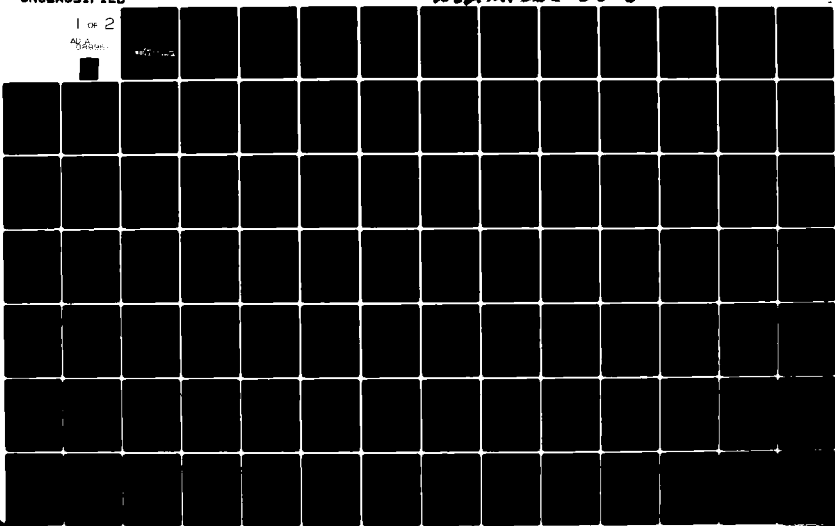
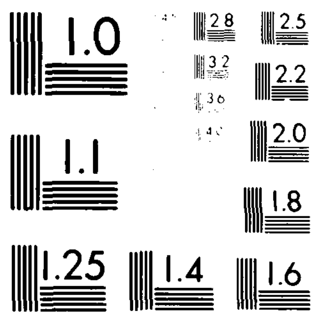
AD-A089 961 SCIENCE APPLICATIONS INC RALEIGH NC F/G 13/2
MARINE WETLAND AND ESTUARINE PROCESSES AND WATER QUALITY MODELI--ETC(U)
SEP 80 P HAMILTON DACW39-78-C-0087
UNCLASSIFIED WES/MP/EL 80-3

1 OF 2
AD A
089961





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

MISCELLANEOUS PAPER EL-80-3

MARINE WETLAND AND ESTUARINE PROCESSES AND WATER QUALITY MODELING; WORKSHOP REPORT AND RECOMMENDATIONS

by

Peter Hamilton

Science Applications, Inc.
4900 Water's Edge Drive
Raleigh, N. C. 27606

September 1980

Final Report

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Contract No. DACW39-78-C-0087

Monitored by Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

(18) WES/MP/EL (11) 80-3

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper EL-80-3	2. GOVT ACCESSION NO. AD-A089	3. RECIPIENT'S CATALOG NUMBER 961
4. TITLE (and Subtitle) (6) MARINE WETLAND AND ESTUARINE PROCESSES AND WATER QUALITY MODELING; WORKSHOP REPORT AND RECOMMENDATIONS.		5. TYPE OF REPORT & PERIOD COVERED (9) Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Peter Hamilton		8. CONTRACT OR GRANT NUMBER(s) (15) Contract No. DACW39-78-C-0087
9. PERFORMING ORGANIZATION NAME AND ADDRESS Science Applications, Inc. 4900 Water's Edge Drive Raleigh, N. C. 27606		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE (11) September 1980 13. NUMBER OF PAGES 118
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) U. S. Army Engineer Waterways Experiment Station Environmental Laboratory P. O. Box 631, Vicksburg, Miss. 39180		15. SECURITY CLASS. (of this report) Unclassified (12) 123 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ecosystems	Salt marshes
Environmental effects	Water quality models
Estuaries	Wetlands
Marine wetlands	Workshops

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the proceedings of a workshop entitled "Wetland and Estuarine Processes and Water Quality Modeling," held on 18-20 June 1979 in New Orleans, Louisiana. The workshop was organized by Science Applications, Inc. (SAI), under the sponsorship of the U. S. Army Engineer Waterways Experiment Station (WES) as part of the Corps of Engineers' Environmental Impact Research Program. In addition, this report includes recommendations for

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

87   411

20. ABSTRACT (Continued).

possible future research that emerged as a result of the presentations and discussions held during the workshop and two other studies performed under the contract: a survey of marine wetland and estuarine water quality and ecological problems in Corps of Engineers Field Offices; and a survey and review of published literature in the fields of hydrodynamics, water quality, and ecosystem modeling as applied to estuaries, coastal bays, and salt marshes.

PREFACE

The workshop reported herein was conducted by Science Applications, Inc. (SAI), for the Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station (WES) as partial fulfillment of Contract No. DACW39-78-C-0087. Joanne Brown of the Boulder Office of SAI organized the practical details of invitations, brochures, workshop siting, and hotel rooms. Peter Hamilton, Keith Macdonald, and Ken Fucik organized scientific aspects of the meeting. Paul Debrule, Martin Miller, and Ivan Show, Jr., provided assistance in the conduct of the workshop.

This report was prepared by Dr. Peter Hamilton, principal investigator. Mr. Ross Hall monitored the study for EL under the direct supervision of Mr. Donald L. Robey, Environmental Research and Simulation Division (ERSD), and under the general supervision of Dr. Rex L. Eley, Chief, ERSD, and Dr. John Harrison, Chief, EL.

Director of the WES during preparation of this report was COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

A

CONTENTS

ATTENDEES

WETLAND AND ESTUARINE PROCESSES
AND
WATER QUALITY MODELING

New Orleans, Louisiana

Robert Ambrose
EPA
Athens, GA

Gary April
University of Alabama
Tuscaloosa, AL

Ranjan Ariathurai
Resource Management Associates
Lafayette, CA

John Barko
Waterways Experiment Station
Vicksburg, MS

David Bartlett
University of Delaware
Lewes, DE

Barry Benedict
University of South Carolina
Columbia, SC

Norman Benson
U. S. Fish and Wildlife Service
NSTL Station, MS

Jack Blanton
Skidaway Institute of Oceanography
Savannah, GA

W. Frank Bohlen
University of Connecticut
Storrs, CT

William Boicourt
The Johns Hopkins University
Baltimore, MD

Joanne Brown
SAI
Boulder, CO

Roger Burke
Massachusetts Institute of Technology
Cambridge, MA

John Bushman
Office, Chief of Engineers
Washington, DC

Christopher Buterra
NASA/ERL
NSTL Station, MS

H. Lee Butler
Waterways Experiment Station
Vicksburg, MS

Hwang Chen
Lawler, Marusky & Skelly
Pearl River, NY

Sherman Chiu
University of Miami
Miami, FL

Tom Chzanowski
University of South Carolina
Columbia, SC

Ellis Clairian
Waterways Experiment Station
Vicksburg, MS

L. Eugene Cronin
Chesapeake Research Consortium
Annapolis, MD

Donald Cundy
University of Connecticut
Groton, CT

Paul Debrule
SAI
Raleigh, NC

Uwe Deegen
Mississippi Marine Research Council
Long Beach, MS

John Edinger
J. E. Edinger Associates
Wayne, PA

Paul Farrar
Waterways Experiment Station
Vicksburg, MS

Ken Fucik
SAI
Boulder, CO

Bharat Gael
Louisiana State University
Baton Rouge, LA

George Gardner
University of Washington
Seattle, WA

Ross Hall
Waterways Experiment Station
Vicksburg, MS

Peter Hamilton
SAI
Raleigh, NC

Kathryn Hatcher
University of Georgia
Athens, GA

Larry Hauck
Espey-Huston & Associates
Austin, TX

James Houston
Waterways Experiment Station
Vicksburg, MS

Joh Hubertz
Coastal Engineering Research Center
Fort Belvoir, VA

Paul Jensen
Espey-Huston & Associates
Austin, TX

Billy Johnson
Waterways Experiment Station
Vicksburg, MS

Robert Johnson
NASA
Hampton, VA

J. van de Kreeke
University of Miami
Miami, FL

Richard Kristof
U. S. Bureau of Reclamation
Sacramento, CA

Ray Krone
University of California
Davis, CA

David Leenknecht
U.S. Army, Corps of Engineers
New Orleans, LA

James Leeman
Dravo Utility Constructors, Inc.
New Orleans, LA

John Lunz
Waterways Experiment Station
Vicksburg, MS

Keith Macdonald
SAI
Boulder, CO

Fred Manley
University of Mississippi
University, MS

Martin Miller
SAI
Raleigh, NC

William Moyer
Department of Natural Resources
Dover, DE

Scott Nixon
University of Rhode Island
Kingston, RI

Donald O'Connor
Manhattan College
New York, NY

Charles Officer
Dartmouth College
Hanover, NH

William Patrick, Jr.
Louisiana State University
Baton Rouge, LA

Willis Pequegnat
Tereco Corporation
College Station, TX

Edward Pullen
CERC
Ft. Belvoir, VA

Robin Radlein
NASA/ERL
NSTL Station, MS

Donald Raney
University of Alabama
University, AL

Pulak Ray
State University of New York College
Buffalo, NY

Robert Reid
Texas A&M University
College Station, TX

Philip Roberts
Georgia Institute of Technology
Atlanta, GA

Don Robey
Waterways Experiment Station
Vicksburg, MS

Saul Saila
University of Rhode Island
Kingston, RI

Lynn Shay
Naval Oceanographic Office
NSTL Station, MS

Peter Sheng
ARAP
Princeton, NJ

Ivan Show
SAI
LaJolla, CA

Harold Stevenson
University of South Carolina
Columbia, SC

Keith Stolzenbach
Massachusetts Institute of Technology
Cambridge, MA

Rudd Turner
Corps of Engineers
Mobile, AL

John Wanstrath
Tetra Tech, Inc.
Houston, TX

Dong-Ping Wang
Chesapeake Bay Institute
Baltimore, MD

George Ward
Espey-Huston & Associates
Austin, TX

R. G. Wiegert
University of Georgia
Athens, GA

Jerome Williams
U. S. Naval Academy
Annapolis, MD

Charles Wilson
University of South Carolina
Columbia, SC

Myron Young
Center for Wetlands Resources
Louisiana State University
Baton Rouge, LA

AGENDA

WETLAND AND ESTUARINE PROCESSES
AND
WATER QUALITY MODELING

New Orleans, Louisiana
June 18-20, 1979

Monday - June 18th

8:45 - 9:00	Welcome and Opening Remarks
SESSION I	PHYSICAL PROCESSES
9:00 - 10:00	Invited Paper *Turbulence in Estuaries* G. B. Gardner, A. R. M. Nowell, and J. D. Smith University of Washington, Seattle, Washington
10:00 - 10:20	*Circulations in the Chesapeake Bay* Dong-Ping Wang Chesapeake Bay Institute, Baltimore, Maryland
10:20 - 10:40	*Three-Dimensional Circulation Processes in the Potomac River Estuary* W. Boicourt Chesapeake Bay Institute, Baltimore, Maryland
10:40 - 11:00	Coffee Break
11:00 - 11:20	*The Mixing of Fresh Water off a Many-Inleted Coastline* J. O. Blanton Skidaway Institute of Oceanography, Savannah, Georgia
11:20 - 11:40	*Circulation in a Tidal Creek Interconnecting Two Estuaries* P. K. Ray State University of New York College, Buffalo, New York
11:40 - 12:00	*Hydrography and Circulation Processes of Gulf Estuaries* G. H. Ward, Jr. Espey, Huston and Associates, Inc., Austin, Texas
12:00 - 1:20	Lunch

