BUOYANCY AND NUTRIENT EXCHANGE IN THE MISSISSIPPI RIVER OUTFLOW REGION

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Source Function Variability[1]

Daily-average water discharge values are plotted versus time for the lower Mississippi River (Figure 1). The time period shown spans the NECOP study period. Horizontal dashed lines near the top of the plot area correspond to NECOP-funded research cruise time windows. Asterisks are monthly averaged data points (per calendar month), and open octagons are annual average data points (per calendar year). Plotted sinusoid depicts the long-term (last forty years) annual average cycle of discharge with associated variation limits (shaded areas). Horizontal dashed line shows the long-term mean for the same period. Over the last several decades, approximately 80% of all monthly-average discharge values fall within the shaded region (10% above and 10% below). Most "outliers" are due to phase shifts in the annual cycle and do not exceed the absolute maximum or minimum of the shaded region. Note that the variation limits must be skewed in amplitude (~2:1) to account for the greater likelihood of

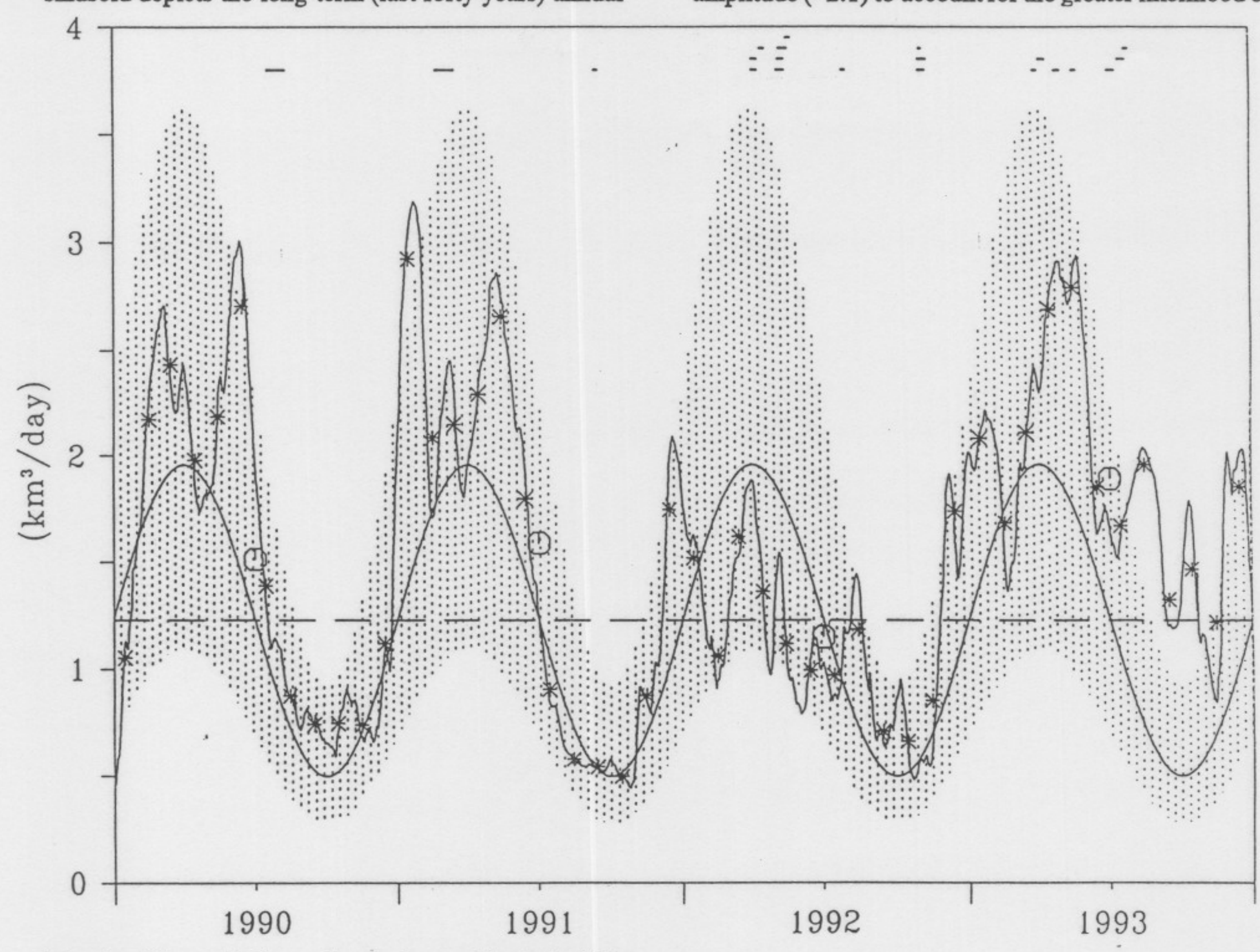

Fig. 1. Water discharge for the lower Mississippi River.

larger-than-average versus smaller-than-average flow events in a given month.

