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Spatial Distribution of Sediments Within the Charleston Harbor Estuary Following Drainage Modification

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ABSTRACT

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The Charleston Harbor estuary in South Carolina experienced major changes in hydrographic conditions in 1985 as a result of discharge modification in the Cooper River. Monthly mean flow was reduced from 418 to 122 m^3/sec. In 1988, the spatial distribution of surficial sediments was surveyed by sampling 178 sites throughout the lower portion of the estuary. Results from this survey provided a basis for comparisons with data collected from a similar study conducted prior to rediversion in 1972. Sediment distribution patterns observed throughout most of the study area during 1988 were generally similar to those observed during 1972, with the exception of localized changes along the east bank of the Cooper River, the lower Ashley River and the upper harbor basin. These differences were not attributed to rediversion, since similar differences were also noted in other studies conducted prior to the major alteration in water flow through the Cooper River.

ADDITIONAL INDEX WORDS: *Charleston Harbor, fluvial deposition, river discharge, river diversion, sedimentation, sediments.*

INTRODUCTION

Charleston Harbor occupies the lower portion of a large, productive estuarine system located in the central portion of South Carolina's coast line. The harbor also serves as a major naval and commercial seaport (Figure 1). Historically, the maintenance and deepening of shipping channels for these port facilities have required an extensive and costly dredging program.

Prior to 1985, sedimentation in Charleston Harbor was primarily attributed to the construction of a water diversion project that was completed in 1942 (Figure 1). The Cooper River, once a drainage for 3,077 km^2 of the Coastal Plain of South Carolina, suddenly became the major discharge route for 40,674 km^2 of the Santee watershed and mean fresh water discharge from the Cooper River increased from 2 to 418 m^3/sec (DAVIS and VAN DOLAH, 1992; NEIHEISEL and WEAVER, 1967; KJERFVE, 1976). The ensuing increase in suspended sediments from upland sources, bedscour, bank erosion, and disruption of the estuarine hydrography resulted in significant annual increases in the amount of dredging required to maintain the channels (U.S. ARMY CORPS OF ENGINEERS, 1966).

In response to increased shoaling attributed to the 1942 diversion project, the U.S. Army Corps of Engineers constructed a rediversion canal that was completed in 1985 (Figure 1). This project rediverted approximately 70% of the fluvial discharge of the Cooper River back into the Santee River. Freshwater flow into the Cooper River was to assume a relatively stable average of 122 m^3/sec. The anticipated hydrographic changes prompted numerous concerns regarding physical and biological changes in the estuary (WATER RESOURCES COMMISSION, 1979; U.S. ARMY CORPS OF ENGINEERS, 1975). Several studies were initiated to evaluate changes in the hydrographic conditions and biological communities of the Charleston Harbor estuary (VAN DOLAH *et al.*, 1990). In two of these studies, the composition of surficial bottom sediments was described as part of an effort to evaluate changes and distribution patterns of benthic infaunal communities present in this estuary. One study evaluated temporal changes in the sediments and benthos over a four-year period, encompassing rediversion at 10 index stations located throughout the estuary. The other study evaluated spatial distribution patterns in surficial sediments and the benthos at 178 sites located throughout the lower portion of the estuary (Figure 2). This survey was conducted in 1988, three years after rediversion. The results were compared with data obtained from an earlier study by COLQUHOUN (1972), who conducted a thorough evaluation of local stratigraphy and sedimentation in Charleston Harbor during 1971. Results obtained from our sedimentological analyses provide an updated and expanded perspective of sediment distribution for this estuarine system.