Monday - June 18th

SESSION II — **MODELING OF CIRCULATION AND WATER QUALITY**

1:20 - 2:20	Invited Paper *Numerical Hydrodynamics of Estuaries* J. E. Edinger and E. M. Buchak J. E. Edinger and Associates, Wayne, Pennsylvania
2:20 - 2:40	*Evolution of a Numerical Model for Simulating Long-Period Wave Behavior in Ocean-Estuarine Systems* H. Lee Butler U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi
2:40 - 3:00	*Tide-Induced Residual Circulation* J. van de Kreeke and S. S. Chiu University of Miami, Miami, Florida
3:00 - 3:20	*Current Measurements and Mathematical Modeling in Southern Puget Sound* P. J. W. Roberts Georgia Institute of Technology, Atlanta, Georgia
3:20 - 3:40	Afternoon Break
3:40 - 4:00	*Box Models* C. B. Officer Dartmouth College, Hanover, New Hampshire
4:00 - 4:20	*Hydrodynamic and Biological Modeling of the Cape Fear Estuary, North Carolina* H. Y. Chen, T. L. Englert, T. B. Vanderbeck, and J. P. Lawler Lawler, Matusky and Skelly, Inc., Pearl River, New York
4:20 - 4:40	*The Movements of a Marine Copepod in a Tidal Lagoon* I. T. Show, Jr. Science Applications, Inc., La Jolla, California
4:40 - 5:00	*Predicting the Effects of Storm Surges and Abnormal River Flow on Flooding and Water Movement in Mobile Bay, Alabama* G. C. April and D. C. Raney University of Alabama, University, Alabama
5:00 - 5:20	*Hydrodynamics and Ecosystem Function in Lake Pontchartrain, Louisiana* B. T. Gael Louisiana State University, Baton Rouge, Louisiana

Monday - June 18th

SESSION II (Continued)	**MODELING OF CIRCULATION AND WATER QUALITY (Continued)**
5:20 - 5:40	*Hydrodynamic-Mass Transfer Model for Deltaic Systems* L. M. Hauch and G. H. Ward Espey, Huston and Associates, Inc., Austin, Texas
5:40 - 6:00	*The Role of Physical Modeling in the Mathematical Modeling of the Sacramento-San Joaquin Delta Estuary* R. C. Kristof Bureau of Reclamation, Sacramento, California

Tuesday - June 19th

SESSION III	**MODELING AND IMPACT ASSESSMENT**
9:00 - 10:00	Invited Paper *Estuarine Fishery Resources and Estuarine Modification, Some Suggestions for Impact Assessment* S. B. Saila University of Rhode Island, Kingston, Rhode Island
10:00 - 10:20	*Combined Field-Laboratory Method for Chronic Impact Detection in Marine Organisms and Its Application to Dredged Material Disposal* W. E. Pequegnat,[1] R. R. Fay,[1] and T. A. Wastler[2] [1]TerEco Corporation, College Station, Texas [2]Marine Protection Branch, U.S. EPA, Washington, D.C.
10:20 - 10:40	*Modeling Toxic Spills in Estuaries* B. A. Benedict University of South Carolina, Columbia, South Carolina
10:40 - 11:00	*A Predictive Model for the Transparency of Estuarine Waters* J. Williams U.S. Naval Academy, Annapolis, Maryland
11:00 - 11:20	Coffee Break

Tuesday - June 19th

SESSION IV	SEDIMENT TRANSPORT PROCESSES
11:20 - 12:20	Invited Paper *Sedimentation Processes in Estuaries* R. B. Krone University of California at Davis, California
12:20 - 1:40	Lunch
1:40 - 2:40	Invited Paper *Mathematical Modeling of Suspended Sediment Transport: A Review* R. Ariathurai Resource Management Associates, Lafayette, California
2:40 - 3:00	*Modeling Sediment Transport in Shallow Waters* Y. Peter Sheng Aeronautical Research Associates of Princeton, Inc. Princeton, New Jersey
3:00 - 3:20	*A Numerical Simulation of the Dispersion of Sediments Resuspended by Dredging Operations in an Estuary* D. F. Cundy and W. F. Bohlen University of Connecticut, Groton, Connecticut
SESSION V	ESTUARINE AND WETLAND ECOSYSTEMS
3:20 - 3:40	*Sources and Export of Detrital Particulates from Coastal Wetland Ecosystems* R. Harris,[1] B. W. Ribelin,[2] and C. Dreyer[3] [1]NASA - Langley Research Center, Virginia [2]Sea Farms de Honduras, Choluteca, Honduras [3]Florida State University, Tallahassee, Florida
3:40 - 4:00	Afternoon Break
4:00 - 4:20	*Characterization of Marsh-Nonmarsh Interfaces* L. H. Stevenson, T. H. Chzanowski, B. J. Kjerfve, and C. A. Wilson University of South Carolina, Columbia, South Carolina
4:20 - 4:40	*Tidal Wetlands and Estuarine Coliform Bacteria* P. A. Jensen and A. C. Rola University of Delaware, Lewes, Delaware

Tuesday - June 19th

SESSION V (Continued)	ESTUARINE AND WETLAND ECOSYSTEMS (Continued)
4:40 - 5:00	*Quantitative Assessment of Emergent Biomass and Species Composition in Tidal Wetlands Using Remote Sensing* D. S. Bartlett and V. Klemas University of Delaware, Lewes, Delaware
5:00 - 5:20	*Applications of Remote Sensing in Simulation Models of Estuarine Ecosystems* R. W. Johnson NASA - Langley Research Center, Virginia
5:20 - 5:40	*Seepage in Salt Marsh Soils* R. Burke, H. Hemond, and K. Stoltzenbach Massachusetts Institute of Technology, Cambridge, Massachusetts

Wednesday - June 20th

SESSION VI	ESTUARINE AND WETLAND ECOSYSTEMS
9:00 - 10:00	Invited Paper *Sedimentation and Nutrient Cycling in a Louisiana Salt Marsh* R. D. DeLaune and W. H. Patrick, Jr. Louisiana State University, Baton Rouge, Louisiana
10:00 - 11:00	Invited Paper *Marsh-Estuarine Coupling and Water Quality Considerations* Scott W. Nixon University of Rhode Island, Narragansett Bay, Rhode Island
11:00 - 11:20	Coffee Break
11:20 - 12:20	Invited Paper *Salt Marsh Modeling* R. G. Wiegert University of Georgia, Athens, Georgia
12:20 - 1:40	Lunch
1:40 - 2:40	Invited Paper *Water Quality Modeling of Estuaries* D. J. O'Connor Manhattan College, New York, New York
2:40 - 3:00	Afternoon Break

Wednesday - June 20th

SESSION VI (Continued) — ESTUARINE AND WETLAND ECOSYSTEMS (Continued)

3:00 - 6:00 — Workshop Panel Session
Research in Estuaries and Wetlands: Needs and Problems
Chairman - Scott W. Nixon

MARINE WETLAND AND ESTUARINE PROCESSES AND WATER QUALITY MODELING; WORKSHOP REPORT AND RECOMMENDATIONS

PART I: INTRODUCTION

1. This report summarizes the proceedings of a workshop entitled, "Marine Wetland and Estuarine Processes and Water Quality Modeling," that was organized by Science Applications, Inc. (SAI), under the sponsorship of the U. S. Army Engineer Waterways Experiment Station (WES). Additionally, the report includes recommendations on possible future research that resulted from presentations and discussions held during the workshop and other studies performed under this contract.

Background to the Workshop

2. This study was initiated by the Environmental Laboratory (EL) at WES in October 1978 for the purpose of assessing the needs and problems of the Corps of Engineers (CE) in the coastal zone. A major emphasis of the study was to assess the state of the art in modeling of hydrodynamic, water quality, and ecosystem processes in estuaries and wetlands.

Survey of the CE District Offices

3. The initial effort involved a survey of the District Offices of the CE with coastal responsibilities. The survey involved onsite visits by investigators from SAI, who held informal meetings with CE personnel from Planning (Environmental Resources), Engineering (Water Quality and Hydraulics), and Construction and Operations (Resource Management and Permits). Information was obtained on the need for predictive modeling techniques for existing and anticipated water quality and ecological problems associated with CE activities in the coastal zone.

A survey report* has been published by WES.

Literature Review

4. Concurrent with the District Office survey and the organization of the workshop, SAI conducted a survey and a review of published literature in the fields of hydrodynamics, water quality, and ecosystem modeling as applied to estuaries, coastal bays, and salt marshes. The literature review** has also been published by WES.

Workshop Preliminaries and Organization

5. Based on initial analysis of the District Office survey, a workshop was organized. The primary subject areas chosen were: physical processes (circulation and mixing), mathematical modeling of hydrodynamics and water quality, sediment transport, and marsh-estuarine coupling. Nine speakers were invited to review special topics, and a call for contributed papers was placed in a number of scientific journals and widely distributed by mail to members of the marsh/estuarine scientific community in universities, government, and industry. The Call for Papers is given in Appendix A. The response to the Call for Papers was excellent, and 26 papers were selected from submitted abstracts by the Workshop Organizing Committee.

6. The workshop was held 18-20 June 1979 in New Orleans, Louisiana.

---

* Hamilton, P. 1980. "Survey of Marine Wetland and Estuarine Water Quality and Ecological Problems in Corps of Engineer Field Offices," Miscellaneous Paper, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., in preparation.

** Hamilton, P. and Fucik, K. W. 1980. "Literature Review of Marine Wetland and Estuarine Water Quality and Ecosystem Models," U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., in preparation.

The Workshop

7. The abstracts of the invited and contributed papers are given in Part II. The sessions were arranged as follows:

Physical processes

8. The opening session emphasized fundamental physical processes that are basic to modeling hydrodynamics and water quality. The invited paper on "Turbulence in Estuaries" was presented by George Gardner and reviewed turbulence and mixing in geophysical stratified flows. These are difficult processes to study and a lack of fundamental research in this area was noted, particularly for shallow, partially mixed coastal plain estuaries that predominate in the United States. Larger scale circulation processes were reported in the subsequent papers of the session, including the importance of wind in driving energetic subtidal transients (Wang), effects of topography on three-dimensional current patterns as revealed by a comprehensive experiment in the Potomac (Boicourt), and the important problem of the interactions of estuaries and the nearshore coastal ocean (Blanton). Hydrodynamics of small-scale tidal circulations in marsh creeks were discussed (Ray), and a final paper reviewed circulation processes found in gulf coast estuaries (Ward).

Modeling of circulation and water quality

9. The emphasis of the second session was on the numerical modeling of the hydrodynamics of bays and estuaries with applications including modeling of water quality and biological parameters. The invited paper "Numerical Hydrodynamics of Estuaries" was presented by John Edinger and reviewed the numerical approaches to solving hydrodynamic problems in estuaries. Papers stressing the applications of two-dimensional vertically integrated storm surge models to a variety of systems followed, including Mobile Bay (April and Raney), Lake Pontchartrain (Gael), Puget Sound (Roberts), deltaic systems (Hauck and Ward), and a number of U. S. Army Corps of Engineers projects around the country (Butler). The effects of boundary conditions of tidal circulation were also discussed (van de Kreeke and Chiu). Two papers used hydrodynamic models as a basis for investigating the migration of fish

larvae (Chen et al.) and planktonic copepods (Show). The former study uses a simple box model for its hydrodynamic model. Box models and their limitations and applications to water quality problems were also reviewed in another paper (Officer). The final paper of the first day of the workshop discussed the use of both physical and mathematical modeling to study the problem of freshwater diversion in the Sacramento-San Joaquin delta estuary (Kristof).

Modeling and impact assessment

10. The morning session of the second day opened with an invited paper "Estuarine Fishery Resources and Estuarine Modification, Some Suggestions for Impact Assessment" presented by Saul Saila. This paper stressed the use of simplified modeling and experimental strategies to address specific management questions of a particular estuary. The subsequent papers examined field and laboratory methods for impact assessment (Pequegnat et al.) and the use of simple analytical models of dispersion in estuaries as management tools (Benedict).

Sediment transport processes

11. This session opened with two invited papers presented by Ray Krone and Ranjan Ariathurai. Dr. Krone discussed sedimentation processes in estuaries from a microscopic point of view. The second invited paper discussed the complexities of modeling these processes in estuaries. This paper was followed by one discussing the modeling of sediment transport as applied to Lake Erie (Sheng). The specific problem of dispersion of suspended sediments due to dredging operations was modeled in the final paper of the session (Cundy and Bohlen).