The annual average value for 1993 is about a 1-in-50 yr "event" based upon values observed since 1900. Elevated summer and fall flow is the anomalous aspect of this flow year as illustrated by the plot.

Hydrographic Fields and Fill Time Estimates[2]

Hydrographic survey data from four research cruises in the Mississippi River outflow region (Louisiana shelf) were analyzed. Data was collected for the NOAA Nutrient Enhanced Coastal Ocean Productivity (NECOP) program. Two cruises were aboard the Louisiana Universities Marine CONsortium (LUMCON) RV Pelican (12-19 April 1992 and 27 March-2 April 1993) and two were aboard the University of Texas RV Longhorn (14-21 May 1992 and 2-12 July 1993).

Louisiana shelf mean flow is generally westward from the Mississippi River Delta, and continuing past the Atchafalaya River Delta, over the winter and spring. Perturbations of this general flow are caused by east-to-west passage of cold fronts. Summer observations suggest possible flow reversal in the western portions of the region, with surface currents to the east.

The Mississippi River discharges into the northern Gulf of Mexico via the Mississippi Delta, of which an average 53% of the flow discharges directly to the west. Approximately 30% of the total Mississippi River System flow discharges via the Atchafalaya River 150 km to the west. Mississippi River daily discharge for the 1992 and 1993 NECOP survey cruise coverage was provided by the U.S. Army Corps of Engineers and was gauged at Tarbert Landing, MS, below the diffluence of the Atchafalaya River. Longterm monthly average flow have a maximum flow of ~22,000 m^3/s (±10,000 m^3/s) in April and a minimum flow of ~7,000 m^3/s (±2,000 m^3/s) in September. The 1992 flow was below average in the spring; while the 1993 flow was above average most of the year. At the time of the April 1992 survey daily discharges were ~15,000 m^3/s, ~6,000 m^3/s below the long-term average, but followed by three weeks the annual high flow of ~22,000 m^3/s. The May 1992 survey also followed a brief, relatively high flow period by two weeks, daily discharges were ~12,000 m^3/s, ~8,000 m^3/s below the annual average. The survey on April 1993 occurred before the annual high flow period; flows were ~27,000 m^3/s in April, ~5,000 m^3/s above the annual average. The highest flows in 1993 occurred in May and were ~35,000 m^3/s. For the July 1993 survey, flow was still ~5,000 m^3/s higher than the annual average, reaching ~18,000 m^3/s near the July cruise.

The general distribution of salinity had a fresher surface layer in the Mississippi Delta near-field (<100km) that evolved downcoast to meso-field (>100km) cross-shelf and vertical gradients. Surface salinities in 1992 had lowest values near the Mississippi Delta with strongest gradients gulfward. Low values extend <100 km to the west of the Mississippi Delta. Surface salinities >100 km to the west establish a parabathic pattern routinely seen on this shelf. Atchafalaya River outflow is seen against the coast west of the Atchafalaya Delta. Surface salinities in 1993 also had lowest values near the Mississippi Delta with the strongest gradients gulfward. There was an apparent surface freshening due east of the Mississippi Delta in April and due south in July. One hundred kilometers to the west the salinity contours again established a parabathic pattern. Atchafalaya River outflow was more readily observed on the inner shelf south and west of the Atchafalaya Delta.

The residence time of river discharge on the shelf is related to varying river discharge magnitudes. Residence times have been estimated for three regions for each of the four survey cruises. Region 1 corresponds to the near-field shelf west of the Mississippi Delta. Region 2 corresponds to the meso-field shelf at distances greater than 100 km from the Mississippi Delta outflow. Region 3 corresponds to the far-field shelf relative to the Mississippi Delta outflow but is the near-field shelf relative to the Atchafalaya Delta outflow.

