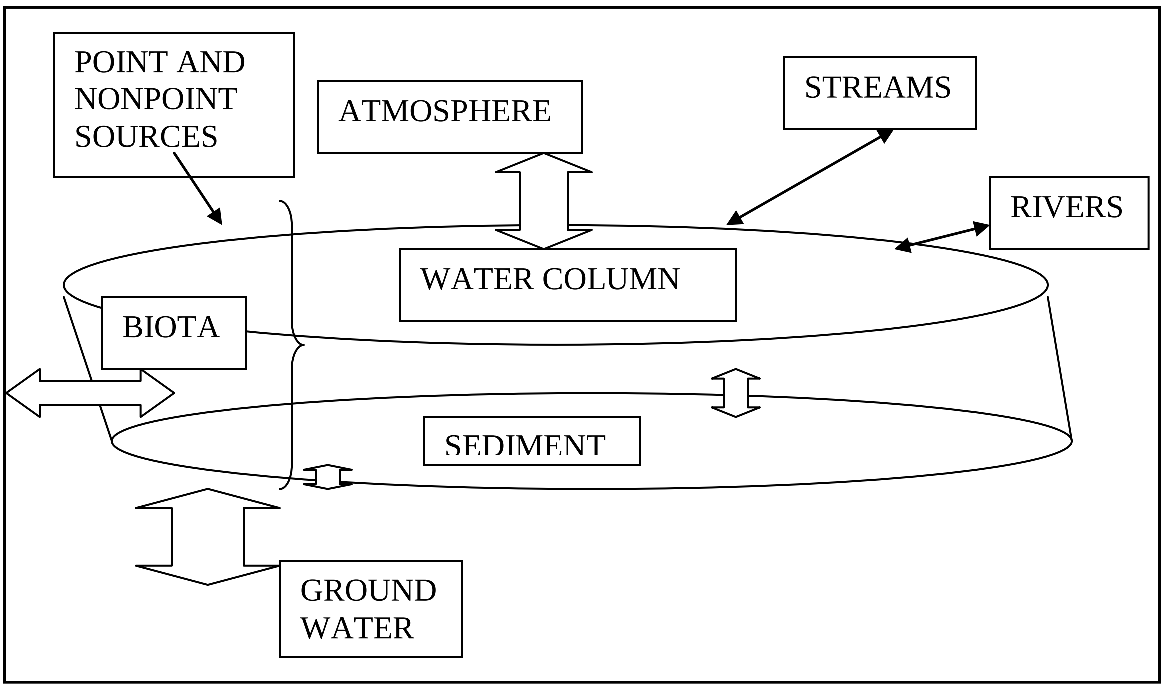


Figure 1: 3-D View of System:

1. Nutrient Sources and Forms

Nutrients impacting coastal waters include nitrogen and phosphorus. However, most coastal systems are Nitrogen limited, meaning productivity levels are most closely linked to Nitrogen levels. Fixed nitrogen inputs to coastal waters are dependent on allochthonous (originating outside the studied system) sources. The identity and relative importance of these nitrogen sources can be identified by examining isotopes for nitrogen and oxygen, $\delta^{15}N$ and $\delta^{18}O$, in dissolved NO_3 as it enters coastal waters. These two stable (non-radioactive) isotope measurements identify the relative influence of the following nitrogen sources:

- rangeland and sewage
- natural soils and residential lands
- manufactured fertilizer
- atmosphere (rain, atmospheric deposition)
- groundwater

The isotopic similarity between resident estuarine organisms and allochthonous nitrogen identifies the relative importance of internal cycling verses flux. Additionally, decadal-scale trends in the relative importance of different nitrogen sources can be obtained by examining stable isotopes, carbon to nitrogen ratio (C:N), and biomarkers preserved in sediment cores. This approach may be useful for establishing targets (i.e., benchmark conditions) within individual coastal ecosystems.

Anthropogenic nitrogen can also be released into the atmosphere from a variety of sources including: fossil fuel combustion (both in the electricity production and transportation sectors), industrial sources, and agricultural emissions (volatilization of ammonia from chemical and organic fertilizers). Although the atmospheric residence times of nitrogen pollutants vary by compound (oxidized vs reduced) and by form (gaseous vs. particulate), these pollutants will eventually return to earth in the form of atmospheric deposition. These nitrogen sources can be deposited in the watershed and make their way to coastal waters through riverine input, or can be deposited directly to estuarine and coastal waters. This latter pathway is unique in that it allows the nutrients to bypass significant watershed processing, such as biological uptake, settling with particles and denitrification.

Previous research has demonstrated that atmospheric deposition of nitrogen can contribute up to 24% of the total nitrogen budget to some systems (Whitall and Paerl 2001).

Groundwater Sources

"Groundwater inflow to estuaries has been, until recently, one of the least studied and, consequently, one of the least understood sources of nutrients to estuaries" (Spruill and Bratton 2008). It is necessary to first understand the regional hydrogeology of an estuary to understand the role that groundwater plays in its ecology (Spruill and Bratton 2008). Because of the large spatial and temporal variability of groundwater discharge in coastal areas (Burnett et al. 2006), the use of several techniques (presented in Burnett et al. 2006) will typically be necessary to reasonably quantify groundwater discharge (Spruill and Bratton 2008).

Groundwater flux is also influenced by the width of the groundwater outflow flow or discharge zone (the area between the shoreline and offshore) (Spruill and Bratton 2008). The area of groundwater discharge in an estuary is restricted by the interface between fresh groundwater and saltwater, which can act as a density barrier (Spruill and Bratton 2008) Estuaries with more saline water restrict fresh groundwater discharge to a narrow zone next to the shoreline, rather than throughout the estuary or further offshore (Spruill and Bratton 2008).

2. Nutrient Loading

Nutrient loading is the quantity of nutrients entering a system over a given period of time. The study questions related to nutrient loading are: what are the nutrient loads per unit of area, per unit of time, and per system? Spatial and seasonal variability in loading can lead to a redistribution of nutrients or a change in nutrient fluxes among compartments and within the system. Table 1 lists the nutrient loading variables and measures that are part of the Nutrients Criteria Research Framework.

Table 1: Nutrient Loading Variables and Measures

Variable	**Measures**
Land use	Event Mean Concentration (EMC)
Hydrography	National Hydrography Dataset + bathymetry
River & stream flow	tidal + non-tidal gauging
Groundwater	
Atmospheric Deposition	Total nutrients in precipitation; nitrogen oxides and ammonia in particulate and gaseous phase

There are two important efforts that will contribute to the Nutrients Criteria Research Framework's assessment of nutrient loading. The NOAA Coastal Hypoxia Research Program is currently funding an examination of coastal estuaries within the Gulf of Mexico with three major components: modeling watershed nutrient fluxes, modeling the nutrient and oxygen responses in estuaries, and evaluating the ecological consequences.