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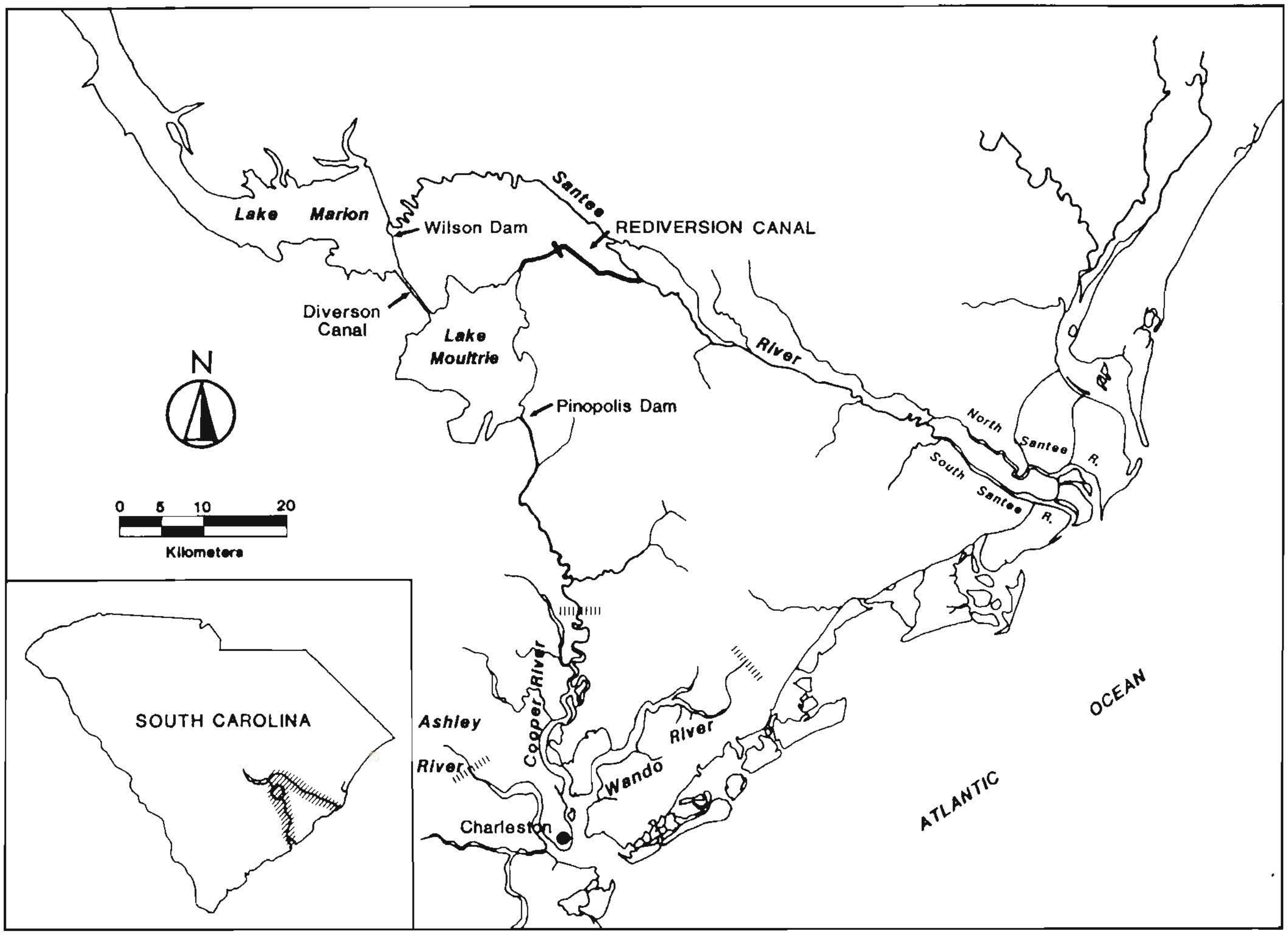

Figure 1. Map of the lower Santee/Cooper drainage system. Dashed lines across each river indicate the approximate extent of the estuary.

SITE DESCRIPTION

The Charleston Harbor estuary is formed by the confluence of the Cooper, Ashley and Wando Rivers (Figure 1). The estuary includes more than 260 km^2 of valuable coastal marshlands and open-water habitat and drains an area of over 41,000 km^2 (TINER, 1977; NOAA, 1985) (see U.S. ARMY CORPS OF ENGINEERS, 1966 for detailed maps of watersheds). Estuarine waters extend from the harbor entrance to distances of more than 30 km above the mouths of all three river systems (VAN DOLAH and ANDERSON, 1991) which are well beyond the extent of our sampling sites.

The Charleston Harbor basin below the mouth of each river covers an area of 65 km^2 (VAN DOLAH *et al.*, 1990). The average depth of the lower harbor basin is 3.7 m and navigational channels in the harbor are maintained at approximately 12 m in depth. Charleston Harbor has a "semi-diurnal" tide with a mean tidal range of approximately 1.6 m and salinities typically range from 24–33 ppt following rediversion (DAVIS and VAN DOLAH, 1992; VAN DOLAH and ANDERSON, 1991).