Estuarine and wetland ecosystems

12. The final session of the second day was devoted to contributed papers on various aspects of wetlands and marsh/estuarine interactions. Two presentations were made on the difficult problem of measuring fluxes of detritus and particulate material in tidal salt marsh creeks (Harris et al. and Stevenson et al.). Remote sensing techniques as applied to wetlands were the subject of two presentations (Bartlett and Klemas; and Johnson). The effect of tidal wetlands on coliform bacteria in estuaries in Delaware was discussed (Jensen and Rola), and

the final paper of the afternoon was on a new experimental method for measuring the water seepage in salt marsh soils (Burke et al.).

13. The first session on the third and final day consisted of four invited papers. William Patrick opened with a presentation on "Sedimentation and Nutrient Cycling in a Louisiana Salt Marsh." He discussed a number of techniques that have been used to measure sediment accretion in a Barataria Bay Spartina salt marsh and the implications for detritus export/import and nutrient cycling. Scott Nixon followed with a review of marsh/estuarine coupling. His main comments were on the difficulty of making measurements and interpreting them in terms of estuarine ecosystems. The concept of well-characterized fluxes from the marsh to the estuary that could be used as inputs to water quality models proved to be an illusion given the present degree of knowledge. The third presentation of the morning, given by Richard Wiegert, was a summary of the modeling studies of the Sappelo Island marshes, which have been performed by ecologists from the University of Georgia. He also commented on a recent study of marsh fluxes at Sappelo Island by Jorg Imberger. This study appears to be unique because water masses were followed in the tidal creek instead of the usual method of using current meters at one cross section. A great deal of interest was shown in this study and some of the discussion it provoked is transcribed in the report of the panel session (Part III). The final paper of the workshop was presented by Donald O'Connor on "Water Quality Modeling of Estuaries." This was a major theme of the workshop and Dr. O'Connor presented four case studies ranging from simple dissolved oxygen-biochemical oxygen demand kinetic models to complex phytoplankton-based eutrophication models.

Workshop Panel Session

14. On the afternoon of the third day, an informal panel session was held. The topic for discussion was "Research in Estuaries and Wetlands: Needs and Problems." The panel consisted of:

Scott W. Nixon	University of Rhode Island (Chairman)
Saul B. Saila	University of Rhode Island
Ray B. Krone	University of California at Davis
Robert O. Reid	Texas A&M University

The transcript of remarks made by the panel and the audience is given in Part III. The panel and major participants (Don Robey and Richard Wiegert) were given the opportunity to edit their own remarks in order to ensure that their ideas were clearly expressed. Ray Krone was unable to edit his remarks due to illness. The remaining remarks from the audience were lightly edited by the authors of this report, mainly by adding clarifying words, deleting repetitious phrases, and adding punctuation.

15. The panel session opened with some discussion on the papers presented in the morning session, which lead to some extensive remarks on marsh processes and the difficulties of making meaningful measurements.

16. After these preliminaries, Saul Saila gave some of his ideas, which included remarks on the use of older European literature and good experimental design. This provoked some dialogue with the audience.

17. Don Robey, from WES, then explained in more detail the purpose of the workshop and asked the panel to give their views on the present state of knowledge and where, in their opinion, further research efforts should be directed.

18. Ray Krone gave his views emphasizing that the primary need was to understand the hydrodynamics. He also gave a hierarchical strategy for modeling processes in estuaries. Some dialogue with the audience followed. Nixon emphasized the importance of outside, independent reviews of contract reports of studies performed for management agencies.

19. Robert Reid then gave a fairly thorough review of the state of the art in the modeling of coastal and estuarine physical oceanographic processes. These remarks lead to further remarks from the audience and panel on the use and limitations of models and the difference between ecosystem and hydrodynamic models.

20. Scott Nixon then gave some of his views. He cautioned against making too much of a distinction between modelers and nonmodelers, remarking that all good scientists build models, even if only conceptual models. He also advocated the use of microcosms as a way to study

processes in the laboratory. In the exchange of views that followed, Richard Wiegert elaborated some of his ideas, presented in the morning session, on the formulation of ecosystem models. Saul Saila made a case for using simple models based on a simplified structure to answer very specific questions. Other views were expressed on the feasibility of developing three-dimensional, time-dependent circulation models.

21. The panel session closed with views being expressed on how models are used to design experimental research programs that are then used in an interactive manner to improve the models. George Gardner made the point that, in this respect, physicists and biologists use models and field experiments in the same manner.

Publication of the Proceedings

22. After the workshop, all contributed and invited papers received outside peer review similar to standard journal practice. On the basis of these reviews and editorial judgment, papers were selected on scientific merit for inclusion in the published proceedings. The authors were asked to revise their papers according to reviewers and editorial comments. The workshop proceedings are to be published by Plenum Press under the title "Estuarine and Wetland Processes; With Emphasis on Modeling." The editors are Peter Hamilton and Keith B. Macdonald.

Recommendations

23. Part IV of this report contains general recommendations on research needs and problems based on the three major parts of this study. The needs and problems of CE District Offices expressed during the survey are reflected in the recommendations. The current state of the art was assessed through the literature review and the workshop presentations. The views expressed in the panel session were considered: the estuarine and wetland, physical, chemical, and biological processes are necessary to the building of satisfactory hydrodynamic, water quality, and ecosystem models.

PART II: ABSTRACTS OF PAPERS PRESENTED

24. Abstracts for 33 papers are presented in the following pages.

TURBULENCE IN ESTUARIES

George B. Gardner, Arthur R. M. Nowell,
and
J. Dungan Smith

University of Washington
Seattle, Washington

ABSTRACT

The relative importance of stratification, time dependence, small-scale bed morphology, and general topographic complexity determines the intensity and dominant scales of turbulence production over the wide spectrum of estuarine types. Mixing in estuaries, especially if they are relatively narrow, is usually dominated by shear produced turbulence and nonlinear internal wave processes rather than wind-induced effects. In these cases, the turbulence sources are bottom boundary layers and free shear layers associated with sharp pycnoclines. Although these sources may be quite local in extent due to estuarine topography, their direct and indirect effects are more ubiquitous. In estuaries such as Puget Sound, mixing can be complete at certain locations over much of the tidal cycle while none at all can occur at the same times in other locations. The salient features of circulation in such estuaries can be understood and modeled with reasonable accuracy once the mixing processes that occur in particular regions, and the internal wave fields that radiate energy out of these regions, are understood. To understand these processes, it is best to examine environments in which one or the other dominate. Having decided to focus in the paper at hand on production of turbulence in bottom boundary layers and free shear layers, it is reasonable to divide the problem again into situations in which the flow is relatively homogeneous and situations in which there is a relatively sharp pycnocline.

In well-mixed estuaries the turbulence source is the bottom boundary layer and it is strongly influenced by bed forms and by the

channel geometry. These produce a spatially inhomogeneous turbulence and mean flow distribution that result in an extremely effective dispersion of sediments, organisms, and chemical species. In many cases these effects can be handled with the methods that we have recently developed for similar problems in rivers. If weak stratification enters the problem, as it sometimes does during certain parts of the tidal cycle, it can be accounted for using techniques similar to those that have been used recently for atmospheric and oceanic boundary layers.

The situation is somewhat different in the case of highly stratified estuaries. Here pycnocline and free shear layer processes become important. Furthermore, spatial imhomogeneities in turbulence and internal wave production result in the radiation of energy from one region to another causing mixing mechanisms which are often subtle in regions where it would not otherwise be expected. Two recent field studies at the University of Washington have addressed such flows. The first is concerned with mixing in a salt wedge estuary, the Duwamish Waterway (Seattle, WA). Initially, maximum turbulence production was expected to occur during the flood when shear between the surface and bottom layers was maximum. However, the Richardson number at this time was found to drop below its critical value only rarely. Most of the mixing, in fact, occurs during a relatively short period centered around the maximum ebb when the river water and the seawater move at essentially the same speed. This results in an internal Froude number very close to the critical value, the presence of relatively large amplitude internal waves on the interface, and numerous turbulent patches in the neighborhood of the pycnocline. The second investigation involves turbulent mixing in fjords. Here, large amplitude flow instabilities in the neighborhood of the sill, lee waves, and internal hydraulic jumps of up to 100 metres in height result in substantial mixing and in the production of nonlinear internal waves that subsequently propagate up and down the inlet. The latter cause mixing in regions tens of kilometres away from the sill. In both the salt wedge estuary and fjord cases, spatially and temporally constant eddy coefficient models yield very bad approximations to the actual circulation. In contrast, with a suitable understanding of the basic physical processes that are active in these and similar estuaries, much more appropriate models can be constructed.

CIRCULATIONS IN THE CHESAPEAKE BAY

Dong-Ping Wang

Chesapeake Bay Institute
The Johns Hopkins University
Baltimore, Maryland

ABSTRACT

In recent years, our understanding of circulations in the Chesapeake Bay has been greatly improved through direct current meter and salinity measurements. Currents are mostly tides, particularly semidiurnal tide. In general, tides progress up-Bay with a phase speed of about 540 km/day. They also have appreciable vertical upward phase propagation, due to friction dissipation. Consequently, large velocity shears occur during part of the tidal cycle, which may significantly enhance vertical mixing.

Nontidal currents, though small compared to tides, are mainly responsible for the transport (advection/dispersion) of salt, sediments, and "pollutants." They are driven primarily by the longitudinal salinity (density) gradient and wind forcing. When averaged over a period of one month or longer, circulation is mainly induced by the density gradient, with a landward flow in the lower layer and a seaward flow in the upper layer. On the other hand, there also exists a large wind-driven circulation at time scales of 1 to 10 days. Bay water response to local wind forcing includes barotropic and baroclinic components, driven by surface slope and wind stress shear, respectively. Nonlocal forcing due to coastal Ekman flux can also be very important.

Tidal motion in estuaries can be reliably modeled. In contrast, relatively little is known about nontidal circulation. Since a full understanding of estuarine circulation is essential to a successful impact study, efforts should be focused on improving knowledge of nontidal circulation.

THREE-DIMENSIONAL CIRCULATION PROCESSES IN THE POTOMAC RIVER ESTUARY

William Boicourt

Chesapeake Bay Institute
The Johns Hopkins University
Baltimore, Maryland

ABSTRACT

An array of 40 current meters on 20 moorings was placed in an 8-km segment of the Potomac River estuary in June and July 1978 to investigate the three-dimensional structure of estuarine circulation. Estuaries often have been approximated by two spatial dimensions (usually longitudinal and vertical) in both theoretical and observational analyses to allow reduction of the problems to tractable levels. Evidence is accumulating that variations of temperature, salinity, and velocity in the lateral direction play important roles not only in the lateral circulation, but also in the longitudinal transport processes. In addition to the moored instrument measurements, two high-resolution, slack-water series of longitudinal and lateral temperature-salinity measurements were made by two surface vessels. Over 500 stations were occupied over the course of the experiment, with one vessel occupying the mooring stations in series, while the other vessel ran a longitudinal section up the estuary from the Chesapeake Bay proper to above St. Clements Island. Preliminary results show that there is much three-dimensional structure to both the wind-driven and the low-frequency flows. The lateral velocity components appear sufficiently large to separate the signal from instrumental effects. This separation will be aided by results from a double-tower frame upon which was mounted five advanced current meters. Examination of records from the acoustic, electromagnetic, vector-averaging, and ducted impeller meters on a rigid mount should provide a clear picture of the ability of conventionally moored instrumentation to detect lateral circulations.

THE MIXING OF FRESH WATER OFF A MANY-INLETED COASTLINE

J. O. Blanton

Skidaway Institute of Oceanography
Savannah, Georgia

ABSTRACT

The inner continental shelf waters between South Carolina and northern Florida are weakly stratified by the many sources of fresh water ejected from the land. The mixing of fresh water in this zone is qualitatively similar to that in a partially mixed estuary. The many inlets along the coast, however, result in a complex orientation to the principal axes of the tidal currents offshore and the resulting mixing processes are nonhomogeneous in the alongshore direction.

These complexities must be faced in any realistic model of similar oceanic regions. Data are presented to show the nature of the nonhomogeneous mixing and to demonstrate that models which neglect alongshore gradients of momentum and properties are unrealistic.