The U.S. Geological Survey (USGS) SPARROW model can be used to examine nutrient loadings in the major Gulf estuaries. This approach will allow for better predictive understanding of the potential causes and consequences of nutrient pollution on estuarine ecosystems and how estuarine hydrology and morphology modulate estuarine and upper trophic level responses. In addition, a basin-wide SPARROW model has been developed for the Mississippi River watershed and regional SPARROW models are in development for the lower Mississippi River watershed to quantify annual nutrient loadings, as well as the timing. The developing SPARROW models will also feature improved estimates of nutrient loads from major point sources.

3. Nutrient Pathways

Nutrients in coastal systems are transformed through physical, chemical, and biological processes as they are transported from land (by streams and rivers) through components of an estuary out to the nearshore waters. Within estuaries, nutrients are transformed and incorporated into system components such as the water column, sediments, phytoplankton, macrophytes, and benthos. Nutrients can also be transported into the estuarine system from nearshore and offshore waters by tides and currents and from atmospheric deposition, which can be important sources in some estuaries.

The Nutrients Criteria Research Framework provides methods to identify pathways that affect the transport and fate of nutrients in coastal ecosystems and answers the following transport and fate questions:

- What are the primary pathways that affect nutrient transport and fate?
- How are source categories and system components partitioned?
- What are the transfer rates between system components?
- What parts of the system components act as nutrient sinks?

The Nutrients Criteria Research Framework's methodology to evaluate nutrient inputs using isotopic composition analysis will also provide data to evaluate nutrient pathways. Internal cycling involves the exchange of nitrogen among biological ecosystem components (microalgae, macroalgae, vascular plants, zooplankton, benthos, and higher trophic levels) and the burial and remineralization of biologically modified nitrogen within coastal sediments. Because internal cycling modifies the isotopic composition of these components, their nitrogen isotopes will differ from the original allochthonous nitrogen entering the system and can be used to identify the dominant internal cycling pathways.

Nutrient transport and fate questions will also be addressed through ecosystem budgets of the primary nutrients, carbon, nitrogen, and phosphorus. Ecosystem budgets are a simple yet effective way to describe a system and the key nutrient pathways affecting nutrient dynamics. Budgets are simple models that result in mass balances for key variables. The Nutrients Criteria Research Framework adopts the methodology for ecosystem budgets developed by the International Geosphere-Biosphere Program's Land-Ocean Interactions in the Coastal Zone (LOICZ) project. LOICZ developed a modeling strategy to estimate the biogeochemical fluxes of nutrients to the coastal zone and transformations within coastal ecosystems (Gordon et al. 1996, see Appendix A). Budgets will be used as an initial step to address transport and fate questions. The following describes the steps in the LOICZ budgetary modeling process.

a. Water budget

Establish a budget of freshwater inflows (such as runoff, precipitation, groundwater, and wastewater discharges) and evaporative outflow. Include compensating outflow (or inflow) to balance the water volume in the system.

Measurements:

- Flow in and out: units of volume per time
- Precipitation and evaporation: units of volume per time
- Freshwater residence time of the system: units of days

b. Salt budget

Salt must be conserved in the system; therefore, salt flux not accounted for by the salinities used to describe the freshwater flows in the water budget, must be balanced by mixing. If there is no salinity difference between the system of interest and adjacent systems or if the pattern of water exchange is too complex to be amenable to description by the combined water and salt budgets, a more complex form of circulation analysis will be required. The water and salt budgets describe exchanges between the studied system and adjacent systems by advection and mixing.

Measurements:

- Average salinity at the system boundaries
- Salinity in the water column and respective inflow and outflow

Approach for Stratified Systems

Many Gulf of Mexico coastal systems are strongly stratified for part of the year. The LOICZ project has developed a modified methodology for water and salt budget for systems with strong vertical stratification to reflect a two-layer system model. In highly stratified systems, the modified, 2-layer model will be applied to determine salinity in stratified water layers (surface and bottom). The 2-layer model applies the same questions and measurement, but incorporates the physical separation between top and bottom water layers.

c. Carbon, Nitrogen, and Phosphorus Budgets

All dissolved materials will exchange between the system of interest and adjacent systems according to the criteria established in the water and salt budgets. Deviations of material concentrations from predictions based on these two previous steps can be quantitatively attributed to net nonconservative reactions of materials in the system.

Measurements:

- Net ecosystem metabolism: flux in dissolved inorganic phosphorus (DIP) times the carbon to phosphorus ratio of the reacting particulate matter $\{(C:P)_{part\ ratio}\}$
- Carbon fluxes: dissolved inorganic carbon (temperature, salinity, pH, total alkalinity, partial pressure (pCO_2); dissolved organic carbon (DOC)
- Phosphorus fluxes: dissolved inorganic phosphorus (DIP)
- Nitrogen fluxes: denitrification, nitrogen fixation, dissolved inorganic nitrogen (e.g. NO_2^-, NO_3^-, and NH_4^+), dissolved organic nitrogen (DON)
- Dissolved nitrogen flux associated with production and decomposition of particulate matter [(DIP flux + dissolved organic phosphorus flux) multiplied by $N:P_{part}$]

d. Stoichiometric Relationships Among Carbon, Nitrogen, and Phosphorus:

It can often be assumed that the nonconservative flux of dissolved inorganic phosphorus is an approximation of net metabolism at the scale of the ecosystem, because there is no gas phase for phosphorus flux. Nitrogen and carbon both have other major flux pathways (notably denitrification, nitrogen fixation, gas exchange across the air-sea interface and in some systems $CaCO_3$ reactions). The deviation of fluxes of these materials from expectation based on C:N:P composition ratios of reactive particles in the system can be assigned to other processes in a quantitatively reproducible fashion.

Measurements:

- Nutrient concentrations
- Suspended sediment load and C:N:P composition ratio

4. Nutrient Transport

Monitoring of physical parameters is necessary to determine transport mechanisms, to provide data inputs to numerical models that might be used to forecast nutrient fluxes, and to understand the distribution of biological communities that participate in nutrient cycling or that may be impacted by nutrient effects. Biological parameters are important and should be estimated as these are both sources (through decay) and sinks (through nutrient utilization) of nutrients.

Physical characteristics of ecosystems can also attenuate or exacerbate the effects of nutrient enrichment and can affect the types and distribution of biological communities. Relationships between physical characteristics and key ecosystem responses can help define key processes and a system's susceptibility to nutrient related impairments. Table 2 lists the nutrient transport variables and measures that are part of the Nutrients Criteria Research Framework.

Table 2: Nutrient Transport Variables and Measures

Variable	Measures
Wind	Direction, speed, period/duration
Waves	Height, length, period, direction
Tides	Water level at high and low tides
Currents	Direction, speed
Water levels	Depth
Bathymetry	Elevation
Flow	velocity, residence time
Stratification	Surface and bottom water temperature and salinity

The seasonal cycle of circulation on the Texas-Louisiana shelf is an example of how physical parameters may affect nearshore nutrients. In the non-summer months (generally September-May), the winds cause the river discharge from the Mississippi-Atchafalaya (M-A) River system to be transported along the coast towards Mexico. In summer (generally June-August), the winds cause a current reversal that results in the pooling of the M-A river influenced waters over the Texas-Louisiana Shelf. It is uncertain how this affects the nearshore environment, but it certainly contributes to the routinely measured, summertime hypoxia problem in Louisiana and sometimes Texas waters as shallow as 5 m, occasionally moving inshore to waters only 5m deep. It is also not clear how short-term variations in near-shore ambient conditions, loading conditions, and transport and transformation processes affects the presence and availability of nitrogen in the estuarine systems, and how those changes can lead to short-term and longer-term negative impacts on the ecosystems.