The lower Cooper River drainage basin comprises an 80.5 km section from the Pinopolis Dam to its confluence with Charleston Harbor (Figure 1). Navigational channel depths are maintained at depths of approximately 11–12 m for a distance of 32 km upstream from the mouth of the river. Tidal changes occur up to the dam. The Cooper River has the greatest concentration of industrial development among the three rivers. Most of this is concentrated on the western shore, and includes a naval base, state port facilities and several commercial industries (Figure 2).

The Ashley and Wando Rivers flow 50 km and 38 km respectively from their headwaters in swamps within the South Carolina Coastal Plain. Natural channel depths in the Ashley River range from 1.8 m to 11.0 m. Wando River channel depths range from 1.5 m to 12.8 m. Both rivers are influenced by tidal action throughout their entire lengths.

METHODS

The 178 stations selected for the 1988 survey included both channel and non-channel bottom habitats. Stations were lo-

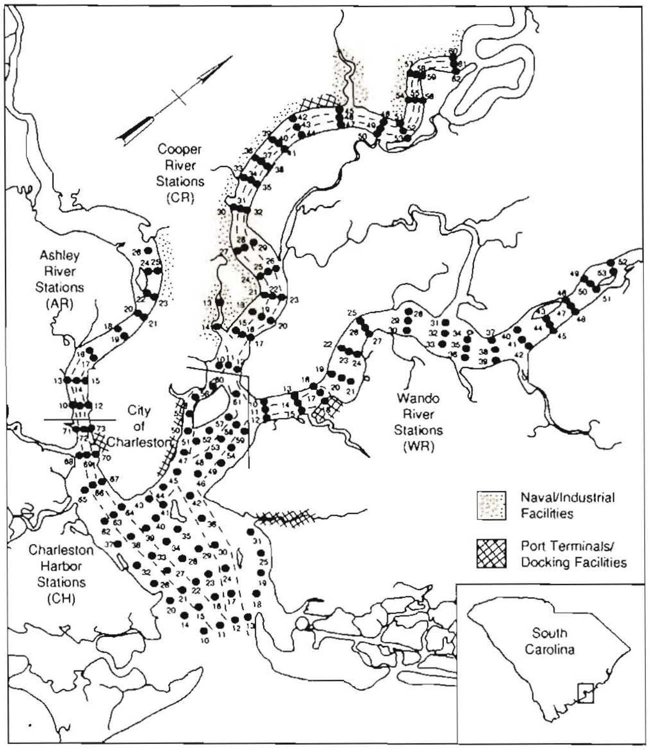

Figure 2. Map of the lower Charleston Harbor estuary and location of stations sampled for the special benthic study.

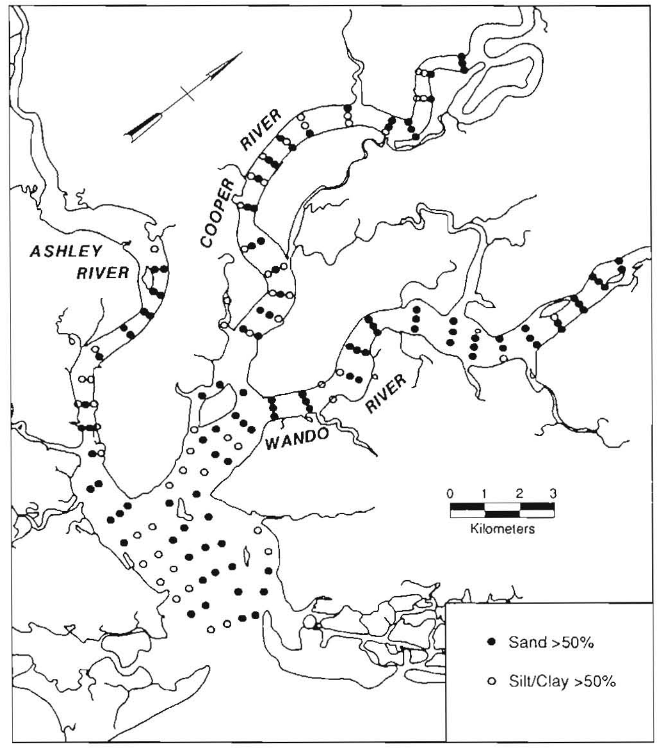

Figure 3. Dominant grain size distribution in the lower Charleston Harbor estuary.