Fill times are used to estimate the residence time of river water on the shelf. Fill time is defined as the length of time it took the river outflow to fill a volume of fresh water present on the shelf at any time.

The river outflows considered here are simply the Atchafalaya River discharge and that portion of the Mississippi River discharge flowing directly west. The volume of fresh water present on the shelf was determined as the volume sum of depth layers multiplied by the associated fresh water fraction, $f = (S_r - S)/S_r$, where S_r is a reference salinity chosen to be 36.3 °/oo, and S is the area weighted average salinity. Average salinity for each region was determined from area-weighted salinity fields produced from contoured cruise data at selected depths (1, 3, 5, 7, 9, 12.5, 17.5, 22.5, 27.5 and 32.5 m).

Regional fresh water volumes are presented in Table 1. In 1992 shelf freshwater volumes decreased from April to May. In 1993 shelf freshwater volumes increased from April to July. Both surveys in 1993 measured the greater volumes of fresh water on the shelf than surveys in 1992. The region proportion of freshwater volume was relatively constant for both surveys in 1992. In 1993 the proportions in the

Table 1. Fresh water volumes (in km^3) and proportion of total volume (in %) in the Mississippi and Atchafalaya Rivers outflow region.

Cruise	Region 1	Region 2	Region 3	Total
Apr 92	11.68	17.51	20.76	49.95
	23%	35%	42%	
May 92	8.14	12.55	14.04	34.73
	23%	36%	40%	
Apr 93	14.57	22.56	29.21	66.34
	22%	34%	44%	
Jul 93	17.05	25.66	46.63	89.34
	19%	29%	52%	

Mississippi Delta near- and meso-field regions decreased while the proportion in the Mississippi Delta far-field increased.

The vertical profiles of weighted salinity and fresh water fraction are similar, only the fresh water fraction is presented here for each region and cruise (Figure 2). The largest fresh water fraction in Region 1 is observed as a 10 m thick low salinity layer for each cruise. Region 2 again had most fresh water contained in a surface layer, but there is considerable more fresh water mixed to greater depths in the 1993 surveys. Although most of Region 3's fresh water is in a surface layer, the amount increases with depth.

Fill times can be determined for each region as if the riverine outflow discharged directly into the region itself (Table 2). This provides (and assumes a steady state in any upstream region) a lower limit estimate of residence time. In reality there will be a storage term (gain or loss of volume over time) for any upstream region. Although the limited data prevents a precise relationship, longer fill times (the fresh water is resident in a region longer) do occur during 1993, the higher discharge year. Region 3 appeared to be filled by the Atchafalaya River over approximately the same interval of time as Regions 1 and 2 were filled by the westward flowing Mississippi River flow. Using both flows the total regional freshwater volumes are filled in 1-1.5 months. Fill times for the Mississippi River near-field (Region 1) are < 2 weeks for moderate flows in 1992 and < 3 weeks for high flows in 1993. Fill times for the meso-field (Regions 2 and 3) are 30-50% longer during the high flows of 1993 than those for the moderate flows in 1992. Fill times in both years are very consistent between survey cruises.

Near-Field Variability of Nutrient and Bio-Optical Variables[3]

In order to understand the distributions of nutrient and hydrographic variables in the vicinity of the Mississippi River plume, relatively simple physical, nutrient, and biological model has been developed to test hypotheses resulting from the analysis of the hydrographic data sets. As part of the development of this model, multivariate analysis of several of the hydrographic data sets was performed to analyze the major components of variability within these data sets.

Intuitively and based on previous observations, one would expect several major components of variability associated with the Mississippi River plume. One major component would be the axis between the offshore relatively unmixed Gulf of Mexico water and the undiluted river water. It is expected that this component of variability would be correlated with salinity, nutrient concentrations, and suspended particulate matter concentrations. A second major component of variability is the vertical hydrographic gradients that are common to the coastal ocean. This component is often correlated with vertical gradients of temperature, salinity, and nutrients, and also with the distribution of phytoplankton biomass and pigments. A third component of the variability is likely to be correlated with phytoplankton productivity and biomass. This may be a part of the second component described or may be independent depending on the stratification and physical processes that determine the patterns of biomass and productivity. It is also common to have a

Table 2. Regional fill times (in days) using Mississippi and Atchafalaya River outflows.

