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Monitoring the Coastal Ocean: Responses to Hurricane Floyd

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INTRODUCTION

Hurricane Floyd struck coastal North Carolina in Sept. 1999 with extraordinary rainfall, causing unprecedented flooding. The impacts of the hurricane on the coastal ocean, particularly the discharges of contaminated floodwaters from the Cape Fear River to the coastal ocean, were studied by a combination of monitoring programs, including a newly funded Coastal Ocean Monitoring program conducted by the University of North Carolina at Wilmington. A series of sampling cruises yielded measurements of many important water quality parameters as the floodwater discharge proceeded. The very great volume of floodwater from the Cape Fear River produced a plume of highly discolored, relatively fresh water extending well out to sea and into South Carolina coastal waters. The floodwater plume exhibited lower nutrient, fecal coliform and chlorophyll concentrations, and higher dissolved oxygen concentrations than were expected from the numerous waste spills upstream.

Public concerns about water quality and other impacts of the flooding were a major issue. The safety of water for drinking and recreational uses was a paramount concern, as was the safety of seafood products. Although data produced by the monitoring programs in place at the time of Hurricane Floyd helped address some of these issues, it is clear that major gaps in data collection, sampling efforts and the distribution of information remain. Monitoring programs that plan data collection and dissemination efforts with disastrous events in mind can serve public needs much more effectively than routine data collection efforts.

Hurricane Floyd

Hurricane Floyd struck eastern North Carolina Sept. on 15-16, 1999 as a Category 2 hurricane with maximum sustained winds at landfall at Oak Island in Brunswick County, North Carolina, of approximately 100 mph (167 kph). Although the storm had weakened considerably in the 48 hours

prior to landfall at approximately 0230, Sept. 16 (from maximum sustained winds of 155 mph (260 kph) at 0900, Sept. 14), its major impact was from torrential rains beginning in the early morning of Sept. 15. Rainfall totals for Sept. 14-16 were as high as 50-60 cm in portions of eastern North Carolina, with highest rainfalls in the lower Cape Fear River basin (data from the National Weather Service, Wilmington Office). These rains fell on an area that had already received substantial rains from Hurricane Dennis during the period Aug. 30 – Sept. 7, saturating soils throughout the coastal plain region. The resulting combination of heavy rains and saturated soils created record-setting flooding throughout eastern North Carolina, with especially severe flooding in the Northeast Cape Fear, Black, Neuse, and Tar River basins.

Flooding and storm-associated power outages caused extensive failures and discharges from waste treatment systems throughout the impacted region. Eastern North Carolina supports the densest concentration of concentrated animal feeding operations (CAFOs) in North America, with especially large populations of swine and turkeys and somewhat smaller concentrations of broiler chickens and cattle. Waste manures produced by CAFOs are generally land-applied, usually as dry litter by poultry CAFOs and as spray-applied liquid from waste lagoons by swine CAFOs. Animal wastes entered floodwaters from Hurricane Floyd through direct surface runoff of land-applied wastes, lagoon breaches, and by external overtopping of waste lagoons at lower elevations. Human waste treatment systems also discharged large quantities of untreated or poorly treated wastes through bypasses of treatment facilities that were flooded or lost power, overtopping of treatment facilities at lower elevations, overflow of collection systems owing to storm water infiltration, and flooding of septic tanks. Several industrial waste storage lagoons also breached, releasing various waste chemicals. Flooded vehicles, storage tanks, and other small but widespread sources released a variety of hydrocarbons and other chemicals into floodwaters. Finally, floodwaters flushed large volumes of swamp water, typically low in dissolved oxygen and high in Biological Oxygen Demand (BOD), from Coastal Plain wetlands and river-bottom swamps. As a result of these pollutant releases, most of which were discovered quickly, there was widespread concern about water quality downstream, particularly as flooding from previous hurricanes had created severe water quality impacts in this region.

