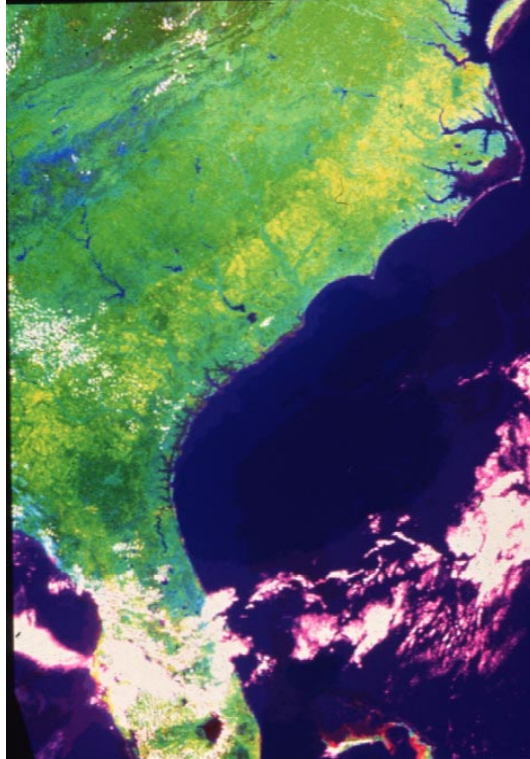


**Urbanization and Southeastern Estuarine Systems (USES)  
Annual Summary Report and Research Proposal**



Submitted to:  
**Office of Oceanic Research Programs  
National Oceanic and Atmospheric Administration**

Via:  
**South Carolina Sea Grant Consortium**

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## Table of Contents

Application for Federal Assistance . . . . .	A-1
Table of Contents. . . . .	i
Introduction . . . . .	1
Part I: Annual Update of Activities . . . . .	2
A. Microbiology . . . . .	2
B. Toxicology . . . . .	3
C. Watershed Analysis, Nutrient Runoff, and Groundwater Modeling . . . . .	5
D. Phycology and Water Column Processes . . . . .	9
E. Geographic Information Processing and Risk Assessment Modeling . . . . .	12
F. Public Outreach and Information Dissemination . . . . .	14
Part II: Proposed Activities for Upcoming Year . . . . .	15
A. Microbiology . . . . .	15
B. Toxicology . . . . .	17
C. Watershed Analysis, Nutrient Runoff, and Groundwater Modeling . . . . .	21
D. Phycology and Water Column Processes . . . . .	22
E. Geographic Information Processing and Risk Assessment Modeling . . . . .	24
F. Public Outreach and Information Dissemination . . . . .	25
Literature Cited . . . . .	26
Budget Justification . . . . .	30
Budget . . . . .	31
Appendix A: Publications . . . . .	32
Appendix B: Presentations. . . . .	33
Appendix B: Human Resource Development. . . . .	34

## Introduction

Left unmanaged, anthropogenic activities threaten the environmental health and economic vitality of coastal estuaries. Historically, the dynamic and complex nature of critical estuarine ecosystems inhibited the successful development of models that could effectively be used by coastal zone and fisheries managers. The complexity and urgency of estuarine problems now associated with coastal growth have led many research and management agencies to explore new spatial analytical techniques to provide valid and timely information to assist with effective coastal zone management. Fortunately, the continuing development of new technologies is enabling scientists to develop predictive models of how ecosystems and components of ecosystems respond to natural and developmental pressures.

In response to these concerns and the identified need for spatial models to support sustainable coastal development, a long-term study was initiated in 1990 to define, measure and model the impacts of urbanization on coastal estuaries of the southeastern United States. The Urbanization and Southeastern Estuarine Systems (USES) project began 1 June 1990. The primary objectives of this long-term study are:

1. to delineate the impact of multiple stresses resulting from urbanization on high-salinity estuaries; and
2. to develop models which will provide a scientifically valid basis for land-use management decision-making in the coastal zone.

Emphasis has been placed on watershed dynamics, including an examination of land-use patterns and the impacts associated with watershed loadings. By comparing the short-term trends and long-term variability in system responses at the North Inlet-Winyah Bay National Estuarine Research Reserve (NI) in South Carolina with those of an adjacent developed estuary, Murrells Inlet (MI), South Carolina, a clearer assessment of the impacts of development can be made than basing management strategies on one estuarine system. The models incorporate land-use patterns and practices, integrated toxicological and risk assessment modeling, and Geographic Information Processing (GIP) approaches.

A strength of the USES project is that it is a long-term monitoring and research project focusing on both current issues of ecosystem and public health. As proposed in the multi-year plan, out years are extremely crucial to the continuing success of the project. It is during this time that the integration of sub-study components via data syntheses; modeling development, testing and calibration; and outreach to coastal zone managers takes place. In addition to the two primary study sites, associated researchers have expanded into additional estuarine systems of the Southeast to conduct similar experiments and compare results and test developed models. As driven both by our science and the needs of natural resource and public health managers, we are able to adjust our research thrusts to focus on those issues most critical to the Southeast. Significant progress has been made related to ecosystem assessment, integrated modeling, and outreach for each of the study components of this past year:

Microbiology,  
Toxicology,  
Watershed Analysis, Nutrient Runoff, and Groundwater Monitoring,  
Phycology and Water Column Processes,  
Geographic Information Processing and Risk Assessment Modeling, and  
Public Outreach and Information Dissemination

The purpose of this report is to summarize the significant efforts of the last year (**Part I**) and discuss proposed research for the upcoming year (**Part II**). Of paramount importance is our ability to continue to extend our research findings to management recommendations useful in development of strategies for

managing the numerous small, high-salinity estuaries typical of the southeastern United States. Efforts of this year and proposed activities for the upcoming year build upon the scientific findings and initial recommendations for resource management as outlined in the USES document *Recommendations for Coastal Zone Management and Continued Research* (March, 1997).

## **Part I: Annual Update of Activities**

### **A. Microbiology**

Urbanization of upland areas adjacent to estuarine ecosystems has resulted in significant inputs of bacterial and chemical contaminants in salt marsh ecosystems of the southeastern United States (Vernberg et al. 1992). During the pioneering stages of urban development, human waste disposal needs were met by use of septic tank based technology. As urban development proceeds and critical carrying capacity for human population density is reached, significant inputs of bacterial pollution from septic tank discharges into estuarine ecosystems may result (El-Figi 1991), often causing closure of shellfish harvesting waters due to the presence of pathogenic bacterial/viral pollution (Leonard 1992). The normal solution to this problem is to construct a central sewer collection system to reduce estuarine inputs from individual septic tank systems (Jolley 1978).

To address this problem of bacterial contamination from human waste associated with coastal urbanization, the USES study has evaluated the effects of human encroachment on estuarine surface waters quality and oyster quality/health. Two estuarine ecosystems were chosen for study: North Inlet (NI), a pristine estuary which is a National Estuarine Research Reserve site, and Murrells Inlet (MI), one of the most urbanized coastal area in the state of South Carolina (based upon population densities => 625/sq. mile).

Microbiology research during this past year of the USES project focused on better quantification of the PFGE and Fatty Acid profiling techniques in environmental samples and in developing long term analysis of coliform data using intervention analysis and other related statistical methods. Research conducted in year 8 has focused on quality assuring results in lab standards, human volunteers, septic tank samples and samples collected from NIOL site at North Inlet adjacent to the watersheds, housing large populations of wildlife and birds. Results have indicated that there are distinct differences among humans in terms of API biotypes and PFGE banding patterns of DNA. Analysis of septic tank samples from the Wedge indicated only two distinct PFGE banding patterns, suggestive of only limited human use of this facility. Samples from North Inlet tidal creeks clearly indicated greater variability in PFGE banding patterns suggesting a diverse number of sources (e.g. wildlife) within this region.

Adhering to the original project plans, additional coastal areas of South Carolina were studied in 1997. These included the Isle of Palms in Charleston County as part of an outreach, technical assistance project with the East Cooper Clean Water Council and the Okatie and Broad Creek in Beaufort County as part of an outreach, technical assistance project with the Beaufort County Clean Water Task Force and the SC Department of Health and Environmental Control and the Bureau of Coastal Resource Management. In each of these studies source identification in samples collected from selected watersheds approximating a gradient of pollution (e.g. pristine with wildlife only, rural with septic tanks only, urban areas with septic tanks only, mixed urban, commercial and industrial development with and without septic tanks as well as sewerage treatment plants) was conducted.

Data for the Isle of Palms Outreach Study were collected beginning in July 1997. Initial water samples collected at a grid of stations in July have been analyzed for total and fecal coliform bacterial densities

and have been analyzed by API biotyping to identify the bacterial species comprising the fecal coliform bacterial group. During the July sampling total coliform bacterial densities ranged from 3,000/100 mls (Forest Trails STP finished water) to 16 million/100 mls (Forest Trails raw sewerage). Fecal coliform bacterial densities ranged from 70/100 ml (Forest Trails STP finished water) to 16 million/100 mls (Forest Trails raw sewerage). Coliform bacteria in surface waters of the Isle of Palms are dominated by *E. coli* bacteria (86%) along with other species including *Providencia* sp. (11%), *Citrobacter freundii* (2%) and *Proteus mirabilis* (1%). These proportions of *E. coli* and other species were similar to coliform biotype ratios seen at other urban sites (e.g. Murrells Inlet).

Additional sampling was conducted during December 1997 at the Forest Trails Plant (raw and finished) and at 41st Avenue (above the STP and below the STP). During the December sampling total coliform bacterial densities ranged from 5,000/100 mls (41st Ave. above the STP) to 30 million/100 mls (Forest Trails raw sewerage). Fecal coliform bacterial densities ranged from 40/100 ml (41st Ave below the STP) to 2.2 million/100 mls (Forest Trails raw sewerage).

Pulsed field gel electrophoresis (PFGE) identified in the July sampling only one *E. coli* DNA profile in the finished sewerage at Forest Trails. This may be indicative of a chlorine resistant strain of *E. coli*. Samples taken during the December sampling did not find this same DNA profile but again only found two DNA profiles present in the finished sewerage at Forest Trails. Additional PFGE of the Wild Dunes Plant found an unusual DNA banding pattern that was also identified positively from a golf course canal site.

Fatty acid profiling was also evaluated and results are on going at this time. Results to date suggest good discrimination between animal and human sources although there appear to be a problem in discerning raccoons from humans.

Results from the Okatie/Broad Creek study in Beaufort are ongoing and will be completed by the summer of 1998.

The statistical technique of intervention analysis was conducted at Murrells Inlet and North Inlet using long-term Storet data (1966-96) from DHEC's coliform monitoring throughout the region to identify if selected developmental activities (e.g. sewer construction, jetty construction) impacted fecal coliform levels in surface waters. Results from Murrells Inlet, pooling all 16 stations, indicated that fecal coliform levels significantly ( $p < 0.001$ ) declined, following completion of the sewer in 1982. Data analyses are being conducted on each individual station basis to identify which geographic regions within the estuary have had significant improvement in bacterial water quality and which regions have not. Working with the GIP component of the USES project we will then use a spatial analysis approach to evaluate land use and attempt to understand if the areas where water quality has not improved are in the 7% of the MI area where septic tanks are still used for sewerage disposal or if some other factors (e.g. wildlife, etc.) are the major sources of bacterial pollution.

## **B. Toxicology**

Studies from estuaries throughout the United States have indicated that urbanization may result in significant runoff of pesticides/fertilizers, polycyclic aromatic hydrocarbons and trace metals from lawns, road surfaces, parking lots and junk yards/dumps. Additionally, activities associated with urbanization (dredging, road construction and bulkheading) may lead to physical modifications of the estuarine habitat that may reduce habitat availability and disrupt physicochemical and ecological processes. In this study a variety of toxicological research techniques have been used to evaluate the impacts of urbanization in an

estuary (Murrells Inlet) with solely urban influences. North Inlet, an undisturbed pristine estuary, has been used for comparison.

Our earlier work has indicated that most of the toxic effects in estuarine biota associated with urban runoff have been chronic in nature. No acute toxicity was observed in in situ bioassays performed in Murrells Inlet. Subtle effects on growth in juvenile fish and increased cytochrome P-450 levels in oysters were, however, observed at Murrells Inlet sites. In laboratory experiments, larval grass shrimp and copepods were exposed to sediments spiked with a mixture which contained the six dominant PAHs observed in Murrells Inlet sediments. The 10-day LC50 was 7.5x the mean PAH concentration at the four most contaminated Murrells Inlet sites. Survival of female copepods was depressed in the 10x treatment and the number of surviving offspring was also reduced. Subsequent experiments were conducted to compare the toxicity of sediments from a pristine North Inlet site, a Murrells Inlet road runoff outfall site (Marina Pipe), and a Charleston Harbor industrialized site (Diesel Creek). Marina Pipe (MP) sediments were not significantly toxic to adult male or female copepods. However, Diesel Creek sediments caused 50.1% higher mortality of adults, reduced clutch sizes to 52.7% of controls, and reduced larval/juvenile production to 2.7% of controls. In contrast, Marina Pipe sediments produced significantly larger copepod clutch sizes than North Inlet controls, but MP sediments were strongly and significantly toxic to hatching larvae/juveniles. Therefore, even though Murrells Inlet sediment contaminant levels are low compared to more heavily urbanized estuaries, contaminants do occur at levels disruptive to reproduction and long-term maintenance of trophically-important infauna. Laboratory experiments have also investigated the uptake of PAHs from contaminated sediments. Eastern oysters (*Crassostrea virginica*) were continuously exposed to suspended [<sup>14</sup>C]fluoranthene spiked-sediment for either: (1) five days followed by 24 days depuration, or (2) 28 days exposure. Uptake and depuration rate constants were estimated using linear and non-linear regression methods. Uptake and depuration rate constants, bioconcentration factors and half-lives were similar regardless of exposure time, sediment fluoranthene concentration or use of data normalization. The results suggest that less-expensive, short-term exposures followed by depuration are effective for estimating kinetic rate constants and that normalization provides little benefit in these controlled studies. Bioconcentration of sediment-associated fluoranthene, and possibly other polycyclic aromatic hydrocarbons, is apparently low compared to either that reported for dissolved forms or levels commonly used in regulatory actions. These measurements are vital for describing the potential exposure of sensitive and/or commercially exploited fauna.

