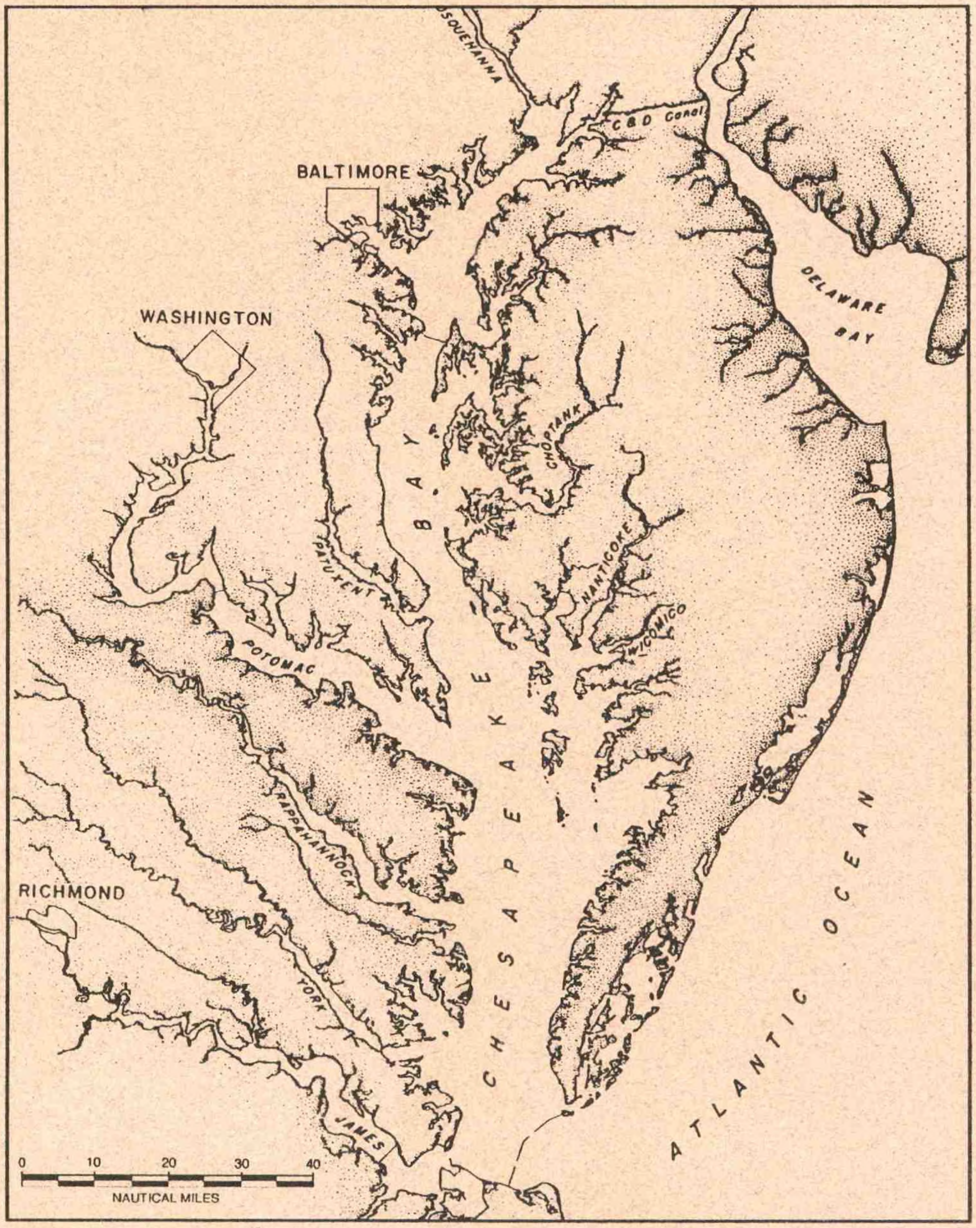
Maryland and Virginia Sea Grant College Programs

Environmental Effects Research on Chesapeake Bay

Toxics Research Program



Sea Grant
University of Maryland

Sea Grant
Virginia

Submitted to the
National Sea Grant College Program
National Oceanic and Atmospheric Administration

June 1999

June 28, 1999

Proposal to: The National Sea Grant College Program
NOAA, U. S. Department of Commerce

Submitted by: VIRGINIA GRADUATE MARINE SCIENCE CONSORTIUM
Virginia Sea Grant College Program
Madison House - 170 Rugby Road
University of Virginia
Charlottesville, VA 22903

Title: ***Chesapeake Bay Toxics Research Program: Virginia Portion for 2000***

Amount requested from Sea Grant: $208,000

Matching funds proposed: $ 1,461

Duration of proposed activity: 12 months

Proposed starting date: 1 January 2000

We, the undersigned, certify that, in the event this proposal is accepted, in whole or in part, our signatures on this proposal constitute acceptance of and compliance with statutes and regulations of the U. S. Government and the U. S. Department of Commerce as detailed in Part Three, "The National Sea Grant Program, Background and Suggestions for Proposals", dated March 1, 1972, and that pages 63 to 107 of that publication are incorporated by references as part of this proposal.

Principal Investigator

____
Signature

William L. Rickards, Director
Virginia Sea Grant College Program
Soc. Sec. No. 221-28-3691
Virginia Graduate Marine Science Consortium
Madison House
170 Rugby Road
University of Virginia
Charlottesville, VA 22903

Institutional Representative

____
Signature

Michael G. Glasgow, Jr.
Director of Sponsored Programs
Soc. Sec. No. 223-21-2883
Office of Sponsored Programs
P. O. Box 9003
Carruthers Hall
University of Virginia
Charlottesville, Virginia 22903

U. S. Department of Commerce
National Oceanic & Atmospheric Administration

ASSURANCE OF COMPLIANCE WITH THE NONDISCRIMINATION CLAUSE

Applicable to:

Title: ***Chesapeake Bay Toxics Research Program: Virginia Portion for 2000***

VIRGINIA GRADUATE MARINE SCIENCE CONSORTIUM
Virginia Sea Grant College Program
Madison House - 170 Rugby Road
University of Virginia,
Charlottesville, VA 22903

(1) hereby warrants, convents, agrees, and assures that it will conduct the program/project described by the above identified application/proposal, as it may be revised or modified prior to any grant award, in compliance with all requirements of the recipient imposed by or pursuant to the Nondiscrimination clause appended hereto, which clause shall also be incorporated into any grant awarded on the basis of such proposal, and

(2) agrees and acknowledges that this assurance of compliance is a prerequisite condition to approval of the proposed or any grant or grant modification or amendment extending any Federal financial assistance which may be in reliance on the representative made by this assurance and that the United States shall have the right to seek Judicial enforcement thereof, and that this assurance of compliance shall be binding upon it, its successors assignees, and transferees.

____________________ Date

____________________ Signature

Michael G. Glasgow, Jr.
Director of Sponsored Programs
Office of Sponsored Programs
P. O. Box 9003
Carruthers Hall
University of Virginia
Charlottesville, Virginia 22903

TITLE PAGE

Date of this Proposal:	June 28, 1999
A Proposal to:	Chesapeake Bay Environmental Effects Committee
Name and Address of Submitting Institution:	University of Maryland Center for Environmental Science Cambridge, Maryland 21613
Title:	Environmental Effects Research on Chesapeake Bay: Toxics Research Prgm
Total Amount Requested	$ 292,000 (Maryland)
Total Matching Funds Proposed:	$ 34,031 (Maryland)
Duration of Proposed Activity:	Twelve months
Proposed Starting Date:	January 1, 2000

Principal Investigator:

Signature: Dr. Jonathan G. Kramer
Interim Director, Maryland Sea Grant
Social Security Number:
016-40-4883

Signature: Dr. Jonathan G. Kramer
Interim Director, Maryland Sea Grant
Social Security Number:
016-40-4883

Signature: Dr. Donald F. Boesch
President,
University of Maryland Center for
Environmental Science
Social Security Number:

U.S. Department of Commerce
National Oceanic and
Atmospheric Administration

Sea Grant College Program

University of Maryland
Center for Environmental Science

(1)hereby warrants, covenants, agrees and assures that it will conduct the program/project described by the above-identified application/proposal, or as it may be revised or modified prior to any grant award or subsequent to any grant award in compliance with all requirements of the "recipient" imposed by or pursuant to the non-discrimination clause appended hereto, which clause shall also be incorporated into any grant awarded on the basis of such proposal and

(2)agrees and acknowledges that this assurance of compliance is a prerequisite condition to approval of the proposal or any grant modification or amendment extending and Federal financial assistance which may be extended to it by the U.S. Department of Commerce will be in reliance on the representation made by this assurance and that the United States shall have the right to seek judicial enforcement thereof, and that this assurance of compliance shall be binding upon it, its successors, assignees and transferees.

Date | Signature of official authorized to sign this assurance on behalf of the above-mentioned organization

Dr. Donald F. Boesch
President
University of Maryland Center for Environmental Science

*** SEA GRANT BUDGET ***

GRANTEE:
Virginia Graduate Marine Science Consortium

PROJECT NO: VIRGINIA TOTAL

PROJECT TITLE:
Chesapeake Bay Toxics Research Program:
Virginia Total

PROJECT STATUS: 2

PRINCIPAL INVESTIGATORS:

DURATION: 1/1/2000 - 12/31/2000

A: SALARIES AND WAGES	No. of Persons	Months	Sea Grant Funds	Grantee Funds
1. Senior Personnel				
a. Prin. Investigator	7	6.7	36,775	0
b. Associates	0	0	0	0
Subtotal	**7**	**6.7**	**36,775**	**0**
2. Other Personnel				
a. Professionals	1	1	4,000	0
b. Research Assoc.	0	0	0	0
c. RA Grad. Stud.	2	16	20,267	0
d. Prof. School Stud.	0	0	0	0
e. Pre-Bac. Stud.	0	0	0	0
f. Secret./Clerical	0	6	0	0
g. Technical/Shop	1	6	16,300	0
h. Hourly Labor	1	0	1,751	0
Total Salaries and Wages	**12**	**35.7**	**79,093**	**0**
B: FRINGE BENEFITS			15,545	0
Total Sal. Wages & Fringe Benefits (A+B)			**94,638**	**0**
C. PERMANENT EQUIPMENT			5,000	0
D. EXPENDABLE SUPPLIES			28,162	0
E. TRAVEL				
1. Domestic - US and Possessions			7,510	1,000
2. International			0	0
Total Travel			7,510	1,000
F. PUBLICATION AND DOCUMENTATION COSTS			3,501	0
G. OTHER COSTS				
1 Gas/Rental			350	0
2 Copying, library, communication			753	0
3 Tuition			11,022	0
4 Contractual			4,200	0
5 Repair/Maintenance			500	0
Total Other Costs			**16,825**	0
TOTAL DIRECT COSTS (A through G)			**155,636**	**1,000**
INDIRECT COSTS: On Campus:			51,351	461
On Campus:			1,013	0
TOTAL INDIRECT COSTS			**52,364**	**461**
TOTAL COSTS			**208,000**	**1,461**

*** SEA GRANT BUDGET ***

GRANTEE:
Virginia Graduate Marine Science Consortium
PROJECT TITLE:
Chesapeake Bay Toxics Research Program
Maryland Total

PROJECT NO: MARYLAND TOTAL

PROJECT STATUS: 2

PRINCIPAL INVESTIGATORS:
Ken Tenore, Joel Baker, Merrill Leffler, Thomas Miller, Guritno Roesijadi, Christopher Rowe

DURATION: 1/1/2000 - 12/31/2000

A: SALARIES AND WAGES	No. of Persons	Months	Sea Grant Funds	Grantee Funds
1. Senior Personnel				
a. Prin. Investigator	6	4.84	13,282	18,100
b. Associates	1	0.48	1,923	0
Subtotal	**7**	**5.32**	**15,205**	**18,100**
2. Other Personnel				
a. Professionals	1	0.48	1,539	0
b. Research Assoc.	2	16	34,000	0
c. RA Grad. Stud.	3	21.5	33,750	0
d. Prof. School Stud.	0	0	0	0
e. Pre-Bac. Stud.	0	0	0	0
f. Secret./Clerical	0	0	0	0
g. Technical/Shop	1	6	14,000	0
h. Hourly Labor	1	6	8,320	0
Total Salaries and Wages	**15**	**55.3**	**106,814**	**18,100**
B: FRINGE BENEFITS			33,690	5,698
Total Sal. Wages & Fringe Benefits (A+B)			**140,504**	**23,798**
C. PERMANENT EQUIPMENT			0	0
D. EXPENDABLE SUPPLIES			33,534	0
E. TRAVEL				
1. Domestic - US and Possessions			4,606	0
2. International			0	0
Total Travel			4,606	0
F. PUBLICATION AND DOCUMENTATION COSTS			2,300	0
G. OTHER COSTS				
1 Computer			200	0
2 Copying, library, communication			10,369	0
3 Miscellaneous			600	0
4 Subcontract			9,000	0
5 Tuition			8,280	0
Total Other Costs			28,449	0
TOTAL DIRECT COSTS (A through G)			**209,393**	**23,798**
INDIRECT COSTS: On Campus: 43% less subcontract, tuition			82,607	10,233
On Campus:			0	0
TOTAL INDIRECT COSTS			**82,607**	**10,233**
TOTAL COSTS			**292,000**	**34,031**

VIRGINIA SEA GRANT COLLEGE PROGRAM

CHESAPEAKE BAY ENVIRONMENTAL EFFECTS STUDIES

TOXICS RESEARCH PROGRAM

ACTIVITY BUDGET - 2000

	NOAA	MATCH
Marine Resources Development		
Pollution - Toxics	$208,000	$1,461
TOTAL	$208,000	$1,461

MARYLAND SEA GRANT COLLEGE PROGRAM

CHESAPEAKE BAY ENVIRONMENTAL EFFECTS STUDIES

TOXICS RESEARCH PROGRAM

ACTIVITY BUDGET - 2000

	NOAA	MATCH
Marine Resources Development		
Pollution - Toxics	$292,000	$34,031
TOTAL	$292,000	$34,031

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INTRODUCTION

CHESAPEAKE BAY ENVIRONMENTAL EFFECTS STUDIES: TOXICS RESEARCH PROGRAM

**Joint Maryland and
Virginia Sea Grant College Programs**

**Jonathan G. Kramer, Interim Director
Maryland Sea Grant College Program**

**William R. Callender, Assistant Director
Virginia Sea Grant College Program**

INTRODUCTION

The Chesapeake Bay Environmental Effects Committee (CBEEC) is a partnership of the NOAA Chesapeake Bay Office, the Maryland and Virginia Sea Grant Programs and EPA's Chesapeake Bay Program Office. CBEEC's mission is to fund research that will provide a scientific context for the sensible management of living resources in Chesapeake Bay that are affected by toxic substances. Since its inception, the research program has been overseen by CBEEC with research projects managed by the Maryland and Virginia Sea Grant College Programs. Congress has appropriated funds to the NOAA Chesapeake Bay Office to support this effort.

CBEEC's original research focus centered on the impacts of low dissolved oxygen on Chesapeake Bay fauna. In 1990, EPA's Chesapeake Bay Program Office joined CBEEC and helped initiate a new research program focused on how Chesapeake Bay ecosystem processes are affected by the transport, fate and effects of toxic substances. CBEEC has awarded over $5 million in grants for toxics research since 1991.

CBEEC BACKGROUND

In order to restore the productivity and ecological health of the Chesapeake Bay, the federal/state Chesapeake Bay restoration program has set as a goal the reduction of nutrients and of toxic substances in the estuary. Implementation of effective management strategies is basic to improvement of habitat for ecologically and economically important species and contributes to the many benefits associated with a properly functioning ecosystem. Such actions require a sound scientific basis, however, and many questions need to be addressed as to the impact of anthropogenic materials in the estuary.

To fill this information need, the National Oceanic and Atmospheric Administration (NOAA), through the Maryland and Virginia Sea Grant College Programs, began a major effort to address the issue of environmental effects due to low dissolved oxygen in the bay. This study, initiated in September 1985, has shed light on both the causes and consequences of hypoxia, and results of this research are now being used by state and federal management and regulatory agencies. Funding levels from NOAA averaged about $400,000 annually, transferred within NOAA's Estuarine Programs Office to be administered by the National Sea Grant Office (NSGO). In 1987, the Chesapeake Bay Environmental Effects Committee (CBEEC) was established by NOAA to oversee this research effort and to provide direction for future programs addressing other critical environmental problems. The committee includes representation from the Maryland and Virginia scientific and management communities.

NOAA was reorganized in 1989 and the EPO disbanded; many of its functions were folded into the new Coastal Oceans Program (COP). Currently, funding from NOAA is transferred from the National Marine Fisheries Service to NSGO and then to the state Sea Grant Programs. In 1990, the Environmental Protection Agency's (EPA) Chesapeake Bay Liaison Office, with approval from the Chesapeake Bay Toxics Subcommittee, joined the Environmental Effects research program by augmenting fiscal support with the stipulation that the Program be redirected from hypoxia to studies of toxic contaminants in Chesapeake Bay, an area where considerable information is needed to support planned management actions.

CBEEC recognized the need to address the issue of toxics and accepted the task of developing a cooperative long-range, multidisciplinary, multi-institutional research effort patterned after the Hypoxia Program. In so agreeing, the Committee noted that there were several continuing hypoxia projects which needed a final year's support. CBEEC further recommended that the initial focus of toxics research be on the ecological effects of contaminants, which complemented previous studies of hypoxia.

TOXICS RESEARCH PROGRAM

CBEEC has a unique role. It shares neither the monitoring obligations or the management goals (commitments) of the Chesapeake Bay Program and state agencies. CBEEC research is characterized by the use of innovative approaches to address scientific questions with clear resource management implications. Using "basic" scientific research to address key management issues has been, and will continue to be, a continuing trademark of CBEEC.

In 1998, CBEEC initiated the development of a five-year research plan to ensure that CBEEC-funded research is relevant to critical scientific questions and resource management needs. To formulate the plan, CBEEC supported a series of workshops focused on the three Regions of Concern, low-level exposure and a synthesis of overall CBEEC goals. As a result of the collective input from both the scientific and management communities during these workshops, CBEEC developed a five-year plan that provides a framework for refocusing and implementing the CBEEC Toxics Research Program. The plan outlines key changes in the structure of the research projects CBEEC will support, the extent to which these studies are coordinated, and the way that scientific data are organized and communicated. CBEEC identified one overarching programmatic goal in the plan. The goal is to develop a predictive understanding of the bioavailability and adverse effects of chemical contaminants on populations and communities of living resources in Chesapeake Bay.

CBEEC plans to accomplish this goal by supporting a single project that is multidisciplinary, substantively collaborative, and highly integrated in terms of data collection and interpretation (i.e., multiple PI's -- geochemists, toxicologists and ecologists, managers and outreach personnel working together within a defined administrative structure). Management input will be included in the project design from the outset to ensure that the results are relevant to and useful by resource managers. It may be appropriate to include managers as co-investigators.

CBEEC's five-year plan is available through the Maryland and Virginia Sea Grant Programs, and can be viewed on the CBEEC home page located at:
http://www.mdsg.umd.edu/CBEEC/index.html

1999 PLANNED PROJECTS

CBEEC will support two projects in 1999. The first project (R/CBT-35) is a renewal project in its third and final year. The second project described below (R/CBT-38) is a new project that directly addresses CBEEC's priorities identified in the five-year plan. Both projects are listed and briefly described below.

The complete project proposals and budgets for these projects appear elsewhere in this proposal package.

R/CBT-35 -- Transport and fate of sediment-associated polycyclic hydrocarbons and trace elements in the Elizabeth River.

The primary investigators for this project are Rebecca Dickhut, Carl Friedrichs, Steven Kuehl, John Brubaker, and Catherine Chisholm-Brause.

The main objectives of this project are to: determine sediment and contaminant (PAHs, metals) "hot spots", deposition zones, accumulation rates, and near surface residence times in the Elizabeth River; and, to determine the direction and magnitude of net transport of particles and associated contaminants in the Elizabeth River as a function of particle properties and hydrodynamic forcings. The results of this project will allow resource managers to make informed decisions with respect to no action, remediation, or dredging of contaminated sediments in the Elizabeth River.

This is a renewal project that was initiated in 1998. This is the third and final year of the project.

A progress report is included at the end of the original proposal text in the body of this CBEEC proposal package.

R/CBT-38 -- Chesapeake Ecotox Research Project (CERP): Quantifying Ecological Risks of Contaminated Sediments on Living Resources in Supporting Decisions on Habitat Restoration Strategies in the Chesapeake Bay.

The two coordinating Principal Investigators are Kenneth Tenore (Director, University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory) and Eugene Burreson (Director for Research and Advisory Services, College of William and Mary, Virginia Institute of Marine Sciences).

CBEEC research seeks to result in a better understanding of the effects of contaminants on living resources, and the extent to which results and conclusions impact management and stakeholders. Among the management questions and research needs that have been identified in CBEEC workshops, the issue that will be CBEEC's focused research priority at this time is "Sediment Contamination: Quantifying Ecological Risks to Support Habitat Restoration". The CERP project directly addresses this priority in 1999. This multi-disciplinary, multi-investigator project includes scientists and outreach specialists from Maryland and Virginia institutions.

The primary objectives of this project will be to: develop experimental mesocosm studies using surrogate species to quantify effects of contaminant exposure on organismal and population processes; develop predictive population models for application to management issues; and, provide a series of "outreach" workshops, conferences, and publication activities to insure informing and seeking feedback of our scientific findings from resource managers and other stakeholders.

This project is planned for a five-year duration, depending on funding availability, and will be critically evaluated on a yearly basis.

PROPOSAL REVIEW AND SELECTION PROCESS

The sequence of events for the proposal selection and review follows:

1997- 1998	A series of four workshops was held in 1998 and 1999 to obtain of the input from scientists and resource managers regarding what they thought should be the top priorities for toxics research in the Chesapeake Bay. The workshops focused on the Anacostia River, Baltimore Harbor, the Elizabeth River, the effects of low levels of contaminants.
September 1998	Draft Five-year Strategic Plan produced by CBEEC (based on input from the four workshops) and distributed to scientists, administrators, and resource managers throughout the Chesapeake area for review and comment.

December 1, 1998	Synthesis Workshop held to discuss review comments on CBEEC Five-year Strategic Plan.
December 18, 1998	Request For Proposals Issued by Virginia Sea Grant. The RFP was based directly on the CBEEC Five-year Strategic Plan.
March – April 1999	Peer review was overseen by Virginia Sea Grant. Two pre-proposals were received and distributed for peer review. Peer review consisted of written mail review comments from appropriate scientists (from outside of the Chesapeake region), written comments from resource managers representing Maryland, Virginia and the District of Columbia, and an *ad hoc* review panel of experts (again from outside of the Chesapeake region) assembled to discuss the merits of each pre-proposal. The *ad hoc* panel was convened to review the proposals and to recommend to CBEEC whether to encourage or discourage full proposals. The Panel identified one pre-proposal as being responsive to the RFP and the recommended that the team of investigators be encouraged to submit a full proposal. The Panel recommended unanimously that the other pre-proposal be discouraged from submitting a full proposal as it was clearly not responsive to the RFP.
April – June 1999	Peer review of full proposals was overseen by the Virginia Sea. One full proposal was received and distributed for review. Peer review consisted of written mail review comments from appropriate scientists and resource managers and an *ad hoc* review panel of experts assembled to discuss the merits of the proposal. All mail reviewers and panelists were selected from outside of the Chesapeake region. The majority of the *ad hoc* panelists were also members of the pre-proposal review panel. The *ad hoc* panel was convened to review all aspects of the proposal and was told to recommend to Virginia Sea Grant that the proposal either be rejected for funding, accepted for funding, or conditionally accepted with modifications. The Panel recommended the latter approach, and in fact, reduced the scope of work of the proposal by eliminating a section that it deemed unnecessary. The Panel recommended that the investigators submit an addendum to the proposal discussing the Panel's comments, prior to initiation of the work. Virginia Sea Grant concurred with the Panel recommendations.

*****SEA GRANT PROJECT RECORD FORM*****
I. PROJECT SUMMARY INFORMATION

SG-SID-No.:__________
Specialist:____________
SG Class:____________

INSTITUTION: Virginia Graduate Marine Science Consortium
ICODE: 5100
TITLE: Transport and Fate of Sediment-Associated Polycyclic Aromatic Hydrocarbons and Trace Elements in the Elizabeth River

PROJECT NUMBER: R/CBT-35
PROJECT STATUS: 1
SUB PROGRAM: Toxics/CBEEC
REVISION DATE: 6/10/97
INITIATION DATE: 1/1/98
COMPLETION DATE: 12/31/00

PRINCIPAL INVESTIGATOR: Rebecca Dickhut **EFFORT:** 0.8
ASSOCIATE INVESTIGATOR: Carl Friedrichs, Steven Kuehl, **EFFORT:** 0.8 each
John Brubaker and Catherine Chisholm-Brause
AFFILIATION: VIMS
AFFILIATION CODE: 5101
S.G. FUNDS: $81,000 **MATCHING FUNDS:** $0
LAST YEAR'S SG FUNDS: $180,749 **LAST YEAR'S MATCH FUNDS:** $0
PASS-THROUGH FUNDS: $ **LAST YEAR'S PASS-THROUGH:** $0
RELATED PROJECTS: All R/CBT Projects
PARENT PROJECTS:
SEA GRANT CLASSIFICATION: Pollution-other-toxics (45)
KEYWORDS: contaminants, sediment, deposition zones, accumulation rates, particle transport, Elizabeth River
OBJECTIVES: (1) Determine sediment and contaminant (PAH, trace metal) "hot spots", deposition zones, accumulation rates, and near surface residence times in the Elizabeth River. (2) Determine the direction and magnitude of net transport of particles and associated contaminants in the Elizabeth River, as a function of particle properties and hydroynamic forcings.
METHODOLOGY: We will conduct a geophysical survey and collect sediment grab samples to identify prospective coring locations and contaminant "hot spots", and a more extensive geochronological study to determine sediment and contaminant accumulation rates. We will also conduct intensive field experiments during spring and neap tidal cycles in both dry and wet seasons to evaluate particle and associated contaminant resuspension and transport in the vicinity of a previously identified "hot spot". Sediment cores and suspended particle samples will be analyzed for particle properties such as organic carbon and nitrogen content, as well as various PAHs and trace elements, including those on the Chesapeake Bay Toxics of Concern list. Finally, we will couple the sediment accumulation and particle transport mechanisms to provide an understanding of short and long term sediment and associated contaminant transport and deposition in the Elizabeth River.
RATIONALE: Many contaminants in aquatic systems tend to associate with fine grained sediments, thus the transport and fate of these particle-associated pollutants are dictated by the processes mediating sediment transport within an aquatic system. In highly channelized tidal environments such as the Elizabeth River, fine sediment and associated pollutant transport and fate will be governed predominantly by physical processes. Consequently, to understand and model the processes controlling contaminant transport from Elizabeth River sediments to the water column, and from historically contaminated areas to lesser or nonpolluted sites, we must quantitatively evaluate particle and associated contaminant resuspension and deposition in the estuary along with likely mechanisms for physical transport.

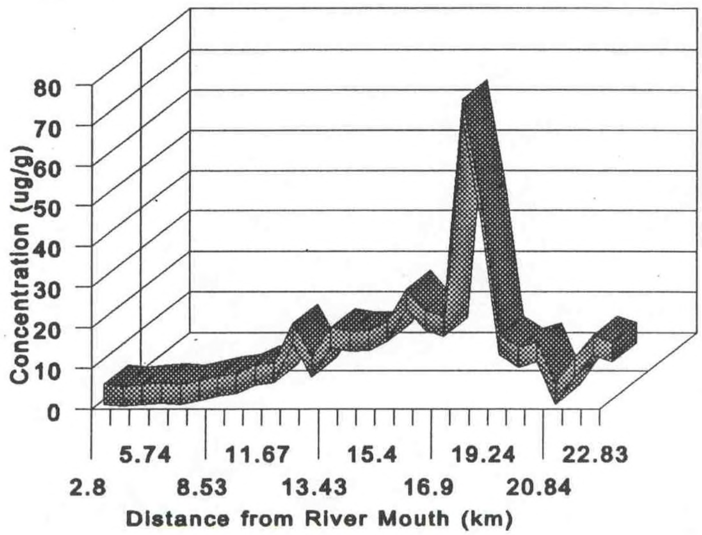
II. COMPLETION REPORT:

The first phase of this research addressed the following objective:

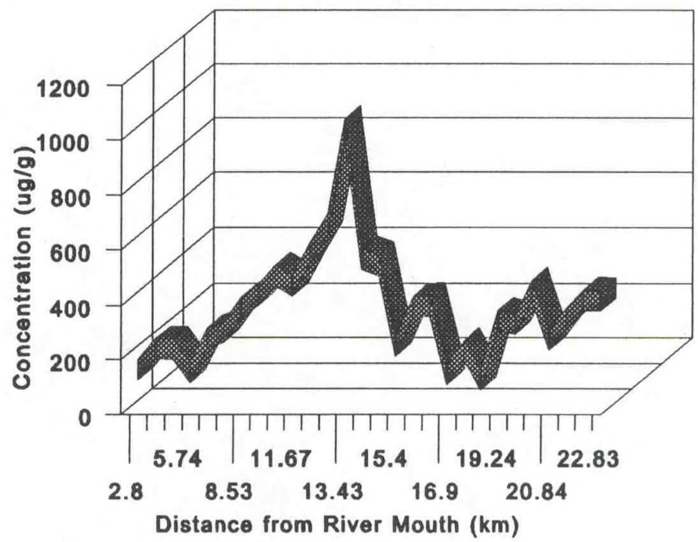
1. Determine sediment and contaminant (PAH, trace metals) "hot spots", deposition zones, accumulation rates, and near surface residence times in the Elizabeth River.

