The South Atlantic Bight

Land Use - Coastal Ecosystem Study (LU-CES)
The State of Knowledge on Issues Pertinent to the Program Mission

A Synthesis

G.S. Kleppel and M.R. DeVoe

LU-CES Program
c/o South Carolina Sea Grant Consortium
287 Meeting Street
Charleston, South Carolina 29401

November 1, 1999

Purpose

The purpose of this report is to provide a synthesis of the results of the first year of research by the LU-CES program. During this year, the current understanding of certain key issues pertinent to the mission (see below) was examined in a series of eight State of Knowledge (SOK) studies. A synopsis of each SOK report is presented in this document. A synopsis or summary, however, differs from a synthesis. The latter is a bringing together of parts to create a "whole". The synthesis that is presented here represents a bringing together of the results of the SOK studies, of meetings and conversations with PI's, the Program Management Team and the User Panel, and of communications with individual members of each group. The goal of this document is to provide guidance for the development of new research projects within LU-CES.

The LU-CES Mission

The overall goal of the LU-CES Program as stated in the concept document is "to develop science-based, predictive decision making models (tools) that integrate changes in land use patterns with effects on hydrodynamics, transport processes and ecosystem function to assist in planning for sustainable coastal land use and resource management."

LU-CES is a multi-disciplinary effort that seeks an interface between two disciplines -- marine and landscape ecology – to provide knowledge and tools for resource management and policy development. The LU-CES research effort seeks to gain a mechanistic understanding of how changes in land use patterns in the Southeast will impact coastal ecosystems. The LU-CES program goes beyond this objective, however, by seeking to produce "process models" that can be coupled with land use information within a GIS framework to address the Program mission. The product, models that predict the outcomes of specified scenarios, will allow users from the management community, particularly at the local level, to gain insights into the potential impacts of specific land use patterns to the salt marsh-tidal creek ecosystems that characterize the estuaries of the southeastern United States.

During the past year, the Program has supported a series of eight "State of Knowledge" (SOK) Studies on key scientific, modeling and data management issues associated with the LU-CES mission. The text of each report is available on the LU-CES web site (http://inlet.geol.sc.edu/luces2/luces/LUCES_1.HTML). Individual SOK reports can be obtained from the LU-CES Program Office:

The Land Use – Coastal Ecosystems Study
c/o SC Sea Grant Consortium
287 Meeting Street
Charleston, SC 29401

Meetings of LU-CES SOK investigators were held in November 1997 and 1998. The first meeting focused on clarifying the LU-CES mission and the on relationship of the PI's to that mission prior to the initiation of SOK research. The aim of the second meeting was to clarify specific findings presented in the SOK reports. A meeting of the LU-CES Program Management Team and Users' Panel was convened in January 1999 to begin developing guidelines for the "Field-Year 1" RFP. We also solicited the input of potential users of LU-CES data products from the management and public sectors to more clearly frame the technical needs of the management community and to identify mechanisms of information transfer from the scientific to the user communities.

Relationship of the LU-CES Program to Resource Management Issues

In 1970, US Census data indicated that population densities in substantial portions of the Southeastern United States were lower than two individuals per square mile. Currently, in-migration to the region is among the highest in the country, and this trend is expected to accelerate in the future. Resource managers and leaders of non-governmental organizations (NGOs; e.g., conservation groups) recognize several major challenges to coastal ecosystem integrity and its management during and following this period of unprecedented growth. The mission of LU-CES is to develop science-based tools (models) that will allow resource managers to address these issues. In most cases scientific research and resource management are different activities. Thus, it has never been the intent of the LU-CES program to respond to the immediate, day-to-day needs of managers; such a goal is intractable. Instead, LU-CES will address more realistic and achievable goals that link science with management. Such goals necessarily focus on larger questions and major or overarching issues.

According to resource managers and land use planners in Georgia and South Carolina the key issues during the next two decades include the following:

> **1.Urbanization** of naturally vegetated land and land that is currently used for silvaculture or agriculture will lead to substantial increases in impervious surfaces along the coast and in upland watersheds. Among the consequences of such changes in land use will be the alteration of mechanisms by which the landscape handles contaminants. The consequences of such changes in land use to the integrity of coastal ecosystems are poorly understood.

> **2. Management of surface and ground water resources** including management of storm water, allocation, contaminant control and pollution abatement are crucial to the maintenance of water quality and ecosystem integrity. The distribution and chemical composition of ground waters are not well known. Nor are the physical, chemical and biotic mechanisms by which contaminants, nutrients and other constituents are transported to and processed within coastal ecosystems clearly understood.

3. During the next two decades Georgia and South Carolina will experience **population growth rates** that are unprecedented in the region. Much of that growth will occur in environmentally constrained coastal areas. There is currently little guidance on how to minimize the environmental impact while maximizing the economic gain associated with that growth.

4. Most decisions regarding development and growth are made on the basis of public mandate or constituency. A clear understanding of the issues associated with land use change is lacking within a large portion of the public sector. **Education and outreach** are crucial to ensure enlightened land use decisions and wise coastal resource management.

Summaries of Individual SOK Reports

In this section we present a brief summary of each of the eight SOK reports. In the next section, we present a summary of the results of the SOK effort as a whole.

