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

Preliminary Recommendations for Coastal Zone Management and Continued Research

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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 which 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, development of newer technologies are 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 for supporting sustainable coastal development, a long-term study was initiated in 1990 to define, measure and model the impacts of urbanization on localized coastal estuaries of the southeastern United States. The Urbanization and Southeastern Estuarine Systems (USES) Project began 1 June 1990. On 1 June 1997, the eighth year of the project begins. 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.

The models incorporate land-use patterns and integrated toxicological and Geographic Information Processing (GIP) approaches. 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 of a relatively pristine estuary, North Inlet (NI), South Carolina, with those of a 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.

As proposed in the multi-year plan, out years are extremely crucial to the success of the project It is during this time that the overall syntheses and integration of the results of the various substudy components takes place. Significant progress has been made on development and validation of models incorporating the results of the various study components:

Chemical Contaminants,
Bacteriology,
Toxicology,
Eutrophication and Nutrients, and
Geographic Information Processing and Spatial Modeling.

The purpose of this report is to summarize the significant scientific findings to date and provide preliminary recommendations for coastal zone management and further research. The major activities for continued support are discussed in relation to the management recommendations. Of paramount importance is the ability to extend our scientific findings to management recommendations useful in development of strategies for managing the numerous small, high-salinity estuaries typical of the southeastern United States.

Recommendations for Coastal Zone Management and Continued Research

Recommendations are beginning to emerge from the Urbanization and Southeastern Estuarine Systems Project. These recommendations are offered to land-use and fisheries managers to be used to lessen impacts of future human population shifts to communities along the 300 high-salinity estuaries on the southeast US coast. Additionally, these recommendations will apply to critical headwaters of larger estuaries.

1. Levels of chemical contaminants do not pose acute but do pose cumulative chronic risks to seafood consumers. These risks are predictable and preventable.

a. Recommendation: Concentrations of chemical contaminants in edible oyster tissues are low compared to industrialized estuaries and low enough that risks are below levels of concern for individual chemicals. However, cumulative levels of multiple contaminants are relatively high in sites near light commercial activity, roads, marinas and parking lots. Harvests of sedentary organisms for human consumption should be restricted near these sites. Transport and fate models, based on sediment and surface water characteristics along with other consequences of landscape alteration, were developed to predict the levels in critical media and biota. *These models should be used to determine risks of chemical toxicity under alternative plans for development and to select practical strategies to minimize impacts during development of these estuaries. Future development should maximize the distance between sources of contaminants and critical habitat such as oyster reefs.*

b. Background and Previous Findings: There are over 300 small, high-salinity estuaries within the southeastern United States that are largely undeveloped yet destined to be altered by commercial and residential urban sprawl in the near future (Vernberg *et al*. 1992). Urbanization often results in runoff containing toxic chemicals entering nearby estuaries. The most toxic group of chemicals emanating from urban areas is the polycyclic aromatic hydrocarbons (PAHs). Surface water contamination by PAHs comes from deposition from air (Jensen 1984), municipal wastewater discharge (Barrick 1982), runoff from coal storage (Stahl *et al*. 1984), effluent from wood treatment (Snider and Manning 1982), oil spills (Giger and Blumer 1974), petroleum processing (Guerin 1978) and urban storm water runoff (MacKenzie and Hunter 1979; Eganhouse *et al*. 1981; Fox 1992; Hoffman *et al*. 1982, 1983, 1985; Varanasi *et al*. 1985). Surrounding land uses have been shown to affect quantities of PAHs in sediments (Kashner and Hunter 1983). Mass emission rate estimates computed from runoff concentrations indicated that the Los Angeles River alone contributes nearly one percent of the annual world petroleum hydrocarbon input into the ocean via runoff (Eganhouse and Kaplan 1981). Several other studies have shown that urban runoff is the primary contributor to specific estuaries (Prahl *et al*. 1984;

Santodonato 1981; Hoffman *et al*. 1982, 1983, 1985). These PAHs are rapidly bound to suspended sediment within runoff that affects their transport and deposition in aquatic systems (Hoffman *et al*. 1982, 1983, 1985).

A major PAH exposure pathway for persons living near estuaries is ingestion of seafood (Adams *et al*. 1994). The relationships of toxicity potential and physical, abiotic and biotic factors are being investigated to find additional tools to predict impacts and to understand the factors contributing to contaminant accumulation and toxicity. Results of this work indicate that specific chemicals accumulate to levels of concern in these unique ecosystems. Efforts are underway to refine the assessment of risks from chemical insults and to identify key factors affecting their accumulation into seafood.

Environmental modeling has the advantage of integrating multiple and sometimes competing processes into a single output of expected transport and fate of chemical contaminants. These models use multiple, simultaneous algorithms that describe, for example, ionization, sorption, bioavailability, photolysis and biotransformation. Very few attempts have been made to model sediment-sorbed PAHs occurring in urban runoff. Still fewer studies of PAH-contaminated runoff entering non-riverine estuaries have been attempted. The Exposure Analysis Modeling System (EXAMS-II) (Burns *et al*. 1982, 1985) is suitable for estuarine systems and acceptable to regulatory agencies. The model accounts for interactions between the aquatic environment, the properties of the chemical of interest and environmental loading characteristics, to predict the exposure, persistence and fate of synthetic chemicals in aquatic systems. Additionally, statistical modeling of the relationships between measures of cumulative risk and various characteristics of developing estuaries are useful for evaluating alternative development strategies.

Fluoranthene (FLR), a four-ring polycyclic aromatic hydrocarbon, was studied as a model toxic chemical resulting from urbanization. Risks caused by FLR in urban runoff were estimated by modeling and assessing exposure in Murrells Inlet, South Carolina. Kinetic rate constants for sediment-associated FLR and FLR runoff concentrations were determined in earlier studies (Siewicki 1995) and used in these assessments. The objectives were: a) predict sediment and oyster concentrations of a model urban pollutant; b) determine relationships between FLR fate and land uses; c) identify factors affecting sediment and oyster concentrations; and d) analyze risk to human consumers of oysters and impacts of different environmental conditions on that risk. In addition, cumulative risks from multiple chemicals were evaluated.

The Exposure Analysis Modeling System (EXAMS-II) was used to examine relationships between land uses and FLR distribution and fate in a sub-watershed (Dog and Allston Creeks) of Murrells Inlet (Siewicki 1997). Chemical and environmental characteristics and loading data were integrated into simultaneous equilibrium and kinetic process equations. The most important processes in this estuary were export, adsorption, biolysis and photolysis. System-wide, 98 % of total FLR was exported, migrating from upper stream segments faster than that downstream. Factors affecting oyster exposure were:

non-point source loading > steady state loading > non-point source hydrologic flows.

Simulated pulse loads equal to that expected in 75 mm storms caused only nearby, short-term increases. Concentrations generally increased for about 9 months then began to plateau. Effects of season and pulses were ameliorated from pelagic to benthic strata and with distance downstream. Risks, as hazard indices, although low, were affected by conditions that cause varying levels of runoff, e.g., boating or traffic changes.

These results indicate that risks from FLR loading are quantitatively related to adjacent land uses and can be predicted by understanding the major factors affecting its transport and fate. Siting of pollution sources and seasonal harvest restrictions can reduce risks to human consumers of contaminated seafood. The model was sensitive to environmental changes. Large pulses of FLR such as storms or spills caused dramatic short-term effects to nearby pelagic and benthic zones but effects were ameliorated before reaching distant benthic zones. Both increasing loading and reducing the distance from sources caused large increases in both sediment and biomass concentrations. Urban size affects expected FLR disposition. An approach is described that can be used to test alternate landscape modifications for minimizing impacts on resident fauna and the consuming public.

Modeling efforts using sums of hazard indices calculated at each of 30 sampling sites within Murrells Inlet as a measure of cumulative risks to human consumers were conducted (Siewicki *et al*. 1996). Principal factor and multiple regression analyses indicate that cumulative risk is dependent upon water quality characteristics, distance to boat ramps and parking lots and nearby housing density. Results suggests that risk estimates are predictable without expensive chemical analyses. These models provide quantitative links between landscape changes and risks that are sensitive to multiple impacts and may be useful in damage assessment and cleanup activities following contamination of estuaries.

2. Microorganisms in shellfish pose acute risks to human consumers.

a. Recommendation: Concentrations of fecal coliform bacteria in surface waters and edible molluscan shellfish (oysters) which are indicators of human fecal pollution are elevated near urbanized estuarine regions and near animals sources including feed lots, migratory birds and other wildlife. Levels in urbanized estuaries are high enough to prohibit harvesting of shellfish for human consumption. The frequency of human pathogens (e.g. *E. coli*) associated with urban runoff was high in urban areas and lower in undeveloped estuaries. The frequency of occurrence in undeveloped regions suggests that birds and wildlife may be major sources of fecal coliform bacteria in these areas. *Future development should maximize the distance between development and shellfish harvesting areas.*

b. Background and Previous Findings: 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 US (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 Project 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, a pristine estuary which is a National Estuarine Research Reserve site, and Murrells Inlet, the most urbanized coastal area in the state of South Carolina (based upon population densities => 625/sq. mile).

Results of the studies conducted during Years 1-7 have indicated:

1.) A total of 67% of the surface water monitoring stations in MI exceeded the SA water quality criteria for fecal coliform bacteria (13/100ml) compared to only 33% of the stations in NI. Poor water quality stations in MI were associated with high densities of septic tanks in close proximity to the estuary and other urban activities (marinas, boat landings and roadways). GIS overlays and statistical analysis indicated that regions in MI with high levels of PAHs, near roadways and marinas, also had concomitant high fecal coliform bacteria densities. This suggests that fecal coliform bacterial densities may be affected (due to biostimulation) in areas with high PAH concentrations. Poor water quality in NI was associated with upland areas housing large populations of birds and wildlife. These findings clearly indicate that fecal coliform bacteria pollution is associated with urbanization and that closure of shellfish harvesting waters may be perhaps the most significant, quantifiable impact from urbanization.

2.) Fecal coliform bacterial serotyping of surface waters indicated there were significant differences in the speciation of coliform positive species in surface waters of MI and NI. In urbanized MI, there was a greater occurrence of *E. coli* bacteria, fewer stations which were coliform negative and a reduced number of bacterial species comprising the coliform group, particularly soil sorbed microbes of the Pseudomonid family. In pristine NI, surface waters had a greater number of coliform negative stations, a reduced occurrence of *E. coli* bacteria and an increased number of bacterial species comprising the coliform group with an increased occurrence of soil-sorbed microbes in the Pseudomonid family. The greater diversity/species richness in the coliform group members in NI resulted from the availability of bacteria from the deciduous hardwood forest when compared to upland watersheds in urbanized MI, which contain more monoculture (i.e. lawns with grass and ornamental plants) habitat.