CIRCULATION IN A TIDAL CREEK INTERCONNECTING TWO ESTUARIES

Pulak K. Ray

State University of New York College
Buffalo, New York

ABSTRACT

Hourly observations of tidal stage, velocity, salinity, temperature, suspended sediments, dissolved phosphate, and dissolved oxygen over fourteen tidal cycles at different locations in Station Creek, which interconnects Port Royal Sound and Trenchards Inlet in South Carolina, indicate that the circulation pattern of the tidal creek depends on:

a) differential tidal elevations at creek mouths,
b) local weather,
c) circulation characteristics of the associated estuaries,
d) freshwater contribution by groundwater,
e) morphology and extent of the floodplain marsh, and
f) channel morphology.

The circulation pattern differs significantly between the creek mouths and the midsection ("nodal zone"). The nodal zone is characterized by prolonged stagnation and active sedimentation.

The maximum flood- or ebb-current velocity which ranges from 60 cm/sec to 80 cm/sec occurs between two to three hours before or after high tide at the creek mouths. Such a relation is complex at the nodal zone. A velocity stratification showing higher velocity near the surface of the water column is well established in the creek. The transportation and deposition of suspended sediments correspond extremely well with the time of maximum and minimum flow velocity in the channel. The maximum suspended sediment concentration at the nodal zone occurs during low water when two diverging tidal currents of high velocity prevail and the particulate matter from the marshes is brought in by the

falling water level. A cursory sediment budget calculation reveals a negative budget even in the area of active sedimentation.

Even though the tidal creek may be considered homogeneous in terms of salinity distribution, which ranges from 28% to 35%, locally it assumes a well-defined reverse salinity stratification. In general, the salinity is inversely proportional to the temperature, but a reversal in this T-S relation is observed during periods of patchy rains and excessive evaporation from the marshes. Dilution by groundwater and desalination by marsh plants result in a lower salinity of the ebbing water. A major portion of phosphates is contributed locally by the bottom sediments, as is evident from the correspondence of time of high suspended sediment concentration and high phosphate value, and the nature of phosphate distribution curves. Consumption of oxygen by biological and chemical processes on the marsh results in a decreasing dissolved oxygen concentration during the ebb tide. A higher concentration of dissolved oxygen is observed in the bottom waters.

The data presented in this paper will be useful in planning and management of the wetlands and evaluating the influence of wetlands on tidal creeks and estuaries.

HYDROGRAPHY AND CIRCULATION PROCESSES OF GULF ESTUARIES

George H. Ward, Jr.

Espey, Huston & Associates, Inc.
Austin, Texas

ABSTRACT

Gulf estuaries (excluding the Mississippi) are lagoonal embayments, which, although possessing qualitative features common to most estuarine circulations, frequently exhibit these in extreme ranges or altered importance. These hydrographic features must be considered in developing or applying transport models (and *a fortiori* water quality models) for these systems. In particular the following factors are generally the most important to hydrography: meteorological forcing, tides, freshwater inflow, and density currents. Examples are presented to display the characteristics and significance of each of these, and available modeling techniques (both physical and mathematical) are appraised with respect to each. Insofar as general water quality considerations are concerned, the density current is probably the most important of these, dictating the overall large-scale circulation and transport within the bay. Its effect is extremely important when the bay is transected by deep-draft ship channels (as are most of the gulf estuaries). Accurate modeling of this phenomenon requires a coupling of the salinity and momentum transports, which is rather poorly advanced at present. Mathematical water quality (including salinity) models usually parameterize the density-current transport by an inflated dispersion coefficient. This approach is poorly founded theoretically and can lead to large errors in the water quality predictions. Finally, a summary is presented of the types of water quality problems to which models are being applied in the gulf estuaries.

NUMERICAL HYDRODYNAMICS OF ESTUARIES

John Eric Edinger
and
Edward M. Buchak

J. E. Edinger and Associates
Wayne, Pennsylvania

ABSTRACT

Classically, estuaries have been classified dimensionally on the basis of the dominant salinity gradients. Following Pritchard (1958)* the general classifications based on spatial averaging of the constituent transport relationship are: (1) three dimensional; (2) laterally homogeneous with longitudinal and vertical spatial gradients dominant; (3) vertically homogeneous with longitudinal and lateral spatial gradients dominant; and (4) sectionally homogeneous with longitudinal gradients dominant. Development of the hydrodynamic (momentum transport) relationships follow similar spatial averaging and classification.

In general, the momentum balances determine the flow field by which the constituent is transported. The momentum and constituent transport are interrelated in estuaries through the horizontal density gradient as determined from the constituent distribution. Only the fourth case, sectional homogeneity, is solvable for the distribution of constituents for a few limiting situations without use of the hydrodynamic relationships, and are situations for which the advective flow field can be inferred from freshwater inflow.

The development of numerical hydrodynamics for estuaries begins with a presentation of the equations of motion and constituent transport in three dimensions. The basic equations are: (1) the u-velocity or longitudinal momentum balance; (2) the v-velocity or lateral momentum

---

* Pritchard, D. W. 1958. "The Equations of Mass Continuity and Salt Continuity in Estuaries," J. Mar. Res., Vol 17, pp 412-423.

balance; (3) the pressure distribution, P , as determined from the vertical momentum balance as the hydrostatic approximation; (4) the w-velocity or vertical velocity as determined from local continuity; (5) the salinity, S , constituent transport; (6) the equation of state relating density, ρ , to the constituent concentration, and (7) the free water surface elevation, ζ , as determined from vertically integrated continuity. The general numerical problem is, therefore, to spatially integrate numerically over time seven equations for the seven unknowns of u , v , w , P , S , ρ , ζ given appropriate geometry and time-varying boundary data. The seven equations are interrelated with the constituent distribution, S , determining density, ρ , with density and the free water surface elevation, ζ , determining pressure, P , and with the pressure distribution entering the momentum balance.

The two-dimensional and one-dimensional cases are derived from the three-dimensional relationships by spatial averaging. The laterally homogeneous estuary dynamics include a majority of the interrelationships of density, pressure, and surface elevation incorporated in the three-dimensional equations. Explicit and implicit solution procedures can be illustrated for the laterally homogeneous relationships as they depend upon the inclusion of vertically integrated velocities in the surface elevation computations. Laterally averaged hydrodynamic solution procedures that utilize simplifying assumptions for the longitudinal density gradient are also examined. The sectionally homogeneous hydrodynamics is shown to be a reduced case of the laterally homogeneous relationships.

The two-dimensional vertically homogeneous dynamics is presented as a reduced form of the vertically integrated three-dimensional case. The vertically homogeneous case has spatially explicit and implicit solution procedures, the properties of which can be illustrated from the basic equations. It will be shown that a surface elevation relationship exists for this case that has a variational statement leading to spatial finite element description.

The above relationships will be reviewed with reference to recent applications to different estuaries, the different solution techniques, and discussion of boundary condition problems.

EVOLUTION OF A NUMERICAL MODEL FOR SIMULATING LONG-PERIOD WAVE BEHAVIOR IN OCEAN-ESTUARINE SYSTEMS

H. Lee Butler

USAE, Waterways Experiment Station
Vicksburg, Mississippi

ABSTRACT

Numerical modeling of water-wave behavior has progressed rapidly in the last several years and is now generally recognized as a useful tool capable of providing solutions to many coastal engineering problems. This paper discusses the evolution of a numerical hydrodynamic model including its applications to a variety of problems in which long-wave theory is valid. To achieve a solution to the governing equations, finite difference techniques are employed on a stretched rectilinear grid system. The most recent version of the model permits a selection of solution schemes. Choices include both implicit and explicit formulations written in terms of velocity or transport dependent variables. The model predicts vertically integrated flow patterns as well as the distribution of water surface elevations. Code features include the treatment of regions which are inundated during a part of the computational cycle, subgrid barrier effects, variable grid, and a variety of permissible boundary conditions and external forcing functions. Reproduction of secondary flow effects is an important aspect for a hydrodynamic model. Discussion of methods which are appropriate for treating the nonlinear terms in the governing equations (terms which cause secondary flow effects) is given. Direction of future code developments also is discussed.

Applicability of the numerical model is demonstrated through a presentation of various ocean-estuarine system problems for which the model was applied. These include simulations of tidal circulation as well as coastal flooding from hurricane surges and tsunami waves.

TIDE-INDUCED RESIDUAL CIRCULATION

J. van de Kreeke and S. S. Chiu

Rosenstiel School of Marine and Atmospheric Science
University of Miami
Miami, Florida

ABSTRACT

It has been suggested[1] that in addition to the classical mechanisms, density currents, and dispersion, the tide-induced mass transport or mean current can play an important role in renewing the waters of shallow bays and bights.

When assuming a linear friction, the vector equation for the residual transport q_* (m^2/sec) is

$$\frac{F q_*}{h} = \Upsilon - gh\nabla\overline{\eta} - \frac{F}{h^2}\,\overline{q\eta} + \Omega x q_* + \nabla^2 q_* \qquad (1)$$

in which

F = friction coefficient

h = depth with respect to Still Water Level

Υ = tide stress[2]

q = flux of water per unit width

η = water level with respect to Still Water Level

Ω = Coriolis parameter

- = averaging over tidal cycle

Equation (1) is useful in explaining the physics of the tide-induced circulation. However, it cannot be solved directly because the first three terms on the right-hand side depend on the instantaneous tidal motion. Therefore, for the computation of the tidal residual circulation, recourse is taken to the numerical solution of the long-wave equations in q_x , q_y (the instantaneous fluxes in the x- and y- direction,

respectively) and η . Integration of q_x and q_y then yields q_* .

Because the residual current is of a second-order nature, attention should be paid to errors introduced by the approximate nature of the numerical solution and the formulation of the boundary conditions.

This paper describes some of the results of an investigation on the effects of 1) the geometry, 2) the various terms in Eq (1), 3) the formulation of the boundary conditions, and 4) the numerical scheme on the tide-induced circulation.

The long-wave equations used in the computations do not include the terms representing the Coriolis force and lateral momentum exchange. A quadratic bottom friction is used. Tides at the open boundaries are sinusoidal with a range of 0.30 m and a period $T = 45{,}000$ sec. Velocities at the open boundaries are assumed perpendicular to those boundaries. At the clo-ed boundaries a slip condition is assumed. The numerical scheme is explicit and time and space staggered. The time step $(\nabla t/T)^2 = 2.8 \times 10^{-6}$ as compared to $(a/h) = 0.1$ for the tidal stress. A typical velocity q_*/h for the SW quadrant is 0.3 cm/sec. For this example, the term Υ , $gh\nabla\bar{\eta}$, and $\frac{F_{q_*}}{h} + \frac{F}{h^2}\,\overline{q\eta}$ in Eq (1) are all of the same magnitude.

1. van de Kreeke, J., and Dean, R. G. 1975. "Tide-Induced Mass Transpo-t in Lagoons," Journal of the Waterways, Harbors and Coastal Engineering Division, ASCE, Vol 101, No. WW4, pp 393-403.

2. Nihoul, J. C. J., and Ronday, F. C. 1975. "The Influence of the 'Tidal Stress' on the Residual Circulation," Tellus, Uppsala, Sweden, Vol XXVII, No. 5, pp 484-489.

CURRENT MEASUREMENTS AND MATHEMATICAL MODELING IN SOUTHERN PUGET SOUND

Philip J. W. Roberts

Georgia Institute of Technology
Atlanta, Georgia

ABSTRACT

A project was recently completed whose primary objective was the prediction of oil spill movement in Nishqually Reach, Southern Puget Sound. The main tool of prediction used was mathematical modeling; to support this effort, extensive physical field measurements were made. These measurements included the use of continuously recording current meters for several months. Eight meters were used at four locations, each location having meters at two depths.