Inputs	Direct Mississippi River			Atch. River	Miss. River	Both Rivers
	Region			Region	Total	Regions
Cruise	1	2	3	3		
Apr 92	10	19	22	29	69	31
May 92	11	19	22	27	45	29
Apr 93	14	24	33	39	68	41
Jul 93	19	26	40	49	69	42

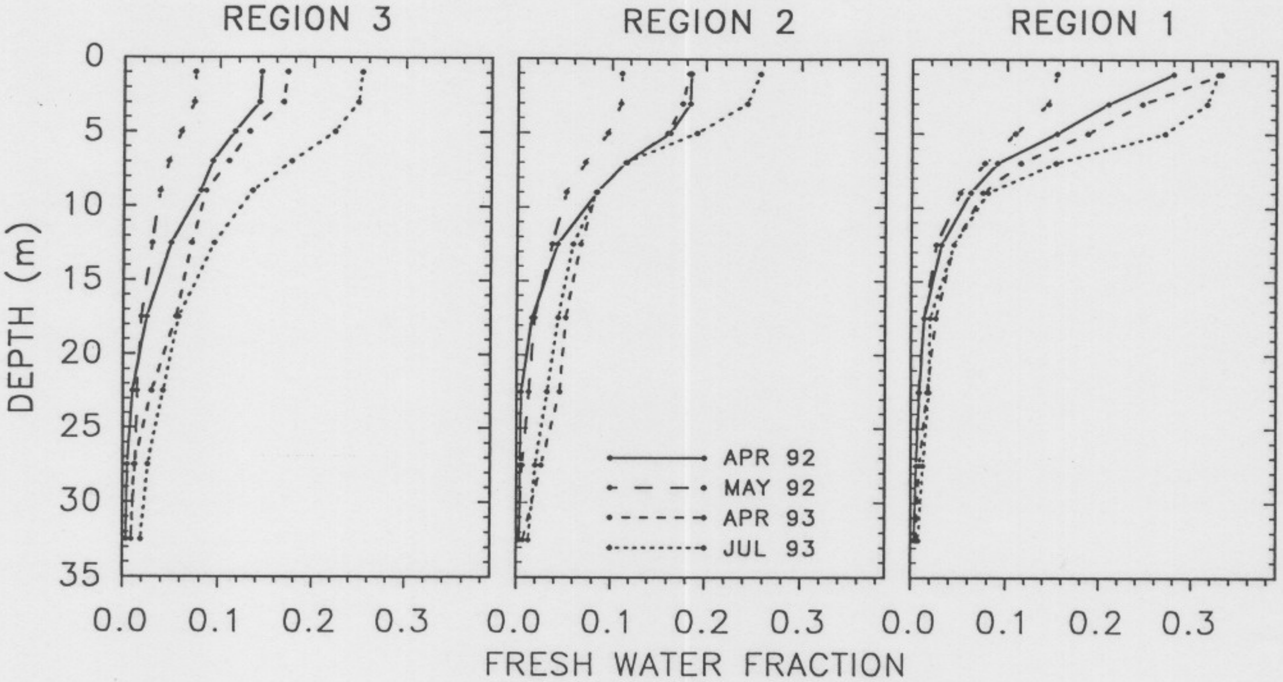

Fig. 2. Regional freshwater fraction for four survey cruises.

significant component of this variability dominated by ammonium and nitrite, indicative of nutrient regeneration processes.

In early July 1993 the R/V Longhorn hydrographic data set from that included relatively closely spaced stations in the vicinity of the Mississippi River outflow from Southwest Pass, the first three principal components accounted for 71% of the variability in the data set (Table 3).

The first component accounted for 39.3% of the variance, as expected it was dominated by salinity and beam c, indicative of high suspended particulate matter (SPM) concentrations. Other variables that contributed to this component include nitrate, phosphate, silicate, and chlorophyll fluorescence. The general trend of this component is that low salinity is correlated with high nutrients, SPM and chlorophyll fluorescence. The factor score for this component has the highest absolute value in the vicinity of Southwest Pass and decreases to the west and south.

