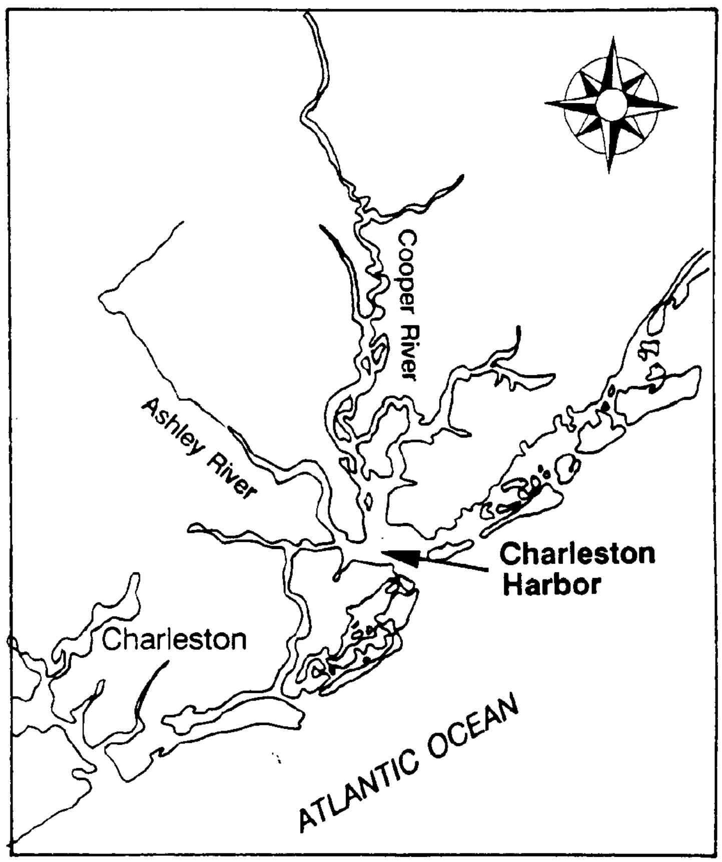
NOAA Estuary-of-the-Month
Seminar Series No. 16

Charleston Harbor: Issues, Resources, Status, and Management

JULY 1989



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NOAA ESTUARINE PROGRAMS OFFICE

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Charleston Harbor: Issues, Resources, Status, and Management

Proceedings of a Seminar
Held April 4, 1989
Washington, D.C.

JULY 1989

U.S. DEPARTMENT OF COMMERCE
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National Oceanic and Atmospheric Administration
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NOAA Estuarine Programs Office
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THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION,

U.S. FISH AND WILDLIFE SERVICE,

AND

U.S. ENVIRONMENTAL PROTECTION AGENCY

PRESENT AN

ESTUARY-OF-THE-MONTH SEMINAR

ON

CHARLESTON HARBOR: ISSUES, RESOURCES, STATUS, AND MANAGEMENT

TUESDAY, APRIL 4, 1989

Preface

The following are the proceedings of a seminar on Charleston Harbor held on April 4, 1989, at the Herbert C. Hoover Building of the U.S. Department of Commerce in Washington, D.C. It was one of a continuing series of "Estuary-of-the-Month" seminars sponsored by the NOAA Estuarine Programs Office (EPO), held with the objective of bringing to public attention the important research and management issues of our Nation's estuaries. To this end, the seminar first presented a historical, scientific overview of the Harbor by senior investigators, followed by an examination of management issues by scientists-managers of research institutions and science agencies involved with the Harbor.

We acknowledge the assistance of Dr. Melvin H. Goodwin of the South Carolina Sea Grant Consortium who had principal responsibility for assembling the speakers and whose long involvement with the Harbor and its people was invaluable. The seminar was coordinated by Dr. Joseph M. Bishop of the NOAA Office of Chief Scientist, with the assistance of the EPO Staff.

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Overview of South Carolina Estuaries

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Charleston Harbor is located on the South Carolina coast approximately mid-way between North Carolina and Georgia. This estuary and its associated waterways are part of the diversified coastal environment characteristic of southeastern United States. As background to the following extensive discussion of Charleston Harbor, the subject of this volume, this paper presents an overview of some distinctive features of South Carolina's estuaries and coastal waters.

The South Carolina coast abuts on that portion of the Atlantic Ocean commonly referred to as the Georgia Embayment. Approximately 55 miles from the coast is the Gulf Stream. Although in many studies emphasis is placed on an estuary as a discrete entity, we should not forget that various oceanic processes influence estuaries and the exchange of materials between an estuary and the ocean is a dynamic interrelationship. At times an estuary functions as a sink removing substances form the incoming oceanic water, but, at other times, materials, including carbon, are exported to the sea (Dame *et al.*, 1986). Relatively little is known of the fate of substances in the nearshore waters. It has been strongly suggested that a coastal boundary exists separating coastal shelf water from near coastal waters. This landward mass of water moves along the coast sometimes in a northerly direction, sometimes southerly. Materials exported from one estuary into this coastal water mass may be imported to and be utilized in an adjacent estuary or they may slosh in and out of one specific estuary. Detailed analyses of the coastal boundary layer and adjacent waters are needed to understand interestuarine interactions.

Estuaries are also influenced by far-field oceanic events such as seastorm surges and changes in sea level. Earlier Kjerfve *et al.* (1978) found that the annual sea level height varies at different times of the year, a phenomenon not to be confused with the long-term changes in sea level due essentially to glacier formation or glacier melting. This seasonal change can be as much as 6.4 cm. Recently Morris *et al.* (in preparation) reported that when this increase in tidal height occurs during the warmer months, increased flooding of estuarine marshlands results increasing the amount of habitat available to those species dependent on wetlands as a nursery ground. This increase in available habitat was correlated with increased in production and harvesting of commercially important species. The relative importance of these far-field physical effects to the ecological dynamics of all Carolina estuaries has not been systematically studied. In this volume, Kjerfve discusses physical processes in more detail, especially as they pertain to Charleston Harbor.

The South Carolina coast from Georgia to North Carolina is about 300 km (187 mi) long. However, if you measure the shoreline of all of the estuaries and coastal water, the distance is 4,632 km (2,879 mi) an indication of the extensive convoluted nature of the numerous small sized estuarine-coastal water systems characteristic of the southeast. Associated with these estuaries there are approximately 200,000 ha (500,000 acres) of tidelands in South Carolina. The coast is also characterized by having a number of barrier and sea islands (33 in South Carolina and 16 in Georgia). These various estuaries, wetlands, and islands extend through eight counties comprising the coastal region.

The major coastal systems ranging from the south northward are Port Royal Sound, St. Helena Sound, Charleston Harbors, Bulls Bay, Santee Estuary, and Winyah Bay. The principal river systems influencing the coast are (from south to north): Savannah, Combahee/Salkehatchie, Edisto, Santee/Cooper, and Pee Dee; Waccamaw/Black rivers. Of the major drainage basins, Winyah Bay is the largest receiving run-off from much of North and South Carolina uplands and now that the upland river drainage has been recently diverted to the Santee River, this system is second in size surpassing the Cooper River.

Another important feature of the coast is the presence of over 320 small, high salinity creeks, inlets and estuaries between Cape Fear, North Carolina and Cape Canaveral, Florida (Scott, personal communication). Nearly half occur in South Carolina alone. This total includes about 40 inlets that open to the ocean but dead end (*i.e.*, do not connect to another body of water). These range from tiny, unnamed inlets to those as large as Murrells Inlet, S.C. An additional group of small ocean-opening inlets and creeks also open to other water bodies (*i.e.*, the inland waterway). There are about 50 of these. Finally, there are at least 230 small, dead end creeks that open near the mouths of rivers and sounds. The actual number of high-salinity creeks for the purposes of this abbreviated review. Instead a conservative estimate was made by simple perusal of nautical charts. These creeks are probably very ecologically similar to the ocean-opening creeks and inlets. The 320-plus high-salinity inlets and creeks along the coasts of Florida, Georgia, North and South Carolina are extremely delicate ecosystems that by and large do not have the benefit of significant flushing that riverine estuaries do. All of these inlets currently have very low population densities, less than 100 people per square mile, but many are targeted for rapid development over the next 20 years because of their aesthetic appeal and easy access to the ocean.

Early in the colonial history of South Carolina, rice culture became an important economic endeavor in the coastal area. As a vital part of this agriculture practice, numerous, large impoundments were created with slave labor. In these impoundments rice was grown. Although the rice industry collapsed after the Civil War, these impoundments, which are in various stages of disrepair, still exist. Charleston County has 9,307 ha (22,999 acres) of impoundments, Colleton County 8,335 ha (20,596 acres), and Georgetown County 4,832 ha (11,940 acres). These impoundments play an important role in the ecology of the coastal ecosystem.

A rich and diverse biota exists in the estuaries and coastal water (see Zingmark, 1978; Fox and Ruppert, 1985; Ruppert and Fox, 1988; Van Dolah, this volume, for details on biota). South Carolina is located in the biogeographical category of the Carolina Province which is divided into a North Carolina Zone extending from Cape Hatteras to the Santee River and the South Atlantic Zone from the Santee River to St. Johns River, Florida.

Absent from estuaries and coastal waters is a noticeable submerged grass habitat which is found north and south of South Carolina. However, during the colder months, extensive large stands of macroalgae are present in many estuaries. The absence of sea-grass beds results in a dominance of bare, exposed benthic regions. As a result this habitat is relatively more important in our estuarine ecosystem than in other systems. Hence the dynamic coupling of the water column and the benthic communities is an area of active research in South Carolina.

Sediment loading is heavy in most South Carolina estuaries. The presence of high levels of sediment has influenced the distribution of marine/estuarine organisms, perhaps playing a role in limiting seagrass beds. Later papers in this volume will stress the problem of sediment loading in

Charleston Harbor. The tidal height varies along the coast. Near the Georgia border the spring tide tidal amplitude is 2 meters and is 1.62 meters in the North Inlet Estuary located near Georgetown.

Water quality of the different estuaries varies. Some estuaries are pristine-like and have excellent water quality while others experience severe problems. For example, recently the highest level of dioxin in estuaries was reported in Winyah Bay. A more detailed discussion of water quality especially in Charleston Harbor, is found in the paper of Dr. Blood (this volume). However, a few examples of some general water quality characteristics of Carolina estuaries is presented here.

A normal feature of coastal waters is variation in many water quality parameters, including dissolved oxygen, salinity, water temperature, and pH. Some recent data of Scott *et al.* (1989) demonstrates this point very well. Dissolved oxygen levels may reach extremely low levels during normal daily fluctuations in temperature. These low levels are well below the acceptable DO levels established by numerous state agencies. Following a rain event, the salinity dropped to 15 ppt but returned to 25-30 ppt within 1-2 tidal cycles.

Coastal Research Sites

Along the coast of South Carolina a number of research sites and facilities are important in facilitating research on coastal and estuarine environments. In the southern portion of the state near Beaufort is the Waddell Mariculture Center, a state facility operated by the S.C. Wildlife and Marine Resources Division. Nearby, the University of South Carolina - Beaufort campus manages Pritchard's Island, a 615 ha (1520 acre) barrier island donated to the University of South Carolina for research and teaching. In Charleston is located the research facilities of the S.C. Wildlife and Marine Resources Division, the Fort Johnson Marine Laboratory of the College of Charleston, the office of the South Carolina Sea Grant Consortium, and a research laboratory of National Marine Fisheries Service. On the Wando River, USC owns 404 ha (1000 acres) of wetlands which are to be used by long-term studies. North of Charleston on the South Santee River, the College of Health, USC has a 486 ha (1200 acre) research facility which emphasizes research on vector borne diseases and on aquaculture. On Hobcaw Barony, a 7,082 ha (17,500 acre) site established in perpetuity by the Belle W. Baruch Foundation for the study of marine ecology, forestry and conservation, is located the field research laboratories of the Baruch Institute for Marine Biology and Coastal Research, USC. These facilities are located adjacent to the pristine-like North Inlet estuarine ecosystem which is part of the Long-Term Ecological Research program funded by the National Science Foundation (NSF).

Future Considerations

The conversion of upland areas near South Carolina's many small high salinity estuaries to residential and urban development is occurring at a very rapid pace. In the Waccamaw River Basin alone, it is estimated that 1,376 ha (34,000 acres) of forested and agricultural land will be converted to urban and residential use over the next 20 years. While some additional industrial expansion may occur, all indications are that most remaining coastal development will be urban development, including residential housing and related tourism/ services related industries (*i.e.*, restaurants, shopping centers, specialty shops). Throughout the United States coastal areas are perceived to be the preferred place to live. Over half of the people in the nation now live and work within coastal counties, yet these areas represent only some

10% of the country's land mass. Population experts estimate that coastal areas will become even more crowded in the future, and by the turn of the century it is predicted that 75% of the U.S. population will live within 80 km (50 mi) of a coastline. Thus further urbanization seems inevitable.

The implications of this urbanization to the environment are many. Acre for acre, run-off from sites where homes, shopping centers, parking lots and highways are under construction may contribute more sediment to waterways than any other single activity. In addition to sediments, chemical pollutants including polycyclic aromatic hydrocarbons (PAHs), trace metals, solvents, oils, tars, and pesticides, may be washed into estuarine systems. Once urban development is completed, then there is an urban run-off problem: sediments, oil, grease, heavy metal particles from paved surfaces and pesticides and fertilizers from lawns and golf course. Hoffman *et al.* (1984) reported that over 80% of the PAHs entering Narragansett Bay emanated from non-point sources (NPS) urban run-off. Klein *et al.* (1974) similarly reported that almost 50% of the trace metals entering the Hudson River were discharged from NPS urban run-off. Recently Scott *et al.* (1989) have similarly reported significant NPS run-off of pesticides into estuarine habitats. While NPS run-off events are episodic, the inputs of the many persistent organic and inorganic pollutants, with long half-lives, may result in both acute and chronic exposure to estuarine organisms. It is clear that once an area is urbanized, there will be a continuous urban run-off problem.

In addition to the NPS run-off problems, concern must be focused on the increased problems of population growth and resulting demands for drinking water and water for sewage disposal. In South Carolina, for example, significant population increases are predicted in coastal counties. The "Grand Strand" area of Horry County is literally overflowing with people during the summer months with as many as 400,000/day (Waccamaw Regional Planning and Development Council, 1987). The Grand Strand Chamber of Commerce has estimated that 11 million people annually visit the entire Grand Strand. From 1985 - 2000, projections indicate population growth of permanent residents from 400,065 to 786,206, or a 74.6% increase. Similarly, the Charleston Metro area may grow from 482,145 to 740,548 or a 53.6% increase, and southern Beaufort County may grow from 25,544 to 120,370 or a 751% increase (Waccamaw Regional Planning and Development Council, 1987). During this same time period the population for the remainder of the State of South Carolina will only increase 22%.

These significant increases in population growth will result in significant run-off inputs into estuarine ecosystems. The increase in storm water run-off alone is almost staggering. Marcus (1988) has predicted that storm water run-off volume in the Waccamaw River Basin, off from a 12-hour storm event will increase from 65×10^6 l (17.2×10^6 gal) in 1985 to 527×10^6 l (139.3×10^6 gal) in 2005. This represents a 700% increase (Figure 3). In addition to NPS run-off, the volume of sewage discharged is expected to increase from 257×10^6 l/day (68 million gal/day) over the next 20 years in this area (Marcus, 1988). Since the major receiving system (the Waccamaw River and Atlantic Intercoastal Waterway) has little assimilative capacity left according to wasteland allocation simulation models, it is clear that urbanization of coastal habitat will have a significant impact on water quality in estuarine habitats.

The impact of these large increases of run-off will be especially acute in the many small, high salinity estuaries which occur with regularity along the coast of South Carolina, North Carolina, Georgia, and Florida. Scott *et al.* (1988) have shown that the effects of NPS agricultural runoff are greatest in drainage basins where runoff is only diluted 100-fold or less. This means that small tidal creeks, which serve as nursery grounds for finfish and shellfish, will have a greater probability of impact from NPS runoff than larger watersheds with greater dilution and assimilative capabilities. These small high salinity estuaries are dynamic systems serving as a nursery ground fro finfish and shellfish. Individually, the commercial and recreational fisheries each estuary sustains may not be large, but, collectively these many small, high salinity estuaries are very important in terms of the fisheries they support.

Along with development pressures, the proliferation of marinas has the potential for having a negative impact on coastal waters.

One problem in assessing the health of the coastal waters is separating environmental fluctuations which are man-induced from those which are natural. In South Carolina, we have initiated studies to attack this problem. A comparison of two distinct South Carolina estuaries (North Inlet estuary near Georgetown and Charleston Harbor) is underway with funds provided by the NSF and NOAA. North Inlet Estuary is a pristine - like estuarine system which has been intensely studied for 20 years, and for the past 9 years this site has been funded by the NSF as a Long-Term Ecological Research site. As a result one of the best long-term databases on an undisturbed estuary exists for this site. In contrast, Charleston Harbor has a long history of being perturbed by humans as is highlighted in this volume. The results of this interinstitutional comparative ecosystem study should be invaluable in providing the basis for further extensive investigation.

Summary

The South Carolina coast is a region rich in wetlands and diverse waters ranging from large drainage basins to small pocket estuaries. This coastal area is being subjected to numerous developmental pressures. Although various research institutions have studied numerous aspects of the Carolina coastal environment, only recently have preliminary interestuarine comparative investigations been undertaken, a necessary step in management of coastal resources.

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The Charleston Harbor Estuary: Historic, Geographic and Socio-Economic Setting

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Geographic Context

Most people acquainted with the South Carolina Lowcountry understand that Charleston is where the Ashley and Cooper Rivers meet to form the Atlantic Ocean. If this is not immediately apparent to the unbiased observer, it would have been even less so during the Paleocene epoch 60 million years ago. At that time, the Carolina coast was roughly 100 miles inland of its present location. The present geologic structure of the coastal plain reflects this history in a series of sedimentary strata that include shales, clays, limestone, and phosphates, the latter eventually to play a role that is still evolving in contemporary Charleston history.

The wind and tides of that ancient shore built sand dunes that became the Sandhills of the South Carolina midlands, as the coastal plain experienced a gradual uplift that continued sporadically for about 50 million years. By 8 to 10 million years before present, most of the low country had emerged from the sea, but the coast was destined to undergo still more sculpting during the Pleistocene Epoch that began about 2 million years ago. At least four cycles of glacial advance and retreat during the Pleistocene exposed various portions of the low country shore to the erosional and depositional processes typical of coastal regions, forming South Carolina's maritime islands and shaping the coast more or less to its present form.

The central area of the state included within Charleston County is drained by the Santee, Stono, North and South Edisto, Wando, Cooper, and Ashley Rivers. All of these are involved in the total picture of the Charleston Harbor estuary, but the most direct connections are shared by the Wando, Cooper and Ashley Rivers (*cf.* pg 14). All three rivers are tidally influenced throughout their lengths. The Wando drains an area of about 298 km^2 (115 mi^2), while the Ashley has a drainage area of 906 km^2 (350 mi^2). The Cooper is considerably larger, and exerts major influence on the Charleston Harbor estuary system. Originally, the Cooper drained an area of 1865 km^2 (720 mi^2), meandering across the coastal plain with a flow of about 6 m^3/s (200 ft^3/s).

These characteristics have been radically altered in the recent history of Charleston Harbor by human activity, a circumstance that will illustrate two of the principal points I would like to make today: First, that the Charleston Harbor estuary system has been highly manipulated by man for several hundred years; and second, that most manipulations have been undertaken in response to immediate short-term concerns. Long range planning and a vision of the future are not conspicuous features in the history of Charleston Harbor.

South Carolina's Barrier Islands include the Isle of Palms, Cape, Bull, Capers, Dewees, and Sullivan's Islands to the north of Charleston, and Folly, Kiawah, and Seabrook Islands to the south. Murphy, Lighthouse, Raccoon Key, and Morris Islands comprise the marsh islands, while Edisto, James, John and Wadmalaw are known as sea islands.

Historic Context

The names of these coastal features should remind us that is has been a long time since Charleston Harbor was shaped by natural forces alone. The first South Carolinians arrived roughly 12 - 15,000 years ago. Coastal Indians, including the Kiawahs, Edistos, Stonos, and Wandos, built their principal villages on the mainland and sea islands, and used barrier islands for hunting and fishing. When English settlers arrived in South

Carolina, they found large grassy savannahs interrupted by coastal forests that resulted from the Indian practice of firing cane breaks and woods to drive game toward waiting hunters.