To determine contaminant "hot spots" and deposition zones in Elizabeth River sediments, a set of 50 surface sediment grab samples were collected in order to identify both the along-channel contaminant concentration gradients in the southern branch and main stem of the estuary, as well as shoal regions that may be contaminated due to adjacent industrial activities. These surface sediment samples were analyzed for a suite of 25 PAHs and 7 trace metals, as well as particle properties including grain size, organic carbon and nitrogen content, and surface area. Distinct peaks for both PAHs and trace metals were observed in channel sediments. These contaminant "hot spots" or deposition zones are located in the channel of the southern branch of the Elizabeth River, but are in different locations for metals versus PAHs. This result indicates that two distinct regions of contaminated sediments exist in the channel of the southern branch of the Elizabeth River, such that it will be necessary to consider these sediment pools separately when planning our particle transport experiments (described below), as well as designing remediation strategies for the river.

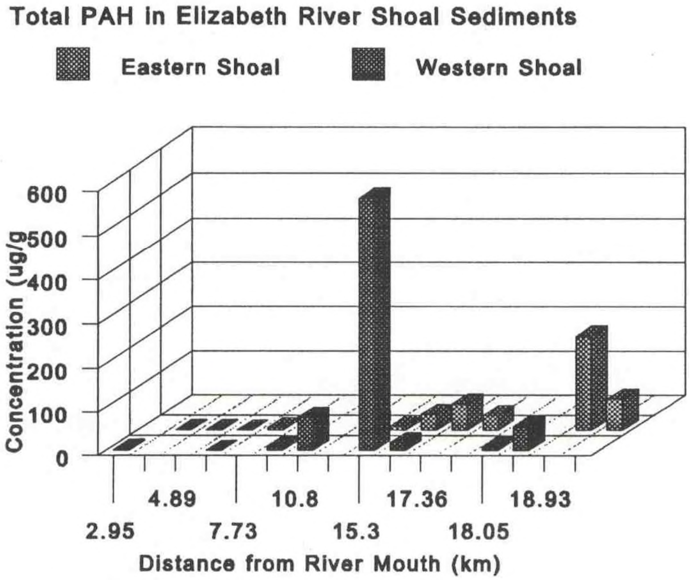
Total PAH in Elizabeth River Channel Sediment



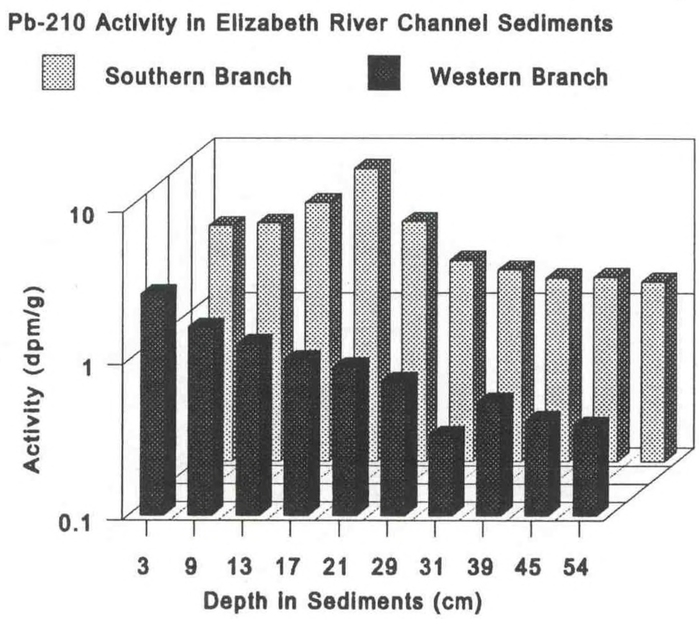
Total Metals in Elizabeth River Channel Sediments



"Hot spots" were also found in the shoal regions of the southern branch of the Elizabeth River. These "hot spots" were well-defined for PAHs and differed in location between the eastern and western shoals. The eastern shoal "hot spot" has PAH concentrations ~3-fold higher than the adjacent channel "hot spot". However, the observed western shoal "hot spot" has sediment PAH concentrations up to 10-fold greater than those observed in the channel sediment "hot spot", and this area is located farther down-river away from the region of highest channel sediment contamination.



To determine sediment and contaminant accumulation rates and near surface residence times in the Elizabeth River, sediment cores were collected in addition to the surface sediment grab samples. Six 2 m kasten cores were collected from the channel areas: two in the Lafayette River, two in the western branch, and two in the southern branch of the Elizabeth River. Only the most landward channel sample from the western branch demonstrated a typical sediment accumulation profile based on ^{137}Cs and ^{210}Pb analyses. This core had and exponentially decreasing ^{210}Pb profile and a depth of ^{137}Cs penetration of 40-42 cm, which indicates that sediments above this horizon have accumulated since 1954. Sediment from the western branch core is currently being analyzed to determine contaminant accumulation rates in this region of the river. All of the other channel areas appear to be well-mixed (e.g. southern branch) as indicated by elevated and relatively uniform ^{210}Pb profiles and ^{137}Cs penetration below 120 cm. The high degree of sediment mixing in Elizabeth River channel sediments is likely due to dredging activities. Thus, most of the channel cores will not be of use in determining sediment and contaminant accumulation rates or surface sediment residence times.



Various box core samples were also collected in the shallower creek regions adjacent to the southern branch of the Elizabeth River. Again, with one exception in Paradise Creek, sediments in these cores are well-mixed and will not be useful for determining sediment and contaminant accumulation rates or near surface residence times. However, useful information on sediment and contaminant accumulation rates is being obtained using core samples collected from marshes and wetlands (see student projects described below).

The second phase of this research will address the following objective:

2. Determine the direction and magnitude of net transport of particles and associated contaminants in the Elizabeth River, as a function of particle properties and hydrodynamic forcings.

Results related to this objective are to be completed (TBC) in the current and subsequent project year.

III. ACCOMPLISHMENTS/BENEFITS REPORT

A. ACCOMPLISHMENTS

Effects on user groups / marine resource management / scientific knowledge -
Remediation efforts are currently being planned for the southern branch of the Elizabeth River . Our evaluation of sediment contamination in this region of the river will directly support these efforts by supplying data on the specific locations of contaminated sediments. Moreover, our particle transport experiments will further support remediation efforts in the southern branch of the Elizabeth River by helping to determine what processes act to move contaminated sediments in the estuary.

We are also pursuing the advancement of scientific knowledge with this project. One example is the exploration of relationships between sediment PAH content and particle properties. Simple relationships between sediment PAH content and sediment organic carbon content, grain size, or surface area are apparent in aquatic systems that are not heavily impacted by point sources of pollutants (e.g. the York River, VA). However, sediment PAH content is not correlated with basic particle properties in the Elizabeth River estuary. The lack of a simple correlation to explain the distribution of PAHs in the Elizabeth River sediments may be related to the multitude of sources impacting this system and/or higher order particle properties. This is being explored by a grant to C. Chisholm-Brause from the National Science Foundation.

Publications - TBC

Copyrights, patents, etc. - N/A

Presentations -
Dickhut, R.M., C. Friedrichs, S. Kuehl, J. Brubaker and C. Chisholm-Brause. "Transport and Fate of Sediment-Associated Polycyclic Aromatic Hydrocarbons and Trace Elements in the Elizabeth River" presentation to the Army Corp of Engineers/Elizabeth River Project Restoration Group, May 14, 1999 at the Virginia Beach Office of the Department of Environmental Quality.
Fugate, D. Comparison of Sedimentary Patterns in Marsh Systems of Dredged and Natural Estuaries,

poster presentation at the American Society of Limnology and Oceanography meeting, Santa Fe, NM, Feb. 1999.

Kimbrough, K. L. and R. M. Dickhut. "Utilization of Wetland Core Profiles to Determine the Effect of Land Use on Contaminant Input to the Elizabeth River, Virginia" poster presentation at the 19th annual meeting of the Society of Environmental Toxicology and Chemistry, Charlotte, NC, Nov. 15-19, 1998.

Student Involvement -
Kimani Kimbrough (Citizenship U.S., African-American male) is a student in the Dept. of Physical Sciences in the School of Marine Science of the College of William and Mary. Kimani is currently working on his Ph.D. degree (R. Dickhut - major professor) in association with this project. Kimani's proposed dissertation title is "Historical and Present Effects of Urbanization and Land Use on Wetlands". His expected graduation date is Dec. 2000.

Briefly, the overall objective of Kimani's Ph.D. research is to assess PAH concentrations, sources trends, and fluxes into wetlands of the Elizabeth River watershed in relation to adjacent land use. The initial data he has collected shows that wetlands adjacent to urban land have significantly elevated levels of PAHs in surface sediments. Kimani will further explore this preliminary finding as part of his Ph.D. research, as well as examine how historical changes in land use have affected PAH concentrations in wetland sediments. This information will then be used to determine the overall magnitude of PAHs input to Elizabeth River wetlands from urban runoff.

David Fugate (U.S. citizenship, Caucasian male) is a student in the Dept. of Physical Sciences in the School of Marine Science of the College of William and Mary. Dave is currently working on his Ph.D. degree (C. Friedrichs - major professor) in association with this project. The title of his dissertation is "Study of Hydrodynamics and Sediment Transport in an Urban Estuary". Dave expects to graduate in May 2001.

Shelby Walker (U.S. Citizenship, Caucasian female) is a student in the Dept. of Physical Sciences in the School of Marine Science of the College of William and Mary. Shelby is currently working on her Ph.D. degree (C. Chilsholm-Brause, R. Dickhut - co-major professors) in association with this project. Shelby's proposed dissertation title is "Influence of Organic Matter Properties on Contaminant Partitioning in Estuarine Sediments". Her expected graduation date is May 2002.

Christine Conrad (Citizenship U.S., Caucasian female) is a student in the Dept. of Physical Sciences in the School of Marine Science of the College of William and Mary. Christine is currently working on her Ph.D. degree (C. Chilsholm-Brause - major professor) in association with this project. Christine's proposed dissertation title is "Spatial Variability in the Concentrations and Distributions of Sediment-Bound Trace Metals in the Elizabeth River, VA". Her expected graduation date is May 2003.

Interactions - TBC

Personnel News - TBC

B. BENEFITS - TBC

*** SEA GRANT BUDGET ***

GRANTEE: Virginia Graduate Marine Science Consortium

PROJECT NO: R/CBT-35

PROJECT TITLE: Transport and Fate of Sediment-Associated PAHs and Trace Elements in the Elizabeth River

PROJECT STATUS: 2

PRINCIPAL INVESTIGATORS: Rebecca Dickhut, Steven Kuehl, Catherine Chisolm-Brause, Carl Friedrichs and John Brubaker

DURATION: 1/1/2000 - 12/31/2000

A: SALARIES AND WAGES	No. of Persons	Months	Sea Grant Funds	Grantee Funds
1. Senior Personnel				
a. Prin. Investigator	4	4	19,892	0
b. Associates	0	0	0	0
Subtotal	**4**	**4**	**19,892**	**0**
2. Other Personnel				
a. Professionals	0	0	0	0
b. Research Assoc.	0	0	0	0
c. RA Grad. Stud.	1	4	5,267	0
d. Prof. School Stud.	0	0	0	0
e. Pre-Bac. Stud.	0	0	0	0
f. Secret./Clerical	0	0	0	0
g. Technical/Shop	0	0	0	0
h. Hourly Labor	1	0	1,751	0
Total Salaries and Wages	**6**	**8**	**26,910**	**0**
B: FRINGE BENEFITS 27% salaries, 7.65% wages			5,505	0
Total Sal. Wages & Fringe Benefits (A+B)			**32,415**	**0**
C. PERMANENT EQUIPMENT			0	0
D. EXPENDABLE SUPPLIES			14,000	0
E. TRAVEL				
1. Domestic - US and Possessions			3,250	0
2. International			0	0
Total Travel			3,250	0
F. PUBLICATION AND DOCUMENTATION COSTS			1,500	0
G. OTHER COSTS				
1 Gas/Rental			350	0
2 Communication/Printing			300	0
3 Tuition			5,022	0
4 Contractual			4,200	0
Total Other Costs			9,872	
TOTAL DIRECT COSTS (A through G)			**61,037**	**0**
INDIRECT COSTS: On Campus: 40% less*			19,700	0
On Campus: 5% of RA			263	0
TOTAL INDIRECT COSTS			**19,963**	**0**
TOTAL COSTS			**81,000**	**0**

* RA, publications, tuition

TRANSPORT AND FATE OF SEDIMENT-ASSOCIATED POLYCYCLIC AROMATIC HYDROCARBONS AND TRACE ELEMENTS IN THE ELIZABETH RIVER

School of Marine Science, College of William and Mary,
Virginia Institute of Marine Science, Gloucester Point, VA 23062

A proposal submitted to the
Chesapeake Bay Environmental Effects Committee
Toxics Research Program

April 14, 1997

Rebecca M. Dickhut

Rebecca Dickhut
Principal Investigator

John A. Boon, III

John Boon, III
Chair, Dept. of Physical Sciences

Eugene M. Burreson

Eugene Burreson
Director for Research and Advisory Services

Jane Lopez
Manager, Sponsored Programs

TRANSPORT AND FATE OF SEDIMENT-ASSOCIATED POLYCYCLIC AROMATIC HYDROCARBONS AND TRACE ELEMENTS IN THE ELIZABETH RIVER

Principal Investigators:

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Dept of Physical Sciences, School of Marine Science, College of William and Mary, Virginia Institute of Marine Science, Gloucester Point, VA 23062

INTRODUCTION

The Elizabeth River subestuary of Chesapeake Bay is historically contaminated with both polycyclic aromatic hydrocarbons (PAHs) and trace metals due to three centuries of human activity along the river, in addition to more recent industrial activity along its shores (Helz and Huggett, 1987). For example, high sediment loads of PAHs, particularly in the Southern Branch of the Elizabeth River (Figures 1- 2), have been linked to two accidents where thousands of gallons of creosote, a wood preservative, were spilled into the estuary during the 1960's (Merrill and Wade, 1985; Bieri et al., 1986). Although these carbonized coal products are the major source of carcinogenic PAHs in the river, petroleum related sources in the area also contribute to contamination of the Elizabeth River (Merrill and Wade, 1985). Extreme enrichments of trace elements have also been noted in sediments of the Elizabeth River (Helz and Huggett, 1987).

Many contaminants in aquatic systems tend to associate with fine grained sediments, thus the transport and fate of these particle-associated pollutants are dictated by the processes mediating sediment transport within an aquatic system (Olsen et al., 1984). In highly channelized tidal environments such as the Elizabeth River, fine sediment and associated pollutant transport and fate will be dictated predominantly by physical processes. Consequently, to understand and model the processes controlling contaminant transport from Elizabeth River

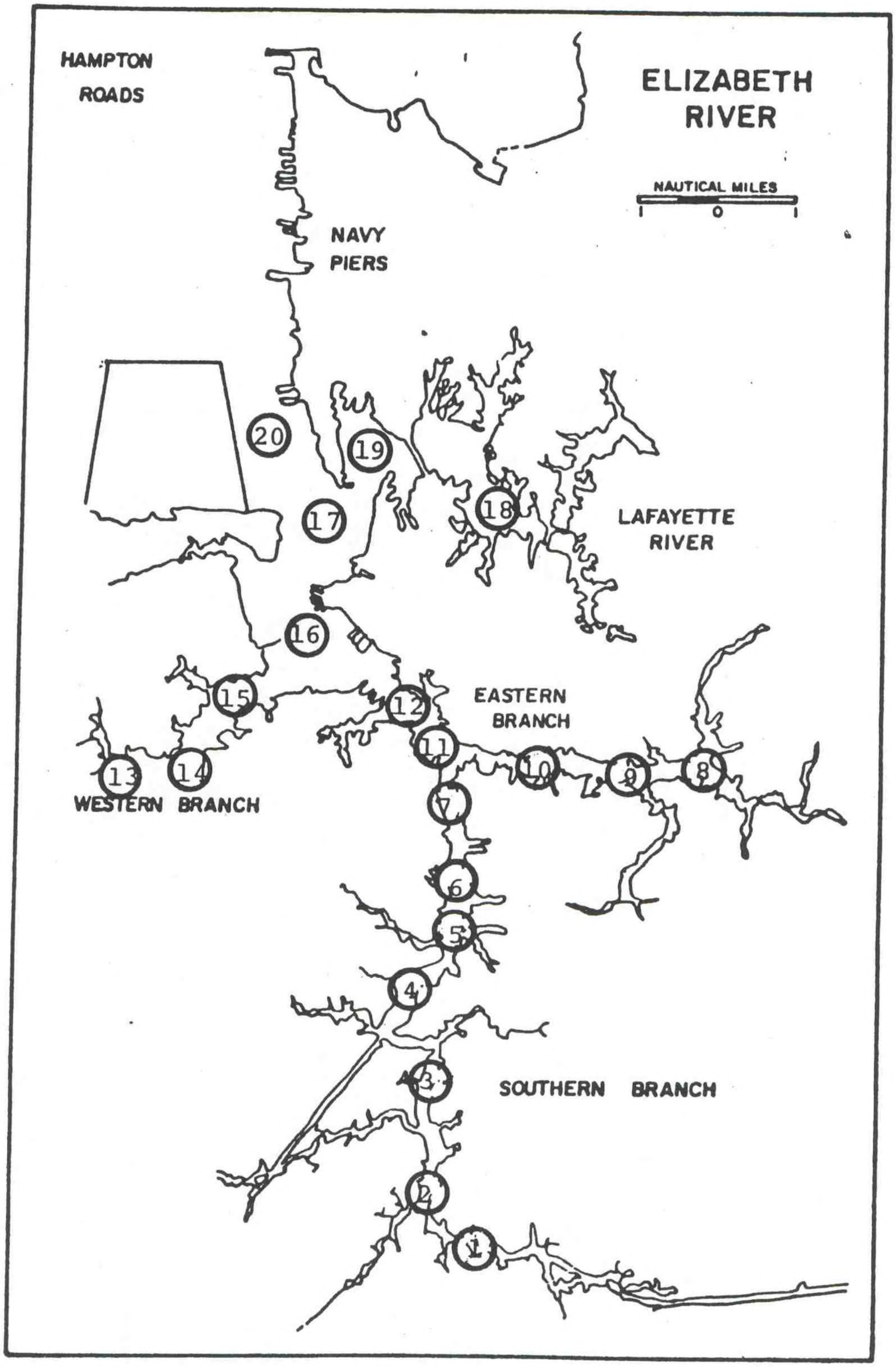


Figure 1. From Cerco and Kuo, 1977.

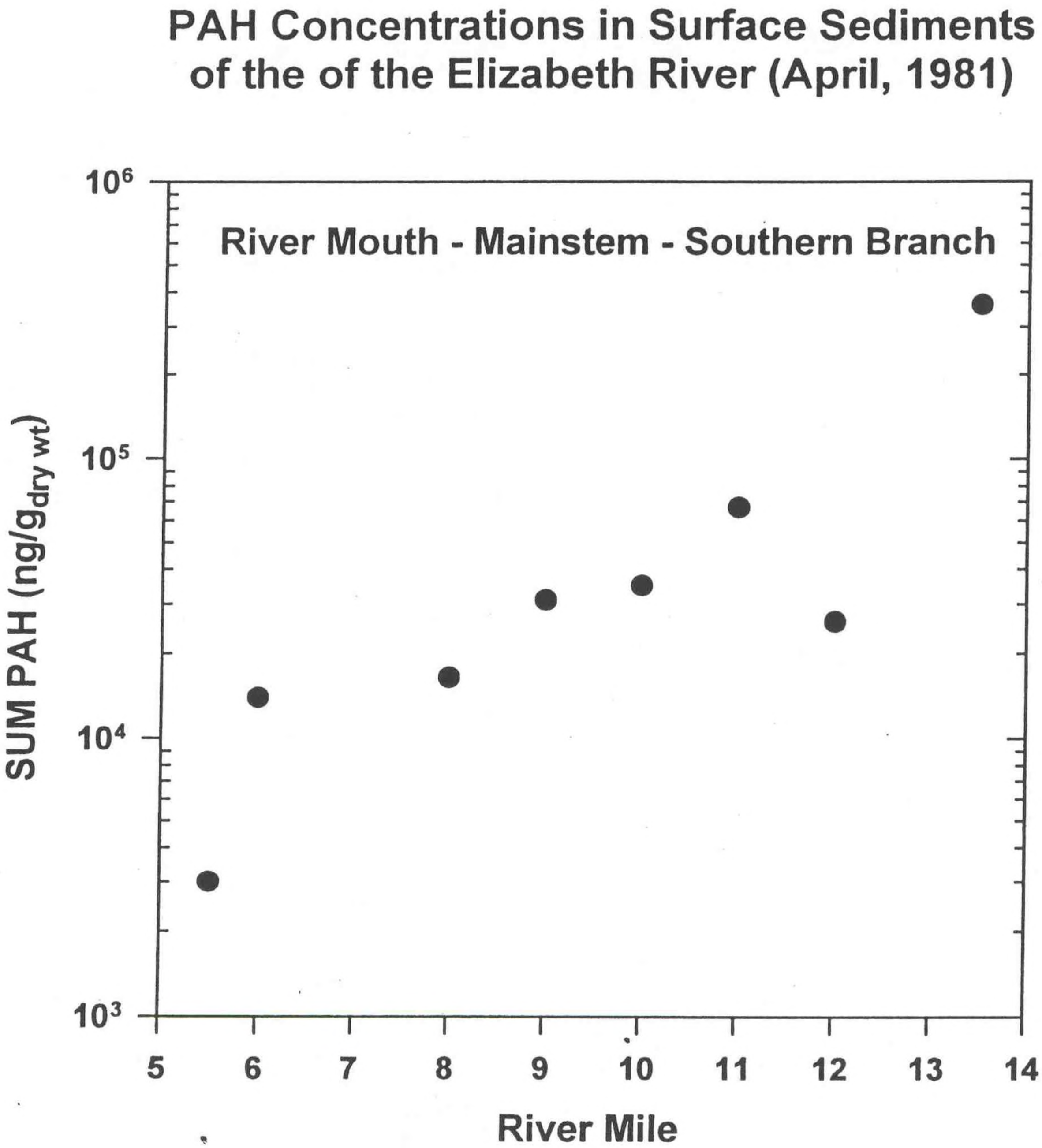


Figure 2. Data from Bieri et al., 1986.

sediments to the water column, and from historically contaminated areas to lesser or nonpolluted sites, we must quantitatively evaluate particle and associated contaminant resuspension and deposition in the estuary along with likely mechanisms for physical transport.

The proposed work will examine the transport and fate of sediment-associated PAHs and trace elements in the Elizabeth River subestuary of Chesapeake Bay. Specifically, we will determine contaminant deposition zones and quantify rates of PAH and trace metal burial in the sediments by assessing sediment inventories of the pollutants, sediment accumulation rates, surface mixed layer thicknesses, and particle residence times in the nea surface sediment. In addition, we will evaluate particle and associated contaminant resuspension and transport along the Elizabeth River by tidal currents and density-induced circulation by examining suspended particle properties, current profiles, and resulting contaminant loads over spring and neap tidal cycles during both wet and dry seasons.

RELEVANCE OF THE PROBLEM

PAHs are established carcinogens (Denissenko, et al., 1996), are on the Chesapeake Bay Toxics of Concern list, as well as the U.S. Environmental Protection Agency and World Health Organization lists of priority pollutants, and are ubiquitous environmental contaminants largely due to anthropogenic activities such as the combustion and accidental release of fossil fuels and petroleum byproducts, including creosote. As noted above, the Elizabeth River subestuary of Chesapeake Bay is highly contaminated with both PAHs and trace metals rendering it a "Region of Concern" in the Chesapeake Bay. Nonetheless, sediment and contaminant deposition zones and accumulation rates in the Elizabeth River have not yet been identified. Moreover, a specific research need identified in the Elizabeth River Regional Action Plan to support management action in this urban estuary is to "define and model processes involving fate and transport of chemical contaminants from bottom sediments into overlying water and from contaminated regions to nearby sites where sediments have been remediated."

The proposed research will support the Regional Action Plan for the Elizabeth River (see attached letter from Dr. Carl Fisher, Co-Chairman of the Restoration Implementation Team of The Elizabeth River Project). Specifically, this research will allow managers to make informed decisions with respect to no action, remediation, or dredging of contaminated sediments in the Elizabeth River. We will determine contaminant deposition zones and quantify rates of PAH and trace metal burial in the sediments, as well as evaluate particle and associated contaminant resuspension and transport by tidal currents and density-induced circulation. Deliverables will include a map of

THE Elizabeth River Project

April 11, 1997

Dr. Rebecca Dickhut
Department of Physical Sciences
School of Marine Science
Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, VA 23062

Dear Dr. Dickhut,

On behalf of the Elizabeth River Project, I appreciate the opportunity to review your research proposal, "Transport and Fate of Sediment-Associated Polycyclic Aromatic Hydrocarbons (PAHs) and Trace Elements in the Elizabeth River" that has been submitted to the Chesapeake Bay Environmental Effects Studies Toxic Research Program. The Elizabeth River Project is very interested in your proposal and highly supports it for approval. The proposed research will determine contaminant deposition zones and quantify rates of PAH and trace metal burial in the sediments by assessing sediment inventories of the pollutants, sediment accumulation rates, surface mixed layer thicknesses, and particle residence times in the near-surface sediments. In addition, the investigators will evaluate particle and associated contaminant transport into the water column, and potentially out of the Elizabeth River subestuary by tidally induced resuspension and transport.

I believe the proposed research would definitely address our need to understand the processes controlling contaminant transport from Elizabeth River sediments to the water column and from areas that are contaminated to areas that have been remediated or unremediated areas having lower levels of contamination. I have discussed your proposal with the Project Manager of the U.S. Army Corps of Engineers' Elizabeth River Basin Restoration Project, and it appears the Corps is also very interested in your proposal. This project's purpose is to remediate the most seriously contaminated sediments, restore wetlands, and improve the shoreline, where in the interests of the Nation, the Commonwealth, and the cities. It is the result of a partnership between the Corps of Engineers, the Elizabeth River Project and the cities of Chesapeake, Norfolk, Portsmouth and Virginia Beach. In addition, the Commonwealth of Virginia and the Hampton Roads Planning District Commission are providing strong support. In March 1997, the Corps commenced the first phase of this restoration project, a Reconnaissance Study to determine the scope of work that would be cost-shared with the cities and other sponsors during future phases of the project. The next phase is a two to three year Feasibility Study that should commence in March 1998. The results of your research would be most valuable during this phase, as well as during the engineering and design phase and the project implementation phase.

109 East Main Street ~ Suite 305 ~ Norfolk, Virginia 23510 ~ 757-625-3648 ~ Fax 625-4435

501.c.3 tax exempt organization

During the Elizabeth River Watershed Action Plan development, I was Chairman of the Sediment Quality Task Force. One of the most difficult issues we addressed was the lack of accurate information about the extent of sediment contamination in the river. The existing data is quite sparse. We know that some regions of the river are definitely contaminated with PAHs, PCBs, heavy metals, and other toxic contaminants, but we know little about their horizontal and vertical distribution in the sediments. We proposed as our goal, to "reduce sediment contamination in the Elizabeth River to levels non-toxic to humans and aquatic life." The Watershed Action Plan recognizes that, due to high cost and other factors, it is not likely that all contaminated sediments in the river will be remediated. Therefore, we recommended remediation of only the most seriously contaminated sites at this time. However, this strategy leads to unanswered questions, such as: Will the remediated sites be recontaminated by contaminants transported from nearby unremediated sites, and what will happen to contamination levels at the unremediated sites? We need to know more about the distribution of contaminants in the sediments and understand the processes controlling contaminant transport. Your research would add greatly to our knowledge and enable project managers to make informed decisions with respect to remediation and dredging of contaminated sediments in the Elizabeth River.

Sincerely,

Carl W. Fisher

Dr. Carl W. Fisher
Co-Chairman, Restoration Implementation Team

sediment deposition zones and contaminant "hot spots". Moreover, observations will provide data for calibration and validation of numerical water quality models presently proposed or under construction (Boon et al., 1997). We expect observations will provide data that will help determine weekly to seasonal variations in the direction of net particle-associated contaminant transport.

OBJECTIVES AND HYPOTHESES

Objectives

(1) Determine sediment and contaminant (PAH, trace metal) "hot spots", deposition zones, accumulation rates, and near surface residence times in the Elizabeth River.

(2) Determine the direction and magnitude of net transport of particles and associated contaminants in the Elizabeth River, as a function of particle properties and hydrodynamic forcings.

Hypotheses

(1) Long-term accumulation rates for sediments and associated contaminants in the Elizabeth River will be:

- a. higher in shoals vs. channels because of disturbance by channel dredging,
- b. greatest near historical contaminant "hot spots" and current point sources, and
- c. correlated with measurable and predictable patterns of particle transport associated with estuarine hydrodynamics and characteristic particle properties.

(2) Particle-associated contaminant transport in the Elizabeth River is expected to be:

- a. down the contaminant concentration gradient if tidal dispersion is strong, especially for contaminants associated with smaller, lighter particles,
- b. landward if density driven circulation is strong, especially for contaminants associated with larger, heavier particles, and
- c. generally toward areas of weaker tidal currents, with more slowly settling particles carried farthest.

Work Plan - Overview

The proposed project is comprised of two distinct field surveys, followed by sample analysis, data interpretation and modeling (Table 1). In the first year of the project we will conduct a geophysical survey and collect sediment grab samples to identify prospective coring locations and contaminant "hot spots", and conduct a more extensive

Table 1. Project Time Line.