LU-CES State of Knowledge Report on Physical Oceanography

J. Blanton and T. Gross

Particle transport and fate in the estuaries of South Carolina and Georgia are strongly influenced by the interaction between two circulation components: regional, high-energy tidal circulation and density-driven circulation related to freshwater discharge. The details of this interaction are largely unknown in salt marsh and tidal creek ecosystems. Small asymmetries in the large scale transport are responsible for the net tidal fluxes of material. These asymmetries are difficult to estimate. Emphasis for LU-CES needs to be on developing a 3-dimensional model of the salt budget that is sufficiently detailed to capture the complexities of circulation in these ecosystems. The model must be supported by observations. It is most important to determine how changes in the hydrological cycle affect salt transport, hydrodynamic communication and materials exchanges between marshes and estuaries.

Indicators of Trends Toward Coastal Eutrophication

H.L. Windom, H.N. McKellar, Jr., C.R. Alexander, Jr.
Craig, A. Abusam and M. Alford

This report assessed the extent to which data on water column nutrient levels and sediment indicators of eutrophication are available for use in modeling nonpoint and point source loading to coastal ecosystems. Several data bases were searched to assess the geographical extent of time series capable of addressing the land use - coastal ecosystem impacts questions of LU-CES. Such information is needed to enable the eventual prediction of coastal eutrophication as a function of land use. Few of the data sets from Georgia and South Carolina that were searched were adequate for model development. Of the data sets that encompassed an adequate time span, spatial resolution was often severely limited, and vice versa. Sites where adequate data exist include the Savannah, Cooper and Ogeechee Rivers. Mass balance/nutrient flux modeling proved useful for defining the spatial and temporal variability in nutrient dynamics and for quantifying the magnitude of point and nonpoint source inputs. Measurements of selected tracers in sediment cores from Georgia rivers appear to provide an historical record of eutrophication. Trends toward and away from eutrophication can be detected in long term water column monitoring data and in the sediment record when the sediment record is relatively undisturbed. In heavily urbanized, hydrologically modified estuaries, nutrient inputs are dominated by local point sources. Trends toward or away from eutrophication are controlled by local wastewater management decisions rather than by land use change. An articulate expression of land use will be required to identify the relationship between land use and coastal eutrophication. The LU-CES mission on eutrophication will be best addressed by focusing on less developed estuaries, at least initially.

State of Knowledge of Respiratory Processes and Net Productivity of Intertidal Marshes of South Carolina and Georgia

Cai, W.- J. and L. Pomeroy

Respiratory processes and net productivity are metabolic parameters that reflect community to ecosystem scale responses to environmental variability in coastal salt marshes. These complex variables are affected by numerous factors, which in turn may influence many aspects of the chemical and biological environments of the estuary. In order to predict human impacts on salt marshes and tidal creek ecosystems, it will be necessary to understand the fundamental processes that drive salt marsh metabolism. Anthropogenic activities associated with urbanization include eutrophication, and the modification of river flow patterns and estuarine geomorphometry. The consequences of such activities include harmful algal blooms, hypoxic events and other phenomena that are linked to salt marsh metabolism. Fluxes of CO_2 and O_2 between marsh, water and atmosphere are relatively easy to estimate and provide a “measure of system status” including susceptibility to low oxygen events and the action of the estuary as a source or sink for organic matter and inorganic nutrients. The authors recommend management and preservation of existing data. They also suggest that data bases incorporate land-use parameters, that the Satilla, Cooper, Altamaha and the Savannah Rivers be the focal points of the LU-CES field study, that the research be interdisciplinary and that observational and modeling research be well integrated and incorporate remote sensing. Finally, it is recommended that questions be appropriate to the level of funding.

The Influence of Land use Groundwater Derived Nutrients and Organic Inputs to the South Atlantic Bight

S.B. Joye, W.-J. Cai, D.A. Bronk, W.S. Moore

Coastal waters are highly fertilized ecosystems. Concern about nutrient and organic contaminant loading to coastal waters is increasing because loading is increasing. The contribution of groundwater to coastal eutophication is largely unknown and the impacts to coastal ecosystems from nutrients loaded via the groundwater are likely to differ from surface water impacts. More information on groundwater distributions and impacts on nutrient fluxes is available for South Carolina than for Georgia. Recommendations of the report include: (1) establish a baseline on nutrient concentrations and fluxes; (2) identify sources of nutrients and organic matter to quantify links between groundwater and land use; (3) assess the bioavailability of organic and inorganic nutrients from groundwater to coastal phytoplankton; (4) evaluate the abilities of aquifer microbes to alter the forms and concentrations of nutrients prior to delivery to coastal environments; (5) merge source and availability data with groundwater flux estimates to assess the contribution of groundwater to coastal eutrophication; (5) develop a mechanistic model relating groundwater nutrient loading to land use in coastal environments.

Microbial Indicators and Phytoplankton and Bacterial Communities as Evidence of Contamination Caused by Changing Land Use Patterns

M. Fletcher, P.G. Verity, M.E. Frischer, K.A. Maruya and G.I. Scott

This report addresses several topics – microbial indicators, phytoplankton and microbial communities and novel techniques and technologies -- into a single document. Unlike other monitoring parameters, long term data sets for certain indicators of bacterial contamination of estuaries do exist for South Carolina and Georgia estuaries. These data sets allow one to identify trends in sewage contamination and to differentiate development trends in the two states (e.g., in SC, fecal coliform levels are declining and are lower than in GA, where secondary treatment is not yet fully implemented in the coastal zone). Currently, there is a need to distinguish agricultural, urban and natural (i.e., wild life) fecal coliform sources. The review supports the hypothesis that microorganisms are fundamental indicators of ecosystem status and, hence, are useful in detecting functional shifts in ecosystem function as a result of human activities. Technologies exist to use microorganisms and microbial communities for bioassessment of specific land-use impacts on estuaries and salt marshes, but in most cases they will require further development to be fully applicable.