In 1997, polycyclic aromatic hydrocarbon (PAH) bioaccumulation by the polychaete worm, *Streblospio benedicti* was measured under exposure to PAH contaminated sediments in the field and for 28-d in the laboratory. *Streblospio benedicti* collected from field sediments contaminated at 2.94, 1.07, and 1.52 mg-g-1 fluoranthene (FLU), benz[a]anthracene (BAA), and benzo[a]pyrene (BAP) bioaccumulated those PAHs at 1.53, 0.215, and 0.332 mg-g-1, while worms isolated from less contaminated field sediments (0.399, 0.228, 0.288 mg-g-1 FLU, BAA, and BAP) had FLU, BAA, and BAP body burdens of 0.543, 0.236, and 0.083 mg-g-1. Worms incubated for 28-d in PAH spiked sediments (1.52, 0.991, 0.504 mg-g-1 FLU, BAA, and BAP) bioaccumulated those PAHs at 0.382, 0.966, and 0.602 mg-g-1 respectively. Data normalization to organism lipid and sediment organic carbon (biota-sediment accumulation factors, or BSAFs) strongly suggests that *Streblospio* PAH bioaccumulation was directly related to percent sediment organic carbon, but BSAFs were substantially lower than predicted by equilibrium partitioning theory. BSAFs decreased with increasing PAH log Kow in worms collected from field sediments, but in spiked sediments, BSAFs increased with increasing PAH hydrophobicity. This disparity may have been caused by insufficient spiked-sediment equilibration time (1.5 hrs) in the case of the laboratory test sediments. BSAF's were also determined at both field sites for the predominant meiobenthic copepod in southeastern estuaries, *Microarthridion littorale*. Murrells Inlet copepods showed BSAFs of 1.40 and 0.64 respectively for fluoranthene and benz[a]anthracene. Copepods from the much more urbanized and

contaminated site, Diesel Creek, showed very similar BSAFs of 1.19 and 0.24 respectively, suggesting similar uptake kinetics for the two sediment habitats. Also in 1997, sediment samples were collected from a series of stations in Murrells Inlet to determine if contaminants are distributed along spatial gradients of higher to lower concentrations as one moves ebbward from pollution loading sources (e.g. storm water runoff pipes, marinas). Five loading sources were identified and samples were collected from a gradient of stations extending out to 200 m away from each source. Chemical and toxicological characterizations of these sediments are underway. In addition to the sediment collections, water samples were collected for analysis of nutrients, chlorophyll, and total and fecal coliforms. These data will be used in modeling the relationship between pollution loading sources and the spatial distribution of contaminants.

### **C. Watershed Analysis, Nutrient Runoff, and Groundwater Monitoring**

The overall objectives of this phase of USES research have been:

1. to quantify controlling mechanisms and empirical relationships for watershed hydrology, nutrient runoff and land-use in small coastal drainage basins,
2. to develop watershed-scale models of land use, hydrology, and nonpoint source runoff in small coastal drainage basins. The model will be developed and calibrated with data from the preceding and ongoing USES investigations of nutrient distributions and watersheds sources in North Inlet and Murrells Inlet (Blood and Smith 1996; Wahl et al. 1996; Wahl et al. 1997). After testing in these specific study sites, the model should be applicable on a broader-scale, as an integrative tool in long-term planning of local land-use and watershed/water quality management in the southeastern US coastal zone, and
3. examine the denitrification process in groundwater and aquifer sediments.

Related to items 1.) and 2.), this year we focused our efforts on three areas of research. The first area involved final calibration and evaluation of the AGNPS nutrient export model of the pristine (Oyster Creek, 37 ha) and developed (Dog Creek, 11 ha) watersheds. This was an expansion of prior work (Corbett et al. 1997) that implemented hydrology and sediment export characteristics of the two watersheds based on an extensive set of storm event data collected during 1993 and 1994 (Wahl et al. 1997).

AGNPS (Young et al. 1996) is a grid-cell based model that was designed for use with ungauged watersheds to predict the effect of various land management practices (development, cropping practices, etc.) on watershed hydrology and sediment and nutrient export. These are modeled as surface runoff phenomena. In our application, we have field estimates of these fluxes for eight storm events in each watershed (including data from each basin for three coincident storms). The storms are of varying duration and intensity. Model implementation involved modification of key model parameters to obtain agreement between model prediction and field results. Important field data are:

- watershed geometry and physiographic characteristics (drainage channels, slopes, soils, and land uses);
- storm duration and volume;
- runoff volume and peak discharge, and;
- sediment and nutrient concentrations and total export per storm event.

Model parameters are estimated from this information or taken from literature sources. Calibration involves parameter adjustment to achieve a good fit between field measurements and model predictions. Key parameters are:

- Soil Conservation Service (SCS) curve number (CN);
- Manning's roughness coefficient for both channels and overland flow;
- soil type, and;
- surface and channel slopes.

Model fit was assessed using the paired t-test of the null hypothesis that the mean difference was zero.

The SCS CN is an indicator of soil water storage capacity. Storage capacity is influenced by soil type, antecedent conditions, and land use. The soils in both watersheds are sand and fine sand (Stuckey 1982). They differ primarily in that Dog Creek soils are well-drained while those at Oyster Creek are poorly drained. The mean CN in the Dog Creek models was 83 (except for those cells specified as impervious surface, CN=99); for Oyster Creek it was 73. The larger curve number for Dog Creek indicates a greater potential for surface runoff generation from that watershed. This could result from soils less likely to allow infiltration. Wahl et al. (1997) concluded that most storm runoff in these basins is generated from bank storage and shallow groundwater flow; very little surface runoff occurs. In the Dog Creek basin in particular, channelization during development resulted in straight, deeply incised channels designed to intercept and drain shallow groundwater. So although the CN in the calibrated models reproduces field results, it apparently does so for the wrong reasons.

This conclusion is further supported by the calibrated runoff volume and peak discharge results. The storm event runoff volume calibrated well ( $p=0.242$  for Dog Creek;  $p=0.159$  for Oyster Creek), while the predicted peak discharge was greater for both basins (eight storm mean of 1.86 cfs observed versus 4.63 cfs modeled in Dog Creek,  $p=0.05$ ; 1.54 cfs observed versus 4.44 cfs modeled in Oyster Creek,  $p=0.08$ ). This probably reflects the AGNPS assumption of surface runoff. Time of concentration would be shorter without the shallow groundwater flow-path, so for a given runoff volume there would be a greater peak discharge.

Further indication of the difference in surface water generation between the model and the actual watershed is seen in the sediment delivery results. The model predicted an order-of-magnitude greater sediment than was measured at Dog Creek (eight storm mean of 0.096 versus 0.473 tons). This reflects the model simulation of streamflow from overland movement of water and concurrent erosion. Oyster Creek sediment simulation was similar to field measurements (eight storm mean of 0.054 versus 0.053 tons). The curve numbers used for Oyster Creek cause greater infiltration of rainwater and less erosion.

Field estimates of total sediment delivery in Dog Creek were greater than for Oyster Creek. Wahl et al. (1997) concluded this resulted from the excavated channels and greater stream-bank exposure to erosion. The model prediction of sediment delivery in Dog Creek that was much greater than was measured, may again indicate a disparity between model mechanisms and those at work in the watershed.

Dog Creek produces greater runoff volume expressed as both area-weighted and absolute quantities (Wahl et al. 1997). Yet the Dog Creek basin is smaller than Oyster Creek. The effects of development and, in particular, the deep channels that intercept more shallow groundwater, causes greater water generation from storm events.

Calibrated nitrogen ( $p=0.17$  for Dog Creek;  $p=0.14$  for Oyster Creek) and phosphorus ( $p=0.368$  for Dog Creek;  $p=0.405$  for Oyster Creek) simulations closely corresponded with the field data. Nutrient export

from urbanized Dog Creek is greater than from forested Oyster Creek (mean nitrogen flux of 0.07 pounds  $\text{ac}^{-1}$  for Dog Creek and 0.01 pounds  $\text{ac}^{-1}$  for Oyster Creek; mean phosphorus flux of 0.01 pounds  $\text{ac}^{-1}$  for Dog Creek and 0.0 pounds  $\text{ac}^{-1}$  for Oyster Creek). Microbial activity and vegetative uptake in actively growing forested watersheds significantly reduce nonpoint source nutrient loading to streams (Lowrance et al. 1984; Peterjohn and Correll 1984; Phillips 1989). Wahl et al. (1997) studied the mechanisms of nitrogen transformation and mobilization in Dog Creek. They concluded that the excavated channels facilitate oxidation of reduced forms into nitrate in the hyporheic zone. Nitrate is a more mobile form of nitrogen than reduced species. Aelion et al. (1997) also found larger quantities of nitrate, and less ammonium, in the groundwater below Dog Creek than in Oyster Creek.

The second research effort this year involved additional fieldwork at Murrells Inlet. We delineated the overall Murrells Inlet upland, began delineation of additional sub-basins, began biweekly nutrient sampling of all major streams, and worked toward implementing the REAFS (Remotely Enabled Automated Field Station) automated storm sampling system for the Gasque Creek sub-basin. The REAFS was developed by Siewicki (1995) to support automated sampling necessary for USES-related monitoring and modeling efforts. Nutrient analysis for both the biweekly and storm sampling will include total and dissolved fractions of nitrogen and phosphorus. Additional data from the storm sampling includes discharge and interval rainfall amounts.

The Gasque Creek storm sampling will provide additional detailed flux data for calibration of another sub-basin in Murrells Inlet. Gasque Creek is distinct from Dog Creek in size (125 ha versus 11 ha for Dog Creek), physiography (impoundments versus no impoundments), and degree of development (Gasque is more developed). These data, when implemented in the model, will provide essential understanding of how watershed characteristics that are likely to occur in developing southeastern coastal uplands can affect nutrient export from small streams.

The third area of research involved preparation to migrate our modeling to the EPA SWMM (Storm Water Management Model) modeling system (Huber and Dickinson, 1992). Field observation in Oyster and Dog Creeks suggest that shallow groundwater is a key mechanism in storm discharge generation. AGNPS does not explicitly address this. We were able to successfully compensate for this in the models. However, the necessity to compensate raises concern about the ability to effectively use the model in ungauged watersheds to make pre-development estimates of the effects of alternative development scenarios.

In relation to item 3.) above, we examined the denitrification process as a major removal mechanism for anthropogenic nitrate inputs in groundwater and aquifer sediments, and investigated further the impact of different salinities on denitrification rates. We also examined the relative rates of denitrification and dissimilatory nitrate reduction to ammonium (DNRA) in groundwater and surface sediments in order to evaluate whether this was possibly responsible for the relatively high ammonium concentrations and low nitrate concentrations measured in the ground water in Oyster and Dog Creeks in earlier years (Aelion et al. 1997). Certain environmental factors are assumed to affect the relative rates of denitrification and dissimilatory nitrate reduction to ammonium including temperature, nitrate concentrations and nitrogen-to-carbon ratio (Schipper et al. 1994; King and Nedwell 1984). We examined the importance of these factors on the relative rates of denitrification and dissimilatory nitrate reduction to ammonium in aquifer sediment microcosms. To examine these questions, nitrate was added to sediment collected from three different sites along Oyster Creek, from upland freshwater areas down to the high salinity areas at the mouth of the salt marsh. Results from the microcosm incubations indicated that salinity impacted rates of denitrification. The rates of denitrification were greater at the mouth of the creek which is tidally influenced, than in upland areas. The creek mouth may have a more diverse and adaptable microbial community than other more stagnant creek bed areas upstream. The rates at the mouth of the stream

were not different from those measured at the local golf course, our third study site, which receives significant inputs of nitrate into the surface water areas. Of all the sites, Dog Creek was shown to have the lowest efficiencies for nitrate removal.

DNRA also was estimated and compared to denitrification by measuring simultaneously nitrate depletion, ammonium production and nitrous oxide production. In our sandy golf course sediments, ammonium production was not as great as that in the soil of high organic carbon content present at both Dog Creek and Oyster Creek. The majority (as high as 79% at the highest nitrate concentration level added) of nitrate added was converted to nitrous oxide (and subsequently nitrogen gas in the environment), representing removal of anthropogenic nitrate from the system. At all three Oyster Creek sites, DNRA accounted for a large percent of the initial nitrate added, particularly at the lower nitrate concentrations added. At 0.1 mg/g approximately 46 to 63 % of the added nitrate was converted to ammonium. In contrast, only 5 % of the nitrate was converted to ammonium in Dog Creek sediments at this same level of nitrate addition. These results strongly suggest that bacteria are playing a significant role in reducing nitrate concentrations in sediment and potentially increasing ammonium concentrations in Oyster Creek. In contrast, bacteria are less successfully removing nitrate from Dog Creek and play less of a role in ammonium production at that site. These results corroborate groundwater sampling results determined previously. Although relatively low at both sites, concentrations of nitrate were elevated at Dog Creek relative to Oyster Creek. Concentrations of ammonium were greater at Oyster Creek than at Dog Creek, and were an order of magnitude greater than nitrate concentrations at both sites (Aelion et al. 1997).

Organic carbon and the organic carbon to nitrate ratio is also thought to affect DNRA. Results of our study found that organic carbon was not limiting, even at the Litchfield site that had the lowest organic carbon content of the sediment. Denitrification rates did not increase with additional readily metabolized organic carbon additions. Instead, the low nitrate concentrations appeared to be limiting. Nitrate concentrations in surface water at the Litchfield site were significantly greater than those at Dog and Oyster Creeks, from 10 to 100 times greater. Low concentrations of nitrate in pore water at the golf course site indicated that there was rapid turnover of nitrate in sediment.