Year 1

First Quarter -	conduct geophysical survey and sediment grab sampling to assess potential coring sites.
Second Quarter -	analyze sediment grab samples for contaminants and evaluate results of geophysical survey; select locations for sediment coring.
Third Quarter -	conduct extensive core sampling of the Elizabeth River and initiate sedimentological and radiochemical analyses.
Fourth Quarter -	continue sedimentological and radiochemical analyses; initiate contaminant analyses of sediment cores based on available sedimentological and geochronology data.

Year 2

First Quarter -	continue radiochemical and contaminant analyses of sediment cores; select site for sediment transport tidal cycle intensives in the Elizabeth River based on the sediment data.
Second Quarter -	conduct wet season sediment/contaminant transport intensive; initiate geochemical and contaminant analyses of suspended particles and evaluation of geophysical (e.g. current velocity) data.
Third Quarter -	conduct dry season sediment/contaminant transport intensive; continue geochemical and contaminant analyses of suspended particles and evaluation of geophysical (e.g. current velocity) data.
Fourth Quarter -	report results of geochronolgical study of the Elizabeth River; prepare manuscripts for publication.

Year 3

First Quarter - complete contaminant analyses of sediment cores; continue geochemical and contaminant analyses of suspended particulates; initiate modeling of suspended sediment transport.

Second Quarter - complete geochemical and contaminant analyses of suspended particulates and modeling of suspended sediment transport.

Third Quarter - interpret and integrate results from geochronological and sediment-contaminant transport studies, prepare manuscripts for publication.

Fourth Quarter - report results of sediment-contaminant transport study of the Elizabeth River.

geochronological study based on the preliminary survey results to provide historical sedimentation patterns and facilitate determination of contaminant deposition zones and accumulation rates in sediments. During the second year of the study we will conduct intensive field experiments during spring and neap tidal cycles in both dry and wet seasons to evaluate particle and associated contaminant resuspension and transport in the vicinity of a previously identified "hot spot". We will analyze sediment cores and suspended particle samples for particle properties such as organic carbon and nitrogen content, PAHs and trace elements (Cd, Cu, Cr, Pb, Zn) throughout the project. Finally we will couple the sediment accumulation and residence time data for the surface mixed layer with information on current profiles and particle transport mechanisms to provide an understanding of short and long term sediment and associated contaminant transport and deposition in the Elizabeth River.

Field Work

Geophysical Survey and Core Collection. A site survey will be conducted using a 3.5 kHz DataSonics high-resolution subbottom profiler in order to identify prospective coring locations and to characterize the distribution of bottom types (e.g., hard vs. soft; smooth vs. rough) based on acoustic character. Sediment cores will be collected from a variety of environments in and adjacent to the Elizabeth River. In order to assess the contaminant inventories in the river channel, a 3-m long kasten corer and a standard spade box corer will be used to obtain cores from the thalweg and areas accessible to the R/V Bay Eagle. A smaller box corer will be deployed from a small boat to sample representative environments adjacent to the river (channel flanks, creeks, and shallow embayments). Cores will be returned to VIMS and dissected to remove slabs for x-radiographic, chemical and radiochemical analyses.

Samples for contaminant analyses will be collected from sediment box cores by sub-coring using acrylic tubing (~ 8-9 cm diameter). Cores tubes will be sealed, transported to the laboratory and held in a cold room at 4^{0}C or frozen until analysis. Based on the radiotracer sedimentological data, selected cores will be sub-sectioned at appropriate intervals and analyzed for contaminant levels providing historical as well as recent depositional profiles.

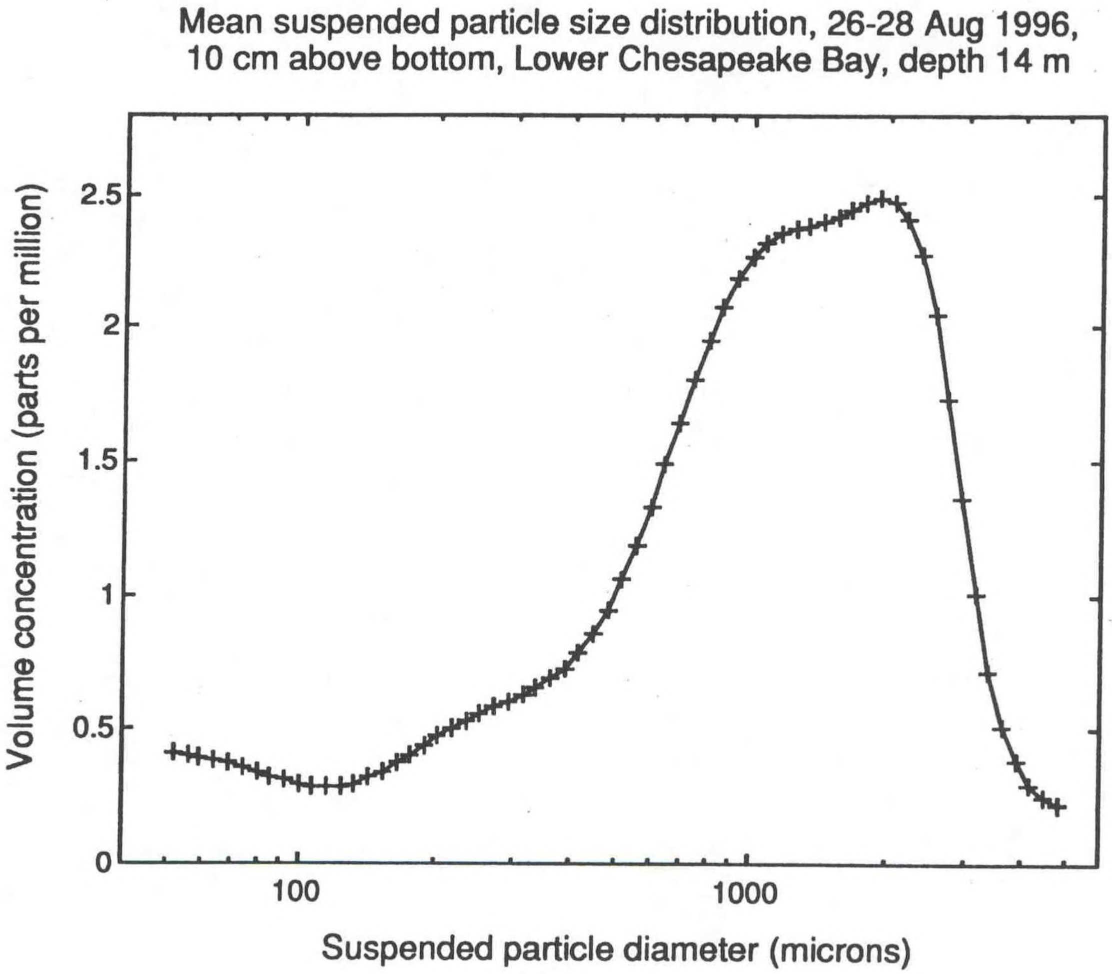
Resuspension and Particle Transport - Over a spring and neap tide during dry and wet seasons, an instrumented water sampler will be used to profile the water column of the Elizabeth River at a location with a strong along-channel contaminant gradient selected after sedimentological assessment of contaminant "hot spots". Based on historical information, we expect the study site to be within the Southern Branch the Elizabeth River (Figures 1&2). Deployments will each last 50 hours (4 full tidal cycles).

Eight times each tidal cycle (approximately every 90 minutes), the profiler will collect particle laden water samples at 1 m and 3 m above the bed, in the middle water column, and 1 m below the surface. Between profiles the sampler will rest on the bottom and collect water samples every 90 minutes from intakes positioned 10 and 30 cm above the bed. During spring tides, additional samples will be collected at 10 cm above the bed every 30 minutes. In all, about 850 samples will be collected over the course of the four intensive field experiments.

Along with two pump intakes, the profiler will also be equipped with a laser in-situ scattering and tranmissiometry instrument (LISST) that will continuously monitor particle volume concentration as function of particle diameter, recording concentration in 64 logarithmically spaced bins ranging from 5 to 500 microns. Figure 3 displays the mean particle size distribution previously observed over 48 hours, 10 cm above the bed of the Lower Chesapeake Bay using the LISST during August 1996 (Friedrichs, unpublished data). Even though the constituent particle grains were primarily silt and clay (i.e., less than 65 microns), most of these "fines" were contained in low density aggregates with diameters in the "sand" size range.

A Hi-8 mm video camera on the profiler will also continually monitor a settling tube on the profiler. On the macro setting, the 15 x 24 mm screen with 400 lines of resolution will have a pixel size of 40 microns, meaning that when the profiler is resting on the bottom, the video camera and settling tube can be used to estimate concentration and settling velocity of particle aggregates with diameters larger than about 100 microns. Figure 4 shows in situ estimates of particle settling velocity measured by a similar video camera and settling tube combination constructed by the University of Washington and deployed off the coast of Northern California by Dr. R. Sternberg in the winter of 1995-96 (Sternberg et al., 1997).

Besides these primary sensors for particulate concentration, size distribution and settling velocity, the profiler will also support an optical backscatter sensor, an acoustic Doppler velocimeter (ADV) for which the strength of the acoustic response is proportional to particle concentration, a conductivity-temperature-depth recorder (CTD), and an oxygen sensor. The ADV will continually measure 3-D current velocity at 25 Hz. When the profiler is resting on the bottom, the ADV will provide direct measurement of turbulent properties and therefore bottom stress. Throughout the water column it will provide a good measurement of the tidal current speed. In addition, a downward looking acoustic Doppler current profiler (ADCP) will be moored nearby. The moored ADCP will provide acoustic response proportional to particle concentration as well as current measurements for 25 cm bins throughout the water column.



Mean suspended particle size distribution, 26-28 Aug 1996,
10 cm above bottom, Lower Chesapeake Bay, depth 14 m
Volume concentration (parts per million)
0
0.5
1
1.5
2
2.5
100
1000
Suspended particle diameter (microns)

Figure 3

Settling velocity as a function of particle size from video camera on a settling tube, continental shelf off Northern California, winter 1995-6 (Sternberg et al., 1997)

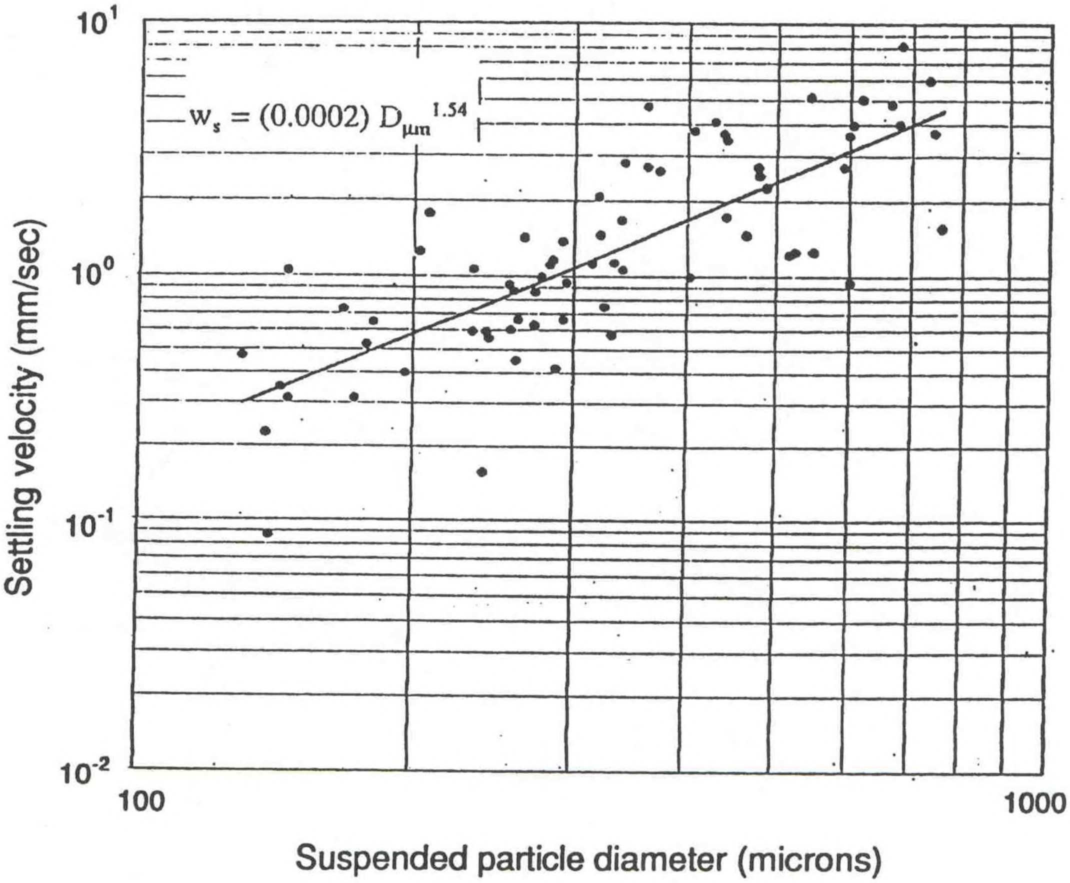


Figure 4

During each deployment, spatial variability of the flow field in the vicinity of the profiler station will be mapped with underway velocity sampling. A towed ADCP, engaged in spatial mapping of currents, will provide acoustic backscatter strength data that can be related to particulate concentration. This bottom-tracking ADCP with 1 m vertical resolution will be deployed to survey spatial variability in the flow field within a reach of the river including the profiler station. A series of repeated surveys will be executed in order to resolve the residual current and the evolution of the flow field over tidal time scales.

Suspended particle samples for bulk geochemical property and contaminant analyses will be collected shipboard using submersible pumps mounted on the profiler. Suspended particulate matter for PAH analyses will be collected onto glass fiber filters (Gelman Type A/E, pre-combusted at 450 °C) using N_2 at low pressure (< 8 psi) in a closed system. Suspended particles for trace metal analyses will be collected on pre-cleaned, pre-weighed, polycarbonate filters; these filters will be stored in plastic containers. All samples will be refrigerated (metals) or frozen (organics) until processed further.

Geochemical Methods

Sediment Geochronology - Natural and bomb produced radioisotopes will be utilized along with sedimentological observations to provide a temporal framework for understanding the passage of particulates and sediment-associated contaminants from the near surface mixed layer to the zone of preserved strata, and to assess contaminant inventories in the Elizabeth River system. Sediment accumulation rates will be determined using ^{210}Pb geochronology. With a half life of 22.3 years, ^{210}Pb is useful in determining sediment accumulation rates integrated over about a 100y time scale (e.g., Kuehl et al., 1986, 1995). ^{210}Pb profiles in sediment cores also can be used to examine the depths of physical and biological mixing in estuarine and near shore environments (e.g., Kuehl et al,. 1995, 1996; Dellapenna et al., 1997). In addition, ^{137}Cs will be employed as an independent check on ^{210}Pb accumulation rates using the approach of Kuehl et al. (1986). This is necessary as slow diffusive biological mixing can affect accumulation rates derived from ^{210}Pb geochronology. As the first input of ^{137}Cs to the marine environment occurred in the mid 1950's (from atmospheric thermonuclear testing), its first appearance in the sediment column can be used to distinguish ^{210}Pb profiles created from sediment accumulation versus those created from diffusive mixing. Rapid biological or physical mixing of surface sediments will create a surface mixed layer (SML), distinguishable in ^{210}Pb profiles from the nearly-uniform excess activity near the seabed surface. The depth of this uniform ^{210}Pb layer is taken as the depth of rapid mixing, and can be used to calculate particle residence times (i.e., SML thickness/accumulation rate).

Radiochemical and sedimentological analyses will be performed at the sedimentology lab at VIMS. ^{210}Pb measurements will be made using partial leaching of sediments and analysis of the Po granddaughter by alpha spectroscopy following the technique described by Kuehl et al. (1986). ^{137}Cs analyses will be made by gamma spectroscopy through the direct measurement of its 661 KeV line.

Sedimentary Structures and Textures - Physical and biological processes operating near the sea bed impart unique character to sediments in the mixed layer as well as in the zone of preserved strata. Sedimentary structure and sorting affects certain aspects of the sediment geochemistry through their control on such basic parameters as porosity and permeability. X-radiographic analysis will be performed on all cores using the techniques described by Kuehl et al. (1985) to examine fine-scale sedimentary structures that will provide additional supporting evidence for interpretation of the radiochemical profiles. For example, the absence of bioturbation would eliminate the possibility that the ^{210}Pb profile was derived from diffusive mixing. Textural analysis of sediment cores will be conducted as necessary to aid in the interpretation of radionuclide profiles and x-radiographs.

Suspended Particle Properties - For all 850 water samples, we will determine total dry weight suspended solids (TSS) concentration, total particulate nitrogen (TN), particulate organic carbon (POC), and total volatiles; selected samples will also be analyzed for chlorophyll a. TSS will be determined by drying preweighed sample filters in an oven at 60°C until there is no change in filter weight, and reweighing. Bulk constituents (POC, TN) will be analyzed by standard methods using a Fisions CHN analyzer (Model EA1108) after removing inorganic carbon according to the method of Hedges and Stern (1984). Chlorophyll a concentrations and total volatiles will be analyzed by the VIMS Nutrient Laboratory.

Contaminant Concentrations - Concentrations of selected PAHs and trace elements will be determined on a subset of the sediment cores and suspended particulate samples. Selected contaminants will include various PAHs: naphthalene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz[a]anthracene, chyrsene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[e]pyrene, indeno[123cd]pyrene, dibenz[ah]anthracene, benzo[ghi]perylene; and trace elements: cadmium, chromium, copper, lead, and zinc, many of which are on the Chesapeake Bay Toxics of Concern and EPA list of priority pollutants. These toxic metals and carcinogenic PAHs also exhibit a range in physical-chemical characteristics, such that they are representative of a wide range of contaminant behaviors in the environment.

The number of samples to be analyzed for bulk properties, radioisotopes, metals and PAHs will be progressively less because of the increasing difficulty and expense of the respective analytical procedures. For example, trace element concentrations will be measured in the 100 samples collected at 10 cm above the bed during each spring tide deployment, whereas only every fourth one of these samples (i.e., 25 per season), will be analyzed for PAHs. Fewer core profiles or less resolution for trace elements and PAHs, respectively, in accumulated sediments will likewise be generated as compared to radioisotope data. Nonetheless, during each tidal cycle intensive (spring and neap), we will analyze particles from 10 cm above the bottom, the middle of the water column and 1 m below the surface for both metals and PAHs at each peak flood and ebb.

PAHs will be quantified using gas chromatography/mass spectrometry following extraction with organic solvents and clean up of samples via silica column chromatography. Briefly, each sample (filter or sediment) will be spiked with a surrogate standard mixture containing deuterated PAHs (anthracene, benz[a]anthracene, benzo[a]pyrene, and benzo[ghi]perylene) and then sequentially Soxhlet extracted for 24 h each, or sonicated for 1 h each, with acetone followed by dichloromethane (DCM). The acetone fractions will subsequently be batch extracted three times with hexane and purified water to remove polar solvents and sequester organic chemicals in the hexane phase. The resulting hexane fraction will then be combined with the DCM fraction, concentrated to ≈ 5 ml using rotoevaporation, and dried over anhydrous Na_2SO_4. Samples will then be subjected to solid-liquid chromatography on silica to separate organic contaminants and potential analytical interferents (Dickhut and Gustafson, 1995). Prior to analysis for PAHs, the extracts will be spiked with an internal standard mixture consisting of additional deuterated PAHs (phenanthrene, chrysene, perylene), and reduced to a volume of <200 μL under a stream of purified N_2. The samples will then be analyzed for selected PAHs using gas chromatography/mass spectrometry (GC/MS) on a Hewlett Packard 5890A Series II GC and 5971A MS operated in the selective ion monitoring mode with a 30 m long x 0.25 mm I.D. DB-5 column (J&W Scientific). A standard mixture (EPA Method 610- Supelco) supplemented with benzo[e]pyrene will be used to generate PAH response factors relative to deuterated standards. Individual PAHs are quantified relative to the closest eluting PAH surrogate standard, therefore, PAH concentrations are automatically corrected for recovery. Average recoveries for deuterated surrogate PAHs from various sampling media range from 78% ± 10% to 111% ± 17%, and our procedures for quantitation of PAHs have been determined to be unbiased and precise to within ±20%, with an analytical uncertainty of ±25% (Dickhut and Gustafson, 1995).

Metals will be extracted from the filter and sediment samples by acid leaching. Analyses will be based on dry weight. Metals concentrations will be determined using inductively-coupled plasma atomic emission spectrophotometry (ICP-AES). Specifically, data will be collected on a Thermo Jarrell Ash TraceScan® ICP outfilter with an axial torch. Acid leachates of the sediment samples will be diluted with ultrapure water to minimize matrix effects. Select samples with low metals concentrations will be analyzed using the method of standard additions and internal standards. Multielement standards will be prepared from commercially available ICP standards. The accuracy of the measurements will be assessed by comparison with an external, instrument standard.

Data Analysis

Sedimentation Patterns and Seabed Particle Residence Times - The geophysical and sedimentological observations and measurements will be merged to characterize and quantify the various subenvironments of the Elizabeth River system (e.g., thalweg, channel flanks, embayments, tributaries). Although contaminant loading in the Elizabeth River has long been recognized as a significant environmental concern, little work has been done in establishing patterns of sediment and contaminant dispersal, even from the well known "hot spots". $^{210}Pb/^{137}Cs$ geochronological studies will be used to generate maps of sediment accumulation rate and thus allow us to identify areas of significant particle and contaminant removal. In addition, calculation of seabed particle residence times (mixed layer thickness/accumulation rate) will provide managers with a mechanism to assess the time scale for bioavailability of sediment-associated contaminants before deep burial in the sediment column. Coupled with the geochronological studies, we anticipate that the high-resolution seismic survey will allow us to extrapolate our point (core) observations along and across the Elizabeth River. For example, areas of rapid fine-grained accumulation often are seen as acoustically "transparent" layers in seismic records, and mapping of such layers will provide us with a continuous record of the spatial distribution of sedimentation patterns. This approach, along with PAH and trace element measurements will provide us with the means to accurately assess the spatial distribution of contaminant inventories in the study area.

Particle and Contaminant Transport - The particle laden water samples collected at each height in the water column every 90 minutes for 50 hours will allow us to estimate tidally averaged sediment transport at a single location in the Elizabeth River in the vicinity of highly contaminated sediments for both spring and neap tides during both dry and wet seasons. We will get a direct estimate of particle associated metal and PAH transport from the analyses done on sediment samples collected at peak flow and slack water and by least-squares correlations with other measured particle properties. Another option for estimating particle-associated contaminant transport would be to spread what resources we have for analysis among the remaining sediment samples collected at 90 minute intervals. Instead we have chosen to focus our analysis on a near bed time series of water samples collected where we expect suspended particle concentrations to be greatest (probably up to several 100s of mg/liter at peak flow). By using the LISST, video settling tube and other analyses to associate contaminants with given particle size classes, nutrient (TN, POC, chlorophyll *a*) content and total volatiles, we can then construct a statistical model to map best-fit contaminant levels to all of the water samples collected throughout the water column at spring and neap tides.

Specifically, we will apply an algebraic inversion technique using the LISST and video settling tube to determine suspended particle volume concentration and fall velocity as a function of particle size while simultaneously sampling for a multitude of bulk particle properties (e.g., contaminant concentration, nutrient concentration, etc.). Through this least-squares statistical technique, we will use the LISST and video output to solve for the most likely distribution of each particle property as a function of particle size. The size dependent properties one can determine include density, porosity, nutrient concentration, total organic component, contaminant concentration, or any other quantity that is measured from the bulk water sample. The more bulk samples collected, the smaller the error bars on the properties (such as contaminant concentration) determined for each size class. Because of limited resources for sample analysis, the inversion technique will be applied only for the spring tide deployments when absolute particle concentrations will be highest. Nonetheless, the resulting insights concerning particle properties as a function of particle size can largely be transferred to the same locations at neap tides.

We first tried this technique in the Lower Chesapeake Bay when we deployed the LISST and collected particle laden water samples over a two day period in August 1996. Based on 20 bulk water samples, we were able to determine that fine particle aggregates (< 65 micron diameter) were significantly denser and less porous than large aggregates (> 65 micron diameter). Also, fine particles contained significantly more combustible material and chlorophyll, and had a significantly greater beryllium activity. Together these properties suggest that finer aggregates in the Lower Chesapeake Bay are younger, more labile and less worked over by microbes than larger aggregates.

Using the LISST and video settling tube to determine the particle size distribution and then a statistical inversion to map properties to each size class is not as direct a method as filtering particles into separate grain sizes before performing chemical or other analyses. However, the latter approach destroys the in situ aggregate size distribution that controls particle resuspension and transport. Furthermore, chemical transformation rates can be expected to be a function of overall suspended particle surface area, porosity and density, properties that are all irrevocably altered in the filtering process.

Not only will we determine chemical and other properties as a function of grain size, we will also determine how the concentration of each grain size varies over the tidal cycle and between the wet and dry seasons. We will also cross-correlate variations among particle properties over the tidal cycle. In this way we can determine both the net transport of various contaminants and also with which components of the total suspended particle population each contaminant is most closely associated. Comparison of component concentrations with estimates of tidally varying bottom stress will give us insight into the ease of resuspension of particles associated with each contaminant.

Finally, we will produce least-squares estimates of contaminant distribution and transport as a function of grain size and other particle properties over the entire measurement period at each location during each deployment. Through simultaneous CTD and ADCP observations, we will be able to monitor mean current shear and stratification and therefore investigate the relative importance of density induced estuarine circulation versus tidal dispersion at spring and neap tide and during the wet and dry season. Sampling under such a wide range of conditions will allow us to extrapolate toward likely long term patterns of net contaminant transport with more confidence.

EXPECTED RESULTS

We expect to observe little or negligible long-term accumulation of sediments, as well as contaminants, in the main channel of the Elizabeth River due to historical and continued dredging activities. Sediment and contaminant deposition is expected to be greatest in shoal areas of the river, particularly in the vicinity of present and past point sources. In deposition zones near previously identified contaminant point sources such as the Atlantic Wood creosote manufacturing plant, evidence of documented creosote spills should be preserved in the sediments. Likewise, Pb is expected to show a maximum signal in the sediment corresponding to the peak production and use of leaded gasoline. Overall, long-term geochronologies will probably show evidence of increased contamination in the sediments of this estuary due to increased inputs resulting from industrialization and urbanization of the watershed. Additionally, it is likely that sediment transport in the Elizabeth River over the last 15-20 years has resulted in increased dispersion of contaminated sediments from "hot spots" throughout the river/estuarine basin. Thus, in many instances contaminant signals in areas previously identified or assumed to be lesser impacted, may be higher than formerly measured.

We expect to observe that particle properties have a strong influence on the transport pathways, deposition zones, and accumulation rates of associated contaminants. For example, if a given contaminant is associated with fine particles of low density, such as small, primarily organic flocs, we expect that contaminant to be resuspended high into the water column such that landward flowing, density-induced circulation near the bed will not effectively move the contaminant upstream. Instead, the contaminant will respond more strongly to tidal dispersion, which acts on the entire water column, and the contaminant will be transported down the concentration gradient. Sites of accumulation for this type of contaminant will then be less intense, more spread out, and found far up and down stream of its source. In contrast, if a contaminant is associated with negatively buoyant particles, such as larger flocs containing terrigenous material, we expect that density-driven circulation may favor transport upstream. Zones of accumulation for this type of contaminant will then be distributed largely upstream of its source. Superimposed on these patterns, we expect to see particle-associated contaminant transport toward areas of weaker tidal currents because of less favorable conditions for resuspension. Higher accumulation rates are also favored toward these area. As particles are transported toward regions of low energy, coarser, heavier particles settle out first, and finer, more slowly settling particles are carried further. Thus the location and extent of contaminant accumulation will depend strongly on the settling velocity of the associated particle.

We also expect the direction of net transport of a given contaminant to be highly dependent on the observed hydrodynamics of the Elizabeth River estuary. Previous field studies of by VIMS investigators (Neilson, 1975; Neilson and Sturm, 1978) indicate that the density stratification of this estuary varies strongly as a function of season and between spring and neap tide. Stratification favors density driven circulation, while homogeneous conditions are indicative of tidal mixing. If our observations indicate dominance by tidal dispersion, we expect net transport of particle-associated contaminants overall to be down the concentration gradient, i.e., seaward transport along stretches of the river immediately seaward of the very high contamination seen in the Southern Branch of the Elizabeth River. Then accumulation rates should be roughly symmetric around the contaminant source. In contrast, if particle transport is dominated by density driven circulation, we expect landward transport of PAHs and metals throughout the entire brackish portion of the estuary. Then accumulation should be asymmetric around the contaminant source, with significantly higher accumulation rates upstream of the source. We also expect the importance of tidal dispersion versus density driven circulation (and perhaps then the direction of net contaminant transport) to vary with the spring-neap cycle and runoff. During neap tide in the wet season, landward contaminant transport is more likely, while during spring tide in the dry season, seaward contaminant transport is more likely.

DISSEMINATION OF RESULTS

The results of this research will be shared with The Elizabeth River Project Restoration Implementation Team, The U.S. Army Corp of Engineers' Elizabeth River Basin Restoration Project Manager, the Chesapeake Bay Environmental Effects Committee, and other interested managers through participation and presentations at local and regional workshops. We also expect to present results of this research at regional and national conferences attended by marine and environmental resource managers such as meetings of the: Chesapeake Research Consortium, Estuarine Research Foundation, and the Society of Environmental Toxicology and Chemistry. Interpretations of our data will be published in the peer-reviewed literature with detailed data files in electronic format available through the VIMS Data Archiving Service.