Cultural eutrophication is a clear result of land development. Theoretical and mesocosm studies indicate that changes in nutrient concentrations and ratios result in coincident changes in phytoplankton community structure, frequently producing undesirable communities, and having negative impacts. The nutrient environments in the estuaries of South Carolina and Georgia appear to be changing as a result of land development and urbanization. Nutrient concentrations and ratios and concomitant estuarine productivity are clearly altered in Georgia (the data have not been completely analyzed in South Carolina). Models and mesocosm studies suggest that continued change in the nutrient environment may have significant consequences.

Recommendations include: (1) develop more fully the technology to differentiate human and animal bacterial contamination derived from alternative land uses; (2) monitor eutrophication effects by developing long-term programs focused on heterotrophic bacterial abundance and proportionalities; (3) expand current studies in North and Murrells Inlets and Wassaw Sound to include research on chemical contaminants; (4) utilize certain microbial indicator organisms and microbial communities to detect the impacts of changing land use patterns; (5) develop a better understanding of how land-use and other factors affect variability in microbial and phytoplankton communities; (6) focus attention on further development of promising molecular approaches for profiling microbial community structure and establishing their relationship to specific land uses; and (7) work with regulatory agencies to help mitigate human impacts. To address these recommendations it is suggested that (1) long term microbial data collection be folded into existing monitoring programs and (2) fundamental relationships between microbial communities, specific contaminants and specific land use patterns be defined.

Biogeochemical Processes and Toxicant Impacts from Land Uses Affecting the "Head of Tide" in the South Atlantic Bight

T.J. Shaw and G.T. Chandler

Numerous studies have documented the distribution of contaminants in estuaries. Considerably less research, however, has sought to characterize the processes that regulate the form, fate, persistence and bioavailability of potentially toxic metals and synthetic organic compounds in estuaries. This report focuses on the physicochemical processes that regulate the behaviors of potentially toxic contaminants at the "head of tide" region of riverine estuaries. This region is likely to be one of importance to the LU-CES program because critical and readily detectable geochemical and biochemical activities tend to occur at the head of tide. In many cases the head of tide region represents a location at which contaminants transported from point and non-point sources, at levels too low to cause acute impacts, are concentrated; effects in biological community structure, genetics, and population density become discernible.

Fine sediments are among the principal vectors affecting contaminant transport to the head of tide region. Chronic impacts are determined largely by the physical processes that govern sediment trapping and accumulation. Toxicity often depends upon phase associations during transport and phase transitions after deposition. While transport and early phase-diagenesis studies are numerous in the literature, the relation of phase-diagenesis to contaminant exposure is not well studied. Phase is particularly important to the mobilization and bioavailability of relic contaminants (e.g., organochlorines, metals). Biological mediation of phase transitions, particularly in the sediments, has a significant influence on the mobility and impact of potentially toxic contaminants. Such phase transitions are expressed as alterations in redox and organic carbon dynamics.

Studies of how biologically-physically coupled activities affect contaminant phase, availability and toxicity are needed. Phase association, and the kinetics of partitioning are influenced by pore water and colloidal associations of contaminants. Studies of phase associations and phase exchange as related to feeding strategies, trophic transfer kinetics, persistence, residence time and toxicity will be among the key elements in developing a mechanistic understanding of the dynamics of toxic contaminants associated with various land uses and geomorphic scenarios.

Database Management and Environmental Modeling to Characterize Sources and Effects of Natural Parameters and Anthropogenic Contaminants in Coastal Ecostystems

D.E. Porter, T.C. Siewicki, J. Allen, D. Edwards and W.K. Michener

Database management (DBM) is crucial to the success of large, multidisciplinary projects, particularly with respect to the ability of potential users to apply the data products generated by the project to the solution of problems. Frequently, however, DBM is accorded minimal attention or neglected entirely by researchers. Poor researcher participation in DBM schemes may reflect concerns over data quality, ownership and availability. Poor participation also increases the risk that these concerns will be realized. To ameliorate these problems, a DBM scheme needs to be in place when the data collection program begins and researchers must be (a) required to participate in it and (b) be able to benefit from it. The first step in developing a DBM strategy is to conduct a User Needs Assessment. This is followed by development of data protocols that reflect the identified needs and concerns of users, identification of common software formatting and metadata procedures, development of QA/QC procedures and the design of an information hub. Among the guidelines suggested for a LU-CES DBM strategy, investigators need to submit a data management plan, be trained in appropriate software and metadata development procedures (consistent with FGDC guidance), have first-use of their data yet provide their data to a data hub on a timely basis, and be credited for data contributions to the program.

Numerous models exist and the current trend is to link these to explain complex environmental processes. There is a need within LU-CES to seek linkage between upland and estuarine dynamics models and to seek consensus among users on model development and application. Recent trends suggest that Geographical Information Processing (GIP) will become increasingly important in model development and application. The linking of models and GIP techniques will increase the need for efficient DBM and is already creating a need for improved statistics and methods for examining results.