In addition to examining the removal of nitrate in sediments, we also continued some of our research on atrazine removal by sediment-associated bacteria in Dog Creek, Oyster Creek and the golf course site. Previous results from our experiments using atrazine suggest that this contaminant was not significantly mineralized (completely degraded) to CO<sub>2</sub> by the surface sediment bacteria. Similar to result obtained from the denitrification experiments, of the activity measured, the golf course bacteria consistently degraded more atrazine than the other two sites, perhaps due to some previous exposure to pesticides, and Dog Creek bacteria appear to be the least able to degrade this anthropogenic contaminant. Although the bacteria were not readily mineralizing atrazine at any of our study sites, there was production of intermediates of atrazine degradation. Most recent results indicated that as early as the first day of incubation, 18 to 39 % of the initial atrazine added was associated with the sediment fraction. Based on sequential extractions of the sediment and liquid fractions, by the 22<sup>nd</sup> day of incubation, the fraction of atrazine extracted with water and methanol decreased with time. The fraction which was not extractable from sediment (or the strongly sorbed fraction) increased, particularly at the Oyster and Dog Creek sites which were high in organic carbon. The greatest formation of polar compounds occurred in the sandy golf course sediments.

#### **D. Phycology and Water Column Processes**

Scientific research to assess the impacts of urbanization on coastal estuaries of the Southeast has not only provided new insight and understanding of many previously identified problem areas but has also

identified additional areas requiring study. Foci of the USES project have been on man-land-estuary interactions, benthic processes, sediment chemistry, and water-sediment interactions. This past year the USES project began initial efforts to understand the impacts of urbanization on the planktonic environment and water column processes.

Over the last year, one study has analyzed ambient phytoplankton community structure and productivity, and conducted bioassay experiments with those communities, with the purpose of testing the following hypothesis. Urbanization of Murrells Inlet has caused a decrease in the efficiency of primary production, because 1) increased  $\text{NO}_3$  loading has caused a shift in phytoplankton composition, favoring larger diatoms which have relatively slower nutrient turnover rates (i.e. primary production is less efficient when normalized to nitrogen supply), and relatively higher iron requirements than smaller flagellates, and 2) reduction of organically-bound iron through clearcutting has reduced iron bio-availability to phytoplankton. This hypothesis has been tested by combining analyses on ambient physical profiles (salinity, temperature, dissolved oxygen), nutrients ( $\text{NH}_4$ ,  $\text{NO}_3/\text{NO}_2$ ,  $\text{PO}_4$ , Si, DON, DOC), phytoplankton community biomass and composition (total chlorophyll, size-fractionated chlorophyll, HPLC pigments, microscopic analyses), primary productivity rates ( $^{14}\text{C}$ ), photosynthetic capacity and efficiency (P vs. I curves), and daily integrated primary production (P vs. I curves, suspended sediments, irradiance depth profiles).

Thus far, the following results from four sampling periods (6 Murrells Inlet and 2 North Inlet sites) support the hypothesis:

- the proportion of diatoms to flagellates (microscopic counts, fucoxanthin/Chl ratio) was greater in Murrells Inlet,
- smaller phytoplankton (< 8  $\mu\text{m}$ ) made up a greater proportion of total chlorophyll in North Inlet,
- chlorophyll was similar between estuaries,
- chlorophyll-normalized primary productivity rates were similar or higher in North Inlet,
- the light-harvesting ability (alpha of P vs. I curves) and the capacity for photosynthesis (Pmax) were higher in North Inlet,
- daily integrated primary production was higher in North Inlet,
- bio-available iron was higher in North Inlet,
- the population growth of Murrells Inlet phytoplankton could be enhanced by iron enrichment, but not North Inlet populations, iron enrichment of Murrells Inlet water selected for the growth of diatoms and *Synechococcus*, which were relatively more abundant in Murrells Inlet than in North Inlet, and which are reported to be generally more sensitive to iron stress.

A second new initiative is a study of zooplankton dynamics in the inner reaches of North and Murrells Inlets. The intent of the study is to describe the seasonal variation in the diet and egg production of a dominant copepod species, *Acartia tonsa*, at adjacent sites that represent, respectively, the control or reference location and the “impacted” or developing portion of the USES study area. The protocol involves two experimental periods one in the fall (October), when egg production is expected to be low, and one in the spring (June) when egg production should be high. To date, the fall sampling and experiments and analyses are close to completion.

The fieldwork was conducted in October 1997. Samples were collected from the inner reaches of the main channel at Murrells Inlet, and at Clam Bank, in the inner reaches of North Inlet. Both locations have been sites of considerable during USES. At both locations, the zooplankton was samples from a small boat by obliquely towing a 0.5 m-diameter plankton net constructed of 202  $\mu\text{m}$  mesh Nitex and

equipped with a solid, one liter, cod end, through the water column for 3-5 minutes during flood tide. The zooplankton was transferred to coolers in which temperature was maintained slightly below ambient and the water was oxygenated to reduce the stress during transport. In addition, 20 liters of water from each site were returned to the USC field laboratory, operated by the Belle W. Baruch Institute for Marine Biology and Coastal Research, at Georgetown, SC, along with the zooplankton samples, for experiments. Adult (copepodite stage 6), female *Acartia tonsa* (10/liter) from each location was sorted into one-liter containers filled with water from the collection location for egg production studies. Simultaneously, ten stage 5 copepodites (C5), were sorted into containers for nutrient assimilation studies. The C5's were used because, while this stage has a physiology similar to that of the adult (Marshall and Orr 1955), the copepodites do not produce eggs. For this report, it is assumed that the diets of the C5's and adults are the same. That assumption, while probably valid, (Paffenhofer 1984; Roman 1991; Gismervik 1997), is currently being tested. The samples, referred to as "experimentals", were incubated at ambient temperature under reduced natural light for 24 h. A set of "controls", water without copepods, was incubated under the same conditions. Finally, a series of subsamples from each location was preserved for microscopic analysis (in Lugol's iodine) and for nutrient analysis (350 ml filtered on GF/C filters and frozen in liquid nitrogen). We measured the concentrations of primary macronutrients, protein (Lowry et al. 1951; Clayton et al. 1988), carbohydrate (DuBois et al. 1956 as modified by Head 1992) and lipid (Barnes and Blackstock 1973) in these samples.

Following incubation, subsamples were from experimental and control containers were fixed with Lugol's iodine for determination of ingestion rates and diets. The taxonomic composition of the copepod diets was determined by microscopic enumeration of the microplankton (by which is meant, phytoplankton, microzooplankton and unidentifiable cells smaller than 5 µm in diameter which are referred to hereafter as nanoplankton). Details of this procedure are provided in Kleppel (1992) and Kleppel et al. (1996). Taxon-specific C-biomass was estimated by standard cell volume: C equations (see Kleppel 1992) and ingestion rates were computed by the equations of Frost (1972).

In addition, water from the experimental and control groups was passed through GF/C filters for nutrient analysis. When the Frost (1972) grazing equations are used with nutrient data, the assimilation rate, A, rather than the ingestion rate, of each nutrient emerges naturally. Thus, according to Frost (1972), in the control container, the microplankton is assumed to be growing at an intrinsic rate,  $\mu$  ( $d^{-1}$ ) [the effects of microzooplankton grazing are obviated by an approach described by Nejstgaard et al. (1997)]. In the experimental container, both microplankton growth and feeding, at an intrinsic rate  $\mu - g$  ( $d^{-1}$ ) is occurring. When we solve the Frost equations with cell counts these are the only two processes that are measured. Thus,

$$C_t = C_0 e^{\mu t} \quad (1)$$

$$C^*_t = C_0 e^{(\mu - g)t}, \quad (2)$$

where  $C_0$  is the initial cell concentration, and  $C_t$  and  $C^*_t$  are the cell concentrations (C-biomass/ unit volume) after time  $t$  in the control and experimental containers.

Solving for  $m$  and  $g$ ,

$$\mu = 1/t \ln (C_t/C_0) \quad (3)$$

$$g = \mu - 1/t \ln (C^*_t/C_0) \quad (4)$$

When the feeding is assessed using nutrients, however, a third process, egestion is also measured in the experiment. That is, a portion of the nutrients that are ingested are not assimilated. These are returned to the medium and must be accounted for in the egestion term.

$$C^*_t = C_0 e^{(\mu-g+\mu)t} \quad (5)$$

and

$$g-\mu = \mu - 1/t \ln (C^*_t/C_0), \quad (6)$$

where  $e$  = the intrinsic rate of egestion ( $d^{-1}$ ).

By definition, ingestion,  $g$ , minus egestion,  $\mu$ , is assimilation,  $a$ . Thus, the initial steps in the Frost equations define the intrinsic rate of assimilation when nutrients are evaluated.

Ultimately, digestion modifies the macronutrients (proteins, lipid and carbohydrates) such that lower molecular weight structural components, e.g., amino and fatty acids, may be more appropriate to measure. However, for the sake of the present analysis, the approach as used here with protein, lipids and carbohydrates should provide at least a first-order indication of macrnutrient assimilation rates. The technique is conservative in the sense that this study seeks to identify nutrient limitation. The technique, however, may overestimate assimilation, thereby biasing against detecting limitation.

Initial results indicate that microplankton biomass at North Inlet was composed approximately equal proportions of diatoms microzooplankton and nanoplanktonic species. Dinoflagellate biomass was low. At Murrells Inlet, nanoplankton dominated the biomass.

At North Inlet, the diet of *Acartia tonsa* was taxonomically diverse. Dietary diversity is thought to increase the likelihood that the animal will obtain a nutritionally complete ration (Kleppel 1993). At Murrells inlet the diet was relatively narrow. Ingestion rates were relatively low, accounting for <50% of body C  $d^{-1}$ , as is normal at this time of year.

That particulate nutrient levels in the seston were relatively low is not surprising for this time of year. Concentrations were consistent with the relatively low levels of carbon biomass detected in the cell count data. What was somewhat surprising was the low rate of assimilation, particularly of protein, at both locations and especially at Murrells Inlet. A bit more subtle is the relatively high assimilation of carbohydrates at North Inlet, and the high assimilation of lipids at Murrells Inlet. This leads to suspect that the energetics of the copepods differed between locations. Further, differences in lipid assimilation might be differential bioaccumulation of lipophilic contaminants such as PAHs. The egg production rates copepods from the two locations were similar and relatively low, as is not inconsistent with expectations for the season.

## **E. Geographic Information Processing and Risk Assessment Modeling**

As with past years, the Geographic Information Processing (GIP) and Risk Assessment Modeling Component of the USES project has had three primary responsibilities:

1. provide for database development and database management for the project;
2. provide GIS, geostatistical, and integrative spatial modeling assistance to all project components; and
3. perform applied modeling research applicable to coastal zone management.

Responsibilities and accomplishments for item #1 are consistent with previous years. Database maintenance and metadata development continue to require significant time and effort. These efforts are providing benefits as other research programs are now interested in using USES databases and GIS data layers. This is leading to potential collaborative efforts and providing background data and information necessary to address research issues of related programs (e.g. NOAA/Sea Grant LU-CES, NASA MTPE, EPA/NOAA/NASA CISNet). Refer to annual reports from previous years for an overview of these ongoing activities. Assistance in GIS and spatial analysis (item #2) provided to other components are referenced in previous sections. For the current year, three research efforts are underway.

The first USES research sub-study is designed to assess and model the impact of urbanization on the spatial patterns and temporal cycles of *P. marinus* infections in oysters. Oyster harvests along the Atlantic coast of the United States have been in decline for nearly a century. Much of this decline is a result of overharvesting and habitat loss, but two parasitic pathogens (*Haplosporidium nelsoni*, the agent of MSX disease, and *Perkinsus marinus*, the agent of Dermo disease) have had a major impact during the last 40 years. Presently, *P. marinus* represents a primary obstacle for the restoration of natural oyster populations and the successful cultivation of this commercially valuable species.

Our understanding of *P. marinus*' ecology and its relationship with *C. virginica* is only partially understood, particularly at the population and ecosystem levels. Within an estuary, *P. marinus* infections are often positively correlated with salinity. Its northern range appears to be limited by cold temperatures. Seasonally, infections intensify following warm, dry (i.e., high salinity) periods and decline during and after cold, wet (i.e., low salinity) periods. Clearly, infection intensities are inversely related to temperature and salinity, but these physical parameters only explain a portion of the temporal and spatial variability.

Preliminary data from the microbiology and toxicology components of USES project indicated elevated infection intensities in oysters from the Murrells Inlet estuary compared to oysters from North Inlet estuary (J. Weinstein unpublished data). We hypothesized that *P. marinus* and *C. virginica* normally coexist in a semi-stable equilibrium that is upset by urbanization of the surrounding environment. We also hypothesized that deficiencies in spatial and temporal sampling regimes can grossly confound interpretation of infection patterns and identification of potential controlling mechanisms.

We are currently in our second year of monitoring spatial and temporal patterns of *P. marinus* infections. One site in each estuary (Oyster Landing in NI and TP2 in MI) is monitored monthly. Data from these sites are shared with SCDNR MRRI to help support their statewide oyster disease monitoring program. This year, a temperature logger was deployed intertidally at these two sites to determine the range of temperatures oysters and the parasites within them experience throughout tidal cycles. Thirty sites in Murrells Inlet and 40 sites in North Inlet are monitored quarterly to determine whether or not spatial patterns change seasonally and to correlate these patterns with surrounding landscapes, land usage and other USES data sets. The following list summarizes results to date.