RELATIONSHIPS TO OTHER WORK

The proposed project is similar in nature to ongoing research in the Lower Chesapeake Bay and its tributaries funded by the Office of Naval Research Marine Environmental Quality/Harbor Processes Program. As part of the ONR funded research we have measured sediment accumulation rates and surface mixed layer thickness in various subenvironments of the Southern Chesapeake Bay region (York River, Wolf Trap, Cherrystone Flats), as well as conducted two tidal cycle intensives to examine particle and associated contaminant transport at two of these sites (York River, Cherrystone Flats). Our proposed Elizabeth River project is related to the U.S. Army Corp of Engineers Elizabeth River Restoration Project, in that the purpose of the latter project is to remediate seriously contaminated sediments in the Elizabeth River basin; an endeavour that will require information to be generated by the proposed project (see attached letter from Dr. Carl Fisher, Co-Chair of the Restoration Implementation Team of the Elizabeth River Project).

BUDGET JUSTIFICATION

Travel: In year 1, funds for local travel for field site assessment, sampling, and meetings with local or regional managers are requested ($500). During years 2&3, additional funds for conference travel for principal investigators and/or students to attend workshops and regional/national meetings are requested ($2-3K/year). The estimated cost of attending regional/national conferences is $500-$1000/person/meeting.

Supplies: The supplies budget includes vessel fuel and general field supplies including filters, sample containers, core tubes and accessories, hoses and pumps, and parts for maintaining the field instruments (LISST, ADV, ADCPs, CTD), as well as a Hi-8 video camera ($1500), and parts for manufacturing a settling tube and a mooring for the anchored ADCP. Laboratory supplies include: high purity solvents, acids, and gases, standards and standard reference materials, GC columns, glassware and labware to support organic contaminant, trace element, radionuclide and bulk particle property measurements.

Salary: Graduate Research Assistants are budgeted at an annual salary of $14,5000 for 1998 with a 5% increase in stipend per year for 1999 & 2000. Technical support staff salaries budgeted average $25,000/year and also include an estimated annual increase of 5%.

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*****SEA GRANT PROJECT RECORD FORM*****
I. PROJECT SUMMARY INFORMATION

SG-SID-No.:__________
Specialist:____________
SG Class:____________

INSTITUTION: Virginia Graduate Marine Science Consortium
ICODE: 5100
TITLE: CHESAPEAKE ECOTOX RESEARCH PROJECT (CERP): Quantifying Ecological Risks of Contaminated Sediments on Living Resources in Supporting Decisions on Habitat Restoration Strategies in the Chesapeake Bay

PROJECT NUMBER: R/CBT-38
PROJECT STATUS: 1
SUB PROGRAM: Toxics/CBEEC
REVISION DATE: 6/29/99
INITIATION DATE: 1/1/2000
COMPLETION DATE: 12/31/2000

PRINCIPAL INVESTIGATORS: Eugene Burreson[1], Kenneth R. Tenore[2] **EFFORT:** 1.6
ASSOCIATE INVESTIGATORS: Pete Van Veld[1], Linda Schaffner[1], William DuPaul[1], Joel E. Baker[2], Thomas Miller[2], Christopher Rowe[2], Guritno Roesijadi[2], Merrill Leffler[3] **EFFORT**: 0.8 each
AFFILIATION: Virginia Institute of Marine Science[1]
Chesapeake Biological Laboratory[2]
Maryland Sea Grant[3]
AFFILIATION CODE: 5101[1], 52-6002033[2,3]

S.G. FUNDS: $419,000
MATCHING FUNDS: $35,492
LAST YEAR'S SG FUNDS: $
LAST YEAR'S MATCH FUNDS: $0
PASS-THROUGH FUNDS: $0
LAST YEAR'S PASS-THROUGH: $0
RELATED PROJECTS: All R/CBT Projects
PARENT PROJECTS:
SEA GRANT CLASSIFICATION: Pollution-other-toxics (45)
KEYWORDS: contaminants, sediment, bioaccumulation, mesocosms, population modeling

OBJECTIVES:
Provide predictive information for management needs on sediment contamination effects on living resources

METHODOLOGY:
Combine and intrgrate scientists with chemical, toxicological, and ecological expertise to conduct experimental mesocosm studies relating to organisms through population response from exposure to sediment contaminants to develop models of quantization prediction in such contaminants in Chesapeake Bay.

RATIONALE: Use results from studies of surrogate test organisms to develop predictive models of potential sediment contaminant effects on benthic living resources in Chesapeake Bay.

*** SEA GRANT BUDGET ***

GRANTEE: Virginia Graduate Marine Science Consortium

PROJECT NO: R/CBT-38 (MD-VA Combined)

PROJECT TITLE: Chesapeake Ecotox Research Program (CERP): Quantifying Ecological Risks of Contaminated Sediments on Living Resources in Supporting Decisions on Habitat Restoration Strategies in the Chesapeake Bay

PROJECT STATUS: 1

PRINCIPAL INVESTIGATORS: Ken Tenore, Eugene Burreson

DURATION: 1/1/2000 - 12/31/2000

A: SALARIES AND WAGES	No. of Persons	Months	Sea Grant Funds	Grantee Funds
1. Senior Personnel				
a. Prin. Investigator	9	7.54	30,165	18,100
b. Associates	1	0.48	1,923	0
Subtotal	**10**	**8.02**	**32,088**	**18,100**
2. Other Personnel				
a. Professionals	1	1.48	5,539	0
b. Research Assoc.	2	16	34,000	0
c. RA Grad. Stud.	4	33.5	48,750	0
d. Prof. School Stud.	0	0	0	0
e. Pre-Bac. Stud.	0	0	0	0
f. Secret./Clerical	0	0	0	0
g. Technical/Shop	2	12	30,300	0
h. Hourly Labor	1	6	8,320	0
Total Salaries and Wages	**20**	**77**	**158,997**	**18,100**
B: FRINGE BENEFITS			43,730	5,698
Total Sal. Wages & Fringe Benefits (A+B)			**202,727**	**23,798**
C. PERMANENT EQUIPMENT			5,000	0
D. EXPENDABLE SUPPLIES			47,696	0
E. TRAVEL				
1. Domestic - US and Possessions			8,866	1,000
2. International			0	0
Total Travel			8,866	1,000
F. PUBLICATION AND DOCUMENTATION COSTS			4,301	0
G. OTHER COSTS				
1 Computer			200	0
2 Copying, library, communication			10,822	0
3 Tuition			14,280	0
4 Repair/Maintenance			500	0
5 Subcontract			9,000	0
6 Miscellaneous			600	0
Total Other Costs			35,402	0
TOTAL DIRECT COSTS (A through G)			**303,992**	**24,798**
INDIRECT COSTS: On Campus:			114,258	10,694
On Campus: 5% of RA			750	0
TOTAL INDIRECT COSTS			**115,008**	**10,694**
TOTAL COSTS			**419,000**	**35,492**

*** SEA GRANT BUDGET ***

GRANTEE:
Virginia Graduate Marine Science Consortium

PROJECT NO: R/CBT-38 (Virginia Portion)

PROJECT TITLE:
Chesapeake Ecotox Research Program (CERP): Quantifying Ecological Risks of Contaminated Sediments on Living Resources in Supporting Decisions on Habitat Restoration Strategies in the Chesapeake Bay

PROJECT STATUS: 1

PRINCIPAL INVESTIGATORS:
Eugene Burreson, William DuPaul, Linda Schaffner, and Peter Van Veld

DURATION: 1/1/2000 - 12/31/2000

A: SALARIES AND WAGES	No. of Persons	Months	Sea Grant Funds	Grantee Funds
1. Senior Personnel				
a. Prin. Investigator	3	2.7	16,883	0
b. Associates	0	0	0	0
Subtotal	**3**	**2.7**	**16,883**	**0**
2. Other Personnel				
a. Professionals	1	1	4,000	0
b. Research Assoc.	0	0	0	0
c. RA Grad. Stud.	1	12	15,000	0
d. Prof. School Stud.	0	0	0	0
e. Pre-Bac. Stud.	0	0	0	0
f. Secret./Clerical	0	0	0	0
g. Technical/Shop	1	6	16,300	0
h. Hourly Labor	0	0	0	0
Total Salaries and Wages	**6**	**21.7**	**52,183**	**0**
B: FRINGE BENEFITS 27% salaries			10,040	0
Total Sal. Wages & Fringe Benefits (A+B)			**62,223**	**0**
C. PERMANENT EQUIPMENT			5,000	0
D. EXPENDABLE SUPPLIES			14,162	0
E. TRAVEL				
1. Domestic - US and Possessions			4,260	1,000
2. International			0	0
Total Travel			4,260	1,000
F. PUBLICATION AND DOCUMENTATION COSTS			2,001	0
G. OTHER COSTS				
1 Tuition			6,000	0
2 Copying, library, communication			453	0
3 Repair/maintenance			500	0
			0	0
Total Other Costs			6,953	
TOTAL DIRECT COSTS (A through G)			**94,599**	**1,000**
INDIRECT COSTS: On Campus: 46.14% less *			31,651	461
On Campus:			750	0
TOTAL INDIRECT COSTS			**32,401**	**461**
TOTAL COSTS			**127,000**	**1,461**

* RA, Tuition, permanent equipment

*** SEA GRANT BUDGET ***

GRANTEE: Virginia Graduate Marine Science Consortium

PROJECT NO: R/CBT-38 (Maryland Portion)

PROJECT TITLE: Chesapeake Ecotox Research Program (CERP): Quantifying Ecological Risks of Contaminated Sediments on Living Resources in Supporting Decisions on Habitat Restoration Strategies in the Chesapeake Bay

PROJECT STATUS: 1

PRINCIPAL INVESTIGATORS: Ken Tenore, Joel Baker, Merrill Leffler, Thomas Miller, Guritno Roesijadi, Christopher Rowe

DURATION: 1/1/2000 - 12/31/2000

A: SALARIES AND WAGES	No. of Persons	Months	Sea Grant Funds	Grantee Funds
1. Senior Personnel				
a. Prin. Investigator	6	4.84	13,282	18,100
b. Associates	1	0.48	1,923	0
Subtotal	**7**	**5.32**	**15,205**	**18,100**
2. Other Personnel				
a. Professionals	1	0.48	1,539	0
b. Research Assoc.	2	16	34,000	0
c. RA Grad. Stud.	3	21.5	33,750	0
d. Prof. School Stud.	0	0	0	0
e. Pre-Bac. Stud.	0	0	0	0
f. Secret./Clerical	0	0	0	0
g. Technical/Shop	1	6	14,000	0
h. Hourly Labor	1	6	8,320	0
Total Salaries and Wages	**15**	**55.3**	**106,814**	**18,100**
B: FRINGE BENEFITS			33,690	5,698
Total Sal. Wages & Fringe Benefits (A+B)			**140,504**	**23,798**
C. PERMANENT EQUIPMENT			0	0
D. EXPENDABLE SUPPLIES			33,534	0
E. TRAVEL				
1. Domestic - US and Possessions			4,606	0
2. International			0	0
Total Travel			4,606	0
F. PUBLICATION AND DOCUMENTATION COSTS			2,300	0
G. OTHER COSTS				
1 Computer			200	0
2 Copying, library, communication			10,369	0
3 Miscellaneous			600	0
4 Subcontract			9,000	0
5 Tuition			8,280	0
Total Other Costs			28,449	0
TOTAL DIRECT COSTS (A through G)			**209,393**	**23,798**
INDIRECT COSTS: On Campus: 43% less subcontract, tuition			82,607	10,233
On Campus:			0	0
TOTAL INDIRECT COSTS			**82,607**	**10,233**
TOTAL COSTS			**292,000**	**34,031**

Ref. No. [UMCES]CBL 99-0067a

PROPOSAL TITLE: CHESAPEAKE ECOTOX RESEARCH PROJECT (CERP): Quantifying Ecological Risks of Contaminated Sediments on Living Resources in Supporting Decisions on Habitat Restoration Strategies in the Chesapeake Bay.

SUBMITTED TO: The Chesapeake Bay Environmental Effects Committee (CBEEC). Toxics Research Program

SUBMITTED ON BEHALF OF: The Chesapeake Research Consortium Institutions: The Academy of Natural Sciences Estuarine Research Center (ANSERC), Old Dominion University (ODU), The University of Maryland Center for Environmental Science (UMCES), Virginia Institute of Marine Sciences (VIMS)*

PRINCIPAL INVESTIGATORS:

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ESTIMATED DURATION AND STARTING DATE: Five years starting January 1, 2000

PROPOSED CBEEC FUNDING: $2,500,000 for five years; year 1 (2000) request is $500,000

*CERP proposed activities are organized and presented across institutional lines. The budget component of this proposal is submitted in two sections: one section from the University of Maryland Center for Environmental Science, which includes a subcontract to the Academy of Natural Sciences Research Center; and one section from the Virginia Institute of Marine Science, which includes a subcontract to Old Dominion University. Institutional signatures are included with the respective budgets.

1. Introductory Statement of Overall Project Objectives and Relevance to Resource Management.

CBEEC-funded research on toxics in the Chesapeake Bay over the last decade has increased our understanding considerably about contaminant transport, the effects of sediment flux processes and the ecological implications of contaminant exposure, uptake and trophic transfer. There are, however, significant missing data, especially on quantifying organismal response to contaminants, especially in linking organismal effects to population, community, and ecosystem levels of biotic organization. Furthermore, resource management agencies have been unable to make effective use of what available scientific knowledge we do have to develop reliable strategies of pollution abatement, remediation and habitat restoration. The scientific community has not provided results in a form that allows managers to predict the effects of alternative management decisions on the bioavailability and effects of chemical contaminants on living resources. Because such predictive capabilities are critical for resource management agencies, the Chesapeake Bay Environmental Effects Committee (CBEEC) has focused its request for proposals on quantifying the ecological risks of sedimentary contaminants to living resources, especially commercially valuable and key food chain species.

Towards these ends, we are proposing a five-year Chesapeake Ecotoxicology Research Project (CERP) that seeks to provide predictive information for management needs on sediment contamination effects on living resources. CERP combines and integrates efforts of scientists with a broad spectrum of chemical, ecological, and toxicological expertise, from four major research institutions on the bay: the Academy of Natural Sciences Research Center (ANSERC), Old Dominion University (ODU); the University of Maryland Center for Environmental Science (UMCES); and the Virginia Institute for Marine Science (VIMS). CERP activities (tasks) are organized to: (1) provide needed scientific information on the links between organism response and effects on higher levels of biotic organization (population/ community/ system); (2) inform, embed, and evaluate that research into an assessment format of synthesizing existing data; and (3) provide a series of 'outreach' workshop, conferences, and publication activities to insure informing and seeking feedback of our scientific findings from all societal stakeholders.

While our research efforts will focus on the three regions of concern (ROCs) that the Chesapeake Bay Program (CBP) has identified, the Anacostia and Elizabeth Rivers and Baltimore Harbor (CBP, 1994), the results will serve broader application throughout the Bay and for similar aquatic ecosystems nationally. The three ROCs, though geographically dispersed, ecologically different, and subject to different contaminants, still have much in common: all are highly urbanized, the sediments exhibit potentially high levels of similar suites of metals and/or organic pollutants, living resources show some level of contaminant uptake, benthic communities have been altered (i.e., reduced ecological value), and harvestable resources are to different degrees and for varying reasons restricted. Thus we can in great part integrate our proposed research on these different sites. The comparative scientific information needed for resource management of the ROCS, such as characterizing exposure-response relationships across contaminant gradients and environmental parameters, also will provide valuable information for bay-wide management needs, e.g., in predicting "halo effects" of contaminants associated with sediment/living resource transport from ROCs or similar areas.

Identifying and predicting lethal and sub-lethal ecological risks of sediment contaminants on living resources requires an integration of chemical, ecological, and toxicological expertise for identifying contaminant exposure effects across several levels (organismal- population-community) of biological organization. We propose to make the causal link between exposure (bioavailability), toxicological effects on individuals, and resulting effects on fitness and dynamics of their populations the paradigm of CERP (figure 1). We are focusing on these exposure-to-population level effects because of the limited state of our conceptual knowledge beyond population level effects (Pratt and Cairns 1996). Similarly, we are focusing our efforts at this time on experimental mesocosm-based research that we feel is best suited to answering our research hypothesis. We are able to build upon previous information on contaminant fate from previous CBEEC-funded research. The present proposed research focuses on quantifying and predicting the effects of varying contaminant levels characteristic of these bay sites on biological processes, including not only organismal survival but also affects on population dynamics and survival. We expect that the information we shall generate would allow for quantitative interpretation and prediction of following field monitoring programs.

CERP proposes linking: (1) existing data from the ROCs organized in a framework of an ecological risk assessment (ERA) with (2) development of experimental mesocosm studies using surrogate species to quantify effects of contaminant exposure on organismal and population processes, and (3) development of predictive population models for application to management issues concerning contaminated sediment management in the Chesapeake Bay. While the CBEEC request for proposals emphasized the need for synthesis, suggesting a fifth year devoted to that activity, we propose to integrate synthesis throughout the five year period: (1) initial emphasis will aim at organizing the information already available on potential sediment contaminant effects via a risk assessment exercise, (2) small workshops will focus on specific issues that relate scientific findings to target management issues; these workshops will bring together project scientists, managers/ stakeholders and special experts throughout the middle years of the grant, and (3) researchers will integrate project findings into the initial risk assessment assay and provide specific management recommendations. These activities will provide a framework for a continual input of management/ stakeholders into the scientific research. An integral element for successful interaction among research, management and other stakeholders is a program of outreach and communications (see section 4). To accomplish this goal, and insure integration across the individual research elements, we allot what we feel are necessary amounts of funds into the 'management' and 'outreach' budgets of this CERP; but we emphasize that those funds are designed and will be used to enhance cross-scientific/managerial integration and synthesis into the CERP research as well as community stakeholder participation and input through facilitating not only information flow but true cross communication.

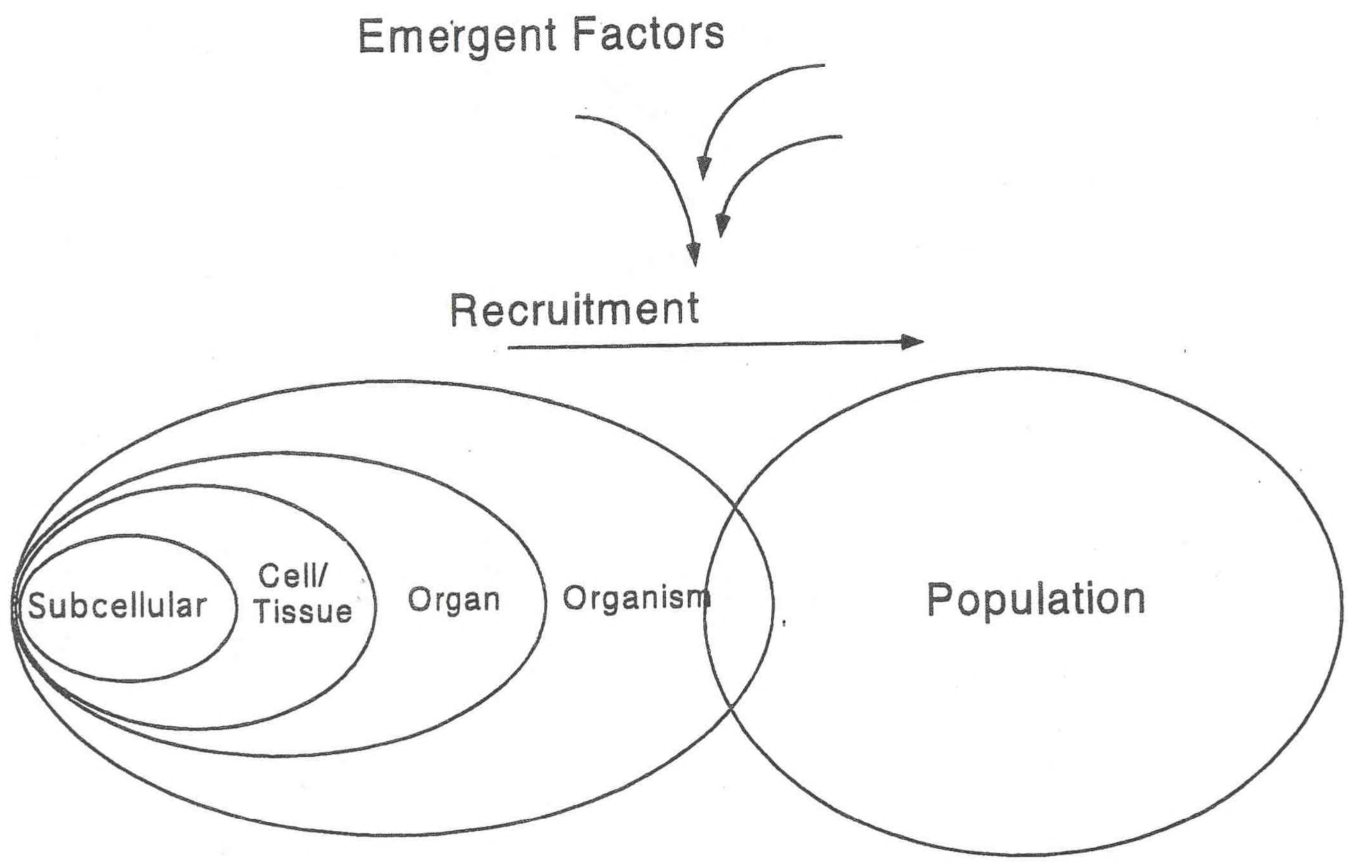


Figure 1. Nested view of biological organization at individual level with emergent factors affecting organism/population coupling.

2. Description of CERP Proposed Research Project

2.a Project Organization, Integration and Synthesis Efforts.

Two major objectives that we view as paramount in insuring good transdisciplinary science pertinent to management needs are: (1) integration across participating institutions and scientific disciplines (chemical, ecological, toxicological) and (2) support for continual scientist-management/stakeholder communication. We propose three infrastructures in the organization of the CERP project that will provide project integration and two-way communication with managers to achieve information germane and organized to address management issues:

2.a.(i) CERP Advisory Council and AC Steering Committee. We propose to facilitate planning, co-ordinate project activities, integrate, and implement CERP research and reporting activities, and facilitate project-management interaction through a CERP Advisory Council. The Council will be co-chaired by the Director of the Chesapeake Research Consortium (Dr. M. Grant Gross) and the two Co-ordinating Principal Investigators (Drs. Ken Tenore and Gene Burreson). The Council will include CERP Principal Investigators and representatives of major state and federal managers and other stakeholders. We shall facilitate communication of all Council participants, as well as other CERP activities, with a web-accessed CERP bulletin board. Meeting agenda will focus on progress and implications of ongoing research, synthesis, and outreach activities. Short progress reports on ongoing activities will be posted on the bulletin board ahead of any meeting and council members will be expected to review and familiarize themselves with these briefs. Thus time at the Council meetings will focus on input from management decision makers and project scientists on insuring continuing feedback and integration of CERP research elements, synthesis activities (Focused Issues Workshops and SIERA activities described below), and outreach activities (section 4). An AC steering committee composed of co-chairs and representatives of the state and federal management stakeholders and team leaders of the CERP research project elements (described in 2b), will meet more regularly and plan for council meetings, help define issues and format for the issues workshops, and work with the outreach team in insuring effective science-management-public interaction (see section 4). Through CRC, the Advisory Committee will also provide coordination and cooperation with other ongoing sediment contaminant efforts including: The Chesapeake Bay Ambient Toxicity Monitoring Program (AMTOX), any projects funded by the EPA Chesapeake Bay Toxics Committee on chemical contaminant characterizations in the Chesapeake Bay's tidal rivers, NOAA's Biological Effects Associated with Sediment Contamination Study, and the MAIA-Estuaries Information Management Team.

2.a(ii) Issues Workshops. We recognize that initially and throughout the CERP effort there will be specific issues that need to be addressed both for scientific validity and applicability to management needs as substantively outlined in the CBEEC RFP. One example would be the rationale and criteria for use of surrogate species to represent the diverse living resources of Chesapeake; another might be the need to distinguish applicability to monitoring living resources using toxicological assays as 'biomarkers of exposure' versus 'biomarkers of effect'. We propose to organize during the course of the project one-day workshops to focus on such specific questions to benefit continued oversight and planning of CERP activities by scientists and managers on the advisory council. Where appropriate, council members, both scientists and managers, or outside experts will be invited to prepare short 'white papers' defining and framing the question in hand and providing a background for the workshop agenda for group discussion. These white papers and summary of discussions will be edited and published as a product of CERP by the outreach group (see section 4). Where appropriate, white papers will be adapted as CERP Briefs or fact sheets for reaching stakeholders such as the Chesapeake Bay Program, government agencies, environmentalists and others - the aim here is to ensure that these public have access in "plain language" to important research issues with management implications.

2.a(iii) Synthesis of Information for Ecological Risk Assessment (SIERA) A focused research strategy is proposed by CBEEC to better link chemical contamination of sediments to effects on living Bay resources. This strategy aims at a tighter integration of information than afforded by past research programs and at the production of information directly applicable to assessing risk to living resources.

Because CBEEC states that its past funding (1) produced high quality information, (2) yielded information that was not integrated into a form directly useful to resource managers and stakeholders, and (3) its current funding will be used to provide more integration of scientific information into a form useful to managers and stakeholders, we propose funding for a scientific re-analysis of current information and a synthesis of that information into the framework of the National Academy of Science (NAS) Risk Assessment Paradigm.

Risk assessment is the formal process for estimating the probability or likelihood of an adverse effect to humans or a valued ecological entity. It applies scientific methods and information in a way that provides risk managers enough information to make wise decisions. According to the NAS paradigm, any risk assessment will have four components: hazard identification, exposure assessment, effect assessment, and risk characterization. Hazard identification defines the potentially hazardous situation including the chemicals of concern, the ecological entity to be protected, a plan for conducting the assessment, and production of a conceptual model around which the assessment will be built. After the potentially hazardous situation is defined, exposure assessment estimates the magnitude of releases, identifies potential pathways of exposure to the protected entity (e.g., to a commercially valued or ecologically crucial species), evaluates bioavailability, and then estimates exposure. Next, in the effect assessment, the effect resulting from the exposure is calculated. This may involve the re-analysis of published information or the generation of new information. The information from the exposure and effect assessments are then combined to produce the risk characterization. This final statement of the actual risk includes discussion of associated uncertainties and assumptions. The level of confidence in any extrapolations (e.g., from well-studied bioassay species to dominant species in the field) is outlined.

There are several advantages to this risk assessment paradigm. First, it is fast becoming the favored context for evaluating the danger associated with environmental agents. Second, it requires resource manager involvement in the initial problem formulation (hazard characterization), assuring that the process will produce results useful to them. Third, what is to be protected is clearly identified as being worth protecting for ecological, legal, commercial, recreational or some other reason. Fourth, the scenario being assessed is formally and explicitly formulated, reducing the danger of providing an ambiguous answer to an unclear, initial question. Fifth, the emphasis is on calculating and expressing risk in quantitative terms. Sixth, discussion and calculation of uncertainty is a required component of risk characterization. These advantages of ecological risk assessment combine to produce a powerful tool for translating scientific knowledge into a form directly useful to resource managers.

SIERA Objectives: The CBEEC Program has funded numerous research projects that produced high-quality information describing diverse aspects of contamination in the Bay. Our emphasis will shift toward one inter-institutional program producing integrated information of direct use to natural resource managers. To greatly enhance integration, a synthesis of existing information is proposed in the framework of the NAS risk assessment paradigm. A team of scientists, focusing on one NAS risk assessment component at a time, will develop written and electronic Synthesis of Information for Ecological Risk Assessment (SIERA) documents. Key components of these documents will be those crucial in the four steps of any ecological risk assessment, especially those associated with sound decision-making (weight-of-evidence and uncertainty analysis) They will emerge from a re-analysis and integration of existing data during SIERA team meetings, information generated from the CERP research proposed herein, quarterly workshops with regional scientists and resource managers, and external reviews. Deficiencies in risk assessment methodologies will also be addressed with results being published in the peer reviewed literature, and presented to local regulators and stakeholders.

Products: The SIERA project will not provide ecological risk assessments for the regions of concern. It will synthesize information for the Chesapeake Bay area, especially the regions of concern, in the context of the NAS risk assessment paradigm. The numerous, but highly dispersed, data sets and conclusions of researchers and regulators will be reviewed, re-analyzed as required, and thoughtfully integrated in a risk assessment context. It will produce a body of information that will be easily applied to ecological risk assessment (ERA), indicating and illustrating the tools available for conducting an ERA with the synthesized information. It will also identify significant data gaps.

SIERA Documents: Four (electronic and written) SIERA documents will be produced, SIERA - Hazard Identification, SIERA - Exposure Assessment, SIERA - Effect Assessment, and SIERA - Risk Characterization. Each will be framed around the Chesapeake Bay region with particular emphasis on the Elizabeth River, Baltimore Harbor, and Anacostia River. Involvement of regional resource managers, stakeholders and scientists will be provided at quarterly Bay community meetings when the working group's progress will be presented and then critically evaluated. An important component of these documents will be analyses of decision uncertainty, ranging from weight-of-evidence to formal statistical analyses. The SIERA documents will be written as living documents requiring periodic revision. They will be produced in paper and electronic formats with the electronic version integrated into the CERP outreach website. Links will also be made to important sources of information and methods elsewhere on the web. Sections of these documents will be revised as information from the CERP research component becomes available. At the completion of each document, informal workshops involving SIERA personnel, local regulators and stakeholders will be held with the purpose of sharing information immediately with potential users.