Flooding caused by Hurricane Fran in Sept. 1996 caused very large quantities of wastes and BOD from the same sources cited above to enter the Cape Fear River system, resulting in extremely low dissolved oxygen levels throughout much of the basin, especially the Northeast Cape Fear River, and causing fish kills and malodorous conditions for up to a month after the storm (Mallin et al., 1999). Hurricane Bonnie in 1998 and the spring 1998 El Niño rains also produced flooding in the Cape Fear River system, but to a lesser degree and with relatively minor impacts. Consequently, there was concern that flooding from Hurricane Floyd might have severe water quality impacts, but no firm basis for predicting actual impacts.

MONITORING PROGRAMS

Monitoring in the lower Cape Fear River has been conducted since 1995 by the University of North Carolina at Wilmington under the direction of Dr. Michael Mallin (Mallinm@uncwil.edu). This effort pools financial support from a group of NPDES dischargers in the lower basin for the sampling work, satisfying their respective permit requirements and providing the University with a long-term data base on water quality. Sixteen sampling stations have been established throughout the lower Cape Fear basin, extending from stations on the lower Black, Northeast Cape Fear, and main stem Cape Fear Rivers to the mouth of the estuary near Southport, NC. Sampling is conducted monthly for a variety of parameters, including conventional physical, chemical and biological variables, i.e., salinity, temperature, dissolved oxygen, nutrients, chlorophyll *a*, as well as metals.

UNC Wilmington also conducts a Tidal Creeks monitoring and research program with support from New Hanover County. This effort aims to monitor water quality in the small estuaries along the county's Atlantic side, identify possible remedies for problems, and evaluate their effectiveness. Water samples are collected monthly in 5 tidal creeks and the adjacent IntraCoastal Waterway. This project is also directed by Dr. Mallin.

UNC Wilmington has begun a new Coastal Ocean Monitoring program funded by a congressional appropriation through NOAA's Oceanic and Atmospheric Research office. Funding for this effort was received in late August 1999 and work began on Sept. 1, just before the region was struck by Hurricane Floyd. The overall monitoring program includes several elements that supported subsequent work in response to Hurricane Floyd's flooding, including studies of the Cape Fear River plume's chemical and biological effects on the coastal ocean and measurement of physical, chemical and biological properties of coastal ocean waters. The Principal Investigator for this program is Dr. Lawrence B. Cahoon (Cahoon@uncwil.edu).

Response to Hurricane Floyd

Hurricane Floyd did relatively little damage along the coast and it became quickly apparent that flooding was the major impact of the storm. News of the flooding effects also developed quickly, with numerous reports of waste spills and contamination. Consequently an effort to assess the effects of the flooding on coastal water quality was both physically possible and highly desirable.

Water quality sampling efforts began with sampling by the Cape Fear River program on Sept. 22 and by the Coastal Ocean Monitoring program on Sept. 23 using UNC Wilmington's vessels. The extent of flooding impacts on the coastal ocean was obviously quite impressive, so additional assets were sought to assist with the ocean monitoring work. NOAA's NESDIS program made satellite imagery available for use in assessing turbidity and chlorophyll levels in the coastal ocean. These images then guided sampling efforts by research vessels. Owing to the large extent of the plume of river water in the nearshore ocean we used a larger oceanographic vessel, R/V CAPE HATTERAS, for two sampling cruises (Oct. 1, 1999 and Oct. 7-8, 1999). Financial support was provided in rapid response by UNC Sea Grant, the National Sea Grant Office, the National Undersea Research Center at UNC Wilmington, and the Duke-UNC Oceanographic Consortium.

COASTAL OCEAN WATER QUALITY

Several potential water quality problems were suggested by experiences after previous hurricane floods: low dissolved oxygen, stimulation of algae blooms by nutrient loading, and microbiological contamination. Our sampling efforts were designed to determine if these problems occurred and, if so, quantify their magnitude and extent.

The flood waters were characterized by high turbidity, high levels of coloring material, lowered salinity, and cooler temperatures than typically observed at our sampling stations in September. Secchi depths (a measure of water transparency) in the mouth of the river were as low as 0.35 m, compared to normal values of > 1 m.