Extensive analyses of the current meter data were made. These analyses included the computation of the principal axes of the currents, that is, the eigenvectors of the covariance matrix at each location. The principal components of the currents in these directions were then found. Analysis of these components showed the first principal component, which is approximately parallel to the local channel walls, to be strongly tidal. The second principal component, orthogonal to the first, showed relatively more high frequency content, but contained less energy than the first. Correlations and phase relationships between individual meters and between tidal current data were also investigated. Low frequency current fluctuations were analyzed to find the mean currents and to compute flushing times. These analyses yielded much information on the nature of the currents and the local circulation patterns. The analyses, results, and methods to predict currents in the absence of measurements are discussed.

Mathematical modeling of the circulation patterns in the region was performed by means of a finite element model. The results were compared with the measured currents. It was found that certain features

of the currents could not, by the nature of the model, be predicted.

Both physical measurements and mathematical modeling contribute to an understanding of the physical behavior of the estuary. Some features cannot be predicted by the model, and some cannot be inferred from measurements alone. These, and other implications for mathematical modeling, are the subject of this paper.

BOX MODELS

Charles B. Officer

Dartmouth College
Hanover, New Hampshire

ABSTRACT

A methodology in terms of box models has been reexamined for the investigation of conservative and nonconservative quantities in estuaries. Both one- and two-dimensional models and both tidal exchange and circulation effects are included. Various types of loss relations, sources and sinks, and vertical exchanges are considered. The box model results are tested against analytic solutions of the same problems where available and against two more refined, hydrodynamic numerical model results for a nonconservative loss problem and for a suspended sediment distribution.

The physical oceanographic inputs to the method are salinity, estuary geometry, and riverflow, which are often known quantities. There are no undetermined or undefined hydrodynamic coefficients. In each case the relations are given by a set of linear algebraic equations. They can be solved by computer matrix algebra procedures, or, because of their particular form, by successive approximations with a hand calculator.

The methods presented do not pretend to add to our physical oceanographic knowledge of estuarine circulations, mixing, and the like. It is, however, hoped that they may be of use to those examining biological, chemical, engineering, and geological distributions, transformations, and other effects, which depend, in part, on estuarine hydrodynamics for their explanation.

HYDRODYNAMIC AND BIOLOGICAL MODELING OF THE CAPE FEAR ESTUARY, NORTH CAROLINA

H. Y. Chen, T. L. Englert,
T. B. Vanderbeck, and J. P. Lawler

Lawler, Matusky and Skelly, Inc.
Pearl River, New York

ABSTRACT

The formulation and application of two mathematical models, one hydrodynamic and the other biological, to the Cape Fear estuary are presented. These models provide predictions on the impact of the Brunswick Steam Electric Plant (BSEP) on key fish species which utilize the Cape Fear as a nursery.

Most of the fish species that utilize the Cape Fear Estuary are ocean-spawners. During their early life stages (larvae and postlarvae), they are carried into the estuary by the tidal action. Once inside the estuary, they are mostly transported by the advective flows. However, they also exhibit some behavioral mechanisms such as vertical diurnal migration to seek their preferred nursery areas such as marsh wetland and upriver regions. Therefore, two separate models were developed. The hydrodynamic model computes the net nontidal flows in the estuary under various freshwater flow conditions. The biological model, named the Fish Population Model (FPM), then incorporates these flows with the life cycle parameters, behavioral mechanisms, and the plant operating data to compute the distribution and growth of these species inside the estuary.

The hydrodynamic model is a three-dimensional, steady-state model. The model is based on the principles of flow continuity and conservation of mass as applied to salinity to compute the net nontidal flows. The Cape Fear Estuary is divided into 28 longitudinal segments from the estuary mouth to approximately 37 miles upstream. At most segments, the river geometry consists of shoals on both sides of a deep midchannel.

Therefore, a two-layer system with one upper and one lower layer is adopted for the midchannel while only an upper layer is present for the east and west shoals. Modifications of this "four-box" scheme were used for other segments with different geometries.

A series of intensive salinity surveys were conducted during 1977 and 1978 under low, medium, and high freshwater flow conditions. Tidally averaged salinity profiles along the Cape Fear River were computed from the collected salinity data. Using these salinity values and the freshwater inflow as input and starting from the salt front, the model then computes the following parameters at each downstream segment: (1) the longitudinal outflow for the upper and lower layer, (2) the vertical flow between the upper and lower layer, and (3) the vertical dispersion coefficient.

The Fish Population Model is formulated based on the concepts of population-balance. The model translates these concepts into mathematical expressions that include such terms as the hydrodynamic transport, natural mortality, maturation, migration, entrainment, and impingement. Due to the complexities in the model formulation, a numerical solution procedure is required. In the numerical solution of the model equations, the Cape Fear Estuary is divided into seven longitudinal segments. Each of these segments is further subdivided into as many as six control volumes representing the upper and lower layers, tributary creeks, and marshes. The hydrodynamics in the estuary are simulated using tidally averaged flows in the upper and lower layers computed by the hydrodynamic model. Behavioral characteristics such as vertical diurnal migration and residence of the larvae in the marshes are simulated by moving the organisms into and out of the control volumes at rates computed from field data.

Calibration of the model using data collected during 1976-1977 for the spot population in the Cape Fear is presented. Graphical comparisons of field data and model output are included to illustrate the calibration procedure.

Following discussion of the calibration of the model, an example application is presented. Predicted reduction in the young-of-the-year spot population is obtained by running the model with and without the plant on-line. The impact of the plant is then determined by comparing the reduction in the end of the year population with the plant on-line to that resulting without plant operations.

THE MOVEMENTS OF A MARINE COPEPOD IN A TIDAL LAGOON

Ivan T. Show, Jr.

Science Applications, Inc.
La Jolla, California

ABSTRACT

It has been hypothesized that marine copepods are able to react to water movements in an estuary in such a way as to minimize advective losses to the open ocean. This hypothesis is operationalized and tested by use of a stochastic model. Several processes are investigated as contributing to the minimization of advective loss.

The model treats the time-varying spatial patterns of marine plankton. In the present instance, the model is used to describe the small-scale movements of *Acartia tonsa* (Copepoda) in a tidal lagoon on the eastern end of Galveston Island, Texas. Four distinct processes are considered: advection by currents, behavioral response to environmental variable (current velocity fields, temperature, and salinity), intra-specific aggregation, and birth-death processes. The portion of the model dealing with biological processes is a stochastic compartmental model. The biological model is driven by a three-dimensional physical dynamic model which provides numerical solutions for current velocity, temperature, and salinity fields.

The coupled physical-biological model used to simulate the distribution of *A. tonsa* provides numerically accurate estimates for the time histories of the physical and biological processes involved. The success of the model is probably attributable to a number of factors which involve the nature of the ecological situation modeled, the parameterization of the biological model, the manner in which the lagoon was compartmentalized, and the nature of the sampling data used to test the results.

Assuming then that the results of the numerical simulation were accurate by other than random chance, the most important conclusion was that _A. tonsa_ appears to owe its spatial distribution in the lagoon to the combined effects of advection by currents and behavioral response to environmental stimuli: tides, light, temperature gradients, salinity gradients, and the population density gradients of its own species; the most important being tidal advection. It also appears that the resultant movement of the organism is sufficient to minimize losses from the lagoon to the extent that it maintains an endemic population inside the lagoon which is distinct from the population found immediately outside. Finally, it was concluded that the spatial distribution of _A. tonsa_ was heterogeneous, that the patches were of the order of 240 metres long by one or two metres deep, and that changes in density occurred as a result of an increase in within-patch density rather than an increase in the number of patches.

PREDICTING THE EFFECTS OF STORM SURGES AND ABNORMAL RIVER FLOW ON FLOODING AND WATER MOVEMENT IN MOBILE BAY, ALABAMA

Gary C. April and Donald C. Raney

The University of Alabama
University, Alabama

ABSTRACT

The threat of man-made and natural disturbances to the coastal environment is a continuing and perplexing problem. With the advent of rapid, numerical simulation models describing coastal water behavior, the ability to better understand these regions and to provide data to offset the adverse impacts caused by these disturbances has greatly improved.

This paper discusses the recent numerical modeling activities of the Mobile Bay system under severe conditions. Results are presented in terms of changes that occur in water elevation and movement and in salinity distribution patterns when the bay is subjected to river flood inflows and storm surges.

At a river flood stage of 7000 m^3/sec, water behavior in the northern and central portions of the bay is totally governed by the freshwater inflow. A salinity level of 5 ppt is restricted to the lower bay at a point 15 km from the Main Pass. Usual salinity values under normal conditions are in the range of 15 or 20 ppt in this area. A critical river flow rate of 8500 m^3/sec is also identified. At or above this flow, saline water intrusion in the lower bay becomes stabilized at 10 ppt on a line 6 km north of the Main Pass.

HYDRODYNAMICS AND ECOSYSTEM FUNCTION
IN LAKE PONTCHARTRAIN, LOUISIANA

Bharat T. Gael

Louisiana State University
Baton Rouge, Louisiana

ABSTRACT

The role of hydrodynamics in the functioning of the Lake Pontchartrain ecosystem was examined using numerical models. Mechanical energy budget calculations, numerical models, and tidal pass transport estimates indicated that, on an annual basis, wind was the most important power source for lake motions. These motions in turn were responsible for maintaining the mictic and trophic character of the lake as well as helping distribute plankton and nursery species within, into, and out of the lake.

Numerical simulations indicated that patterns of circulation established by the wind were not easily disrupted by substantial increases in tidal or riverine inputs. Simulations emphasized coastal jetting of the wind-driven currents and transport along the littoral zone of the lake. Longshore drift, during the ecologically important spring-summer season, was estimated to be 7 to 16 km per day and was substantiated by field measurements. Longshore drift was generally with the wind direction, whereas counterflow through the lake center was often opposite wind direction.

Life cycles of estuarine species and their abundance appeared strongly coupled with seasonal variations of the forcing functions of salinity, temperature, and water turbulence. The distribution of the nekton and other plankters appeared coupled to the circulation pattern and emphasized the importance of the circulation to the use of the littoral zone in the lake. Wind-induced water level variations were also significant on transport of organics from the surrounding wetlands into the lake.

HYDRODYNAMIC-MASS TRANSFER MODEL FOR DELTAIC SYSTEMS

Larry M. Hauck and George H. Ward

Espey, Huston and Associates, Inc.
Austin, Texas

ABSTRACT

A branching section-mean model was developed and tested by application to several estuarine deltaic systems along the coast of Texas. The model is specifically developed to simulate hydrodynamic and nutrient transport in deltaic marsh systems which consist of areas of low relief with narrow, interconnected channels. These systems are fed above by inflow from a river or river system and are terminated below by a tidally forced, open-water area, either a coastal embayment or the Gulf. The mathematical model is a numerical solution of the equations of longitudinal momentum and continuity in their full nonlinear forms. Model outputs include water elevations, velocities, and concentrations for phosphorus, carbon, organic nitrogen, ammonia, nitrite, nitrate, two algal species, and salinity. Applications on the Lavaca, Guadalupe, Colorado, and Trinity deltaic systems involved development and verification of models capable of accurately simulating marsh inundation and dewatering as a function of tidal fluctuations and variable streamflows. The Trinity Delta application also involved the aspects of water quality modeling.

THE ROLE OF PHYSICAL MODELING IN THE MATHEMATICAL MODELING OF THE SACRAMENTO-SAN JOAQUIN DELTA ESTUARY

Richard C. Kristof

USDI, Bureau of Reclamation
Sacramento, California

ABSTRACT

The delta of the Sacramento and San Joaquin Rivers in California is subject to ocean salinity intrusion as a natural consequence of its connection to the Pacific Ocean via Suisun and San Francisco Bays and of its arid region hydrology characterized by long periods of low freshwater inflow. The delta is located between the water-sufficient northern part of the state and the water-deficient southern part of the state.

Federal and State agencies have developed water projects that store water in the northern basin, release it on schedule to the delta where it is diverted for agricultural, municipal, and industrial uses in the San Francisco Bay area, the San Joaquin Valley, and Southern California.

A key element of this plan of diversion is the maintenance of a "hydraulic barrier" which requires enough freshwater outflow from the delta to the ocean to prevent salinity intrusion from damaging beneficial uses of the water diverted from the delta. The amount of water required to maintain the hydraulic barrier has eluded precise definition due to the inability to adequately measure delta outflow or define all of its components. This leads to uncertainty in the salinity-outflow relationship and limits the amount of water available for beneficial use.