SIERA Website including Integration with the CERP Outreach Website: Ready accessibility of existing risk assessment information, methods, software, local expertise and documentation will be provided on an extensive website. It will be modeled after the Oak Ridge National Laboratory site (http://www.hsrd.ornl.gov/ecorisk/ecorisk.html) with more emphasis on accessibility to resource managers not fully trained in ecological risk assessment (e.g., the VIMS web pages, http://www.vims.edu/env/departments/riskchem/index.html). The website development and integration will be facilitated by technical exchange between the SIERA program personnel and the CERP outreach team of this project. The significant website and GIS expertise at VIMS and Maryland Sea Grant will be used together to produce a high quality site.

Peer Reviewed Publications: During the course of the activities described above, technical and scientific publications will be produced in the areas of estuarine risk assessment and statistical means of analyzing associated data. Although other topics will emerge during the development of SIERA documents, representative topics tentatively identified are the following:

1. Re-sampling statistics improve the application of species sensitivity distribution information in risk assessment. Assessment of risk to ecological communities is now being performed by parametric statistical analysis of collections of data about sensitivity of individual species. Although an improvement over assessment based on the hazard quotient of the most sensitive species, these are several shortcomings to these new methods. They rely on the assumption of a log normal distribution of sensitivities and gross estimates of adequate sample size. A bootstrap method will be developed that removes these problems. These methods will be developed using data from the Chesapeake Bay region.

2. Predicting relative metal toxicity in estuarine sediments with quantitative ion character-effect relationships. Although quantitative structure-activity relationships are applied often in ecological risk assessment for organic contaminants, no such relationships have been applied for metals. Methods developed by Newman to do this will be focused on species and metals relevant to the Chesapeake Bay region. An attempt will also be made to apply them to the CERP mesocosm data for bioaccumulation from sediments to fish and amphipods.

3. Improving risk characterization with meta-analysis. Often a series of statistical statements from published research are available to the risk assessor for determining the likelihood of an adverse effect occurring. Informal methods are applied for integrating this information into a statement of risk. However, formal meta-analysis can be applied to these data to generate a more definitive and defensible statement. These methods will be developed using data and sites relevant to the Chesapeake Bay region. They will also be applied to the CERP mesocosm results.

4. Methods for correctly calculating univariate statistics and testing hypotheses for data sets with "below detection limit" observations. In ecological risk assessments, concentrations of contaminants at the site of concern are compared to background or ambient concentrations. If the concentrations are higher than ambient and a risk of an adverse effect is suspected, remediation may be recommended. This decision process is hampered by the presence of "below detection limit" observations in the samples from reference sites. Informal ways of handling these data (e.g., use the detection limit in place of the nondetects) are statistically invalid and often result in inappropriate decisions. Straightforward methods for estimating univariate statistics (i.e., mean and variance) and hypothesis testing (e.g., are concentrations higher at the site relative to ambient levels?) will be examined and the best described for such data sets. Example data sets will be taken from the CERP mesocosms and the regions of concern in the Chesapeake Bay area.

5. A comparison of conventional and bootstrap estimates of adequate size (number and weight) for environmental samples. Assessing exposure in risk assessments involves accurate determination of concentrations of chemicals of concern in different media, e.g., water, sediment, and biota. However, conventional methods for estimating the sample necessary to get an accurate estimate of concentrations are often inadequate. An easily-applied, bootstrap method for determining adequate sample size (i.e., number of samples and weight of sample) will be described and compared to conventional approaches. Example data sets will be taken from the CERP mesocosms and the regions of concern in the Chesapeake Bay area.

2.b Key research questions to be addressed by experimental mesocosm studies.

The fundamental question of interest is "what are the relationships between sub-lethal levels of contamination and the ecology of estuarine organisms?" A quantitative understanding of these relationships will enable management agencies to rank the importance of control and amelioration efforts with respect to the likely impacts on ecologically and commercially important species. Within this broad interest we have developed several specific hypotheses:

-H1. Sub-lethal levels of contaminants alter the size-structure in estuarine populations;

-H2. Sub-lethal levels of contaminants reduce the reproductive fitness of individuals by altering 1) time to first reproduction, 2) fecundity or 3) offspring quality of estuarine organisms;

-H3. Sub-lethal levels of contaminants reduce the population growth rate of estuarine organisms;

-H4. Sub-lethal levels of contaminants alter the distribution or behavior of estuarine organisms;

Exploration of each hypothesis will yield insights into the long-term effects on populations of exposure. The results have consequences for understanding the distribution, characteristics, abundances, and productivity of populations in the three ROC's

2.b.(i) Chemical Contaminants in Chesapeake Bay Regions of Concern. The Chesapeake Bay Program has identified three areas within the Chesapeake Bay ecosystem as 'Regions of Concern' due to elevated levels and impacts of chemical contaminants in sediment (Chesapeake Bay Program, 1994). Here we briefly review what is known about chemical contaminant levels in the Baltimore Harbor, Anacostia River, and Elizabeth River ROCs and discuss the types of chemicals present in these sediments that will serve as the stressors in our mesocosm experiments. It is important to note that the proposed study takes advantage of the detailed characterizations of the ROCs that have already been completed--thus it is not necessary to include an extensive field component to this program. We emphasize that our strategy is to use actual ROC sediments as the stressor in the mesocosms in order to provide exposure to a realistic complex mixture of chemicals. It is not our intent here to map the spatial variability of contaminant stresses in these complex environments, or to ascribe the observed effects to individual components of the mixture. Rather, we have chosen in this design to focus on quantifying the effects of a realistic exposure to actual ROC sediments at the individual and population level.

Baltimore Harbor and Patapsco River: The Baltimore Harbor system, including the Patapsco River estuary is surrounded by the Baltimore metropolitan region. During the past several years, extensive studies have been conducted of the levels of metals, mercury and organic contaminants in Baltimore Harbor sediments (Ashley and Baker, 1999; McGee et al., 1999; Mason and Lawrence, 1999), surface waters (Bamford et al., 1999), and the atmosphere (Offenberg and Baker, 1999). Large spatial gradients in contaminant levels in the sediments due to relatively poor mixing result in 'hot spots' near storm water outfalls and industrial areas. Elevated levels of polycyclic aromatic hydrocarbons (PAHs) and metals are found around Sparrow's Point, historically the site of intensive coal coking and steel production. Organochlorines, including polychlorinated biphenyls (PCBs), are elevated adjacent to storm water outfalls. Forty percent of the sites within the Baltimore Harbor have PCB levels that exceed the 'effects range-medium' value of Long et al. (1995). Survival of the estuarine amphipod *Leptocheirus plumulosus* was reduced in seven of twenty-five Baltimore Harbor sediment sites studied by McGee et al. (1999). Toxicity at stations in Bear and Colgate Creeks may have been due to sediment-associated metals, while sediment toxicity in the Inner Harbor was likely due to both metals and organic contaminants (polycyclic aromatic hydrocarbons). In addition to the studies above, several current research programs are ongoing to characterize the sources and transport of nutrients and chemical contaminants in the Baltimore Harbor system, including the NSF Long-Term Ecological Research Baltimore Ecosystem Study and the Comprehensive Harbor Assessment and Regional Modeling Study sponsored by the Maryland Department of the Environment. These concurrent studies will provide complementary field observations to the mesocosm studies and population modeling proposed here.

The Anacostia River: Most of the Anacostia's relatively small watershed (440 km^2) is within the highly urbanized and suburbanized regions surrounding Washington D.C. The sediments of the Anacostia River are contaminated with a number of pollutants, including organics (PCBs, PAHs, and pesticides) and trace elements (As, Cd, Cu, Hg, Pb, Ni and Zn; Velinsky et al., 1994; 1997; Wade et al., 1994) that have had substantial biological impacts to benthos (Schlekat et al., 1994). Levels of PCBs, chlordanes and other hydrophobic organic chemicals (HOCs) in wild fish tissues from the Anacostia and the Potomac have also been documented (Velinsky and Cummins, 1994; 1996). These two chemicals, and possibly others, pose an ongoing concern for consumers of fish from these rivers in the District of Columbia (DC), Maryland and VA and has resulted in fish consumption advisories being posted by the DC government. Current studies of fish tissue concentrations indicate that concentrations of many bio-accumulative organics (e.g., PCBs, chlorates and others) are highest in the bottom-dwelling channel catfish (*Ictalurus punctatus*) and common carp (*Cyprinus carpio*) in the Anacostia River (Velinsky and Cummins, 1994; 1996). The benthos in this system has also been highly impacted, with substantial decreases in species richness of oligochaete and chironomids, the dominant infaunal benthos in the more impacted areas of the river (Schlekat et al., 1994). Recent and current field studies of contaminant transport and bioaccumulation in the Anacostia River system (supported by CBEEC) will provide comparative data for our mesocosm studies.

The Elizabeth River: The Elizabeth River watershed is a complex system of branches and small tributaries that also contains a deep water harbor used by the US Navy and many maritime industries. The watershed is approximately 600 km^2 and ambient water and sediment quality is influenced by the highly industrialized commercial and military activities and densely populated urban areas of the metropolitan Hampton Roads Region. The water and sediment within the River contain at least trace amounts of most pollutants expected to originate from the use of the harbor system since colonial times, the intensity of industrial and military activities, and the relatively dense urban population. PAHs occur in sediments in moderate concentrations throughout most of the Elizabeth River and occur in extremely high concentrations in the sediments in the vicinity of sites where creosote was historically used to treat wood for use in the marine environment (Greaves, 1990; Alden and Winfield, 1995). Trace elements and tributyl tin (TBT), an antifoulant used on ship hulls, are also of concern. The Elizabeth River is closed for harvesting fish and shellfish. Residue concentrations PAHs, PCBs, 4,4'-DDE as well as trace elements (Ag, As, Cd, Cr, Cu, Hg, Pb, Ni, Zn) are present in the muscle and hepatopancreas of the blue crab (Greaves 1990; Alden and Winfield, 1993). The macrobenthic communities of the Elizabeth River are considered to be highly impacted with lower species diversity, lower abundance of individuals, lower biomass, and dominance by pollution indicative taxa (Hawthorne and Dauer 1983; Dauer et al. 1993; Dauer 1993; Dauer et al. 1998). Currently, several studies of the occurrence, impact, and efficacy of remediation strategies are underway in the Elizabeth River system. Several of the our investigators (Newman, Dauer, VanVeld) are involved in these studies, and will provide links with the mesocosm and modeling studies proposed here.

Trace elements: A number of trace element contaminants are present in Chesapeake Bay sediments at concentrations that can potentially have harmful effects (Eskin et al., 1996). Trace element contaminants can be categorized into different groups depending on their chemical and toxicological behavior. Simply knowing the concentrations of toxic trace elements, either in solution or in sediment, is insufficient to predict their behavior and effects; one must also know their geochemical form and context. One important group, consisting of Ag, Cu, Cd, Ni, Pb and Zn form strong, highly insoluble precipitates in the presence of sulfide, a common, but temporally and spatially variable component of sediment (e.g., van den Hoop et al, 1997). The 'AVS-SEM' hypothesis concerning this group is that if the acid volatile sulfide present is greater than the molar sum of the SEM metals, the metals will be almost exclusively bound to sulfide, their bioavailability will be extremely low, and toxicity is unlikely (e.g. Di Toro et al., 1990; Ankley et al., 1991). While mercury does form a highly insoluble sulfide, and geochemically could be considered a member of the AVS-SEM group, its toxicological properties are uniquely defined by the formation of methylmercury (MeHg). MeHg is more toxic than inorganic Hg, and highly bio-accumulative (e.g. Lawson and Mason, 1998). MeHg is formed from inorganic mercury by biological methylation (Gilmour and Henry, 1991; Matilainen, 1995). Arsenic and selenium form another group unusual among trace elements in that they are anions under environmental conditions. Both exhibit complex geochemistry, including alternate redox states, and the formation of covalently bound organic species (e.g. Cutter, 1992; Tokunaga et al. 1997; Riedel et al., 1997; Riedel et al, In Press).

Persistent Organic Chemicals: Organic chemicals in sediments may cause deleterious effects through direct toxicity to aquatic organisms (narcosis, chitin synthesis inhibition, neurotoxicity) or through biomagnification to apex predators, including humans. In the Chesapeake Bay Regions of Concern, hydrocarbons, including PAHs, are the most likely organic chemicals causing ambient toxicity, while the persistent organochlorines are most likely of concern in biomagnification. Although a myriad of organic chemicals are produced and released to the Chesapeake Bay region, only those with sufficient persistence and particle-reactivity will accumulate in sediments. These organic chemicals may be classified by source or by their potential effects. Many organic chemicals found in Chesapeake Bay sediments are inadvertently produced through the combustion of fossil fuels (PAHs) and the incineration of industrial, medical, and municipal wastes (chlorinated dioxins and furans). Others are industrial and agricultural chemicals that enter the environment during manufacturing and shipping (chlordane in Baltimore Harbor, Kepone in the James River), through improper disposal practices, or through agricultural runoff.

2.b.(ii) Use of test animals. Relatively few of the ecologically or commercially important species of Chesapeake Bay are readily amenable to experimentation in ecotoxicological research. For the proposed work, we selected several surrogate species that we feel are both amenable to culture, have been previously used in toxicological research, represent different ecological types, and are suitable for studies of contaminant exposure effects at the individual to sub-individual levels.

The amphipod, *Leptocheirus plumulosus*. Benthic amphipods are increasingly favored for evaluating sediment toxicity because they are sensitive to a wide range of contaminants (Swartz et al. 1979; MDE 1991; USEPA/USACE 1991, 1994; US EPA 1996). *Leptocheirus plumulosus,* an ecologically-important estuarine species of Chesapeake Bay (Diaz and Schaffner 1990), is easily cultured, exhibits high survival under a variety of environmental test conditions and displays sensitivity to reference toxicants similar to those of other amphipods (Schlekat et al. 1992, Kane Driscoll et al. 1997). Standardized methods that use *Leptocheirus* to evaluate chronic effects of contaminated sediments (McGee et al. 1993, USACE 1996, De Witt 1997, personal communication) have been used in Chesapeake Bay (McGee et al. 1999). These factors contribute to the value of using *Leptocheirus* to assess current sediment quality, and to imply levels of clean-up required to minimize impacts from sediment-associated pollutants.

***Fundulus* spp.** The genus *Fundulus* includes several species of widely studied, ecologically- important, nonmigratory estuarine fish (Bigelow and Schroeder 1953; Fritz et al. 1975), with *F. heteroclitus* common in saline parts and *F. diaphanus* common in tidal freshwater regions of Chesapeake Bay. Increasingly popular sentinels of environmental contamination in biomarker and population genetics studies, these fish exhibit a dose-dependant response to contaminants (e.g., PAHs, PCBs, Van Veld et al. 1997) and elevated prevalence of hepatic and extrahepatic lesions with increasing pollution (Vogelbein et al. 1990). Reproduction, embryonic development, and behavioral characteristics are well studied, as are teratogenic effects of environmental toxicants (Atz 1986; Weis 1989; Zhou and Weis 1998). These small fish are easily collected, inexpensive to maintain and rear, breed several times a year and bear large, easily visualized eggs and embryos. An EPA STAR-funded study of *Fundulus* population genetics in the Elizabeth River currently underway will provide insights into use of this species.

2.b.(iii) Rationale and description of mesocosms. Extensive information exists on the acute response of aquatic animals to exposure. This information is helpful in determining limiting concentrations of chemicals of concern with respect to survival and sustainability of populations in the environment. Importantly, as the organism's response of interest in acute studies is the limit of its biochemistry or physiology, experiments can be conducted over short time and small spatial scales. In contrast, information on chronic, sub-lethal effects of contaminants is less available. In part, the paucity of information reflects the difficulty of scaling the organism's exposure and responses to its life cycle and ecology (Perez 1995). The need to adequately address these scaling issues has hindered quantification of chronic, sub-lethal effects.

Mescosm studies have become widespread in ecology in the last twenty years as biologists have tried to address population and community responses across a range of temporal and spatial scales (Resetarits and Bernardo 1998). Two ongoing studies involving the use of mesocosms are underway within the Chesapeake region (i.e., MEERC within UMCES, and COASTES within ANS-ERC). We propose to use a mesocosm-based experimental approach over four years to quantify the relationships between sub-lethal contaminant exposure and ecological function. Use of mesocosms will permit us to manipulate and measure the effects of contaminant exposure on the ecological function of both surrogate species. In our studies we will: (1) measure sediment-bound and dissolved levels of contaminants, (2) characterize the exposure of individual organisms by quantifying sub-organismal biomarkers of exposure and body residues, 3) quantify the ecological responses (growth, survival and reproduction) of populations of surrogate species in the mesocosms, and (4) develop population-level models that examine the consequences of exposure, assessed by biomarkers of exposure and changes in growth, survival, reproduction, and behavior, to the dynamics of the population.

In the first suite of mesocosm experiments in the first two years of the project, we will focus on defining the sediment ecotoxicology of *Leptocheirus plumulosus* when exposed to sediments from each ROC. This amphipod can be found in high density local patches and has a generation time of approximately 28d. We will use 90 d. exposures in 20-100 L mesocosms, thereby allowing approximately three generations to develop. Mesocosms will be maintained with a continuous flow of screened 35 μm unfiltered water, under natural light, to provide a constant source of fresh detritus and local production to fuel benthic processes. Exposure treatments will be generated by generating contaminant gradients for each of the three regions of concern (Anacostia River, Baltimore Harbor and Elizabeth River) separately. We will combine sediments from each ROC with "control" sediment (low contaminant level) of similar texture collected from a reference site, to produce a gradient of 5 levels of contamination, from the most polluted sites within the ROCs to levels similar to the low contaminant levels found in less impacted areas. Two experiments will be conducted as a 3 ROC x 5 contaminant level x 3 replicates factorial experiment. Sediments will be defaunated of macrofauna with heat and anoxia by covering the sediments with heavy black polyethylene prior to initiation of each experiment. Animals will be sampled from the mesocosm using pre-positioned trays on six occasions at equally spaced intervals during the experiment. Sampled organisms will be studied for: exposure and bioaccumulation (Riedel & Baker), biomarkers of exposure and effect (Roesajadi & VanVeld), and impact of exposure on behavior, survival, growth and reproduction (Schaffner, Rowe and Miller).

In the first year, a mesocosm experiment (Experiment L1) will be used to quantify the patterns and consequences of contaminant exposure across the 5-level gradient at the individual level. Analyses will focus on identification of the dose-response relationship of potential biomarkers, behavioral patterns and bioenergetics. Individual-level data, such as growth and fecundity will be analyzed using the life table response methodology (Levin et al. 1996, Caswell 1996). This approach provides direct estimates of sub-lethal chronic effects and sensitivities of population rates of change. These data will be used to parameterized population level models.

Bioenergetic, stage-based and individual-based simulations will be developed (see 2.b.(ii). In combination, these models will enable us to predict growth rates, generation times and population-level characteristics such as the dynamics of the size distribution and body burdens of animals in the population from biomarker-based quantification of exposure. In addition multi variate analyses such as multiple discriminate analysis will be used to examine the patterns of covariation among the contaminant, biomarker and ecological datasets in combination (Green 1979). In the second year, the duration of the mesocosm experiment will be doubled (Experiment L2). The results of this experiment will be used as a direct test of the predictions of the population level models, in addition to further quantifying dose-response relationships.

The second suite of experiments, conducted in the third and fourth years of the project, will focus on mummichogs (*Fundulus heteroclitus*). Concern over ensuring appropriate spatial and temporal scales of any experiment are particularly relevant for our fish experiments. We will use 1.8 m diameter cylindrical mesocosms, filled to a depth of 1 m. Fish will be maintained in the mesocosms at densities of between 8-32 m^{-3}. This will permit us to stock between 21-84 individuals in each mesocosm. However, the increase in the size of individual mesocosms will prevent us from conducting experiments involving sediments from each of the ROC's. Instead, we will use sediments from a single site to produce a gradient of contamination. Three contaminants levels will be used. Choice of sediments will be based on results from the SIERA process and from the results from both the *Leptocheirus* experiments conducted in the previous years. Mesocosms will be stocked with marked juvenile mummichogs (20 mm TL), and the experiments continued for 120 d, allowing for production of at least one new generation. In addition to the sediment treatment, we will examine the role of food supply, by offering pelleted food at two different rates in the experiment. The design will be a 2x3x3 (food x sediment concentration x replicate) factorial experiment. Fish will be sampled twice from the mesocosm using minnow traps during the experiment. Sampled organisms will be studied for the impact of exposure on behavior, growth, and bioenergetics (Schaffner, Rowe and Miller). Following these trials, the sampled individuals will be examined for exposure and bioaccumulation (Riedel & Baker), and biomarkers of exposure and effect (Roesajadi & VanVeld). Animals removed from the mesocosms will be replaced with marked individuals to ensure that the specific feeding rate represented in the food treatment is consistently applied. Reproductive effort will be assessed throughout the duration of the experiment. Effort will be measured by checking artificial samplers for the presence of eggs. When eggs are collected, they will be moved to incubation chambers. The eggs and subsequently larvae will be maintained under optimal, uncontaminated conditions to follow hatching success and larval growth.

We propose using the same repeated experimental design. Experiments conducted in the first year (F1) will be analyzed to provide data on the patterns and consequences of a dosed exposure to individual-level processes. These data will also be used to develop population-level models that will be used to predict the results of independent experiments (F2) conducted in the following year.

2.b.(iv) Mechanisms of exposure and bioaccumulation. A fundamental management question is whether contaminants in sediments are permanently removed from the ecosystem or whether natural (tidal- or storm-induced resuspension; bioturbation) or anthropogenic (dredging, prop wash) processes can re-inject these contaminants into the aquatic food web. This component of the study quantifies the factors that control the rates of contaminant transport from historically-contaminated sediments into benthic and epi-benthic organisms.

Exposure may be defined as the time-integrated rate of delivery of a chemical to the appropriate site within an organism. Chemicals may follow several pathways from contaminated sediments to active sites within target species, and the quantification of total exposure requires a detailed description of each route. Exposure pathways are often divided into 'external' -transport from sediments to organism and 'internal' -disposition of the chemical within the organism. Exposure includes passive uptake of dissolved chemicals across the skin and gill surfaces, ingestion of contaminated prey, and filtration/ingestion of contaminated sediments. While the magnitude of total exposure scales to the total concentration of the chemical in the environment, the actual delivered dose depends strongly upon the physicochemical properties of the chemical, the physics of the local environment, and the behavior and physiology of the target organism. In order for chemicals bound to sediments to exert toxicological responses, they must first physically desorb from the matrix. Desorption rates depend upon the geochemical form of the chemical and the chemical properties and physical form of the sediments. Often, desorption is the slowest in a series of steps and controls the overall bioavailability of sedimentary contaminants. Bioavailability of ingested solids, either prey or sediments, depends upon the rates of contaminant desorption and transport across the gut wall relative to the residence time of the solids in the digestive tract. Exposure of dissolved species by transport across membrane surfaces depends upon the permeability of the membrane, the diffusivity of the compound, and in the case of gills the organism's overall respiration rate.

Exposure to an individual organism is generally parameterized in a pharmokinetic model. While these models successfully describe contaminant uptake rates and resulting body burdens in simple laboratory systems, they generally do not include any feedbacks between the organisms behavior or physiology and exposure. Many biotic processes may alter either the magnitude of exposure or the bioavailability of sedimentary contaminants. For example, gut residence times, and therefore assimilation efficiency, in deposit feeding organisms vary with the food quality. Organisms living in carbon-rich sediments may ingest less sediment (and thus consume less contaminant), but more efficiently extract chemicals than those in carbon-poor environments. Also, the bioavailability of sediment-bound chemicals may change from benthic organism reworking. Dietary exposure to fish depends upon the non-linear, density-dependent feeding behavior, and the resulting burdens of chemicals in fish depend upon their growth rates, which also scale to their feeding rates. These types of feedbacks are not typically revealed in studies with individual organisms and are not included in pharmokinetic models. The mesocosm studies and dynamic population models proposed here will allow us to investigate how organism behavior and physiology influences bioavailability and exposure.

2.b.(v) Biomarkers of exposure and effect. In the ecotoxicological context, the significance of toxicological effects at the individual level, expressed as changes in physiology and behavior, lies at the population level; in contrast, the underlying mechanisms are based in changes at cellular and molecular levels (Figure 1.). Cellular and molecular alterations are, in principal, diagnostic, and predictive of effects on individuals and potentially useful in regulatory activities and management as early indicators of exposure and effect. Effects at the organismal level can be of direct ecological significance, which is the level at which resources must be ultimately managed. To establish such relationships requires focusing on suborganismal and organismal responses that underlie biological parameters of known ecological relevance, such as mortality, growth, and reproduction. Using animals from mesocosm studies, we will conduct experiments using biomarkers and physiological and behavioral responses. They are planned to couple directly with (sections 2.b.iv and 2.b.vi) the exposure module and individual fitness parameters associated with bioenergetics and behavior, which will be useful for developing the population models.

Responses at molecular and cellular levels can be sensitive biomarkers of environmental exposure and biological effect (Stegeman et al 1992). They provide linkage between the chemical environment and biological effects expressed at higher levels. Cytochrome P4501A (CYP1A) and metallothionein will be used as biomarkers of exposure; measures associated with endocrine and immune functions, which are indicative of reproductive fitness and disease susceptibility, will be used as biomarkers of effect. Changes can be related to the exposure module through the estimation of critical body residues (Kane Driscoll et al, 1997).

Induction of CYP1A (Van Veld et al 1990) and MT (Roesijadi, 1992) is responsive to environmental concentrations of organic pollutants and metals. Tissue specific expression of CYP1A and MT can be used to identify exposure routes; e.g., both are expressed in gill and gut. Activation of PAHs to carcinogenic metabolites and biotransformation of steroid hormones link CYP1A to carcinogenic and reproductive effects. MTs are believed to play a role in metal regulation and detoxification; induction confers increased metal tolerance. Genes for CYP1A and MT may be under coordinate regulation in higher animals.

Altered levels of reproductive hormones and other abnormalities are often seen following exposure of aquatic animals to environmental estrogens. Thus, vitellogenin, a precursor of yolk protein, and steroid reproductive hormones such as estradiol, testosterone, and 11-keto-testosterone, which are known to be altered by exposure, will be used as biomarkers of endocrine and reproductive dysfunction. For example, pollutant exposure alters VT levels in females and causes inappropriate VT expression in males (Gimeno et al 1997). Changes in these biomarkers can be related to higher-order, organismal-level effects on reproductive parameters such as fecundity and viability of offspring.

Exposure to chemicals can trigger enhanced progression and intensity of parasitic disease (Anderson et al., 1996). Impaired macrophage functions of phagocytosis, production of reactive oxygen intermediates (ROI), and antimicrobial activity occur in fish and invertebrates (Roszell and Anderson, 1994; 1996). These measures will be used to assess immunotoxicity associated with sediment exposure in mesocosms. Changes can be related to increased risk of infection; diminished health, growth and reproductive capacity; and increased mortality.

Organisms exposed to contaminated sediments in the mesocosm experiments will be analyzed for the above responses. *Fundulus* is a commonly used species in ecotoxicological research, and existing procedures are either available or readily adaptable. *Leptocheirus*, on the other hand, has primarily been used in whole animal bioassays or behavioral studies. Responses identified above have yet to be measured in this small crustacean and will have to be developed as part of this study. This will mainly be done in the first year of the project, which is devoted to developing and testing procedures that will later be used to analyze organisms from the mesocosms.

To describe the proposed research protocols to carry out the objectives described above we shall outline the proposed work organized according to test organism: the amphipod, *Leptocheirus* and *Fundulus heteroclitus*:

Observations using the amphipod, *Leptocheirus*: Because of the small size of this organism, analyses will be conducted on the whole organism. Efforts with this species will be focused on measurement of vitellogenin and metallothionein:

----Vitellogenin purification and monoclonal antibody production. Purification of vitellogenin and monoclonal antibody production will be performed according to procedures used for *Callinectes sapidus* (Lee and Puppione 1988; Lee and Walker 1995). These activities will be carried out in collaboration with Dr. Richard F. Lee (Skidaway Institute of Oceanography). Briefly, our approach will involve homogenization of a collection (e.g., 5 g) of adult sexually mature female amphipods followed by gradient centrifugation to obtain the high density lipoprotein and vitellogenin fraction. After dialysis, lipoproteins will be separated on vertical electrophoretic slab gels. Protein bands will visualized with 0.3 M copper chloride. Bands corresponding to vitellogenn will be cut from the gel and eluted by electrodialysis. The eluted vitellogenin will be subjected to SDS-PAGE to verify purity. Purified vitellogenin will be used for the preparation of monoclonal antibodies.

For Mab production, female BALB/c mice will be immunized with *Leptocheirus* vitellogen mixed with Freund's completed adjuvant. The injections will be repeated twice (4 weeks and 6 weeks after the original injection). After the last injection the mice will be sacrificed and the spleens removed. Spleen cells will be fused with a mouse myeloma strain Sp2/0 using polyethylene glycol as the fusing agent. After fusing, cells will be plated in hypoxanthine/aminopterin/thymidine selection medium in microplates on a feeder layer consisting of mouse peritoneal macrophages. The wells will be screened by direct ELISA for antibodies to *Leptocheirus* vitellogen. The positive hybridomas will be cloned by limiting dilution and grown on RPMI 1640 medium (Gibco, Grand Island, NY) supplemented with 10%

fetal calf serum and 0.01% streptomycin and penicillin. Vitellogen expression will be evaluated in *Leptocheirus* by Western blot analysis as described above.