Dissolved Oxygen

On the cruises conducted Sept. 23, Sept. 28, and Oct. 14, surface dissolved oxygen values were measured using a hand-held YSI 85 DO meter with automatic temperature and salinity compensation.

Dissolved oxygen in surface water and in bottom waters was measured using the Winkler method for the more extensive cruises on Oct. 1 and Oct. 7-8. Dissolved oxygen levels in the freshwater portions of the Cape Fear River were as low as 2.0 milligrams per liter (mg/l) in the first week after Floyd and rose subsequently. Some dissolved oxygen levels in the river's ocean plume were below the NC standard of 5.0 mg/l in the first two weeks after the hurricane, but most sampled waters had reached levels above that standard by the Oct. 7-8 cruise (Table 1). Stratification of the coastal ocean waters suggested the possibility of oxygen depletion in the layer below the pycnocline, but dissolved oxygen levels in this layer were found to be as high as surface levels. As of Oct. 14 dissolved oxygen values were generally above 5.0 mg/l in the Cape Fear River Estuary and adjacent ocean waters. These dissolved oxygen data indicated that although there was a discernible impact from the hurricane flood, dissolved oxygen levels did not get low enough to cause major fish kills; no fish kills were observed in the estuary or coastal ocean.

Table 1. Results of dissolved oxygen (DO) sampling in the Cape Fear River's lower estuary and ocean plume, Sept. 23, 1999- Oct. 14, 1999, indicating surface or bottom samples (S/B), number of stations (# Sta.), and range of DO values in milligrams/liter.

Sample Dates	S/B	# Sta.	DO, mg/l
Sept. 23, 1999	S	6	3.0-6.5
Sept. 28, 1999	S	6	3.45-6.35
Oct. 1, 1999	S	13	4.26-7.00
Oct. 7-8, 1999	S	25	4.53-7.73
Oct. 7-8, 1999	B	17	5.18-8.75
Oct. 14, 1999	S	8	4.46-6.06

Chlorophyll *a*

Chlorophyll *a* concentrations in the Cape Fear River estuary and the coastal ocean (measured by fluorometry using a Turner 10-AU fluorometer according to Welschmeyer [1994]) never exceeded 5.0 $\mu\text{g/l}$ during the period Sept. 28 – Oct. 14 (Table 2). Concentrations in the surface waters of the flood plume averaged about 1 $\mu\text{g/l}$, well below the North Carolina standard of 40 $\mu\text{g/l}$, and were actually higher in ocean water unaffected by flood waters.

Table 2. Results of chlorophyll *a* sampling in the Cape Fear River's lower estuary and ocean plume, Sept. 23, 1999- Oct. 14, 1999, indicating number of stations (# Sta.), and range of chlorophyll *a* values in micrograms/liter.

Sample Dates	# Sta.	Chla, $\mu\text{g/l}$
Sept. 23, 1999	6	0.7 - 2.6
Sept. 28, 1999	6	0.8 - 3.0
Oct. 1, 1999	13	0.6 - 1.1
Oct. 7-8, 1999	27	0.6 - 4.6
Oct. 14, 1999	8	1.22 - 2.52

Nutrients

Water samples for total nitrogen and total phosphorus were digested using the wet persulfate method (Valderrama, 1981) and analyzed for nitrate and orthophosphate using standard wet chemistry methods on an Alpkem Flow Solution 3000 autoanalyzer. Concentrations of total nitrogen and phosphorus were relatively low compared to values at comparable salinities typically observed by the Cape Fear River program during non-flood conditions (Figures 1 and 2).

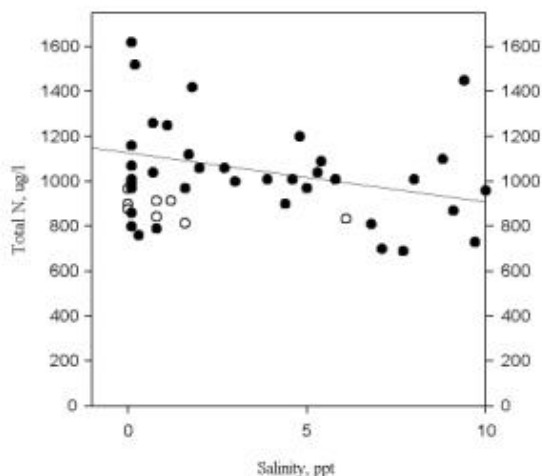


Fig. 1. Total nitrogen (micrograms per liter) in the Cape Fear River vs. salinity. Open circles are data from samples taken after Hurricane Floyd. Closed circles are data from samples collected in the previous 12 months.