5. Nutrient Fate

There are four objectives for the monitoring of nutrient fate in estuaries described below. The Nutrients Criteria Research Framework will focus its efforts on the fate of nitrogen by first connecting the dissolved nitrogen source to the hydrologic cycle. Second, the effects of nitrogen on the metabolic instability of the ecosystem will be determined. Third, the effects of land use on the higher trophic levels of the ecosystem will be detected. Fourth, the incorporation of nitrogen into the estuarine living resources can be traced from primary producers to top predators. This fourth objective is most difficult to achieve and so may be qualitative. Required measurements and methods for each objective are given below.

i. Dissolved N and P source and hydrologic connectivity

Required measurements:

- Nitrogen and Carbon species-specific concentrations using standard methods
- $\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$ of DIC and nitrate (using bench top isolation chemistry and mass spectometry)
- Streamflow (using a gauge)

Isotopic signatures allow identification of land use/cover sources that contribute nitrogen to the estuary. $\delta^{13}C$ and $\delta^{15}N$ have broad application for identifying sources and hydrologic connectivity. Measuring both $\delta^{15}N$ and $\delta^{18}O$ in dissolved NO_3 increases source discrimination capability. When combined with streamflow data, seasonal changes in hydrologic connectivity can be observed.

ii. N and P effects on ecosystem metabolic instability

Method 1: Relationship between dissolved oxygen (DO) and carbon dioxide (CO_2)
Required measurements:

- Dissolved Oxygen (using an electronic sensor)
- Dissolved CO_2 (calculated from pH using an electrode; temperature using a thermistor; and alkalinity using a benchtop probe

A strong positive relationship between DO and CO_2 indicates ecosystem productivity to respiration ration (P:R) instability and an associated increased chance of dissolved oxygen stress.

Method 2: $\delta^{18}O$ enrichment
Required measurement:

- Dissolved oxygen $\delta^{18}O$ (using GC/mass spectrometer)

Photosynthesis does not fractionate ambient oxygen. Plant and animal respiration favors use of ^{16}O, which causes enrichment of $\delta^{18}O$ in water. When community respiration rates are relatively high (low P:R), dissolved oxygen becomes enriched in $\delta^{18}O$. Low P:R (enriched $\delta^{18}O$) is an indicator of increased risk of dissolved oxygen stress. $\delta^{18}O$ is a relatively new proxy for P:R, and can be compared with the DO vs. CO_2 method above.

Note: P:R undergoes a daily light-dark cycle, the amplitude of which is also an indicator of risk of dissolved oxygen stress.

iii. Detecting land-use effects on higher trophic levels

Nitrogen isotope mixing models for striped mullet or other primary consumers (e.g., bivalves) can be used to describe land use effects on higher trophic levels.

Required measurements:

- Animal tissue $\delta^{15}N$ (using a mass spectrometer, fin clips may be used)
- GIS land use/cover in the watershed

Models or established quantitative relationships between higher trophic species, such as fish or shellfish, and nitrogen assimilation will be used to detect secondary effects. Models for striped mullet work very well in west-central Florida estuaries (12 estuarine areas, $r^2 = 0.89$ for predicted vs. observed fish tissue isotopes). These models require good hydrologic connectivity with the watershed. Effects of low hydrologic connectivity are currently being modeled. Fitted numerical coefficients are a potentially powerful tool for evaluating both the connectivity and bioavailability (fate) of nitrogen from different land use/covers. Results from Objective i enhance model performance.

iv. Optional - Tracing nitrogen incorporation into estuarine living resources: from primary producers to top predators

Required measurements:
$\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$ from:

- Particulate Organic Matter (by filtrations using mass spectrometer)
- Benthic microalgae (by grab samples or samples grown in situ; using a mass spectrometer)
- Vascular plants (by leaf samples, using mass spectrometer)
- Zooplankton (by plankton net; using mass spectrometer)
- Invertebrate benthos (by grab samples; using mass spectrometer)
- Bivalves, fishes (by hand collection, seines, trawls, traps - fin clips may be used; using mass spectrometer)

By matching nitrogen sources to biological sinks, dominant bioavailable nitrogen sources can be identified. Discrimination capability is enhanced by using multiple stable isotopes

6. Nutrient Parameters

The Nutrients Criteria Research Framework applies the nutrient parameters in Table 3 to surface water, ground water, the water column, porewater sediments, and as practical rainwater and other atmospheric depositions to the water body of concern. Sampling will be conducted to collect data so that the spatial and temporal distributions, trends, and variability for each parameter can be determined. Comparisons between shallow and relatively deep waters and between nearshore and offshore water should also be undertaken.

The Nutrients Criteria Research Framework adopts the National Water Quality Monitoring Council's design for the nutrient components of the National Water Quality Monitoring Network for U.S. Coastal Waters and their Tributaries (the Network). Appendix B provides additional details on the development of the design for the nutrients components. The Network is a framework for linking water quality monitoring in coastal waters with observations in upland areas and offshore waters. A description of the Network design is available at http://acwi.gov/monitoring/network/design.

Table 3 provides a tiered list of nutrient parameters with corresponding analyses by the National Water Quality Monitoring Council. Tier I parameters represent the required constituents; Tier II parameters represent the constituents that would add significant value but may not be essential to some programs. The requirements for the river, estuary, nearshore coastal and offshore coastal systems are the same.

Table 3: Required nutrient parameters for National Water Quality Monitoring Network

Component	**Nutrient Analyses**		**Related analyses**	
	Tier 1	**Tier 2**	**Response Variables**	**Ancillary Analyses**
Rivers, Estuaries, Nearshore Coastal, Offshore Coastal	Total nitrogen*; Dissolved ammonium; Dissolved nitrate plus nitrite; Total phosphorus+; Dissolved orthophosphate; Dissolved silica	Total dissolved nitrogen; Total dissolved phosphorus; Particulate nitrogen; Particulate phosphorus	Chlorophyll *a;* Dissolved oxygen; Conductivity/salinity	Dissolved organic carbon; Dissolved inorganic carbon; pH ; Total suspended sediments; Photosynthetically active radiation; Particulate carbon
Groundwater	Dissolved nitrate plus nitrite	Dissolved ammonium; Dissolved orthphosphate		Dissolved organic carbon

Atmospheric deposition	Dissolved nitrate plus nitrite; Dissolved ammonium; Dissolved orthophosphate	Dry deposition; gaseous and particulate species		Major ions; pH
Wetlands (sediment only)	Particulate nitrogen; Ammonium; Dissolved orthophosphate; Particulate phosphorus		Chlorophyll *a*	Particulate carbon

* May be determined by analysis of total dissolved nitrogen and particulate nitrogen (TN=TDN+PN)
[+] May be determined by analysis of total dissolved phosphorus and particulate phosphorus (TP=TDP+PP)

Remotely sensed data will also be used to collect data on nutrient parameters. Appendix C provides a detailed description of the approach that will be used to define specific water quality and nutrient parameters that can be obtained through remote sensing. A relationship between the selected parameters and the remotely sensed imagery will be established with the use of empirical algorithms and other data analysis methods.