----**Metallothionein.** Tissues will be homogenized in two volumes of ice-cold buffer of 20 mM tris-HCl, pH 8.6, 275 mM NaCl, 5 mM dithiothreitol (DTT), 0.1 mM phenylmethylsulfonylfluoride. Following centrifugation at 80,000 x g for 90 min, the cytosolic fraction will be subjected to acetone precipitation at 60% final acetone concentration to remove the bulk of cellular material and 80% to precipitate MTs (v/v assuming additive volume), all steps at -20 C. The 80% acetonic pellet will be re-dissolved in 20 mM Tris-Hcl pH 7.5 or in 25 mM ammonium acetate. Total MTs will be estimated in two ways: first by SDS-polyacrylamide gel electrophoresis (PAGE) using the fluorescent sulfydryl stain monobromobimane (MBB) for detection (Viarengo et al., 1997) and, second, by reverse phase HPLC in 25 mM ammonium acetate. For electrophoretic analysis, acetone-precipitated oyster metallothionein extracts will be reacted with MBB (Molecular Probes, Inc.) in 20 mM tris-HCl pH 7.5, 3 mM EDTA, 2 mM DTT, and 6 mM MBB. Samples will be separated in 15% PAGE gels (Laemmli, 1970), which, following electrophoresis, will be fixed in 12% trichloroacetic acid and washed in 7% acetic acid, 45% methanol. Gels will be visualized on a UV illuminator and photographed using a Sypro filter (Molecular Probes, Inc.). For quantification, photographs will be scanned and analyzed using NIH Image software. Commercially-available rabbit metallothionein will be used as standards in lieu of purified crustacean metallothionein, which is not readily available. Our detection limit of 8 ng metallothionein is adequate for detection of basal levels of MTs in other species. Reverse phase HPLC in 25 mM ammonium acetate will also be used to analyze acetone precipitated MTs. This procedure is appropriate for detection of metallothionein isoforms whose presence can have physiological or toxicological significance. Efforts in the first year will focus on adapting these procedures to *Leptocheirus* that will be exposed to cadmium in the laboratory. Cadmium is a potent inducer of metallothionein.

Observations using *Fundulus heteroclitus*: Work on *Fundulus* will include analysis of xenobiotic detoxification activity, plasma steroids, plasma vitellogenin, macrophage function, and metallothionein and metallothionein mRNA induction.

----**Hepatic cytochrome P450, CYP1A and EROD**. Measurement of hepatic CYP1A and EROD have previously been described in detail (Van Veld et al 1990; Van Veld et al 1997). Fish will be killed by immersion in a saline ice bath and livers frozen in liquid nitrogen. Cytochrome P450 content of microsomal preparations will be determined by dithionite difference spectra of microsomes that had been bubbled with CO as described previously by Stegeman et al. (1987). Microsomal protein will measured by the method of Bradford (1976) using BSA as a standard. CYP1A content will be quantitated by Western blot analysis using monoclonal antibody Mab C10-7 (kindly provided by Dr. Charles Rice, Clemson University) as described previously (Kloepper-Sams et al., 1987) with modifications. Microsomal proteins will be separated on polyacrylamide gels and transferred to nitrocellulose. After a blocking step, the nitrocellulose will be incubated with primary antibody followed by alkaline phosphatase-linked goat anti-rabbit secondary antibody (Bio-Rad) and AP Color Development Reagents (Bio-Rad). Blots will be analyzed with a dual wavelength thin-layer chromato scanner (Shimadzu) and quantified by comparison with spot (*Leiostomus xanthurus*) microsomal CYP1A standards that were previously calibrated against purified CYP1A standards as described previously (Van Veld et al., 1990). EROD activity will be determined spectrophotometrically (Klotz et al., 1984).

----**Steroids.** Plasma steroid levels and *in vitro* steroid production will be assessed for use with *Fundulus*. P. Van Veld has experience with both approaches in other fish species, but not *Fundulus*. The method found to be most suitable for *Fundulus* in preliminary experiments will be used to analyze mesocosm experiments. Plasma estradiol, testosterone, and 11-ketotestosterone levels will be measured by radioimmunoassay (RIA) following ether extraction as described previously (Wade and Van Der Kraak, 1991). *In vitro* steroid production in the presence and absence of stimulation by human chorionic gonadotropin (hCG) will be assessed using the methods established for goldfish testis pieces (Wade and Van Der Kraak, 1991) and preovulatory ovarian follicles (Van Der Kraak, 1990; Van Der Kraak and Chang, 1990). Testes and ovaries will be removed and portions (20 mg) from each fish will be placed in wells of polystyrene tissue plates containing Incubation Medium 199 (Robinson 1994). Prior to beginning the incubations, the medium will be replaced with either fresh Medium 199 or fresh Medium 199 amended with human chorionic gonadotropin. Tissues will be incubated at 18 C for 18 and stored at -20°C prior to measurement of steroids by RIA as before.

----**Vitellogenin.** Plasma vitellogenin will be evaluated in mummichog by Western blot analysis, essentially as described above, but with polyclonal antibodies provided by Dr. Nancy Denslow from the Protein Chemistry Research Facility at the University of Florida. These antibodies were raised against a peptide derived form the conserved N-terminal region of teleost vitellogenin (Heppel et al., 1995). The results of Western blotting indicate that this antiserum specifically recognizes VTG in plasma or serum from teleost fish of diverse families (Heppel et al., 1995).

----**Macrophage function**. Macrophages will be separated by discontinuous Percoll gradients from homogenates of pronephros of *Fundulus* (Bayne, 1986). Phagocytic capacity of the cells will be quantified by the uptake of fluorescently-labeled FITC-yeast (Hed, 1986), as modified for fish macrophages (Roszell and Anderson, 1994). Phagocytosis assays will be carried out in a fluorescence analyzer. ROI production by macrophages will be measured by luminol-augmented chemiluminescence (CL) (Muhvich et al., 1995). This CL technique measures activity of the myeloperoxidase-dependent antimicrobial pathway, one of the most significant mechanisms of pathogen destruction in fish. Bactericidal activity will be measured by a modification of Graham et al. (1988). Macrophages will be challenged with *Vibrio anguillarum*, and lysed. The surviving bacteria will be grown out and quantified with MTT, a probe for mitochondrial respiration, in an EIA reader. Bactericidal activity will be represented by a reduction in MTT relative to control *V. anguillarum* processed similarly, but in the absence of macrophages.

----Metallothionein and metallothionein mRNA. Procedures described above for analysis of metallothionein in *Leptocheirus* will also be used with *Fundulus*. In addition, analysis of transcriptional induction of metallothionein is possible in fish. DNA and cDNA sequences have been described (Bonham et al., 1987; Chan et al., 1989; Zafarullah et al., 1989; Chan, 1994), and there is high homology in fish metallothionein sequences. Probes and primers derived from these sequences can be used for analysis of metallothionein mRNA induction. To develop probes for analyzing metallothionein mRNA induction, cDNA for *Fundulus* metallothionein will be obtained from RT-PCR of metallothionein mRNA. Amplified cDNA will be subcloned in a T-A cloning vector such as pGEM-T. The identity of the amplified sequence as that of metallothionein will be verified by the dideoxynucleotide chain termination method (Sanger et al., 1977). Probes derived from the amplified sequence will be used in Northern or slot blot assays. These procedures will be developed using metallothionein mRNA purified from cadmium-exposed fish.

Work conducted to date indicates that the gill of *Fundulus* is more informative organ to analyze for metallothionein than other organs. Liver, which often used for metallothionein analysis, can have a high basal level that is insensitive to induction in this species. The gill, on the other hand, exhibits concentration-dependent induction.

2.b.(vi) Impact of exposure on individual and population level processes. The deleterious effects of contaminant exposure on physiological processes and behavior within individual organisms is ultimately expressed in the patterns of growth, reproduction and survival at the population level. Even in the absence of lethal effects, the consequences of individual-level responses to the subsequent dynamics of the population remain of fundamental importance. We need to fully understand and predict the consequences of contaminant exposure to patterns of growth, reproduction and survival if we seek to understand population level responses. We will examine various lethal and sub-lethal responses by individuals that can lead to higher order effects, including behavioral changes and modified energy allocation strategies. This suite of responses can then be directly related to the results of biomarker investigations.

Impact on bioenergetics and behavior: Individual-level processes that both are impacted by pollution stress and, at the same time, are responsible for phenomena that influence fitness, are most likely candidates to produce higher-level effects. If an individual is to contribute to the next generation it must be able to: 1) derive an adequate supply of resources from the environment, 2) allocate assimilated energy to basic survival requirements (maintenance), and 3) allocate energy that remains after maintenance requirements have been met to production of new tissue (growth, energy storage, and reproduction). The relationship between net energy assimilated and allocation processes can be expressed simply as $N = M + P$, where N = net energy assimilated (a finite quantity based upon resource availability, harvesting, and assimilation efficiency), M = allocation to maintenance (supporting basic physiological costs), and P = allocation to production of new tissue. The production budget (P) supports the processes of growth (G), energy storage (S), and reproduction (R). Given a finite amount of assimilated resources, the maintenance and production budgets can be viewed as competing processes, such that M ~ -(S + G + R). Clearly an environmentally- induced change in expenditures for one portion of the budget must detract from energy available to support the remaining portion.

The maintenance pathway, supporting basic survival costs, is the most energetically-demanding allocation pathway. Congdon et al. (1982) determined that maintenance costs accounted for greater than 80% of the annual total energy budgets of several reptiles. Thus only a small proportion of the total energy acquired (less than 20%; Congdon et al., 1982) can be allocated to processes that are not essential to maintenance, but nonetheless influence individual fitness traits and population dynamics. Maintenance costs may be slightly less for invertebrates (i.e., 60-80%) but remain a substantial portion of the energy budget (Valiela 1995). Any change in maintenance costs, therefore, would be expected to produce a greater proportional gain or loss in energy available for the pathways supporting growth, energy storage, and reproduction.

Increases in maintenance expenditures have been observed in vertebrates and invertebrates chronically exposed to mixtures of various organic and inorganic compounds (Bayne et al., 1979; Moore et al., 1987; Koehn and Bayne, 1989; Sibly and Calow, 1989; Calow and Sibly, 1990; Calow, 1991; Widdows and Donkin, 1991; Forbes and Depledge, 1992; Weber and Spieler, 1994; Rowe, 1998; Rowe et al., 1998; Hopkins et al., in press). Elevated maintenance costs may result from energetic expenses incurred via cellular repair, excretion of toxicants, and elevated protein turnover rates in pollution-stressed individuals (see Hawkins et al., 1986; Koehn and Bayne, 1989; Hawkins, 1991). The relative roles that these and other processes play in modifying maintenance costs are unknown, and likely to vary with conditions of the particular habitat. Yet from an ecological perspective, the cause for the increased maintenance costs is not as important as the potential effects of the elevated costs: an associated decrease in energy available for production, influencing processes such as growth and reproduction.

Using a micro-respirometry system available at CBL, we will examine maintenance expenditures in experimental animals by measuring standard metabolic rate (oxygen consumption at rest in unfed animals) of both *Leptocheirus* and *Fundulus*. We will simultaneously measure hourly oxygen consumption rates over time by independently-sampled individuals (see Rowe et al., 1998). Multiple, independent trials will be conducted in order that replicate measures from each treatment will be obtained; we will randomly assign treatments to trials to avoid temporal bias in measurements. Following each trial, animals will be weighed for wet and dry mass to provide the basis for estimates of specific metabolic rates, e.g., mg O_2/ g tissue. The dried animal carcasses will then be extracted under boiling petroleum ether to determine concentration of non-polar (storage) lipids, using micro-methods when necessary (Gardner et al., 1985). The measures of maintenance, growth, and lipid storage will be supplemented with measurements of egg production and egg quality (lipid content) in reproductive females. Effects of ROC-related conditions on specific portions of the energy budget will thus allow us to examine the effects on individuals (maintenance budget) as well as on those processes that can influence population-level features (production budget).

Changes in organism behaviors, particularly those associated with feeding and maintenance activities, have direct implications for organism energy balance. Decreased energy uptake and increased maintenance expenditures by individuals in polluted habitats can detract from energy available for growth and reproduction, thereby potentially influencing fitness (Calow And Sibly, 1990; Forbes And Depledge, 1992; Weber, 1997; Rowe, 1998; Rowe et al., 1998; Hopkins et al., in press). For amphipods, feeding behaviors and burrow irrigation rates have significant implications for organism energy balance. To develop indices of sub-lethal effects these behaviors will be evaluated using a non-invasive, computer-aided monitoring system available at VIMS. This system includes four miniature, ultra-low light video cameras (2 color, 2 b+w), with underwater housings, infra-red and visible lights, time lapse (1) and real-time (1) video recorders, a 4 channel multi-plexer, and a "medusa" unit with six flow-thermistors coupled to a data logger. The video cameras will allow direct observations of organism behaviors, either in the mesocosms or, more likely, in smaller laboratory "ant-farm" type microcosms. The flow thermistors are placed at the amphipod burrow openings in order to directly record water flow velocities and periodicity of flow through the burrow.

We shall make observations of multiple individuals for all experimental units as specified in the experimental design (2.b.iii) with age class, sex and density as additional factors (neonates vs. juveniles vs. adults; males vs. females for adults only; 0.5x, 1x and 2x ambient population density). Multiple, independent trials will be conducted in order that replicate measure from each treatment will be obtained, with the final sample size dependent on variance structure determined in preliminary experiments. We will randomly assign treatments to trials to avoid temporal bias in measurements. Using the thermistors, burrow irrigation behaviors will be recorded continuously for each individual for a period of 24 hours. From these records we can determine maximum flow speed, mean flow speed, and volume flow through a burrow. Fourier transformations will be used to detect patterns in the duration and periodicity of burrow irrigation behavior(s). Video imagery during selected time intervals will be used to verify changes in behaviors and to categorize specific behaviors which may influence energy uptake (e.g. feeding), energy expenditure (normal activity level, hypoactive, hyperactive, no activity) or increase predation risk (e.g. time spent at burrow opening or on sediment surface). Amphipods retained at the conclusion of each trial will be sexed and measured (length and weight).

Recording behavioral responses of fish in estuarine mesocosms is problematical (E. D. Houde, UMCES, personal communication). We have previously attempted to collect such observations by eye, and with sophisticated video systems. For this project, we will employ a high resolution video camera with an underwater housing to estimate swimming speeds of fish in the experimental mesocosms. Trials will be conducted on each mesocosm individually. The order of mesocosms selected for observation will be randomly assigned. Video recordings will be taken for 1 hr periods at 06:00, 12:00, 18:00 and 24:00. Swimming speeds of individual fish will be estimated from PC-based imaging of successive frames.

Pollutant-mediated behavior changes associated with reproduction and predator avoidance also have significant implications for fitness. For example, altered swimming behaviors or escape reflexes may indirectly lead to mortality via elevated predation risks (Jung and Jagoe, 1995; Weis and Weis, 1995, Drewes, 1997; Raimondo et al., 1998). For *Fundulus,* swimming trials will be used to examine swimming speeds and responses to predation-related stimuli (Atchison et al., 1987; Weis and Weis, 1995; Weber et al., 1997). We will quantify both the swimming speed and latency of response of larval, juvenile and adult *Fundulus* that have been exposed to contaminants to a predation threat (looming silhouette or sound pulse) in experimental arenas. Trials will be conducted in an 80-L experimental arena that permits video recordings to be made in two orthogonal planes. The images from each plane will be recorded to separate time-locked VCR's. Subsequently, 3-D kinematic data will be derived from PC-based motion analysis of the video records. Trials will involve groups of five individuals. Swimming behavior will be quantified for 1 hr following an acclimation period to the experimental arena. The trial groups will then be exposed to each predation threat. The number of animals responding, the latency of response (time from threat to initiation of escape response) and escape swimming speed will be quantified.

The ability of *Leptocheirus plumulosus* to re-burrow following removal from the sediment is sensitive to pollutant exposure (Mcgee and Schlekat, 1992) and will be used as an indicator of predator avoidance ability. Amphipods obtained from mesocosms at selected time intervals during the exposure period will be tested for their ability to re-burrow into "clean" control site sediment. We will make observations of multiple individuals for all experimental units as specified in the experimental design (2.b.ii) with age class and sex as additional factors (neonates vs. juveniles vs. adults; males vs. females for adults only). Multiple, independent trails will be conducted in order that replicate measure from each treatment will be obtained, with the final sample size dependent on variance structure determined in preliminary experiments. We will randomly assign treatments to trials to avoid temporal bias in measurements. Amphipods will be transferred from holding dishes by pipette and released into small bowls that contain sediment from the control site. Time to re-burrow will be recorded as the period between initial sediment contact and the time at which the amphipod is no longer visible from the sediment surface.

In addition, pollutants can disrupt the complex precopulatory behavior necessary for successful mating in some amphipods (Linden, 1976; Davis, 1978; Lyes, 1979; Pascoe et al. 1994). We will evaluate the utility of a precopulatory behavior assay (Pascoe et al. 1994) for *Leptocheirus plumulosus*. The reproductive behavior of most amphipods (and other crustaceans such as the blue crab) involves a complex behavior in which the male holds and carries the female during a precopulatory guarding phase (Hynes 1955). This insures that insemination can occur as soon as the female molts and is ready to release eggs into the brood pouch. For *Gammarus pulex*, a well-studied species, the strength of this coupling is highly dependent on exposure to sublethal concentrations of contaminants such as cadmium, copper, lindane, atrazine and 3,4-dichloroaniline. Male and female *Leptocheirus* show strong sexual dimorphism (Schaffner, pers. obs.). Therefore we expect them to exhibit similar precopulatory behaviors.

We shall perform a precopulatory separation test (PST) for 20 precopulatory pairs of *Leptocheirus plumulosus* for all experimental units as specified in the experimental design (2.b.ii). Paired animals will be transferred to bowls containing an anaesthetic (2-phenoxyethanol). The time taken for each pair to separate will be noted and the median induced separation time (IST_{50}) can be calculated.

Impact on population processes: In a polluted habitat, organisms can experience reduced allocation of energy to the production pathway due to increased costs of maintenance (discussed above). The relationship between the maintenance pathway, supporting short-term survival of the individual, and the production pathway, supporting processes that influence population-level processes, illustrates a potentially strong link between toxicological responses occurring at the individual level and effects at the population level.

The specific processes supported by the production budget are clearly interdependent, such that effects on one process can have an important influence on other processes. For example, female size (growth history) and provisioning of stored resources influence reproductive traits via effects on egg production and egg quality. Furthermore, changes in the production budget can have ramifications for ecological processes such as competition and predation, which are strongly size-dependent in aquatic systems. Smaller individuals are often inferior competitors and more vulnerable to predation than larger individuals. Growth and reproductive investment are compounding process; small changes in growth rates or reproduction can have dramatic impacts when summed across an entire life cycle (Gotelli 1995). Long term changes in growth can lead to delays in the onset of maturity, affecting rates of population growth by reducing the number of lifetime reproductive events, or increasing the likelihood of mortality prior to reproduction (Sibly 1996). At the same time, energetic restrictions can affect the investment strategy by females, influencing the trade-off between the number of offspring produced and the per capita energetic investment made for each offspring (see Sinervo, 1990; Bridges and Heppell, 1996; Reznick et al., 1996). Reduced production of offspring (fecundity) clearly can have population-level consequences. Yet, even in the absence of an effect on offspring number, reductions in the energy invested per egg (offspring quality) may reduce offspring survival or performance. Thus, the sub-lethal responses discussed above (2.b ii) can have a variety of important ramifications for population dynamics. We will explore the implications of individual level responses to contaminant stress on population dynamics through controlled mesocosm experiments and modeling.

Using whole life-cycle exposures in mesocosms and field-enclosures, we will examine relationships between chronic pollutant exposures and traits related to reproductive fitness, energy storage, growth and survival. Repeated sampling of individuals from the series of experiments will provide measures of growth, maintenance expenditures, and storage of energy throughout the life-cycle. Further, time to first reproductive event will be scored for each treatment, and gravid females will be analyzed for egg number, size, and egg quality (lipid content). A sub-sample of eggs from females in each treatment will be hatched and raised under optimal conditions throughout the juvenile period to examine effects of maternal exposure on offspring survival.

We shall thus examine the strength of the relationship between sub-lethal responses by individuals and reproduction/ recruitment. Results of this work will be important in our developing predictive models (below) of population-level changes related to specific responses by individuals in polluted environments.

As the length of the life cycles of many commercially or ecologically important species preclude experimental approaches to documenting population level impacts of contaminant exposure we propose to develop a range of population-level models to assess the impacts of contaminant exposure. Our models will be used to explore the impacts of contaminant exposure to Chesapeake Bay fauna generally, and to interpret the outcome of mesocosm experiments involving exposure to contaminated sediments from the three ROC's.

The dynamics of populations exposed to contaminant stress will be examined in three model frameworks. We will develop bioenergetics models using estimates derived from independent respirometry measurements of the surrogate species. These models quantify the effects of changes in physiology resulting from contaminant stress on the partitioning of the energy ingested to maintenance, growth and reproduction (Rice 1990; Beyers et al. 1999a and b). In this application, the bioenergetic model will be used to predict growth of individual organisms, given estimates of their consumption. The underlying algorithm for the model is

$$\Delta B + G = C - (R + A + S) - (F + U)$$

where somatic growth (ΔB) and gonadal production (G) is supported by the energy difference between consumption (C) and the costs of metabolism (resting, R, active, A, and specific dynamic action, S), excretion (feces, F, and urine, U) (Hanson et al. 1997). Estimates of R, A, S, F and U as a function of contaminant exposure developed from the respirometry trials will be used to parameterized the model.

We will also develop stage-based projection models for all target organisms (Caswell 1989; Brewster-Geisz and Miller 1999) to quantify the relative sensitivity of population growth rate to exposure at different life stages. Stage-based models are demographic models that share similarities with the analysis of life tables, but that represent the entire organism's life cycle by a small number of discrete stages that represent functional biological units (Caswell 1989). Thus, unlike the life table analysis that requires estimates for every year the organism lives, the stage-based model only requires estimates for each stage. Therefore, the realism of a many-staged model can be balanced with the precision of a simpler model when parameter estimation error is of concern. Caswell was one of the first to apply this model format to ecotoxicology (Caswell 1996). However, stage-based models have been widely used to explore the dynamics of marine and estuarine animals generally (polychaetes, Bridges and Heppell 1996, Levin et al. 1996; sea turtles, Crouse et al. 1987; Crowder et al. 1994; sharks, Brewster-Geisz and Miller 1999; blue crabs, Miller and Houde 1998; and anchovies, Pertierra et al., 1997). Central to the approach is the ability to formally estimate the sensitivity of the population growth rate to changes in the vital rates of life history stages within the organism's life cycle. The fundamental equation is:

$$N_t = A^t \cdot N_0$$

where N_t, and N_0 are the population sizes at times 0 and t, and A is the projection matrix. A is a square matrix with elements that represent the probability of an individual of stage I surviving and being in stage j at the next time step. The probability estimates, as a function of contaminant exposure, will be derived from growth estimates from the mesocosms.

At the most highly resolved level we shall also develop individual-based models (IBM's) for the fish species. We shall use simulation approaches that track individual organisms throughout their life cycle (Van Winkle et al. 1993). By explicitly integrating the range of responses among individuals to exposure these models allow one to quantify the overall population level response (Madenjian et al. 1995). The model combines details of the bioenergetics developed above, with estimates of food availability and sources of mortality to predict both the number and characteristics of survivors. In the model, contaminant exposure can be through consumption of contaminated food item, or through direct contact with contaminated sediments. At each time step, and for every individual, the model assesses whether or not the individual feeds. If it feeds, the model calculates the net energy gain via simple bioenergetic rules. This surplus energy is partitioned between somatic and gonad growth. The model then evaluates whether the individual is vulnerable to sources of mortality and determines whether the individual dies or survives. During these subroutines, the model will also track the body burden (total contaminants and specific concentration) in each individual. At the end of each time step, population level summary statistics are reported. The process is then repeated for the next time step. The models will be parameterized using existing literature-derived information and from estimates developed from the pharmokinetic and bioenergetic studies conducted in this project. The IBM's will be used to estimate both the effect of sub-lethal concentrations of contaminants on population abundance and characteristics, and on the distribution of body-burdens within the population. Recently, researchers at CBL have developed similar IBM's that track the fate of hydrophobic organic contaminants in a simplified food web in which fish are the top predators (Ashley 1999).

2.c Chemical analyses

2.c (I) Trace element analysis. Trace elements and the geochemical conditions of sediments and experimental animals from the several mesocosm experiments will be analyzed. For initial characterization, sediment will be analyzed for both total metals and acid volatile sulfur-simultaneously extracted metals (AVS-SEM). Target metals include those most likely to cause toxicity, including the mettaloids arsenic, selenium, and mercury. Because total trace elements will not change substantially during the course of these experiments, monitoring will focus on trace element speciation that can alter the toxicity and bioaccumulation of the trace elements.. Periodically, core samples will be collected and analyzed for AVS-SEM and pore water trace elements. Because uptake of contaminants by the test organism will depend upon a balance between water-borne and sediment-borne contaminants, it will also be necessary to carry out sampling for water borne trace elements. Dissolved trace element concentrations will be measured using trace metal clean procedures routinely used in our laboratories (see Mason and Lawrence 1999; Riedel et al. 1999), which includes extensive quality assurance procedures. Except for initial screening, due to the high cost of analysis, only elements or groups of elements reasonably suspected to contribute to sediment toxicity will be analyzed, and this list may vary somewhat from site to site. In general sampling and analytical methodologies (atomic absorption and ICP mass spectrometry) will follow documented protocols (Mason and Lawrence 1999; Riedel et al. 1999). Needed analytical expertise and instrumentation exists at the participating CERP institutions.

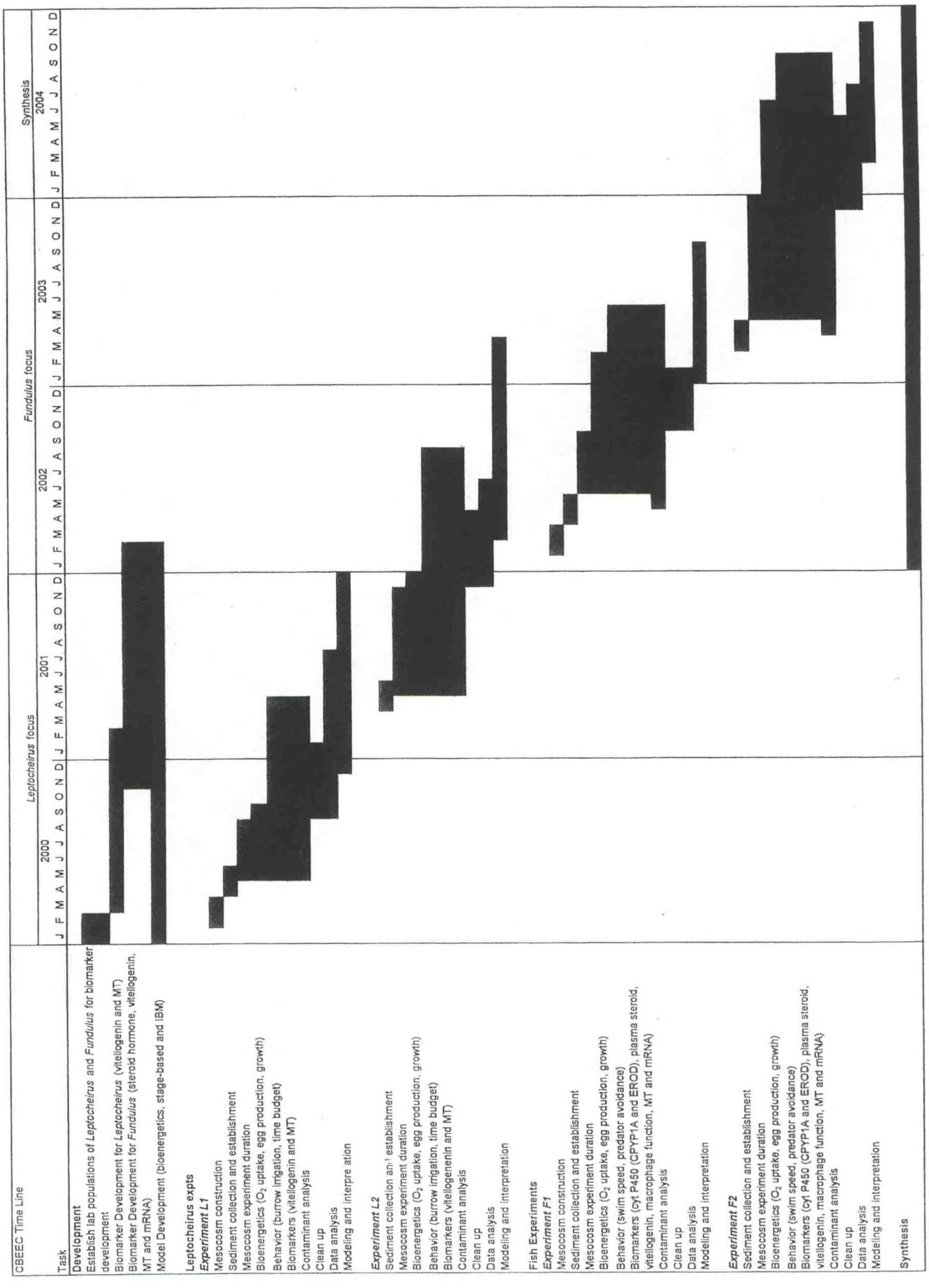
2.c (ii) Organic analysis. Organic contaminants in sediments, biota, and water will be quantified using research-grade analytical methods developed in the investigators' laboratories during the past decade (Ko and Baker, 1995; Kucklick and Baker, 1998; Harman et al., 1999; Ashley and Baker, 1999; Schaffner et al., 1997). Target organic analytes include 42 parent and methyl substituted polycyclic aromatic hydrocarbons (PAHs), ca. 80 polychlorinated biphenyl (PCB) congeners, and organochlorine pesticides, including chlordanes. Strict quality assurance protocols are followed, including laboratory inter-calibrations with the National Institute of Standards and Technology. We have developed sensitive microscale measurements that allow quantification of organic contaminants in very small (e.g., milligram) tissue samples (Merten and Baker, 1999). In addition, we have the capability to measure dissolved organic contaminants within the mesocosm waters (Bamford *et al.*, 1999; Merten and Baker, 1999), using solid adsorbent concentration and suitable clean techniques.