3.) Fecal coliform bacterial serotyping of oysters indicated that unlike results for surface waters, there were no significant differences in the speciation of coliform positive species in oysters from MI and NI. One factor related to this observation may have been that the high levels of fecal coliform bacteria which were measured at ebb tide, may have been diluted significantly at flood tide (when oyster feed) to comparable densities, which were then bioconcentrated equivalently by oysters in each estuary.

4.) Results from surface water coliform serotyping indicated that there were greater potential risks of oyster exposure to *E. coli* and other pathogenic coliform members in urbanized MI than in pristine NI. Oyster results indicated that the greater potential human health risks measured in surface waters were not translated into greater actual or realized human health risks in terms of oyster bioconcentration potential. These results suggest that while there are clearly greater inputs of fecal coliform bacteria from human waste sources in urbanized areas, the process of tidal dilution and dispersion resulted in no discernible differences in oyster bioconcentration of these pathogens. Indeed the fecal coliform "finger prints" based upon oyster bioconcentration were not significantly different nor were there quantifiable differences in coliform densities in oysters between the two estuaries. This suggests that the current Interstate Shellfish Sanitation Conference (ISSC) method of regulating shellfish harvesting which is based on surface water quality provides a margin of safety but may be some what over protective, as there were no actual differences in fecal coliform levels in oysters between the two estuaries. With recent international agreements reached on trade (i.e. NAFTA and GATT) there may be increased pressures for the U.S. to adopt a new policy on oyster meat standards in addition to our current shellfish harvesting surface waters standard.

5.) Pulsed Field Gel Electrophoresis (PFGE) and Fatty Acid Profiling (FAP) techniques were used to discriminate animal versus human sources of *E. coli* bacteria using techniques and methods developed by Dr. George Simons at Virginia Tech University. Results to date have focused on confirming Dr. Simon's methods and evaluating selected wildlife, human volunteers and septic tank samples. PGFE results indicated that when *E. coli* sources could be identified (human versus wildlife= 60% of the time), there was a 90% probability in discriminating wildlife versus human sources. FAP was able to discriminate between human and wildlife samples some 96.2% of the time using principal component analysis. The PFGE and FAP methods have the potential ability to discriminate between human and wildlife sources of *E. coli*. This information would be invaluable to environmental managers to better manage these impacts from urbanization.

6.) Study of oyster disease and Vibrio bacteria interactions indicated that oysters parasitized by *Perkinsus marinus* as a result of the higher salinity waters in MI estuary, had a greater portion of *Vibrio vulnificus* (MI = 77.3% versus NI = 34.1%) and *Vibrio parahaemolyticus* (MI = 77.6% versus 53.2%) bacteria distributed within internal tissues (gonad, digestive diverticulum, and adductor muscle) than in more external tissues (gills, mantle, and labial palps). There were no significant differences between fecal and total coliform distributions in NI and MI oysters, as the majority of the bacterial burden was found in internal tissues (MI = 89.4-89.7% versus 78.6-83.4% in NI, respectively).

c. Needed Research: Microbiology research in Year 8 of the USES Project will focus 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 7 has focused on quality assuring results in lab standards, human volunteers, septic tank samples and samples collected from the Oyster Landing site at North Inlet adjacent to the watersheds, housing large populations of wildlife and birds. Research in Year 8 will focus on 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) throughout the state of South Carolina. This research will be conducted in concert with the SC Department of Health and Environmental Control Office of Coastal Resource Management. Intervention analysis will be conducted 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) impact fecal coliform levels in surface waters.

3. Chemical contaminants partition to sediment and are toxic to resident biota.

a. Recommendation: Overall concentrations of chemical contaminants in both runoff water and sediment are generally low compared to industrialized estuaries. Hydrophobic chemical contaminants in the water column are nearly all bound to suspended sediment and this is a major source of exposure to fauna. Cumulative levels of multiple contaminants in sediment are relatively high in sites near roads, marinas, parking lots, housing and other potential sources. These levels are, in fact, toxic to larval copepods, a critical forage species in these fish nurseries. Even relatively low contaminant concentrations can have dramatic effects on long-term population dynamics if they significantly reduce fertility rates of, for example, infauna. Uptake of sediment-bound chemicals is different than dissolved forms of the same chemical and regulatory criteria devised for aqueous chemicals do not adequately evaluate risks from the more common forms in these estuaries. Our research showed cost effective means to estimate uptake of sediment-bound chemicals and should be used in a broad strategy to address risks. *Future development should maximize the distance between upland development and the aquatic environment. Methods to retain sediment, e.g., basins, should be employed. Models have been developed to assist in predicting both individual and multiple risks given distances from sources and these models should be used to identify distances that are protective. Additional information related to the hazard associated with specific contaminants in sensitive species will enhance our ability to utilize these existing models.*

b. Background and Previous Findings: 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 previous work has indicated that most of the toxic effects in estuarine biota associated with urban runoff have been cronic in nature. No acute toxicity was observed in *in situ* bioassays performed with grass shrimp and mummichogs in Murrells Inlet. Subtle effects on growth, however, were observed in juvenile sheepshead minnows deployed at the same site in Murrells Inlet. Oysters deployed at Murrells Inlet sites bioaccumulated higher body burdens of PAHs and

Cytochrome P-450 levels increased in North Inlet oysters transplanted to sites in Murrells Inlet. In laboratory experiments, larval grass shrimp were exposed for ten days 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. In a similar 14-day experiment, survival of female copepods was depressed in the 10x treatment and the number of surviving offspring was also reduced. Subsequent copepod 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 (Amphiascus tenuiremis). 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 (~14.5 vs 12 eggs/clutch), but MP sediments were strongly and significantly toxic to hatching larvae/juveniles (49% fewer offspring per female survived despite a larger mean clutch size). 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. Experiments in the laboratory have also investigated the uptake of PAHs from contaminated sediments. Eastern oysters (*Crassostrea virginica*) were continuously exposed (Siewicki 1995) to suspended [^{14}C]fluoranthene spiked-sediment for either: (1) five days followed by 24 days depuration (Branson *et al*. 1975), or (2) 28 days exposure. Oysters were held in an all-glass flow-through system and exposed to suspended sediment. 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. The chemical half-life for fluoranthene in oysters was about 3.5 days indicating cleanup can be rapid after loading ceases. These measurements are vital to describing the potential exposure of sensitive and/or commercially exploited fauna.

c. Needed Research: Sediment-associated contaminants appear to pose the most significant risk to fauna residing in urbanized estuaries. The limited data currently available from Murrells Inlet suggests that sediments from some sites adjacent to contaminant sources are toxic to benthic organisms. We do not yet know if sediment-associated contaminants are distributed along spatial gradients of higher to lower concentrations as one moves ebbward from pollution loading sources (e.g. parking lots, storm-water runoff pipes) in Murrells Inlet. Toxicologically and ecologically it is important to know if such gradients exist, if they are predictable / modellable / manageable, and if they exhibit significant gradients of bioaccumulation and effects in sediment infauna. If bioaccumulation / toxicity / trophic-transfer only occurs for fauna over a limited area, then overall ecosystem health may not be compromised. In 1997/98, we will select tidal creek systems in Murrells Inlet receiving the highest pollution loadings from rainwater runoff. We anticipate selecting approximately 10 “hot spot” sites for study. Once these sites have been identified, we will extensively sample sediments along a geometrically increasing spatial gradient extending from well known contaminant-loading points ebbward to approximately 500 m. Samples will be collected and analyzed for organic and inorganic pollutants from each tidal creek gradient sampling point. A subset (2-3) of these “hot spot” gradients will be evaluated toxicologically using a full life-cycle copepod bioassay and a 10-day bioassay with juvenile clams (*Mercenaria mecenaria*). The use of these two species will allow us to evaluate the toxicity of these sediments in two species representing different phyla and feeding strategies. Additionally, a PAH body-burden/bioaccumulation assessment of the most abundant infaunal organism in this system (and much of the southeast US), Streblospio benedicti will be made. The GIS tools developed to date in USES will allow us to explore contaminant spatial extent:toxicological interactions at small (m^2) to large (km^2) scales once the character of such gradients are determined for Murrells Inlet.

4. Geostatistical and geographic information processing techniques are becoming essential for monitoring estuarine ecosystems.

a. Recommendation: Chemical and microbial distribution in runoff and environmental partitions throughout small, high-salinity estuaries has been poorly understood, in part because of deficiencies in methodology for adequately assessing runoff. Techniques were devised to statistically sample these estuaries and remotely monitor unpredictable climatic events. Data were incorporated into a GIS database for statistical and spatial analyses. This allows the integration and analysis of sampled information with other remotely sensed and geographic data. *These techniques should be evaluated and enhanced through continued research focusing on current study sites and also used to assess risks of anthropogenic alterations and contamination in similar estuaries.*

b. Background and Previous Findings: Better tools for the analysis of estuarine ecosystems have become increasingly important to proper resource management (Michener *et al.* 1992; Porter *et al.* 1997). The complexity and severity of environmental problems, existing or potential, associated with coastal growth have led many agencies and organizations to explore new spatial analytical techniques to provide timely, valid information to aid problem solving and to assist with effective coastal zone management. The geostatistical method known as kriging is one such analytical technique now attaining widespread use. Developed by Matheron (1963), who named it after D.G. Krige, kriging uses a variable’s values in a spatially explicit sample to generate predictions of the variable’s values at unobserved locations. Kriging is especially appealing in that it requires minimal user intervention, is remarkably robust to model misspecification (Journel and Rossi 1989; Cressie and Zimmerman 1992), generates statistically optimal predictions under a given set of assumptions, and can provide standard errors to accompany predictions.

For the USES Project, kriging has been 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. For example, Porter *et al.* (1997) have used spatially indexed samples to map the concentration of fluoranthene in oysters and sediment in Murrells Inlet, and through integration into a GIS analysis have been able to relate this concentration to distances to roads and docks. As another application, Porter *et al.* (in press) used sampled *pugio* densities at spatially dispersed sites in Murrells Inlet and North Inlet to create kriged maps of adult and juvenile density. These were integrated into a GIS to allow the assessment of possible stressors on these populations, and the generation of hypotheses regarding human-induced bottlenecks in their life cycles.