The second component contained 21.8% of the variance in the data set. Temperature had the highest correlation with this component, suggesting that it may be related to the vertical structure in the water column. Oxygen and chlorophyll fluorescence were also correlated with this component, and nitrate was negatively correlated with this component. The trend in these variables are all consistent with the general pattern in vertical structure, but when mapped in the surface layer, highest absolute values are in the nearshore area and decrease offshore. In this particular component, the Mississippi River mouth and deep water appear to have similar values. So it appears that both the vertical structure and the biomass/productivity gradients are part of this component.

The third component accounted for less than 10% of the variance. It was strongly correlated with both nitrite and ammonium, indicating that it was

Table 3. Results of principal components analysis of bottle variables.

	Principal component loading of each variable				
	1	2	3	4	5
% of variance	39.3%	21.8%	9.6%	7.3%	6.0%
Variable					
Temperature	-0.309	-0.739	-0.043	0.037	-0.211
Salinity	0.846	0.434	0.082	0.050	0.074
Sigma-t	0.811	0.522	0.083	0.037	0.104
Oxygen	-0.159	-0.598	0.086	0.086	0.432
Beam C	-0.878	-0.153	-0.073	-0.197	0.069
Chlor. Fluor.	-0.668	-0.474	-0.032	0.007	0.059
PO_4	-0.622	0.593	-0.045	-0.208	-0.064
SiO_4	-0.691	0.215	-0.142	-0.281	-0.144
NO_3	-0.703	0.544	-0.049	0.164	0.164
NO_2	-0.271	0.087	0.741	-0.425	-0.489
NH_4	-0.257	-0.049	0.743	0.358	0.397

representative of nutrient regeneration processes in the system. In the surface layer it generally decreased from east to west, suggesting that there was a measurable input of both of these nutrients related to the Mississippi River plume. Either the plume contained elevated concentrations of these two nutrients, or the high organic load of the river was undergoing nutrient regenerative processes as it entered the coastal region. Oxygen concentration did not seem to have any relationship to this component in the July data set.

Another relationship of the variables in this analysis that has not been brought out in the above discussion is that beam c and silicate concentration, mapped closely with each other in principal component space. This may result from both beam c levels (SPM) and silicate being high in the Mississippi River. It may also suggest that there is significant regeneration of silicate occurring in relationship to high concentrations of SPM.

In this particular analysis, oxygen concentrations and temperatures are correlated with each other and with the second principal component. Both are relatively uncorrelated with the first principal component. This appears to be primarily correlated with the vertical hydrographic structure, and with primary productivity. One might infer from this result that low oxygen water is unrelated to the inputs from the Mississippi River water. However, the correlations that exist within a data set do not explain the pathways leading from one variable to another variable. Therefore, concluding that low oxygen water is not coupled to the nutrient input would not be warranted based on this analysis alone.

As in the source data, the gradients in the principal component scores are very large in the vicinity of the Mississippi River plume and indicate the spatial variability in this region is very large. In a study such as this, it is difficult to adequately resolve this variability.

Nutrient Concentrations in the Gulf of Mexico Resulting From Summer 1993 Mississippi/Atchafalaya River Outflows[4]

The discharge of the Mississippi/Atchafalaya Rivers (MAR) carries large quantities of dissolved nutrients of nitrogen, phosphorus and silicon and there are clear indications that their concentrations have increased in the river water over the past four decades as agricultural fertilizer application in the watershed have increased. The nutrients in the freshly discharged river are utilized rapidly by phytoplankton growth after entering the relatively low nutrient Gulf of Mexico waters. While dissolved silicon and phosphorus are important to support the phytoplankton growth, nitrogen in the form of nitrate is normally the most critical nutrient necessary to promote rapid plant growth. However, there are strong indications that the changing proportions of nitrogen, silicon and phosphorus in the river water have affected the amounts and types of plants that respond to the nutrient efflux.

The typical nitrate concentration observed at the mouth of the MAS ranges from 60 to 120 micromoles per liter. Values in the range of 150-200 micromoles per liter were measured in July 1993 during the period of flooding in the upper river basin. This corresponds closely to those values reported in the lower Mississippi River by Goolsby (in Dowgiallo, 1994) at that time. The excess water in 1993 that caused flooding appeared to mobilize more of the applied fertilizer than in a normal rainfall year and the higher than normal water speeds of the river may have increased turbidity and shortened transit time in the lower river which, in turn, reduced biological uptake and removal rates that occurred in the lower reach of the river proper.