IV. ECOLOGICAL ENDPOINTS

Meaningful regulation of nutrients requires an understanding of the effects of different nutrient concentrations and loadings on biological communities in the waters being managed. Identifying key ecological endpoints allows assessment efforts to be focused on a subset of the community, thereby minimizing the cost of collecting information while being protective of the full community.

Ecological endpoints will be selected for study systems to best represent biological components that are sensitive to changes in nutrient levels and for which a cause and response relationship can be described. The establishment of predictive and quantitative relationships between nutrient levels and ecological endpoints is important in the development of nutrient criteria. The following will also guide endpoint selection:

- Nutrients can have both beneficial/essential and negative impacts on the environment, therefore, both positive and negative effect based endpoints need to be considered.
- Numeric endpoints need to maximize linkages to other ecosystem components, especially higher trophic levels with strong public interest such as fisheries. These “linkage endpoints” may require qualitative translators defined by conceptual models until the data necessary to demonstrate explicit relationships is developed.

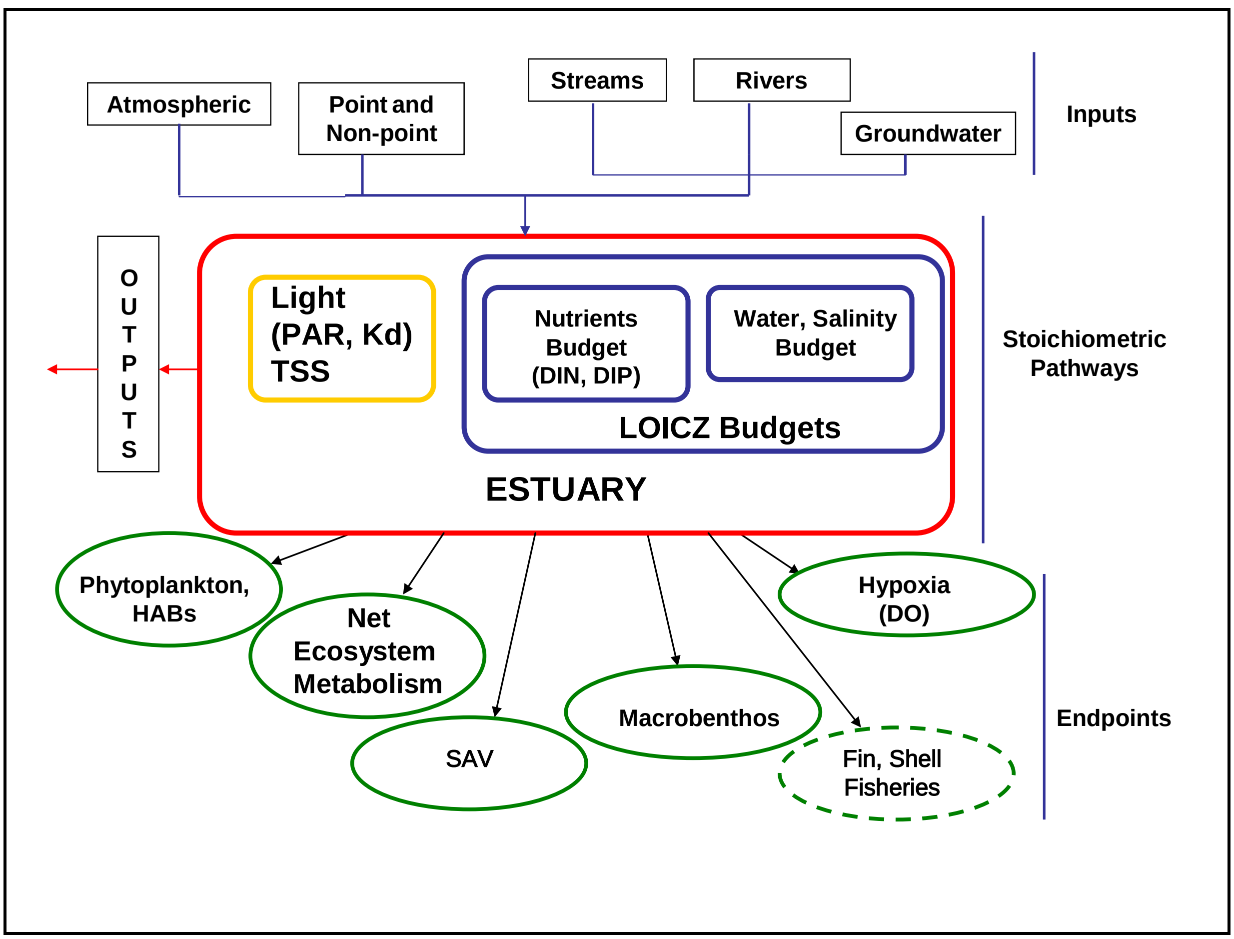
- Peer reviewed science needs to be the foundation for both positive and negative endpoints. It is important that the adopted endpoints consider monitoring efficiencies in order to effectively implement the endpoints.

A. Conceptual Model of Ecosystem Response

The Nutrients Criteria Research Framework identifies ecological endpoints that are tightly coupled with ecosystem response to nutrient concentrations and loadings and develops study methods to answer the following ecosystem response questions:

1. What ecological endpoints are most sensitive to nutrient inputs?
2. What is the spatial and temporal distribution of ecological endpoints?
3. What are the trends and thresholds of significant change for ecological endpoints?
4. What mechanisms control the abundance and distribution of ecological endpoints?

Figure 2: Conceptual Model of Ecological Endpoints



B. Overview of Endpoints

The following table provides an overview of potential endpoints. Each endpoint will be considered in the Nutrients Criteria Research Framework and evaluated using the frequency of occurrence, duration of the associated conditions, and the area affected or covered. Appendix D provides examples of the connections between nutrient pathways and endpoints.