cated equidistantly along transects that were perpendicular to the maintained navigational channels and separated by a distance of approximately 1 kilometer from one another (Figure 2). The three meter depth zone marked the shoreward extent of each transect. Loran-C was used to position the vessel during sampling with loran coordinates ground-truthed by using fixed landmarks throughout the study area. Surficial sediment were collected at each station using a 0.05-m^2 ponar grab. A vertical cross section of the grab sample was obtained by inserting a 3.4 cm diameter coring tube into the grab sample to the base of the grab, providing approximately 100 ml of sediment for analysis of sediment grain size and composition.

In the laboratory, sediment samples were analyzed to determine percent weights of sand, calcium carbonate, silt, and clay fractions using procedures described by FOLK (1980) and PEQUEGNAT *et al.* (1981). Noncarbonate sand fractions were dry sieved using a Ro-Tap mechanical shaker and fourteen ½ phi interval screens for grain size determinations. Measurements of organic matter content were obtained by burning a portion of each sample at 550 °C for 2 hours as described by PLUMB (1981).

RESULTS AND DISCUSSION

The distribution of surficial sediments observed during our 1988 survey was generally similar to that described by COLQUHOUN (1972). As with the 1972 survey, sand was the major component (> 50%) in 112 of the 178 sediment samples that we collected throughout the study area (Figures 3 and 4). Similarly, the Wando River had the highest percentage of stations (86%) with predominantly sandy sediments. All three river systems and the harbor basin had at least 51% of the stations where sand was the major sediment component.

Fine-grained sediments (< 63 microns) occurred more frequently in the Cooper and Ashley Rivers than in the Wando River (Figures 3 and 5). The Cooper River had the highest percentage of stations (43%) with predominantly silt/clay sediment fractions. Mann-Whitney U tests revealed no significant differences between channel and non-channel stations with relation to the occurrence of silt and clay throughout the system ($p \leq 0.05$).

Organic matter was widely distributed throughout the study area, and 40 stations had greater than 10% organic content by weight. All of these stations were in areas where silt/clay fractions comprised the majority of the sediment sample.

Calcium carbonate was also widely distributed throughout the survey area, with 33 stations having more than 10% $CaCO_3$ content by weight (Figure 6). The majority of these stations were in the lower harbor basin and Wando River, at sites where sand was the major sediment component. However, dissimilar methods in carbon analysis prevent direct comparisons of this component between the two surveys.

Prior to rediversion, the Charleston Harbor estuary was

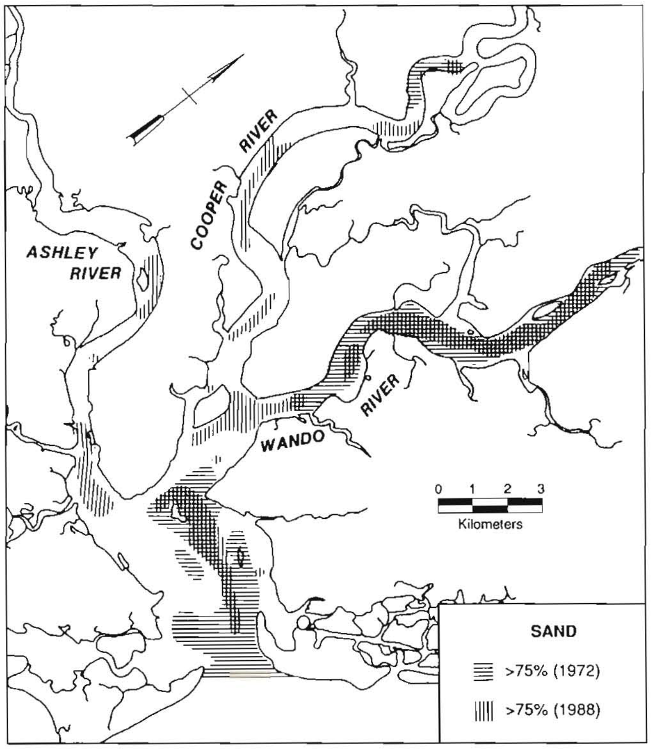

Figure 4. Comparison of percent sand in surficial sediments of the lower Charleston Harbor estuary. The 1972 data was derived from Colquhoun, 1972.