State of Knowledge on GIS Databases and Land Use/Land Cover Patterns: South Carolina

D. J. Cowen, J.R. Jensen and M. Hodgson

The documentation of land use is prerequisite for determining human impacts on coastal ecosystems, and is, therefore, a key component of the LU-CES program. The ability to obtain high quality land use data is critical to the overall success of the project. Current land use patterns must be interpreted from historical patterns, and updated periodically. The land use data that will be employed in the program must be able to support complex spatial models. Further, they must be of sufficient resolution to support local planning activities. There must be wall-to-wall spatial coverage in the study area and classification categories should be mutually exclusive and non-overlapping. The findings of this report are that: (1) Land use descriptions engendered by LU-CES must be consistent with those of the Federal Geographic Data Committee (FGDC); (2) Land use is a more complex measurement than land cover and careful selection of land use categories is crucial to the success of the program; (3) While GIS software is relatively flexible and user friendly with regard to data structure, spatial and attribute resolution (i.e., data source-dependent attributes) may be troubling and should be evaluated early in the program; (4) The kind of source data used (i.e., land ownership records, manually interpreted aerial photographs or automatically classified remotely sensed satellite data) will determine the spatial and categorical (i.e., the quality and) resolution of the data base available to the GIS; (5) It is not feasible to assemble a parcel-scale GIS database for all coastal counties in the LU-CES study area (C-CAP and similar federally supported, remotely sensed data sources will not be adequate to meet the needs of LU-CES); (6) The most reasonable alternative for describing land use with the resolution necessary for LU-CES is 1:40,000 scale color IR aerial photography collected by the National Aerial Photography Program (NAPP) every 5 years. NAPP overflight years are 1998 for Georgia and 1999 for South Carolina. These data are expensive to collect and interpret. It is suggested that land use data specifications for the LU-CES program be reevaluated within the context of resolution and accuracy needs. A feasibility study should be undertaken to determine the extent to which various existing databases can meet the land use needs of the LU-CES program.

Summary of Findings of SOK Effort: Common Themes

Several themes seem common to the SOK reports.

1. There is considerable information about the concentrations and distributions of nutrients and contaminants in the estuaries and watersheds of South Carolina and Georgia. However, the processes that regulate these distributions or their impacts in coastal ecosystems are poorly understood. Inasmuch as most contaminants in coastal ecosystems occur as a function of particular activities on land, the relationship between land use and contamination is poorly understood. Furthermore, many of the existing data sets are temporally or spatially constrained. That is, data may be temporally extensive but limited to one or a few stations. Conversely, data may be

spatially extensive (many stations or much of the coast) but data acquisition may be confined to a narrow time window or a small sample size. Such data sets are subject to time/space aliasing and will be difficult to relate quantitatively to land use patterns. These constraints obviate a robust correlative analysis. Instead, the mechanisms that govern the associations between changing land use patterns and the integrity of coastal ecosystems will need to be characterized and evaluated for their broader predictive power.

2. Coastal ecosystems in South Carolina and Georgia are influenced by one of the most energetic tidal regimes on the eastern seaboard. Tidal and buoyancy driven processes dominate the circulation patterns of the region's estuaries. However, small, poorly understood, asymmetries in transport actually determine the net fluxes of materials. Models that seem capable of resolving local circulation patterns within salt marsh and tidal creek systems are accessible without major investment in software development. Information on freshwater inputs from groundwater is an important, but largely missing, element in the knowledge-base.

3. Variability in organic and inorganic nutrient and carbon loading influences estuarine "metabolism" and the structure of microbial and phytoplankton communities. Changes in land use patterns appear to be altering the amounts of, and proportionalities (i.e., N:P:Si ratios) among major phytoplankton nutrients in estuaries. The susceptibility of the region's coastal ecosystems to eutrophication and possibly harmful algal blooms (HABs) has been suggested in several SOKs. There are clear links between eutrophication and harmful algal blooms in other southeastern coastal areas, such as the Neuse River, NC. Nutrient concentrations and proportionalities in the estuaries of South Carolina and Georgia seem to be changing in a direction that may favor HABs.

4. Identification of human sewage contamination in estuaries has been based largely on microbial indicators, particularly fecal coliforms. Several techniques, including pulsed gel electrophoresis, ribotyping, fatty acid analysis and multiple-antibiotic resistance, are beginning to provide the means for discriminating between fecal coliform bacteria from human and various non-human sources. A growing data set suggests that much of the fecal coliform contamination in estuaries may be attributable to sources other than human sewage (e.g., wildlife, livestock). Given the appropriate development effort, several source-specific coliform analyses and a number of other source-specific bacterial assays (Table 1) may provide a suite of sensitive "microbial indicators" of specific land uses.

5. The influence of potentially toxic contaminants (Table 2) on living resources in salt marsh and tidal creek ecosystems depends ultimately upon the phase relationships and associations between toxicants and sediments, as well as on the chemical characteristics of dissolved and colloidal substances in the water column. Particular contaminants and binding phases may be definitive of particular land uses. During transport from source regions to salt marshes, toxicant associations with particulates,

colloids and dissolved molecules, as well as environmental conditions (e.g., pH, UV insolation), influence the form, fate (e.g., sediment, water column) and bioavailability of the toxicants in the ecosystem.

6. The ability to create a high resolution, mechanistic understanding of the relationships between land use and coastal resources will require wall-to-wall remotely sensed and ground-truthed determination of land use at the parcel level. Such a goal is unattainable on a regional scale at current funding levels. However, regional coverage at the mosaic scale, with localized, high-resolution coverage at one or a few specific target locations, appears feasible.