1. Both estuaries show typical seasonal patterns, but infection peaks tend to be shifted towards late fall/early winter rather than late summer/early fall as reported further north. These patterns were clear in the spatial data sets collected quarterly, but not in the monthly data sets, indicating the importance of a spatial perspective.
2. Infection intensities were relatively low compared to levels commonly reported from the mid-Atlantic and Gulf coasts, indicating an important opportunity to identify controlling mechanisms through comparative studies.

3. Significantly different mean weighted prevalences were observed between the two estuaries on all quarterly sampling dates except for June 1996:
  - North Inlet weighted prevalences were higher on all dates except during seasonal peaks.
  - Murrells Inlet weighted prevalences were more variable than North inlet both within and among sampling dates. Thus, the amplitude of the seasonal cycle in Murrells Inlet encompassed the range of values from North Inlet. That is, seasonal fluctuations in North Inlet were more stable.
  - A dramatic difference in mean weighted prevalence was observed only during the December 1996 peak.
4. The geostatistic kriging enhanced visualization of spatial patterns and their relationship to other spatial data, demonstrating the utility of this method for disease monitoring and analysis.
5. Hot spots of infection intensity appeared during seasonal peaks and were clearly related to physical characteristics or land-use patterns of each system.
  - Hot spots in North Inlet were localized around tidal nodes, suggesting that hydrographic characteristics that affect water residence time and flushing rates may be important.
  - Hot spots in Murrells Inlet were widespread and clearly associated with development. These patterns appear to correlate with sediment distributions (higher infections associated with sandy sediments) and to a lesser degree with PAH concentrations.
6. Temperature probes indicated that intertidal surface temperatures can span a range of 30°C within 24 hours throughout the year.
  - In winter, intertidal surface temperatures fell below freezing during night time low tides and reached 35°C during mid-day low tides.
  - In summer, mid-day surface temperatures nearly reached 50°C.

The temperature data has suggested some intriguing new hypotheses. Laboratory studies have demonstrated that *P. marinus* ceases proliferation and begins to die at temperatures above 40°C (Bushek 1996; Dungan and Hamilton 1995). Thus, lower infection intensities along the southeast Atlantic coast may be maintained by upper thermal tolerances of *P. marinus*. Higher infection intensities associated with sandy sediments in Murrells Inlet may be related to boat wakes. During summer, Main Creek is heavily utilized by recreational and commercial boaters. Wakes created by passing boats wash over intertidally exposed oysters. The cooling effect of these wakes may help *P. marinus* escape summer temperature extremes, increasing both survival and proliferation. Laboratory studies are being designed to test the effect of thermal regulation on *P. marinus* infections. Next year, additional probes will be placed throughout each estuary to measure differences in intertidal surface temperatures along creeks with varying amounts of boat traffic.

Presently, we are continuing both monthly and quarterly monitoring efforts. September and December 1997 patterns showed similar trends to 1996. Peak infections in Murrells Inlet were lower than in 1997 compared to 1996 and North Inlet infections peaked during September rather than December. Nevertheless, hot spots were observed during peak intensities near the same locations in both years, indicating that the patterns are temporally stable.

The second study was initiated as a result of the need to have bathymetry data for input into models – in particular NPS and exposure surface modeling efforts. The shallow often turbid waters of intertidal estuaries are dynamic and difficult to map, causing a knowledge gap in the ecological function of these critical areas. These shallow waters are the primary interface between upland activities and deep-water marine environments. Mapping the physical structure and characteristics of these shallow waters can lead to a greater understanding of these ecosystems. Historically, the development of bathymetric datasets and models have been very expensive in terms of time (if done manually) and equipment (if

using automated data acquisition techniques). As a proof of concept project within USES, we took advantage of the advancement and economy of real-time differential GPS (DGPS) and video sounding depth finders to develop an integrated, low-cost procedure for mapping bathymetry. We have demonstrated that the creation of shallow-water digital elevation models (DEMs) using our technique is practical. These shallow-water DEMs can also be incorporated into upland DEMs and GIS databases for multi-disciplinary focused research in the coastal zone.

A shallow-water DEM was created for Murrells Inlet, SC during the summer of 1997. This multi-step process began with the development of a land cover data set using 1:40,000-scale NAPP photography. The marsh and hydrography were extracted from the land cover data layer and overlaid with eight tidal stations located throughout Murrells Inlet. Using a modified kriging technique which utilizes in-water distances rather than Euclidean distances (Little et al. 1997), a continuous surface was interpolated from the tidal stations data allowing us to calculate differences in time to high tide for the entire estuary. A video-sounding depth recorder was linked to a DGPS unit and a field laptop computer. The equipment was mounted on a small (16') boat. As the boat traveled at a no-wake speed along left bank, right bank, and mid-channel transects, a data stream of depth, latitude, longitude and time was transferred to the laptop. Approximately 3,500 soundings were recorded in the Murrells Inlet estuary. At approximately 30 locations depth and location was manually checked using a depth pole and a hand-held GPS unit. Depth data and differentially-corrected location data were compared to data output by the developed system to assess accuracy.

Using the continuous surface generated using kriging and the data from the tidal stations, a point in polygon analysis was performed to calculate the difference to high tide from time of acquisition. This difference, measured in minutes, combined with duration of tide and range of tide yields a correction factor that is applied to each point to get depth at mean low water (MLW) for each point. An interpolated surface from the corrected soundings was used to create a depth map at (MLW) or any tidal height. We are now working to create a digital elevation model (DEM) from the corrected soundings to do volumetric calculations for different tidal cycles.

## **F. Public Outreach and Information Dissemination**

Due to **real** public health risks associated with certain environmental conditions, and limited funds to assess, monitor and manage these risks, it is more imperative than ever before to ensure that research findings and their implications to health are transferred to both the public and health and environmental managers. Throughout the USES project, and in particular the last two years, the dissemination of results and transfer of information have been strong points of this long-term effort. This project has a strong track record for disseminating research results through the traditional means of presenting scientific findings (i.e. publications and presentations at scientific forums) (Appendix C.). Unfortunately, these scientific meetings are often poorly attended by public health and environmental resource managers. Cost and time commitments tend to preclude those most in need of learning of new findings and techniques. This past year, USES researchers have worked closely with several organizations functioning as oversight groups for monitoring environmental conditions and associated public health implications in South Carolina.

Resultant from USES-related research, project investigators were asked to participate as members of public outreach and technical assistance projects of the East Cooper Clean Water Council, the Beaufort County Clean Water Task Force, and the Murrells Inlet 2007 Task Force. USES findings and recommendations for coastal zone management are being incorporated as integral components of the vision plan under development by the Murrells Inlet group.

## Part II: Proposed Activities for Upcoming Year

### A. Microbiology

#### Topic 1. Coliform source identification

**Rationale:** The discharge of coliform bacteria into estuarine surface waters may result in significant pollution which may lead to closure of shellfish harvesting waters. The current fecal coliform bacterial assay is unable to discern between coliform bacteria from human versus animal sources. While both animal and human sources of bacterial pollution may be a significant human health threat, differentiating between sources is critical in formulating effective environmental management strategies to reduce loading from bacterial pollution sources. Several techniques have been evaluated to discriminate between animal and human sources including Pulsed Field Gel Electrophoresis (PFGE), Fatty Acid Profiling (FAP), Analytical Profiling Index (API) biotyping and Antibiotic Resistance Testing (ART).

1. Pulsed Field Gel Electrophoresis (PFGE)- is a method which involves isolation of DNA banding patterns from *E. coli* bacteria. Animal and human DNA have different banding patterns and these differences may be potentially used to discriminate animal versus human pollution sources.
2. Fatty Acid Profiling (FAP)- is a method which involves isolation of lipid profiles from *E. coli* bacteria. Animal and human lipids have different lipid profiles and these differences may be potentially used to discriminate animal versus human pollution sources.
3. Analytical Profiling Index (API) Biotyping is a method used to identify the fecal coliform species composition comprising the coliform group. This method is used to identify *E. coli* bacteria for PFGE and FAP.
4. Antibiotic Resistance Testing (ART) is based on the fact that human *E. coli* bacteria will have a higher proportion of antibiotic resistant strains than bacteria from wild animals> Researchers at the University of Florida (Tamplin et al) have found that antibiotic resistance dropped by 70% in going from sewerage treatment plant discharges to rural areas dominated by NPS runoff from wildlife.

#### Research questions:

1. What are the primary sources of fecal coliform bacteria in North Inlet and Murrells Inlet? In MI, it has been concluded that most pollution stems from areas still serviced by septic tanks where as in NI the primary pollution source is wildlife (e.g. deer, raccoon, wild hogs).
2. Are PFGE, FAP, API Biotyping and ART appropriate techniques to discriminate animal versus human pollution sources?

Water samples from selected sites in NI, MI, the Isle of Palms, Broad Creek and Okatie Creek will be evaluated for fecal coliform pollution levels. Coliform source identification methods will use PFGE, FAO, API Biotyping and ART to assess human versus wildlife pollution sources. Samples from septic tanks, human volunteers, sewerage treatment plants and selected wildlife species will be evaluated as well. Results obtained from each source identification technique will be used to develop a matrix for determining coliform pollution source using a “weight of evidence” approach.

## Topic 2. Toxicological effects of urban pollution sources on coliform and *E. coli* bacteria

**Rational:** The toxicological effects of urban pollution sources such as trace metals (As, Cr, Cu from treated lumber), polycyclic aromatic hydrocarbons (PAHs = chrysene, fluoranthene and pyrene) and pesticides (atrazine = herbicide; chlorpyrifos = termiticide/insecticide; and endosulfan = insecticide) are unknown. Marcus and Scott (1989) reported that water soluble fractions of shale and marine diesel fuels altered the growth of coliform bacteria. At low concentrations, coliform growth was stimulated where as at high concentrations toxicity occurred. Current modeling is unable to predict the impact of chemical contaminants from urbanization on fecal coliform bacteria, particularly *E. coli* which is the dominant member of the *E. coli* group.

### Research questions

1. What impact do chemical contaminants from urbanization have on fecal coliform and *E. coli* bacteria?
2. Can appropriate models be developed to predict effects from chemical contaminants from urbanization on fecal coliform and *E. coli* bacteria?
3. What effect does nutrient enrichment have on chemical contaminant-fecal coliform and *E. coli* bacteria interactions?

Coliform bacteria from NI and MI will be biotyped and the dominant *E. coli* strain from each estuary will be assayed in terms of their survival and growth following exposure to selected trace metals (As, Cr, Cu from treated lumber), polycyclic aromatic hydrocarbons (PAHs = chrysene, fluoranthene and pyrene) and pesticides (atrazine = herbicide; chlorpyrifos = termiticide/insecticide; and endosulfan = insecticide) with and without nutrient enrichment with N and P. Dominant coliform strains for NI and MI will be identified using existing API biotyping results from each estuary. Similarly, N and P concentrations will be based on existing nutrient data for surface waters in each estuary. Results from each compound tested will be used to develop a GIS-based water quality model which would be predictive of changes in fecal coliform bacterial densities in NI and MI as well as other estuaries within the region.

## Topic 3: Completion of intervention analysis

**Rational:** Intervention analysis is a statistical method that allows for the assessment of different regulatory interventions to be made to evaluate the efficacy of a particular regulation or management decision. For example, intervention analysis was used to evaluate the effectiveness of mandatory seat belt laws in reducing morbidity and mortality from automobile accidents. This year an intervention analysis was successfully used to evaluate the effectiveness of a central sewer collection system in reducing in stream fecal coliform bacterial densities in MI.

### Research questions:

1. Does the construction of sewer systems within near coastal estuarine drainage areas result in significant reductions in fecal coliform bacterial densities?
2. Are there other obvious temporal trends noted with intervention analysis in terms of fecal coliform bacterial densities, which may be linked temporally with other land-use activities?

In Year 9, intervention analysis for MI will be completed including station by station analysis. The derived information will be used by the GIP component in ongoing integrative modeling efforts. Additionally, other estuarine areas in South Carolina including NI, Pawleys Island and Litchfield Beach will be assessed. Initially, each of these estuaries will be evaluated on an estuarine-wide basis (pooling all stations). If significant temporal interventions are detected, then each estuary will be assessed on a station by station basis, so that additional spatial analyses may be performed.

## **B. Toxicology**

### **Topic 1: Phototoxicity of polycyclic aromatic hydrocarbons (PAHs) in estuarine ecosystems**

**Rationale:** The toxicity of PAHs may be modified by UV radiation due to either photomodification or photoactivation/photosensitization. Photomodification and photoactivation are insolation dependent. Insolation intensity is driven by season, time of day and tidal stage. PAHs strongly absorb solar UV radiation resulting in photomodification (usually oxidation) of the carbon skeleton. This makes the compounds more polar and may make the more bioavailable. This photomodification may also result in the production of complex mixtures of photoproducts that are more toxic than the parent compounds. Photoactivation/photosensitization occurs within the tissues of organisms when UV radiation is absorbed by the conjugated bonds of PAH molecules. This energy can be transferred to ground-state dissolved oxygen forming singlet-oxygen intermediaries. These are highly oxidizing compounds and can destroy biomolecules in the tissues.

#### **Research questions:**

1. Is the toxicity of PAHs in estuarine sediments of small, high salinity estuaries enhanced by UV radiation-induced photoactivation or photomodification? If the toxicity of these compounds is modified by either of these processes, risk assessment models must account for this potential.
2. What is the role of tidal change and associated tidal cover in the mediation of PAH photomodification on exposed intertidal mudflats?
3. Can GIS and spatial models predict exposed/unexposed PAH contaminated surfaces with concurrent integration of seasonal PAH loadings and seasonal/daily changes in UV insolation intensities?

We propose to evaluate the toxicity of PAH-contaminated sediments from Murrells Inlet in the laboratory with and without UV irradiation. If enhanced toxicity is observed with UV irradiation, we propose to conduct additional experiments to determine if the increased toxicity is due to photoactivation, photosensitization or both. Test species for these experiments will include juvenile clams, *Mercenaria mercenaria*, embryonic grass shrimp, *Palaemonetes pugio* and copepods, *Amphiascus tenuiremis*. We will then attempt to integrate the results of these experiments with spatial analytical techniques to determine if these phenomena are important in a shallow estuary such as Murrells Inlet.