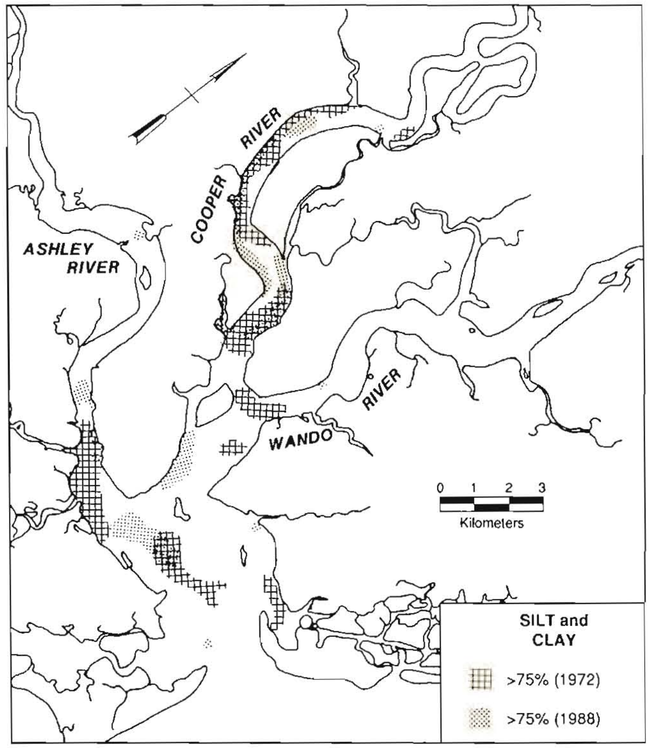

Figure 5. Comparison of percent silt and clay in surficial sediments of the lower Charleston Harbor estuary. The 1972 data was derived from Colquhoun, 1972.

vertically stratified with tides and fresh water flow being the primary factors controlling gravitational circulation patterns in the lower estuary (U.S. ARMY CORPS OF ENGINEERS, 1966; NEIHEISEL and WEAVER, 1967). The saltwater wedge resulting from this stratification was considered to be the primary factor responsible for sedimentation in the lower Charleston Harbor estuary (SIMMONS, 1966; U.S. ARMY CORPS OF ENGINEERS, 1966; MEADE, 1969). SIMMONS (1966) estimated that this wedge extended to about 2 km above the mouth of the Cooper River, which corresponds to stations CR18–20 of our survey (Figure 2). Hence, a zone of no-net motion resulting from the saltwater wedge caused sediment to become entrained within this region, settling where tidal current was temporarily insufficient for further transport, only to be resuspended and redeposited within this zone during subsequent tidal cycles (NEIHEISEL and WEAVER, 1967; VAN NIEUWENHUISE, 1978). After rediversion, the estuary remained stratified, becoming vertically well-mixed during spring tides (KJERFVE, 1989).

Prior to 1985, the Cooper River was considered to be the major source for fluvial sedimentation in Charleston Harbor, since the flow through this river was much greater than the flows through the Ashley and Wando Rivers combined (VAN NIEUWENHUISE *et al.*, 1978). NEIHEISEL and WEAVER (1967) used ratios of different clay minerals in bottom and suspended sediments as diagnostic indicators of sediment origin. This revealed that sediments transported down the Cooper River consist primarily of silt and clay. The ratios of the clay constituents indicated that the sediment originated inland, primarily from Piedmont sources and that they were settling to form the western shoals of the harbor basin.

VAN NIEUWENHUISE *et al.* (1978) used another tracing technique, Fourier Series grain shape analysis, to provide additional information. Sand originating from the proximal continental shelf was found to be the major cause of shoaling in the navigational channels of Charleston Harbor. Grain shape analysis also revealed that the silt fraction had been transported from upland sources by way of the Cooper River.