It isn't certain whether the settlers who arrived in 1670 fully appreciated the fact that they were about to colonize the source of the Atlantic Ocean; actually, Charleston's founding fathers appear to have been more concerned with ease of defense and amenability to shipping. In the interest of defense, the first settlement was along a creek off the Ashley River, from which ocean-going vessels could arrive and depart only on the flood tide, which greatly restricted the hours in which attack from the sea was possible. Security was further enhanced by the fact that one side of the settlement was flanked by virtually impassable marshes.

Within ten years, however, increased capacity for shipping became an overriding concern, and the settlement was moved to the peninsula. The original town wall on the east ran long the bank of the Cooper River, paralleled small creeks on the north and south, and followed the slight rise on the center of the peninsula to the west along what is now Meeting Street. The city grew rapidly, expanding first south, then westward, and then to the north, in the process filling many of the creeks and marshes that indented the peninsula.

A diversity of economic pursuits have supported this expansion. Cattle ranching was the first major cash crop, and began a year after the colony was founded. The grassy savannahs produced by Indian hunting practices were ideal forage areas, as were the sea islands that also provided ample supplies of salt in the form of marsh grasses. The concept of open ranging inevitably brought the settlers into conflict with coastal Indians who were pushed inland, opening additional land for a new enterprise: rice production. In 1696 the emerging value of rice was formally acknowledged when the crop was added to the list of commodities with which Carolinians could pay debts.

Initially, rice plantations were located in natural swamps that were dammed and cleared of native cypress, gum, and tupelo. But these operations experienced major problems with weed control. Just before the revolution, experiments began with culture in coastal swamps using upstream inflows to provide freshwater and downstream dikes to control the inflow of saltwater to provide weed control. This technique allowed vast acreages to be brought under production at great profit to a few planters.

Lack of adequate supplies of freshwater excluded the sea islands from this prosperity, and in the mid-1700's indigo was introduced as a crop ideally suited to the sandy soil and arid climate of these islands. By the beginning of the revolution, indigo was South Carolina's second most important cash crop. But because England had provided substantial incentives for indigo production, as well as the principal market, the revolutionary war brought an end to this crop's profitability.

In the late 1780's sea island cotton was introduced to South Carolina and quickly joined rice as the basis for much of the coastal economy. But both crops were extremely labor intensive, and the abolition of slavery following the Civil War signaled the end of the plantation system and the beginning of the end for profitable rice and cotton production, adding serious economic hardship to the destruction caused during a tragic period in our history.

A significant spinoff from plantation agriculture was the development in the 1870's of a fertilizer industry based on phosphate deposits found along the coast. One of the first such deposits to be exploited was located along the Ashley River which proved to have the richest beds for phosphate-bearing land rock. Fertilizer companies operated in the Charleston area to produce super phosphates by processing the raw rock with sulfuric acid. But by the end of the 1880's the industry had begun to decline, primarily because of competition from more productive deposits in Florida. The end of the phosphate industry was soon followed by the final demise of the rice and cotton industries as a result of the hurricane of 1911 and boll weevil infestations between 1910 and 1920.

Though impermanent, these cattle, indigo, rice, and cotton and phosphate industries were among the mainstays of South Carolina's economy for two hundred years. At least part of their success was due to the presence of superior shipping facilities at the Port of Charleston. A major advantage of Charleston Harbor over neighboring ports was that ships' berths could be located only six or seven miles from the ocean, and the port of Charleston still has one of the fastest turn-around times for cargo vessels of any American port.

Charleston Harbor is a drowned river basin, about 39 km^2 (15 mi^2) in area. In the 1800's, the narrow channel between Morris and Sullivan's Island was more than 24 m (80 ft) deep, but a 16 km (10 mi) long sand bar stretched across the entrance from Sullivan's Island to Folly Island formed by sand deposited during storms. Three shifting channels (Sullivan's Island Channel, Swash Channel and Pumpkin Hill Channel) through the bar were formed by tidal flow and runoff during storms, usually with depths of 3.4 – 4 m (11 to 13 ft) at mean low tide.

Dredging to maintain channels was briefly undertaken by the City of Charleston in 1854, but extensive removal of an estimated 76,000 m^3 (100,000 yd^3) of sand from the main channel and the bar did not take place until 1874. Because the bar was quickly re-formed by approaching waves and drift material carried by coastal currents, the Army Corps of Engineers erected stone jetties completed in 1896 to concentrate water discharge from the harbor to maintain scouring action. But these measures were not sufficient to guarantee the passage of vessels with increasingly greater draft. In 1928, maintenance dredging was begun to maintain depths in shipping channels. For the next 14 years, maintenance dredging removed about 230,000 m^3 (300,000 yd^3) of material each year.

In 1942, 96% of the flow from the Santee River was diverted to the Cooper via Lake Moultrie as part of a hydroelectric project located at Pinopolis. This added 38,000 km^2 (14,700 mi^2) to the Cooper River's original 1865 km^2 (720 mi^2) drainage area, and increased the average flow rate from 6 m^3/s (200 ft^3/s) to more than 425 m^3/s (15,000 ft^3/s). Because the Piedmont drainage basin of the Santee produces more runoff per square mile than the Coastal Plain, the resulting increase in freshwater inflow was even greater.

At about the same time, navigation channels in the Harbor were deepened from 9 m to 10.6 m (30 ft to 35 ft) below mean low water. Together, these modifications to the Charleston Harbor estuary system necessitated a twenty-fold increase in maintenance dredging. As a result, in 1966 the U.S. Army Corps of Engineers proposed to redivert 80% of the flow into Lake Moultrie back to the Santee River. This rediversion was to be accomplished by constructing a canal from Lake Moultrie to the Santee River, with a new power generating facility to be located on the canal near St. Stephen (*cf.* pg 14). The rediversion project was completed in 1985, accompanied by somewhat diverse predictions of its ultimate effects on the functioning of the Charleston Harbor estuary system.

Studies undertaken prior to rediversion indicated that Charleston Harbor was a stratified or salt-wedge type of estuary with two well-defined density layers. At that time, untreated industrial wastes and raw municipal sewage were discharged directly into the lower reaches of the Ashley and Cooper Rivers. Accumulations of sludge caused reductions in dissolved oxygen concentrations to 52% of saturation in these areas. The primary input of dissolved oxygen to the system was provided by large volumes of tidal oceanic inflow.

Under the reduced flow conditions resulting from rediversion, it was predicted that the estuary would change from a stratified to a vertically mixed system, resulting in prolonged residence times in the upper portions of the Harbor and more pronounced effects of tidal action in the lower Harbor. Water quality was thus expected to improve in the lower Harbor, but significant deterioration was foreseen for portions of the Cooper and Ashley Rivers. Particular concern was directed toward the fact that requirements for improved treatment of municipal waste did not extend to industrial point sources. Discharges from fertilizer, chemical, and paper industries were expected to become particularly problematic unless industrial waste treatment requirements were enacted. Determination of the actual response of the Charleston Harbor Estuary system to rediversion has been a major focus of the work that will be reported here today.

Contemporary Context

These investigations are taking place in a much broader context. In reviewing the history of the Charleston Harbor estuary for this presentation, I was struck by repeated cycles of disaster that have interrupted periods of prosperity; disasters that in most cases appear to have been unanticipated or at best poorly evaluated. In a place like Charleston, one might suppose that we would be disposed to learn from history.

But most of our citizens have been transplanted from elsewhere; though Charleston has suffered at least seven hurricanes since 1800, the majority of the population in the Charleston Harbor estuary has not experienced such disasters, and is wholly unprepared for their consequences. If hurricane Gilbert had made landfall in Charleston, at least half the single family dwellings would have been destroyed, and many single story commercial structures would have been severely damaged, as would schools using unreinforced masonry walls. The latter is of particular concern as schools are often used as evacuation shelters.

On a less dramatic scale, the South Carolina coast is visibly dynamic and changing, yet we continue to build in erosion prone areas, ignoring the inevitability of certain natural processes. To some extent, we are still dealing with the consequences of past decisions. Portions of Charleston regularly flood during spring tides, particularly when these coincide with rainfall. The distribution of this flooding coincides strikingly with former marshlands that have been filled during the last 300 years. And we wonder about the consequences of disturbing sediments in the Ashley River in the vicinity of former phosphate and other chemical production facilities that are known to have discharged a variety of hazardous effluents into the river.

But there are also some positive signs for the Charleston Harbor estuary. Charleston has recognized the value of some of its unique characteristics, even before these could be interpreted in dollar terms. Charleston's record with regard to historic buildings is the most obvious example, and it is noteworthy that the Society for the Preservation of Old Dwellings was founded in 1920, during one of the city's periods of economic hardship. The result is that Charleston today has roughly 5,000 pre-1900 structures; the highest concentration of historic structures of any American city.

The Charleston Harbor Estuary today hosts a multiplicity of uses and users. Commercial fishing in South Carolina generates more than $38 million annually in total economic impact. Recreational fishing in a variety of forms is part of the state's $3 billion/yr tourist industry, and many of the most important recreational and commercial fisheries depend upon estuaries, including Charleston Harbor. Added to the dollar value associated with these fisheries is the symbolic value of the traditional fisherman to the low country heritage. Similarly, the pleasure of consuming fresh seafood to many is synonymous with the quality of life in South Carolina. Recreational boating and beach bathing are also conspicuous in Charleston Harbor, and like fisheries are particularly dependent upon water quality; a dependence that often raises concerns with regard to other economically important activities.

Charleston is the third largest commercial port on the east coast of the United States, and the second largest homeport for the U.S. Navy. Other industrial users of the Harbor and Estuary include Uniroyal, Dupont, General Dynamics, Mobay Chemical Co., Amoco, West Vaco and the South Carolina Gas and Electric Company. Many of the major industrial activities depend upon the Charleston Harbor Estuary both as a source of water as well as a means of waste disposal. The Back River provides water for industrial intakes, and Bushy Park, Goose Creek and the Edisto River provide drinking water for Metro Charleston. At the same time, the Cooper River receives waste water from most of these industries, and major centralized sewage treatment facilities discharge into the western side of Charleston Harbor at Plum Island. A colleague once remarked that human settlements in estuaries are like sea anemones in that they feed and excrete via the same orifice. A sobering thought, perhaps; particularly as there is every reason to expect these sorts of demands on resources of the Charleston Harbor Estuary to increase.

As the population of Berkeley, Charleston, and Dorchester counties grows from 500,000 to 750,000 in the next 15 years, the number of motor vehicles in the region is projected to increase by more than 40%. Together with additional parking facilities and roadways to accommodate these vehicles and attempts to reduce stormwater accumulation, there is reason for concern about increased non-point source pollution. Solid waste disposal needs are also expected to increase by 50%, while the volume of wastewater will nearly double from 2.15×10^8 l/day (57 mgd) to 3.9×10^8 l/day (103 mgd).

These increases can be viewed as part of progress and increased prosperity, but there is increasing awareness that other estuary systems have suffered badly as a result of poorly planned growth. An indication of this concern is that more than 3,000 people participated in South Carolina's Beach Sweep last September, focussing attention on growing problems of waste disposal. Those of us involved with the Charleston Harbor study see these growth projections as a challenge; the challenge to extend the historically short-term vision of resource development and management to a more synoptic focus on the future. While other estuaries are faced with damage control in attempts to correct the mistakes of the past, the task in Charleston Harbor is to engage in forward planning to avoid similar mistakes as the areas surrounding the Charleston Harbor Estuary experience increased economic development.

Some initial steps toward meeting this challenge are already being taken. The research that is discussed elsewhere in this volume is intended to improve our understanding of the functioning of the Charleston Harbor Estuary system and the response of this system to various demands of human society.

A series of technical workshops has been initiated with support from the National Oceanic and Atmospheric Administration and the Environmental Protection Agency to define an agenda of applied research to support effective management of Charleston Harbor Estuary resources for long-term benefit. A simultaneous series of citizens' workshops is being convened to identify common concerns among the Estuary's diverse users, and to identify and implement action needed to achieve long-term development goals. Perhaps the most important task for this group, however, is public education and building a constituency for long-term management of the Charleston Harbor Estuary.

Physical Processes in Charleston Harbor

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University of South Carolina

Charleston Harbor, South Carolina, is located near the apex of the gently curving Atlantic coastline of the southeastern United States. The Carolina Bight (CB) is an appropriate name for this North Atlantic embayment, which is often incorrectly referred to as the South Atlantic Bight.

Three rivers discharge into Charleston Harbor: the Ashley, the Cooper, and the Wando (Figures 1, 2). The harbor proper and each of the three rivers experience 1.6 m semidiurnal tides, which are the primary source of current and water level variability. Freshwater discharge into Charleston Harbor primarily occurs via the Cooper River, which, since 1985, has been regulated to a near constant flow of 122 m^3/s. The total surface area of the Charleston Harbor system measures 112 km^2, and the water volume measures 0.84 km^3 at mean tidal elevation. Since the late 1890's, conditions in Charleston Harbor have been altered by man several times, initially to improve harbor navigation, later to increase the discharge of the Cooper River for power generation, subsequently to reduce sedimentation resulting from the altered river flow, and most recently to allow navigation of deeper draft vessels. Alterations to estuaries used as major ports and harbor are common, but associated physical and ecological repercussions are seldom investigated fully, and can sometimes outweigh the benefits. It can be argued that this has been the case in Charleston Harbor.

Charleston Harbor Prior to 1942

Prior to 1895, depths in the Charleston Harbor entrance channel ranged from 3.0 - 3.9 m, but were considerably deeper in the harbor proper (Simmons and Herrmann, 1972). Combined discharges from the Ashley, Cooper, and Wando rivers measured only 10 m^3/s (U.S. Army Corps of Engineers, 1966). The estuary as a whole was well-mixed due to dominance of tidal processes, and the circulation was primarily tidally driven. Also, the salinity was high, measuring 30.1 ppt at the Customs House Wharf (Zetler, 1953).

Construction of jetties and dredging of the entrance channel to 6.4 m opened the harbor for navigation in 1895. But the channel deepening had little effect on physical regimes in the estuary. The channel was essentially self-maintaining at 6.5 m, and the estuary as a whole was gradually deepening because removal of sediments by net downstream flow occurred faster than deposition (Simmons and Herrmann, 1972). To further open navigation to large vessels, a 9-m deep ship channel was dredged in 1917 from the harbor entrance to the port of Charleston (Simmons and Herrmann, 1972). Still, the ship channel required little maintenance dredging for several decades.

Charleston Harbor After 1942

As demand arose for hydroelectric power generation in the late 1930's, the Santee River (Figure 1) was targeted as a source for hydropower because of its high mean discharge of 525 m^3/s (S.C. Water Resources Commission, 1979). The South Carolina Public Service Authority (SCPSA) therefore initiated the Santee-Cooper Hydroelectric Power Project, which was completed in 1942. Completion of the project produced several major changes in the lower Santee and Cooper rivers, including the construction of (1) the Wilson Dam on the Santee River, creating Lake Marion; (2) the Pinopolis Dam on the Cooper River, creating Lake Moultrie; and (3) a 12-km long canal, diverting river flow from Lake Marion to Lake Moultrie and into the Cooper River (Figure 2). An average of 88% of the Santee River flow was channeled through the diversion canal into the Cooper River (Kjerfve, 1976). The mean Santee River discharge thereby decreased to 62 m^3/s (S.C. Water Resources Commission, 1979), while the mean

Figure 1. **Area map of the Charleston Harbor system.**

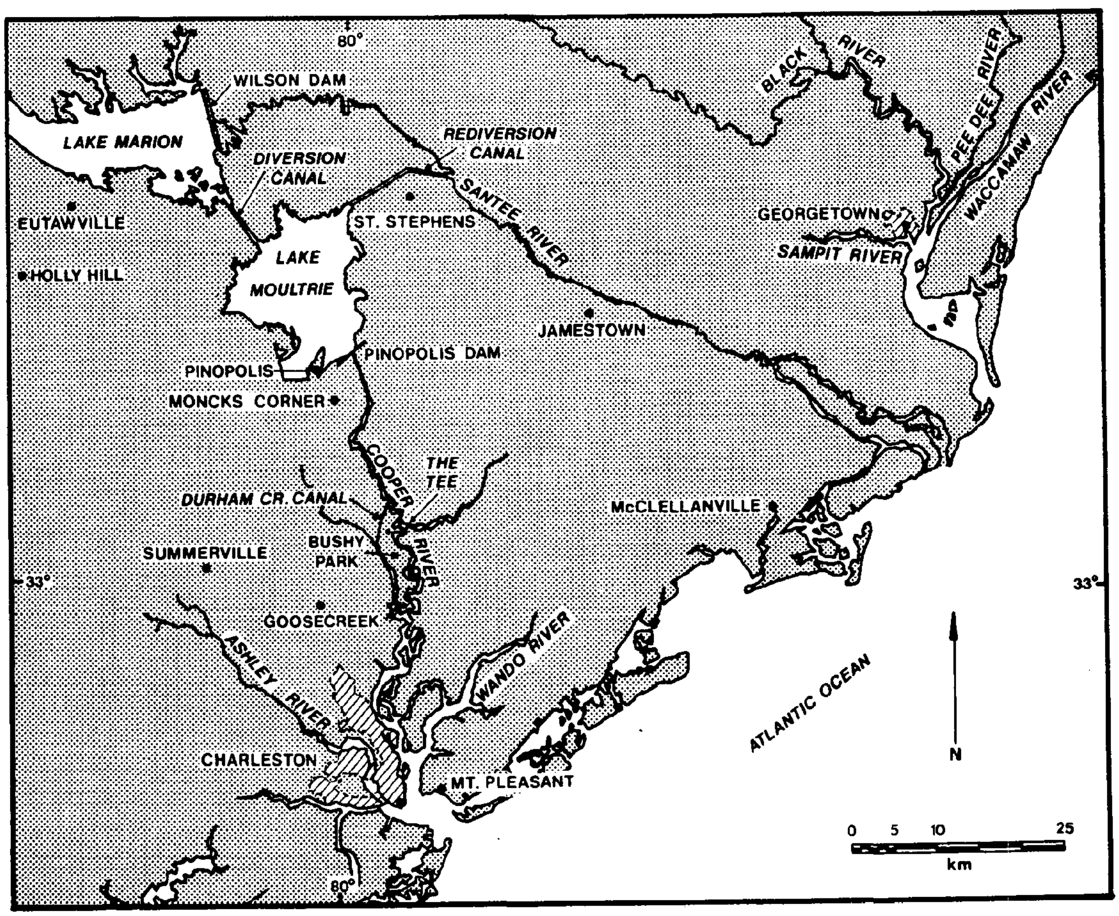
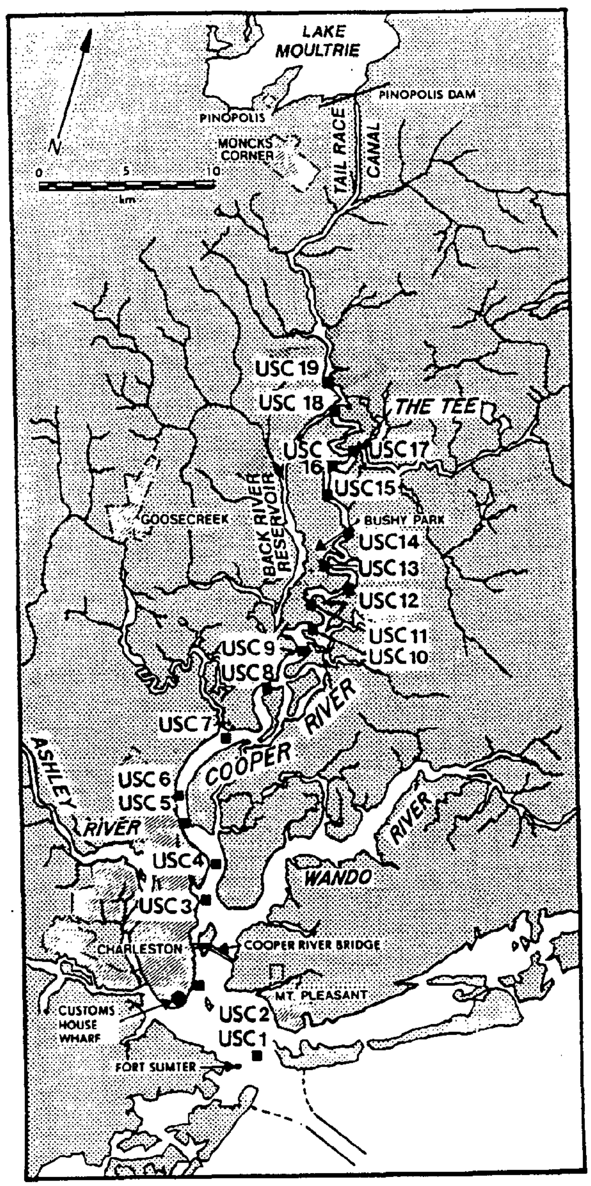
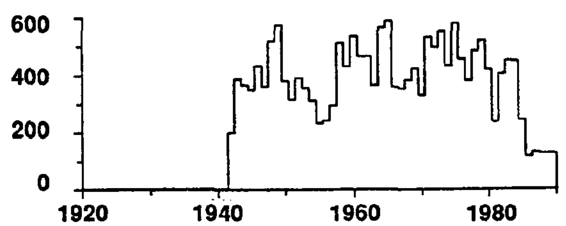


Figure 2. **Detailed map of Charleston Harbor and the Cooper River, indicating location of the 19 longitudinal stations used in the USC studies.**



Cooper River discharge increased to 418 m^3/s (Kjerfve, 1976; Figure 3).