A variety of facilities have been examined, and some constructed, in an effort to minimize the amount of freshwater outflow required to prevent salinity intrusion, thus, making more water available for diversion.

In order to define the salinity-outflow relationship, efficiently operate existing facilities, and evaluate the benefits of the proposed

facilities, a number of hydraulic and water quality models have been developed. Among the models developed are a variety of mathematical models and a physical model, the San Francisco Bay and Delta model, constructed by the Corps of Engineers in Sausalito, California.

Controversy often arises over whether it is best to use a mathematical model or a physical model. Because of the complexity of the system, all models have suffered from difficulties in defining various system parameters and boundary conditions. For mathematical models, these unknowns have usually been determined during model calibration by modeling a historical sequence of inflows and adjusting the unknowns to force the model output to match the protytype data collected during the historical sequence. While this is an accepted procedure, it tends to result in a model that performs well under conditions similar to those used in the calibration process, but is of uncertain reliability when applied to significantly different conditions, which are often the most important application of the model. Calibration of a physical model involves a similar approach and encounters similar difficulties. However, one aspect of a physical model that is commonly overlooked is that, apart from how well it simulates the prototype, it is a real hydraulic system. If it is scaled such that the force of gravity is correctly simulated (Froude number) and the flow falls into the appropriate regime (Reynolds number), then the model should obey the same mathematical formulations as the prototype. The importance of this is that it allows the testing of mathematical abstractions on the physical model where geometry, boundary conditions, and system parameters are known or are readily determined. Successful application of a mathematical technique to the physical model provides a basis for application to the prototype where geometry, boundary conditions, and system parameters are less readily defined. Thus, it may be concluded that optimal understanding of the system will result from the appropriate "blend" of mathematical and physical modeling.

The purpose of this paper is to demonstrate this approach with reference to the San Francisco Bay and Delta model. Applications ranging from derivation of relationships based on a simple mass balance to development of a two-dimensional finite difference model are presented.

ESTUARINE FISHERY RESOURCES AND ESTUARINE MODIFICATION SOME SUGGESTIONS FOR IMPACT ASSESSMENT

S. B. Saila

University of Rhode Island
Kingston, Rhode Island

A review of economically important fishery resources which are estuarine dependent in some life history stage is given and the economic value of these resources is estimated. Some physical changes and consequences of these estuarine modifications are categorized, and the major probable fisheries impacts are described with some indication of tolerance by various life history stages.

Examples of analytical procedures designed to assess fisheries impacts of estuarine modification are presented and discussed. The advantages, disadvantages, and limitations of certain statistical procedures are pointed out.

The differences between management decision-oriented problems and key ecological questions are emphasized. The objective of this paper involves developing pragmatic procedures for describing ecosystem responses to man-induced perturbations.

COMBINED FIELD-LABORATORY METHOD FOR CHRONIC IMPACT DETECTION IN MARINE ORGANISMS AND ITS APPLICATION TO DREDGED MATERIAL DISPOSAL

W.E. Pequegnat,[1] R.R. Fay,[1] and T.A. Wastler[2]

[1]TerEco Corporation, College Station, Texas
[2]Marine Protection Branch, EPA, Washington, D.C.

ABSTRACT

A major problem facing those who must assess the environmental effects of the disposal of dredged material into the marine environment is determining whether the given materials elicit chronic deteriorative responses in important species of organisms. The full importance of such low-level, nonlethal effects is not known, but it is suspected that repeated elicitations may result in ecosystem changes as important as those caused by more easily determinable acute effects. Such considerations are important to the marine environment, where dumped pollutants may be quickly diluted to legal nonlethal concentrations, but may still bring forth cumulative chronic response patterns.

Equally difficult to monitor in the field are the related phenomena of metabolic bioaccumulation and trophic level biomagnification that develop in response to low levels of certain pollutants. The problem of discerning these subtle chronic responses is that they take time to reach detectable levels; hence, when such work has been attempted in the field, it has been difficult to demonstrate in a dynamic environment such as the water column that the organisms sampled for testing were actually exposed to the waste disposals being monitored. When the work is done in the laboratory, on the other hand, there is always some doubt that the findings can be extrapolated to the natural environment.

The principal objective of the present study has been to develop a method for assessing in the field the impacts of the disposal of various waste materials. The gauge of the significance of the impact is not mortality measured against time, but the induction of certain metabolic

enzymes that signal that the organism is under stress from a class of wastes. The test organisms are exposed for selected periods of time in the field in devices called Biotal Ocean Monitors (BOM's) of which there are two types, the free-floating pelagic BOM's and anchored benthic BOM's. After exposure in the BOM's, the control and test organisms, ranging from bivalves and polychaetes to pelagic and demersal fishes, are assayed for enzyme induction.

After testing and abandoning several enzymes, presently we are using ATPase, which is found in cell mitochondria and responds particularly to excess biphenyls in the environment; catalase, which is dissolved in the cytosol and responds to excesses of toxic metals; and cytochrome P-450, which responds to metals but particularly to cyclic and long-chain hydrocarbons. In addition, we are studying the applicability of the adenylate energy charge system to this problem. The advantages of the energy charge are that a complicated set of enzyme reactions is reduced to a single parameter that relates all control mechanisms to the energy level of the cell.

The Biotal Ocean Monitoring System has been applied with promising results to studies of the impacts of ocean incineration of organochlorine wastes by M/T VULCANUS in the Gulf of Mexico, the disposal of sewage sludge and dredged material in the New York Bight, and dredged material disposal at offshore Louisiana sites. Further tests and other applications are discussed in the paper.

MODELING TOXIC SPILLS IN ESTUARIES

Barry A. Benedict

University of South Carolina
Columbia, South Carolina

ABSTRACT

Wetland systems located around estuaries are often highly interconnected with the estuary and therefore very dependent upon the water quality of the estuarine waters for their own quality. Of increasing concern today is potential impact due to spill of materials which may be toxic to biological systems. This paper attempts to review the modeling techniques available for water quality constituent behavior from an accidental spill in estuaries, with potential linkage to wetland areas which either act as sources or sinks for the constituents of interest.

Both analytical and numerical solutions are available for treatment of estuarine problems, but the primary emphasis in this paper will be on the analytical methods, for they offer the most direct and easily used solutions by agencies and individuals charged with investigating impact of a spill. In addition, it is usually easier to see the influence of the various parameters on the behavior of the spill.

The models discussed represent solutions to the three-dimensional convective diffusion equation. Several models will be mentioned and reviewed, but the most attention will be provided to the model by Yeh and Tsai and by Holley and Harleman. In formulating a solution to this problem, numerous assumptions are always made and various averagings occur. The significance of these assumptions and averaging steps will be discussed in reference to the coefficients required by the model to express dispersion and diffusion. These coefficients are extremely critical in terms of being able to make adequate predictions, but they are functions not only of the physical site but also of the formulation of the equation and its solution. Items which will be discussed as being

of importance in estuaries include density stratification, density differences between effluent and receiving waters, influence of lateral and bottom boundaries, effect of sources and sinks, influence of bends, effect of any time averaging which occurs, and the significant impact of lateral variation of velocities. It will be pointed out that there are frequently misunderstandings about the meaning of these coefficients which lead to improper use of the model and inadequate predictions.

Examples will be given to illustrate the ability to model in the environments and to show some of the pitfalls. In addition, linkage to wetland areas, especially those which can be considered shallow, slow-moving embayments or attached arms, will be considered and developed. It is believed that the discussion provides a thorough review of the usefulness of analytical models to study water quality parameters in a complex estuarine environment.

A PREDICTIVE MODEL FOR THE TRANSPARENCY OF ESTUARINE WATERS

Jerome Williams

U.S. Naval Academy
Annapolis, Maryland

ABSTRACT

At any time the transparency of an estuarine region will be related to some ambient value in association with various sources and sinks. This model includes runoff, bottom resuspension, and living organisms as turbidity sources along with settling and transport out of the estuary as sinks. These sources and sinks are described in terms of measureable parameters such as salinity, rainfall, population density, gross national product per capita, local environmental protection effort, nature of watershed, boat traffic, wind, bottom characteristics, and nutrient inflow.

The resulting model specifies turbidity in terms of the beam attenuation coefficient, with each of the sources and sinks either adding to or subtracting from some ambient level of alpha determined primarily from the local salinity. A total of eight constants are specified, many of which are location specific in their value. The effect of a typical summer storm is shown by computer simulation for various assumed values of the eight constants for a specific location.

MATHEMATICAL MODELING OF SUSPENDED SEDIMENT TRANSPORT: A REVIEW

Ranjan Ariathurai

Resource Management Associates
3706 Mt. Diablo Blvd., Suite 200
Lafayette, California

ABSTRACT

The various approaches that have been adopted to simulate suspended sediment motion in open waters are reviewed. Considerations that must be made for the description of the transport processes and the solution of the governing equations are described. Finally, the future needs in practice and the direction that research must take to address these needs are presented.

MODELING SEDIMENT TRANSPORT IN SHALLOW WATERS

Y. Peter Sheng

Aeronautical Research Associates of Princeton, Inc.
Princeton, Inc.
Princeton, New Jersey

ABSTRACT

The transport and resuspension of sediments in the shallow western basin of Lake Erie have been investigated by means of numerical modeling, utilizing findings from laboratory and field experiments and remote sensing. Both resuspension of sediments due to wind waves (with a period of a few seconds) and resuspension due to time-dependent currents (with a period of a few hours) were considered. Various wave hindcasting models (JONSWAP, Mitsuyasu, Liu, SMB, SMC) were compared against data from Lake Erie. The SMB (Sverdrup-Munk-Bretschneider) method was chosen for this study. A previously verified hydrodynamic model was used to compute the time-dependent currents.[1] Based on laboratory experiments on the actual sediments, the resuspension rate as a function of bottom stress was formulated. Numerical experiments were performed with the 2-D model to analyze the sensitivity of the wind direction and wind speed. The 3-D model was used to simulate an actual two-day event in March 1976, during which a strong horizontal gradient of suspended sediments was observed in the basin. The model results were in good agreement with remote sensing data and demonstrated the dominant role of resuspension of sediments by both waves and currents. The present study clearly indicates the importance of accurate computation of the bottom stress, which generally requires knowledge of the vertical profile of currents, bottom roughness, and surface winds. Existing vertically integrated models for a shallow lake or estuary could result in significant error in the estimated bottom stress. Possible approaches to accurately predict the bottom stress for a variety of bottom conditions are discussed.

REFERENCE

1. Sheng, Y. P. et. al. 1978. "Numerical Computation of 3-D Circulation in Lake Erie: A Comparison of a Free-Surface and a Rigid-Lid Model," J. Physic. Oceanogr., Vol 8, No. 4, pp 713-727.

A NUMERICAL SIMULATION OF THE DISPERSION OF SEDIMENTS RESUSPENDED BY DREDGING OPERATIONS IN AN ESTUARY

Donald F. Cundy and W. Frank Bohlen

University of Connecticut
Groton, Connecticut

ABSTRACT

The removal of substantial quantities of sediment by mechanical dredging is required to maintain the navigability of many estuarine waterways. Much of the sediment removed during these projects is contaminated by a variety of organic and inorganic compounds, and, as a result, dredge-induced suspensions have the potential to perturb water quality and impact local biota.

In 1977 a study intended to detail the spatial characteristics of these suspensions and to incorporate the observations within a predictive numerical scheme was initiated. Primary emphasis was placed on resuspension produced by clamshell bucket dredging in typical estuarine areas. Hydraulic techniques, previously discussed by several investigators,[1] were not considered. Field data, including suspended material concentrations and composition and local hydrography, permit evaluations of input characteristics, dominant transport factors, and the resultant spatial distributions. These results are described in several previous papers.[2,3] In addition, the observations provide a framework for the development of a predictive model and a means to calibrate the selected numerical scheme. The characteristics and initial application of this model are discussed in the paper.