Much of the research and discussion regarding the shoaling in Charleston Harbor has addressed the concerns of the eastern channels of the harbor basin. As described by NEIHEISEL and WEAVER (1967), sediment deposition in this region was dictated by flood flow which carried littoral sands from the nearby longshore currents. While this was consistent with findings of both pre and post-rediversion surveys, substantial differences were noted in the upper harbor basin at the confluence of the Cooper and Wando Rivers. COLQUHOUN (1972) encountered a fine silt and clay substrate in this region prior to rediversion, whereas we retrieved samples that consisted primarily of sand (Figures 4 and 5). This difference in composition continued into the lower reach of the Wando River. VAN DOLAH *et al.* (1990) monitored a station within this region for four years that spanned rediversion. Surficial sedi-

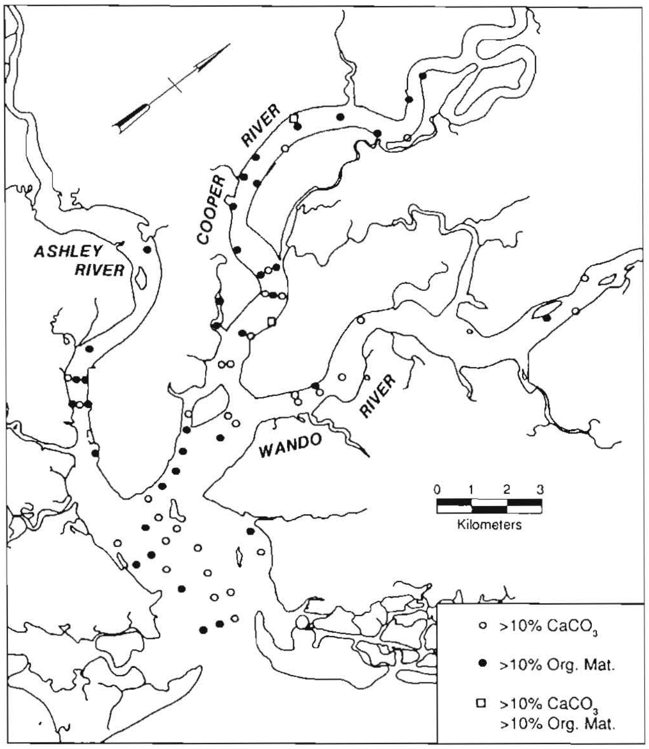

Figure 6. Calcium carbonate and organic matter distribution in surficial sediments of the lower Charleston Harbor estuary during July, 1988.

ment at this site was found to be consistently sandy both prior to and following rediversion. Above this region, most stations composed of sediments contained greater than 90% sand. This was similar to the pre-rediversion conditions described by COLQUHOUN (1972).

Site specific differences were also noted in the surficial sediments of the Cooper River and Ashley River during our study compared to the 1972 study. Both rivers contained sandy regions that were historically composed of silt and clay (Figures 4 and 5). These areas included portions of the east bank of the Cooper River and the lower Ashley River. One index station sampled over a four-year period encompassing rediversion, located near CR41 (Figure 2) along the east bank of the Cooper River, displayed no variation in sediment type relative to rediversion or season (VAN DOLAH *et al.*, 1990). Therefore, the shift towards a sandier bottom type in this area appears to predate rediversion and may be the result of other hydrodynamic influences in the system. NEIHEISEL and WEAVER (1967) demonstrated prior to Colquhoun's study that marine sands contribute substantially to surficial sediments of the lower Cooper River. Possibly, the change in sediment type within this region reflects the continued accumulation of this material over the course of time between the studies compared here. Sand derived from the lower Ashley River was predominantly marine also and may reflect a similar trend.

The distribution of silt and clay material at many of the stations sampled in the estuary appears to be related to anthropogenic influences. Stations adjacent to the naval/industrial complex along the western bank of the Cooper River, stations CR13 and CR14 within a shipyard, and stations adjacent to the port facilities of the western harbor basin were all primarily composed of fine-grained material. The accumulation of this material is probably the result of reduced water flow around docks and pilings associated with these facilities. COLQUHOUN (1972) also noted predominantly muddy sediments in these areas during his 1971 survey. Similarly, an isolated concentration of clay at CH73 may be related to the presence of a private marina in the Ashley River. Of the relatively few muddy stations in the Wando River, one was adjacent to a discharge pipe from a diked dredge spoil area (WR16), while another was adjacent to a port terminal (WR18) (Figures 2 and 5).