***Figure 3.* Discharge of the Cooper River (m^3/s).**



The increase in Cooper River discharge caused several physical changes in the Charleston Harbor estuary:

1. The mean surface salinity at the Customs House Wharf (Figure 1) decreased from 30.1 ppt to 16.8 ppt (Zetler, 1953) and the extent of the estuarine zone shifted seaward, establishing tidal freshwater conditions upstream of Durham Creek on the Cooper River (Figure 2).
2. Gravitational circulation, characterized by average seaward flow of fresh water in a surface layer, bottom layer inflow of saline oceanic water, and mixing between the two layers, became the dominant type of residual circulation (Kjerfve, 1976).
3. The estuarine salinity/density structure changed from being vertically well-mixed to being partially-mixed (*cf.* Pritchard, 1967).

Another major consequence of flow diversion (*cf.* Pritchard, 1967; Kjerfve, 1976) was that sediment deposition and shoaling in the estuary became a chronic problem (Patterson, 1983). Shoaling is due to the combined action of fresh and salt water mixing, tides, and flocculating properties of sediments (Partheniades, 1970). Disturbances to systems that change the salinity/density structure, *e.g.*, increasing freshwater flow or deepening of the system, will cause an increased rate of shoaling.

In 1944, the Army Corps of Engineers deepened the main ship channel from 9.1 m to 10.7 m, and shoaling and sediment deposition increased even further. The deepening facilitated an increased bottom inflow of saline water, followed by landward transport and deposition of marine sands into Charleston Harbor (*cf.* Meade, 1969; Van Nieuwenhuise *et al.*, 1978).

As the cost for the Army Corps of Engineers to maintain the ship channel and anchorage basin skyrocketed to over $5 million annually (Little, 1974), the Corps pursued alternative ways to continue hydroelectric power generation but alleviate shoaling. Because the increased river discharge and subsequent shift to partially mixed conditions were pinpointed as the prime cause for high sedimentation rates and shoaling in the harbor, the Army Corps of Engineers devised a plan to redivert 85% of the Cooper River flow back to the Santee via a rediversion canal (Figure 2). The initial plans called for a minimum weekly Cooper River discharge of 84 m^3/s, which was to include 3 days of no flow and 4 days of peak operation at 147 m^3/s. This freshwater release schedule was criticized because the high discharge during the post-diversion period, 1942-1985, maintained fresh water conditions in the Durham Creek Canal on the Cooper River. This was a requirement for industrial users, and several industries that had settled along the Cooper River withdrew freshwater from the Back River Reservoir (Figures

1, 2) for industrial operations. It was feared that the proposed reduction in discharge would result in salinity intrusion into the Durham Creek Canal and contamination of the Back river reservoir. Salinities of 0.5 ppt or higher will force industries to shut down (SC Water Resources Commission, 1979). A low-flow study carried out in 1978 (SC Water Resources Commission, 1979) to simulate the proposed weekly Cooper River post-rediversion discharge schedule confirmed that salinity could intrude as far upstream as Durham Creek. The original discharge schedule was thus modified by increasing the mean discharge in such a way that freshwater inflow is always maintained at the Durham Creek Intake Canal.

Charleston Harbor Since 1985

Rediversion was completed in 1985. The major feature was the construction of an 18.5 km long canal from Lake Moultrie to the Santee River (Figure 2). Most of the flow from the upper Santee River is now channeled into Lake Moultrie, through the rediversion canal, and back to the lower Santee River. In addition, a hydroelectric power plant with the potential to produce 1% of the generating capacity of South Carolina was constructed near St. Stephens on the rediversion canal.

After rediversion was completed, it was once again necessary to alter the modified discharge release plan to avoid salinity intrusion. Presently, the SCPSA releases an average 122 m^3/s (Figure 3) into the Cooper River at Pinopolis, or 50% more than originally planned by the Corps of Engineers (Kjerfve and Magill, 1989). The implications of this schedule with respect to salinity intrusion and estuarine circulation are now being determined through a series of studies carried out by the University of South Carolina, South Carolina Sea Grant Consortium, and various state and federal agencies.

To further complicate the evaluation of physical conditions in Charleston Harbor, the Army Corps of Engineers is presently in the process of deepening the navigation channel to 11.5 m. It is still too early to tell what effects this modification will have on physical processes, salinity intrusion, and sediment shoaling in Charleston Harbor.

The USGS has for several years operated eight water level/water quality gauges along the upper Cooper River and Durham Creek Canal, with real-time data transmittance via satellite every 15 minutes. The USGS monitors conductivity and temperature along the river and advise the SCPSA of low conductivities and the need to increase the discharge at Pinopolis to counteract any salinity intrusion.

The effect of the Cooper River rediversion on the hydrology of the Charleston estuarine system is still being investigated. Kjerfve and Magill (1989) have analyzed salinity and discharge data (Figure 3) from 1922 to 1987 as well as data from the 1978- 1979 low-flow experiment (SC Water Resources Commission, 1979). According to Kjerfve and Magill (1989), high correlation between salinity and discharge existed in Charleston Harbor after diversion, 1942-1985, but discharge now exerts little control over salinity variations because of the nearly constant discharge. Instead, tidal phase, the spring-neap tidal cycle, and far-field meteorological forcing appear to be the most important controlling factors on Cooper River salinity variations. This same scenario has been reported in other estuaries as well. For example, Lepage and Ingram (1986) found that an 80% flow reduction of the Eastmain River Estuary resulted in salinity intrusion and more variable circulation and salinity regimes, which rapidly responded to wind and tidal forcing. Sharp *et al.* (1986) also found a poor relationship between freshwater flow and salinity stratification in the Delaware Estuary during low discharge.

Longitudinal Salinity and Turbidity Distribution

To investigate the responses of the Charleston Harbor estuary to the decrease in Cooper River discharge subsequent to rediversion, the University of South Carolina (USC) instigated an intensive hydrographic field investigation coupled with numerical modeling. The program has been ongoing since 1987 with funding from the South Carolina Sea Grant Consortium.

One aspect of the USC project has focused on the salinity distribution and transport of nutrients and sediments from the upper Cooper River. Nineteen stations (Figure 2) were used to characterize the longitudinal-vertical salinity distributions extending for 51 km from the mouth of the harbor to the upper Cooper River near the Tee (Figures 1,2). Vertical profiles of conductivity, temperature, density (CTD), and light transmissivity were measured at each station following the upstream propagation of high tide for several month-long sampling periods 1987-1989. The data have been used to produce graphics of transects of longitudinal-vertical salinity, transmissivity, and density profiles. Examples of three of these transects are shown in Figure 4. The data are presently being used to describe and analyze responses of the estuarine system to the current freshwater discharge release schedule.

The 1 ppt isohaline is conveniently chosen to mark the upstream limit of the estuary. In spite of the constant rate of freshwater discharge since the rediversion, the extent of the Charleston Harbor estuarine zone varies significantly, from 36-45 km up the Cooper River (Figure 4). The isohalines oscillate 7-12 km horizontally between high and low water. This large variability of the estuarine zone is not a function of freshwater discharge but is due to changes in the coastal ocean climate (Rutz, 1987), for example, storm events on the continental shelf.

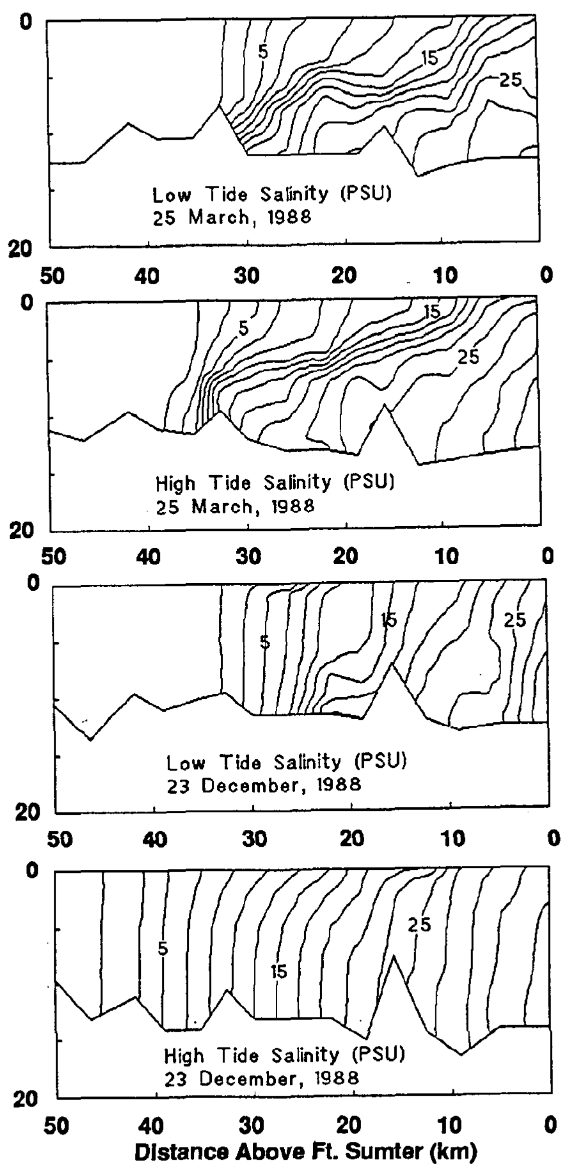
During spring tides (Figure 4), the estuary becomes vertically well-mixed. This is the consequence of strong tidal currents associated with a tidal range frequently exceeding 2 m, which dominates the tendency towards stratification. During neap tides, on the other hand, the tidal currents are not sufficiently strong to break down the salinity (density) stratification resulting from freshwater discharge. The stratification is particularly strong in the middle part of the mixing zone, 10-30 km from the Fort Sumter cross-section, where the vertical salt gradient reaches 1 ppt/m.

A well-defined turbidity maximum zone exists 20-35 km from Fort Sumter (Figure 5), where the salinity varies from 7-17 ppt. The zone is characterized by only a 50% light transmission over a 5 cm path-length near the bottom of the turbidity maximum zone, as compared to a 70-95% transmission near the bottom elsewhere in the estuary. Typical suspended sediment concentrations in the turbidity maximum zone measure 50-100 mg/l as compared to 20-60 mg/l elsewhere.

Cross-Sectional Variability

Another aspect of the USC investigation focuses on the estimation of fluxes of water, salt, and suspended sediments between Charleston Harbor and the adjacent coastal ocean. A cross- section was defined based on three stations across the harbor mouth from Fort Sumter to Fort Moultrie (Figure 2). Hourly vertical profiles of current

Figure 4. **Vertical-longitudinal distributions of salinity (PSU) from Fort Sumter to 50 km up the Cooper River during neap tide (25 March 1988) and spring tide (23 December 1988)**



velocity, conductivity, temperature, salinity, density, and transmissivity were measured at each station, during several complete tidal spring and neap tidal cycles during 1987 and 1988. An example of the tidally-averaged cross-sectional distributions of salinity, transmissivity, temperature, and σ_T for one complete tidal cycle is presented in Figure 6, indicating significant lateral and vertical gradients across the harbor entrance. Currents, salinity, temperature, density, and turbidity (transmissivity) vary cross-sectionally and for each stage of the tide. This is makes it all the more difficult to use field data to estimate tidally averaged fluxes of salt and sediment.

In conjunction with the USC investigation, National Ocean Service (NOS/NOAA) has been conducting coordinated field studies to update the tide and current tables for Charleston Harbor. This became necessary in view of the present situation with greater water depth and lower river discharge as compared to the previous field studies to compute and verify tidal predictions in the har-

Figure 5. **Vertical-longitudinal distribution of transmissivity (a measure of turbidity) from Fort Sumter to 50 km up the Cooper River, 9 March 1988. The turbidity maximum lies approximately 22 km upstream from Fort Sumter. Isopleths in % transmissivity.**

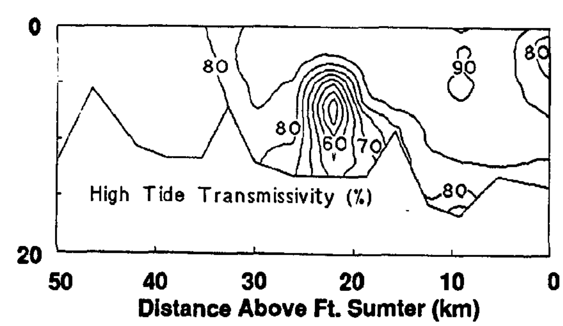
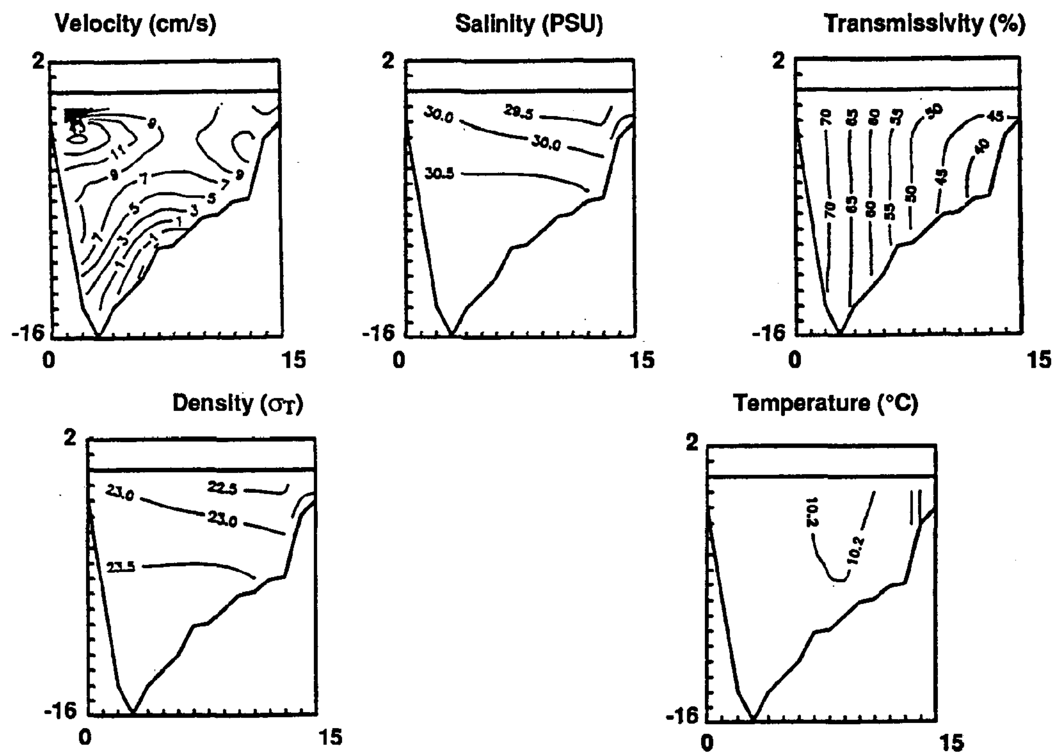


Figure 6. **Example of cross-sectional distributions of velocity, salinity, transmissivity, density, and temperature in the Fort Sumter to Fort Moultrie cross-section, averaged over 1 tidal cycle, 18 February 1988.**



bor. Simultaneous with the USC cross-sectional sampling, NOS installed two Remote Acoustic Doppler Systems (RADS) in the Fort Sumter to Fort Moultrie cross-section in 1987-1989. Each RADS unit records current velocities based on the doppler shift principle from 17 vertical bins in 15-20 m water depth on each side of the navigation channel. NOS and USC are sharing the various data sets and are presently using these to calculate the magnitude and variability in instantaneous cross-sectional fluxes of water, salt, and sediment. These data may, in conjunction with dispersion modeling, be useful for calculating budgets of salt and suspended sediment between Charleston Harbor and the adjacent coastal ocean.

Numerical Modeling

The USC investigation also focuses on the implementation of a coupled numerical circulation and dispersion model (Kjerfve *et al.*, 1988) for the Charleston estuary, including the Ashley, Cooper, and Wando rivers. The depth-averaged tidal model simulates water level variations, tidal currents, and the distribution of conservative constituents such as salt. The field data are being used to calibrate and verify the model. The model is also used to test hypotheses concerning temporal and spatial responses in the physical regimes of the estuary for different freshwater discharge, tidal, wind, and dredging scenarios.

The hydrodynamics (circulation) portion of the model is based on the Blumberg (1977a, b) model of the Chesapeake Bay, but has been modified extensively. It is two-dimensional and vertically integrated, with the formulation based on the global shallow water equations. Because of vertical integration, the model does not portray the vertical structure of the water column, but it simulates well the instantaneous currents and residual tidal circulation. The three rivers are simulated using three coupled one-dimensional models.

A companion tidal dispersion model is coupled with the circulation model. It allows for the calculation of concentration distributions as a function of time within the model grid domain. It is assumed that the dissolved or suspended constituent to be modeled behaves conservatively. Should this not be the case, it is necessary to add one or more terms describing the non-conservative rate of change of the constituent. Dispersion characteristics are also calculated for the three one-dimensional linked river models.

The dispersion model is time-varying, fully non-linear, utilizes a Manning parameter to simulate bottom friction, and assumes horizontal dispersion to be proportional to the local instantaneous velocity and the grid spacing. The non-linear set of partial differential equations is solved explicitly as finite difference equations using a leap-frog scheme in time and a staggered central difference parameter representation in space on a compact single grid. The finite difference equations are second order accurate in space and first order accurate in time. Dispersion coefficients are assumed to be proportional to the instantaneous local velocity and grid spacing. The model is forced by prescribed tidal constituent amplitudes and phases at the open ocean boundary, freshwater discharge at one or more locations within the model, and temporally and spatially varying wind stress. Quasi-steady state conditions are achieved after three tidal cycles with respect to flow modeling but only after 20-25 tidal cycles with respect to modeling of concentration distributions.

Other Related Studies

Other research teams from USC are investigating nutrient dynamics in response to the changes in Cooper River discharge, ecological characteristics of adjacent wetlands as a function of the Cooper River salinity gradient, and larval recruitment of shrimp (*Penaeus setiferus*) into the harbor. The numerical simulation model and the hydrographic data are used to assess components of these investigations, such as (1) identification of nutrient point sources or sinks in Charleston Harbor and along the Cooper river; (2) mechanisms of larval recruitment and dispersal; (3) the response of fresh and salt water marsh ecosystems to tidal forcing and freshwater discharge; and (4) simulation of structural changes in fresh and salt water marsh ecosystems along the Cooper River in response to the decrease in flow.