### **Topic 2: PAH contamination of the seston and its implications to the productivity of planktonic ecosystems in southeastern estuaries experiencing varying degrees of urbanization**

**Rationale:** The effects of contaminants such as PAHs on the pelagic/planktonic food web is not well understood. Research is needed to examine and characterize these effects and their implications for small, high salinity estuaries.

**Research questions:**

1. What are the PAH levels in the seston and in the copepod *Acartia tonsa* at North and Murrells Inlet?
2. What is the impact of PAHs loaded to phytoplankton food, at observed levels in the inlets, on copepod egg production, and what is the role of UV light in mediating the aforementioned PAH impacts on egg production and copepod nutrient limitation.

We propose first to determine PAH levels in seston and zooplankton samples collected from both Murrells Inlet and North Inlet. Experiments will then be performed to evaluate the effects of a PAH contaminated diet on copepod egg production. Additional experiments will examine the interaction of factors such as limited food availability, reduced food quality and direct contaminant effects on copepod egg production.

**Topic 3: Microbial transformation of PAHs in sediment and water**

**Rationale:** Chemical hydrolysis, photolysis and microbial degradation may account for a significant portion of chemical transformations in the aquatic environment. Microbial pathways are of importance because metabolic transformation products of PAHs may be more polar than the parent compound which may impact toxicity and transport of the chemical.

We propose to address specific gaps in knowledge regarding the fate and persistence of PAHs and their bacterial degradation products at the USES study sites. Without this information on transformation products, a quantitative assessment of the impact of PAH contamination to estuarine organisms is not possible.

Many studies using sediment examine only changes in concentration of the parent compound (White et al. 1997) and do not examine transformation products. Research using bacterial isolates (Grifoll et al. 1992; Narro et al. 1992; Pothuluri et al. 1992) and fungi (Field et al. 1992) has demonstrated complete microbial degradation of PAHs and formation of intermediate products, but isolates are not representative of field conditions. Relatively few studies have documented complete degradation using field sediments in estuarine systems (Heitkamp and Cerniuglia 1987). We suspect that naturally occurring bacteria in our estuarine sediments may not completely degrade or mineralize PAHs to the end products of CO<sub>2</sub> and water. However, bacteria may contribute significantly to the formation of transformation products.

**Research question:**

1. What are the relative occurrence, identity and bioavailability of bacterial and chemical transformation products of PAHs at the North Inlet and Murrells Inlet study locations?

We propose to examine biological transformations of PAHs such as fluoranthene in sediments and water at our study locations which contain large concentrations of organic material. Although most PAHs are associated with sediment, sorption of chemicals onto colloids or organic material in the water fraction may also be an important mode of transfer and transport in the estuarine environment (Chin and Gschwend 1992; Johnson and Amy 1995). Differential sorption and subsequent bioavailability of non-ionic organic contaminants may be bacteria-specific as well as a function of the type of organic matter (Guerin and Boyd 1992). Many of these important environmental factors and how they impact PAH bioavailability and biodegradation are unknown at our study locations.

Our objectives will be accomplished by using natural sediment and water along a gradient of stations, previously identified and monitored for contamination by PAHs by the USES sediment toxicology group, and incubating these sediments with <sup>14</sup>C-radiolabeled chemicals such as fluoranthene. Both <sup>14</sup>CO<sub>2</sub> production and the production of <sup>14</sup>C- intermediates will be measured using a scintillation counter, after sequential washing and extractions using solid phase extraction cartridges as we have done previously in the laboratory (Cresci 1997). The production of chemical and biological transformation products and their relative occurrence will be verified by using appropriate control sediment and water microcosms which have been metabolically inhibited (abiotic controls). By using gas chromatography/mass spectrometry, the identity of transformation products and any changes in their concentrations over time in the sequential solvent extractions can be compared at the different North Inlet and Murrells Inlet sites.

**Topic 4: Interactions of UV-irradiation on the bioavailability of PAH compounds**

**Rationale:** Contamination of estuaries by polycyclic aromatic hydrocarbon (PAHs) molecules is a major factor affecting water-quality, and their suitability for recreational and commercial uses. On shallow-water mudflats, PAH compounds experience significant exposure to ultraviolet (UV) irradiation. Photochemical transformations resulting from UV-exposure may make PAH compounds more toxic. Understanding the bioavailability and bioaccumulations of these compounds in mudflat dwelling animals, especially commercially-important species, will provide sound scientific information to be utilized by policy-makers and urban planners. The ultimate goal of this research will be to determine how efficiently PAH compounds are taken up by estuarine animals, and if these compounds may become potential risks to water-quality. This work will consist of two major phases: bioavailability and bioaccumulation studies.

**Research question:**

1. Are PAH compounds more bioavailable to animals after phototransformation by UV-irradiation?

To test this idea we will conduct two types of studies: (1) laboratory feeding experiments, using radiolabeled (<sup>14</sup>C) fluoranthene as an example of a model PAH compound; (2) field-microcosm studies using controlled additions of PAH compounds. In the laboratory feeding experiment <sup>14</sup>C Radiolabeled fluoranthene will be sorbed to fine-sediment aggregates and fed to the oyster (*Crassostrea virginica*). Its uptake, and assimilation efficiencies will be determined using a mass-balance approach involving radioisotope techniques. This will determine the absorption of intact fluoranthene by oysters. UV-irradiated forms of <sup>14</sup>C fluoranthene will then be used feeding experiments to determine changes assimilation efficiencies due to phototransformations of the parent compound.

For the field-microcosm study natural mudflat sediments will be exposed to four treatments to examine photochemical transformation effects on PAH compounds. The experimental design will consist of the following treatments and controls:

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	<u>(4 Day Exposure)</u>				
Light:		UV-Irradiation		No-UV	
Sediment addition:		Clean fluoranthene		Clean fluoranthene	
	<u>(10 Day Exposure)</u>				
Animal exposure:	UV	Dark UV	Dark UV	Dark UV	Dark

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Bioaccumulation will be determined in animal tissues using GC-MS. This will allow the uptake and assimilation of specific fluoranthene congeners to be differentiated.

### **Topic 5: Microbial-pathogen studies**

**Rationale:** Contamination of estuaries by bacterial pathogens is a major factor affecting water-quality, and their suitability for recreational and commercial uses. Major sources of microbial contamination of estuaries largely result from terrestrial and freshwater input. Understanding the entry, survival, dispersal and propagation of bacterial pathogens entering estuaries will provide sound scientific information to be utilized by policy-makers and urban planners. The ultimate goal of this research will be to determine how pathogen bacteria entering estuaries, survive and propagate to become potential risks to water-quality. The first phase of this work will examine the mechanism of survival of pathogenic bacteria entering estuaries. The second phase of this work will examine how pathogens are transferred to food-web consumers (i.e. seafood). These studies will involve laboratory feeding experiments using radioisotope techniques.

#### **Research questions:**

1. Which pathogens survive salinity shock, toxin interactions? Field collections of aggregates and free cells living in the water column of estuaries will be conducted. We will examine the samples for the presence of specific pathogenic bacteria using molecular probes specific to those bacteria. We will also examine these samples for the presence of live vs. dead bacteria, using specific fluorescent probes which select for membrane integrity (i.e., live cells) vs. damaged membranes (i.e. recently dead cells). These studies will help us determine if the majority of pathogens exist as free living cells, or are contained within suspended aggregates.
2. How do the pathogens survive? These experiments will examine the resiliency of pathogenic bacteria living in three different states: a) as aggregate-associated bacteria; b) as free-living cells; and c) as sediment-associated bacteria. The bacteria will be subjected to two different stressors, salinity-shock and a metal-shock, which contact bacteria upon entering estuaries. We hypothesize that aggregate- and sediment-associated bacteria will be more resilient in their abilities to tolerate such stressors, than will free-living cells, and thus constitute a “safe-haven” for protecting pathogens in these environments.
3. How are pathogens most efficiently taken up by seafood and other animals? Laboratory feeding experiments will be conducted to examine the uptake efficiencies of aggregate-associated-cells vs. free-living cells. These experiments will utilize laboratory strains of pathogenic bacteria which are commonly found in estuarine waters.
4. How do pathogens survive ingestion to infect seafood and do metal-contaminants interact in this process? Does the presence of metal contaminants enhance the survival (i.e. decrease digestion efficiency) of bacteria by bivalve consumers, especially within aggregate bacteria? Since metals often stabilize the membranes, cell walls, and extracellular polymers, we hypothesize that the binding of certain metals under seawater conditions will posit protective effects to cells in surviving digestion by consumers.

### **C. Watershed Analysis, Nutrient Runoff, and Groundwater Monitoring**

Specific research objectives for the 1998-99 study year will be:

1. To continue a two-year sampling of 8-12 local streams in the North Inlet and Murrells Inlet study sites for development of empirical relationships among hydrology, land-use and nutrient runoff over a variety of land-use patterns.

As a needed complement to our earlier site-specific research at a limited number of streams, these data will provide a broader context over which to evaluate NPS relationships for these type low-gradient, coastal drainage systems. The additional sampling sites will represent watersheds that vary considerably in terms of sub-urban development and modification. We will continue biweekly grab-samplings of water quality (nitrogen and phosphorus) in these watersheds with a focused effort toward sampling during base flow and local storm events.

2. Complete current Murrells Inlet watershed modeling activities.

The overall objective is a calibrated SWMM model of the entire Murrells Inlet upland. This model will allow us to predict storm discharge and nutrient export into the marsh from Murrells Inlet at its current level of development as well as under various scenarios of additional development. The model will have a GIS interface to facilitate the input and export of data and information.

To accomplish this we will focus most of our activity in the Gasque Creek basin. This includes collection of rainfall quantity and storm discharge and nutrient export data through at least December 1998. The objective is intensive sampling over complete storm events (rising hydrograph, peak discharge, and falling hydrograph) representing a range in duration and intensity. We will also review the Gasque Creek basin delineation prepared by Wahl et al. (1996) and update it if necessary. A land-use classification from remotely sensed images acquired during 1997 will be developed in conjunction with the GIP and modeling component. These data will be used to parameterize and calibrate a SWMM model of the Gasque Creek watershed.

Concurrent with the activities in Gasque Creek and the biweekly stream sampling, we will complete watershed delineation of the remaining ungauged basins within the Murrells Inlet upland. These delineations, coupled with the land-use classification and the modeling results from Dog Creek and Gasque Creek, will be used to parameterize a SWMM model of the entire Murrells Inlet upland. This model will be used to predict the effects of various development scenarios.

3. The identities of the intermediate compounds formed from microbial transformation of atrazine were not identified in the previous research described in Part I, Section C, objective 3. The identities of these compounds are important. More sophisticated analytical techniques, such as gas chromatography/mass spectrometry of the sequential extraction fractions, are available. We propose to identify these daughter products.

If the daughter products which are formed have sorption coefficients which are greater than the parent compound, then the persistence of these products may be greater than that of the parent. Similarly, if the toxicity of the daughter products is greater than that of the parent compound, then monitoring for only the parent compound may underestimate the environmental impacts of atrazine applications.

We can use the same techniques we have developed for examining atrazine transformations to examine transformations of selected PAHs in sediment, to complement on-going USES research on these environmentally important chemicals. Previous researchers in the USES sediment toxicology group have measured the concentrations, and assessed the toxicity of selected PAHs in sediment and water. Building on this wealth of data from the research sites, we propose to examine the contribution of bacteria to PAH

degradation in sediment and water. A description of this proposed research is incorporated into the Toxicology section, Part II, Section B, Topic 3.

#### **D. Phycology and Water Column Processes**

We plan to continue efforts initiated last year to analyze ambient phytoplankton community structure and productivity through another year because it is valuable to determine how these between-estuary differences vary from one year to the next. This is an El Nino year, and the enhanced runoff may accentuate differences in phytoplankton dynamics related to nutrient loading patterns. In addition, we propose to test the hypothesis that urbanization can increase and alter DON loading patterns, and this may select for dinoflagellates, including harmful bloom types. One of the fallouts from current Pfiesteria research is the idea that dinoflagellates are nutritionally versatile (i.e. they are opportunists). Certain DON compounds, particularly urea, appears to select for their growth, which could explain their ability to bloom (e.g. they outcompete more "photosynthetically inclined" species). We propose to examine this question by determining dinoflagellate distributions in the North Inlet and Murrells Inlet estuaries, and following the time-course response of natural and cultured dinoflagellates to DON additions. Pfiesteria will be targeted, along with other species, local and otherwise. Current related research has resulted in North Inlet clones of Pfiesteria and Gyrodinium galatheanum, and will attempt isolation from Murrells Inlet.

The motivation for new efforts is that copepod diets and dietary physiology appear, in both estuaries, to be food, in fact protein, limited. Further, diet composition and possibly energy physiology may differ between sites. It is also apparent that the levels of certain contaminants, particularly those of PAHs are increasing in South Carolina's estuaries (Kuklick et al. 1997). Although there is strong evidence that chronic exposure to PAHs reduce the fitness of meiobenthic copepods (Lotufo 1997; Lotufo and Fleeger 1997), it is uncertain how they affect the production of planktonic calanoid species. Given the link to regulation of copepod production by food availability and quality, established during the current year's work, it seems reasonable we define the interaction between dietary physiology, PAH contamination and zooplankton production in the coming year.

It is currently believed that light, particularly in the ultraviolet region, can enhance the activity of PAHs. One of the research themes for the coming year will be to focus on UV-activation of PAH activity in benthic organisms. Because zooplankton are logically exposed to higher light intensities in the water column than are benthic invertebrates, it seems logical to address this same concern in the plankton.

Thus, the proposed research addresses three new questions.