Previous studies of non-point source loading of environmental contaminants were limited by sampling constraints. A few discrete measurements of contaminant loading over limited time periods at specific sites do not give true representation of transport to an estuary and cannot address temporal and spatial variations or cumulative effects of several sources. An apparatus was needed that would allow continuous monitoring and sampling of ecosystems affected by unpredictable climatological events as well as seasonal and other environmental variables.

A study was carried out to: a) design, construct and test remotely enabled automated field stations (REAFS); b) monitor runoff conditions, collect critically timed non-point source samples during a variety of climatic events and hydrologic conditions and measure these for chemical loading; c) collect and analyze environmental samples to describe fluoranthene distribution in Murrells Inlet; d) identify underlying factors affecting chemical distribution; and, e) develop regression models to predict cumulative chemical risks from estuary characteristics.

Two REAFS field stations for environmental monitoring and remotely controlled sampling of runoff were deployed along a drainage for suburbanized Murrells Inlet, i.e., Dog Creek (Siewicki 1995). Continuous measures of rainfall, dissolved oxygen, pH, salinity, specific conductivity, temperature and stream level allowed optimal sampling of storm events. These parameters were monitored and controlled 140 km from the study area. The stream rising limb, peak outfall and falling limb of storms were sampled and measured for sediment and FLR concentration . Correlation coefficients for FLR and sediment, and FLR and time after peak rain rate ranged from 0.63 to 0.99 and -0.61 to-0.87, respectively. Runoff averaged 12.8 mg FLR/hectare/cm rain and a flux of 0.53 g/capita/y. Interestingly, this flux is nearly identical to more populated residential areas of Narragansett, Rhode Island and Los Angeles, California (Hoffman *et al*. 1983; Eaganhouse *et al*. 1981). The highest runoff concentration in Dog Creek was only 4.6 and 1.4 percent of chronic and acute toxicity values, respectively (United States Environmental Protection Agency 1991). Likewise, sediment concentrations remained below Threshold and Probable Effects Levels of 0.76 and 3.2 ug/g, respectively (MacDonald *et al*., 1992) suggesting toxic effects on Murrells Inlet organisms is unlikely.

The REAFS apparatus allowed monitoring and sampling of critical time-points otherwise impossible from remote locations thereby improving non-point source pollution research capabilities. The runoff results suggest a pathway for exposure of filter-feeders in these systems: FLR and other hydrophobic toxic chemicals bind to suspended small particles, deposit in sediment, are disturbed and resuspended, then filtered. Concentrations were low but flux per capita was nearly identical to much more populated areas suggesting management techniques need to be unique for residential areas but may be standardized for use in urban areas of widely varying sizes. Management should emphasize placement of roadways and boating activities away from critical habitat.

Sediment and oyster tissue samples were collected at 30 stations in Murrells Inlet and measured for polycyclic aromatic hydrocarbons (including FLR) and subjected to cluster analysis to identify 1) patterns of FLR distribution within Murrells Inlet, and 2) relationships of FLR with other parameters (Siewicki 1995). Independent variables included oyster and sediment FLR; distance to nearest boat dock or paved road; dock density within typical shellfish buffer zones (305 meter radius); sediment hydrogen, nitrogen and particle size; and water and sediment fecal coliform concentrations. These parameters were tested to determine combinations of variables that explain most of the variation in the system and to resolve a compact and efficient model to predict fluoranthene concentrations in oysters.

Most of the system variance was explained by two linear combinations of variables pertaining to sediment quality and pollution sources (Siewicki 1995; Porter *et al*. 1997). Oysters preferentially filter similar particles as those transporting fluoranthene and other toxic chemicals in these small estuaries (Newell and Jordan 1983). Regression modeling showed the following model was predictive of oyster fluoranthene:

ng fluoranthene/g lipid = 687 + 785,000/foot to paved road + 3.7*oyster fecal coliform ($R^2 = 0.74$)

Just two phenomena were primarily responsible for governing transport and fate of fluoranthene within Murrells Inlet: sediment quality and pollution sources. The variables identified by linear regression are inexpensive and practical tools for predicting impacts. These studies magnify the importance of understanding environmental fate of anthropogenic chemicals and underscore both the need for and ability to achieve cost-effective management tools.

Recent modeling efforts using more independent variables has been done (Siewicki *et al*., 1996). The sum of multiple chemical "Effects Range Low" (ERLs; Long *et al*. 1995) was used as a measure of risk to resident benthic biota. The ERL was selected because values are available for many chemicals, it's based on most sensitive impacts and it does not depend upon uncertainty factors. Seven PAHs and six metals were included (measured levels of chlorinated chemicals were too low for inclusion) in calculations for each of 30 sites in Murrells Inlet. 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 population expansion. Multiple regression analyses resulted in two models with high adjusted R^2s. The first contains variables for sediment and water quality, distance to parking lots and boat ramps, proportions of upland and open water within 305 meters, and housing density. The second, more compact model, is dependent upon variables for water and sediment quality only. This later model does not necessitate geographic measurements making it more appropriate for some circumstances. These results (if correlated to 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.

c. Needed Research: We believe that kriging (in some evolved form), in conjunction with GIS, will someday be indispensable for estuarine management. This is clear, since so many ecosystem parameters can only be measured at a limited number of spatial locations, and this limitation will always be present. But kriging today is still in its infancy as a statistical method, and research on the nuances of its application in estuaries is ongoing (Rathbun 1996; Little *et al*, in press; Moise *et al*, in prep). Further research is needed to assess the accuracy of kriging predictions, and to study the use and reliability of accompanying measures of accuracy. Supporting the development of this methodology will pay double dividends, for USES research itself and for building the foundations of modern estuarine management methods.

The USES project is in a position to spearhead its development in this area and lay the foundations for its use for years to come. Current research on applications of kriging to estuarine research includes explorations into specialized distance measures specific to estuaries (Rathbun 1996; Little *et al*, in press) and the use of kriging to validate or enhance traditional data analytic techniques such as analysis of variance (Moise *et al*, in prep). In addition, we will study the accuracy of kriged predictions and the effects of this accuracy on conclusions drawn via integration into a GIS analysis. Research is being proposed which will provide estimates of the within-site variability for chemical contaminant concentrations in Murrells Inlet. In previous years, single sediment samples were collected from approximately 30 randomly selected sites within Murrells and North Inlet and analyzed for a suite of organic and inorganic contaminants. Thus, we currently have no estimate of the variance associated with the chemical contaminant concentration for a particular, spatially-defined site. In order to optimize our ability to utilize the kriging method and to apply our findings to other estuaries, we believe that estimates of variance for measured chemical contaminant concentrations at specific sampling sites is essential. We propose to collect replicate (3) samples from approximately 15 of the original Murrells Inlet sampling areas to address this question.

Controlled experiments are useful in ecosystem research, but can at best merely simulate complex systems; they are inherently simplistic in these simulations. Assessment of new management strategies on real systems is essential, yet there is little or no possibility of replication, nor of controlling extraneous influences (Michener, submitted). Data collected on such “unreplicated experiments” are typically of time series form. Traditional time series analysis methods, though, are focused either on econometric forecasting (Box and Jenkins 1976) or the detection and assessment of periodicity in time series (Bloomfield 1983). Time series analyses are vital to the assessment of management techniques, but not under either of the traditional approaches. In order to assess effects of management policies in unreplicated experiments, intervention analyses are necessary (Rasmussen *et al.* 1993; Chapal and Edwards 1994). These analyses allow for quantification of temporal trend before and after some change in management policy or natural event, and formal tests of the effects of such interventions. They can also assess the severity of possible traumatic effects at or immediately after this “intervention point”. These methods have been used very successfully for management policy assessment in other fields; for example, they have been the norm for assessing the beneficial effects of changes in seatbelt and drinking-age laws on accident rates, and are largely responsible for current government attitudes about these laws. Intervention analyses have not yet found widespread use for ecosystem management, but under the USES project are currently being used for comparisons of septic tank and sewer systems in the control of coliform levels in the marsh (Nelson *et al*, in prep). Further application of intervention analyses are expected, a technology transfer which will expand the general level of analytical sophistication and effectiveness in ecosystem management science.

Seven years of intensive research in Murrells Inlet and North Inlet have led to enhanced understanding and new theories regarding urbanization and anthropogenic influences on marsh ecosystems. It is time to extend, test and refine these results by cross-validation to other sites. To avoid the pitfalls of pseudoreplication, it will be necessary to make observations in several other estuaries for these purposes; budgetary constraints, however, will not allow intensive sampling in any one new estuary. A modern statistical approach to this dilemma involves the use of hierarchical analyses, alternately referred to in the literature as empirical Bayes methods (Ver Hoef 1996), mixed general linear models (Searle *et al* 1996), or meta-analyses (Gurevich and Hedges 1996). These statistical methods allow for careful and comprehensive analysis of multi-site studies via the use of a hierarchy of structural statistical assumptions. At the top level of the hierarchy, certain patterns are assumed to be shared among sites when these are supported by the data; at lower levels in the hierarchy, site-specific patterns are allowed where these are necessary and appropriate. By comparing the goodness-of-fit of these analyses under a variety of structures at the top levels, similarities in observed patterns across sites can be tested, and when encountered can be efficiently incorporated into the analytical infrastructure. Data from new estuaries can be incorporated into the analytical framework, and patterns shared with other estuaries used to obtain more powerful and accurate results for all.

5. Removing riparian forests changes nutrient dynamics to estuarine phytoplankton.

a. Recommendation: Forested wetlands filter contaminants and excess nutrients, control hydrology and store carbon. Dissolved organic matter (DOM) leached from coastal forests was the major source of nearby estuarine DOM. The chelation of iron by DOM is thought to be an important mechanism for supplying the iron requirements for phytoplanktonic and macro algal growth. *Forest buffers along drainage streams and at the marsh-upland interface should be protected to maintain iron bioavailability to phytoplankton in adjacent estuaries.*

b. Background and Previous Findings: Kawaguchi *et al*. (1994) proposed bioavailable iron and associated algal growth as new indicators of ecosystem health in the interface of the coastal forest and salt marsh estuary. The bioavailability of iron is enhanced by chelation to dissolved organic matter (DOM) produced by forest floors. Forest clearing, and subsequent changes due to coastal development (e.g. grading, building, paving, ditching) can alter the quality and quantity of stream DOM, and thus affect the amount and type of iron species available to algae.

Iron has long been recognized as an essential growth requirement for phytoplankton, having functional roles in electron transport, oxygen metabolism, nitrogen (nitrate, nitrite) assimilation, and DNA, RNA, or chlorophyll synthesis (Weinberg 1989). Although iron may play an important role for the optimal growth of phytoplankton, the relationship between primary production and iron bioavailability in tidal creek estuaries rarely has been explored, because iron is generally abundant in marsh sediments in forms such as pyrite (FeS_2), geothite (-FeOOH) or lepidocrocite (-FeOOH). However, the availability of iron to phytoplankton critically depends on its speciation, and not necessarily quantity (Rich and Morel 1990; Wells 1991; Kuma and Matsunaga 1995).