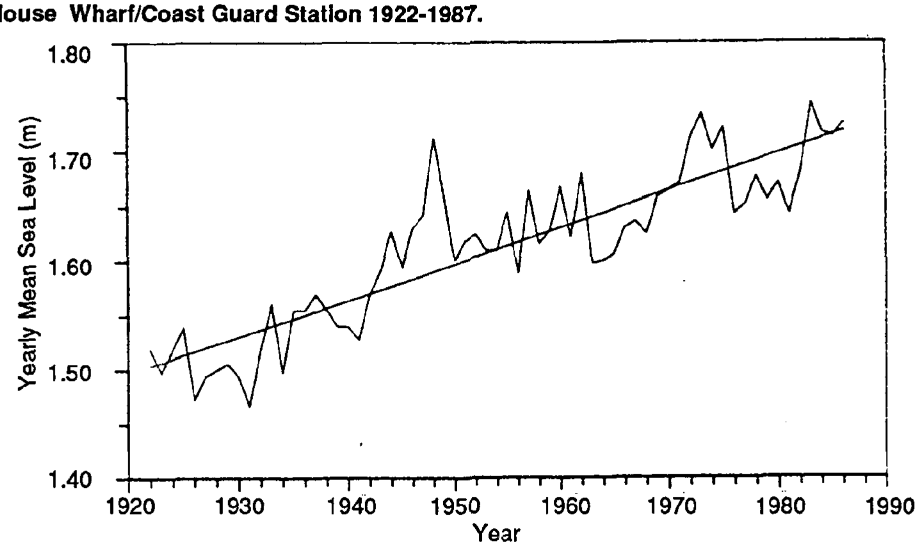
Implications of Sea Level Rise

The major future impact on the Charleston system is associated with rising sea level as a function of greenhouse-related climatic warming. Analysis of NOAA water level data (Figure 7) from Charleston Harbor since 1922 (Hicks and Cosby, 1974; Kjerfve and McKellar, 1980) indicates that (1) mean sea level varies seasonally by 0.25 m with highs in September and lows in February in response to steric and meteorologic effects (Patullo *et al.*, 1955), and (2) the relative mean sea level is increasing at a rate of 0.38 cm/year. The relative mean sea level increase is a combination of eustatic sea level rise and local tectonic subsidence. As the sea level rate of increase continues to accelerate, a portion of wetlands and low-lying areas in the Charleston Harbor area will become permanently indundated with marine waters, and the estuarine zone will extend further inland. The most likely rate of relative sea level rise for the subsiding South Carolina coast is from 1 to 2 m in the next 100 years.

Concluding Remarks

Although Charleston Harbor has much in common with other coastal plain estuaries on the U.S. east coast, the relative importance of different physical processes and dynamics varies from one estuarine system to the next. For example, tidal processes are significantly more important in Charleston harbor as compared to Chesapeake Bay because of a greater tidal range and stronger tidal currents. As a result, residual tidal circulation is an important circulation mode in Charleston Harbor in addition to the gravitational circulation, which predominates only in the dredged navigation channels. The residual motions due to the interplay between residual tidal and gravitational circulations and far-field ocean forcing (because of variations in coastal ocean climate) justifies the continued study of Charleston Harbor and other estuaries. In many respects, estuaries with pronounced tidal forcing, such as Charleston Harbor, only partially fit the Chesapeake Bay model of estuarine circulation.

Figure 7. **Annual mean sea level increase in Charleston Harbor based on NOAA measurements from Customs House Wharf/Coast Guard Station 1922-1987.**



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Charleston Harbor Water Quality

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Charleston Harbor Estuary encompasses the Cooper River from the Lake Moultrie Dam to the entrance to the harbor, Ashley River, Wando River, and Stono River which all drain into Charleston Harbor. The major source of freshwater into the harbor comes from the Cooper River. Cooper River discharge is controlled by releases from the Pinopolis Hydroelectric Plant and averages 3500 cfs. The Cooper, Ashley and Wando Rivers are tidally influenced their entire lengths. The Wando River is saline its entire length and salt water incursion occurs 45 km at high tide in the Cooper River.

South Carolina waters are classified by the State's water quality division of the South Carolina Department of Health and Environmental Control according to water use. Numeric criteria have been established for three water quality parameters (dissolved oxygen, fecal coliform and pH) associated with the water use classification. The majority of the surface waters in the Charleston Harbor estuary are classified SC. SC classification is the lowest salt water class. No contact recreation and no harvesting of shellfish are allowed in SC waters. These waters may contain up to 1000 cells/100 ml fecal coliform in any 30 day period with up to 2000 cells/100 ml for 20% of samples collected. Dissolved oxygen (DO) levels are allowed as low as 4 mg/l. Although the Wando River is classified SB (100 cells/100 ml up to 200 cells/100 ml fecal coliform, DO 5 mg/l; harvesting of shellfish for personal consumption and contact recreation), no shellfish harvesting is allowed. The upper portions of the Ashley River and Cooper River are classified B (100 cells/100 ml up to 200 cells/ 110 ml fecal coliform, DO 5 mg/l) because these segments are fresh water and better quality than the tidal portions of each river.

Charleston Harbor waters provide numerous uses to the local communities and industries in the area. Within the watershed, the City of Charleston owns two fresh water reservoirs that provide recreation and municipal and industrial water supplies. The Back Creek and Goose Creek Reservoirs are located in the Cooper River watershed. Back Creek receives water from the Cooper River and Foster Creek. Both of these reservoirs receive local municipal drainage and non-point source runoff from urban developments. Power generation from the Pinopolis Hydroelectric Plant is a significant use of Charleston Harbor Estuary waters and concurrently has a major impact on water quantity and quality in the Cooper River. The Cooper River is impounded to create Lake Moultrie and the flows in the Cooper are totally regulated by releases from the dam. From 1944 to 1985 flow was diverted from the Santee River through the Pinopolis Dam to the Cooper River resulting in flows in the Cooper River averaging 425 m^3/sec (15,000 cfs). Due to high siltation in Charleston Harbor in 1985 flows were rediverted back to the Santee River resulting in flows currently averaging approximately 99 m^3/sec (3500 cfs; South Carolina Water Resources Commission,1983).

Navigation is a major water use in the Harbor. Charleston Harbor is a significant port for both commercial and defense activities. Commercial ports are located on the Cooper, Ashley and Wando Rivers. Defense installations include extensive naval base operations for 20 km along the Cooper River and an Air Force Installation on the Ashley River.

Charleston Harbor waters serve an important role in assimilating municipal and industrial discharges. Currently secondarily treated sewage is discharged at numerous locations on the Ashley, Cooper, and Wando Rivers, directly into the harbor and through smaller creeks into the harbor. Prior to 1975 no sewage treatment occurred in

Charleston Harbor and raw sewage was discharged directly into the surface waters. Numerous industrial discharges are permitted to discharge into harbor surface waters. Petroleum, paper production, electric generation, chemical manufacturers are examples of industrial dischargers with permits to discharge into Charleston Harbor. The Harbor surface waters also are receiving waters for non-point source runoff from urban, industrial and rural areas. The relative influence of non-point source runoff varies in Charleston Harbor with the more developed areas such as the Ashley River having substantially higher inputs than other areas.

Based on the current water quality classification, water quality contraventions are limited. Problems primarily occur in the Goose Creek reservoir and upper Ashley River. Several organizations (South Carolina Department of Health and Environmental Control, citizens groups, Berkeley-Charleston-Dorchester Council of Governments) have expressed a desire to upgrade Charleston Harbor water quality to SB. The Berkeley-Charleston-Dorchester Council of Governments (BCD-COG) evaluated water quality for dissolved oxygen, fecal coliform and total coliform using South Carolina Department of Health and Environmental Control (SCDHEC) STORET data for January 1984 to December 1985 (BCD-COG 1987). With the exception of the upper Ashley River and Goose Creek Reservoir, monitoring data showed generally good water quality in the region's main water bodies — the lower Ashley, Cooper and Wando Rivers. This evaluation was very limited in scope and did not address other important water quality parameters such as nutrients, toxics, hydrocarbons or sediment loads. Technical workshops conducted by South Carolina Sea Grant Consortium concluded that major water quality concerns still exist over the impact from municipal loading, industrial loading, urban non-point source loading, port activities and rediversion.

***Table 1.* Charleston Harbor Water Quality Studies**

SC Department of Health and Environmental Control Monitoring Stations (1970 - present)
SC Water Resources Commission Monitoring Stations
US Geological Survey Monitoring Stations
US Dept of the Interior Federal Water Pollution Control Administration (1966 - 1967)
US Army Corps of Engineers Cooper River Rediversion Project (1966, 1972)
A. D. Little, Inc., Environmental Impact of Charleston Port Development (1974)
Enwright Associates, Inc for Ports Authority on Wando River Port (1981 - 1984)
Matthews and Shealy (1973 -1977)
Marine Resources Research Institute, Office of Coastal Resources Management project (1984 - present)
Marine Resources Research Institute, National Marine Pollution Program Office project (1970 - 1985)
McKellar and Blood (1988 - present)

Data available to assess water quality status and trends are limited in basin coverage, temporal duration, attention to tidal stage and are often only collected at the surface. Most studies are one to two year duration on specific portions of the harbor system.

Continuous monitoring of water quality is conducted by SCDHEC, South Carolina Water Resource Commission (SCWRC), and U. S. Geological Survey (USGS). The USGS stations are located only in the upper portion of the Cooper River and measure only pH, conductivity and temperature. The SCDHEC stations cover the basin (20 stations) but are sampled approximately monthly at the surface without regard to tidal stage (often not identified in the STORET data). Two ongoing studies will provide a more detailed analysis of Charleston Harbor water quality. The Marine Resources Research Institute (MRRI) National Marine Pollution Program Office project is assessing the status and trends in Charleston Harbor for the years 1970-1985 (Van Dolah and Davis). The MRRI Office of Coastal Resources Management project will provide a detailed assessment of the impacts of rediversion (Van Dolah). A study to identify linkages between water quality, primary producers, wetlands and non-point source runoff has been initiated (McKellar and Blood).

Only one assessment of point source versus non-point source loading has been conducted on Charleston Harbor. SCDHEC assessed the relative BOD_5 contribution from each source in 1975 (SCDHEC, 1977). The harbor was divided into five sub basins (Upper Cooper River, Lower Cooper River, Wando River, Ashley River and Harbor) and BOD_5 loading estimated from industrial, municipal, municipal and industrial combined point sources and animal production and urban nonpoint sources. In 1975 only 2% of the BOD_5 was due to non-point source inputs for the harbor system. However, the Ashley River system had the greatest urban development during that period and non-point source loading was 24%. No assessments have been completed since the conversion to municipal sewage treatment. A detailed study is currently underway in the Ashley River sub basin (Chigges, personal communication) No assessments have been conducted which focus on source apportionment between point and non-point source inputs for nutrients, sediments or toxics (heavy metals, hydrocarbons, pesticides or herbicides). By the year 2005, population in the Charleston Harbor watershed is expected to increase by *fifty percent*. It is unclear at this time what impact this will have on non-point source contributions.

Currently within the Cooper River, Ashley River, Wando River and Harbor there are 78 SCDHEC permitted point source discharges (Table 2, BCD-COG 1987). Municipal discharges total 42 and industrial discharges total 36. Sixty percent of the discharges are into the Cooper River or Cooper River tributaries.

***Table 2.* Number of Permitted Point Source Discharges into the Charleston Harbor System by River or Harbor Locations.**

River Basin	Industrial	Municipal
Cooper River	26	2
Ashley River	7	16
Wando River	2	1
Harbor	1	5

Of the 42 permitted municipal discharges eight are permitted to discharge more than 3.785×10^6 l/day (1 mgd; Table 3).

Fecal coliform levels give some insight to municipal impacts on water quality. Fecal coliform levels were less than 100 cells/100 ml for most of Charleston Harbor during 1984 and 1985 (BCD-COG, 1987). Goose Creek and Goose Creek Reservoir and the upper Ashley River had numerous contraventions of the fecal coliform standards. Municipal problems in these areas have been persistent.

The elevated fecal coliform levels are influenced by samples collected (1970-1975) prior to implementation of secondary treatment. Persistent municipal problems in the Ashley River and Goose Creek are evident in the long term average. Secondary treatment has not alleviated problems in these areas, though municipal treatment has substantially reduced the fecal coliform levels

Table 3. **Permitted Municipal Sewage Treatment Plants**

Plant	MGD	Receiving Stream
Plum Island Plant	18.0	Harbor
Mount Pleasant	1.4	Harbor
North Charleston	18.0	Cooper River
Pepperhill Subdivision	1.2	Cooper River
Lower Berkley	10.0	Cooper River
Pierpoint	3.0	Ashley River - Church Creek
Summerville	6.0	Ashley River
Hanahan	1.2	Cooper River - Goose Creek

in other portions of Charleston Harbor (Figure 2). Fecal coliform levels have been reduced up to 40 fold between 1964 and 1984 (Van Dolah and Davis - SCDHEC STORET data, FWPCA 1966). If municipal inputs consisted only of fecal coliform bacteria, one would conclude that Charleston Harbor is not greatly affected by municipal loading. However, several municipal systems accept treated effluent from industries within the watershed and the levels of toxics, nutrients and other pathogens being discharged from municipal sources are not known. Technical workshops conducted by SC Sea Grant Consortium identify the associated discharges from municipal sources as an area of great concern. Even with reduced fecal coliform levels in the waters problems with municipal inputs still persist. Charleston Harbor is closed to shellfish harvesting due in part to fecal coliform contamination.

The U.S. Army Corps of Engineers (ACOE) predicted that decreased flow associated with rediversion would decrease flushing and enhance retention of pollutants and allow greater degradation within the harbor system. Fecal coliform data (SCDHEC monitoring, 1986-1989) indicate these processes are occurring. Fecal coliform levels decreased by approximately 50% from 1984 to 1989.

Concentrations of pollutants in sediments and bioaccumulation in biota integrate water quality problems over the period of exposure. Often concentrations of dissolved constituents are near the detection limits and many pollutants are associated with sediments or flocculant materials being discharged. The National Status and Trends Program conducted by NOAA is assessing a number of pollutants in sediments and biota from estuaries along the entire US coastline. Samples have been collected from 212 estuaries and data analyzed to rank and compare pollutant

Figure 1. **Long term average (1970-1984) fecal coliform levels for selected stations within Charleston Harbor. Stations within each river system are listed from head waters to junction with the harbor.**

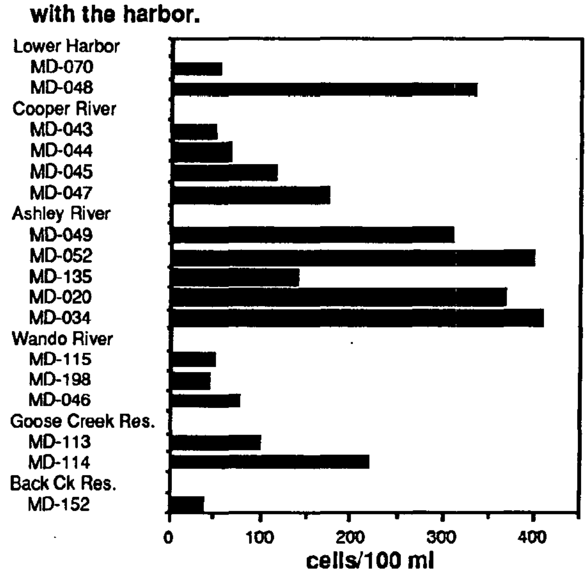
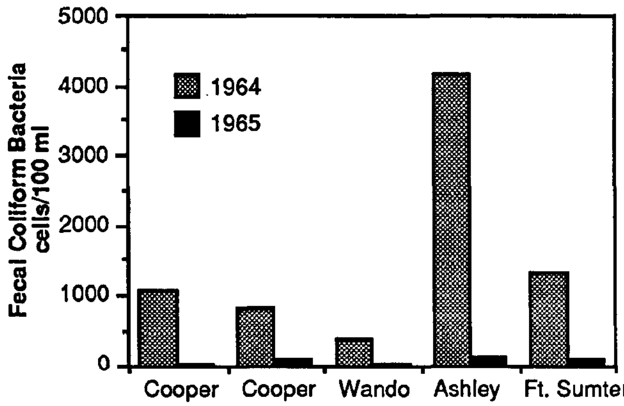


Figure 2. **Annual Average Fecal Coliform (cells/100 ml) in Surface Water**



levels regionally and nationally. Coprostanol is an enteric sterol that is produced by higher mammals and its presence in the sediments results primarily from human fecal wastes. Coprostanol is persistent and degrades very slowly and therefore is an excellent municipal waste indicator. Two sites were sampled in the lower harbor and the results are presented in Figure 3. Coprostanol concentrations in Charleston Harbor ranked 6th highest in the nation and first in the southeast, again suggesting that municipal loadings have had (or are having) a significant impact on Charleston Harbor.

Many of the small municipal discharges are scheduled to be routed to the larger municipal treatment plants and over the next 20 years the total loading from these large plants is expected to increase 2-4 times over current capacities. There are some doubts that Charleston Harbor will be able to assimilate these wastes. Waste assimilation is determined by SCDHEC using the Charleston Harbor Dynamic Estuary Model and determinations are made on the maximum amount of BOD that can be added to each stream reach without causing deterioration in ambient stream dissolved oxygen. Several areas in Charleston Harbor have chronic dissolved oxygen problems due in part to municipal discharges (Figure 4).

The upper Ashley and Goose Creek reservoir dissolved oxygen concentrations range from 1.3 mg/l to 5.4 mg/l, while average DO at the remaining stations is greater than 7 mg/l. The most recent assessment of assimilative capacity was conducted in April 1986 by SCDHEC. This study only assessed the Ashley River, Wando River, Lower Cooper and Harbor. Little or no assimilative capacity (less than 1.89×10^7 l/day (5 mgd) secondary effluent can be discharged) is available in the upper Ashley and Wando River and their associated tributaries. The harbor and lower Cooper River were identified as having sufficient (greater than 7.57×10^7 l/day (20 mgd) secondary effluent) assimilative capacity. There is some question about the validity of the lower Cooper River and harbor estimates. The model is

Figure 3. **Coprostanol in Sediments from the top 10 most contaminated sites sampled during the 1984 status and trends survey (NOAA 1989).**

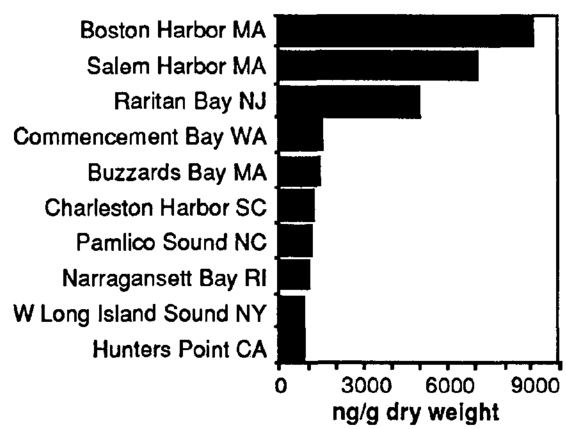
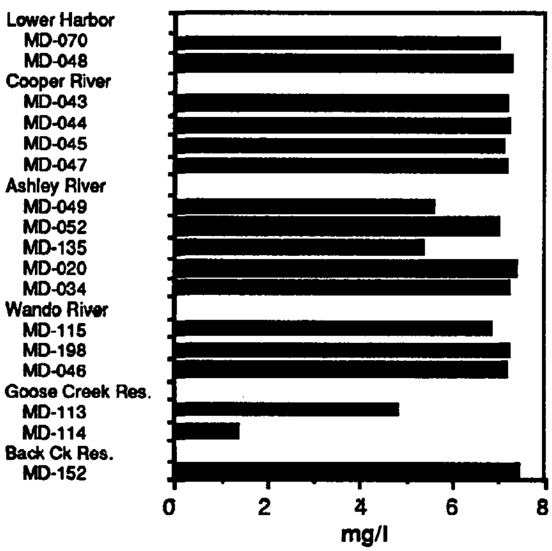


Figure 4. **Average Dissolved Oxygen Concentrations (mg/l, average 1970-1984) from selected SCDHEC monitoring stations in the Charleston Harbor System. Stations within each river system are listed from head waters to junction with the harbor.**



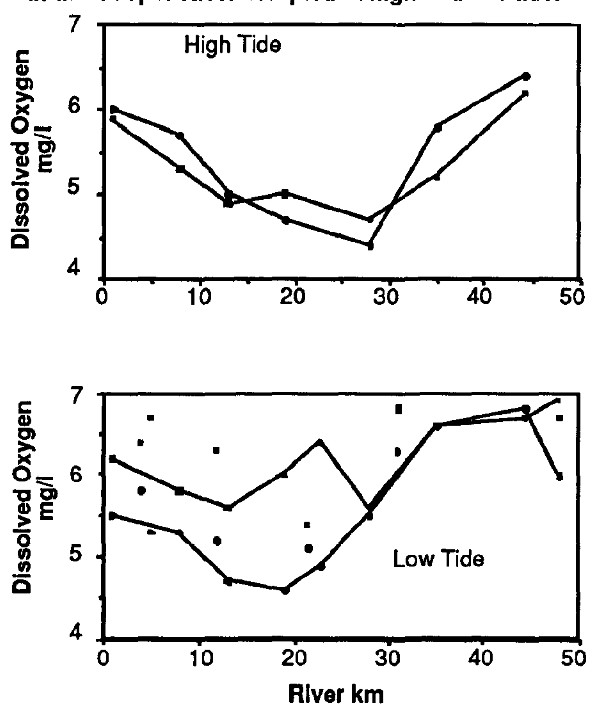
based on calibration data collected prior to rediversion and it is unclear how higher salinities and changes in stratification modify the outcome. Unpublished data by Van Dolah on benthic dissolved oxygen levels (2 to 3 mg/l) indicate that some areas in the lower harbor are currently stressed. Increased municipal loads combined with potentially greater stratification may generate areas of hypoxia during summer months (Van Dolah, personal communication).