The downstream distribution of the column of materials introduced by each vertical pass of the dredge bucket is evaluated using a modified conservation of mass equation for suspended sediments in a turbulent flow. This modification based on a technique suggested by Aris[4] and applied to open channel flows by Sayre,[5] substitutes a horizontal moment term for the spatial distribution of the suspended mass concentrations.

The technique provides a description of the gross characteristics of the dispersing mass in three dimensions without requiring large amounts of computer time and storage.

The simulation assumes that the velocity field over the cross section is unidirectional, steady-state, and varies only as a function of depth. Gravitational settling affecting the dispersing mass is assumed to result in two characteristic settling velocities. Under these conditions, the governing equation in finite difference form is solved using Thomas' algorithm.[6] This solution provides a time history of the 0th to 4th moments of the dispersing mass introduced by each bucket pass. A representation of the sum total effect of these discrete injections forming the downstream plume is then developed through linear superposition.

Preliminary comparisons suggest that the results of this modeling scheme represent a reasonable analogue of the observed field conditions and provide some indication of the extent and character of the work required to improve the accuracy of the numerical predictions.

REFERENCES

1. Barnard, W. D. 1978. "Prediction and Control of Dredged Material Dispersion Around Dredging and Open-Water Pipeline Disposal Operations," Technical Report DS-78-13, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

2. Bohlen, W. F., Cundy, D. F., and Tramontano, J. M. 1978. "Suspended Material Distributions in the Wake of Estuarine Channel Dredging Operations," Estuarine & Coastal Marine Science (in press).

3. Bohlen, W. F. 1979. "Factors Governing the Distribution of Dredge Resuspended Sediments," Proceedings of 16th Coastal Engineers Conference, Hamburg, Germany (in press).

4. Aris, R. 1956. "On the Dispersion of a Solute in a Fluid Flowing Through a Tube," Proceedings of Royal Society of London, Vol 235 A, pp 67-77.

5. Sayre, W. W. 1967. "Dispersion of Mass in Open-Channel Flow," Hydrology Papers No. 75, Colorado State University, Fort Collins, Colo.

6. Koh, R. C. Y., and Chang, Y. C. 1973. "Mathematical Model for Barged Ocean Wastes," Prepared for U.S. Environmental Protection Agency, National Environmental Resources Center, Corvallis, Oreg.

SOURCES AND EXPORT OF DETRITAL PARTICULATES FROM COASTAL WETLAND ECOSYSTEMS

Robert C. Harris,[1] Benny W. Ribelin,[2] and C. Dreyer[3]

[1]NASA--Langley Research Center, Hampton, Virginia
[2]Sea Farms de Honduras, Choluteca, Honduras
[3]Florida State University, Tallahassee, Florida

ABSTRACT

Salt marsh ecosystems bordering the northeast Gulf of Mexico are a source of particulate materials to adjacent coastal waters. More than 98 percent of the detrital material exported from these coastal wetlands is comprised of amorphous aggregates, derived primarily from organic films produced by benthic microflora. Vascular plant fragments from the predominant macrophyte in the marshes, Juncus roemerianus, are not an important source of detritus to the estuarine water column. These results suggest that reevaluation of contemporary theory, which emphasizes the role of decomposer-based detritus production, is required to understand the origin of organic-rich aggregates exported from these extensive salt marshes of the northeastern Gulf. Tidal cycle, light levels, and weather-related phenomena all influenced the production and export or suspended particulates from the marsh systems which were intensively monitored. This paper will assess the relative importance of each of these "potential forcing functions" for water quality monitoring and modeling of particulate export from coastal wetland ecosystems.

CHARACTERIZATION OF MARSH-NONMARSH INTERFACES

L. Harold Stevenson, Thomas H. Chzanowski,
B.J. Kjerfve, and Charles A. Wilson

University of South Carolina
Columbia, South Carolina

ABSTRACT

The distribution, fluctuation, and short-term transport of total microbial biomass (measured as adenosine 5' triphosphate (ATP)) was investigated in several salt marsh creeks that comprise interchange points between marsh and nonmarsh environments. A transect was established across each creek and water samples were collected hourly for 27 h from three to ten stations depending on the width (60 to 320 m) of the creek. Velocity measurements were made at each location at the time of water sample collection. At those locations that formed interfaces with the oceanic environment, maximum levels of ATP observed at high tide reflected phytoplankton populations while that recovered from low tide samples was predominately bacterial in origin. Bacteria accounted for a much larger proportion of the total biomass at those locations that monitored exchange points between the marsh and a river-estuarine embayment. Computations of the next flux of ATP across each interface indicated that the deep, primary channel of each creek was a region exporting ATP from the marsh; whereas, a net import of ATP into the marsh was evident in the shallow, secondary channel of each creek.

TIDAL WETLANDS AND ESTUARINE COLIFORM BACTERIA

Paul A. Jensen[1] and Andrew C. Rola[2]

[1]Delaware Sea Grant Marine Advisory Service
University of Delaware

[2]University of Delaware
Lewes, Delaware

ABSTRACT

Practically all of the tidal river estuaries in Delaware are closed to shellfishing because of high coliform bacteria levels. In some cases the shellfish closures can be attributed to industrial or municipal wastes, but in others there are no significant point sources. There is considerable evidence suggesting that tidal wetlands are a major factor in the observed estuarine bacterial levels.

In order to estimate the importance of tidal wetlands as potential sources of coliform bacteria and to examine the relative importance of environmental parameters, a statistical investigation was performed on two similar estuaries, one with and one without point source inputs. The independent variables employed were: temperature, light intensity, freshwater flow, time since last major rainfall, turbidity, organic nitrogen and chloride concentrations, tide stage, and tide amplitude proceeding data collection. Statistical results are used to determine those parameters most significant in affecting observed coliform levels in the two streams, and in suggesting the most appropriate form for a predictive model of coliform bacteria concentrations. In addition to statistical analysis, other data such as stream coliform profiles, direct marsh coliform measurements, and relevant literature are summarized.

QUANTITATIVE ASSESSMENT OF EMERGENT BIOMASS AND SPECIES COMPOSITION IN TIDAL WETLANDS USING REMOTE SENSING

David S. Bartlett and Vytautas Klemas

College of Marine Studies
University of Delaware
Lewes, Delaware

ABSTRACT

Modeling and other techniques applied to quantitative assessment of wetland energy and nutrient flux depend, in part, upon accurate data on vegetative species composition and primary production. Remote sensing techniques have been applied to mapping of emergent wetland vegetation but not to quantitative measurement of emergent plant biomass.

Recent research in the tidal wetlands of Delaware has shown that spectral canopy reflectance properties can be used to measure the emergent green and total biomass of S. alterniflora (saltmarsh cordgrass) periodically throughout the peak growing season (April through September in Delaware). Such measurements could be applied to calculations of net aerial primary productivity for large areas of S. alterniflora marsh in which conventional harvest techniques may be prohibitively time-consuming. The method is species specific and, therefore, requires accurate discrimination of S. alterniflora from other cover types. Exploitation of seasonal changes in species spectral signatures is shown to have potential for improving multispectral categorization of wetland cover types in Delaware.

The study was conducted using multispectral reflectance measurements in the four LANDSAT/MSS wavebands (4: 0.5-0.6mm; 5: 0.6-0.7mm; 6: 0.7-0.8mm; and 7: 0.8-1.1mm) but has implications for other remote platforms or use of handheld instruments in the field.

APPLICATIONS OF REMOTE SENSING IN SIMULATION MODELS OF ESTUARINE ECOSYSTEMS

Robert W. Johnson

NASA--Langley Research Center
Hampton, Virginia

ABSTRACT

A simulation model has been developed of the Galveston Bay, Texas, ecosystem. Secondary productivity measured by harvestable species (such as shrimp and fish) is evaluated in terms of man-related and controllable factors, such as quantity and quality of inlet fresh water and pollutants. This simulation model used information from an existing physical parameters model, as well as pertinent biological measurements obtained by conventional sampling techniques. Predicted results from the model compared favorably with those from comparable investigations.

Parameters identified in the Galveston Bay and other ecosystem models indicate that certain key model inputs may be obtained from ground station (e.g. streamflow) and remotely sensed measurements. Remotely sensed measurements include atmospheric (such as cloud cover) and water (such as particles, chlorophyll, salinity, and temperature) parameters that have been determined from aircraft and satellite platforms. This paper will discuss remotely sensed and conventional measurements in the framework of prospective models that may be used to study estuarine processes and ecosystem productivity.

SEEPAGE IN SALT MARSH SOILS

R. Burke, H. Hemond, and K. Stoltzenbach

Massachusetts Institute of Technology
Cambridge, Massachusetts

ABSTRACT

A new device for measuring water seepage across the surface of tidal wetland soil as it is inundated by flooding tides was designed and constructed. The performance characteristics of the infiltrometer, the potential sources of error, and their impact on the seepage measurements were analyzed. The infiltrometer was used to measure seepage at a number of sites in Great Sippewissett Marsh, in Cape Cod. The depth of water over the sampling sites at high tide ranged between 4 and 35 cm. The results revealed three major patterns: (1) infiltration during flood tide, followed by exfiltration (water flow out of the sediment) during ebb. In some cases, as much as 11% of the total amount of water flooding the marsh infiltrated down into the soil during flood tide; the exfiltration component during ebb achieved similar magnitudes; (2) a decrease in total flux (found by summing infiltration and exfiltration) with distance from the creek bank. The total flux ranged from 6 cm in one run to 1 cm in another; and (3) a net water flux out of the sediment close to the creeks, changing to a net flow into the sediment farther back. Those cases reporting a new downward flux had values of net infiltration less than 1 cm, while those cases having a net exfiltration had slightly higher values, the maximum being about 2 cm.

As the seepage measurements involve taking small differences between large numbers, even relatively minor errors can appreciably affect the net flow rates. Still, however, the infiltrometer presented here represents a definite step forward in the attempt to understand the seepage component in the water budget of the flow over tidal wetlands. Initial tests have shown that the device can directly quantify the water flux across the sediment interface under relatively undisturbed conditions.

SEDIMENTATION AND NUTRIENT CYCLING IN A LOUISIANA SALT MARSH

R. D. DeLaune and W. H. Patrick, Jr.

Center for Wetland Resources
Louisiana State University
Baton Rouge, Louisiana

ABSTRACT

The gulf coast salt marshes in the deltaic plain of the Mississippi River are in a rapidly subsiding zone where accretion processes are important for maintenance of the marsh surface within the intertidal range. Incoming sediment is essential for maintaining the marsh surface and for supplying nutrients for plant growth. In an area that is apparently maintaining its surface with respect to sea level ^{137}Cs dating of sedimentation rate shows an accretion of 1.34 cm/yr. In an adjacent deteriorating marsh, the sedimentation rate is 0.75 cm/yr, not enough to compensate for subsidence. The incoming sediment is also a major source of plant nutrients for *Spartina alterniflora* with inputs as great as 31, 23.1, and 991 kg/ha of nitrogen, phosphorus, and potassium, respectively. Mineralization of these nutrients in the sediment provides a significant portion of the plant's requirements, but the marsh is still limiting in nitrogen, as nitrogen fertilizer experiments show.

MARSH-ESTUARINE COUPLING AND WATER QUALITY CONSIDERATIONS

Scott W. Nixon

University of Rhode Island
Narragansett Bay, Rhode Island

ABSTRACT

The paper reviews the accumulated evidence from twenty years of research into the role of coastal marshes in the coastal marine ecosystem. Topics reviewed include the deposition of sediments on marshes, the accumulation of carbon, nitrogen, phosphorus, and metals in sediments, evidence for the fluxes of these nutrients and metals between marsh and estuary, and primary production and fisheries of nearshore waters. Data from a large number of marshes ranging from New England to the gulf coast are compared, and tentative conclusions on the behavior of marshes regarding the cycling and export of nutrients and metals are made.

Abstracted from Nixon's review: "Between Coastal Marshes and Coastal Waters - A review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry" by the editor, from the proceedings volume.