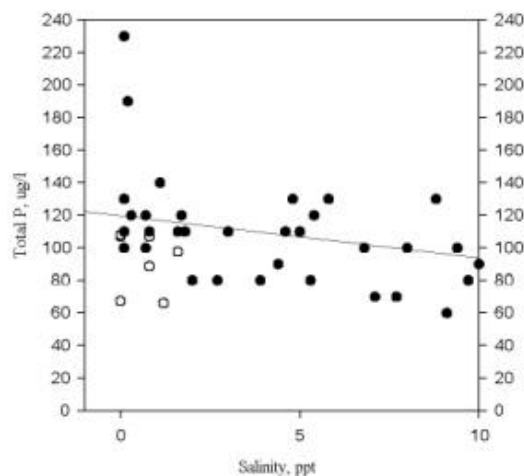


Figure. 2. Total phosphorus (micrograms per liter) in the Cape Fear River vs. salinity. Open circles are data from samples taken after Hurricane Floyd. Closed circles are data from samples collected in the previous 12 months.

Microbiological Contamination

Fecal coliform analysis was performed using the mFC method (APHA, 1995). Subsequent analysis of anomalous colonies employed API 20 tests to identify bacteria species present on the coliform test filters. Fecal coliforms (usually = *E. coli*) were present at low concentrations in all samples. The NC standard for body contact is 200 Colony Forming Units (CFU) per 100 ml. All samples collected on Sept. 23 were below this standard. All samples collected from ocean waters were at or below 3 CFU/100 ml. These values would normally indicate that these waters were microbiologically safe for swimming. However, the pathogens *Salmonella*, *Shigella*, *Klebsiella*, and other potentially pathogenic species were identified in at least one sample, suggesting that coliform counts were not an adequate indicator of microbiological contamination in this situation. It is likely that much of the microbiological contamination observed was derived from local sewage and animal waste sources, not from sources much further upstream.

SUMMARY

The major water quality impacts feared in response to the flooding from Hurricane Floyd did not materialize in the Cape Fear River Estuary or the coastal ocean downstream of the river mouth. Very high volumes of floodwater were discharged, but aside from the high turbidity and color associated with this water, nutrient and chlorophyll a levels remained low and dissolved oxygen levels did not fall low enough to cause mortality among aquatic organisms. We attribute these results to the very high dilution of nutrient and organic loadings to the river by the extremely heavy rainfall associated with Floyd. Rain water is naturally low in nutrients and high in dissolved oxygen. Previous hurricanes, especially Fran, may have driven similarly heavy loadings of nutrients and organics but with substantially less dilution, thus causing major water quality impacts. Therefore, we should consider that no two hurricanes are alike, with a spectrum of possible effects. Also, a series of storms occurring in quick succession likely created different effects than if they had occurred with more time in between to allow return to pre-storm conditions.

Public concerns about water quality were a major issue for the Cape Fear region. Results of this monitoring effort were able to assuage many of these concerns. We have been able to reassure the local citizenry and visitors to the area that water quality in the coastal ocean recovered within about one month of Hurricane Floyd, and that impacts were not as severe as first feared.

Although our response to Hurricane Floyd was reasonably effective, it was very much an ad hoc effort. The lack of data on normal conditions in the coastal ocean, lack of automated data collection systems that would have provided coverage throughout the storm and immediate aftermath, and the damage associated with such powerful storms all make effective, planned monitoring of these events difficult. Nevertheless, the importance of these events makes such efforts necessary. UNC Wilmington's monitoring programs are now well positioned to address this need in this region.

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