Detailed studies are currently being conducted in the Ashley River by SCDHEC to better assess the water quality problems and identify causes. Two ongoing studies in Charleston Harbor with emphasis on the Cooper River (McKellar and Blood, Van Dolah) are providing the much-needed detail on dissolved oxygen variation with tidal stage and surface-to-bottom differences. Figure 5 provides an example of the variation observed in the Cooper River from the lower harbor (km = 0) to the "Tee" (km = 49). A dissolved oxygen sag occurs between km 8 and 30 at low tide (bottom) and km 8 and 35 (both surface and bottom) at high tide. Within this reach are an industrial (Westvaco) and municipal (Lower Berkeley sewage treatment plant) point source that have a combined permitted BOD_5 loading of 7040 kg/day. Goose Creek enters the Cooper River at km 22 with dissolved oxygen concentrations of 5.1 (bottom) and 5.4 (surface) mg/l. At low tide differences between surface and bottom DO reach 2 mg/l in the oxygen sag zone. Although overall average DO concentrations determined from SCDHEC monitoring data do not indicate a potential assimilative problem in the Cooper River, more detailed studies suggest that potential problems do exist between km 8 and 35 during the summer months.

Permitted industrial discharges occur in the Ashley, Cooper and Wando Rivers and one into the harbor. Industrial inputs to Charleston Harbor include: heavy metals, hydrocarbons, pesticides, herbicides and dioxin. Table 4 contains a partial list of permitted discharges from selected industries within the basin.

Numerous petroleum industries (*i.e.*, Exxon, Hess, Texaco, Marathon) have discharges which contain oil, grease and petroleum products. In 1966 two areas were identified as problem areas due to industrial discharges; the Ashley River due to inputs by chemical and fertilizer companies discharging organophosphorus compounds, heavy metals and phenol and the Cooper River in the

Figure 5. **Dissolved oxygen concentrations (mg/l) in the Cooper River sampled at high and low tide.**



area of Westvaco due to discharges of suspended solids and dissolved organic material which contributed materially to depletion of dissolved oxygen (FWPCA 1966). These two areas continue to be problematic. SCDHEC monitors dissolved and sediment heavy metals at its primary monitoring sites annually. Average sediment concentrations for 1970-1984 for selected sites are presented in Table 5.

Sediments from a site in the Cooper River adjacent to Highway 17 have the highest concentrations of heavy metals (copper, cadmium, chromium and mercury). Studies conducted by

Table 4. **Permitted Industrial Discharges and Rivers in Which Wastes Are Discharged.**

Charleston Air Force Base *Ashley, Cooper Rivers*	Petroleum Hydrocarbons
Charleston Int'l Airport *Ashley River*	TOC, TSS, Cd, Cr, Pb, Hg, Ag, Zn, Cu
Charleston Naval Shipyard *Cooper River*	Zn, Cu
Chevron *Shipyard Crk - Cooper River*	Benzene, Toluene, Xylene, Ethylbenzene
Cummins Engine Co. *Ashley River*	Al, Pb
Lockheed - Georgia *Brickyard Crk - Ashley River*	Cr, Phenols
Macolloy Corp. *Shipyard Crk - Cooper River*	Cr, Hexavalent Cr, Mn

the Corps of Engineers (1975) found higher levels of dissolved lead, mercury and copper in the same area. Dissolved mercury (seven times higher than any other station) and lead from SCDHEC water quality monitoring were highest in the Ashley River. Only two sites were selected in the lower harbor for the National Status and Trends program. If sediment heavy metal concentrations from the Cooper River were included in the analyses, Charleston Harbor would be considered the most polluted estuary in the US for copper, cadmium (7 times) and mercury (20 times).

No thorough studies have been conducted for hydrocarbons, DDT, PCBs or chlorinated pesticides throughout Charleston Harbor. Heavy metals, aromatic hydrocarbons, DDT, PCBs and chlorinated pesticides are measured in the National Status and Trends program in sediments and biota (NOAA 1987a, 1987b). For heavy met-

Table 5. **Average Heavy Metal Concentrations (mg/kg) in Sediments from the Lower Harbor (National Status and Trends (NST) program), Cooper River (SCDHEC data) and Highest Concentration Detected in NST program.**

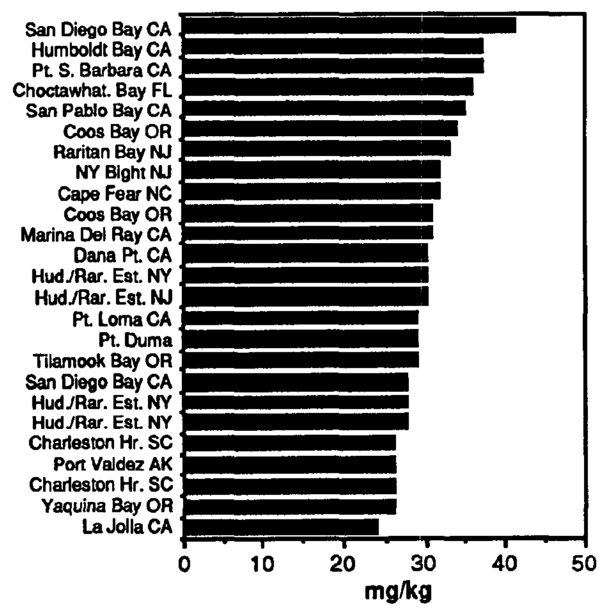
Metal	Harbor	Cooper River	Highest
Cu	25.	400.	320.
Cd	0.23	71.	11.
Hg	0.1	82.	4.3

als, Charleston Harbor sediments in general have fairly low concentrations on a regional and national comparison. Charleston Harbor ranked in the top 20 of 212 only for arsenic in sediments (Figure 6).

Analysis of bivalves indicated very high levels of arsenic. Bivalves ranked 4th and 5th out of 145 sites and 15th for silver and 11th for tin. However, Charleston Harbor ranked last for cadmium and lead in fish liver tissue (43 sites sampled) and in the lower half of estuaries monitored for nickel, silver, tin and chromium. Mercury and copper levels in fish liver tissue were in the upper half. There are potential problems with total aromatic hydrocarbons in the estuaries monitored. Charleston Harbor ranked 16th out of 212 sites nationally and second in the southeast for total aromatic hydrocarbons in the sediments, and 19 in the nation for these compounds in bivalve tissue. Detectable levels of PCBs were found in sediments and fish liver tissue, placing the harbor third in the southeast for sediment PCBs but in the lower third for PCBs in fish liver tissue. These data indicate that Charleston Harbor is affected by the point and possibly non-point source inputs of toxics to surface waters and for some parameters ranks among the most contaminated in the southeast and nationally. The National Status and Trends program may be underestimating the problem in certain areas of the harbor. If samples were collected from the Ashley River or Cooper River above the Highway 17 bridge (areas with higher toxic concentrations) Charleston Harbor might have been classified among the most polluted for other heavy metal parameters.

Only one study has been conducted on non-point source discharge into Charleston Harbor (SCDHEC 1977). An evaluation of BOD loading (1975 data) from point sources and non-point sources was conducted for each sub basin in Charleston Harbor. In 1975, only 2% of the 51,113 kg/day (112,683 lbs/day) BOD loading to the total system was from non-point source runoff. The proportion was substantially higher in the Ashley River (24%) and in the upper Cooper

Figure 6. **Arsenic in sediments (mg/kg) from the top 25 most polluted estuaries sampled in the Status and Trends survey (NOAA 1989).**



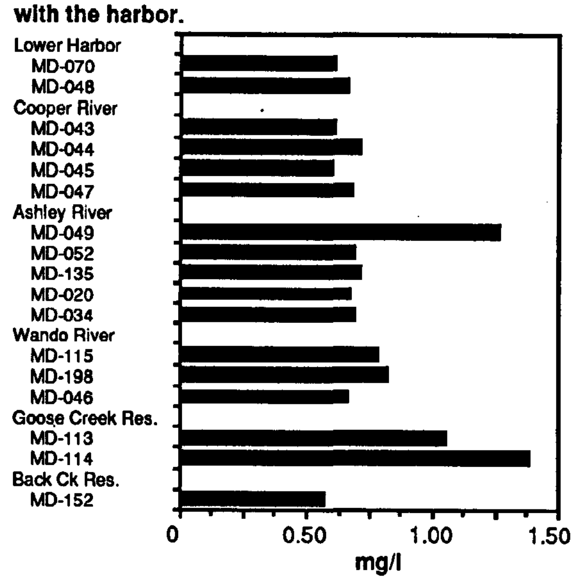
River (10%). The land surrounding the Ashley River had a larger urban component than the remainder of the basin. No studies have been conducted specifically to address non-point source runoff of sediments, heavy metals, nutrients, hydrocarbons or pesticides/herbicides. The National Coastal Pollutant Discharge Inventory was created by NOAA to provide a screening tool to point out which estuaries may be at risk due to pesticide application patterns (*i.e.*, potential for non-point source runoff) in the estuarine drainage areas (Pait *et al.* 1989). Twenty eight pesticide/herbicide/fungicides were evaluated and Charleston Harbor ranked among the lowest in the southeast for total use and toxicity normalized use. The low ranking was due in part to the low percentage (<5%) of agricultural acreage in the drainage basin.

Nutrient concentrations in Charleston Harbor are influenced by both point and nonpoint sources. No studies have been conducted to assess the apportionment between sources but analysis of SCDHEC monitoring data and recent more detailed studies (McKellar and Blood, Van Dolah and Davis; unpublished) indicate that the dominant source varies with sub basin. When Charleston Harbor is compared to two other South Carolina estuaries (Winyah Bay - influenced by nonpoint source runoff, and North Inlet - pristine, not affected by either point or nonpoint source inputs) overall average Kjeldahl nitrogen, ammonia and nitrate/nitrite concentrations are comparable to Winyah Bay but range from approximately 2 (Kjeldahl nitrogen) to 10 (ammonia) times higher than concentrations in North Inlet. Several areas in Charleston Harbor have elevated levels of nitrogen (SCDHEC Monitoring Data 1970-1984; Figure 7). The upper Ashley had high concentrations of Kjeldahl nitrogen (1.26 mg/l) and nitrate/nitrite (0.26 mg/l). Goose Creek and Goose Creek Reservoir were higher in Kjeldahl nitrogen 1.05 and 1.38 mg/l, respectively. Fertilizer production in the Ashley River and municipal discharges into the Ashley River and Goose Creek contribute to the elevated nitrogen concentrations (Blood, unpublished data, FWPCA 1966, SCDHEC 1977).

Similar results were obtained in recent studies by Van Dolah (Figure 8.) Highest inorganic nitrogen concentrations were detected in the Ashley River. Twenty miles from the harbor inorganic nitrogen was 7 times higher than concentrations in the harbor indicating a significant point or non-point source.

Detailed sampling (McKellar and Blood, unpublished) suggests a significant point source for

***Figure 7.* Total Kjedahl nitrogen (mg/l, TKN) from selected stations (SCDHEC monitoring data, average 1970-1984). Stations within each river system are listed from head waters to junction with the harbor.**



nitrogen in the mid Cooper River. Westvaco (located at km 20) is permitted to discharge 16,048 kg/day ammonia. This permitted discharge is 3.6 times higher than the total permitted discharge (4451 kg NH_3/day) from the municipal dischargers given in Table 3.

Phosphorus levels in Charleston Harbor were 5 (total phosphorus) to 200 (ortho-phosphate) times higher than North Inlet. There were comparable total phosphorus levels in Winyah Bay but Charleston Harbor had 10 times the ortho-phosphate in Winyah Bay. The upper and lower Ashley River, Goose Creek and Goose Creek Reservoir, as with nitrogen, had elevated levels of both ortho-phosphate and total phosphorus. Municipal and industrial point and nonpoint source runoff is responsible for the elevated phosphorus levels in the Ashley River. Several fertilizer companies which produce organophosphates have been located on the upper Ashley River and two large municipal discharges occur in the lower Ashley. Problems in Goose Creek and the reservoir are from a combination of municipal discharge and urban nonpoint source discharges (FWPCA 1966, SCDHEC 1977).

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Figure 8. Concentrations of ammonia (NH_3), nitrite (NO_2) and nitrate (NO_3) from selected stations (MRRI OCRM) in the Charleston Harbor System (Van Dolah and Davis, unpublished data).

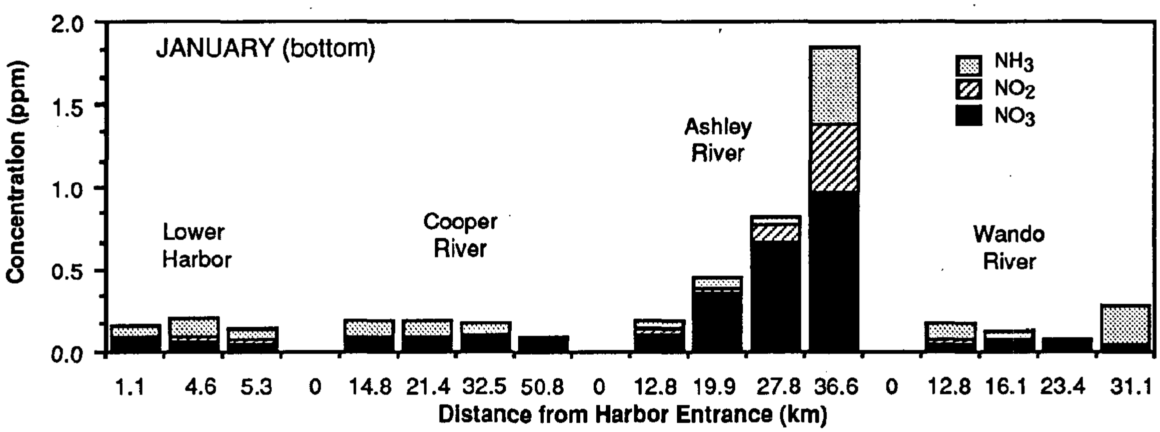
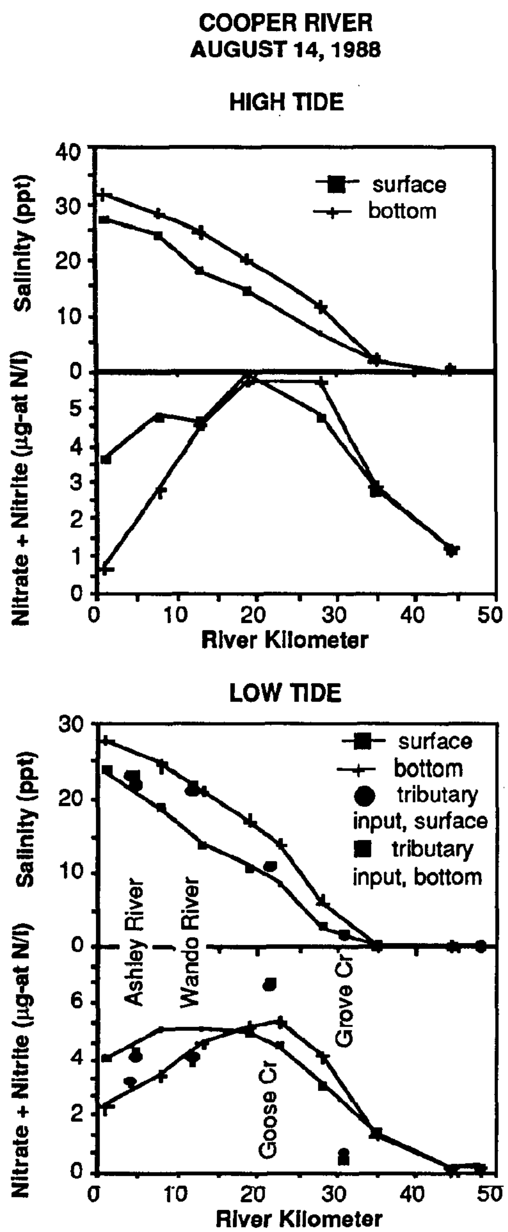


Figure 9. Nitrate plus nitrite concentrations (µg-at./l) sampled at high and lo the Cooper River (McKellar and Blood, unpublished data).



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Living Resources of Charleston Harbor

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Several of the previous presentations have shown how physically complex the Charleston Harbor estuary is, and how much it has been impacted over the past 48 years (Blood *et al.*, 1989; Goodwin, 1989; Kjerfve, 1989). In fact, the level of perturbation caused by the original Diversion Project and the Rediversion Project is unique compared to other estuaries in the country. Additionally, as Goodwin (1989) noted, the harbor system has been subjected to significant increases in urban and industrial development during this time period, and the lower harbor basin has been modified by extensive dredging activities.

With all of these changes, two obvious general concerns in attempting to manage the Charleston Harbor estuary are:

1. What biological resources does the estuary support and how do these resources function within the system?
2. How are these resources affected by the physical changes occurring in the estuary?

This paper provides an overview of the biota supported by the Charleston Harbor estuarine system and identifies what is known about some of these resources from past and current studies. With each of the biological categories considered, we note some of the general biological changes that are either expected or are occurring as a result of Cooper River Rediversion Project and other physical alterations. Some of these changes are currently being evaluated as part of a large study of the system, which is being funded in part by the NOAA Office of Ocean and Coastal and Resource Management (OCRM). Major research and management's needs as expressed by scientists familiar with this system are also identified.

Four major resource categories are described in the following sections: (1) macrophyte vegetation, (2) plankton, (3) benthic invertebrates, and (4) finfish resources. Although this estuary supports a diverse assemblage of bird species, as well as some reptiles and marine mammals such as sea turtles and dolphins (Zingmark, 1978), studies of these assemblages are quite limited.

Vegetation

The marsh vegetation bordering Charleston Harbor is probably the most important macrophytic component of this estuary. The area covered by marsh is quite extensive, largely due to a relatively high tidal range combined with a very low coastal topography. The estimated total marsh acreage for the Charleston Harbor system is 51,575 acres, which represents about 10% of the total coastal marsh acreage for South Carolina (Tiner 1977). This acreage equates to approximately 39% of the estimated marsh acreage for the much larger Chesapeake Bay (Tiner and Flinn, 1986).

The best description of the marsh vegetation present in the Charleston Harbor estuary is provided by Tiner (1977), who completed a general inventory of all coastal marshes throughout South Carolina. Additional surveys have also been conducted in the estuary by others (SCWMRD, 1972; Batson, 1974; Stalter, 1974; Duncan, 1975; Williams, 1984; Jensen and Davis, 1986; USFWS, unpublished) but these generally have been limited to small portions of the estuary (Figures 1 and 2). All of these studies document a diverse assemblage of plant species which are typically found throughout the southeast, with distribution patterns of the species determined primarily by salinity and duration of tidal flooding (Stalter, 1974). The general distribution pattern of the dominant plant species is summarized in Table 1.