Based on the above information, we hypothesized that urbanization-associated deforestation has reduced iron availability to Murrells Inlet estuarine phytoplankton. As a first step to testing the hypothesis, we conducted a bioassay experiment to determine whether the potential for iron depletion by phytoplankton was greater in populations transferred to Murrells Inlet water than in those transferred to North Inlet (forested) water. Results from that experiment support the hypothesis in that iron enrichment caused a significant stimulation of total phytoplanktonic biomass (chlorophyll a) and several constituents of the natural phytoplankton population when grown in Murrells Inlet water but not North Inlet water.

The ultimate goal of this section is to develop an indicator of estuarine ecosystem health using bioavailable iron and related iron bioassay. This indicator may be used as “early warning” indicator of estuarine ecosystem degradation.

We have accumulated evidence implicating organically-bound iron as the main source of bioavailable iron to phytoplankton in two high-salinity salt marsh estuaries of the southeastern US, and indicating that this source, under certain conditions, may be in limiting supply. However, in contrast to oceanic environments where the main producers of organic ligands may be phytoplankton (Rue and Bruland, in press), forest-derived DOM appears to be the main source in these estuaries. Small, low gradient, blackwater streams with high humic substance content dominate freshwater input in these systems (Mullholland and Kuenzler 1979) and commonly the predominant source of estuarine DOC is fulvic acid-rich humic matter leached from upland forests (Beck *et al*. 1974; Wolaver *et al*. 1986). In comparing the potential for iron limitation in two of these estuaries, one (Murrells Inlet) impacted by urbanization and associated forest clearcutting, and the other (North Inlet) unimpacted by development and surrounded by forests, we found sharply contrasting patterns of iron composition and phytoplankton iron-enrichment responses (Kawaguchi *et al*. 1994, in press; unpublished data). Most notably, the deforested Murrells Inlet was marked by much lower levels of organically-complexed iron and a strikingly greater iron stimulation of phytoplankton growth. This result provide strong support for the core hypothesis of this research: organically-bound iron produced by coastal forests plays a critical role in maintaining iron bio-availability to salt marsh estuarine phytoplankton.

c. Needed Research: Within Murrells Inlet, there are different degrees of development in the watershed adjacent to the salt marsh. Therefore, more spatial data of iron bioassay within Murrells Inlet is required to confirm that the reduced iron bioavailability to phytoplankton in Murrells Inlet water.

We will combine 1) measurements of ambient iron composition along a transect from the creeks to the estuaries, 2) a bioassay of iron availability using natural populations from North Inlet and Murrells Inlet that are transferred to filtered water each estuary and incubated under treatments varying in iron (EDTA-Fe, natural organically-bound iron), nitrogen (NO_3, NH_4) and PO_4

content, and 3) a bioassay on cultured phytoplankton (axenic iron-replete and iron starved cultures of *Synechococcus* spp., *Cylindrotheca closterium*, and *Phaeodactylum*) transferred to water from each estuary.

6. Runoff and channelization increase eutrophication.

a. Recommendation: Considerably higher nutrient loading and lower organic carbon concentrations occur in both ground and surface water in urbanized watersheds compared to forested watersheds. Ground water may be discharging more at deeply excavated urban streams. The higher nutrient loading from urban areas is due in part to higher concentrations in runoff from impervious surfaces as well as nonpoint source influences from septic tank drain fields close to the stream channel. An equally important reason for higher loading (especially for nitrogen) was the hydrologic condition of the urban stream, which had been deeply excavated and channelized to improve drainage. *Surrounding upland should be maintained with natural drainage patterns and riparian wetland buffers adjacent to local streams. In addition, developments should be converted to central waste water collection and treatment for areas using septic tanks, especially where existing drainage fields are close to streams and drainage ditches.*

b. Background and Previous Findings: Freshwater inputs to high-salinity marsh estuaries of the Southeast are often dominated by discharge from a network of small, low-gradient blackwater streams. These streams typically have high concentrations of dissolved organic matter (DOM, 10-30 mg/l), due largely to low retention of DOM by sandy soils, and extended contact between water and organic debris in the low-gradient streams and riparian areas (Mulholland and Kuenzler 1979). This organic matter represents an important energy source for downstream aquatic systems where labile fractions of DOM are assimilated by bacteria, forming an important link in aquatic food webs (Meyer *et al*. 1987). These streams typically contain low concentrations of inorganic nutrients which vary considerably with storm-tide intrusions of salt water (Wolaver and Williams 1986, Blood *et al*. 1991).

Coastal watersheds in the southeastern US are rapidly changing to accommodate an explosive growth in population (Vernberg *et al*. 1992). Changes to coastal watersheds may significantly alter nonpoint source runoff to local steams with resultant changes in the downstream transport of sediments, organic matter and nutrients to sensitive estuarine areas (Meyer *et al*. 1988, Reddy *et al*. 1989, Triska 1989). The main objective of this component of the USES study has been to quantify the spatial and seasonal distributions of nutrients (carbon, nitrogen, and phosphorus) within the North Inlet and Murrells Inlet estuaries and to further quantify the effects of coastal urbanization on local stream hydrology, and transport of critical nutrient fractions. The principal streams (12 total) that empty into the Murrells Inlet marsh were excavated in the 1930's by the Civilian Conservation Corps. This was done to improve overall drainage, develop pine plantations, and reduce the threat of malaria. These channels were deeply excavated perpendicular to the coast, and were directed across the topographic ridge boundary to the marsh. However, 50% of the them empty into impoundments that are formed by bulkheads along the marsh frontage, and these impoundments serve to alter stormwater runoff. Analysis of stormwater quality flowing in and out of Gasque Pond (October 1993) at Murrells Inlet indicated

2.5 x higher mean concentration of orthophosphate phosphorous in the outflow (43 vs. 12 μg/1). However, a stormwater moderation and reduction of mineral nitrogen (40% less NH4-N and 44% less NOx-N) was observed in stormwaters flowing out of the impoundment to the marsh.

Spatial patterns of organic carbon distribution within the two estuaries showed that the stations influenced by forested runoff at North Inlet were significantly higher in DOC than the ocean-influenced stations (Anishetty 1991). This trend was not found at Murrells Inlet, suggesting that runoff from more urbanized watersheds may contain less dissolved organic matter than in typical forested watersheds. These patterns were corroborated by results from a 3-yr sampling of stream runoff, (Wahl *et al*. 1997) which documented lower mean concentrations of DOC in runoff from suburbanized watersheds at Murrells Inlet (12.5 ± 0.3 mg/l) than from the forested watershed at North Inlet (25.6 ± 0.7 mg/l). Reduced organic matter concentrations in the urbanized watersheds coincided with areas of stream excavation and channelization with reduced streamwater exchange with riparian zones. The urbanized streams exhibited more rapid hydrograph responses to storm events reflecting more impervious surfaces and less.

Spatial patterns of inorganic nutrient distribution showed few significant differences except during the summer and fall when nitrate and orthophosphate were significantly higher in the urbanized Murrells Inlet estuary (Blood *et al*. 1997). The highest concentrations (> 100 μg/l) were observed in waters adjacent to a densely developed trailer park suggesting the influence of urban storm water runoff on estuarine nutrient concentrations. Investigation of the upland stream dynamics showed that the urbanized watershed at Murrells Inlet delivered more that twice as much dissolved inorganic nitrogen as the forested watershed at North Inlet (Wahl *et al*., in press). Greater runoff volume in the urbanized stream (due to stream channelization and deeper excavation) combined with higher mean annual concentrations (130 vs 43 μg NOx/l) to culminate in 11 times more NOx loading in the urbanized stream than in the forested stream (18 and 1.6 kg N/yr, respectively).

The higher nutrient loading from urban areas was due to a number of influences including geologic differences, hydrologic modifications, higher concentrations in runoff from impervious surfaces as well as nonpoint source influences from septic tank drain fields close to the stream channel. The uplands at the urbanized site are characterized by steeper topography with extensive areas of excessively drained and well drained sandy soils (>70%), whereas, the uplands at the forested site include a much smaller portion of these well drained soils (<30%). This added natural drainage would also favor soil aeration and promote oxidized forms of DIN in stream runoff from the Murrells Inlet drainage system.

Stream channelization at the urbanized site further promoted NOx-N loading. Channelization in the Murrells Inlet upland was generally directed against the natural drainage, which flows predominately in a direction parallel to the marsh. This physical change not only lowers the natural water table near the channel, but also reduces the retention time of stream water in the channel. Both of these factors may serve to produce higher stream NOx-N concentrations, as well as remove less stream NOx-N on its way to the marsh.

The overland runoff that was observed at the urbanized stream during the most intense rainfalls comprised less than 1% of the total runoff amount. However, the overland flow did contain higher concentrations than channel water of both PO_4-P (444 vs. 36 µg P/L) and NOx-N (505 vs. 127 µg N/L). Thus, overland flow from impervious surfaces was a potential source of soil N, which could have subsequently made its way by groundwater seepage into the channel.

Septic fields provide another possible source of stream DIN. A significant downstream increase of NOx-N concentration in the urbanized stream implicated a lateral septic. However, elevated NOx-N concentrations found during stormflow (>500 µg N/L) were not likely produced by saturated groundwater (<50 µg N /1). This is because saturated groundwater below the channel (< 40 cm) was under low oxygen tension with relatively high denitrification potential (Aelion *et al*. in press). Therefore, the source of stormwater NOx-N at Dog Creek was during this time was confined to displaced unsaturated soil moisture, by groundwater rising up around the channel. These analyses at the Murrells Inlet uplands suggest many factors combine to produce the observed elevated nutrient loading to the marsh, from geologic (deeper soils) to anthropogenic (loss of wetlands, channelization, impervious surfaces, septic fields, and fertilizers).

c. Needed Research: In order to extrapolate our findings to a broader scale of conditions throughout Murrells Inlet and other high-salinity salt marshes, we need to develop a more mechanistic understanding of watershed hydrology and nutrient transport in these systems. For this year of study we propose to compare patterns observed at the intensive study sites with more expanded survey of watersheds along the entire border of Murrells Inlet. This estuary system includes 8-12 upland watershed inputs which vary considerably in terms of intensity of urban development and degree of hydrologic and riparian wetland modification. We propose to conduct bi-weekly samplings of water quality (carbon, nitrogen, phosphorus, and TSS) in 5-6 of these watersheds with a focused effort toward sampling throughout periods of water deficit (April through September) and water surplus (October through March). Instantaneous discharge at five streams combined with a determination of water quality will provide us with an estimate of the overall freshwater loading of a variety of parameters (TSS, DOC, NH4-N, NOx-N, PO4-P, TON and TOP) and offer a comparison with the intensively studied stream.