Other areas where silt and clay dominated the samples were probably the result of natural hydrodynamic forces within the estuary. For example, NEIHEISEL and WEAVER (1967) hypothesized that the Coriolis force directs the ebb discharge to the western side of the harbor basin. Sediment deposited in this region has historically consisted of fine material. Fourier grain shape analyses revealed that the source of this shoaling material was primarily from the Cooper River (VAN NIEUWENHUISE, 1978). The consistent formation of an extensive shoal in the western harbor basin was one motivating factor for channel realignment from the western to the eastern side of the harbor in 1955. This shoal was a recognizable feature of the harbor basin in both pre- and post-rediversion surveys (Figure 5).

Patchy distributions of muddy sediments were found throughout the upper Ashley and Cooper Rivers in our study. Samples collected by COLQUHOUN (1972) in the upper third of the Cooper and his seismic profiles from the upper half of the Ashley reflected similar bottom conditions.

Colquhoun's study provides a thorough description of the organic content in the Charleston Harbor sediments. While the methods used to measure this component were not comparable with our study, we did observe that sediment samples having >10% by weight organic matter were associated with fine-grained material and were located around pier and docking facilities (Figure 6).

COLQUHOUN (1972) did not report on calcium carbonate content from his survey of the estuary prior to rediversion, and there are no other extensive data bases on $CaCO_3$ distribution to compare pre- versus post-rediversion conditions. In our survey, several stations with high shell content were located in areas where there were high mollusk densities (primarily *Mulinia lateralis*). However, we observed no correlation between $CaCO_3$ concentrations and the number of live mollusks collected from the same grab samples as the sediment cores ($r^2 < 0.01$). Elevated $CaCO_3$ numbers were therefore attributed to accumulated shell hash (Figure 6).

An Oligocene formation known as the Cooper Group lies beneath a thin veneer of Holocene sands throughout the lower Charleston Harbor estuary. This stratum is characterized by calcareous microfossils which contribute calcium carbonate to surficial sediments. Fossilized foraminifera were especially abundant at CR40, CR41, WR20 and AR13 (Figure

2). Scouring and dredging of the Cooper Group has possibly elevated the distribution of $CaCO_3$ throughout much of the lower estuary (Figure 6).

CONCLUSIONS

In summary, sand was the major component of more than half of the stations within all three river systems and the harbor basin in this study, which was similar to Colquhoun's 1971 survey. Silt and clay sized particles (< 63 microns) were most prevalent in the Cooper River. Distribution of this material appeared to be concentrated near docks and port facilities. Calcium carbonate and organic matter were distributed widely throughout the study area. Calcium carbonate, usually in the form of shell hash was most often associated with coarse-grain sediment. Organic matter occurred most frequently with fine-grain material.

Substantial differences between this study and the historical data set were noted at the confluence of the Cooper River and Wando River where an apparent shift from silt and clay to sand was evident. The lower east bank of the Cooper River and lower Ashley River displayed a similar shift in sediment type as well. However, these changes were not attributed to rediversion since sampling conducted in these locations by VAN DOLAH *et al.* (1990) just prior to rediversion indicated that sediment composition had already changed to predominantly sandy sediments. TEETER (1989) predicted a reduction in overall shoaling of 74% at 85 m^3/sec, while recognizing that the recently completed deepening project, shifts in unconsolidated mud, and natural variability in the hydrodynamic regime will delay conclusions about the net effects of rediversion on the shoaling problem in Charleston Harbor. Additionally, both PATTERSON (1983) and TEETER (1989) have noted that the net effects of rediversion may not be evident for several more years.

LITERATURE CITED

COLQUHOUN, D.J., 1972. *Charleston Harbor, South Carolina Estuarine Values Study.* U.S. Army Corps of Engineers, Charleston District, 53p.

DAVIS, K.B. and VAN DOLAH, R.F., 1992. *Characterization of the physical, chemical and biological conditions and trends in three South Carolina estuaries. Volume 1. Characterization of the physical, chemical, and biological conditions and trends in Charleston Harbor estuary.* 1970–1985. South Carolina Sea Grant Consortium, Charleston, S.C., 123p.