1. What are the loads of PAHs in seston and copepods (*Acartia tonsa*) at North and Murrells Inlets?

Seasonal surveys will be conducted to determine the amounts of PAHs associated with the seston and the zooplankton. Samples will be collected in chemically clean containers. Zooplankton will be sorted to elaborate species, age structure and gender.

2. How do food and PAH contamination individually and jointly influence copepod egg production?

In an environment where zooplankton production may be nutritionally limited it is necessary to distinguish between the effects of nutrition and those of contaminants. Unless a specific nutrient such as an amino or fatty acid is missing from the diet, addition of more food will result in higher egg production rates if nutrients regulate egg production. However, addition of food to contaminant-inhibited copepods should lower egg production.

Extended bioassay experiments will be performed with seston from North and Murrells Inlets and with laboratory algae, grown under “clean” and “PAH-spiked” conditions. Seston from each inlet will be analyzed for microplankton and nutritional compositions and for PAH levels. The food will be provided at 1X, 2X, 5X, 10X and 20X concentrations and feeding, nutrient assimilation and egg production will be monitored. The experiment will be performed with copepods from each inlet as well as with animals originally obtained from North Inlet but grown in culture since December 1997. Switching experiments, in which copepods from one inlet are exposed to seston from the other will also be conducted.

Using cultured algae with similar nutrient compositions as North and Murrells Inlet seston, the above experiments will be repeated with cultures of algae grown under PAH-free conditions and at PAH levels that result in a cell-burden similar to that found in the seston.

### 3. Does UV-radiation enhance the effect of PAHs on copepod egg production?

Algae will be grown under white light and UV-enhanced light either with or without PAH contamination of the medium. Copepods will be fed the cultures in the dark or under a light-dark cycle (14 h L: 10 h D) with white or UV-enhanced illumination. Ingestion, nutrient assimilation and egg production rates will be monitored. This design controls for the effect of both light intensity and quality (wavelength) on copepod feeding, nutritional physiology and reproduction any and all of which may change, not only as a function of chemical contamination but because of differences in the optical environment as well. This experiment will be repeated over a range of food concentrations and light intensities.

## **E. Geographic Information Processing and Risk Assessment Modeling**

We will continue oversight of database development and data management for the USES project and interacting with other USES research activities by providing GIS and spatial modeling support as described above. In addition we will focus on the following research initiatives.

We will continue both monthly and quarterly monitoring efforts of *P. marinus* in North Inlet and Murrells Inlet. The current El Niño Southern Oscillation and related weather events (excessive rainfall) provides a unique opportunity to examine the impact of freshets and the importance of flushing on this host-parasite relationship. We hypothesize that the hydrologic differences between the two estuaries that have already been documented by USES will yield different responses in terms of magnitude, timing, duration and spatial extent. However, because infections typically decline to low levels during the spring, we are unlikely to see any effect until the fall 1998 peak infection intensities occur. Continuation of our quarterly monitoring through this spring and throughout the next year will allow us to document El Niño's impact on *P. marinus* in developed and pristine salt marsh ecosystems. In addition to monitoring, we will begin to analyze spatial and temporal patterns of *P. marinus* in relation to other estuarine conditions such as nutrient levels and PAHs. Data on *P. marinus* will be integrated into other modeling activities described below.

Environmental scientists recognize the need to acquire, communicate and incorporate ecological information in more useful formats for resource management and policy decisions. Environmental modeling involves abstraction or simplification of complex systems and is being increasingly adopted by coastal researchers and resource managers to address ecosystem, landscape, and global issues. Models are being used to predict cumulative impacts from measurable parameters. Oftentimes, these impacts are described in terms of risks. Risks can be approximated from contaminant concentrations in specific media using, for example, LC<sub>50</sub>s, LD<sub>50</sub>s, RfDs, Carcinogenicity Potency Factors, ASTDR Minimal Risk

Levels, LOECs and NOECs. Risks from individual chemicals or microorganisms are not indicative of real cumulative risks to fauna; however, a major impediment to associating contaminants to *in situ* measures of effects. An alternative approach is to combine the measures of risks from multiple stressors. For example, Long et al. (1995) proposed effects ranges for many chemicals derived from large data sources. The Effects Range Low (ERL), for example, is the level where there is a ten percent likelihood of finding effects in sensitive faunal. ERLs for several contaminants were combined and modeled to associate combined urban impacts with land uses in Murrells Inlet (Siewicki et al. 1996). Combined impacts were highly correlated to measures of landscape and water quality. Risks were highly predictable at a wide range of concentrations of chemicals. Principal factor analyses indicated that a few linear combinations of variables will explain most of the variance of the system. Underlying factors were identified that have heavy weighting of variances upon landscape characteristics, water characteristics and other variables of human population expansion. These results (if correlated to faunal population effects) suggests that risk estimates are predictable without expensive chemical analyses and provide quantitative links between landscape changes and risks to resident biota that are sensitive to multiple impacts. A similar approach will be used in the present study to predict effects of alternative development strategies. This new project will use parameters derived by other USES researchers in environmental models to predict impacts/risks.

Linear regression modeling with measures of chemical concentrations, effects and risks as the dependent variables will be conducted using the procedures described by Neter et al. (1990) and SAS Institute, Inc. (1987). Multivariate analyses, including principle components and principle factor analyses, will be used to identify a linear combination of variables that account for most of the system variance (Mulaik 1972; SAS Institute, Inc. 1987). The geostatistical technique known as kriging will be used to develop surface data layers for GIS analysis of parameters which are expensive or time-consuming to measure in large numbers over the entire study areas of Murrells Inlet or North Inlet.

Related to environmental modeling specific tasks to be pursued during the 1998 - 1999 study year include:

- Refine models to predict cumulative impacts based upon measurements made in the impacted Murrells Inlet study area.
- Evaluate the utility of “new” parameters (e.g., oyster infection by *Perkinsus marinus*), as data become available, to predict cumulative impacts in small, high-salinity estuaries.
- Cross-validate above models in the less impacted North Inlet estuary.
- Test utility of models in predicting impacts along gradients away from runoff points representing differing land-uses, depending upon availability of chemical data (see description of gradient study under Toxicology component).

A new integrative initiative of this component during the upcoming year will be related to the efforts described in the section on Toxicology to develop a risk assessment model to identify estuarine areas susceptible to phototoxic release of PAHs. We will be addressing whether or not GIS and spatial models can be used to integrate information on exposed/unexposed PAH contaminated surfaces, seasonal PAH loadings, seasonal/daily changes in UV insolation intensities, and findings from laboratory and field-microcosm studies determining whether PAH compounds more bioavailable to animals after phototransformation by UV-irradiation, and our DEM of Murrells Inlet to create exposure surface maps of photo-induced toxicity.

## **F. Public Outreach and Information Dissemination**

USES researchers will continue their active involvement with local public interest groups such as the Beaufort Clean Water Task Force and the Murrells Inlet 2007 Task Force. In addition we will work to coordinate with the outreach and education specialist at the North Inlet-Winyah Bay National Estuarine Research Reserve.

A new initiative will be to foster ties between the research community and those responsible in South Carolina and the Southeast for making rules and regulations governing the coast and coastal development.

The 2<sup>nd</sup> International Symposium on Shellfish Restoration is planned for November 1998 in Hilton Head Island, SC. The USES project supported and co-sponsored the first symposium as well as the shellfish restoration workshop. The USES project will also support and co-sponsor the 2<sup>nd</sup> International Symposium on Shellfish Restoration by providing input to the Steering Committee and by possibly providing staff support for the meeting.

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## **Budget Justification**

For the following categories, a brief justification for use of requested funds is provided.

### Personnel

Budget requests for personnel are designated to cover salary and benefits for:

1. summer support for 9-month faculty (partial support)
2. annual support for 12-month research faculty (partial support)
3. post-doc support (full-time)
4. field technicians (full-time)
5. the GIS Manager (full-time)
6. graduate research assistantships (half-time)

### Equipment

Equipment requests are designated to cover laboratory and field equipment required to carry out proposed research activities as well as funds to maintain the GIS component of this project.

### Travel

Travel funds will be used for:

1. travel between various locations in Columbia, Charleston and Georgetown to research sites for field sampling and data collection;
2. travel between various locations in Columbia, Charleston and Georgetown to Santee, SC for project meetings;
3. travel between various locations in Columbia, Charleston and Georgetown to interact with local, state and federal decision makers and lawmakers; and
4. travel to professional meetings to present results of research.

## **Budget**

## Appendix A: Publications

- Aelion, C.M., J.N. Shaw and M. Wahl. 1997. Impact of suburbanization on groundwater quality and denitrification in coastal aquifer sediments. *Journal of Experimental Marine Biology and Ecology* 213:31-51.
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Gardner, L.R., W.K. Michener, B. Kjerfve and D.A. Karinshak. 1991. The geomorphic effects of Hurricane Hugo on an undeveloped coastal landscape at North Inlet, SC. *Journal of Coastal Research* 8:181-186.

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Green, A.S., G.T. Chandler and W.W. Piegorsch. In press. Life-stage specific toxicity of sediment-associated chlorpyrifos to a marine infaunal copepod. *Environmental Toxicology and Chemistry*.

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Kawaguchi, T., M.H. Wahl, C.M. Aelion and H.N. McKellar. 1994. Organically-bound ferrous iron (org.-Fe(II)) as an indicator of ecosystem health: a comparison of suburbanized and forested streams in the southeastern US. *Env. Sci. and Health A29*: 1761-1776.

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Siewicki, T.C. 1995. *Bioaccumulation of sediment-associated fluoranthene by Eastern Oysters (Crassostrea virginica): Kinetics, environmental fate, statistical and environmental modeling and exposure assessment*. Doctoral dissertation, University of South Carolina, Columbia, SC. 309 pp.

- Tufford, D., H. McKellar, and J. Hussey. In press. In-stream nonpoint source nutrient prediction with land-use proximity and seasonality. *Journal Environmental Quality*.
- Vernberg, F.J. 1997. Ecology of Southeastern Salt Marshes. In *Sustainable Development in the Southeastern Coastal Zone*. Edited by F.J. Vernberg, W.B. Vernberg, and T. Siewicki. Belle W. Baruch Library in Marine Science, No. 20. University of South Carolina Press, Columbia, SC.
- Vernberg, F.J. and W.B. Vernberg. In press. Comparative long-term ecological research of a relatively pristine estuary and a man-impacted estuary. In *Change in Marine Benthos: The Case for Long-term Studies*. P.J.D. Lamshead, B.F. Keegan, and B.C. Coull (eds.). Commission of the European Communities. Brussels, Belgium.
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- Vernberg, W.B. and F.J. Vernberg. 1996. Effects of Urbanization on Marine Invertebrates. In *Estuarine Ecosystem and Species*. Edited by E. Styczynska-Jurewicz. Polska Akad. Nauk.
- Wahl, M., H. McKellar and T. Williams. 1997. The effects of coastal development on watershed hydrography and transport of organic carbon. In *Sustainable Development in the Southeastern Coastal Zone*. F.J. Vernberg, W.B. Vernberg and T. Siewicki (eds.). Belle W. Baruch Library in Marine Science, No. 20. University of South Carolina Press, Columbia, SC.
- Wahl, M., H. McKellar and T. Williams. 1997. Patterns of nutrient loading in forested and urbanized coastal streams. *Journal of Experimental Marine Biology and Ecology* 213:111-132.
- Weinstein, J.E. 1995. Fine structure of the digestive tubule of the eastern oyster, *Crassostrea virginica* (Gmelin, 1791). *Journal of Shellfish Research* 14(1): 97-103.
- Weinstein, J.E. 1995. Seasonal responses of the mixed-function oxygenase system in the American oyster, *Crassostrea virginica* (Gmelin 1791), to urban-derived polycyclic aromatic hydrocarbons. *Comparative Biochemistry and Physiology* 112C(3): 299-307.
- Weinstein, J.E. 1997. Anthropogenic impacts on salt marshes. In *Sustainable Development in the Southeastern Coastal Zone*. F.J. Vernberg, W.B. Vernberg and T. Siewicki (eds.). Belle W. Baruch Library in Marine Science, No. 20. University of South Carolina Press, Columbia, SC.
- Wirth, E.F., G.T. Chandler, L.M. DiPinto and T.F. Bidleman. 1994. Accumulation of PCB's from sediment by marine benthic copepods using a novel micro-extraction technique. *Environmental Science and Technology* 28(9): 1609-1614.