These data will be used in a continued effort to develop nonpoint source runoff models to test the consequences of development scenarios on watershed loading. In the coming year, the existing NPS loading model (Corbett *et al*. in press) will be expanded to simulate nutrient and sediment runoff from the entire upland drainage of Murrells Inlet. The expanded model will be used to test the possible impacts of increased urbanization and other land use changes surrounding the estuary. By the end of the current year, the existing model will be calibrated and validated for nutrient loading functions for the forested and urbanized watersheds documented by Wahl *et al*. (in press). Watershed morphometry for the Murrells Inlet watershed will be based on existing 7.5' USGS topographic maps in conjunction with more detailed data on topography and channel geometry collected during the study year. For model application to the entire Murrells Inlet watershed, grid cell size will be increased to account for the larger study area and less detailed parameterization data on each sub-basin. Parameters controlling water, sediment, and nutrient transport will be derived from detailed storm data from the urbanized (Dog Creek) in conjunction with more extensive data from ongoing sampling of water quality in the other sub-basins of Murrells Inlet.

7. Where coastal communities are sewered, ground water nutrient quality is not deteriorated.

a. Recommendation: Increased nitrate concentrations in ground water were measured at the urbanized site. However, current concentrations of nitrate at both sites are below levels of concern for human health, and overall ground water nutrient quality (e.g. nitrate and nitrite) is good in both urbanized and non-urbanized estuaries. *Although routine monitoring of ground water at both sites may not be necessary, ground water concentrations at the urbanized site and those sites which are susceptible to elevated inputs of nutrients should be monitored to assure that the elevated concentrations remain at current levels*. Inclusion of an additional sampling site with significantly greater inputs of nutrients for a worse case scenario site is suggested. Ground water microbiological activity is substantial at all sites investigated, and microbiological processes appear to be a key factor in reducing nitrate concentrations in subsurface sediment and ground water. Further investigation of nitrate removal by native bacteria, and overall native bacterial community health will assist in predicting risks to ground water quality from additional nitrate inputs. *If nitrate concentrations in ground water continue to increase beyond acceptable levels and removal capacity of native ground water bacteria, investigation of nitrate application practices should be addressed to reduce the infiltration of nitrate into subsurface sediments and ground water.*

b. Background and Previous Findings: Contaminants and nutrients entering estuarine systems often do so through surface water and groundwater inputs (Bokuniewick 1992). Ground water contamination is difficult to remediate once it occurs. Nitrate is highly soluble therefore readily transported through sediments to groundwater. Nitrate contamination of ground water has been documented in many states, normally as a result of the land application of nitrate-based fertilizers, and septic tanks as evidenced by the coastal eutrophication in Florida (LaPointe and Clark 1992). Pesticide contamination is an additional threat to groundwater resources. Atrazine is one pesticide which has been found in several groundwater wells in South Carolina (Hess, personal communication 1996). Although we do not expect elevated atrazine concentrations at our study locations in groundwater at this time, it is probable that concentrations will increase as more land development occurs. Concentrations of atrazine in the ng/L range were measured by Kucklich and Bidleman (1994a; 1994b) in the microlayer and subsurface layer of surface water in Winyah Bay and North Inlet, SC.

Microbial processes have been shown to be a significant mechanism for chemical transformations in the environment. These processes are particularly important is sediment and groundwater systems which are characterized by few biological species, no light input or photolytic processes and therefore reduced numbers of chemical reactions, and slow flow rates relative to surface water systems, which reduce the number of physical reactions. Most of the biological activity associated with sediments is due to bacteria. Not only are they extremely active, but also lower organisms such as bacteria and protozoa are the only organisms that live in groundwater and aquifer sediments.

In our previous research on the USES project we have measured groundwater quality in Oyster and Dog Creeks. Concentrations of nitrate were elevated at Dog Creek relative to Oyster Creek, and this may indicate that the suburbanized system does not have the capacity to accommodate increased nitrate inputs. However, the levels of nitrate at both sites are still below those levels which pose a threat to human health. Regardless, they should be monitored particularly in the Dog Creek area, to assure that they remain at acceptable levels. We also found that ammonium and organic carbon concentrations in ground water were significantly greater at Oyster Creek than at Dog Creek, and that ammonium concentrations were an order of magnitude greater than nitrate concentrations at both locations.

Understanding the dynamics between nitrate and ammonium in aquifer sediments and groundwater may help elucidate the cycling of inorganic nitrogen in the two study areas and the relative concentrations of both constituents in groundwater. Nitrate introduced into the environment may be biologically reduced either by denitrification to N_2 or by dissimilatory nitrate reduction to ammonium (Jorgenson 1989). Both processes require anaerobic or microaerophilic conditions which exist at our study locations. Depending upon which of these processes is dominant, nitrogen will either be conserved in the sediments as NH_4^+ or organic N, or lost to the atmosphere as nitrous oxide (N_2O) or nitrogen gas (N_2) (Atlas and Bartha 1993).

Many studies have demonstrated the importance of these nitrate reduction reactions in the top layer of soil (0-15 cm depths), but results from our recent studies (Aelion *et al*. 1997 in press) suggest that denitrification may be important in aquifer sediments at greater depths in the saturated zone. We have measured the amount of nitrate that the denitrifying bacteria can consume in sediment microcosms, and the impact that different levels of nitrate have on denitrifying activity. At higher concentrations of nitrate, denitrification activity declines. At more environmentally-relevant concentrations of 0.1-1.0 mg/L, denitrifying bacteria consume most of the available nitrate. We suggest that at current levels of nitrate in groundwater, it will be denitrified rapidly by groundwater aquifer bacteria which are extremely active consumers of nitrate.

Because we observed decreased denitrification rates at greater anthropogenic nitrate concentrations (5 mg/L) in aquifer sediment microcosms, we expanded our study to include sediment collected from an area of higher anthropogenic nitrate input, Litchfield Country Club, and have measured concentrations of nitrate at Litchfield Country Club in both surface waters and sediment. Application of nitrate is episodic, and we have measured nitrate concentrations ranging from 0.08 to 1.2 mg/L in surface water.

When sediment from the three locations was incubated in the laboratory under different nitrate concentrations, the lag time prior to nitrate consumption was shortest at Litchfield Country Club, followed by Dog Creek and then Oyster Creek. Denitrification rates were greatest at the Litchfield site which receives the greatest input of nitrate, and these bacteria were able to convert the nitrate to N_2 most efficiently, with greater than 80% efficiency, followed by Oyster Creek (75% efficiency) and then Dog Creek (approximately 50% efficiency). Despite elevated nitrate inputs, the activity of the denitrifying sediment bacteria was significant at Litchfield Country Club, and also at Oyster Creek and Dog Creek.

Results from our experiments using atrazine suggest that this contaminant was not significantly mineralized (completely degraded) to CO_2 by the sediment bacteria. Of the activity measured, Litchfield Country Club bacteria consistently degraded more atrazine than the other two sites, perhaps due to some previous exposure to pesticides. Dog Creek bacteria appear to be the least able to degrade this anthropogenic contaminant. Although the bacteria were not readily mineralizing atrazine, they were oxidizing organic chemicals as evidenced by the decrease in oxygen content in the incubation vials after approximately 20 days of incubation, and the production of intermediates of atrazine degradation. Interestingly, atrazine degradation in higher salinity areas in North Inlet, Oyster Landing, was greater than in the freshwater Oyster Creek system in preliminary experiments. This suggests that the estuary may be able to accommodate some of the contamination if the upland freshwater areas do not significantly degrade the contaminants. However, in general, mineralization rates were slow, suggesting that if atrazine were applied to the land surface and transported to the groundwater aquifers, it would not be readily consumed by aquifer sediment bacteria, unlike nitrate which was readily consumed.

In the majority of our studies we have found that the Dog Creek bacterial groundwater community was not as active as the other two sites, even though one of the sites, Litchfield Country Club would not be considered pristine. Overall microbial activity as measured by amino acid respiration, for example, was greatest at North Inlet and Litchfield Country Club, and significantly reduced at Dog Creek. Denitrification rates were slowest at Dog Creek, and atrazine degradation was more limited at Dog creek than the other study sites. The suburbanization at Dog Creek appears to have negatively affected the bacterial community activities measured in our experiments, although the specific cause has not yet been determined. Conversely, the development associated with Litchfield Country Club does not appear to limit bacterial activity, and may alter the bacterial community in such a way as to increase activities measured in our experiments.

c. Needed Research: Our results clearly demonstrate the importance of the biologically-mediated conversion of nitrate to nitrogen gas which effectively removes nitrate from the estuarine system. As the next step in our research, we propose to continue our examination of the denitrification process as a major removal mechanism for anthropogenic nitrate inputs in groundwater and aquifer sediments, and investigate further the impact of different salinities on denitrification rates. We also propose to examine the relative rates of denitrification and dissimilatory nitrate reduction to ammonium in groundwater sediments in order to evaluate whether this is possibly responsible for the relatively high ammonium concentrations and low nitrate concentrations measured in the ground water in Oyster and Dog Creeks. Currently, we have no idea of the competing reactions of groundwater bacteria to convert nitrate to nitrogen gas or ammonium. 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 will examine the importance of these factors on the relative rates of denitrification and dissimilatory nitrate reduction to ammonium in aquifer sediment microcosms. Finally, we will carry out spot monitoring of groundwater nutrient concentrations to ascertain whether changes or degradation of groundwater quality is occurring in Dog Creek.

8. Upland channelization and impervious surfaces increase suspended sediment.

a. Recommendation: Increased average sediment concentrations in urban runoff is largely attributed to changes in channel morphology. Deep V-shaped creek channels that are sparsely vegetated enhance sediment mobility compared to natural, trapezoidal-shaped channels. *Trapezoidal cross-sectional shaped channels with riparian vegetation buffer should be used where channels are necessary in future development.*

Increasing impervious surface area in small, unconnected clusters produces higher sediment loads than one contiguous surface of equal area. Urban sediment mobilization increases as previously forested and open land becomes covered by impervious materials. *Developments should utilize single centralized, high density development approach with vegetated buffers separating impervious surfaces and receiving waterbodies within a watershed rather than multiple medium density developments to minimize total impervious surface area.*

b. Background and Previous Findings: Non-point source pollution (NPSP) describes the degradation of water quality by materials which are of diffuse origin. (Novotony and Chesters 1981). Wetlands are particularly sensitive to NPSP because they function as pollutant sinks (Kadlec and Knight 1996). Pollution associated with urban development of the adjacent uplands is now endangering the health of valuable coastal wetlands in South Carolina (Vernberg *et al.* 1992).