7. LU-CES requires that two kinds of data bases be merged: (1) Mosaic-to-local scale land use data; and (2) Mechanistic descriptions of processes (process models) that describe and predict impacts by land use-specific activities or contaminants on salt marsh and tidal creek ecosystems. To accomplish this, a GIS must be created with (1) existing land use/land cover databases (in part with data bases maintained by local municipal planning organizations [MPOs]) and (2) a variety of remote platforms. A set of process models will be overlayed onto the GIS foundation. These models will describe the mechanisms by which markers for specific land uses are transported to salt marshes and their fates and effects therein. Among the models required are:

    a. 3-D circulation within specific salt marshes and tidal creeks,

Table 1. Alternative microbial indicators. Source: Fletcher et al. (1998)

INDICATOR	CONTAMINANT	COMMENTS	KEY REFERENCE
Clostridium perfringens 1997	Fecal Pollution	Long time scale Monitoring	Edberg et al.,
Enterococcus	Fecal Pollution	Persistance greater than *E. coli*	Edberg et al., 1997
Streptococcus bovis	Fecal Pollution	Farm Animals	Jagals, 1997
Rhodococcus coprophilus	Animal Fecal Pollution	High Specificity for Animal Source Material	Jagals et al., 1995
Sorbitol-fermenting-bifidobacteria Grabow,	Human Fecal Pollution	High Specificity for Human Source Material	Jagals and 1996
Bacteroides fragilis phages	Remote Fecal Pollution	Persistence, model Virus	Lucena et al., 1996
Coliphages	Fecal Pollution	Persistence	Borrego et al., 1990
Staphylococcus aureus	Fecal Pollution	Pathogen	Ashbolt et al., 1993
Campylobacters	Fecal Pollution	Pathogen	Ashbolt et al., 1993
Pseudomonas spp	Fecal Pollution	Human Pathogen	Milner and Goulder,
	Eutrophication	Specific contaminants	1985 (many others)
Pseudomonas aeruginosa	Urban Runoff	Human Pathogen	Guimaraes et al.,1993
Soil Bacteria	Soil Contamination	Indigenous soil specific	Madsen et al., 1992
(*Bacillus mycoides*, *Myxococcus xanthus* *Chromobacterium violaceum*)	(erosion)	bacteria	
Aeromonas spp. Kator,	Eutrophication	Human Pathogen (Not Effective)	Rhodes and 1994
Heterotrophic Bacteria 1997	Eutrophication	Ubiquitous	Sabrilli et al.,
Pseudomonas putida 1997	Chemical Pollution	Indigenous organism (not effective)	Lemke et al.,
Acinetobacter spp. 1997	Chemical Pollution	Indigenous Organism calcoaceticus)	Lemke et al.,
Burkholderia cepacia 1997	Chemical Pollution	Indigenous organism (not effective)	Lemke et al.,
Purple Nonsulfur Bacteria	Chemical Pollution	Indigenous organism	Sinha and Banerjee, 1997
Luminecent Bacteria	Chemical Pollution	Indigenous organism	Ramaiah and Chandramohan, 1993

Table 2. Trace metal and organic analytes analyzed in recent GA-SC studies. Source: Fletcher et al. (1998).

Analyte	USES[1]	SC Tidal Creek[2]	Savannah River[3]	Turtle/Brunswick[4]
Aluminum (Al)		Y	Y	
Antimony (Sb)			Y	
Arsenic (As)	Y	Y	Y	Y
Cadmium (Cd)	Y	Y	Y	Y
Chromium (Cr)	Y	Y	Y	Y
Copper (Cu)	Y	Y	Y	Y
Iron (Fe)		Y	Y	
Lead (Pb)	Y	Y	Y	Y
Manganese (Mn)		Y	Y	
Mercury (Hg)	Y	Y	Y	Y
Nickel (Ni)	Y	Y	Y	Y
Selenium (Se)		Y	Y	
Silver (Ag)	Y	Y	Y	Y
Tin (Sn)		Y	Y	
Zinc (Zn)	Y	Y	Y	Y
PAHs	Y	Y	Y	
PCBs	Y	Y	Y	Y
DDTs	Y	Y	Y	Y
Chlordanes	Y	Y	Y	Y
Endosulfans				
Aldrin-Dieldrin-Endrin		Y	Y	
HCHs[5]		Y	Y	
Toxaphene				Y
Organotins (TBT)			Y	

[1] Fortner et al. (1997)
[2] SCDNR/NOAA/NMFS (1996)
[3] Alexander et al. (1997)
[4] Kannan et al. (1997); Maruya and Lee (1998); Maruya (unpublished data)
[5] HCHs -- hexachlorocyclohexanes (including lindane)

b. mass balance and residence time relationships for NPS's and PS's of nutrients, bacteria and synthetic organic and metallic contaminants,
c. rates and processes governing contaminant phase and bioavailability

Meetings with the LU-CES Program Management Team and the Management-User Panel emphasized the need to create data products that can address specific needs without becoming limited to a few current issues of short term or ephemeral significance. Although beyond the scope of the current program, it is believed that ultimately LU-CES data products may be adaptable to problems as specific as:

Development of design criteria for ecological buffers
Determination of the processes that control the impacts of impervious surfaces in watersheds
Identification of sensitive lands for conservation and areas for growth-inducing infrastructure
Development of regional development criteria based on a mechanistic understanding of landscape-scale environmental forcing parameters

It has become apparent from these meetings that the LU-CES Program has the capability to create prototypic tools for use by planners and policy makers that will contribute to land use decision making on a variety of space and time scales. One of the principal tools envisaged is a process model that estimates fates and effects of contaminants introduced to a generic southeastern salt marsh as a function of transport through a watershed or subwatershed. The model might then be overlayed onto the land use database of a specific MPO and tuned and validated for that geographic location.

Synthesis of observations

Based on current projections, the Carolinas and Georgia will experience some of the highest rates of population growth in the coterminous United States during the next 25 years (Culliton et al. 1991; DeVoe and Kleppel 1995). The majority of this growth will occur along the coast and will be associated with an in-migration of retirees, estimated to represent some 14% of the post WWII baby-boom generation (Campell et al. 1998). While silvaculture is expected to remain the principal industry in the Southeast during this period of time, retirement and tourist-oriented businesses will dramatically increase the economic investment and level of development within the region. As a result of this in-migration and development, significant changes will occur in the ways that land is used. Recent studies suggest that urbanization will have major impacts on infrastructure (BCD-COG et al. 1998) and environmental quality (SCDNR/NOAA/NMFS 1996; Kucklick et al. 1997).