FOLK, R.L., 1980. *Petrology of Sedimentary Rocks.* Austin: Hemphill, 182p.

KJERFVE, B., 1976. The Santee-Cooper: A study of estuarine manipulations. *In:* WILEY, M. (ed.), *Estuarine Processes.* Vol. 1. Orlando, Florida: Academic, pp. 44–56.

KJERFVE, B. and MAGILL, K.E., 1990. Salinity changes in Charleston Harbor 1922–1987. *Journal of Waterway, Port, Coastal and Ocean Engineering,* 616(2), 153–168.

MEADE, R.H., 1969. Landward transport of bottom sediments in estuaries of the Atlantic coastal plain. *Journal of Sedimentary Petrology,* 39, 222–234.

NEIHEISEL, J. and WEAVER, C.E., 1967. Transport and deposition of clay minerals. Southeastern U.S. *Journal of Sedimentary Petrology,* 37, 1084–1116.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, 1985. *National Estuarine Inventory—Data Atlas—Volume 1—Physical and Hydrologic Characteristics.* NOAA, Washington: United States Department of Commerce.

PEQUEGNAT, W.E.; PEQUEGNAT, L.H.; JAMES, B.M.; KENNEDY, E.A.; FAY, R.R., and FREDERICKS, A.D., 1981. Procedural guide for designation surveys of ocean dredged material disposal sites. *Final Report Prepared by TerEco Corp. for U.S. Army Engineer Waterways Experiment Station,* Technical Report EL-81-1, 268p.

PLUMB, R.H., JR., 1981. Procedures for handling and chemical analysis of sediment and water samples. *Technical Report EPA CE-81-1,* prepared by Great Lakes Laboratory, State University College at Buffalo, Buffalo, N.Y., for the U.S. Environmental Protection Agency/Corps of Engineers Technical Committee on Criteria for Dredged and Fill material. Published by the U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

SIMMONS, H.B., 1966. Tidal and salinity practice. *In:* IPPEN, A.T. (ed.), *Estuarine and Coastal Hydrodynamics.* N.Y.: McGraw Hill, pp. 711–731.

SOUTH CAROLINA WATER RESOURCES COMMISSION, 1979. Cooper River controlled low-flow study. *SCWRC Technical Report No. 131.* 353p.

TEETER, A.M., 1989. Effects of Cooper River Rediversion flows on shoaling conditions at Charleston Harbor, Charleston, S.C. *Technical Report No. HL-89-3,* U.S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi.

TINER, R.W., 1977. An inventory of South Carolina's coastal marshes. South Carolina Wildlife and Marine Resources Department. *Technical Report No. 23,* 33p.

U.S. ARMY CORPS OF ENGINEERS, 1957. Investigation for reduction of maintenance dredging in Charleston Harbor, South Carolina. *Technical Report No. 2-444.* USACOE, Waterways Experiment Station, Vicksburg.

U.S. ARMY CORPS OF ENGINEERS, 1966. *Survey Report on Cooper River S.C.* (Shoaling *in Charleston Harbor*). U.S. Army Corps of Engineers District, Charleston. Appendix A–G. 62p.

U.S. ARMY CORPS OF ENGINEERS, 1975. *Final Environmental Impact Statement,* Cooper River rediversion project, Charleston Harbor, South Carolina. USACOE, Charleston District, Charleston, 201p.

VAN DOLAH, R.F. and ANDERSON, G.S., 1991. Effects of Hurricane Hugo on Salinity and Dissolved Oxygen Conditions in the Charleston Harbor Estuary. *Journal of Coastal Research,* Special Issue No. 8, pp. 83–94.

VAN DOLAH, R.F., WENDT, P.H., and WENNER, E.L., 1990. A Physical and Ecological Characterization of the Charleston Harbor Estuarine System. *Final Report, Marine Resources Division,* South Carolina Wildlife and Marine Resources Department, Charleston, South Carolina, 634p.

VAN NIEUWENHUISE, D.S.; YARUS, J.; PRZYGOCKI, R., and EHRLICH, R., 1978. Sources of shoaling in Charleston Harbor, Fourier grain shape analysis. *Journal of Sedimentary Petrology,* 48, 373–383.