Development of land changes surface water runoff characteristics (Calder 1993). Typically, urbanized watersheds have impervious surface areas and drainage systems designed for efficient removal of surface water (Winter 1990). These alterations to the land surface result in increased runoff volumes, higher peak flow rates, and reduce rainwater infiltration and pollutant filtering by subsurface flow (Riordan *et al*. 1978). Surface runoff carries dissolved, suspended, and sediment adsorbed materials into receiving water bodies. USES studies in Murrells Inlet, South Carolina have detected inorganic pesticide residues and heavy metals, fecal coliform bacteria, and concentrations of nitrogen and phosphorus compounds and polycyclic aromatic hydrocarbons (PAH) that are substantially higher than concentrations observed in more pristine areas. Urban development and the elimination of wetland areas which improve stream water quality by trapping pollutants (Reddy *et al*. 1989) are suspected to be responsible for the accumulation of nutrients and pollutants in receiving estuarine waters.

Storm water runoff volumes, flow rates, and sediment loads from a forested watershed and an urbanized watershed were compared using the distributed parameter (grid cell) Agricultural Non-point Source Runoff (AGNPS) model. The comparisons were based on ten simulated rainfall events. Effects of impervious surfaces on runoff and sediment transport were also investigated with the model. The 38 ha forested watershed, representing undeveloped land in coastal South Carolina, was covered with mixed second-growth hardwoods and pines with interspersed cypress wetlands. The urbanized watershed was 15 ha of single-family residential and commercial land

and included a four-lane interstate highway segment. Both watersheds had sandy soils and low stream bed slopes (<0.5%). The hydrologic submodel was calibrated with ten rain events ranging from 19 - 102 mm total rainfall. Simulation results indicated runoff volume was on average 5.5x (±2.7) and sediment yield 5.5x (±2.3) greater from the urban watershed than from the forested watershed. The ratio of rainfall volume to runoff volume was on average 14.5% higher in the urban watershed compared to the forested watershed. In the AGNPS model, runoff volumes were governed by the total impervious area and were independent of other impervious surface spatial characteristics (size, shape, location, contiguity). Simulation results indicated eroded sediment from both watersheds originated predominantly within the channels. Adding simulated impervious surface area increased runoff volumes linearly and peak flow rates exponentially. Flow rates and sediment loads were controlled by impervious surface spatial characteristics. Maximum sediment loads from the urban watershed occurred when disconnected patches of impervious surface covered 35% of the watershed. Maximum differences between the forested and urban watersheds occurred at low rainfall depths (<75 mm).

c. Needed Research: Current research has focused on small watersheds within both the North Inlet and Murrells Inlet study sites. Continuing efforts will focus on the collection of both topographic and bathymetric data as well as runoff data for the entire Murrells Inlet estuary required to implement the model for the entire estuary. In addition a three-dimensional model of the estuary will be developed using a combination of standard surveying techniques, GPS and geostatistical methods.

9. Upland/wetland interface alterations are associated with the loss of vegetated wetland buffers.

a. Recommendation: Marsh-upland interfaces separated by bulkheads and sea walls are characterized by a lack of a vegetated transition zone between estuarine creeks and developed uplands. Bulkheading aids in the offsite transport of toxic chemical contaminants, both organic and inorganic. *Minimize or eliminate the use of hard erosion control devices within residential developments while encouraging the use of wetland buffers for erosion control. Existing bulkheads should be removed and remediated with Spartina marsh.*

b. Background and Previous Findings: Low altitude, 1:6,000-scale, color infrared photography of the North Inlet and Murrells Inlet estuaries during leaf-off conditions was acquired to be used as source data for vegetation mapping. Individual 9.5 x 9.5 inch frames were registered to 1:4,800 scale base maps of both Murrells Inlet and North Inlet. Coupled with extensive vegetation ground surveys of grids and selected points, the photographs were manually interpreted and digitized to create GIS data layers representing wetland vegetation associations. Land-use data layers for the upland areas of both study sites were developed using a combination of the 1:6,000-scale photography and 1:40,000-scale color infrared photography collected as part of the National Aerial Photography Program. Upland land use and wetland vegetation data layers were integrated for each site and spatial associations analyzed using GIS techniques.

Analysis of the vegetation GIS layers indicated the North Inlet salt marsh-estuarine system contains extensive stands of *Spartina alterniflora* that are bordered on terrestrial margins by a complex mixture of high marsh species, a scrub-shrub zone, and loblolly and longleaf pine forest. Composition of the salt marsh vegetation community varies across the elevation gradient from the creeks to the forest border. Tall-form *Spartina* borders the salt marsh creeks and may extend several meters inland. At slightly higher elevations (above MSL), medium-form *Spartina* dominates. With increasing elevation, the vegetation shifts to a monotypic short-form *Spartina* zone followed by mixed stands that include short-form *Spartina*, *Limonium carolinianum*, and *Salicornia*. Monotypic stands of *Salicornia* and *Juncus* generally occur at the highest salt marsh elevations. The high marsh community occupies a broad zone which can be on the order of 10's of meters wide. A narrow shrub zone (predominantly *Iva*) demarcates the transition between marsh and forest.

The Murrells Inlet salt marsh also contains extensive stands of *Spartina alterniflora*. Whereas the extensive high marsh zone in North Inlet consists of numerous plant species and a variety of shrub species, the high marsh zone in Murrells Inlet is very restricted or absent due to upland development and bulkheading, which extends to the edge of the *Spartina* marsh and typically define the marsh perimeter. *Juncus* and *Borrichia* may be present in a very narrow high marsh zone in developed portions of Murrells Inlet. The high marsh community in Murrells Inlet, when present, occupies a narrow band only a few meters wide, except at the southern end near Huntington Beach State Park where development is minimal.

10. Landscape alterations reduce estuarine fauna populations.

a. Recommendation: Populations of a major forage species, the grass shrimp (*Palaemonetes pugio*), are significantly reduced in urbanized estuaries. The causes appear to be cumulative including habitat loss, physicochemical changes and chronic contaminant stress. *Population levels of grass shrimp are being modeled against other variables and these models should be used to regulate the type and degree of development of similar urbanized estuaries.*

b. Background and Previous Findings: The grass shrimp, *Palaemonetes pugio*, is a common inhabitant of southeastern and Gulf coast estuaries of North America. These shrimp are a major force in accelerating the breakdown of detritus in the estuary (Welsh 1975) and are important dietary components for many commercially and recreationally important juvenile fin fish species (Wood 1967). Additionally, this species is highly sensitive to many chemical contaminants (Scott *et al*. 1990; 1992). In South Carolina estuaries, *P. pugio* occur year round at densities ranging from < 1000/50 m of stream in winter to 28,000/50 m of stream in summer. Grass shrimp may comprise 56% of the total macrofaunal stream density on an annual basis. Monitoring of grass shrimp populations to the impact of nonpoint source agricultural runoff indicated that significant impacts observed in field populations were highly correlated with impacts observed in field and laboratory toxicity tests (Scott *et al*. 1990; 1992).

To assess the impacts of urbanization grass shrimp, a multi-tiered approach was used which assessed impacts of urbanization in Murrells Inlet (MI) and at a pristine reference site, North Inlet (NI) and included: 1) block seining at one site in MI (MIF) and one site in NI (NIOL) for a 1.25 year period; 2) push net sampling at 6 sites in MI (MIF, TP, PS3, AC1, AC2 and OC6) and one site in NI (NIOL) monthly for a 3 year period; and 3) estuarine-wide sampling in MI (n=30 sites) and NI (n=30 sites) during the peak period of grass shrimp abundance (late July-early August) approximating an estuarine geographical gradient (inner=land-estuarine interface; mid=mid estuary; and outer estuarine-ocean interface). Adult and larval grass shrimp abundances, sex ratios and egg production/female at each site were correlated with physicochemical water quality and chemical contaminant levels in sediments at each site.

Results of block seining at one site in MI (MIF) and NI (NIOL) indicated that total macrofaunal biomass and density were significantly ($p < 0.05$) reduced in urbanized MI. The reduced population of one species, the grass shrimp, accounted for these observed differences in biomass and total abundance. There were no significant differences observed in commercially/recreationally important species of fin fish and shellfish with the exception of the penaied shrimp, *Penaeus aztecus* (reduced biomass and abundance in MI) and the blue crab, *Callinectes sapidus* (reduced juvenile densities in MI). These results suggested that grass shrimp abundances were reduced by 90% in urbanized MI when compared to the NI reference site.

Results of push net sampling at 6 sites in MI (MIF, TP, PS3, AC1, AC2 and OC6) and one site in NI (NIOL) monthly for a 3 year period confirmed that adult grass shrimp abundances were significantly ($p < 0.05$) reduced in MI by some 85%. These reduced adult grass shrimp abundances were significantly ($p < 0.05$) correlated ($r^2 = 0.93$) with salinity and sediment Polycyclic Aromatic Hydrocarbon (PAH) concentrations. Salinity and sediment PAH concentrations were inversely related in additional statistical testing, suggesting that high sediment PAH concentrations occurred in areas receiving large amounts of urban NPS runoff. Additionally, there were significant ($p < 0.05$) alterations in reproduction observed in gravid adult females grass shrimp (delayed egg production in young of the year females) which changed the ratio of overwintering:young of the year females from 50%:50% (1:1) to ratios of 93%:7% at highly contaminated urban sites. This effect on overwintering: young of the year gravid females ratio followed an increasing trend along a pollution gradient (from south to north in MI) and was highly correlated ($P < 0.01$; $r2=0.975$) with dissolved oxygen (inversely related), temperature and sediment PAHs levels. Also at some highly contaminated sites (MIF, TP) there were extremely skewed sex ratios with little to no gravid females observed in MI

Estuarine-wide sampling at 30 sites/estuary indicated that estuarine wide adult grass shrimp abundances were significantly ($p < 0.01$) reduced by 83%. GIS modeling and kriging further indicated that 85% of the estuarine surface area of NI has higher adult grass shrimp abundances that the highest grass shrimp abundance observed in MI, which was observed on the least developed southern end of MI. Spatial analysis further revealed that highest grass shrimp abundances in MI were found in the mid -estuarine stations away from major physical disturbances and pollution sources found at the inner and outer sites. In pristine NI, grass shrimp abundances increased in moving from the inner -> mid -> outer regions. Larval grass shrimp abundances were not significantly different in comparisons of NI and MI. This indicated that predation pressures in NI must be significantly higher than observed in MI. These findings suggest there is significant mortality as grass shrimp mature from larvae to adults. Laboratory toxicity test with model PAH concentrations in sediment can only explain a small portion of this effect. What may be a more likely explanation is that the increased disturbance of the physical environment due to boating and other urban activities, may enhance larval grass shrimp exposure to sediment sorbed contaminants.

c. Needed Research: We propose to complete additional sampling in the ACE Basin and Charleston Harbor watersheds to discern if impacts from coastal development in mixed urban and industrial areas, approximating a larger gradient of pollution in riverine estuaries, are similar to impacts observed in non-riverine high salinity estuaries such as Murrells Inlet. Another interesting aspect of this work will be to better understand grass shrimp abundances in large rivers and small tidal creeks of a pristine riverine estuary such as the ACE Basin relative to North Inlet, since both sites are NOAA NERRS sites. Additional analysis of data will be conducted to use multivariate statistics to identify impacts associated with urbanization.