The LU-CES State of Knowledge (SOK) reports examined some of the key research issues pertinent to the Program mission of understanding the impacts of sustained, rapid changes in land use patterns on living marine resources and on the integrity of ecosystems in coastal South Carolina and Georgia. Among the factors that emerged from the SOK analysis as critical to the success of LU-CES are *scale* and *process*. These factors influence significantly the relationships between land use patterns, salt marsh and tidal creek ecosystem function, and the transport, fates and effects of contaminants within these systems.

The SOK reports emphasize that urbanization is linked to estuarine eutrophication in much of South Carolina and Georgia with significant implications to regional water quality, biotic processes (e.g., fisheries production, harmful algal blooms, bio-invasions) and ecosystem metabolism (e.g., hypoxia and anoxia). In addition, there are crucial links between the chemistries of the aquatic and terrestrial environments through which contaminants pass and their fates and effects within estuaries, salt marshes and tidal creeks. The SOK reports identify several kinds of contaminants that may prove useful as "markers" for specific land uses (Table 3).

In addition to clarifying trends in coastal processes and creating a conceptual framework within which to understand land use–coastal ecosystem interactions, the SOK reports establish boundaries on the scope of the Program. It is clear that existing data for nutrient and contaminant loading are constrained spatially and temporally, and cannot be used in the correlative mode to predict impacts. It is also clear that groundwater hydrology, which influences both the estuarine salt-balance and contaminant transport, is poorly understood.

It was previously established that LU-CES field activities are constrained by funding to the region below the head of tide in riverine systems. Further, regional parcel-level resolution is unattainable and even site-specific information is time-limited (5 years for NAPP). However, LU-CES can and will address questions at the land-use mosaic (10 x 10 m^2 30 x 30 m^2) scale descriptively. The availability of ground truth data (e.g., GIS land use and infrastructure maps) is important for verifying remotely sensed land use patterns. Higher resolution analysis may be feasible at one or two carefully selected sites with the following characteristics:

1. Site has an historic record of geo-referenced NAPP data.
2. Land use and infrastructure data currently exist in a GIS (through some MPO).
3. Site is currently undeveloped, but trends suggest that development will occur.
4. Site contains salt marsh and tidal creek ecosystems.
5. Monitoring data (meteorology, tides, bacteria, nutrients, ground water) exist.
6. Watershed is relatively pristine, but considered for development.

Table 3. Some land use indicators.

Indicator	Application	Reference
Uranium, ^{210}Pb, ^{137}Cs, dissolved Si	cultural eutrophication	Windom et al. 1998
E. coli analyses: pulsed gel electrophoresis, ribotyping, fatty acid composition, multiple antibiotic resistance	distinguish human from other animal wastes; can distinguish domestic, farm and wild animal fecal coliform	Fletcher et al. 1998
Specific bacteriophages	certain bacteriophages attack bacteria specific to human sources (e.g., sorbitol-fermenting bifidobacteria	Fletcher et al. 1998
Specific microbial taxa	urban runoff, eutrophication, chemical contaminants	Fletcher et al. 1998
Luminescent bacteria	toxic contaminants	Fletcher et al. 1998
Phytoplankton composition	nutrient distributions	Fletcher et al.
O_2/CO_2	estuary metabolism	Cai and Pomeroy 1998
Dissolved DIN, DON, DIC, DOC, CH_4, CO_2, N_2O in aquifer	potential for eutrophication; discriminate surface from ground water inputs; possibly discriminate agricultural from domestic nutrient sources	Joye et al. 1998
Veterinary pharmaceuticals	agriculture	Shaw and Chandler 1998
Metal phase; organic C/fulvic and humic acids	discriminate forested, agricultural and urban inputs	Shaw and Chandler 1998
PAHs	particular forms associated with urbanization	Kucklick et al. 1997
Specific pesticides	differentiate agriculture from suburban land use	G. Scott pers. comm.

The LU-CES paradigm encompasses a continuum in time and space from the microscale (≤ min and ≤cm) to the mesoscale (days – seasons and 100-1000 km). The project will relate land use patterns occurring within watersheds and drainage basins to processes that may be occurring between molecules to predict impacts and implications to the integrity of salt marsh and tidal creek ecosystems. As a result, LU-CES has always been designed as a scale-integrating project. And although we cannot address all scales, we also cannot pretend that activities and processes occurring at one scale do not affect others, simply because we cannot afford to make measurements at those scales.

By scale integration we recognize the fractal character of natural systems. That is, events and processes occurring on one scale frequently affect events and processes at other scales, thereby creating connection between them. Although LU-CES cannot address the entire drainage basin scale in a detailed, quantitative manner, this scale must nonetheless be considered in a descriptive context, as part of a "land use mosaic", within which the LU-CES paradigm is anchored.

Existing remote sensing capabilities permit a coarse-scale (30x30 m^2 or 10x10 m^2) imaging of the land cover mosaic at relatively high frequencies (e.g., one or more regional scene/month), for a reasonable cost. When sufficient groundtruthing of the land cover mosaic exists, then land *uses* can be estimated (see BCD-COG et al. 1998).