Table 4: Overview of Endpoints

Endpoint	Indicator	Frequency	Duration	Area
Phytoplankton	Chlorophyll a HPLC pigments	Annual average concentration, growing season average, or 90th percentile.	Length of time concentration exceeds threshold levels annually and seasonally.	Percent of estuary area
Net Ecosystem Metabolism Stability	Production minus Respiration	Annual, in season of maximum productivity	24-hour assay	Statistical representation of estuary area
Macrobenthos and zooplankton community structure, abundance, distribution, biomass, and biomass-spectrum slope	Species identification, abundance and diversity	Percentage of waters with tolerant or sensitive species, impaired index scores	Average and maximum extent of time waters supporting healthy benthic conditions exceed relevant water quality conditions	Percent of waters with impaired benthos
Fish/shrimp/crab community structure, abundance, distribution, biomass, and biomass-spectrum slope.				
Herbivore abundance and biomass				
Shell Fishery	Shrimp Oysters	Percent of waters supporting shellfish species; number of times a year shellfish harvest is restricted due to water quality degradation	Average and maximum length of time shellfish waters exceed a range of nutrient levels and harvest restriction are in place	Extent of shellfish; percent of harvestable shellfish area
Dissolved Oxygen Stress	Dissolved Oxygen Concentration	Number of times a year dissolved oxygen falls to anoxic or hypoxic levels	Average and maximum length of time for which dissolved oxygen remains at anoxic or hypoxic levels	Extent of hypoxic and anoxic conditions; depth of conditions in water column

V. IMPLEMENTATION PLAN

The Nutrients Criteria Research Framework described in this document will be implemented through the leadership of the Gulf of Mexico Alliance as resources become available. Initially, the Nutrients Criteria Research Framework will be tested in one coastal ecosystem to evaluate framework components. An ecosystem that has significant sources of data and models will be chosen as the test case for application of the framework over a one-year period. Information gaps will be identified, framework components will be implemented, and results will be analyzed by the Gulf of Mexico Alliance to refine the Nutrients Criteria Research Framework.

Following the test case, implementation of the Nutrients Criteria Research Framework, with resulting modifications, will be conducted in four to five coastal ecosystems that demonstrate significant differences in their physical or biological characteristics. Selected ecosystems will have significant sources of data and models to inform sampling design and interpretation of results. Parallel round robin studies will be used to establish comparability for lab and field methods used by the Gulf States and other partners.

The selection of study sites will consider the following criteria:

- Sites where a range of nutrient related responses or impacts can be measured;
- Relatively simple systems, including smaller areas and areas with fewer complex influencing factors;
- Sites with a range of nutrient forms and types of pathways;
- Sites to capture the range of physical characteristics including freshwater input, flushing rate, salinity regime, and other key physical conditions in the region; and
- Sites to capture the range of dominant primary producers in the region.

The pilot studies will be used to identify ecosystem specific minimum monitoring programs, comparable methods, and appropriate monitoring endpoints and their indicators. Together, system specific analyses will result in a core Nutrients Criteria Research Framework for Gulf of Mexico coastal waters and estuaries that will provide sufficient information to allow scientifically valid nutrient criteria to be established and regular monitoring to prevent nutrient related impacts. In addition, data to aid in the selection of a classification system for the framework will be collected. Appendix E provides additional information about potential classification methods for study sites.

VI. CORE NUTRIENTS CRITERIA RESEARCH FRAMEWORK

A core Nutrients Criteria Research Framework will be the simplest, least expensive nutrients monitoring program for coastal waters and estuaries in the Gulf of Mexico region. In addition, results will be used to develop a classification system to refine a monitoring program for clusters of coastal systems that share similar physical or biological characteristics or vulnerability to nutrient related impacts.

The following research questions will guide development of the core framework, selection of ecological endpoints that best describe key effects of nutrient inputs, and ecosystem assessment and comparison among similar types of systems in the Gulf of Mexico region.

Question 1) What types of 'critical points' exist in the system to be studied, where are they located, and what environmental variables control them?

> ***Why This Question**?* Identification of appropriate critical points would focus the research effort on smaller areas while still providing the information necessary to set nutrient criteria that are protective of the entire system. This would reduce costs and simplify research logistics.
> Rates of nutrients transport vary with flow rates, which is not consistent across coastal waters and estuaries. In general, important ecosystem changes tend to occur when environmental conditions change from one type to another. Critical points are the locations or conditions under which the impairment would first be demonstrated. Thus a nutrient concentration or load that prevented problems at a critical point could be presumed protective for that particular effect, at least until another critical point was reached.
>
> ***Approach:*** Using existing information where available, critical points i.e., locations at the interfaces between ecosystem components, will be identified within a study system. This selection would be based on the primary nutrient pathways found in a particular system. For example, critical points might be the physical conditions (and associated locations) where retention time in the system becomes such that phytoplankton blooms are possible. Another example are deposition zones at salinity interfaces where flocculation and settling shift nutrients from dissolved to solid forms and cause a resulting shift in nutrient availability. Water quality monitoring in the vicinity of the suspected critical points could help locate the area in which the effect might occur under a particular set of conditions.
>
> It is also necessary to confirm that the system is sufficiently understood to identify where the critical spots occur or are likely to occur. Additionally, the range of systems studied may result in more than one critical point with different ecological effects.

Question 2): What endpoints best measure the nutrient caused degradation or risk of degradation at each critical point in the system?

> ***Why This Question**?* There is a need to be able to measure ecosystem responses to nutrient concentration and loading in such a manner as to be able to identify indicator threshold values and assess trends towards an undesirable or degraded state. Measuring an ecological endpoint, while normally more complicated than measuring a physical or chemical parameter, provides a more accurate indication of ecosystem response than inferring it from environmental measures. It also lends scientific backing if the endpoints are later used in creating nutrient criteria.

Approach: Select ecological endpoints that are sensitive indicators of nutrient related ecological effects using the best available science and data. For each endpoint, define the key nutrient pathways and physical and chemical parameters that control responses.

Question 3): For the ecological endpoint(s) identified as sensitive to nutrient inputs, what ecological changes can be linked to changes in nutrient concentration or load and what indicator best reflects these changes?

Why This Question? Indicators are strongly correlated to the ecological endpoint and describe the effects related to changes in nutrient concentration or load. Indicators can simplify the monitoring and assessment needed to understand the linkages and ecological effects directly explained by changes in nutrient concentration or load.

Approach: Select indicators for each endpoint. For each indicator define the specific parameters to be measured, overall monitoring design, and thresholds or expected ranges of values.

VII. NUTRIENT MODELS

A. Modeling Approaches in support of the Nutrients Criteria Research Framework

It is important to plan for monitoring data needed to set up, calibrate, and validate models that will be used for system studies. Models can also be used to inform the monitoring approach, optimize the sampling design, and help understand the links between nutrients, water quality, and biological responses, as well as, ultimately, to make predictions that help inform management decision-making.

The type modeling that is employed will to some degree drive the details of the data collection required to support it. Process-oriented models (designed to help elucidate important relationships and interactions between system components) may require dedicated data-collection efforts. Model forecasting, on the other hand, may be supported by existing, ongoing monitoring efforts. The sections below offer a brief overview of different modeling approaches, benefits, and data requirements.

1. Framing the Modeling Approach

There is a wide range of models and modeling approaches that could be used to aid the development of nutrient criteria in estuarine and coastal systems. These include:

- simple box models to characterize the long-term fluxes and partitioning of important reactants between different system components;
- watershed models to estimate nutrient loading of receiving waters as well as predict changes in loading in response to changing land use;
- hydrodynamic (circulation) models to characterize water and solute residence times in one, two, or three spatial dimensions;

- biogeochemical models, often used in concert with circulation models, to simulate the biological, chemical, and geological sources and sinks of nutrients and related quantities (e.g. dissolved oxygen); and
- ecosystem models to simulate the linkages between nutrient-related water quality and ecosystem dynamics.