## Appendix B: Presentations

- Aelion, C.M., J.N. Shaw, and P. Raji. 1996. Bacterial removal of nitrate in a shallow coastal aquifer. South Carolina Environmental Law and Technology Conference, May 23-24, Greenville, SC.
- Aelion, C.M. and D.C. Cresci. 1997. Microbial mineralization of  $^{14}\text{C}$  atrazine in estuarine sediments. 97th Annual Meeting of the American Society for Microbiology. 4-8 May, Miami Beach, FL.
- Bushek, D., D. White, D. Porter and D. Edwards. 1998. Land-use patterns, hydrodynamics and the spatial pattern of Dermo disease in two South Carolina estuaries. Aquaculture '98, Las Vegas, NV, February 1998.
- Chandler, G.T., A.S. Green and A.L. Wilson-Finelli. 1995. Giving meiofauna culture...*Haut* expectations for the little buggers in contaminated sediment risk assessment and ground-truthing of micropaleochemical assumptions. 9<sup>th</sup> International Meiofauna Conference, Perpignan, France.
- Chandler, G.T. 1993. Application of high-density meiofauna culture to assessment of contaminated sediment problems in coastal South Carolina, U.S.A, wetlands. Invited platform presentation, 14<sup>th</sup> SETAC Conference Special Session on Wetland Contamination Issues, Mike Lewis, Program Chair, USEPA - Gulf Breeze.
- Chandler, G.T. and T. Donelan. 1993. Utility of meiobenthos for assessment of sediment contaminants in tidal wetlands. Presented: Society of Environmental Toxicology and Chemistry, Houston, Texas.
- Chandler, G.T., M.H. Fulton, G.I. Scott, T.L. Donelan and E.D. Strozier. 1993. Multiple-phase toxicity, persistence and trophic-transfer potential of *Azinphosmethyl* in meiobenthic copepods and their predators. Invited platform presentation, 14<sup>th</sup> SETAC Conference Special Session on the NOAA Coastal Ocean Program.
- Chandler, G.T. 1992. Application of high-density meiofauna culture to bioassay of sediment-associated pollutants. Invited platform presentation to the *Eighth International Meiofauna Conference*, August 9-14, 1992, University of Maryland.
- Chandler, G.T., G.I. Scott, M.H. Fulton, T.L. Donelan and E.D. Strozier. 1992. Toxicity of sediment-, aqueous and porewater-associated *Azinphosmethyl* to estuarine infaunal copepods. 13<sup>th</sup> Annual Meeting, Society of Environmental Toxicology and Chemistry, Cincinnati, OH.
- Corbett, C., D.E. Porter and D.A. Karinshak. 1995. Modeling surface water runoff, sediment and nutrient loading in coastal South Carolina: a comparison of an undeveloped and urbanized watershed. 13<sup>th</sup> International Estuarine Research Federation Conference. Corpus Christi, TX. 12-16 November 1995.
- Corbett, C., D.E. Porter and D.A. Karinshak. 1995. Surface water runoff, sediment and nutrient loading in coastal South Carolina: a comparison of an undeveloped and an urbanized watershed. Third Thematic Conference on Remote Sensing for Marine and Coastal Environments. Seattle, WA. 18-20 September 1995.
- Coull, B.C. and G.T. Chandler. 1992. A review of pollution and meiofauna. Invited, Eighth International Meiofauna Conference, August 9-14, 1992, University of Maryland.

- Daugomah, J.W. 1995. The effects of urbanization on *Palaemonetes pugio*, grass shrimp densities. American Indian Science and Engineering Society Annual Meeting, Detroit, MI.
- Daugomah, J.W. and G.I. Scott. 1994. An ecotoxicological assessment of nonpoint source urban runoff effects on the grass shrimp, *Palaemonetes pugio*. 15<sup>th</sup> Annual Meeting of the Soc. of Env. Toxicol. and Chem. Denver, CO.
- Daugomah, J. W., M.H. Fulton, and G.I. Scott. 1998. The effects of urbanization on the population structure of *Palaemonetes pugio* in small, high salinity estuaries. SECOR Meeting. 8-10 April, Savannah, GA.
- DiPinto, L.M., M.H. Fulton and G.T. Chandler. 1995. Trophic-transfer of a sediment-associated organophosphate pesticide from meiofauna to fish. 16<sup>th</sup> Annual Society of Environmental Toxicology and Chemistry Conference, Vancouver, Canada.
- Donelan, T.L., G.T. Chandler and G.I. Scott. 1996. Overview of sediment toxicity testing with the benthic harpacticoid copepod *Amphiascus tenuiremis*. The Benthic Ecology Meeting, Columbia, SC.
- Douglas, A.P., E. Blood and H. McKellar. 1993. Spatial and temporal patterns of nutrient distribution in the Goose Creek sub-estuary of the Cooper River/Charleston Harbor estuary. 12<sup>th</sup> Biennial International Estuarine Research Federation Conference, Nov. 14-18, 1993, Hilton Head, SC.
- Edwards, D., D.E. Porter. B. Jones, E. Moise and W.S. Street. 1998. Alternatives to the paired t-test for testing spatial change. Conference on Southeast Coastal Ocean Research. 8-10 April, Savannah, GA.
- Ferguson, P.L. and G.T. Chandler. 1995. Bioaccumulation of the polynuclear aromatic hydrocarbon, fluoranthene, in the polychaete annelid, *Streblospio benedicti*. The Benthic Ecology Meeting, Columbia, SC.
- Finley, D.B., J.W. Daugomah, S. Layman and G.I. Scott. 1996. An ecotoxicological approach to nonpoint sources urban and agricultural runoff effects on the grass shrimp, *Palaemonetes pugio*, with an emphasis on PGP and multi drug resistant protein synthesis. Medical University of South Carolina Graduate Student Research Day, Charleston, SC, Poster Presentation: 1<sup>st</sup> Place Award.
- Finley, D.B., J.W. Daugomah, S. Layman and G.I. Scott. 1995. An ecotoxicological approach to nonpoint sources urban and agricultural runoff effects on the grass shrimp, *Palaemonetes pugio*. Medical University of South Carolina Graduate Student Research Day, Charleston, SC, Poster Presentation: 3<sup>rd</sup> Place Award.
- Fortner, A.R. 1993. Variation in selected polynuclear aromatic hydrocarbon and metal burdens in oyster and sediment from two high-salinity estuaries in South Carolina. 23<sup>rd</sup> International Symposium on Environmental Analytical Chemistry, Jekyll Island, Georgia.
- Fortner, A.R., M. Sanders, and S. W. Lemire. 1993. Variation in selected polynuclear aromatic hydrocarbon and metal burdens in oyster and sediment from two high-salinity estuaries in South Carolina. 14<sup>th</sup> Annual Meeting of the Society of Environmental Toxicology and Chemistry. Houston, Texas.

Fulton, M., G. Scott, A. Fortner, T. Bidleman and B. Ngabe. 1992. Urbanization effects on small high-salinity estuaries of the southeastern United States. Society of Environmental Toxicology and Chemistry, Cincinnati, Ohio.

Green, A.S. and G.T. Chandler. 1995. Life-table evaluation of sediment-associated chlorpyrifos chronic toxicity to the benthic copepod, *Amphiascus tenuiremis*. 16<sup>th</sup> Annual Society of Environmental Toxicology and Chemistry Conference, Vancouver, Canada.

Green, A.S., G.T. Chandler and E. Blood. 1992. Toxicity and bioavailability of sediment associated cadmium to an infaunal copepod. Proceedings of the 13<sup>th</sup> Annual Meeting of the Society of Environmental Toxicology and Chemistry.

Green, A.S., G.T. Chandler and E.R. Blood. Toxicity and bioavailability of sediment-associated cadmium to an infaunal harpacticoid copepod. *Eighth International Meiofauna Conference*, August 9-14, 1992, University of Maryland.

Jefferson, W.H., W.K. Michener, D.A. Karinshak, W. Anderson and D.E. Porter. 1991. Developing GIS data layers for estuarine resource management. GIS/LIS 91. Atlanta, GA.

Jensen, J.R., D.E. Porter and C. Coombs. 1998. Biophysical remote sensing of coastal wetlands. AAAS Annual Meeting and Science Innovation Exposition. February, Philadelphia, PA.

Jones, B.C., D.E. Porter, D. Edwards, G. Scott and T. Siewicki. 1997. A multi-disciplinary approach to monitoring and predicting estuarine conditions using spatial modeling techniques. Fourth International Conference on Remote Sensing for Marine and Coastal Environments. Orlando, FL. 17-19 March 1997.

Jones, B. and D.E. Porter. 1996. A multidisciplinary approach to modeling estuarine conditions. Eco-Inforna '96. Lake Buena Vista, FL. 4-7 November 1996.

Jones, B., D.E. Porter, D. Edwards, T. Siewicki and G. Scott. 1996. Integrated spatial modeling techniques for coastal research and management. 16<sup>th</sup> Annual Environmental Systems Research Institute Users' Conference. Palm Springs, CA. May 1996.

Karinshak, D.A., D.E. Porter and C. Corbett. 1995. Comparing remote sensing platforms for mapping wetland vegetation within a localized coastal estuary: evaluation of C-CAP protocols. Third Thematic Conference on Remote Sensing for Marine and Coastal Environments. Seattle, WA. 18-20 September 1995.

Karinshak, D.A. and D.E. Porter. 1994. Utilizing large-scale remote sensing imagery for monitoring human impacts on a localized coastal estuary. American Association of Geographers Annual Meeting. San Francisco, CA.

Kawaguchi, T., A.J. Lewitus, C.M. Aelion and H. McKellar. 1995. Can urbanization limit iron availability to estuarine algae? 13<sup>th</sup> International Conference of Estuarine Research Federation, Corpus Christi, Texas, Fall 1995.

Kawaguchi, T., C. M. Aelion, M. Wahl and H. McKellar. 1994. Reduction of organically-bound ferrous iron (Org.-Fe(II)): A potential effect of coastal urbanization. Southeastern Estuarine Research Soc. Spring meeting, 10-12 March, Jekyll Island. GA.

- Kucklick, J.K., G.I. Scott, M. Sanders, S. Silvertsen and E. Long. 1995. Polycyclic aromatic hydrocarbons in South Carolina estuarine sediments. 13<sup>th</sup> International Conference of Estuarine Research Federation, Corpus Christi, Texas, Fall 1995.
- Lewitus, A.J., E.T. Koepfler, K.C. Hayes, B.M. Willis, and R.J. Pigg. 1998. Phytoplankton uptake of dissolved organic nitrogen: implications to the potential eutrophication of southeastern salt marsh estuaries. Southeast Coastal Ocean Research Conference. 8-10 April, Savannah, GA.
- Lewitus, A.J., T. Kawaguchi, J. Keesee and B.M. Willis. 1998. Relationships between nutrient quality, iron bio-availability, and primary production in an undeveloped vs. urbanized salt marsh estuary. SouthEast Coastal Ocean Research Conference. 8-10 April, Savannah, GA.
- Lewitus, A.J., T. Kawaguchi, J. Keesee, and B.M. Willis. 1998. Urbanization and associated deforestation can affect estuarine phytoplankton composition and primary production by altering nutrient and iron loading patterns. Society of Wetland Scientists 1998 Meeting. 8-12 June Anchorage, AK.
- Little, L., D. Edwards and D.E. Porter. 1995. Kriging in estuaries: As the crow flies or as the fish swims?. 13<sup>th</sup> International Estuarine Research Federation Conference. Corpus Christi, TX. 12-16 November 1995.
- McKellar, H., A. Smith, A. Douglas and R. Rao. 1995. Wetland nutrient exchange in an urbanized estuary: relationships to point-source discharges and nonpoint runoff. 13<sup>th</sup> International Estuarine Research Federation. Nov. 12-16, Corpus Christi, TX.
- McKellar, H., A. Douglas, A. Smith and R. Rao. 1994. Tidal exchange of carbon and nitrogen in an oligohaline marsh: seasonal patterns and relationships to point-source discharges and nonpoint runoff. 3<sup>rd</sup> Symposium on Biogeochemistry of Wetlands. June 26-29, Orlando, FL.
- McKellar, H., E. Blood, A. Douglas, T. Munnerlyn, R. Rao, P. Smith, P. Darbar and P. Conrads 1993. Seasonal patterns and mass balances of organic carbon and nutrients in an urbanized sub-basin of the Cooper river estuary. 12<sup>th</sup> Biennial International Estuarine Research Conference, Nov. 14-18, 1993, Hilton Head, SC.
- Porter, D.E. 1998. Murrells Inlet under the microscope: preliminary findings and recommendations for coastal zone management. Invited presentation to the Murrells Inlet 2007 Task Force and community of Murrells Inlet. January, Murrells Inlet, SC.
- Porter, D.E. 1998. Linking land use to estuarine health: an overview of the USES project. Conference on Southeast Coastal Ocean Research. 8-10 April, Savannah, GA.
- Porter, D.E., D. Bushek, D.L. White and J. Keesee. 1998. Host-parasite relationships and disease status as a measure of ecosystem health. Conference on Southeast Coastal Ocean Research. 8-10 April, Savannah, GA.
- Porter, D.E., J. Allen, T. Siewicki, M. Gielazyn, D. Edwards and W.K. Michener. 1998. Defining the role of database management in support of long-term, multidisciplinary environmental research efforts. Conference on Southeast Coastal Ocean Research. 8-10 April, Savannah, GA.
- Porter, D.E. and B. Jones. 1997. Real-time DGPS and video soundings for shallow-water DEMs. Presented at GIS/LIS. Cincinnati, OH. October 1997.

Porter, D.E. 1996. Linking land use and associated anthropogenic activities to coastal ecosystem health. Invited presentation at the South Carolina Sea Grant Consortium Land Use - Coastal Ecosystem Health Workshop. Savannah, GA. 24-25 June 1996.

Porter, D.E., B. Jones, D.J. Cowen, D. Edwards, C. Corbett, T. Siewicki and G. Scott. 1996. Integrated risk assessment modeling in support of sustainable development in an estuarine environment. Third International Conference / Workshop on Integrating GIS and Environmental Modeling. Sante Fe, NM. 21-25 January 1996.

Porter, D.E., F.J. Vernberg, W. Vernberg, T. Chandler, H. McKellar, M. Aelion, T. Kawaguchi, G. Scott, M. Fulton, T. Siewicki and B. Jones. 1996. Multidisciplinary ecosystem assessment of anthropogenic influences on localized coastal estuaries: a research and management approach. South Carolina Environmental Symposium. Myrtle Beach, SC. 2-4 October 1996.

Porter, D.E., F.J. Vernberg, W. Vernberg, T. Chandler, H. McKellar, M. Aelion, T. Kawaguchi, G. Scott, M. Fulton, T. Siewicki, B. Jones, and D. Edwards. 1996. Integrated ecosystem assessment of anthropogenic influences on localized salt-marsh estuaries: a research and management approach. Third Marine and Estuarine Shallow Water Conference. Atlantic City, NJ. 1-5 December 1996.

Porter, D.E. 1995. Defining the role of database management in marine resources research and management. Invited presentation at the LEO-15 Workshop. Rutgers University Marine Field Station, Tuckerton, NJ. 28-29 November 1995.