***Figure 1.* Vegetation Studies Conducted by Transect Analysis for the Charleston Harbor Estuary**

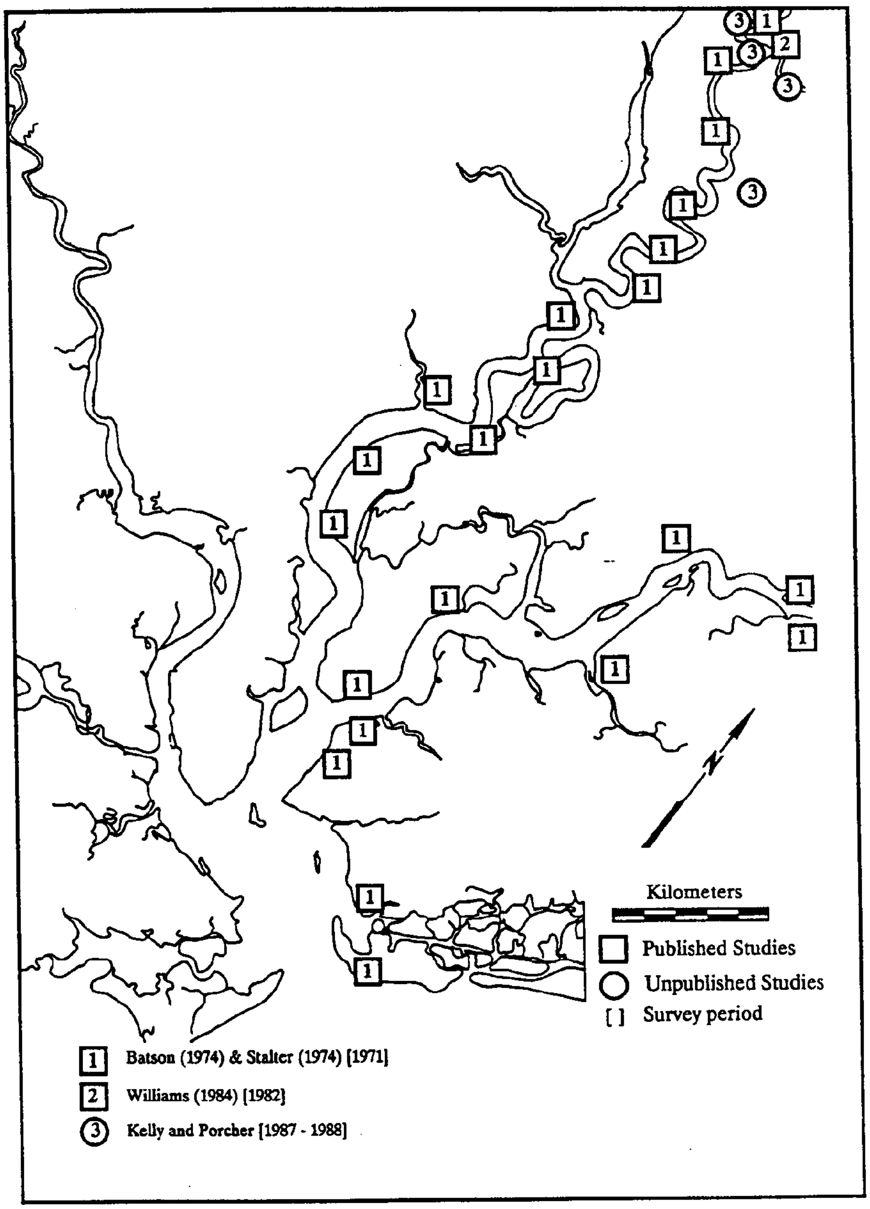


Figure 2. **Vegetation Studies Covered by Aerial Photography Analysis for the Charleston Harbor Estuary.**

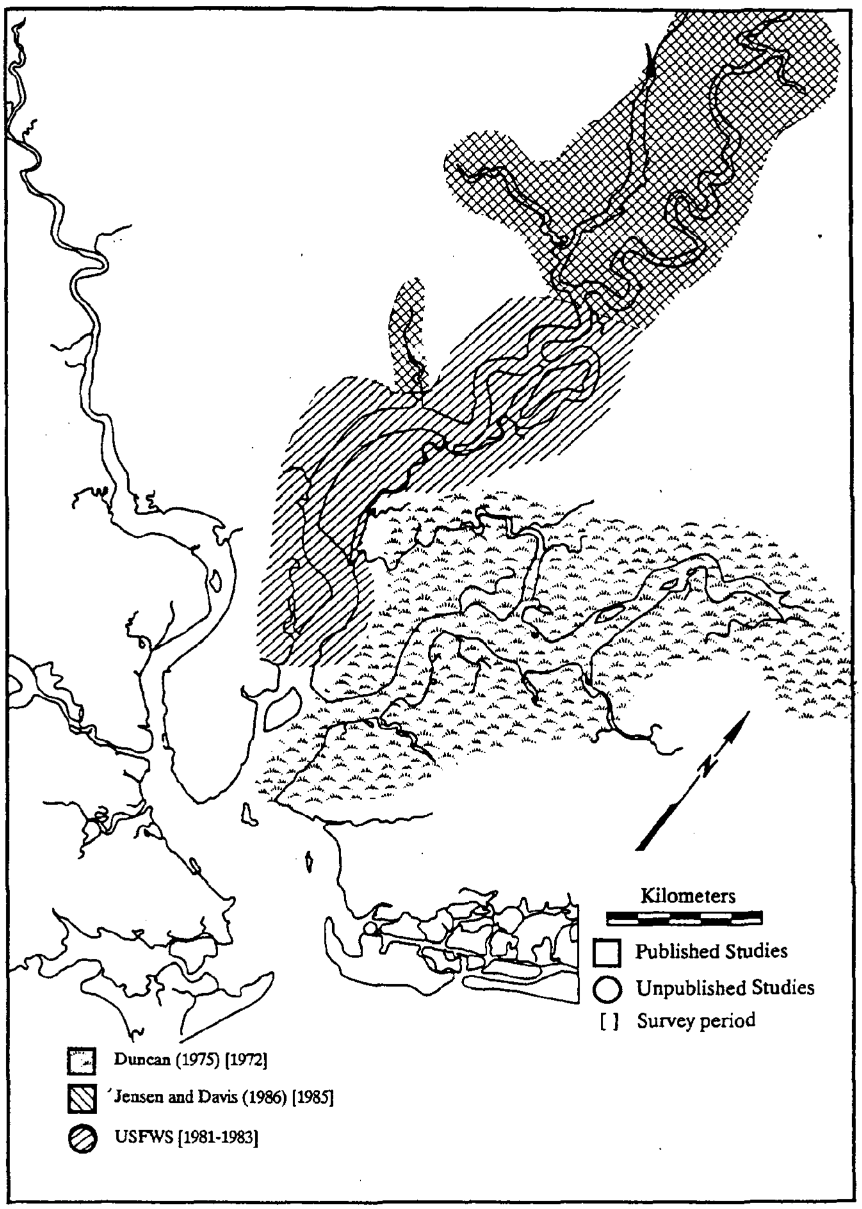


Table 1. **Dominant Species of Marsh Vegetation by Salinity Zones in the Charleston Harbor Estuary.**

Zone	Low	High
Salt Marsh	*Spartina alterniflora*	*Juncus romerianus* *Borrichia* sp. *Distichlis spicata* *Salicornia* sp. *Spartina patens*
Brackish Marsh	*Juncus romerianus* *Spartina cynosuroides* *Scirpus validus* *Sagittaria* spp.	*Pontederia cordata* *Juncus romerianus* *Sagittaria* spp.
Fresh Marsh	*Scirpus validus* *Pontederia cordata* *Sagittaria* spp.	*Zizaniopsis miliaceae* *Alternanthera philoxeroides* *Pontederia cordata* *Peltandra virginica*

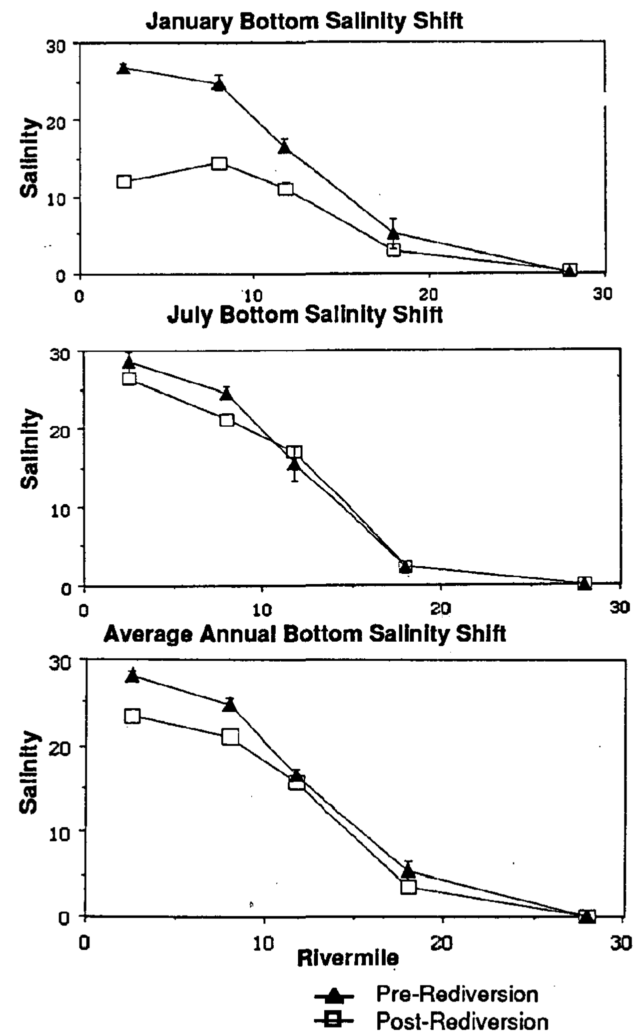
An estimated 5,111 acres of the marsh vegetation in the Charleston Harbor system are located in coastal impoundments (Tiner, 1977), which were formed in the early 1700's for rice cultivation. The majority of these impoundments are located in the upper Cooper and Ashley Rivers and much of this acreage is presently used for enhancement of waterfowl populations.

In contrast to many other estuarine systems along the Atlantic coast, the Charleston Harbor estuary is not known to support extensive subtidal sea grass beds or benthic macroalgae communities, except in the upper Cooper River where *Egeria densa* beds are common. This may be due to high turbidity levels in this estuary combined with a lack of suitable shallow water substrate in the subtidal zone. Only a few algal species have been collected in trawl or dredge samples taken within the harbor, (Sandifer *et al.* 1980), although beds of *Porphyra* sp. and *Ulva* sp. have been observed in the shallow subtidal and intertidal areas of the lower harbor basin.

Some changes in the vegetation are anticipated as a result of the Cooper River Rediversion Project, although it may take many years before some of these changes are manifested. With the reduction of fresh water flow down the Cooper River, a net upstream shift in the various salinity regimes within the estuary is expected. The extent of this shift in salinities is not well documented due to the general lack of pre-rediversion hydrographic data which is comparable to post-rediversion data. However, during a controlled low-flow study prior to rediversion, significant upstream intrusions of the salt wedge were noted (SCWRC, 1979). Hydrographic data which has been collected on standardized trawl cruises conducted over a four-year period encompassing the period of rediversion shows an upstream shift in comparable salinities which varies with season and location within the estuary (Figure 3). While these data are limited, they suggest that the range of vegetative species associated with particular salinity regimes may be redistributed upstream within the estuary. Furthermore, the changes may be greatest in the Cooper River as compared with the Ashley and Wando Rivers, which receive freshwater inputs that are more similar to pre-rediversion conditions. Fresh and brackish water marsh vegetation in the upper Cooper River may also be affected by a reduction in flooding of wetlands adjacent to the river (U.S. Army Corps of Engineers, 1975). The reduced water levels may result in changes in the vertical zonation of plant species as well as affect the composition of vegetation in the impoundments on this river.

One study may provide the best information on changes in the distribution of macrophytes within the Cooper River that will occur as a result of rediversion. From 1981-1983, the USFWS (unpublished data) conducted detailed surveys throughout much of this river system using low altitude infrared imagery combined with ground-truthing transects at several sites in the river to determine species composition. Equivalent surveys planned for the future should define distributional shifts in the assemblages observed in that study. Another study in the upper Cooper River currently being conducted by Kelly and Porcher (Citadel, unpublished data) includes a quantitative comparison of vegetated plots in several remnant impoundments and a qualitative survey of one open marsh area on the upper Cooper River. These areas have also been sampled prior to and following rediversion by other studies. Additionally, the extensive aerial imagery available for the Charleston Harbor system should provide ample

Figure 3. **Average January, July, and Annual Bottom Salinities at Five Standardized Trawl Stations During One Pre-Rediversion Year and Three Post-Rediversion Years in the Charleston Harbor Estuary**



opportunities for researchers to compare the pre- and post-rediversion distribution of vegetation throughout the entire estuary in the future.

Other physical changes may also affect the wetlands in Charleston Harbor. Wetland loss in the estuary through developmental pressures should be minimal, since the alteration of wetlands is highly regulated by the South Carolina Coastal Council. However, it is unknown whether the overall productivity of these marshes may be modified by anthropogenic inputs from adjacent highland areas. Additionally, the wetlands in Charleston Harbor may be substantially altered in the future due to the anticipated rise in sea level. Kana *et al.* (1984) evaluated the changes which may occur in Charleston Harbor as a result of future rises in sea level and identified shoreline changes that would affect the acreage of marsh. Loss of wetlands through sea level rise is a concern shared by other researchers in the area, based on discussions at a recent technical workshop hosted by the Sea Grant Consortium. Other concerns and research needs related to the macrophyte vegetation are to:

1. Update the database on the extent and distribution of the intertidal macrophyte communities
2. Conduct research to better establish wetland functions and values, especially with respect to how economically valuable species of fauna are utilizing the marsh vegetation
3. Identify the extent and role of submerged vegetation in the estuary
4. Determine effects of anthropogenic alterations (including the changes in water flow) on the distribution and productivity of marsh grass assemblages
5. Manage the marsh and adjacent highland areas to minimize habitat loss due to coastal development

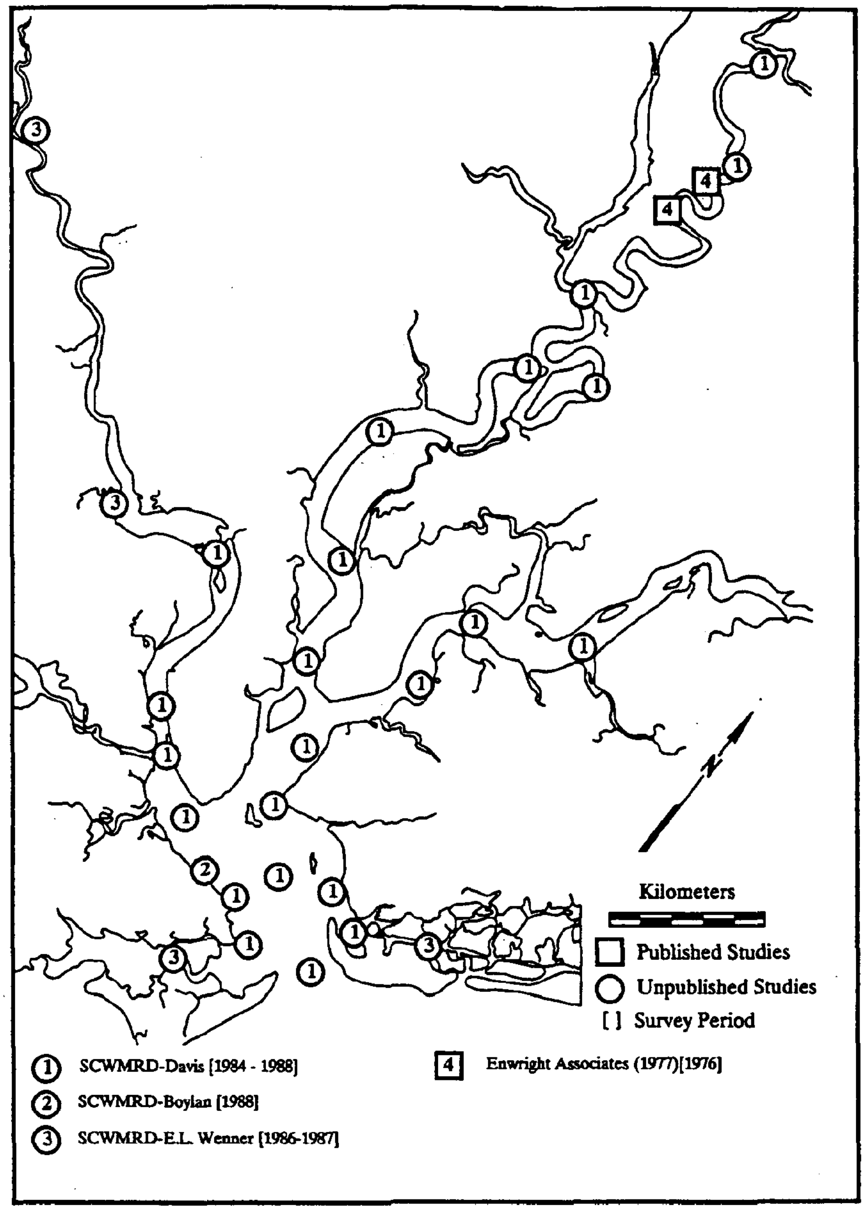
Plankton

Relatively few studies have been published which have examined the phytoplankton and zooplankton communities in Charleston Harbor (Bears Bluff 1964; Federal Water Pollution Control Administration, 1966; Enwright Laboratories, 1977). The location and sampling periods of those studies, as well as some unpublished studies that have sampled planktonic assemblages are shown in Figure 4. These studies have identified over 450 species of phytoplankton and more than 130 zooplankton taxa.

The more recent unpublished studies provide the most comprehensive information on the planktonic assemblages in the harbor. Davis (SCWMRD) processed more than 1850 phytoplankton samples collected from 1984-1988 and documented distinct trends in both community structure and abundance with salinity. General trends he observed from samples collected prior to rediversion include decreased phytoplankton abundance with decreased salinity, and seasonal changes in species composition: diatom species were dominant during the spring and early fall, while cyanophytes and small flagellates dominated summer and winter periods. Post-rediversion samples collected by Davis have not been completely analyzed to date, but they should provide evidence of range extensions within the estuary resulting from upriver shifts in the salinity regimes noted previously. Other changes in the phytoplankton populations related to rediversion are not known at this time.

Another study currently being conducted by McKeller and Blood (University of South Carolina) will provide additional information on the distribution of phytoplankton chlorophyll in the estuary. This study involves monthly measurements of nutrients and chlorophyll at 15 sites in the harbor

***Figure 4.* Studies of Phytoplankton and Zooplankton Conducted within the Charleston Harbor Estuary**



basin and the Cooper River during 1988. The results should provide a much better understanding of the relationship between these two parameters. We have identified only two published zooplankton studies available for the Charleston Harbor system (Bears Bluff, Inc., 1964; Enwright Laboratories, Inc., 1977). Both studies were limited to sampling in the Cooper River (Figure 4). These studies documented seasonal changes in the zooplankton assemblages sampled, which included larvae and post-larvae of several recreationally and commercially important species. The Bears Bluff Inc. (1964) study indicated that overall zooplankton abundance was lowest in this river compared with other rivers they sampled in South Carolina, with the exception of penaeid shrimp larvae and postlarvae.

Some of the more important studies related to management concerns are those which have examined the ingress and distribution of postlarval organisms in the estuary. These include unpublished studies on penaeid shrimp postlarvae and blue crab megalopae in several areas of the lower harbor system and Ashley River (E.L. Wenner, Boylan; SCWMRD) and unpublished studies of finfish postlarvae in the same areas and in the Wando River (C.A. Wenner, Jackson; SCWMRD). All of these studies have documented periods of ingress for many commercially and recreationally important species and other fauna, and they have defined general areas of the estuary which support greatest abundances of these organisms.

Technical workshops that were recently held by the South Carolina Sea Grant Consortium in Charleston identified several research needs specific to the planktonic assemblages. These include studies to:

1. Determine the contribution of phytoplankton to the overall primary productivity of this estuary
2. Identify nutrient limitations to the phytoplankton assemblages and determine how nutrient metabolism by phytoplankton may be affecting nutrient concentrations within the estuary
3. Continue studies to better understand the recruitment and distribution of economically valuable species which utilize the estuary for nursery habitat
4. Identify the exchange of estuarine and coastal plankton populations
5. Better identify the distribution of planktonic species throughout the estuary

Benthic Invertebrates

Charleston Harbor supports a diverse assemblage of benthic invertebrate species, but detailed ecological studies on the macroinfaunal communities have been very limited prior to 1984 (Calder and Boothe, 1977a; Enwright Laboratories, Inc., 1981a-d, 1982a-d, 1983a, b, 1984; Jones, Edmunds and Assoc. 1982a, b, 1983; Williams 1984). To our knowledge, no studies that have been conducted on the meiofauna in the estuary. The location and dates of published and unpublished studies on the macroinfauna are shown in Figure 5.