The results of the SOK study support the initial premise of the concept document (DeVoe and Kleppel 1995) that, in order to develop the scientifically valid models needed to guide land use and resource management decisions, research must focus on the mechanisms by which activities associated with various land use patterns are translated into impacts in salt marsh and tidal creek ecosystems. A mechanistic (rather than a correlative) approach is mandated by the variety of factors that can influence the fates and effects of contaminants during transport to and residence within coastal ecosystems (cf. Shaw and Chandler 1998). In addition, spatial and temporal constraints on existing data sets (cf. Windom et al. 1998) obviate the correlative approach and mandate that a first principles or mechanistic approach be taken.

Perspectives on the research strategy

In order to address the issues with which LU-CES is concerned, one must be acutely aware of the time/space scales across which the paradigm is framed. One must determine the spatial dimensions of the landmass that impact a particular salt marsh - tidal creek system, i.e., the watershed or subwatershed. The watershed is composed of rivers, creeks and streams that drain the landcover/landuse mosaic within a particular topographic divide. It includes both surface and subterranean hydrosystem components. Field observations and experiments performed during LU-CES will focus on distributions and processes within salt marsh – tidal creek ecosystems. Virtually all of the work will be conducted below the head of tide. However, the availability of the descriptive land use mosaic within the watershed will facilitate the understanding of the distributions, fates and effects of "land use indicators", such as contaminants, within a particular salt marsh or set of tidal creeks that are the research sites.

The results of the LU-CES SOK study lead us to propose the following general strategic planning recommendations for the initial field year. The overarching strategy for the field work should involve "spatial scale integration". The elements of this strategy include:

- Identification of appropriate land use "indicators".
- Development of a set of basin-scale, land use mosaics prepared by combining ground truthed, remotely sensed land cover data and visual observations and GIS information on land use and infrastructure.
- Implementation of experiment protocols to determine the fates and effects of land use indicators in salt marsh and tidal creek ecosystems that drain different landscapes.

Among the landscape characteristics desirable for study:

Relatively undeveloped estuaries. The SOK reports suggest that nutrient and contaminant loading models will be easier to generate with data from an undeveloped site. The likelihood that development of the watershed draining into a particular salt marsh will begin during the research program is also appealing as it will permit investigators to monitor changes and possibly verify models at the test site.

Relatively few land uses in the drainage basin. The focus of much of the effort should be on defining the response to land uses that will dominate the region in the future. These include silvaculture, agriculture, residential and tourist-based urban, and upstream industrial development. The role of the region's rivers and tides as they influence transport and fate of contaminants in salt marsh and tidal creek ecosystems needs to be evaluated.

Dominance of a single land use in the basin. It is most realistic to attempt to generate process models for simple land use mosaics dominated by single uses.

Availability of high quality ground-truth data, preferably in GIS format for all or part of the region. Several municipal planning organizations currently have excellent data on roads, sewer and water lines and residential, commercial, industrial and institutional land use. These locations are appealing for study.

LU-CES is a multidisciplinary effort. The research team must be integrative and have the ability to generate and interpret remotely sensed and GIS-based land use mosaics. The group will require expertise in remote sensing, GIS, geology and hydrology, as well as in hydrodynamics, nutrient analysis, metals and synthetic organic chemicals analyses, ecotoxicology, organic and biochemistry, microbiology and ecology. Finally, a modeling and data management group will be required to complete the team.

References

Alexander,C., J. Ertel, R. Lee, B. Loganathan, J. Martin, R. Smith, S. Wakeham, and H. Windom. 1997. Pollution history of the Savannah estuary. NOAA Tech. Mem. NOS ORCA 115, Silver Spring, MD.

Ashbolt, N. J., C. S. Kueh, and G. S. Grohmann. 1993. Significance of specific bacterial pathogens in the assessment of polluted receiving water of Sydney, Australia. Wat. Sci. Technol. 27:449-452.

BCD-COG (Berkley, Charleston, Dorchester Counties – Council of Governments) et al. 1998. Urbanization patterns along the coasts of South Carolina and Georgia. Charleston, SC.

Blanton, J. and T. Gross. 1998. LU-CES state of knowledge report on physical oceanography. Land Use – Coastal Ecosystem Study, Charleston, SC.

Borrego, J. J., R. Cornax, M. A. Morinigo, E. Martinez-Manzanares, and P. Romero. 1990. Coliphages as an indicator of faecal pollution in water. Their survival and productive infectivity in natural aquatic environments. Wat. Res. 24:111-116.

Cai, W.-J. and L. Pomeroy. 1998. State of knowledge of respiratory processes and net productivity of intertidal marshes of South Carolina and Georgia. Land Use – Coastal Ecosystem Study, Charleston, SC.

Campell, P. 1998. Population projections, 1995 – 2025. Current Population Reports. Census Bureau, U.S. Department of Commerce, Washington, D.C.

Cowen, D.J., J.R. Jensen and M. Hodgson. 1998. State of knowledge on GIS databases and land use/land cover patterns: South Carolina. Land Use – Coastal Ecosystem Study, Charleston, SC.

Culliton, T.J., M.A. Warren, T.R. Goodspeed, D.G. Renner, C.M. Blackwell and J.J. McDonough III. 1990. Fifty years of population change along the nation's coast, 1960-2010. National Ocean Service, NOAA, Rockville, MD.

DeVoe, M.R. and G.S. Kleppel. 1995. The South Atlantic Bight Land Use – Coastal Ecosystem Study (LU-CES): Conceptual Framework. SC Sea Grant Consortium, Charleston, SC.

Edberg, S. C., H. LeClerc, and J. Robertson. 1997. Natural protection of spring and well drinking water against surface microbial contamination. II. Indicators and monitoring parameters for parasites. Crit. Rev. Microbiol. 23:179-206.