2.d Time line of project activities and effort.

The mesocosm research projects and related chemical, toxocological and ecological studies will be conducted in the first four years of the project. Overall, the focus of research will be on *Leptocheirus* in the first two years of the project, and on *Fundulus* in years three and four. Although this reflects the major balance of effort in the project, some work will be conducted on both species in all years of the project. For example, the modeling component will be conducted throughout the project. Below we describe the distribution of effort for each species.

In the first year we will develop and refine the biomarker assays for *Leptocheirus*. We will also conduct the first set of mesocosm experiments (L1) on *Leptocheirus*s. Using animals from L1 we will quantive the biomarker, bioenergetic and behavioral responses to exposure as described in 2.b.(iv) - 2.b.(vi). Work on these components of experiment L1 will continue into

Figure 2. Timeline of Project Activities



the second year of the project. However, the principal focus of work in the second year will be a *Leptocheirus* exposure experiment of longer duration to quantitatively test prediction of population models develop from the data collected in year 1. We will predict the response of the population in the medium term, given the observed biomarker-based levels of contaminant exposure.

Fundulus work will begin in year 2 during which we will develop and refine the biomarker assays for species. The principal effort on *Fundulus* however, will be expended in years 3 and 4 of the project. In an approach parallel to the one adopted for the amphipod, we will first conduct a short mesocosm experiment (F1). Using animals from F1 we will quantive the biomarker, bioenergetic and behavioral responses to exposure as described in 2.b.(iv) - 2.b.(vi). Work on these components of experiment F1 will continue into the fourth year of the project. However, the principal focus of work in the third year will be a *Leptocheirus* exposure experiment of longer duration to quantitatively test prediction of population models develop from the data collected in year 3. We will predict the response of the population in the medium term, given the observed biomarker-based levels of contaminant exposure.

3. Specific Linkages to Resource Management Objectives.

Our strategy is to combine measurements, modeling, synthesis, and outreach to reduce the uncertainty which currently plagues the management of contaminated areas of the Chesapeake Bay. Our work builds upon previous studies, and *moves from fate and transport to bioavailability and effects* by using biomarkers of exposure to determine the bioavailability and mechanisms of exposure. Models developed and refined during this study will improve our ability to *extrapolate from contaminant effects on organisms to impacts on populations*, including characterization of adaptation of populations living in contaminated areas. Mesocosm experiments will be used to *link observations in the laboratory to those in the field*, using dose-dependent biomarkers as the common currency of exposure and effects. The results of the modeling, mesocosm studies, and synthesis will allow us to quantitatively evaluate the *outcomes of several management options for contaminated sediments*, including capping, dredging, and 'natural attenuation'. Our outreach and synthesis program will facilitate discussions of issues such as 'how clean is clean?' and 'how long is required to achieve a desired outcome after management action?', with support by the results of this study.

4. Outreach, Communications, and Expected Products.

Informing and seeking feedback of scientific findings with stakeholders is integral to the success of the Chesapeake Ecotoxicological Research Projects. While publication in scientific journals is central to scientific practices and will be expected of CERP's principal investigators, research findings and their implications must be accessible to managers, decision makers and other stakeholders to make effective use of them. Mechanisms are also needed to ensure continual feedback to scientists of managerial concerns that results are relevant and useful. Thus CERP's outreach component includes activities to ensure meaningful interaction between researchers and federal and state management agencies from the beginning through the length of the project (see section 2.a). An important, secondary objective is to promote a clear understanding of the objectives, value and progress of CERP with other important public groups, or stakeholders, e.g, legislators, media, non-governmental and citizen organizations, educators and students. To achieve these objectives, we propose a five-year strategy that includes the following elements. This plan will be refined as necessary, based on evaluations by researchers, managers and other stakeholder groups of the effectiveness of our outreach program.

4.a Web site. The CERP web site will serve a number of purposes: (1) an introduction to the research program and its objectives, participating researchers and associated management entities; (2) bulletin board for meeting, planning and reporting; (3) source for technical documents such as white papers from issues workshops (see section 2.a. ii), information on progress of the SIERA activities paper (see section 2.a(iii), abstracts of scientific and management presentations, bibliography and summary of journal articles resulting from research; (4) a publication, CERP Briefs and press releases written over the course of the project; (5) feature
article for Marine Notes, Tidelines and other publications; (6) links to related research in the Chesapeake Bay region (e.g., MEERC, COASTES) and elsewhere.

4.b. CERP Briefs. To reach more diverse publics, a series of plain-language, 2-4 page fact sheets, CERP Briefs, will be written over the course of the project. The first will serve as an introduction to the purpose and objectives of CERP, the complexity of scientific questions and the value of a scientific understanding for effective management and citizen action. Other topics will derive from research findings, issue workshops and SIERA. CERP Briefs will also serve as the basis for developing press releases on progress of the research program, particularly when special presentations of CERP research are given at scientific meetings (see 4.d below). CERP Briefs and releases will be posted on the web site.

4.c Synthesis of CERP research for stateholder publics. As research develops, communications specialists in the Maryland and Virginia Sea Grant Programs will write articles for program newsletters, the Maryland Marine Notes and Tidelines. The audience reached by these publications are diverse, including scientists, educators, resource managers, environmentalists, governmental decision makers, and others interested in Chesapeake Bay issues. These articles will also be posted on the CERP web page; in addition, they will be sent out as news features to newspapers in the Chesapeake Bay region. Such articles are often published as is or serve as background material for subsequent in-depth articles by environmental journalists.

Opportunities will be available to relate CERP research findings in such articles to current multi-investigator studies that are examining the ecological impacts of chemical contaminants, for example, MEERC, COASTES, ODRP (Oyster Disease Research Program coordinated by the National Sea Grant College Program). In addition, the Chesapeake Bay Program has a major focus on chemical contaminants through the Toxics Subcommittee, Maryland Sea Grant Communications is working with the Subcommittee and the Alliance for Chesapeake Bay in developing fact sheets on critical issues related to such contaminants. Sea Grant communicators will work with the CERP Steering Committee to ensure that CBEEC research findings are incorporated into the Bay Program's outreach efforts.

4.d Briefings. Scientific presentations of CERP results at meetings of such organizations as the Estuarine Research Federation (ERF) and ASLO could provide the opportunity for media briefings by researchers and managers. Maryland and Virginia Sea Grant will coordinate with the co-P.I.s and the National Sea Grant media relations specialist in exploring the opportunities for such briefings. Other briefings will be coordinated with current on-going efforts, e.g., committees of the Chesapeake Bay Program or other management and education-oriented venues in the Bay region.

4.e Scientific Publications. While CERP researchers will write papers for publication in scientific journals, a symposium in the fifth year will be designed to lead to a scientific synthesis that will provide the material for a book, Ecological Risk Assessment for Estuaries, that should be of value nationally and internationally. Communications will work with the co-P.I.s in developing the structure of the book and in exploring the opportunities for publication as well as an accompanying plain language report that summarizes the book. One relevant model is Oxygen Dynamics in the Chesapeake Bay (1992), published by the Maryland Sea Grant College and the follow up workshop report: "Dissolved Oxygen in the Chesapeake Bay: A Scientific Consensus."

4.f Evaluation of Communication Efforts. In years 1 and 2 and years 3 and 4, Maryland and Virginia Sea Grant communicators will work with the co-P.I.s in developing two surveys that will evaluate the effectiveness of CERP communications efforts; one questionnaire will be designed for resource managers, a second for other publics. Based on the responses, communications efforts may undergo revision.

5. Project Management.

From the four participating CRC institutions a group of scientists who demonstrate sound and documented expertise in the broad array of chemical, toxicological, and ecological disciplines and bay experience needed to carry out such a transdisciplinary endeavor have come together as Co-Principal Investigators to design a truly integrated project that will assess existing and proposed research results to address key management needs for dealing with effects of contaminated sediments on living resources in the bay. Drs. Joel Baker and Fritz Riedel provide solid expertise in environmental organic and trace element geochemistry. Drs. Michael Newman, Guri Roesijadi, Christopher Rowe, and Peter Van Veld provide the wide array of toxicological expertise underpinning the proposed project. Drs. Daniel Dauer, Thomas Miller, Linda Schaffner, and Kenneth Tenore provide ecological expertise for benthos and fish at organismal, population, and community levels. There is also first hand knowledge of the three regions of concern: the Anacostia River (Riedel), the Elizabeth River (Dauer), and Baltimore Harbor (Baker). Drs. Gene Burreson, William du Paul and Merrill Leffler have extensive experience in marine advisory outreach activities and great familiarity with the Chesapeake Bay scientific and management communities and interacting with the general public. A short one-page curriculum vitae of each of the Co-Principal Investigators documenting their expertise and proficiency are attached as Appendix A. Further analytical and research chemical, toxicological, and ecological expertise are available at the participating institutions that can be tapped to augment any planned research.

The individual research activities identified in this proposal involve collaborative teams of the principal investigators across institutional lines and depend on integrated action. Thus this issue of project management was introduced early on in section 3 outlining the proposed research plan. The actual research will take place at several CERP research facilities but will involve a cross cut of the principal investigators. To insure the efficient and effective trans-institutional and cross expertise in planning, carrying out, evaluating, and publishing the results from CERP we have set up teams with team leaders (*) for seven areas of project activity:

-outreach informational services (Leffler*/DuPaul)

-risk assessment/synthesis activities (Newman*/Baker/ Dauer/ Friedel)

-mesocosm facility support (Miller*/Baker/Schaffner)

-contaminant analysis (trace element and organic contaminant analysis (Riedel*/Baker)

-mechanisms of exposure and bioaccumulation (Baker)*/Riedel)

-biomarkers of exposure and effect (Roejijadi*/Rowe/Van Veld)

-impact and modeling of survival, growth, behavior, and population processes (Miller*, Rowe, Schaffner)

These teams will be responsible for carrying out day-to-day project activities and informing , coordinating, and interacting across teams.

The overall logistical co-ordination and progress report of the ongoing research activities will be the responsibility of the lead principal investigators (Tenore and Burreson) working with the team leaders from above. The principal investigators will use appropriate mixtures of email and web-based bulletin boards, conference calls, and general meetings to plan and oversee the joint project activities. The outreach team (Leffler/duPaul) will interact closely both with the activities of the advisory council and its steering committee in insuring effective and timely researchers-managers-general public interaction.

The CERP Advisory Council (see 3.a.i) will share in that ongoing information exchange and help organize the issues-oriented workshops (see 3.a.ii). Regularly-scheduled meetings, more often with the AC steering committee, but regularly with the full council, will allow continual cross fertilization of scientific and management input into the ongoing project activities and development of responses to management and public sector issues and scientific issues associated with remediation options.

6. Developing Partnerships

The CRC institutions are committed to help encourage ancillary additional funds through further partnerships with state and federal agencies to provide funding for chemical, toxicological, and ecological research that would relate to and build upon the core research questions addressed in this present CERP project. Appendix A is a letter from Drs. Donald Boesch (UMCES President) and Donelson Wright (VIMS Director and Dean) outlining their commitment to seek additional support for expanding the CERP project. (Appendix A).

We feel that part of our effort in the course of the CERP work will be to identify scientific projects that could provide additional targeted answers to management issues. The CRC institutions will work with agencies/foundations whose missions relate to the proposed research activity to achieve funding of specified research topics. Initially we can identify such modules that would provide useful scientific input to broader management issues on contaminated sediments if there was additional funds available:

6.a Effects on Oyster Reefs. Oyster reefs are critical habitats within Chesapeake Bay that have the potential to occur in or adjacent to at least two of the ROCs. How contaminants released from the sediments affect both the oysters and other species associated with them is an important question not addressed as part of the main CERP program. Questions such as : (1) the feasibility of using oyster reefs as part of a management program to stabilize contaminated sediments or mitigate their effects and (2) the effects of contaminants on the incidence or virulence of oyster diseases are seen as the focus of ancillary studies that can be conducted in conjunction with the CERP study. The feasibility of using oyster reefs as part of a management program could be examined in conjunction with the mesocosm studies in Year 4 and the effects of contaminants on disease would logically be addressed in experiments conducted in Years 2 and 3 that link with the mesocosm studies. (R. Osman, ANSERC; K. Paynter, CBL; R. Anderson, CBL; project cost estimated at 115K per year for three years.)

6.b Effects of sub-lethal stresses on reproductive physiology and output. The reproductive dynamics of a population can be influenced by the chronic, sub-lethal responses of individuals to chemical stresses. Resource management needs such information on long-term, multi-generational effects on yield of commercially/ecologically-important species to predict system effects. The effects on reproductive investment and offspring health of exposure of various finfish/shellfish to ROC-related contaminants and the implications for sustainable yield of these species in the bay ecosystem will be studied using an extension of the mesocosm and modeling research methods in the CERP project. (C. Rowe, UMCES; T. Miller, UMCES; project cost estimated at 165K per year for three years.)

7. Facilities Available

Institutional facilities and services, as needed, to support the funded research and communications activities are available at the participating institutions– the Academy of Natural Sciences Laboratory (ANSERC) at St. Leonard, Old Dominion University (ODU), Maryland Sea Grant, the UMCES Chesapeake Biological Laboratory (CBL) at Solomons, and the Virginia Institute of Marine Sciences (VIMS). Among these institutions there are the mesocosm facilities, specialized experimental culture facilities, trace element/organics, and toxicological analytical facilities necessary to carry out the proposed work.

8. CERP Proposed Budget and Justification Summary

An overall summary of the five year budget plan by CERP task and institutional component is presented in Tables 1 and 2. Detailed year 1 and 5 year summary budgets by investigator are presented within two partner institutional budget submissions submitted by the University of Maryland Center for Environmental Science (which includes a subcontract for the investigator from the Academy of Natural Sciences) and the Virginia Institute of Marine Science (which includes a subcontract for the investigator from Old Dominion University). These official submissions are attached as Appendix B and C.

CERP is designed as a truly integrated study and the budget summary in Table 1 is organized not by P.I. nor by specific institution but by program tasks (project management/facilitation, outreach activities, focused issue workshops, SIERA synthesis activities, mesocosm research support, chemical analysis, toxicological research, modeling).

Individuals from a cross section of participating institutions actively participate to different degrees in all project activities.

Table 2 presents budget information for the proposed five year program showing institutional budget components for each of the CERP activities.

For administrative efficiency the total project is officially organized under two institutional budget submissions: one from the UMCES (CBL), which includes a subcontract for ANSERC; and one from VIMS, which includes a subcontract for ODU. Within each of these submissions the detailed budget is organized and broken down by Principle Investigator. These budgets are included as Appendix B in the proposal.

Each individual budget presented by the Principal Investigators includes a brief outline of justification for specific details within that particular budget. Most of these individual budgets are quite similar in asking funds for: technician/student support and supplies for carrying out the proposed research; local travel funds for attending CERP organizational meetings and workshops and travel to collect field samples and participation as needed at the mesocosm site at CBL; and communication costs (telephone, computer charges, xeroxing) to support group interaction. Most include funds in year 5 toward publication costs for manuscripts stemming from the project.

Regarding salary requests for the Principal Investigators, the amount of their time for which actual funds are budgeted, 0 to 5% per year, are modest and do not reflect the actual time they will spend on this project. It is important to note that all of the Principle Investigators have some portion of their total annual salary (10 to 25%) that is not part of their institutional contract and that they must raise from grants and contracts to receive. Where appropriate, salary paid by the institution has been listed as matching on the individual budgets.

Several of the budgets have other particular associated budgeted costs that should be noted:

The Advisory Budgets presented by Burreson (VIMS) and Tenore (UMCES) include travel funds in year 5 to support PI attendance at national meetings. Our intent is in that final year to offer sessions focusing on the CERP experience at two national meetings, SETAC and ERF, that would provide an integrated account of CERP to the scientific community. These meetings also include a substantial number of persons in the environmental management sector of the environmental science community. By co-ordinating this project through the lead PIs we hope to insure integration and cross-collaboration in accomplishing this report to the scientific community and to encourage joint manuscript preparation.

Budget Justification - Mesocosm Facilities

The use of mesocosm-scale experiments is central to the approach outlined in the proposal. We will use mesocosms both as systems from which to collect raw data on contaminant levels, biomarkers and ecological responses of individual of both species, and as systems in which to test predictive models. Thus all research components, except for the SIERRA activity rely on the mesocosms. Accordingly, we have chosen to identify specifically support for the mesocosms as a line item in the budget. The total amount budgeted for the mesocosms is $360,000. Principally, the amount requested reflects estimated costs for manpower and purchase of mesocosms.

Mesocosm experiments will be conducted at CBL's NSF-funded mesocosm pad. The pad has room for up to 30 6 ft diameter tanks. It is supplied with ambient water from the Patuxent River. The water is drawn from about 8ft at the end of CBL's research pier. We will filter the water before use in experiments, but will not otherwise adjust salinity or temperature.

Mesocosm experiments will be conducted in the first four years of the project. We are requested a full time research technician for each of these years. The technician will be report directly to Dr. Thomas Miller, although his or her duties will be to support the research of all PI's when as it relates to the mesocosm experiments. This person will have overall responsibility of establishing, executing, sampling and clearing all experiments conducted in the mesocosms. During experiments, their principal responsibilities will be to manage the facility, ensure appropriate water quality conditions are maintained and documented throughout the experiments. They will conduct routine sampling from the mesocosms under the direction of individual PI's. We anticipate hiring a M.S.-level person. We have requested an annual salary of $27,000 + benefits for this person in year 1. In subsequent years, this salary request is adjusted by a 3% cost of living index.

We are also requesting hourly support for the mesocosm experiments. We anticipate hiring 2 undergraduate students, each for 3 months a year. These students will assist in establishing and executing experiments. They may undertake some routine sampling. No other manpower costs are included in the mesocosm support budget.

We have requested funds to purchase 45 100-litre tanks to serve as mesocosms for the *Leptocheirus* experiments. We have estimated that each tank will cost $100. This estimate includes both the purchase price and necessary alterations to plumb each tank into the mesocosm facility. We have also requested funds to purchase 30 6-foot diameter fiberglass tanks to serve as mesocosms for the fish experiments. We have estimated $500 per tank to cover purchase and plumbing. We have also requested funds to pay for filter cartridges to ensure supply of a consistent water quality during the long mesocosm experiments.

Other estimated costs to support the facility include ship time to collect the sediment samples from the three ROC's for the *Leptocheirus* and *Fundulus* experiments as well as from the control or reference site. This is estimated at $300 per day. We have included funds to support the general connection of the mesocosm to the pad, and for funds to support the sampling of the mesocosms during experiments.

I have requested funds to support the population modeling and behavioral observation of *Fundulus*. Principal costs include:

- 1 month salary per year for Miller
- graduate student support - funds are requested for support of graduate student including salary and tuition at U.MD
- supplies - principal costs estimated include chamber for response to predation threat of *Fundulus*, a time code generator for the swimming speed monitoring of *Fundulus* and video tapes
- computer support for the programing of the population dynamics models.

Budget Justification: Mechanisms of Exposure and Chemical Contaminant Analytical Program

Funds are requested in Years 2-4 to support an environmental chemistry graduate student who will be involved in the mesocosm experiments. This student will measure and model the bioavailability and diffusive and trophic exposure of target chemicals to Fundulus during the mesocosm experiments, and will work closely with the other investigators and graduate students in the mesocosm study. Modest funds for supplies to be used by this student are also requested.

Analysis of sediments, water, and test organisms for trace metals, persistent organic contaminants, and correlative parameters will be done through an internal analytical core group. Per sample analytical costs are estimated to be $1400/sample, including sample collection and processing using appropriate clean techniques and suitably sensitive methods. Due to limited funds available for analysis, a strategic subset of the total mesocosm samples generated will be analyzed, based on the results of the bioenergetic and biochemical studies.

Budget Justification: SIERA

The budgeting for the SIERA Synthesis Activities reflects minimal amounts needed for the principal investigator and support staff. In year one critical equipment needs include a computer and computer projector for training courses, meetings and presentations. Travel budgeted include $500 for principal investigator to participate CBEEC meetings and planning sessions. The remaining $1,500 will support travel to quarterly workshops for regional scientist and resource managers, and external reviewers.

The institutional indirect cost rates included in the institutional budgets are those audited IC rates that reflect the actual calculated costs of supporting sponsored research.

Table 1. CERP Summary proposed budget (rounded to nearest hundreds of dollars) showing allotment of total costs to the various project tasks for each of five years. These budget figures are across PI and institutional lines.

CERP PRE-PROPOSAL SUMMARY BUDGET

	Year 1	Year 2	Year 3	Year 4	Year 5	Totals
Project Management/ Facilitation:						
Advisory Council	8	8	8	8	34	66
Resource Management Activities:						
Outreach Activities	40	25	25	25	35	150
Focused Issue Workshops	4	4	4	4	4	20
SIERA Synthesis Activities	93	84	36	69	154	385
Scientific Research:						
Mecocosm Facility Support	80	100	80	100	0	360
Contaminant Analysis/		30	67	30	103	230
Mechanisms of Exposure	0	30	30	30	0	90
Biomarkersof Exposure/Effect	110	85	100	95	80	470
Ecological Impact	165	135	150	139	90	679
TOTAL	500	500	500	500	500	2500

Table 2. CERP summary proposed budget (rounded to nearest thousands of dollars) showing allotment of total costs to the various project tasks by institution for each of five years.

CERP PROPOSAL SUMMARY BUDGET

	Year 1	Year 2	Year 3	Year 4	Year 5	Totals
Project Management/Facilitation						
Advisory Council						
UMCES-CBL	3	3	3	3	20	32
UMCES-SEA GRANT						0
VIMS	2	2	2	2	11	19
ODU						0
ANSERC						0
CRC	3	3	3	3	3	15
Resource Management Activities						
Outreach Activities						
UMCES-CBL						0
UMCES-SEA GRANT	25	15	15	15	22	92
VIMS	15	10	10	10	13	58
ODU						0
ANSERC						0
CRC						0
Focused Issue Workshops						
UMCES-CBL	4	4	4	4	4	20
UMCES-SEA GRANT						0
VIMS						0
ODU						0
ANSERC						0
CRC						0
SIERA Synthesis Activities						
UMCES-CBL						0
UMCES-SEA GRANT						0
VIMS	73	74	26	57	97	327
ODU	8	9	10	12	19	58
ANSERC						0
CRC						0
Scientific Research:						
Mecocosm Facility Support						
UMCES-CBL	80	100	80	100	0	360
UMCES-SEA GRANT						0
VIMS						0
ODU						0
ANSERC						0
CRC						0
Mechanisms of Exposure/Contaminant Analysis						
UMCES-CBL	6	30	30	30	19	115
UMCES-SEA GRANT						0
VIMS						0
ODU						0
ANSERC	6	30	67	30	122	255
CRC						0
Biomarkers of Exposure/Effect						
UMCES-CBL	55	42.5	50	47.5	40	235
UMCES-SEA GRANT						0
VIMS	55	42.5	50	47.5	40	235
ODU						0
ANSERC						0
CRC						0
Ecological Impact						
UMCES-CBL	110	88	100	100	60	458
UMCES-SEA GRANT						0
VIMS	55	47	50	39	30	221
ODU						0
ANSERC						0
CRC						0
TOTALS:	500	500	500	500	500	2500

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Velinsky, D.J., T.L. Wade, C. Schlekat and B.J. Presley. 1994. Tidal river sediments in the Washington, D.C. area. I. Distribution and sources of trace metals. Estuaries 17:305-320.

Velinsky, D.J. and J.C. Cummins. 1994. Distribution of Chemical Contaminants in 1991-1992 Wild Fish Species in the District of Columbia. ICPRB Report # 94-2. Interstate Comm. on the Pot. River Basin, Rockville, MD.

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Wade, M.G., and Van Der Kraak, G.J. 1991. The control of testicular androgen production in the goldfish: Effects of activators of different intracellular signalling pathways. Gen. Comp. Endocrinol. 83, 337-344.

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Weber, D.N. 1997. Mechanisms of behavioral toxicology: an integrated approach. American Zoologist 37:343-345.

Weber, D.N. and R.E. Spieler. 1994. Behavioral mechanisms of metal toxicity in fishes. Aquatic Toxicology: Molecular, Biochemical, and Cellular Perspectives (eds Malins, D.C. & Ostrander, G.K.) pp. 421-467. Lewis Publishers, Boca Raton.

Weber, D.N., W.M. Dingel, J.J. Panos, and R.I. Steinpreis. 1997. Alterations in neurobehavioral responses in fishes exposed to lead and lead-chelating agents. American Zoologist 37: 354-362.

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Widdows, J. and P. Donkin. 1991 Role of physiological energetics in ecotoxicology. Comparative Biochemistry and Physiology 100C:69-75.

Zafarullah, M., P.-E. Olsson and L. Gedamu. 1989. Endogenous and heavy metal-induced metallothionein gene expression in salmonid tissues and cell lines. *Gene* 83: 85-93.

Zhou, T. and J.S. Weis. 1998. Swimming behavior and predator avoidance in three populations of *Fundulus heteroclitus* after embryonic and/or larval exposure to methylmercury. Aqua. Toxicol. 131-148.

Curriculum Vitae of Investigators

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1989-1995	Assistant Professor, Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science

Selected Publications:

Ko, F.C. and J.E. Baker (1995) Partitioning of hydrophobic organic contaminants to resuspended sediments and plankton in the mesohaline Chesapeake Bay. *Marine Chem*, 49, 171-188.

Kucklick, J.R., H.R. Harvey, N.E. Ostrom, P. Ostrom, and J.E. Baker (1996) Organochlorine dynamics in the pelagic food web of Lake Baikal. *Environ. Toxicol. Chem.*, 15:1388-1400.

Baker, J.E., Editor (1997) *Atmospheric Deposition of Contaminants to the Great Lakes and Coastal Waters*, SETAC Press, Pensacola, Florida, 451 pp.

Nelson, E, L.L McConnell, and J.E. Baker (1998) Diffusive exchange of gaseous PAH and PAH across the air-water interface of the Chesapeake Bay, *Environ. Sci. Tech.* 32, 912-919.

Kucklick, J.R. and J.E. Baker (1998) Organochlorines in Lake Superior's food web, *Environ. Sci. Technol.*, 32, 1192-1198.

Ashley, J.T.F. and JE Baker (1998) The influence of varying planktonic and periphytic algal biomass on exposure of polychlorinated biphenyls in mesocosms, *Chemistry and Ecology* In Press.

Ashley, J.T.F. and JE Baker (1998) Hydrophobic organic contaminants in surficial sediments of Baltimore Harbor: inventories and sources. *Environ. Toxicol. Chem.*, In Press.

Harman-Fetcho, J.A., L.L. McConnell, and JE Baker (1998) Agricultural pesticides in the Patuxent River, a tributary of the Chesapeake Bay. *J. Environ. Qual.*, In Press.

Datta, S., L. Hansen, L.L. McConnell, JE Baker, J. LeNoir, and J. Seiber (1998) Pesticides and PCB contaminants in fish and frogs from the Kaweah River Basin, California, *Bull. Environ. Contam. Toxicol.*, 60(6), 829-836.

Turner, K.A., R.P.M. Mason, and JE Baker (1998) The influence of varying planktonic and periphytic algal biomass on copper exposure in mesocosms, *Environ. Tox. and Chemistry.*

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Selected Publications and Presentations

Brubaker, J. M. and J. H. Simpson. Flow convergence and stability at a tidal estuarine front: acoustic Doppler current observations. Submitted to J. Geophys. Res.

Brubaker, J. M. (1996) Three-dimensional structure of a tidal eddy. EOS, Trans. American Geophysical Union, 76 (No. 3, Suppl.):OS178.

Brubaker, J.M. (1995) Field Study of Currents at Norfolk Naval Shipyard, Portsmouth, Virginia. Report to SCS Engineers, Reston, VA. Contract No. N62470-92-D-6450.

Sharples, J., J. H. Simpson and J. M. Brubaker (1994) Observations and modeling of periodic stratification in the upper York River estuary. Est. Coastal and Shelf Sci. 38, 301-312.

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The role of disease in the population dynamics of marine organisms, with emphasis on shellfish; environmental control of disease processes; molecular diagnostics for disease organisms; systematics and phylogeny of the phylum Haplosporidia and of marine leeches.

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Anderson, R.S., Brubacher, L.L., Ragone Calvo, L.M., Unger, M.A. & Burreson, E.M. 1998. Effects of tributyltin and hypoxia on progression of Perkinsus marinus infections and host defense mechanisms in oysters, Crassostrea virginica (Gmelin). J. Fish Dis. 21:371-380

Ragone Calvo, L. M., and E. M. Burreson 1998. Prevalence and distribution of QPX, Quahog parasite unknown, in hard clams Mercenaria mercenaria in Virginia, USA. Diseases of Aquatic Organisms 33: 209-219.

Anderson, R. S., L. L. Brubacher, L. M. Ragone Calvo, E. M. Burreson and M. A. Unger. 1997. Effect of in vitro exposure to tributyltin on generation of oxygen metabolites by oyster hemocytes. Environ. Res. 74: 84-90.

Burreson, E. M. and L. M. Ragone Calvo. 1996. Epizootiology of Perkinsus marinus disease of oysters in Chesapeake Bay, with emphasis on data since 1985. J. Shellf. Res. 15(1): 17-34.