The choice of modeling approach is governed by the specific scientific and management questions to be answered. An initial requirement is a baseline understanding of important biogeochemical fluxes in each system in the study. Following the LOICZ approach (Gordon et al., 1996), this may be done by constructing simple box models that account for the fluxes of freshwater, salt, carbon, nitrogen, and phosphorus. Often these assume a system in steady state. This approach has several advantages for the present purposes: in many candidate study areas there already exists enough data on water, salt, and nutrient fluxes to construct basic budgets (several have been constructed already as part of LOICZ); it provides a common ground on which to perform comparative analysis of very different systems; and both the data collected and understanding generated will be valuable in subsequent modeling efforts where these are deemed desirable.

2. Beyond budgets

Additional research and management questions may drive the use of more complex models. Models based on physical and chemical dynamics are more complex and will require more effort, more data, and potentially more specialized skill to create and operate. However they offer additional benefits, including: 1) acting as a supplement to budgets – when run in long-term/steady state mode; 2) providing a more complete description of system flushing behavior for example the non-steady, spatially variable nature of renewal times; 3) providing a prognostic ability that will facilitate development and assessment of management scenarios; and 4) the ability to inform data-collection efforts to maximize efficiency (e.g. Observing System Experiments); and 5) with data assimilation capabilities, providing a gauge of total system behavior in near-real time as a way to monitor the nutrient levels over a greater region than data sampling can accomplish. Some examples are provided in the sections below.

3. Models for examining renewal times

Budget/box models by their nature deal with quantities averaged over large spatial and temporal scales. Most assume a system in steady state. This approach ignores the actual physical mixing and flushing processes that govern the exposure of biological system components to waterborne pollutants. The concept of characteristic timescales for renewal of water and solutes (e.g. flushing time, mean residence time, transit time) has long been applied in estuarine ecology as an integrative measure of the flushing behavior of an estuary. However there is a growing literature on the time and space dependence of these timescales in estuaries and their importance to ecosystem processes. Recent studies have utilized two-dimensional (Oliveira and Baptista, 1997; Braunschweig et al., 2003; Abdelrhman, 2005) or three-dimensional (Shen, 2004) hydrodynamic models to characterize the spatial distribution of renewal times. More recently, Abdelrhman (2006) developed the concept of local effect time, derived from two-dimensional hydrodynamic modeling, as a means of predicting and mapping the susceptibility of ecological components to changes in pollutant loading in estuaries. This approach speaks directly to the issue of system critical points, discussed above as one of the research questions to be addressed by this study.

4. Models for monitoring design evaluation

Observing System Experiments (OSE's) and Observing System Simulation Experiments (OSSE's) provide model-based means to evaluate existing and potential monitoring systems, respectively. OSE's may be a useful approach once data-assimilative numerical models are developed and evaluated. The OSE estimates how the quality and effectiveness of the information generated by a monitoring system, that uses an associated data-assimilative modeling system, are impacted by the presence or absence of specific existing observations. Model runs are made with data analyses and forecasts by systematically including and excluding observing system data and estimating the impact on the predictive utility of the monitoring system. Results can then be used to evaluate and improve the monitoring system.

The OSSE approach to evaluating a potential monitoring system design again requires that data-assimilative numerical models are developed and evaluated. OSSEs usually generate synthetic observational data with a second, free-running (i.e., no data assimilaton) model of high, known skill as a surrogate for real observations. A subset of these synthetic observations is produced by subsampling according to the sampling protocols of the potential observing system design. This subset of simulated observations is then assimilated into the first model, and the impact on model analyses and forecasts is then assessed. These experiments are a relatively cost effective way to determine a useful investment strategy well in advance of expanding or developing the observing subsystem component for a monitoring system. They also provide, *en passant*, a useful exercise to ensure there is an adequate modeling subsystem available in a timely fashion to assimilate the planned observations.

5. Models for management

A well-validated hydrodynamic/biogeochemical model can be used to simulate different management scenarios, including possible management actions and their likely effects on the managed ecosystem. For example a number of studies have addressed nutrient-loading scenarios in U.S. east coast estuaries, with seemingly good results (e.g. MODMON, Bowen and Hieronymus, 2002; Lung and Bao, 2003), and others are being developed for the Gulf coast (e.g. Mobile Bay; Tampa Bay—see discussion below). Models run in prognostic mode for scenario development are apparently most successful when aimed at determining system responses to forcing, rather than at determining absolute nutrient concentrations and distributions.

In addition to scenario development, a well-validated model with data assimilation capabilities can be used to assist in the continued management of a water body once nutrient criteria have been established. Assimilating available data, the model could be run operationally to estimate nutrient concentrations throughout the water body, thus supplementing the information available from the limited monitoring observations. The model also could be run in a forecast mode to alert management to likely nutrient concentrations, allowing an opportunity for possible action before criteria are exceeded.

Selected case studies:
Given the advanced state of numerical modeling, the ready availability of computing power, and the existence of mature modeling programs within the Gulf of Mexico region, the Nutrients Criteria Research Framework should seek to make use of existing three dimensional circulation models and component biogeochemical models in addition to budget modeling. (An initial inventory of hydrodynamics and water quality modeling in the region is being completed by the Gulf of Mexico Alliance). The use of possibly quite different hydrodynamics models raises the issue of comparability of their respective results. Generally, the same modeling software doesn't have to be used for each study, but the same measurements from the models will be required. Such model measurements from water quality models would basically include concentrations over time and space, and mass fluxes over time across specific transects. Additionally, a mass accounting of nutrient fate is very informative (e.g., % lost through ocean boundary, % lost through sediment-water interface, etc.). The latter is difficult to do and will require models with similar or the same capabilities, such as sediment diagenesis submodel and a good internal mass accounting. In this case, use of the same model would be helpful. Two examples of applications that utilize hydrodynamics-based biogeochemical modeling to address nutrient-related issues in the Gulf of Mexico are given below.

<u>Mobile Bay</u>

Mobile Bay is one system that has been the subject of a number of modeling studies utilizing a range of approaches. Water, salt, and nutrient budgets for the system were developed as part of LOICZ. In this analysis, annual mean fluxes of surface freshwater and salt were taken from the literature, yielding an estimate of system mean residence time of about 8 days. Values for nitrogen and phosphorus fluxes were either taken from the literature, or assumed. Based on assumptions about the C:N:P ratios of new production in the Bay, this study determined that net production to respiration ratio in the Mobile Bay system is negative.

A number of groups have undertaken hydrodynamic modeling of the system; some have constructed or are constructing biogeochemical submodels as well. Tetratech, working with the U.S. Environmental Protection Agency (EPA), Region 4, has built a 3-dimensional model of the Bay system from a few miles south of the estuary mouth inland to include approximately 35 miles of the Mobile River. A principal objective of this work is the development of a Total Maximum Daily Load (TMDL) for dissolved oxygen. At present, the hydrodynamics model is undergoing revision and calibration of the biogeochemical submodel is underway. In support of this effort, EPA has undertaken a program of extensive field sampling over two seasons.