11. Regulatory permitted activities lead to cumulative wetlands impact.

a. Recommendation: When viewed individually, permitted activities associated with residential development (e.g. docks) do not result in detrimental direct impacts which merit permit denial, but the cumulative impacts (primary and secondary) of existing and proposed activities may result in detrimental impacts. *Evaluate potential cumulative impacts of permitted activities when evaluating permit requests and encourage the use of community amenities (e.g. community docks)*.

b. Background and Previous Findings: Accelerated coastal development and the continued influx of people into the coastal zone of South Carolina have increased the pressures on coastal wetlands (Vernberg *et al*. 1992). These continuing pressures threaten salt marsh estuaries, which are sensitive to commercial, industrial, and residential activities as well as physiographic changes brought on by tides, winds, and storms. In view of this, the need was evident for a procedure to estimate the overall spatial and temporal impacts of these alterations to coastal wetlands using currently available data and knowledge (United States Environmental Protection Agency 1988; Kiraly *et al*. 1990). A GIS model for cumulative impact assessment was developed that accounted for both physiographic-induced changes as well as physical alterations to wetlands as permitted under state and federal regulatory permitting programs (Porter *et al.* 1995; 1997).

This approach to environmental assessment was dependent upon a landscape model utilizing land use and regulatory permit data to analyze the impact of physiographic forces and urbanization on localized Southeastern estuaries. Land cover data layers representing conditions in 1983 and 1989 were analyzed using GIS overlay techniques to determine the extent and magnitude of change in acreage of wetlands in both North Inlet and Murrells Inlet. Based on work by Jensen *et al*. (1993) and Porter (1995), front beach areas seaward of the primary sand dunes were excluded from the analyses to minimize potential impacts of tidal stage on photointerpretation of land cover. Using a 45 acre (18.2 ha) grid overlay (Field *et al*. 1990), the results of a paired comparison t-test showed that the mean acreage of wetlands in 1983 was not significantly different ($p > 0.05$) than the mean acreage of wetlands in 1989 for the North Inlet study site. The results of a paired comparison t-test of change in mean acreage of wetlands in Murrells Inlet between 1983 and 1989 suggested there was a difference ($p \leq 0.05$). Both parametric and nonparametric statistical tests were performed to determine whether the Murrells Inlet site experienced a greater rate of wetlands change than the relatively pristine North Inlet site. The results of the inter-site comparisons showed ($p < 0.05$) that the rate of wetlands alteration was greater in the Murrells Inlet estuary than the North Inlet estuary.

Physiographic forces were considered the prime agent of land cover change in North Inlet since no activities requiring permit approval for the alteration of wetlands took place in the study area between 1983 and 1989. A regression model of physiographic alteration was developed from the analysis of change in the distribution and quantity of the wetlands, open water, and uplands composing North Inlet between 1983 and 1989. The model results were subjected to an analysis to determine the strength of the relationship between actual wetlands acreage in 1989 and predicted acreage in 1989 resulting in a significant r^2 of 0.974.

When applied to Murrells Inlet, the model of physiographic alteration only accounted for 44.9% of the measured change in wetlands acreage between 1983 and 1989. When the estimated impact of the 150 wetlands altering activities approved by the United States Army Corps of Engineers (USACOE) and South Carolina Department of Health and Environmental Control's Office of Ocean and Coastal Resource Management (SCDHEC-OCRM) were input as model parameters, the cumulative impact assessment model accounted for nearly 95.0% of the measured wetlands alterations in Murrells Inlet between 1983 and 1989. The model results were subjected to an analysis to determine the strength of the relationship between actual wetlands acreage in 1989 and predicted acreage in 1989 resulting in a significant r^2 of 0.970 (Porter 1995).

c. Needed Research: This effort has shown how GIS, when combined with appropriate data and professional knowledge, can be used to assess the impact to localized coastal ecosystems of physiographic forces and regulatory permitted activities associated with coastal development. The efforts of this research were not without identified limitations. This modeling effort attempted to define a very complex environmental concern, wetlands loss, as a simple model. Two factors, one statistical and one physical, were not incorporated into the original model and will be addressed as research issues during FY97/98. Spatial autocorrelation, or the extent to which adjacent activities influence overall spatial patterns, will be in assessing the statistical significance of both intra- and inter-site variability in wetlands loss. Second, the original work focused only on the physical alteration of wetlands. During the upcoming year, and in conjunction with a NASA/EPSCoR project, the health (as measured by biomass and productivity) of *S. alterniflora* wetlands in Murrells Inlet will be evaluated as a function of proximity to residential and light commercial development and the regulatory permitted activities associated with these land-use types.

12. *Perkinsus marinus* represents a primary obstacle for the restoration of natural oyster populations and cultivation of this commercially valuable species. Improving our understanding of this oyster pathogen and the impacts of urbanization is critical.

a. Recommendation: Perkinsus marinus is prevalent in South Carolina populations (Burrell *et al*. 1984, Crosby and Roberts 1990), but its status is not well known. Because the South Carolina oyster industry is relatively small and the oyster population appears to be relatively healthy, no one has made significant efforts to monitor this oyster pathogen. *As a result, there is* *a unique need to improve our understanding of this oyster pathogen and the impacts of human activities.*

b. Background and Previous Findings: Oysters are a keystone species in many coastal ecosystems. Along the southeastern Atlantic coast of the United States they form extensive intertidal reefs which increase biological diversity by providing a unique habitat for a multitude of other organisms (Bahr and Lanier 1981). Perhaps more importantly, they also function as biological filters which can influence trophic structure and nutrient cycling throughout estuarine ecosystems (Ulanowicz and Tuttle 1992). Perkinsus marinus is an important protozoan parasite in coastal ecosystems because it is a major pathogen of the eastern oyster, its primary host. Epizootics can kill massive numbers of oysters which significantly alters ecosystem function, not to mention the loss of an important recreational and commercial fishery. Existing management strategies that are designed to protect oysters from this parasite (Andrews and Ray 1988) have failed. The failure of these management strategies is evident from the continued decline of oyster populations in the once dominant Chesapeake Bay oyster fishery and the recent expansion the parasite's geographic range (Ford 1996).

During the past two years, researchers have been monitoring the spatial and temporal cycles of *P. marinus* infections in oysters within the undisturbed North Inlet estuary. Interestingly, patterns of prevalence and intensity are similar to those observed elsewhere, but unlike other areas, intensities remain below levels that cause widespread oyster mortality. Spatially, we are able to identify "hot" spots of infections (relatively speaking), some that are persistent while others are ephemeral. Still other areas consistently maintain low levels of infections. Looking at our time series for a North Inlet site only, 1995 shows a typical seasonal pattern with infection intensity tracking temperature, but 1996 does not. In 1995, there was a peak in September of about 3.5, but there was no pattern in 1996 which only showed intensities slightly above 2.0 in 2 of 12 months—the intensities bounce around as a result of sampling error which can be due to the inaccuracy of the assay at low infection intensities. The low level of infections in 1996 is probably due to the excessive rainfall.

The preliminary spatial data collected at 31 and 30 sites in North Inlet and Murrells Inlet beginning in the summer of 1996 is even more interesting. The September data really did not show any patterns. The December data shows patterns in both inlets, but they appear to be related to different processes. In NI, intensities remain low, but the highest levels are in the middle of Town and Jones creek, where water tends to slosh back and forth between the inlet and mud bay instead of flushing out as it does from the other creeks. Intensities were much higher in MI with most sampling sites having moderate to heavy infections (almost all are 3's and 4's on a scale of 0 to 5) except the state park (Oaks Creek) where infections are light (2 or less). This preliminary spatial pattern matches the patterns of residential and light commercial development perfectly with the higher infections start just about where the first sewage input begins.

c. Needed Research: In most South Carolina estuaries, oysters have not been over harvested and healthy populations remain despite high prevalences of *P. marinus*. In developed areas, local oystermen and recreational harvesters complain of declining oyster populations and the SC DNR regularly plants oysters or shell to enhance oyster settlement in these areas. Preliminary data indicate that *P. marinus* intensities are higher in developed areas compared to undeveloped areas. By comparing the status and patterns of *P. marinus* infections in Murrells Inlet and North Inlet, on both temporal and spatial scales, we will gain a better understanding of (1) the natural processes which keep this host-parasite relationship under control and (2) the extent that anthropogenic impacts shift the balance of this relationship to the demise of the oyster population. With this goal in mind our objectives are to identify the temporal and spatial patterns of *P. marinus* in these two inlets and subsequently correlate the patterns with data already being collected on physical, chemical and biological characteristics, including the impacts of human development.

Ten oysters will continue to be sampled from each of 30 sites throughout North Inlet and 31 sites throughout Murrells Inlet on a quarterly basis (June, September, December, March). Temperature and salinity determined at the time of collection. Each oyster will be processed to determine *P. marinus* infection intensity using standard fluid thioglycollate incubations of tissues and read on a compound microscope. Resulting data will be incorporated as a data layer into the USES database. Both standard geostatistical techniques as well as kriging, a spatio-statistical technique used to develop continuos surfaces from point data, will be used to assess intra- and intersite spatial and temporal variability of *P. marinus*. A GIS analysis will also be used to identify potential relationships between land-use practices and the distribution of *P. marinus*.