Due in part to the lack of existing data on the benthos in the Charleston Harbor, the SCWMRD initiated two benthic studies which are still in progress. These include a four-year assessment of benthic infauna at ten index sites located throughout the lower harbor basin, Cooper River and Wando River, and a one-year assessment at three sites in the Ashley River (Figure 5). These sites were visited quarterly from 1984 through 1988 (except in the Ashley River, 1988 only) to provide data on the seasonal and yearly changes that have occurred, including changes that may be related to rediversion effects. More than 320 taxa

Figure 5. **Studies of the Infaunal Invertebrate Communities in the Charleston Harbor Estuary**

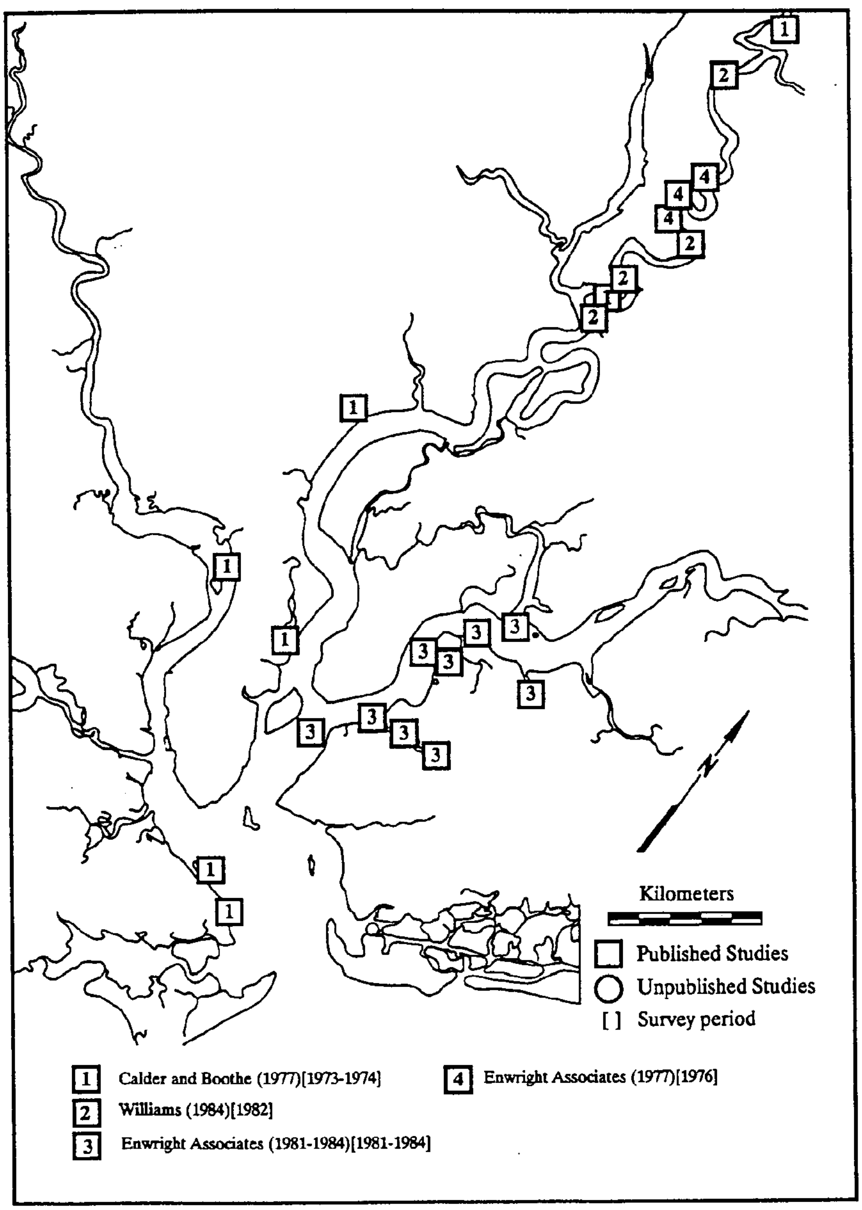


Table 2. **Rank by Abundance of Numerically Dominant Benthic Taxa Collected by Grab at Seven Index Sites in the Harbor Basin and Cooper River.**

Species	Rank by Abundance				
	Pre-Rediv	Post-Rediversion			(84-88)
	Yr 1	Yr 2	Yr 3	Yr 4	Total
Mulinia lateralis (Pelecypoda)	6	5	8	1	1
Paraprionospio pinnata (Polychaeta)	5	2	1	2	2
Leucon americanus (Cumacea)	3	1	2	11	3
Lepidactylus dytiscus (Amphipoda)	1	3	4	6	4
Oligochaeta	2	4	6	3	5
Chiridotea almyra (Isopoda)	11	7	5	8	6
Scolecolepides viridis (Polychaeta)	4	9	7	14	7
Nematoda	35	20	3	9	8
Gammarus tigrinus (Amphipoda)	7	17	11	5	9
Streblospio benedicti (Polychaeta)	13	18	14	4	10
Percent of Total	68.7	61.8	68.9	89.0	79.3
Total number of taxa	104	116	107	113	130*
Estimated Number/m^2	773	1007	1227	3893	1700

*approximate

have been identified from this sampling effort. The analysis of this data has just begun; however, a preliminary evaluation of benthic species collected at six of the sites located in the harbor basin and Cooper River suggests that there have not been large scale changes in the composition of numerically dominant species found at these sites, or major changes in the overall abundance of fauna and total number of species collected from these sites (Table 2). Further analyses of the data will most probably show shifts in the distribution and relative abundance of many species within the estuary related to increased salt water intrusion.

The second benthic study currently in progress (part of the OCRM-funded study) involved sampling the benthos and sediments at 178 sites in the harbor basin and lower portions of the Cooper, Ashley and Wando Rivers during the summer of 1988. The objectives of this study are to:

1. Obtain more detailed information on the distribution of benthic assemblages in the harbor system
2. Determine how these distribution patterns are correlated with various physical parameters
3. Compare communities near sources of pollu-

tants/disturbance with communities present in less disturbed areas having similar hydrographic and sediment characteristics to identify whether there are differences that may be related to these perturbations

Data analyses of these samples have not been completed to date, but this study combined with the longer term monitoring study will provide a much better understanding of the benthic assemblages in Charleston Harbor.

The larger epifaunal invertebrates have been sampled more extensively than the infauna (Figure 6), largely owing to the existence of a number of recreationally and commercially valuable species. These include penaeid shrimps (*Penaeus setiferus, P. aztecus*, and *P. duorarum*) and blue crabs (*Callinectes sapidus*). Additionally, there are approximately 38 acres of intertidal oyster beds (*Crassostrea virginica*), and large subtidal beds of hard clams (*Mercenaria mercenaria*) located in the lower portions of the estuary (SCWMRD, unpublished data). However, both the oyster and clam beds are closed to harvesting due to poor water quality restrictions.

The penaeid shrimp species noted above all have life cycles which are estuarine dependent and they support the largest commercial fishery in South Carolina. The average annual landings value of the South Carolina shrimp fishery is approximately 3.24 million pounds (11.8 million dollars, SCWMRD, 1978-1987 landings data). It is difficult to estimate production of shrimp from a single estuary, but Charleston Harbor appears to produce about 20% of the state's total landings based on area landing statistics. The blue crab fishery is also almost entirely estuarine dependent, with annual landings averaging approximately 471,395 pounds for Charleston Harbor over the past 10 years, which is about 8% of the total state's total landings during that period.

Each of the penaeid shrimp and crab species which are abundant in Charleston Harbor exhibit distinct seasonal periods of ingress by postlarvae or megalopea into upper portions of the estuary, and their distribution changes during various stages of their life cycles (Wenner *et al.*, 1984; Low *et al.*, 1987). Rediversion has probably shifted the location of prime nursery habitats used by each species due to shifts in the salinity regimes, although there is no pre- versus post-rediversion data available to document the extent of these changes.

From 1984-1988, the SCWMRD has conducted bimonthly trawl sampling at several index sites located throughout the estuary in order to obtain data on seasonal and yearly changes in distribution of the demersal decapod and finfish species following rediversion (Figure 6). Preliminary comparisons of the penaeid shrimp and blue crab catches in those standardized trawls provides evidence of upriver shifts in the relative abundance of juveniles and adults of these species following rediversion (Van Dolah *et al.*, 1989), but the effects on total shrimp abundance are less clear due to high yearly variability in the catches. Fishery dependent landings for penaeid shrimps, and fishery independent CPUE data collected by the SCWMRD at two sites in the lower harbor (Whitaker, unpublished data) demonstrate the high yearly variability in shrimp abundance (Figure 7). No consistent changes can be noted in these data following rediversion, although the high yearly variability observed may mask more effects of rediversion on shrimp abundance. A comparison of state-wide landings with landing estimates from Charleston Harbor also have not revealed changes in the catches of white shrimp, brown shrimp, or blue crabs related to rediversion (Van Dolah *et al.*, 1989).

***Figure 6.* Studies of the Epifaunal Invertebrate Communities in the Charleston Harbor Estuary**

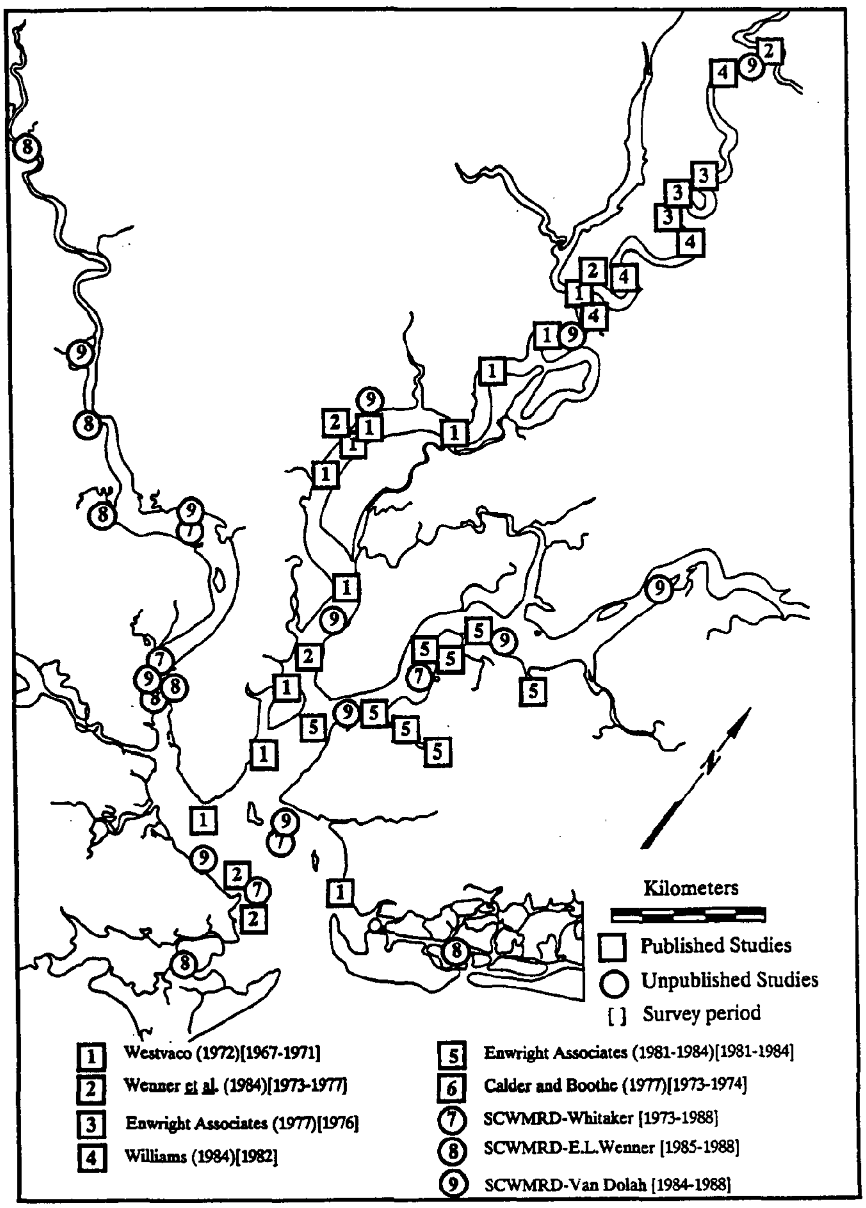
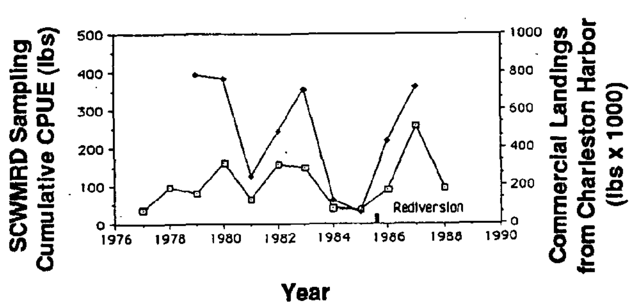
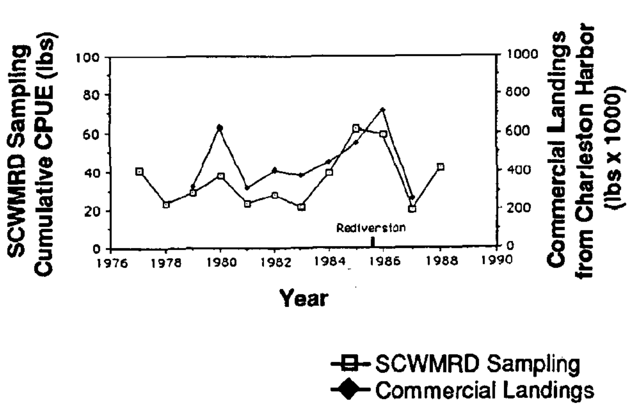


***Figure 7.* Commercial landings and SCWMRD sampling from Charleston Harbor for white shrimp (*Penaeus setiferus*) and brown shrimp (*P. aztecus*). Commercial landings estimates represent catches from Capers Inlet to Kiawah Island from 0 – 12 miles offshore (data provided by Applegate, SCWMRD). SCWMRD sampling data represents the annual sum of monthly catches averaged from two index stations in the lower harbor (data provided by Whitaker, SCWMRD).**

Penaeus setiferus



Penaeus aztecus



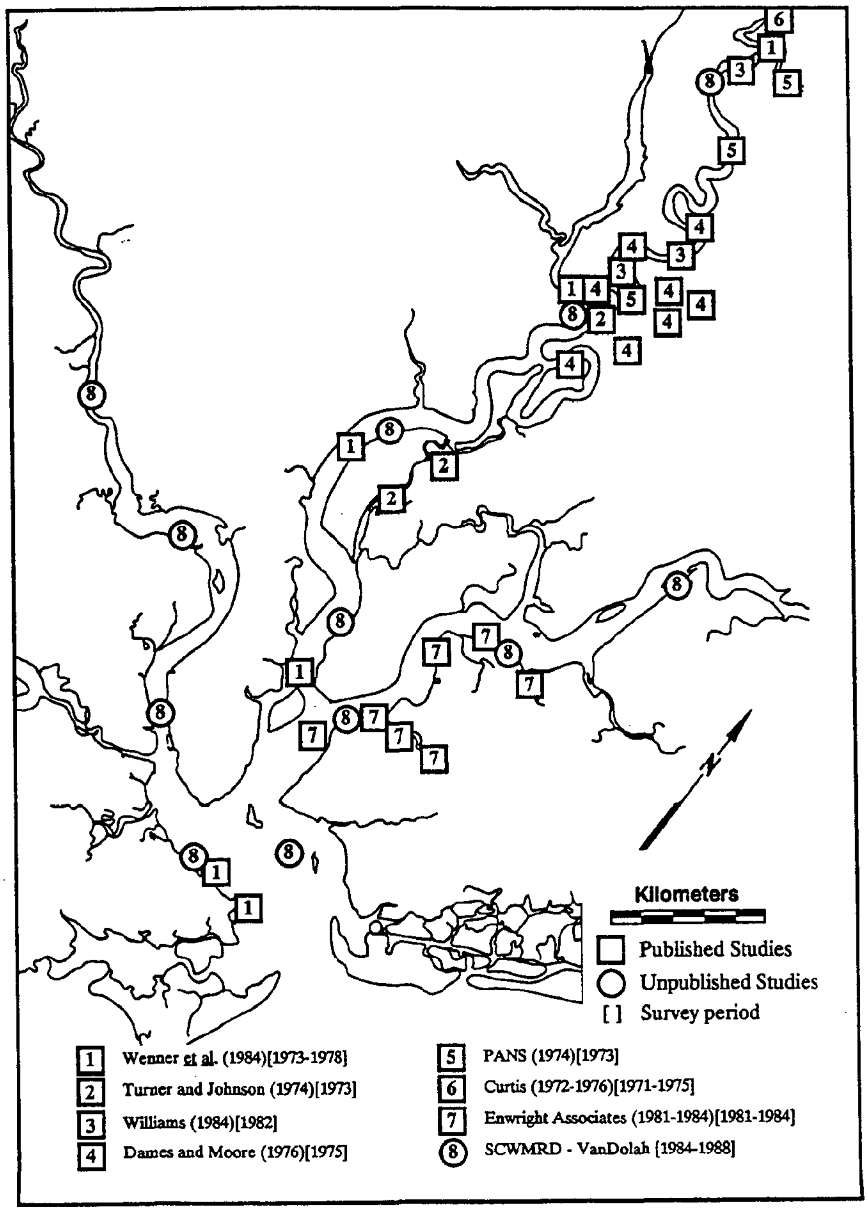
Research and management concerns identified for the invertebrate resources in Charleston Harbor are provided in the next section since most of those concerns also apply to the finfish resources.

Finfish

Finfish communities in the Charleston Harbor estuary have been examined in numerous published studies (Shealy *et al.*, 1974; Philadelphia Academy of Natural Sciences, 1974; Turner and Johnson, 1974; Dames and Moore, 1975; Curtis, 1976; Enwright Associates, Inc., 1977, 1981a-d, 1982a-d, 1983a, b, 1984;Jones, Edmunds and Associates, 1982a, b,1983; Wenner et al., 1984; Williams, 1984). The location and time periods of these and other unpublished studies are presented in Figure 8. These studies have documented that the estuary supports a diverse assemblage of finfish species, including large populations of many recreationally valuable species such as spot (*Leiostomus xanthurus*), croaker (*Micropogonias undulatus*), spotted sea trout (*Cynosiur nebulosus*), red drum (*Sciaenops ocellatus*), southern flounder (*Paralicthys lethostigma*), summer flounder (*P. dentatus*), white perch (*Morone americana*), catfish (*Ictalurus catus, I. furcatus, I. punctatus*) and several other species which are less abundant.

One study conducted from 1973-1977 by the SCWMRD provides the most comprehensive prediversion data on trawl-collected demersal fish assemblages in this estuary (Wenner *et al.*, 1984). A total of 101 fish species and 41 decapod species were collected in that study, with 10 species comprising more than 90% of the total number of fish collected (Table 3). Seasonal and yearly distribution patterns within the estuary are described for these and other numerically abundant species.

Figure 8. **Studies of the Finfish Communities Conducted in the Charleston Harbor Estuary**



The more recent trawl survey conducted from 1984-1988 by the SCWMRD (Figure 7) includes most of the stations which were sampled in the earlier survey (Wenner *et al.*, 1984). Although there were some differences in the trawl configuration and towing methodologies used in the two studies, a comparison of the species collected at sites assessed in both studies documents that 9 of the 10 most numerically abundant species sampled in 1973-1977 were still the most numerically dominant in the samples collected from 1984-1988 (Table 3). Additionally, these species comprised more than 94% of the fish collected in each year of the more recent study. Analyses of the 1984-1988 data are still in progress, but preliminary comparisons of finfish abundance and the total number of finfish species captured by trawl at five stations located in the harbor basin and Cooper River showed no consistent changes over the four year period, that could be attributed to rediversion effects (Table 3).

Finfish biomass decreased substantially over the study period, largely due to decreases in the abundance of spot and blue catfish (Van Dolah *et al.*, 1989). Additionally, the trawl data provide evidence of shifts in the distribution of several numerically dominant species within the estuary. Some of these changes may be attributable to rediversion effects; however, further analysis of these data are needed.