<u>Louisiana Continental Shelf</u>

Modeling efforts in the northern Gulf of Mexico have primarily focused on the causative factors and characterization of annually recurring summer hypoxia. A suite of modeling approaches have been employed, many of which were recently summarized by Justić et al. (2007) and an

EPA Science Advisory Board Report (SAB; 2008). Turner et al. (2005) developed a simple regression model relating the size of the hypoxic zone to spring total kjeldahl nitrogen (TKN). To date, this model has proven a robust tool for predicting the annual size of the hypoxic zone and has been used to examine historical size of the hypoxic zone. Another simple model, developed by Scavia et al. (2003), predicts hypoxic zone size through a steady-state, one-dimensional horizontal dynamics of production and biological oxygen demand approach. This simulation model also uses spring nutrient loadings to predict hypoxic zone size and is able to predict the impact of varying nutrient inputs on hypoxic zone size.

Justić et al. (1996, 2002) developed a two-box, coupled biological-physical model to examine oxygen cycling dynamics in the core of the hypoxic zone. This model utilized a number of model forcing functions including concentrations of nitrate inputs, monthly Mississippi River runoff and oceanographic and meteorological conditions. This enabled the simulation historical oxygen concentrations and the linking of Mississippi River nutrient loadings to eutrophication. Bierman et al. (1994) developed a model based on the EPA Water Analysis Simulation Program and adapted it to a 21-segment 3D spatial grid on the Louisiana shelf. This complex model enabled simulation of food web nutrient oxygen dynamics and was used to forecast the response of dissolved oxygen to reduced nutrient loads. Most recently, Hetland and DiMarco (2007) utilized a modified version of ROMS to develop a 3D hydrodynamic model on the Louisiana-Texas shelf. This model, which embeds simple respiration models into complex physical models, used a number of oceanographic and meteorological forcing variables to examine the effects of stratification and circulation on hypoxia.

Several additional hypoxia models have been developed; however, those above are representative of models developed for northern Gulf hypoxia. In addition, Scavia et al. (2004) used an ensemble model approach (utilizing the Bierman, Scavia, and Justić models) to quantify nutrient reduction levels required to meet the 5,000 km^2 size of the hypoxic zone goal outlined in the *2001 Gulf Hypoxia Action Plan*. The use of an ensemble modeling approach was recommended by the EPA SAB, with the inclusion of the both simple and complex models. The SAB also had several additional recommendations that may be useful. It was recommended that future modeling efforts should not only include nitrogen and phosphorus, but also their interactions. Comprehensive monitoring should be coordinated with model development and should be designed so they are compatible with watershed models. In addition, the SAB suggested that there is value in the development of simple mass balance models, which could also be used to provide a checklist of required measurements during monitoring and research.

B. Data / Monitoring Recommendations

The data requirements for LOICZ-style budget modeling was discussed in earlier sections. Essentially the needs are for accurate physical dimensions of the system (e.g. from high-resolution topobathy); as well as enough data on fluxes of important quantities (fresh water, salt, carbon, nutrients) to characterize meaningful averages over the desired spatial and temporal scales. If an additional goal of the test cases is to study the effects of variation in environmental conditions and uncertainty in rate constants and physical processes, then the monitoring will require in addition sufficiently frequent measurements of chemical constituents and some biological conditions to allow the study to relate changes in inputs to changes in observed conditions. Information about average conditions will not allow those effects to be observed. The spatial scale and temporal resolution required to investigate and quantify those changes, and the results on outputs of those changes, will vary from one system to another, and the test cases can provide valuable information about the degree to which monitoring detail needs to be increased if it is desired to capture the effect of those changes on estuarine systems in general. These same data will also find use in the mechanistic (physical/chemical) modeling that has been the subject of this section.

Physics-based (hydrodynamic) models start by simulating the physical exchange of mass and energy between the riverine, estuarine and coastal systems, leading to natural requirements with respect to the types, location, and frequency of data inputs. Biogeochemical models are often run in tandem with hydrodynamic models, the former taking output fields of flow, temperature, and salinity from the latter and using kinetics-based equations to model the partitioning of reactive species between water, biota, and sediment. The biogeochemical model components are typically not dynamically coupled and have much longer timesteps, substantially reducing the input frequency for biogeochemical data.

Data requirements can be broken into two functional categories: input data needed to run the models and data needed to calibrate the models and validate the results. Normally the input data are required at a specific part of the model domain (the open boundary and tributaries), while the calibration/validation data should be distributed within the model domain. Additional input data may be desirable if the model is to be useful in capturing the effect of changes within the watershed that could lead to improvements in the receiving water. For example management decisions to reduce availability or change timing of nutrient loads need to have information about the linkage of specific loading changes to anticipated changes in the nearby waterbodies and in the ultimate receiving waters. Additional calibration/validation data will require sampling to characterize specific locations within the model domain if the analysis is to include the effects of varying conditions and/or of uncertainty in the data. Those effects will not be captured with data from selected points that are believed to capture a spatial average assuming the domain to be fully-mixed. In some cases the latter may need to be collected along transects, e.g. across or down the length of an estuary. This is especially the case if it is expected that conditions may be different in different parts of the estuary, in order that the model may capture effects of changes such as depth, proximity to freshwater flows, aeration rates, proximity to marine flora and fauna, and other factors that may change with time and location. Tables 5 and 6 summarize the general data requirements for hydrodynamic and biogeochemical models, respectively, in estuarine and coastal systems. Specific model applications in specific locations may have either reduced or more stringent requirements for data.

Table 5. General Data Requirements for Estuarine/Coastal Hydrodynamic Models

Requirement	**Location**	**Frequency**	**Suggested Sources**
1. Model forcing			
Freshwater inflow	Major tributaries	daily	USGS, USACE
Water surface elevation	Model open boundary	hourly	Regional tide model or tidal constituents

Requirement	Location	Frequency	Suggested Sources
Temperature and salinity profiles	Model open boundary	hourly - daily	Regional model
Meteorological (wind, heat flux, precip, cloudiness)	Model interior	hourly	NOAA
2. Model cal/val			
Water surface elevation	Model interior, several sites	hourly	Pressure sensor on fixed station, tide gage
Temperature and salinity	Model interior, several sites	hourly - daily	Fixed station (for surface), regular boat surveys

Table 6. General Data Requirements for Estuarine/Coastal Biogeochemical Models

Requirement	Location	Frequency	Suggested Sources
1. Model forcing			
Flux in freshwater input (all species that are being modeled)	Major tributaries	Daily - monthly	
Air-sea flux (?)			
2. Model cal/val			
Water column (surface & bottom)	Model interior, several sites	Weekly-monthly	
Fluxes to sediment	Model interior, several sites	Monthly?	Sediment grab samples; sediment trap

Wish List

A short "wish list" of data desired by practicing modelers is included below. These are data that would aid in validating a model's output and may help in determining uncertainties.