The plume of the Mississippi River near Southwest Pass as defined by elevated nitrate concentrations was similar in size to the other summer periods from the previous six years, but the higher

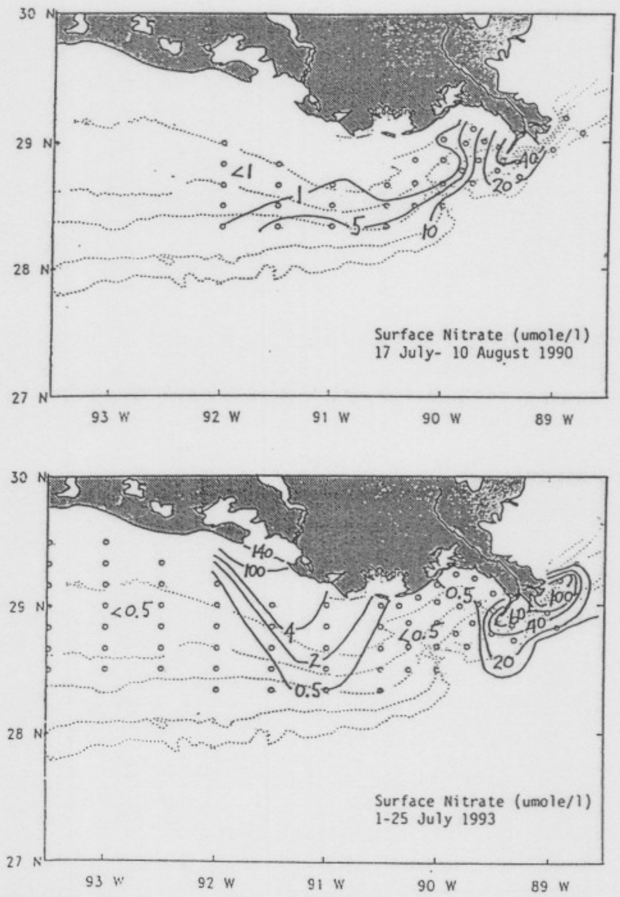

Fig. 3. Surface nitrate distributions in the Gulf of Mexico during July-August 1990 and July 1993.

initial concentrations meant that the horizontal gradients were also very large indicating rapid phytoplankton utilization (Figure 3). The uptake of nutrients was rapid enough to reduce concentrations to less than 1 micromole per liter within a 30 mile radius of the discharge point. Regenerated nutrients begin to become relatively important in this region since 40 to 80% of the available nitrogen is in the form of ammonium. As the discharged water moves even further away from the discharge points the regenerated nitrogen continues to be produced by microbial processes and maintains the enhanced productivity of the river water over a very large area. The total area affected as shown by enhanced chlorophyll concentrations during 1993 is still being assessed but it was certainly larger than normal.

References

1. Bratkovich, A., S.P. Dinnel, B. H. Jones, and T. Whitledge, 1994. Mississippi River fluxes and shelf impacts. AGU Ocean Sciences Meeting, Feb. 1994, San Diego, CA. Abstract published in EOS, Transactions American Geophysical Union, 1994, 75(3).

2. Dinnel, S.P., A. Bratkovich, B. H. Jones, and T. Whitledge, 1994. Louisiana shelf freshwater fill times relative to Mississippi River outflow. AGU Ocean Sciences Meeting, Feb. 1994, San Diego, CA. Abstract published in EOS, Transactions American Geophysical Union, 1994, 75(3).

3. Jones, B.H., A. Bratkovich, T. Whitledge, and S.P. Dinnel, 1994. Near-field variability of nutrient and bio-optical variables in the Mississippi River plume in the Gulf of Mexico. AGU Ocean Science Meeting, Feb. 1994, San Diego, CA. Abstract published in EOS, Transactions American Geophysical Union, 1994, 75(3).

4. Whitledge, T.E., 1994. Coastal oceanographic effect of summer 1993 Mississippi River flooding. M.J. Dowgiallo, ed., Special NOAA Report, Silver Spring, MD, 77p.

Nutrient-Enhanced Coastal Ocean Productivity

Proceedings of 1994 Synthesis Workshop

Baton Rouge, Louisiana

National Oceanic and Atmospheric Administration
Coastal Ocean Program Office

Program Management Committee

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Produced by **Louisiana Sea Grant College Program**
Louisiana State University Baton Rouge, Louisiana 70803

1995

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