Most of the recreationally valuable finfish species utilize the estuary for nursery habitat. Detailed

***Table 3.* Rank By Abundance of Numerically Dominant Fishes Collected by Trawl at Five Index Sites in the Harbor Basin and Cooper River.**

Species	Rank by Abundance				
	Pre-Rediv	Post-Rediversion			(84-88)
	Yr 1	Yr 2	Yr 3	Yr 4	Total
Anchoa mitchilli (Bay anchovy)	3	2	1	1	1
Stellifer lanceolatus (Star drum)	4	1	4	4	2
Leiostomus xanthurus (Spot)	1	3	2	2	3
Micropogonias undulatus (Atlantic croaker)	2	4	3	3	4
Cynoscion regalis (Weakfish)	6	5	9	5	5
Bairdiella chrysoura (Silver perch)	10	6	5	9	6
Urophycis regius (Spotted hake)	11	19	11	6	7
Ictalurus catus (White catfish)	7	7	7	8	9
Brevoortia tyrannus (Atlantic menhaden)	5	8	6	14	9
Symphurus plagiusa (Blackcheek tonguefish)	8	10	10	7	10
Percent of Total Fish Collected	94.0	95.9	94.8	95.9	95.4
Total Number of Species	75	67	78	69	99
Total Number of Fishes/Trawl	723	964	691	977	850
Total Biomass of Fishes/Trawl (kg)	20.5	12.2	5.7	5.6	10.0

studies on the ecology and life history patterns of red drum, spotted sea trout, summer flounder, and southern flounder are currently being conducted by C. Wenner (SCWMRD) in the Charleston Harbor estuary. These studies are documenting the importance of mesohaline creeks as nursery habitat for these and other recreationally valuable species. For example, a rotenone sampling of a section of mesohaline creek in the Wando River (approximately 45 m x 6 m) during March, 1988 yielded 37,221 spot, 2,845 southern flounder, 2,594 Atlantic croaker, 22 summer flounder, and 6,305 larval and juvenile forms of other common fishes (Wenner, unpublished data). Thus, as noted for the economically valuable crustacean species, marsh wetlands play a critically important role in the life cycle of many finfish species.

Researchers working in the Charleston Harbor estuary have identified several research/ management needs related to the finfish and invertebrate fauna in Charleston Harbor, some of which are similar to those identified in earlier sections. They include:

1. Continued studies to better understand how the estuarine fauna are utilizing critical wetland areas
2. Management of the marsh wetlands to prevent alteration of critical habitats from alterations
3. Continued studies to quantify the distribution and abundance of key species, including long-term monitoring of selected species groups to evaluate ecological changes in the estuary
4. Studies to identify and define the effects of anthropogenic inputs on selected living resources, with emphasis on evaluating the effects of non-point source runoff, sewage/ nutrient loading, and industrial effluents

In summary, our review of the existing literature and data available for the living resources of Charleston Harbor indicates that while this estuary faces many problems related to the tremendous population and industrial growth in the area, it still appears to be a highly productive estuary. With proper management of adjacent land use, anthropogenic inputs, and recreational utilization of the estuary, it should be possible to maintain this level of productivity in the future and avoid some of the problems experienced in other estuarine systems.

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Charleston Harbor and Estuary:
The Dilemma of Local Management of a Regional System

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I thought it rather odd that Margaret Davidson would ask me to speak to you on management of the Charleston Harbor and Estuary system. I am neither a manager of resources nor a scientist with a strong reference base to the natural resource system of Charleston Harbor and Estuary. My reference is more closely allied with the up-country river basins which feed that estuary, and my background is that of a social scientist in resource allocation questions. But I agreed, partly because of a belief that some of the insights I have gained can, I like to think, be generalized to a wide range of resource settings and partly because Margaret funds several of my projects.

But, before I focus on the questions pertaining to management needs of Charleston Harbor and Estuary, I wish to offer some thoughts on the management of any public natural resource system. First a generalization - the relationship between people and their environment is marked by a procession of benefits and costs associated with use of natural resources. These benefits and costs are rarely, if ever, evenly distributed; some resource claimant groups derive the majority of benefits while the costs or impacts are borne by other resource claimants, user groups or society as a whole. Impacts result from disparate views of benefits and differing interpretations of what constitutes a "RESOURCE."

In 1951, Zimmerman coined the phrase "Resources Are Not, They Become." This means that objects do not possess inherent value. Objects become resources when given importance or worth by some group of people. These people claim the object as a resource for a particular value or set of values. Often objects are viewed as resources by different groups of claimants who seek legitimate but incompatible use of the object. For example, a tree may be viewed as a source of fiber for paper or lumber by one group of claimants; and valued for aesthetic appreciation and recreation by another group of claimants. Both resource definitions of that tree are legitimate and mutually exclusive. Under those circumstances, if one group of claimants win, the other must lose.

Thus, management of natural resource systems becomes the control of access to resources and the balancing of legitimate claims for resources. This balancing of claims must involve an examination of trade-offs, which requires the enumeration of impacts and the valuation of the consequences of an action. Thus *selection of options becomes a statement of social or societal values*; an expression of the legal and administrative structures by which resources are made available or are withheld. We often delude ourselves into the belief that we manage resources, but in reality resource management is management of human behavior.

The connection in this human-resource equation is between the concept of value and the element of scarcity. If no group of claimants arise for a specific object, it is often labeled wasteland, weed (often with the adjective noxious), or trash. In historic parlance, wilderness, desert, or swamp (quagmire or morass) were used as descriptive terms to identify natural settings in need of human intervention, before they became places having worth or value; before they became resources. Hence, the "great American desert" west of the Mississippi River became the nation's breadbasket, swamps became bottomland farms and wild rivers became hydroelectric stations and waterways for commerce. These conversions of land and water environments were easily justified by the concept of abundance-scarcity and by economic worth. There were, after all, many miles of wild rivers, many million acres of prairie and economic expansion was an imperative.

But unlike many other natural areas, our harbors have long been valued as economic resources, portals of commerce. Those natural environments possessed value in the most widely acknowledged form: monetary value. To the vast majority of persons the term economic value is synonymous with monetary value. Economic value is, however, much broader than the simple dollar component. As Hite (1987) points out, "a thing has value... because it possesses utility. And what we mean by utility is... the thing in question is capable of serving some human need." Hite elaborates that anything that serves a human need, whether or not it can be bought or sold, has economic value. Today the definitions of "value" associated with our harbors and associated estuaries have expanded. Simply being efficient portals of commerce is not enough to provide the range of utility demanded from our harbor and estuary systems.

To meet diverse demands upon these natural areas we typically seek technical solutions to societal problems. The search for technical, quantitative solutions for assessing impacts for specific situations is rational. Management based upon science is, on the surface, more appealing than management based strictly upon judgement. The awe effect of an equation often overrides the conventional wisdoms of applying the meaning or offering understandable explanations. Weinberg (1975), suggests, however, that "by using words, we shall sacrifice the appearance of elegance, but we shall stay closer to the things we want to think about." So why the drive for explanations of outcomes based upon a quantitative foundation rather than a qualitative approach? Perhaps we believe that "The stature of a science is commonly measured by the degree to which it makes use of mathematics." Or perhaps we were, and possibly still are, obsessed with what Egler (1983) terms "Physics Envy." So we push for the technical solution - the objective answers to the often subjective questions. For technical solutions to occur, however, we need a high level of concurrence on social values and on scientific facts, a condition rarely met.

Figure 1 (suggested by Thompson, 1967) offers a paradigm for viewing decision strategies. To understand this paradigm, let's track a decision regarding whether a wetland is to be used for habitat preservation or for residential development. The initial decision is political and occurs in an arena of elected officials who consider the arguments of various interest groups that claim the resource, and the social benefits of the competing claims as perceived by decision makers. Once agreement has been reached on values, to preserve or to build, an assessment of management options can begin. A technical, computational solution is possible only if agreement is reached regarding facts associated with management parameters; parameters of water quality, pollution mitigation needs, the effectiveness of creating substitutable wetlands, and other such points of discussion. Impact assessment is therefore only possible when values have been agreed upon. The review of facts will result in a solution upon which all parties agree; or as an outcome to which judicial review will determine the solution.

While the identification of impacts associated with specific actions or policies is a sound management practice, it is also a requirement of law. Assessing the consequences of an action involves the identification of a variety of impacts. The types of impacts can be grouped into two general categories: environmental impacts which focus on changes to the physical and biological community as the result of some action or management policy; and social impacts which focus on the way actions or management policies affect people (including quality of life).

Figure 1. **Paradigm of Decision Making Strategies**

		Agreement on Facts: *High*	Agreement on Facts: *Low*
Agreement on Values	*High*	Technical/ Computation	Judgement
	Low	Political (compromise)	Inspiration

This simple dichotomy, again, leaves us with a vague notion of benefits. To resource development intent on expanding dollar generation from resource use, new jobs translate into social benefit. But other social interests may consider the environmental consequences of industrial expansion or residential expansion to constitute a deterioration in quality of life. This social argument is most intense when associated with resources perceived as "public or common property."

Dilemma of Common Property

Rivers, wetlands, estuaries and other special places are not owned by private individuals, or by firms. They are "common property." They belong to all of us. Through government actions they are held in trust for "all of us." The government agencies serve as the agent for the public, usually trying to maximize some bundle of benefits for that public. Their management results in excluding some interests and favoring other interests with the everpresent dilemma of defining public benefits.

There are many theories and schemes for defining public benefits and public interests. One might adopt the public choice theory of, Nobel Prize winning economists, James Buchanan and say that public interest is the summation of the individual interests of all those persons living in a particular society at a given time. Under a public choice theory allocation decisions are easy to arrive at via the metaphor of the ballot box (Hite, 1987). On the other hand, if you accept the idea that society is something more than the simple summation of the wishes of persons living at any one point in time, than public interest involves the values of unborn generations facing unseen situations and retention of values from a bygone era. That leads to a public trust theory of resource management and allocation. Public choice theory is an expansionist theory allowing for maximum utilization. Public trust is a minimalist idea, it requires actions be taken to maintain diversity of resources while retaining flexibility for future resource allocation needs.

The dilemma arises in the idea of popular opinion alone directing government action, prevalent in public choice theory and in the foregoing of immediate benefits required under public trust theory. To overcome this situation a thorough enumeration of the values of a resource system is essential before any planning, or management programs are initiated. This should be accomplished in a public forum and the definition should include identification of those variables which are essential for describing that resource system within any resource utilization scheme. For the resource system being discussed today, the question is simple - "What do we need to know about the Charleston Harbor Estuary system in order to determine the benefits and cost associate with any allocation of that resource?"

Unfortunately hundreds of variables and thousands of relationships can usually be identified to describe even the most simple system. Reduction of any system into a workable model is necessary before an assessment or environmental impact study can be undertaken. The difficulty in developing a workable model centers on the sifting of all possible variables to arrive at a parsimonious set of variables which describe the problem and setting. A successful assessment of environmental and social impacts begins with a clear description of the resource setting to be affected and a clear description of the actions which are likely to cause the change.

Imagine an example of assessing the impacts associated with developing an upstream river impoundment project. We may be concerned with alterations to the physical environment. Variables included in this assessment may contain an identification of soils within the projected reservoir (fragility, productivity, depth to bedrock and type); cut and fill requirements, instream flow requirements, downstream habitat alteration; percent and type of habitat conversion; presence of rare or endangered flora and fauna; estimate of biomass removal; and water quality alterations. (Your own list may be even more inclusive.)

Now include the way the project may effect the social qualities of the river basin. We may speculate that the following variables may be important: noise, land use conversions, proximity to population centers, number of existing impoundments, loss of riverine recreation, numbers of visitors, type of visitors, attitudes of current visitors (here we could list many specific items), visibility from promontories and aesthetic alterations. (Again, your list may be different.) Proponents of the dam project may also wish to include variables such as: regional water needs for future growth, economic return to local communities, changes in local land values, potential power revenues, and cost of alternative water and power sources. Various claimants will having their own way of describing the situation.

As the list of variables grow, the complexity of the assessment grows. The number of potential relationships among these variables is the number of variables squared. Thus a system with only fifteen variables may have as many as 225 relationships which must be considered. A system with 20 variables may have as many as 400 relationships! Our task of understanding even simple systems soon becomes enormous. Consequently, it is technically infeasible to fully evaluate all of the interactions which may take place with proposed alterations to natural systems. Therefore, we must rely on procedures and models which systematically sift out a set of critically important variables and relationships which can be used to assess impacts. To work, this model must have the consensus of those natural resource claimants or users who are, or may be, affected by the proposed actions and must have the rigor to withstand judicial review.

Intuitively, we may believe that decisions for allocating resources are made in the context of human judgement. While we may use a technical solution to legitimize a specific decision, the final decisions are based upon the wisdom of experience. Yet, as Miller (1956) points out, the capacity of humans to process information is extremely limited. The limits to understanding interactions, according to Miller, are about seven relationships, plus or minus two. In other words, a brilliant manager will be able to understand a system which has a maximum of nine possible interactions. Since the number of possible paired interactions in a system is the number of variables in the system squared, then the brilliant manager will be able to understand the relationships in a system which has three variables. Thus, when faced with complex multidimensional choices, people naturally devise 'simplifying strategies' and sacrifice much information as they follow some easy road to a decision. Most of these adaptations involve the creation of good/bad evaluation criteria and often result in suboptimal choices in difficult situations. The creation of such valuation scales often tend to characterize situations which are uncertain or which introduce change as 'bad.' Yet change and uncertainty are among the realities which managers are facing and will continue to face.

Change by definition means moving away from the status quo. Whether the change is induced by socio-economic forces, shifting cultural mores, or legislative initiatives, change may cause the manager to focus on a reaction to the effects caused by the change and result in conflict. Often these conflicts put managers at odds with their publics and support groups. Also, the anxiety created by change and conflict results in decreased agency morale - a loss of sense of mission. The managers may feel they are perceived as part of a problem and an "US *vs.*THEM" attitude further crystallizes the conflict, polarizes the groups and heightens the anxiety.

The circular relationship of change and conflict is confounded by a growing social complexity. Complexity is defined as the number of parts in a system. As systems become more complex simple truths and conventional wisdoms become difficult to identify and enumerate. A feeling of isolation and a sense of "they don't understand" further separates resource managers from their publics.

The number of social groups focusing on special narrow issues is growing and these groups place demands on resource managers that are becoming more specific and less negotiable. Thus, as previously mentioned, managers may find themselves in a role as mediators between special interests and as gatekeepers of resources which are sought for often conflicting uses. Special interests often wax and wane with a specific issue and managers are faced with having to deal with groups and interests that may seemingly appear without notice. Thus, the need to anticipate probable conflict situations further stresses resource managers.

Similarly, the explosive growth of knowledge and the increasing specificity of laws and regulations heighten complexity. Knowledge is cumulative - the more that is learned the more things have to be considered when resolving problems. Laws and regulations are likewise cumulative and further increase complexity. As Bonnicksen (1985) points out, all trends seem to indicate that growth in knowledge, growth in referenda and initiatives, and growth in special interest groups will accelerate into the foreseeable future. The result is increased complexity and greater uncertainty. A reasonable question is, "can the capacity of managers to handle increased complexity and uncertainty keep pace?"

Coping with complexity requires developing ways of managing which are not paralyzed by uncertainty. New resource management arrangements must build on the premise, indeed, the fact, that we live in a world of choice rather than determinism and they must provide frameworks for improving decision making when decisions are ultimately based on judgement.

Assessment of impacts in resource recreation, park management, or environmental planning requires a systems approach when integrates the characteristics of the setting with the expectations and demands of the claimant. Bonnicksen and Lee (1982) present Biosocial Systems Analysis as "an approach for organizing and tracking interactions between society and its physical environment." The superiority of Biosocial Systems Analysis is its capacity to require completeness by a manager and to make explicit what a resource decision, policy or study emphasizes or ignores.

FOCUS: A Consensus on Values and the Values of Consensus

Today, too many programs start with a "vaporous wish" phrased in eloquent but elusive language. This penchant for stating policies in vague terms, leaves further definition and clarification to the implementation process. Yet, as Nakamura (1981) stated, as the implementation process gets underway and policies are more clearly defined, conflicts erupt. Those charged with the implementation find disagreement over what should be done and how; policy makers intervene to reformulate priorities or to shift direction and the program bogs down in conflict among various interest groups. The breakdown, encountered during implementation, started much earlier and is rooted in a lack of consensus and a lack of agreement.

Impact assessment and sound resource management are synonymous. The processes used to allocate resources mirror societal values. For resource managers to maintain support and trust they must exercise their stewardship in a manner congruent with the expectations of society. Action which appear capricious will be challenged. As much as any technical values derived from a systematic approach to resource management, consensus building and constituent development must be part of strategic management.

Without this public agenda for defining the explicit values for the natural setting we manage within the context of "benchmarking." Today we have heard an outstanding litany of the condition of the Charleston Harbor and its associated estuary system. These data describe a system that has been extensively manipulated to provide a range of goods or utilities over a two hundred year period. The data are describing *a* Charleston Harbor but not *the* Charleston Harbor. The data can tell us how the Harbor has changed or is continuing to change but only in the context of past condition of the harbor. To answer the question of "So what?" the data must be framed against the values and utilities we wish Charleston Harbor to produce. And that's the rub - those values have not been clarified. There is no unified notion of what this harbor and its estuary should be.

We are a reactive people. Every person may have a view of what the Harbor should be and within those views we espouse scenarios of protection or exploitation consistent with our specific value system. B. J. Kjerfve, eloquently expressed this dilemma at a recent meeting with the notion that "non-focus by the community at large is one of the major problems of Charleston Harbor." For all our science we have fallen short of arriving at a consensus on social values by which data on water quality, sedimentation, habitat quality, and economic components can be effectively evaluated. In addition, we have segmented the Harbor from its associated river basins. The self-focusing joke that Charleston Harbor is where the Ashley and Cooper Rivers join to form the Atlantic Ocean is perhaps a more prophetic framework for the needed management of the Harbor than currently exists.

Given the explosive growth rate in population with concurrent urbanization, in industrial expansion, in port activities, and in recreation and tourism demands projected for coastal South Carolina arriving at a consensus on values is imperative. Recent public participation activities initiated by Congressman Ravenel and conducted by the South Carolina Sea Grant Consortium have moved markedly closer to this consensus. Citizen group, special interest groups, and the broad array of resource claimants have been brought together to define the values and establish information needed to assess to future of Charleston

Harbor. A series of orientation public workshops have been conducted, public participation sessions have been held to seek a focus, and technical committees are now framing those public inputs into needed actions and research programs.

As the citizens appear to be coming together to define the social values and utilities for the Charleston Harbor, the mechanisms for institutionalizing that system are not present. The complexity of Harbor management is illustrated in that 44 local entities, 15 state agencies,and 9 federal agencies have some oversight or direct management authority within the Harbor and estuary system. Like any special interest group these entities rarely have the opportunity or ability to view the Harbor and estuaries as an integrated system. Their focus is a single parameter, such as water quality, or a single purpose, such as navigation, or a single locale, such as the Port terminals. Effective long term management requires a level of resource integration that can only be achieved through a commission authority type structure. Programs like the Columbia River Basin Commission, and the Upper Mississippi River Basin Commission have been effective management coordinators and have provided an excellent forum for maintaining contact between the publics' aspiration for resource utility and the agencies which enhance or impact those values.

But the scientific community shares a responsibility for placing the implications of their data before the larger public. Science can't wait for those isolated moments when technical solutions allow a value free use of data. Likewise scientists cannot define their sphere of interest to a narrowly circumscribed arena of expertise. Just as they espouse the need for well integrated models in which to fit their data, scientists have an obligation to participate in the larger resource allocation realm. Benveniste (1977) describes this relationship in his book *The Politics of Expertise* as follows:

> In recent decades, faith in rationality has dominated our notions of public and private administration... This faith in rationality has emerged unquestioned along with faith in modern technological development and economic growth.... We believed that progress and the use of science had become the universal and dominant mode of political thought, and that modern technological societies had become increasingly similar because they were all subject to the same universal technical constraints. This was to be an age of technology where reason and fundamental technical demands would replace old-style politics and the confusion of competing ideologies...
>
> Recently a reaction has begun to set in. Our faith is not as secure, and a malaise prevails.... The expert whose advice has had no impact on public policy probably far outnumber those whose influence is as discernible as they expected it to be.... Thus expertise is going through a crisis of its own....
>
> Those experts who still believe they are responsible only for a narrow spectrum of technical knowledge and who fail to assume their political responsibility become agents of bureaucratic sterility.

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