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"Investigation of the Effect of Iron Substitution in Minerals on Metal-ion Sorption". C.J. Chisholm-Brause, principal investigator. National Science Foundation.

"Characterization of the Minerals and Iron-Containing Phases of the Aquifer Material at Columbus AFB". C.J. Chisholm-Brause, principal investigator; W.G. MacIntyre, co-investigator. Air Force Office of Scientific Research.

SELECT PUBLICATIONS

"X-ray absorption spectroscopy of Co(II) sorption complexes on quartz (α-SiO_2) and rutile (TiO_2)", O'Day, P.A., **C. J. Chisholm-Brause**, S.Towle, G. A. Parks, and G. E. Brown, Jr.(1996) *Geochimica et Cosmochimica Acta* **60** 2515-2532

"Speciation of uranium in Fernald soils by molecular spectroscopic methods: Characterization of untreated soils", Morris, D. E., P. G. Allen, J. M. Berg, **C. J. Chisholm-Brause**, S. D. Conradson, R. J. Donohoe, N. J. Hess, J. A. Musgrave, and C. D. Tait (1996) *Environ.Sci.Tech.* **30** 2322-2331.

Mason, C.F.V., W.R.J.R.Turney, B.M.Thompson, P. A. Longmire, and **C.J. Chisholm-Brause** (1997) "Carbonate Leaching of Uranium from Contaminated Soils: I. Optimization of Chemical Conditions", submitted to *Environ. Sci. Technol.*

"Speciation of uranyl sorbed at multiple binding sites on montmorillonite", **Chisholm-Brause, C. J.**, S. D. Conradson, C. T. Buscher, P. G. Eller, and D. E. Morris (1994) *Geochim. Cosmochim. Acta*, **58**, 3625-3631.

"Optical spectroscopic studies of the sorption of UO_2^{2+} species on a reference smectite", Morris, D. E., **C. J. Chisholm-Brause**, M. E. Barr, S. D. Conradson, and P. G. Eller (1994) *Geochim. Cosmochim.Acta,* **58**, 3613-3623.

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EDUCATION AND EXPERIENCE

The College of William and Mary - Virginia Institute of Marine Science - Assistant Professor - 1989 to present

University of Wisconsin - Madison - Ph.D. - 1989; M.S. - 1985
Major: Water Chemistry; Minor: Chemical Engineering
Wisconsin Sea Grant Research Assistant 1983-1988
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St. Norbert College - De Pere, Wisconsin - B.S. - 1982
Major: Natural Sciences and Mathematics
Teaching Assistant - Mathematics 1981-1982

RECENT/RELAVENT PUBLICATIONS

Gustafson, K.E. and R.M. Dickhut. 1997. "Distribution of Polycyclic Aromatic Hydrocarbons in Southern Chesapeake Bay: Evaluation of Three Methods for Determining Freely Dissolved Water Concentrations" *Environ. Toxicolog. Chem.* 16:452-461.

Gustafson, K.E. and R.M. Dickhut. 1997. "Particle-Gas Concentrations and Distributions of PAHs in the Atmosphere of Southern Cheasapeake Bay" *Environ. Sci. Technol.* 31:140-147.

Dickhut, R.M. and K.E. Gustafson. 1995. "Atmospheric Washout of Polycyclic Aromatic Hydrocarbons in the Southern Chesapeake Bay Region." *Environ. Sci. Technol.* 29:1518-1525.

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1993-Present. Associate Director for Advisory Services, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia.
1979-Present. Coordinator, Virginia Sea Grant Marine Advisory Program, Virginia Graduate Marine Science Consortium, University of Virginia, Charlottesville, Virginia.

Selected Publications:

Rudders, David B., William D. DuPaul and James E. Kirkley. 1998. A Comparison of Size Selectivity and Relative Efficiency of Sea Scallop Trawls and Dredges. Contract Report to NMFS S-K Fisheries Development Fund. VIMS Marine Resource Report No. 98-6. 73 pp.

DuPaul, William D., Michael J. Oesterling and Laura A. Rose. 1997. Marie Finfish Aquaculture in Virginia. VIMS Marine Resource Report No. 97-4.

DuPaul, William D. and James E. Kirkley. 1997. Evaluation of Crew Size Limits and Dredge Ring Size Restriction in the Atlantic Sea Scallop Fishery. VIMS Marine Resource Report No. 97-3.

DuPaul, William D. (Chair), Rolly Barnaby, Kurt Byers, Chris Dewees, Gary Graham, Mike McDonald, Jim Murray and Ken Roberts. The Role of Sea Grant Extension Programming in an Era of Changing Fisheries. A Report to the Assembly of Sea Grant Maire Advisory and Extension Program Leaders.

DuPaul, William D. (Contributor). 1997. Sustainable Flounder Culture and Fisheries. North Carolina Sea Grant College Program, NC Sea Grant Publication No. UNC-SG-96-14.

DuPaul, William D., Jeffrey C. Brust and James E. Kirkley. 1996. Bycatch in the United States and Canadian Sea Scallop Fishery. Solving Bycatch: Considerations for Today and Tomorrow. University of Alaska, Sea Grant College Program Report No. 96-03, pp. 175-181.

Fisher, Robert A., William D. DuPaul and Thomas E. Rippen. 1996. Nutritional, proximate, and bacteriological characteristics of processed sea scallops, *Placopecten magellanicus*. Journal of Muscle Foods 7(1):73-92.

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EXPERIENCE: The College of William and Mary, School of Marine Science, Assistant Professor, Sep. 1996 to present

The College of William and Mary, School of Marine Science, Visiting Assistant Professor, 1993 to 1996

Woods Hole Oceanographic Institution, Post-Doctoral Investigator, 1993

Woods Hole Oceanographic Institution, Graduate Research Assistant, 1987-1993

SELECTED RECENT PUBLICATIONS:

Friedrichs, C.T., B.A. Armbrust, and H.E. de Swart, in review. Hydrodynamics and sediment dynamics of shallow, funnel-shaped tidal estuaries. J. Dronkers (ed.), Morphodynamics and Self-Organizing Processes in Coastal Seas and Estuaries, Balkema Press, Rotterdam, The Netherlands.

Friedrichs, C.T., J.M. Brubaker, and S.E. Rennie, in review. Mean circulation on the innermost shelf of the Middle Atlantic Bight in fall. Submitted to Continental Shelf Research.

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Friedrichs, C.T. and L.D. Wright, 1995. Resonant internal waves and their role in transport and accumulation of fine sediment in Eckernfoerde Bay, Baltic Sea. Continental Shelf Research, 15:1697-1721.

Friedrichs, C.T. and L.D. Wright, 1997. Sensitivity of bottom stress and bottom roughness estimates to density stratification, Eckernfoerde Bay, Southern Baltic Sea. J. Geophysical Research, 102: 5721-5732

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1954-5 Technical Univ, Delft, Netherlands, Fulbright Scholar
1961 PhD California Institute of Technology, Pasadena, CA, Thesis: Formation of Pleistocene Limestones, Bermuda

Honors:

Honorary Societies: Sigma Xi, Phi Beta Kappa; Fulbright Scholar (Technical Univ, Delft, Netherlands), 1954-5; Office of Personnel Management, SES Fellow, 1988-9; Fellow, Geological Society Am; Fellow, Am. Assoc. Advancement of Science.

Research Interests: Sediments and waste deposits; effects of cities on estuaries and coastal oceans; ocean sciences and marine resources in developing countries; marine science education; careers in ocean and environmental sciences.

Professional Background:

Executive Director, Chesapeake Research Consortium, October 1994-present
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Director, Division of Ocean Sciences, National Science Foundation, 1980-94.
Head, International Decade of Ocean Exploration, NSF, 1979-80.
Director, Chesapeake Bay Inst., Johns Hopkins University, Baltimore, MD, 1974-9.
Head, Oceanography Section, Div. of Environmental Sciences, NSF, 1973-4.
Chief, Ocean Services Division, NOAA, Rockville, MD, 1972-3.
Professor, Marine Sci. Res. Center, State Univ. of New York, Stony Brook., 1968-72.
Associate Curator, Smithsonian Inst., Washington, DC, 1966-8
Asst, and Assoc. Professor, Dept of Oceanography, Univ of Washington, 1961-6.

Publications:

Scientific papers (58), oceanography texts (3), books (2) and monographs (3). Some examples are:

OCEANOGRAPHY: A VIEW OF EARTH, 7 editions (1972-97) Prentice Hall

THE URBAN SEA: LONG ISLAND SOUND. (with L. E. Koppelman, P. K. Weyl, D. S. Davies). Praeger Publ. New York. 1976

OCEAN DUMPING AND MARINE POLLUTION - THE GEOLOGICAL PERSPECTIVE. Dowden, Hutchinson, and Ross, Inc. Stroudsburg, PA (with H. H. Palmer, editors). 1978.

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Most Recent/Relevant Publications

Smoak, J.M., D.J. DeMaster, S.A. Kuehl, R.H. Pope and B.A. McKee. 1996. The behavior of particle-reactive tracers in a high turbidity environment: ^{234}Th and ^{210}Pb on the Amazon continental shelf. *Geochimica et Cosmochimica Acta,* 60:2123-2137.

Kuehl, S.A., C.A. Nittrouer, M.A. Allison, L.E.C. Faria, D.A. Dukat, J.M. Jaeger, T.D.Pacioni, A.G. Figueiredo, and E.C. Underkoffler. 1996. Sediment deposition, accumulation, and seabed dynamics in an energetic fine-grained coastal environment. *Continental Shelf Research,* 16:787-815.

Nittrouer, C.A., S.A. Kuehl, A.G. Figueiredo, M.A. Allison, C.K. Sommerfield, J.M. Rine, L.E.C. Faria and O.M. Silveira. 1996. The geological record preserved by Amazon shelf sedimentation. *Continental Shelf Research,* 16:817-841.

Kuehl, S.A., T.D. Pacioni and J.M. Rine. 1995. Seabed dynamics of the inner Amazon continental shelf: Temporal and spatial variability of surficial strata. *Marine Geology,* 125:283-302.

Dukat, D.A. and S.A. Kuehl. 1995. Non-steady-state ^{210}Pb flux and the use of ^{228}Ra/^{226}Ra as a geochronometer on the Amazon continental shelf. *Marine Geology,* 125:329-350.

Nittrouer, C.A., S.A. Kuehl, R.W. Sternberg, A.G. Figueiredo and L.E.C. Faria. 1995. An introduction to the geological significance of sediment transport and accumulation on the Amazon continental shelf. *Marine Geology,* 125:177-192.

Barua, D.K., S.A. Kuehl, R.L. Miller and W.S. Moore. 1994. Suspended sediment distribution and residual transport in the coastal ocean of the Ganges-Brahmaputra River mouth. *Marine Geology,* 120:41-61.

Segall, M.P. and S.A. Kuehl. 1994. Sedimentary structures on the Bengal shelf: A multi-scale approach to sedimentary fabric interpretation. *Sedimentary Geology, 93:165-180* .

Jorissen, F.J., M.A. Buzas, S.J. Culver and S.A. Kuehl. 1994. Vertical distribution of living benthic foraminifera in submarine canyons off New Jersey. *Journal of Foraminiferal Research,* 24:28-36.

Kuehl, S.A., T.J. Fuglseth and R.C. Thunell. 1993. Sediment mixing and accumulation rates in the Sulu and South China Seas: Implications for organic carbon preservation in deep-sea environments. *Marine Geology,* 111:15-35.

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1975	Admitted to Candidacy for Ph.D., University of Maryland, English Literature, St. Catherine's College, Oxford University (1969-1972)

Professional Background:

1981-Present	Writer, Editor for Science Publications, Maryland Sea Grant College, College Park, Maryland Sea Grant College
1975-77; 79-81	Assistant Professor, English Department, U.S. Naval Academy
1977-Present	Found and teacher, The Writer's Center, Bethesda, Maryland
1973-Present	Publisher, Dryad Press
1966-68	Engineer, Tracor, Incorporated
1962-66	Aerospace-Technologist, Goddard Space Flight Center, NASA

Selected Publications:

Smith, D.E., M. Leffler and G. Mackiernan, eds. 1992. Oxygen Dynamics in Chesapeake Bay: A Synthesis of Recent Research. A Maryland Sea Grant Book, College Park, Maryland.

Leffler, M. , S. Cooper and D. Lipton. 1995. Land-Use Effects on Water Quality in Mid-Atlantic Coastal Waters and Estuaries: Management and Research Needs. A Maryland Sea Grant PubLication, 31pp.

Leffler, M. 1995. Land use and water quality: Connecting ecology and economics. Marine Notes. 13(1&2), 1-5.

Leffler, M. 1994/1995. Multicosm research: Linking basic science to the real world. Marine Notes. 12(7):1-4.

Leffler, M. 1998. 1998. Science and the Bay; Affecting Public Attitudes about the Environment. Marine Notes. 16(6):1-5.

Leffler, M. 1998. Restoring Oysters to U.S. Coastal Waters: A National Commitment. Oyster Disease Research Program, National Sea Grant College Program, 20pp.

Thomas J. Miller, Assistant Professor
Chesapeake Biolgical Laboratory
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Date of Birth: 4/25/
Soc. Sec. Number: 242-37-1529

Education:

1990	Ph.D.	North Carolina State University, Zoology and Oceanography
1984	M.Sc.	North Carolina State University, Ecology
1981	B.Sc. (Hons)	University of York, Human and Environmental Biology

Professional Experience:

Oct. 1994-	Assistant Professor, Chesapeake Biological Laboratory (UMCES)
Nov. 1990-94	Post-doctoral Fellow, Department of Biology, McGill University.
Sept. 1986-90	Research Specialist, Center for Great Lakes Studies, University of Wisconsin

Research Interests: Biological Oceanography with emphasis on physical-biological interactions, spatial and temporal variability; Aquatic Ecology with emphasis on life history, feeding, growth, size-dependent processes and recruitment in fishes;; Quantitative Methods in Ecology with emphasison modeling, experimental design and statistics.

Five Most Recent Publications:

Miller, T. J., T. Herra and W. C. Leggett. 1999. The relationship between larval size and otolith size at hatch in Atlantic cod (*Gadus morhua*). Fish Bull 97: 295-304

Brewster-Geisz, K. K., and T. J. Miller. 1999. Management of sandbar shark (*Carcharhinus plumbeus*): implications from a stage-based model. Fish Bull. U.S. 97: 000-000

Bertram, D. F., T. J. Miller and W. C. Leggett. 1997. Individual variation in growth and development during the early life stages of winter flounder. Fish. Bull. 95:1-10.

Miller, T. J. 1997. The use of field studies to investigate selective processes in fish early life history. Chapter 7, In: Chambers, R. C. and E. A. Trippel (eds.). The Role of Early Life History Studies in Understanding Fish Biology. Chapman and Hall, New York, N.Y.

Dower, J. F., T. J. Miller and W. C. Leggett. 1996. The role of microscale turbulence in the feeding ecology of larval fish. Adv. Mar. Biol. 31:169-220

Gerhardt Riedel, Associate Curator
The Academy of Natural Sciences
Estuarine Research Center
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Date of Birth: 7/8/51
Soc. Sec. Number: 546-80-8349

Education:

1978, 1983	M.S., Ph.D., Biological Oceanography, Oregon State University
1974	A.B., Biology, B.S., Oceanography, Humboldt State University

Professional Experience:

1999-Present	Associate Curator, The Academy of Natural Sciences, Estuarine Research Center.
1993-1999	Assistant Curator, The Academy of Natural Sciences, Benedict Estuarine Research Center.
1987-1993	Senior Scientist, The Academy of Natural Sciences, Benedict Estuarine Research Laboratory.
1985-1987	Postdoctoral Investigator, The Academy of Natural Sciences, Benedict Estuarine Research Laboratory.
1983-1985	Postdoctoral Fellow, Harbor Branch Foundation.

Five Most Recent Publications:

Breitburg, D. L., J. G. Sanders, C. C. Gilmour, C. A. Hatfield, R. W. Osman, G. F. Riedel, S. P. Seitzinger and K. P. Sellner.1999. Variability in responses to nutrients and trace elements, and transmission of stressor effects through an estuarine food web. Limnology and Oceanography, In Press.

Riedel, G .F., J. G. Sanders and R. W. Osman. 1998. Biogeochemical Control on the Flux of Trace Elements from Estuarine Sediments: Effects of Seasonal and Short-term Anoxia. Marine Environmental Research 47:349-372.

Riedel, G. F., G. R. Abbe and J. G. Sanders. 1998. Trace Metals Concentrations in Oysters from the Patuxent River, Maryland: Temporal and Spatial Variation. Estuaries 21: 423-434.

Sanders, J. G. and G. F. Riedel. 1998. Metal accumulation and impacts in phytoplankton. pp 59-76 in: W. Langston and M . Bebianno (eds.) Metal Metabolism in Aquatic Environments. Chapman and Hall, London.

Riedel, G. F and J. G. Sanders. 1998 Trace Element Speciation and Behavior in the Tidal Delaware River. Estuaries 21:78-90.

Guritno Roesijadi, Professor
Chesapeake Biological Laboratory
University of Maryland Center for Environmental Sciences
Post Office Box 38, Solomons, MD 20688

Date of Birth: 4/4/48
Soc.Sec. Number: 559-72-4449

Education:

1970, BS	University of Washington, Seattle, WA, Zoology
1773, MS	Humboldt State University Arcata, CA, Fisheries
1976, Ph.D,	Texas A&M University, College Station, TX, Biology

Professional Background:

1986-Present	Full Professor ('93-), Associate Professor ('86-'93), University of Maryland Center for Environmental Science
1996-1997	Guest Professor, Institute of Biochemistry, University of Zurich, Switzerland
1996-1997	Senior International Fellow, National Institutes of Health
1984-1986	Assoc. Prof of Biology, The Pennsylvania State University, University Park, PA
1976-1984	Senior Research Scientist, Research Scientist, Battelle Pacific Northwest National Laboratory, Sequim, WA

Research Interests: Environmental health and ecotoxicology; comparative physiology, biochemistry, and toxicology; trace element metabolism; cellular function of metallothionein.

Publications: (selected publications from last 5 years):

Roesijadi, G. 1994. Behavior of metallothionein-bound metals in a natural population of an estuarine mollusc. Mar. Environ. Res. 38:147-168.

Fuentes, M.E., M.E. Unger, G. Roesijadi. 1994. Individual variability in the 3'-untranslated region of metallothionein mRNAs in a natural population of the mollusc *Crassostrea virginica.* Molec. Mar. Biol. Biotech. 3:141-148.

Roesijadi, G., K.M. Hansen, M.E. Fuentes. 1995. Cadmium induced expression of metallothionein and suppression of RNA to DNA ratios during molluscan development. Toxicol. Appl. Pharm. 133:130-138.

Unger, M.E. and G. Roesijadi. 1996. Cd pre-exposure and increase in metallothionein mRNA accumulation during subsequent Cd challenge. Aqua. Tox. 34:185-193.

Roesijadi, G., K.M. Hansen, and M.E. Unger. 1996. Cadmium-induced metallothionein expression during embryonic and early larval development of the mollusc *Crassostrea virginica.* Toxicol. Appl. Pharmacol. 140:356-363.

Roesijadi, G., K.M. Hansen, and M.E. Unger. 1997. Metallothionein gene expression in early developmental stages of *Crassostrea virginica* following pre-exposure and challenge with cadmium. Aqua. Toxicol. 39:185-194.

Roesijadi, G., K.M. Hansen, and M.E. Unger. 1997. Concentration-response relationships for Cd, Cu, and Zn exposure and metallothionein mRNA induction in larvae of *Crassostrea virginica.* Comp. Biochem. Physiol. 118: 267-270.

Roesijadi, G., R Bogumil, M Vasák, J.H.R. Kägi. 1998. Modulation of DNA-Binding of a Tramtrack Zinc-Finger Peptide by the Metallothionein-Thionein Conjugate Pair. J. Biol. Chem. 273: 17425-17432.

Roesijadi, G. (in press 1998). The basis for increased metallothionein in a natural population of *Crassostrea virginica.* Biomarkers.

Christopher L. Rowe, Associate Professor
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Date of Birth: 05/04/67
Soc. Sec. Number: 206-60-2939

Education:

1989	B.S. Biology, minor Marine Science, The Pennsylvania State University
1994	Ph.D.,The Pennsylvania State University, Biology, "Effects of abiotic and biotic variables on amphibian communities of temporary ponds."

Professional Background:

1994-1995	Temporary Assistant Professor, Biology, Georgia Southern University, Statesboro, Georgia.
1995-1997	Post-doctoral researcher, University of Georgia, Savannah River Ecology Laboratory, Aiken, South Carolina.
1997-1999	Assistant Professor, Biology, University of Puerto Rico, San Juan, Puerto Rico.
1999-	Assistant Professor, University of Maryland, Chesapeake Biological Laboratory, Solomons, Maryland. .

Research Interests: Physiological, population, and community responses to sublethal pollutants in aquatic systems.

Publications: (Author of fifteen publications.) The following are examples:

Hopkins, W.A., C.L. Rowe, and J.D. Congdon. 1999. Physiological responses of banded water snakes (Nerodia fasciata) exposed to coal combustion wastes. *Environmental Toxicology and Chemistry, in press.*

Rowe, C.L. 1998. Elevated standard metabolic rate in a freshwater shrimp (Palaemonetes paludosus) exposed to trace element-rich coal combustion waste. *Comparative Biochemistry and Physiology A*121(4):299-304.

Rowe, C.L., O.M. Kinney, R.D. Nagle, and J.D. Congdon. 1998. Elevated maintenance costs in an anuran (Rana catesbeiana) exposed to a mixture of trace elements during the embryonic and early larval periods. *Physiological Zoology* 71:27-35.

Raimondo, S.M., C.L. Rowe, and J.D. Congdon. 1998. Exposure to coal ash impacts swimming behavior and predator avoidance in larval bullfrogs (Rana catesbeiana). *Journal of Herpetology* 32:289-292.

Rowe, C.L., O.M. Kinney, A.P. Fiori, and J.D. Congdon. 1996. Oral deformities in tadpoles (Rana catesbeiana) associated with coal ash deposition: effects on grazing ability and growth. *Freshwater Biology* 37:723-730.

Rowe, C.L. and W.A. Dunson. 1995. Individual and interactive effects of salinity and initial fish density on a salt marsh assemblage. *Marine Ecology Progress Series* 128:271-278.

Linda C. Schaffner, Associate Professor
Department of Biological Sciences
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Date of Birth: 12/08/54
Soc. Sec. Number: 063-48-6030

Education:

1976 BA., Drew University, NJ, Zoology
1981 M.S., College of William and Mary, Marine Science
1987 Ph.D., College of William and Mary, "Ecology of the benthos of lower Chesapeake Bay"

Professional Background:

1981 - 1988 Marine Scientist, VIMS
1988 - 1992 Assistant Professor, The College of William and Mary (tenure ineligible)
1992 - 1998 Assistant Professor, The College of William and Mary (tenure eligible)
1998 - present Associate Professor, with tenure

Research Interests: Benthic ecology;natural and anthropogenic disturbance processes; role of benthic systems in ecosystem processes; population dynamics/secondary production of estuarine invertebrates

Publications: (selected)

Thompson, M. T. and L. C. Schaffner. Demography of the polychaete *Chaetopterus pergamentaceus* within lower Chesapeake Bay and relationships to environmental gradients. (accepted, in revision, Bulletin of Marine Science)

Schaffner, L. C., E. K. Hinchey, T. M. Dellapenna, C. T. Friedrichs, M. Thompson Neubauer, M. E. Smith and S. A. Kuehl. Physical energy regimes, sea-bed dynamics and organism-sediment interactions along an estuarine gradient. (accepted, in revision, *Organism-Sediment Interactions*, J. Y. Aller, S. A. Woodin and R. C. Aller, eds. University of South Carolina Press)

Kane-Driscoll, S. B., L. C. Schaffner and R. M. Dickhut. 1998. Toxicokinetics of fluoranthene to the amphipod, *Leptocheirus plumulosus*, in water-only and sediment exposures. Marine Environmental Research 45: 269-284.

Schaffner, L. C., R. M. Dickhut, S. Mitra and P. W. Lay. 1997. Effects of physical chemistry and bioturbation by estuarine macrofauna on the transport of hydrophobic organic contaminants in the benthos. Environ. Sci. Technol. 31: 3120-3125.

Weisburg, S. B., J. A. Ranasinghe, D. M. Dauer, L. C. Schaffner, R. J. Diaz and J. B. Frithsen. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. Estuaries 20: 149-158.

Seitz, R. D. and L. C. Schaffner. 1995. Population ecology and secondary production of the polychaete *Loimia medusa* (Terebellidae). Marine Biology 121: 701-711.

Kenneth R. Tenore, Professor and Director
Chesapeake Biological Laboratory
University of Maryland Center for Environmental Science
P.O. Box 38
Solomons, Maryland 20688-0038

Date of Birth: March 22, 1943
Soc. Sec. Number.: 020-32-7015

Education:

1965 A.B., with honors, St. Anselm College, N.H., Biology
1967 M.S., North Carolina State University, Zoology
1970 Ph.D., North Carolina State University, Zoology, "The macrobenthos of the Pamlico River Estuary, North Carolina"

Professional Background:

1970-1975	Postdoctoral Investigator, Assist Scientist at Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
1975-1984	Assist, Assoc, Professor, at Skidaway Institute of Oceanography, Savannah, GA
1984-Present	Professor and Director, Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, Solomons, MD.
1994 Jan-Jun	Visiting Scholar, Center for Science, Technology, and Values in the Philosophy of Science Program at the University of Notre Dame, South Bend, Indiana (on sabbatical from CBL).

Research Interests: Coastal oceanography; benthic ecology; ecological energetics and nutrition of detritus-based food chains; teaching theory and ethics in scientific practice.

Publications: Author of over seventy-five publications. The following are examples:

Tenore, K.R. and E.J. Chesney, Jr. 1985. The interaction of rate of food supply and population density on the bioenergetics of the opportunistic polychaete, *Capitella capitata* (Type I). Limnol. Oceanogr. 30:1188-1195.

Marsh, A.G., A. Gremare, and K.R. Tenore. 1989. The effect of food type and food ration on growth of juvenile *Capitella capitata* (Type I) (Annelida: Polychaeta): macro- and micro-nutrients. Mar. Biol. 102:519-527.

Marsh, A.G. and K.R. Tenore. 1990. The role of nutrition in regulating the population dynamics of opportunistic, surface deposit feeders in a mesohaline community. Limnol. Oceanogr. 35(3):710-724.

Marsh, A.G., H.R. Harvey, A. Gremare and K.R. Tenore. 1990. Dietary effects on oocyte yolk-composition in *Capitella* sp. I (Annelida: Polychaeta): fatty acids and sterols. Mar. Biol. 106:369-374.

Tenore, K.R. et al. 1995. Fisheries and Oceanography off Galicia, NW Spain: mesoscale spatial and temporal changes in physical processes and resultant patterns of biological productivity. J. Geophysical Res. 100(C6):10943-10966.

Peter A. Van Veld, Associate Professor
The College of William and Mary
Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

Date of Birth: 02/11/52
Soc. Sec. Number: 245-90-2576

Education:

1975	B.S., Biology, The University of North Carolina, Chapel Hill
1980	M.S., Marine Science, The College of William and Mary
1987	Ph.D., Environmental Toxicology, University of Georgia

Professional Background:

1987-1989	NIH Postdoctoral Fellow, Roswell Park Cancer Institute, Buffalo, New York
1989-1995	Assistant Professor, College of William and Mary, School of Marine Science, Virginia Institute of Marine Science, Gloucester Point, Virginia
1995-present	Associate Professor, College of William and Mary, School of Marine Science, Virginia Institute of Marine Science, Gloucester Point, Virginia

Research Interests: Biochemical and molecular responses to pollution, adaptations to chemical stress, chemical carcinogenesis, bioavailability and exposure mechanisms

Selected Publications:

Armknecht, S.L., P.A. Van Veld and S.L. Kaattari. 1998. An elevated glutathione S-transferase in creosote-resistant mummichog (*Fundulus heteroclitus*). Aquatic Toxicol. 41:1-16.

Cooper, P.S., W.K. Vogelbein and P.A. Van Veld. 1999. P-glycoprotein expression in liver and liver tumors of mummichog inhabiting a creosote-contaminated site. Biomarkers 4: 48-58.

Borton, D.L., W.R. Streblow, P. Van Veld, T.J. Hall and T. Bousquet. Comparison of bioindicators of reproduction during fathead minnow (*Pimephales promelas*) life-cycle tests with kraft mill effluents. In Pulp and Paper Effluents in the Aquatic Environment, St. Lucie Press. (In press).

Van Veld, P.A., W.K. Vogelbein, M. Cochran, A. Goksøyr and J.J. Stegeman. 1997. Route-dependent cellular expression of cytochrome P4501A (CYP1A) in fish (*Fundulus heteroclitus*) following exposure to aqueous and dietary benzo[a]pyrene. Toxicol. Appl. Pharmacol. 142:348-359.

Cooper, P.S., W.K. Vogelbein and P.A. Van Veld. 1996. Immunohistochemical and immunoblot detection of P-glycoprotein in normal and neoplastic fish liver. In: Techniques in Aquatic Toxicology. Chapter 17, Ed., G.K. Ostrander, CRC/Lewis Publishers, Boca Raton, FL, pp. 307-325.

Di Giulio, R., B. Benson, B. Sanders and P. Van Veld. 1995. Xenobiotic metabolism and biochemical effects. In: Fundamentals of Aquatic Toxicology. Ed., G. Rand. Taylor and Francis Publishers, Inc., Washington D.C. pp. 523-561.