Fletcher, M., P.G. Verity, M.E. Frischer, K.A. Maruya and G.I. Scott. 1998. Microbial indicators of phytoplankton and bacterial communities as evidence of contamination caused by changing land use patterns. Land Use – Coastal Ecosystem Study, Charleston, SC.

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: Sustainable development in the southeastern coastal zone, Vol. 20. F.J. Vernberg, W.B. Vernberg, and T. Siewicki. (Eds). pp. 445-476. Univ. So. Carolina Press, Columbia, SC, Belle W. Baruch Library of Marine Science #20.

Guimaraes, V. F., M. A. V. Araujo, C. S. Leda, M. Hagler, and A. N. Hagler. 1993. *Pseudomonas aeruginosa* and other microbial indicators of pollution in fresh and marine waters of Rio de Janeiro, Brazil. Environ. Toxicol. Wat. Qual. 8:313-322.

Jagals, P. 1997. Stormwater runoff from typical developed and developing South African urban developments: definitely not for swimming. Wat. Sci. Tech. 35:133-140.

Jagals, P. and W. O. K. Grabow. 1996. An evaluation of sorbitol-fermenting bifidobacteria as specific indicators of human faecal pollution of environmental water. Water SA. 22:235-238.

Jagals, P. W. O. K. Grabow, and J. C. de Villiers. 1995. Evaluation of indicators for assessment of human and animal faecal pollution of surface run-off. Wat. Sci. Tech. 31:235-241.

Joye, S.B., W.-J. Cai, D. Bronk and W.S. Moore. 1998. The influence of land use on groundwater derived nutrients and organic inputs to the South Atlantic Bight. Land Use – Coastal Ecosystem Study, Charleston, SC.

Kannan, K., H. Nakata, R. Stafford, G.R. Masson, S. Tanabe, and J.P. Giesy. 1998. Bioaccumulation and toxic potential of extremely hydrophobic polychlorinated biphenyl congeners in biota collected at a Superfund site contaminated with Aroclor 1268. Environ. Sci. Technol. 32:1214-1221.

Kannan, K., H. Nakata, R. Stafford, G.R. Masson, S. Tanabe, and J.P. Giesy. 1998. Bioaccumulation and toxic potential of extremely hydrophobic polychlorinated biphenyl congeners in biota collected at a Superfund site contaminated with Aroclor 1268. Environ. Sci. Technol. 32:1214-1221.

Kucklick, J.R. S.K. Silvertsen, et al. 1997. Factors influencing polycyclic aromatic hydrocarbon distributions in South Carolina estuarine sediments. J. Exp. Mar. Biol. Ecol. 213:13-29.

Lemke, M. J., B. J. Brown, and L. G. Leff. 1997. The response of three bacterial populations to pollution in a stream. Microb. Ecol. 34:224-231.

Lucena, F., R. Araujo, and J. Jofre. 1996. Usefulness of bacteriophages infecting *Bacteroides fragilis* as index microorganisms of remote faecal pollution. Wat. Res. 30:2812-2816.

Madsen, E. L., A. Winding, K. Malachowsky, C. T. Thomas, and W. C. Ghiorse. 1992. Contrasts between subsurface microbial communities and their metabolic adaptation to polycyclic aromatic hydrocarbons at a forested and an urban coal-tar disposal site. Microbiol. Ecol. 24:199-213.

Maruya, K.A. and R.F. Lee. 1998. Aroclor 1268 and toxaphene in fish from a southeastern U.S. estuary. Environ. Sci. Technol. 32:1069-1075.

Milner, C. R. and R. Goulder. 1985. The abundance, heterotrophic activity and taxonomy of bacteria in a stream subject to pollution by chlorophenols, nitrophenols and phenoxyalkanoic acids. Water Research WATRAG 20:85-90.

Porter, D.E., T.C. Siewicki, J. Allen, D. Edwards and W.K. Michener. 1998. Database management and environmental modeling to characterize sources and effects of natural parameters and anthropogenic contaminants in coastal ecosystems. Land Use – Coastal Ecosystem Study, Charleston, SC.

Ramaiah, N. and D. Chandramohan. 1993. Ecological and laboratory studies on the role of luminous bacteria and their luminescence in coastal pollution surveillance. Mar. Pollution Bull. 26:190-201.

Rhodes, M. W. and H. Kator. 1994. Seasonal occurrence of mesophilic *Aeromonas* spp. as a function of biotype and water quality in temperate freshwater lakes. Wat. Res. 28:2241-2251.

Sabrilli, G., M. Cruscanti, M. Bucci, C. Gaggi, and E. Bacci. 1997. Marine heterotrophic bacteria as indicators in the quality assessment of coastal waters: introducing the “apparent bacterial concentration” approach. Environ. Toxicol. Chem. 16:135-139.

SCDNR/NOAA/NMFS. 1996. The tidal creek project – Interim report. Charleston, SC.

Shaw, T.J. and G.T. Chandler. 1998. Biogeochemical processes and toxicant impacts from land uses affecting the “head of tide” in the South Atlantic Bight. Land Use – Coastal Ecosystem Study, Charleston, SC.

Sinha, S. N. and R. D. Banerjee. 1997. Ecological role of thiosulfate and sulfide utilizing purple nonsulfur bacteria of a riverine ecosystem. FEMS Microbiol. Ecol. 24:211-220.

Windom, H.L., H.N. McKellar, Jr., C.R. Alexander, Jr,.Craig, A. Abusam and M. Alford. 1998. Indicators of trends toward coastal eutrophication. Land Use Coastal Ecosystem Study. Charleston, SC.