Porter, D.E., B. Jones, W. Jefferson and C. Corbett. 1995. The utilization of Geographic Information Processing and advances in telecommunications for the integration and dissemination of data and information in a multi-disciplinary, Multi-Locale Research Project. 13<sup>th</sup> International Estuarine Research Federation Conference. Corpus Christi, TX. 12-16 November 1995.

Porter, D.E., D.J. Cowen, D.A. Karinshak and B. Jones. 1995. Using the tools of Geographic Information Processing to compare the rate of wetlands alterations in an undeveloped and a managed estuary. Third Thematic Conference on Remote Sensing for Marine and Coastal Environments. Seattle, WA. 18-20 September 1995.

Porter, D.E. 1994. The role of database management for marine resources research and management. Invited presentation at the National Estuarine Research Reserve System-wide Monitoring Workshop. Georgetown, SC.

Porter, D.E. 1994. Key points in the development of a GIS-based database management system for environmental management. Invited presentation at the Russian Academy of Sciences Institute of Geochemistry. Irkutsk, Russia.

Porter, D.E. 1994. Design and development of an inter-jurisdictional database management program for marine resources research and management. Workshop on the collection and use of trawl survey data for fisheries management. Invited presentation sponsored by the Atlantic States Marine Fisheries Commission. Charleston, SC.

Raj, P. and C.M. Aelion. 1995. Denitrification in coastal freshwater stream sediments. 13<sup>th</sup> International Conference, Estuarine Research Federation, November 12-16, Corpus Christi, TX.

Reed, L.A. and A.R. Dias. 1996. A comparison of sediment trace metal levels at sites from Charleston Harbor and North Inlet, SC. 17<sup>th</sup> Annual Meeting of the Society of Environmental Toxicology and Chemistry. Washington, DC.

Reed, L.A. and A.R. Dias. 1995. A comparison of selected trace metal levels in sediments from potentially contaminated sites in Charleston Harbor and pristine North Inlet Estuary in South Carolina. 25<sup>th</sup> International Symposium on Environmental Analytical Chemistry. Jekyll Island, Georgia.

Reed, L.A. and A.R. Dias. 1995. A comparison of selected trace metal levels in sediments from potentially contaminated sites in Charleston Harbor and Pristine North Inlet Estuary in South Carolina. Student Research Day 1995 at the Medical University of South Carolina.

Reed, L.A. and A.R. Fortner. 1994. A comparison of selected metal levels in sediment and oyster samples from an urbanized and a pristine estuary in South Carolina. 24<sup>th</sup> International Symposium on Environmental Analytical Chemistry. Ottawa, Canada.

Reed, L.A. and A.R. Fortner. 1994. A comparison of trace metal levels in sediment and oyster from an urbanized and a pristine estuary in South Carolina. 15<sup>th</sup> Annual Meeting of the Society of Environmental Toxicologists and Chemists. Denver, Colorado.

Reed, L.A. and A.R. Fortner. 1994. A comparison of trace metal levels in sediment and oyster from an urbanized and a pristine estuary in South Carolina. Student Research day 1994 at the Medical University of South Carolina.

Schlekat, C.E., A.W. Decho and G.T. Chandler. 1995. Sorption of organic compounds to microbial extracellular polymers: Potential vector for bioaccumulation of sediment-associated contaminants. 16<sup>th</sup> Annual Society of Environmental Toxicology and Chemistry Conference, Vancouver, Canada.

Scott, G.I. 1996. The impacts of coastal development and urbanization on water quality and oyster resources and habitat: The need for shellfish restoration in the southeastern U.S. The South Atlantic Shellfish Restoration Workshop, Charleston, SC, January, 1996. Plenary Session Address.

Scott, G. I. 1996. An overview of the Southeastern Shellfish Restoration Workshop. Southern and Gulf States Interstate Shellfish Sanitation Conference; Folly Beach, SC; Invited Platform Talk.

Scott, G. I. 1996. An overview of the 1996 Shellfish Restoration Workshop for the southeastern US. International Shellfish Restoration Conference, Hilton Head Island, SC; Invited Platform Talk.

Scott, G.I., M.H. Fulton, J. Kucklick, P.B. Key, J.W. Daugomah, and T. Shearer. 1996. A myriad of contaminants: Which ones count? Land Use Coastal Environmental Study Workshop; Savannah, GA: Invited Platform Talk.

Scott, G.I., M.H. Fulton, S.H. Strozier, E.D. Strozier, E.F. Wirth and J.W. Daugomah. 1996. The effects of urbanization on the American oyster, *Crassostrea virginica* (Gmelin). National Shellfish. Assoc. Annual Meeting, Baltimore, MD. Invited Platform Talk.

Scott, G., M. Fulton, P. Key, J. Daugomah, A. Fortner and S. Strozier. 1994. The effects of urbanization on estuarine ecosystem health. Presented: Soc. of Env. Tox. and Chem., Denver, Colorado.

Scott, G.I., M.H. Fulton, J.W. Daugomah and J.T. Waldren. 1992. A comparison of block seining and push netting for estimating ecotoxicological effects of urban and agricultural nonpoint source runoff on the grass shrimp, *Palaemonetes pugio*. Presented: Soc. of Env. Tox. and Chem., Cincinnati, Ohio.

Scott, G.I., M.H. Fulton, and G.T. Chandler. 1992. Ecotoxicological and ecophysiological effects of agricultural insecticide runoff on estuarine organisms. 13<sup>th</sup> Annual Meeting of the Society of Environmental Toxicology and Chemistry.

Scott, G.I., M. Fulton, P. Key, J. Daugomah, A. Fortner and S. Strozier. 1994. The effects of urbanization on ecosystem health. Society of Environmental Toxicology and Chemistry, Denver, CO.

Scott, G.I., M. Fulton, P. Key and J. Daugomah. 1995. The use of *in situ* toxicity tests to assess NPS runoff toxicity of pesticides. 16<sup>th</sup> Annual SETAC Meeting. Denver, CO.

Scott, G. I., M.H. Fulton, G. Richards, B. Thompson, L. Webster, K. Nelson, J. Bemiss, and T. Siewicki. 1998. Impacts of urbanization on surface water quality. SECOR Meeting. 8-10 April, Savannah, GA.

Scott, G. I. 1997. Impacts of urban and agricultural nonpoint source runoff on estuarine ecosystem health. Tulane University Law School, Environmental Law Day. Invited presentation.

Scott, G. I. 1997. The impacts of coastal development on estuarine ecosystems health with a special emphasis on transportation corridors, bridges and roadways. Beaufort County Clean Water Task Force, Port Royal, SC. Invited talk.

Siewicki, T.C., F.J. Vernberg, W. Vernberg, D. Edwards, G. Scott, M. Fulton, D. Porter and H. McKellar. 1996. Combined urban impacts to small, high-salinity estuaries in South Carolina, USA. Fisheries and Pollution 1996, The 2<sup>nd</sup> Annual Conference on Population-Level Effects of Marine Contamination, November 8-9, 1996, Bodega Marine Laboratory, Bodega Bay, California.

Siewicki, T.C. and G.T. Chandler. 1995. Bioconcentration of sediment-associated fluoranthene by the filter-feeding bivalve mollusk, *Crassostrea virginica*. Second SETAC World Congress, November 5-9, 1995, Vancouver, British Columbia.

Siewicki, T.C. 1995. Modeling of sediment-associated fluoranthene and environmental risk due to urbanization of small, non-riverine estuaries. 13<sup>th</sup> International Conference of the Estuarine Research Federation, November 12-16, 1995, Corpus Christi, Texas.

Tufford, D.L., H.N. McKellar, C.M. Aelion, M.H. Wahl, C.W. Corbett and D.E. Porter. 1998. Mechanisms of surface and shallow ground water hydrology and nutrient fluxes into two high salinity estuaries. Conference on Southeast Coastal Ocean Research. 8-10 April, Savannah, GA.

Wahl, M., M. Aelion, T. Williams and H. McKellar. 1995. Water table dynamics and nutrient chemistry in forested and urbanized coastal streams. 13<sup>th</sup> International Estuarine Research Federation, Nov. 12-16, Corpus Christi, TX.

Wahl, M., H. McKellar and T. Williams. 1995. Patterns of nutrient loading in a forested and urbanized coastal streams. 13<sup>th</sup> International Estuarine Research Federation, Nov. 12-16, Corpus Christi, TX.

Wahl, M., C. M. Aelion, H. McKellar, T. Kawaguchi and T. Williams. 1994. Nutrient loading and groundwater and surface water interactions in coastal South Carolina blackwater streams. Second International Conf. on Ground Water Ecology, Atlanta 27-30 March.

Wahl, M., H. McKellar and T. Williams. 1993. The effects of coastal development on watershed hydrography and transport of organic carbon. Symposium: Sustainable Development in the Southeastern Coastal Zone (Organized by F. J. Vernberg and W.B. Vernberg); Sponsored by NOAA, March 2-5, Myrtle Beach, SC.

Wahl, M. and H. McKellar. 1991. Organic carbon dynamics and water quality interactions in impounded woodland streams. SC Fishery Workers Assoc. 1 February, Charleston, SC.

Wahl, M and H. McKellar. 1991. Organic carbon dynamics and stream hydrology in a coastal plain watershed: effects of hurricane, drought, and flood. Annual Meeting of the Ecological Society of America, August, San Antonio, TX.

Wahl, M.H., H.N. McKellar, and C.M. Aelion. 1997. Stormwater quality and water production in coastal blackwater streams, current and emerging issues in aquatic sciences. American Society of Limnology and Oceanography. 10-14 Feb, Santa Fe, NM.

White, D., D.E. Porter and D. Bushek. 1997. A comparison of spatial and temporal patterns of *Perkinsus marinus* in oyster populations in a developed estuary and an undeveloped estuary in South Carolina. Spatial Data and Remote Sensing in Invertebrate Fisheries Habitat, Research and Management Workshop. 19-20 April, Fort Walton Beach, FL.

Wirth, E.F., M.H. Fulton, and G.I. Scott. 1996. The toxicity threshold for sediment associated polycyclic aromatic hydrocarbon in larval grass shrimp. 13<sup>th</sup> Annual Estuarine Research Federation Meeting, Corpus Christi, TX.

Wirth, E.F., M.H. Fulton, G.T. Chandler, P. B. Key and G.I. Scott. 1998. Toxicity of sediment associated PAHs to the estuarine crustaceans, *Palaemonetes pugio* and *Amphiascus tenuiremis*. SECOR Meeting. 8-10 April, Savannah, GA.

## Appendix C: Human Resource Development

### Graduate Student Theses

- Anishetty, Vimala. 1991. *The effects of coastal urbanization on the distributions of chlorophyll and organic carbon in two southeastern salt marsh estuaries*. Columbia, SC: University of South Carolina. 98 pp.
- Cresci, D.C., 1997. Microbial mineralization of atrazine in riparian and estuarine sediments. Master's Thesis, University of South Carolina, pp. 140.
- Douglas, Adriene. 1995. *Spatial and temporal variability of nitrogen and phosphorus distribution in the Goose Creek estuary: Cooper River/Charleston Harbor estuary system*. Columbia, SC: University of South Carolina. 110 pp.
- El-Figi, Kheiria Abouzeid. 1990. *Epidemiological and microbiological evaluation of enteric bacterial waterborne diseases in coastal South Carolina estuary*. University of South Carolina, School of Public Health, Doctoral dissertation. Columbia, SC: University of South Carolina. 154 pp
- Green, A.S. 1995. *A holistic study of sediment -associated chlorpyrifos effects of the benthic harpacticoid copepod, Amphiascus tenuiremis*. Doctoral dissertation. Columbia, SC: University of South Carolina. 131 pp.
- Nybro, Cheryl. 1996. *Spatial and temporal variability of nitrogen and phosphorus in high-salinity estuaries*. Doctoral dissertation. Columbia, SC: University of South Carolina. 207 pp.
- Porter, D.E. 1995. *Use of Geographic Information Processing techniques to model cumulative impacts of regulatory permitting programs on coastal wetlands: a South Carolina perspective*. Doctoral dissertation. Columbia, SC: University of South Carolina. 203 pp.
- Raj, P. 1996. *Comparison of the rates of denitrification in subsurface sediments from a pristine and a suburban watershed*. Columbia, SC: University of South Carolina. 81 pp.
- Siewicki, T.C. 1995. *Bioaccumulation of sediment-associated fluoranthene by Eastern oysters (Crassostrea virginica): kinetics, environmental fate, statistical and environmental modeling and exposure assessment*. Doctoral dissertation. Columbia, South Carolina: University of South Carolina. 309 pp.
- Smith, P. 1992. *The effects of urbanization on spatial and temporal nutrient distributions in two southeastern estuaries*. Columbia, SC: University of South Carolina. 142 pp.
- Strozier, S.H. 1996. *Effects of urbanization on the American oyster, Crassostrea virginica, in terms of bacterial and parasitic infection and physiological condition*. Doctoral dissertation. Columbia, SC: University of South Carolina. 231 pp.
- Wahl, M. 1992. *Carbon transport in low-order, low-gradient streams: the effects of storm events and stream impoundment*. Masters thesis. Columbia, SC: University of South Carolina. 144 pp.

Wahl, M. 1996. *Stream hydrology and stormwater nutrient dynamics in small coastal watersheds: forested versus urbanized catchments*. Doctoral dissertation. Columbia, SC: University of South Carolina.

Weinstein, J.E. 1994. *The molecular, subcellular, and cellular effects of urban-derived Polycyclic Hydrocarbons on the American oyster (*Crassostrea virginica*) (Gmelin 1791)*. Doctoral dissertation. Columbia, SC: University of South Carolina. 166 pp.

Wolfe, T.M. 1995. *A comparison of fecal coliform densities and fluorescent intensities in Murrells Inlet, a highly urbanized estuary, and in North Inlet, a pristine forested estuary*. Masters thesis. Columbia, SC: University of South Carolina. 84 pp.

### **Graduate students fully or partially supported by USES**

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