Methods for Dissemination of Scientific Findings and Management Recommendations

Within the research and academic communities, traditional routes for the dissemination of scientific findings are 1.) publications in refereed journals, proceedings of scientific workshops, and books; and 2.) presentations at scientific meetings. To date, the USES Project has lead to over 125 publications, presentations, and published abstracts which have highlighted efforts to better understand the impacts of urbanization on localized coastal estuaries and the role of technology in assessing and modeling estuarine ecosystems (Appendix A). This project has also supported the professional development of over 30 graduate and undergraduate students studying the roles of biology, chemistry, economics, environmental health sciences, geography, geology, marine science and statistics in coastal zone management (Appendix B).

In addition to traditional routes for information dissemination within the scientific community, the USES Project has recognized that for a variety of reasons (most often available time and cost) coastal resource managers are often unable to keep abreast of current scientific literature or attend scientific meetings. This is especially true among local (i.e. town and municipal governments) resource managers. In an effort to make our scientific findings and management recommendations available to this wider audience, the USES Project has also sponsored or co-sponsored several symposia/workshops targeting not only state and federal but also local coastal resource managers.

<u>First USES Symposium on Sustainable Development in the Southeastern Coastal Zone</u> was an interdisciplinary symposium dealing with the complex problems resulting from the ever-increasing development of the southeastern coastal region. The symposium was held in Myrtle Beach, SC in March of 1993. Approximately 100 persons representing regional, state and federal

agencies as well as colleges and universities attended the four-day event. The focus of the symposium was to examine the influence of rapid population growth on the dynamic interaction between both resource management policy at the federal, state, regional, and local level and the findings of environmental impact studies. This interdisciplinary approach was taken with a view to development of a basis for sustainable development concepts. Resultant from the symposium was a volume containing 26 papers grouped under the major headings of Policy, Development and the Environment, Urbanization Effects on Southeastern Estuaries: Case Studies, and Symposium Summary (Appendix C).

The Shellfish Restoration Workshop sponsored by the USES Project, the Charleston Harbor Project, and the Interstate Shellfish Sanitation Conference, SC Department of Health and Environment Control, and SC Department of Natural Resources brought 88 experts from 17 coastal states and Canada together for a two day meeting to discuss the needs for shellfish restoration in the southeastern US. The first day of the workshop was plenary session involving speakers addressing issues dealing with water quality/public health, resource and habitat restoration around the US including the Gulf of Mexico, northeastern, southeastern, mid-Atlantic and west coast regions of the US. The second day of the workshop, participants spent in three theme areas, breakout groups addressing issues dealing with 1) public health/water quality, 2.) resource restoration, and 3.) habitat restoration.

The International Shellfish Restoration Conference was held at Hilton Head Island, SC in November, 1996. This three-day symposium addressed a variety of issues ranging from oyster disease to innovative methods for restoring shellfish habitat and harvestability around the world. Participants from foreign countries and the US were represented and presented poster and platform talks in three general theme areas: 1.) public health, 2.) resource restoration, and 3.) habitat restoration. A general consensus statement from the conference will be forthcoming which will capture the current state of knowledge and science in dealing with shellfish restoration around the world was conducted at the conclusion of the workshop. Significant findings of the conference include the following.

* There is no central database on the amount of shellfish habitat loss in the southeastern US, although there are more than 6,000 permit/year to potentially alter/modify wetlands in the southeastern U.S.

* Public Health/Water Quality Restoration issues due to increased urbanization will drive future shellfish restoration initiatives in the southeastern US rather than resource or habitat issues.

* There is a clear need to tie shellfish resource and habitat research issues to public health/water quality shellfish restoration research needs, so that a long term database on shellfish production and habitat may be initiated for the southeastern US which is linked with contaminant and land-use/habitat modification data.

* There is a need for the molluscan shellfish industry to better organize themselves in the southeastern U.S. and to do a better job of risk communication to the public. There is particularly a need for the shellfish industry to begin to make the transition from hunter-gather

mode to hatchery based (aquaculture) technology and to effectively communicate aquaculture issues to the public.

* The conference suggested a need to begin to develop long term research and planning for shellfish restoration issues on a watershed basis for the southeastern US South Atlantic Bight region.

* Education of the public to shellfish restoration issues is important in better communicating with an environmentally conscious and literate public on issues dealing with public health/water quality, aquaculture and other resource issues, and the importance of shellfish habitat and its linkup with protection of submerged aquatic vegetation habitat.

* Results of the USES study have clearly indicated the potential for adverse effects of urbanization on bacterial water quality and molluscan shellfish populations. These findings clearly indicated that increased urbanization will result in additional closure of shellfish harvesting areas and concomitant adverse effects on molluscan shellfish health. The Restoration Workshop provides a mechanism to develop a research plan for future research to better manage impacts from urbanization on bacterial water quality, shellfish population health and shellfish habitat quality.

During the upcoming year, the USES Project has plans to support an additional symposia of local and regional significance.

<u>Second USES Symposium on Sustainable Development in the Southeastern Coastal Zone</u> is tentatively planned for the Spring of 1998. This symposium will be designed to bring together local and leading persons involved in coastal and environmental information management and to exchange ideas regarding proposed management recommendations. It will provide an opportunity to highlight models for coastal ecosystem assessment and management which incorporate land-use practices and integrated toxicological and Geographic Information Processing approaches. Locally, it will provide an opportunity for those responsible for managing our coastal resources to see available management tools, data, and recommendations that can help in the region. Resultant will be a second volume representing the proceedings of this symposium.

In addition to the above referenced efforts, the USES Project and associated researchers have supported new research and management initiatives in the Southeast. The Land Use-Coastal Ecosystem Study (LU-CES) is aimed at understanding how alterations in land-use patterns expected to accrue over the coming decade from rapid demographic change and population growth in the southeastern US will affect living coastal marine resources. The USES program has made significant contributions to the conceptual development of LU-CES and, as a result of the interaction between the two programs, the scope and breadth of each has been broadened. The benefits that are predicted for both programs and to the southeastern region in general as a function of the cross cultivation of ideas and resources between programs demonstrate that the whole can be greater than the sum of the parts. Thus, the development of the LU-CES concept, the synthesis of data and the planned approach will have been enhanced by the understanding of how urbanization affects southeastern estuaries that has been gained from years of USES research. Similarly, the regional contact afforded through LU-CES, opportunities for synthesis and for comparative research will augment the USES effort.

USES has strongly supported the conceptual development of LU-CES and has helped to ensure the success of several important activities within the program. Contributions from USES enhanced the production of the original LU-CES concept document, and facilitated (1) meetings of the LU-CES Coordinating Committee (LCC), a group of eight highly respected academics from diverse disciplines who guide the conceptual development and planning of the program, (2) a joint meeting of the Program Management Team and The Users' Panel in Savannah and (3) a workshop in Savannah in June 1996, to permit the research community the opportunity to provide input to the program and to more clearly frame its goals and objectives.

The workshop provided the opportunity to describe the LU-CES conceptual framework to the research community and to place that framework into an historical context with the classical regional work of Odum in ecology, Pomeroy in microbiology and the Vernbergs in estuarine research. Current trends in southeastern coastal science were brought up to date by descriptions of current LMER studies and other efforts to understand riverine and pulsed ecosystem dynamics in Georgia estuaries and coastal waters, by summaries of ongoing studies by SCDNR and NMFS on South Carolina's tidal creek ecosystems and the effects of urbanization on them, and by studies of human demographic patterns in Georgia and South Carolina. Finally, an overview of the USES program was presented which summarized the impacts of urbanization to high-salinity estuaries in South Carolina. Working groups, led by LCC members provided input to the development of a research agenda by focusing on impacts associated with land use and hydrosystem modifications as perceived at four disciplinary levels -- natural science, social science, policy and data management. Synthesis provided by LU-CES program management and the LCC has focused the program on the salt marsh-tidal creek complex and on the processes associated with land-use patterns that can impact resources in these systems.

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Appendix A.
USES-supported Publications, Presentations and Published Abstracts

Aelion, C.M.

Publications

Aelion, C.M., J.N. Shaw and M. Wahl. In press. Impact of suburbanization on groundwater quality and denitrification in coastal aquifer sediments. *Journal of Experimental Marine Biology and Ecology*.

Presentations

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

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.

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Raj, P. and C.M. Aelion. 1995. Denitrification in coastal freshwater stream sediments. *Abstracts*, 13th International Conference, Estuarine Research Federation, Corpus Christi, TX.

Blood, E.R.

Publications

Blood, E.R., P. Anderson, P.A. Smith, K.A. Ginsberg, and C. Nybro. 1991. The effects of Hurricane Hugo on coastal soil processes. *Biotropica* 23(4): 348-355.

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Chandler, G.T.

Publications

Chandler, G.T. and A.S. Green. In press. A 14-day harpacticoid copepod reproduction bioassay for laboratory and field-contaminated muddy sediments. In *Techniques in Aquatic Toxicology.* G. Orstrander (ed.). Lewis Publ., Inc. Boca Raton, FL.

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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.

Presentations

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. 9th International Meiofauna Conference, Perpignan, France.

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, 14th SETAC Conference Special Session on the NOAA Coastal Ocean Program.

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^{th} SETAC Conference Special Session on Wetland Contamination Issues, Mike Lewis, Program Chair, USEPA - Gulf Breeze.

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Fortner, A.R., M. Sanders and S.W. Lemire. 1997. Polynuclear aromatic hydrocarbon and trace metal burdens in sediment and the oyster, *Crassostrea virginica* Gmelin, from two high-salinity estuaries in South Carolina. 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.

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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.

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Fulton, M.

Publications

Fulton, M., G. Scott, A. Fortner, T. Bidleman and B. Ngabe. 1993. The effects of urbanization on small high-salinity estuaries of the southeastern United States. *Arch. Env. Toxicol.* 25:476-484.

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DiPinto, L.M., M.H. Fulton and G.T. Chandler. 1995. Trophic-transfer of a sediment-associated organophosphate pesticide from meiofauna to fish. 16th Annual Society of Environmental Toxicology and Chemistry Conference, Vancouver, Canada.

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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.

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DiPinto, L.M., M.H. Fulton and G.T. Chandler. 1995. Trophic-transfer of a sediment-associated organophosphate pesticide from meiofauna to fish. 16th Annual Society of Environmental Toxicology and Chemistry Conference, Vancouver, Canada.

Gardner, L.R.

Publications

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Weinstein, J.E.

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Appendix B:
Human Resources 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.

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.

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Smith, P. 1992. *The effects of urbanization on spatial and temporal nutrient distributions in two southeastern estuaries*. Columbia, SC: University of South Carolina. 142 p.

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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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Appendix C:

Symposium Volume Table of Contents

Appendix D:

Budget