a. Remote Sensing – high-resolution ocean color products (chlorophyll a, turbidity, POM, DOM)
b. Synoptic time series of flow for various tidal periods (spring and neap) collected by Acoustic Doppler Current Profiler across transects of primary channels/canals within the domain
c. Sediment trap data – for sediment flux measurements

VIII. SAMPLING DESIGN

The sampling design included in Appendix F will be evaluated at study sites to develop a working blueprint for sampling to assess nutrient related water quality conditions and trends and effects on biota in Gulf of Mexico coastal waters and their tributaries. Resource components included in the design are estuaries, near shore marine waters (out to about 3 nautical miles), and adjacent offshore waters beyond the influence of coastal input where background conditions exist (out to approximately the 30-m isobath). The design also monitors rivers that flow directly into estuaries, coastal marine waters, and rivers draining upland watersheds that are tributary to these waters, because fluxes of nutrients from these rivers are typically the dominant source of nutrients to coastal waters. Atmospheric deposition near the coasts will be included as will ground water in those areas where aquifers discharge directly to coastal waters. Details of the sampling design will be developed to allow sufficient spatial and temporal resolution in water quality and environmental conditions to support an analysis of the effect of variation in chemical constituents and environmental responses on the undesirable outcomes that are ultimately to be managed. Data from the proposed design will make a significant contribution to local evaluation of the effectiveness of management actions, identification of problems, and other objectives as described in this section. Results of analyzing effects of variation and uncertainty will be used to make recommendations about the intensity of monitoring agencies can expect in return for attaining a desired degree of uncertainty and a selected capability to encompass variation to within a desired margin of safety for critical conditions in the future. The results will also be used to demonstrate how to calculate a range of results within a selected statistical significance, a more valuable result than a single point estimate with no uncertainty considerations. In combination with comparable studies in other locations around the Gulf, data will also provide information toward a Gulf-wide evaluation of the minimum necessary monitoring necessary to develop coastal nutrient criteria.

IX. QUALITY ASSURANCE PLAN

A Quality Assurance Project Plan (QAPP) will be completed to document the planning, implementation, and assessment procedures of, and how specific quality assurance (QA) and quality control (QC) activities will be applied during this project. A detailed description of the QAPP process that will be followed is included in Appendix G.

A generic QA Project Plan will be developed to address the general, common activities of a program that are to be conducted at multiple locations or over a long period of time. A generic QA Project Plan will describe, in a single document, the information that is not site or time-specific but applies throughout the program. Application-specific information will then added to the approved QA Project Plan as that information becomes known or completely defined. A generic QA Project Plan shall be reviewed periodically to ensure that its content continues to be valid and applicable to the program over time.

X. REFERENCES

Bierman, JR., V.J., S.C. Hinz, D. Zhu, W.J. Wiseman, JR., N.N. Rabalais, and R.E. Turner. 1994. A preliminary mass balance model of primary productivity and dissolved oxygen in the Mississippi River plume/inner Gulf shelf region. Estuaries 17(4): 8886-899.

Bricker, S., B. Longstaff, W. Dennison, A. Jones, K. Boicourt, C. Wicks, and J. Woerner. 2007. Effects of Nutrient Enrichment in the Nation's Estuaries: A Decade of Change. NOAA Coastal Ocean Program Decision Analysis Series No. 26. National Centers for Coastal Ocean Science, Silver Spring, MD 322 pp.

Cloern, James E., 1987, Turbidity as a control on phytoplankton biomass and productivity in estuaries, Continental Shelf Research, Vol. 7, Nos. 11/12, 1367-1381.

Cloern, James E., 2001, Our evolving conceptual model of the coastal eutrophication problem, Marine Ecology Progress Series Vol. 210: 223-253.

Gordon, D. C, Jr., P. R.. Boudreau, K.H. Mann, J.-E. Ong, W.L. Silvert, S.V. Smith, G. Wattayakorn, F. Wulff and T. Yanagi. 1996. LOICZ Biogeochemical Modelling Guidelines. LOICZ/R&S/95-5, vi +96 pp. LOICZ, Texel, the Netherlands.

Hagy, J. D., J. C. Kurtz, and R. M. Greene. 2008. An approach for developing numeric nutrient criteria for a Gulf coast estuary. U.S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Research Triangle Park, NC. EPA 600R-08/004. 44 pp.

Hetland, R.D. and S.F. DiMarco. 2008. How does the character of oxygen demand control the structure of hypoxia on the Texas-Louisiana continental shelf?. Journal of Marine Systems: 49-62.

Justić, D., V.J. Bierman JR., D. Scavia, and R.D. Hetland. 2007. Forecasting Gulf's hypoxia: the next 50 years?. Estuaries and Coasts 30(5): 791-801.

Justić, D., N.N. Rabalais, and R.E. Turner. 2002. Modeling the impacts of decadal changes in riverine nutrient fluxes on coastal eutrophication near the Mississippi River delta. Ecological Modelling 152: 33-46.

Rabalais, N.N. and R.E. Turner. 2006. Oxygen depletion in the Gulf of Mexico adjacent to the Mississippi River. Pages 225-245 in L. N. Neretin, ed., Past and Present Marine Water Column Anoxia. NATO Science Series: IV-Earth and Environmental Sciences, Kluwer.

Rabalais, N.N., R.E. Turner, D. Justić, Q. Dortch, and W.J. Wiseman, Jr. 1999. Characterization of hypoxia: Topic 1 rep. for the Integrated Assessment of Hypoxia in the Gulf of Mexico. NOAA Coastal Ocean Program Decision Analysis Ser. no. 15. NOAA Coastal Ocean Program, Silver Spring, MD.

Ryan, D. A., Heap, A. D., Radke, L., and Heggie, D. T., (2003) Conceptual models of Australia's estuaries and coastal waterways: applications for coastal resource management. Geoscience Australia, Record 2003/09, 136 pp.

Scavia, D., D. Justić, and V.J. Bierman, JR. 2004. Reducing hypoxia in the Gulf of Mexico : advice from three models. Estuaries 27(3): 419-425.

Scavia, D., N.N. Rabalais, R.E. Turner, D. Justić, and W.J. Wiseman, JR. 2003. Predicting the response of Gulf of Mexico hypoxia to variations in Mississippi River nitrogetn load. Limnology and Oceanography 48: 951-956.

Turner, R.E., N.N. Rabalais, E.M. Swenson, M. Kasprzak, and T. Romaire. 2005. Summer hypoxia in the northern Gulf of Mexico and its prediction from 1978 to 1995. Marine Environmental Research 59: 65-77.

U.S. Environmental Protection Agency Science Advisory Board. 2008. Hypoxia in the northern Gulf of Mexico: An update by the EPA Science Advisory Board. Washington, D.C. EPA-SAB-08-004.

Whitall, DR and HW Paerl. 2001. Spatiotemporal Variability of Wet Atmospheric Nitrogen Deposition to the Neuse River Estuary, North Carolina . Journal of Environmental Quality 30:1508-1515

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More information on the Gulf of Mexico Alliance and work by the Nutrients and Water Quality Priority Issue Teams can be found at http://www2.nos.noaa.gov/gomex/nutrients/welcome.html.

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