SALT MARSH MODELING

R. G. Wiegert

University of Georgia
Athens, Georgia

ABSTRACT

Explanatory models of salt marshes must be based on realistic interactions between structure (niches and flow pathways) and function (species and their ecological attributes). These interactions produce behavior changes in rates and standing stocks of energy and nutrients. Such models may be used for management, prediction of perturbations, or development of testable hypotheses. Difficulties facing modelers involve conserved flows, trophic condensation, time delays, and feedback controls. In addition, hydrodynamic problems are important involving sediment water exchanges, matter/energy transport by tides, catastrophic storms and tides, and spatial heterogeneity. Construction and use of a carbon flow model of a coastal Georgia salt marsh are discussed.

PART III: MINUTES OF PANEL SESSION

Fred Manley (University of Mississippi):

25. I was fortunate enough to hear your paper (Scott Nixon) and Richard Wiegert's paper about the water masses moving in the marsh. With your possible lack of conclusive data, might you not think that you are sitting on one water mass and just measuring it like a point in a bathtub with a little slosh and you're getting no change. In other words, you didn't mention anything about water mass. I was wondering what your view is of this, in light of what Dr. Wiegert brought up in the later paper.

Scott Nixon (University of Rhode Island):

26. Let me respond to that this way. First of all, I want to be very careful to emphasize that I wasn't sitting on anything other than a pile of library books. None of those data that I presented are my own, of course, except for one little graph about fish flux. I didn't say anything about water masses because most of the people who wrote the papers that I reviewed didn't say anything about it and the study that Dick (Wiegert) talked about is one of the few, in fact the only one that I can think of right away, where anyone has looked at that kind of phenomena in a salt marsh creek and it's an extremely interesting finding. I think, though, that it again points out that one of our major research needs is to get a better understanding of the physical oceanography, if I can use that word, or hydrodynamics of very shallow coastal waters. I think it is an area where the blue water theory hasn't applied very well and people haven't been very anxious to work with it. My impression is that the application of numerical modeling to really shallow systems, and particularly to intertidal systems, is particularly difficult and is a state-of-the-art problem. We are dealing with sheet flow in marshes, with very shallow channels, with systems that are governed very much by the wind, and with sediment water models, where parts of the system are out of the water one moment and under the water the next moment. It is a very tricky problem. It is one thing to make a model of the circulation of an open bay, and quite another to tackle these

other environments. With so much of our estuarine work, whether it's for Delaware Bay, Chesapeake Bay, or any of the many small creeks that have been studied, we all keep coming back again and again to the question of what is the flushing rate of these systems, or what is the residence time or the half-life of water in this sort of biological reaction vessel. It's an extremely difficult number to come up with, and we don't have very good estimates for most of these systems or for how the flushing varies with winds, tides, etc. You have to model the next larger system to answer these flushing questions. If you know the flushing time of a given bay, then you've got to do some work modeling offshore as well, so that you can get the exchange at the interface. We're always having to go to the next larger system to answer the question, but I've at least gotten a chance to make a plea for more coastal circulation research.

Manley:

27. Well, that's true. I was wondering though if these marsh-estuarine flumes might involve surface wind. Don't you think that could account for the paucity of these real numbers that we're looking for.

Nixon:

28. You mean why we don't see more consistent fluxes out of the marsh? If you look at it another way, if you sit on the middle of Dick's water masses, you get very constant measurements. You get a very low net flux.

Manley:

29. If you sit at the ends, you get an abnormally high flux which is the number you said you don't believe in.

Nixon:

30. I don't know. I have no idea if that has been a problem in any of the studies that have been published. It's certainly another complicating factor, along with numerous others.

Richard Wiegert (University of Georgia):

31. I fully agree with you. This has been a terrible problem, and everybody has usually approached it by getting out the current meters and measuring the flow, standing in one place and sampling. That's the

way I thought it should be done. Imberger came and just took a look at the problem; he hadn't worked with this sort of hydrology before in Australia in salt marshes. He just looked at the Duplin River and said, "That's the wrong way to go about it. First of all, you should be following the water masses...use salinity as a conservative marker." Now it turns out to be a lot less work than using the older sampling technique, sampling continually over a number of tidal cycles.

Nixon:

32. Is his paper written up somewhere?

Wiegert:

33. I've got a copy here. It's subject to revision, but accepted in principle by Limnology and Oceanography.

John Wanstrath (Tetra Tech):

34. I was wondering if you can get into what we mean by the water masses. I know what Gulf Stream water looks like versus Sargasso Sea water, but when you get into the recesses of the marsh I guess I don't have a feel for the kind of differences. How do you identify a separable water mass? You said there are three or four different kinds of water masses.

Wiegert:

35. We identified a small area at the head of the river with salinity gradients which are very sharp. There's no salinity differential within the water mass. This gradient moves up and down the river and doesn't change from day to day—it's very conservative. On that basis we identify water masses. The independence of the water masses gets greater as you go toward the head of the river. The head and water mass are pushed up on the marsh. There is about 8% exchange between water masses per day.

Nixon:

36. Do you think that the fact that you're dealing with a heavy pulse of fresh water and therefore a sharp density gradient between the water masses slowed down mixing?

Weigert:

37. Yes.

Nixon:

38. Normally, when you don't have such a sharp halocline in there, you might not have such discreet water masses.

Wiegert:

39. We're talking about maybe 1-1/2 (parts per thousand, salinity gradient); I'm sure it does have a certain effect, but, on the other hand, if there is a strong physical mixing a salinity gradient that small would be destroyed.

(Unknown):

40. How deep is the channel there?

Wiegert:

41. It varies from all the way to 30 metres; half way up there's a hole that's 30 metres.

________:

42. There's a region there where you have a fresher section on top; how deep is it? Do you measure the salinity gradient vertically?

Wiegert:

43. There's no vertical difference in a water mass.

________:

44. Between the two, yes. You're saying that at the surface the salinity goes up and down; you see that boundary.

Wiegert:

45. The gradient extends top to bottom.

Wanstrath:

46. How does it physically mix if there's no wind agitation?

Wiegert:

47. Well, there is some. It does mix a little.

Nixon:

48. Maybe we should move on, Dick, since we spiraled off into the tales of Imberger's study, and he's not even here to discuss it. It's obviously a good thing to come out, and there's a lot of interest in it.

Wiegert:

49. The one thing of general interest is just how specialized this result is. This is a rather unique system. The Duplin River is a

very narrow estuary. Does this happen very often, particularly where nonmixing is involved? It turns out that Imberger did the same kind of study we did on Netarts Bay, Oregon, on a different kind of marsh, a Zostera bed, and found exactly the same thing: that the top water mass moves up and over the marsh with very little mixing.

Nixon:

50. It looks like we still have some questions from this morning's papers. We might as well go ahead with those.

Chris Buterra (NASA/ERL):

51. I'm not sure who of you that presented papers this morning I should address. Let's say that you have a hypothetical situation, this may be characterized most by the gulf coast marshes. But let's say you had a marsh, maybe an interior marsh that's not subject to daily tidal inundations, and you've got all this plant material that decomposes in an annual cycle. What happens to the plant material? Is it exported to the shoreline where it can be transported to the estuary or is it assimilated within the marsh? Perhaps it never reaches the estuary where it can support the marine organisms.

Nixon:

52. There are probably at least a half dozen different people who would respond in at least half a dozen different ways. I'll give mine first, since I have the honor of chairing this panel and gave the paper on marsh fluxes. I'll be happy to have some other people give their points of view. I know that at least one such marsh has been studied on the Mississippi coast. I think it was the group at Mississippi State that worked on it, but I don't think the studies are out yet. If I recall correctly from their presentation, the story there was that the marsh actually imported carbon, or exported just a very small amount. I've forgotten which, but it certainly wasn't a large export. With the exception of Heinle and Flemer's work which we discussed this morning, I think that no one yet has put together a really detailed carbon budget for irregularly flooded marshes. I think one of the things we're becoming aware of is the large amount of organic matter decomposed in the marshes. It's probably decomposed anaerobically by sulfate reduction.

At least the studies in Georgia and Massachusetts are showing that. One of the things that everybody wondered about was the observation that the marshes put just as much carbon or maybe even two or three times as much carbon production below the ground as they do above. What in the world were they doing with all this organic matter? It turns out that sulfate reduction measurements that are being made require about as much carbon to be reduced as the production figures indicate going on below ground, so a lot of it is being respired on the marsh surface and in the sediments. Certainly, an appreciable fraction is also being buried. As I recall from Woodwell's group for Flax Pond, it was something like 20% or so of the primary production carbon remaining in the sediments. That will vary with accretion rate and with everything else. Some percentage, as we talked about this morning, is walking out of the marsh, swimming out of the marsh, and flying out of the marsh in various ways, though it's likely that it is a minor fraction. But I'm not aware of a good, well-constrained, thoroughly documented carbon budget for an irregularly flooded marsh like that on the gulf coast. I know, for example, that Don Heinle and Dave Flemer studied an irregularly, poorly flooded marsh in Chesapeake Bay and found that only a very tiny fraction of the carbon was exported. But they have not fully accounted for the rest of it. Respiration rate was found to be very high in the sediments from the studies that Chuck Hopkins, John Day, and others have done in Louisiana. Does anyone else want to add anything to this?

Unknown:

53. One of the things that is probably obvious to everyone here, whenever a substance or element or nutrient is being monitored, is that it's in a transient state. There are all sorts of experimental problems; carbon, of course, is one of them. ...There's some indication, although they are not very prevalent in marshes, that these ponds are able to incorporate some CO_2 directly from the sediment.

54. In addition the dissolved organic fractions, which are fairly significant input to estuaries, are very difficult to handle on a mass basis standpoint simply because of the turnover. There is the rate of turnover of that fraction rather than actual movement of the material

from point to point. It's a very difficult determination to make and there may be a lot of error involved by that point.

Nixon:

55. I think that one of the places where DOC (dissolved organic carbon) was looked at most carefully is in Georgia. They've done a fairly careful study of the DOC flux and, as I recall, there's a relatively small fraction of the carbon involved; was it 10% or something, Dick?

Wiegert:

56. The DOC is very small. There is an additional problem; there are two obviously different kinds of DOC depending on the residence time, and one is a very refractory component. Any export due to convective water is also quite small.

Nixon:

57. I have to throw out one little note of perspective, an anecdote, that we have to bear in mind in balancing all these budgets. I have a friend who spent a considerable amount of time working with a sea lion in a cage in the San Diego Zoo. It seems like you ought to be able to budget nitrogen for a sea lion pretty well if you've got it in a zoo. You feed it fish and you keep it on a plastic dish and do all those interesting things with the products of the sea lion; you feed it carefully, and presumably you can weigh a sea lion fairly carefully. That sort of thing. He still couldn't budget the nitrogen within better than about ±10% after several weeks. We have to keep a little perspective on these things. I'm not sure. There isn't any really good answer to your question, I guess.

Wanstrath:

58. I would like to ask a question about your presentation. It appears from your various descriptions of the wetlands and marshes that you were able to research all of them pretty much in the natural state. Looking up and down the coast at the ever increasing desire to stabilize this inlet or that inlet, and also the interactions of the inlets, can you make any generalizations such as: Are these really good baseline studies in order to assess what we do when we put a jetty system or a

deposition system to try and trap the various sediments? Is there going to be an offsetting trend?

Nixon:

59. I don't know. I think the message of my talk this morning is that we haven't got a very good idea of what's going on with them now. Anybody who makes a very dogmatic statement of what's going to happen to them if we do something to them is in deep trouble. Or they ought to be in deep trouble, anyway. I don't think we know.

Saul Saila (University of Rhode Island):

60. I don't know if this is an oblique answer to your question. However, I would like to state that, from a scientific point of view, as Scott points out, there's a lot that we don't know about salt marshes, the interaction between marshes and estuaries, etc. On the other hand, I think that there are, if you are willing to take a segment of the problem, ways that you can get answers to questions, site-specific questions, which will essentially aid a decisionmaker in saying this particular project is feasible or isn't in terms of the kind of trade-offs that are presented. I think that, in this sense, one should look at it not as a conceptual model, but merely as a way to answer a very explicit question about what is impacting a particular proposed project or a segment of a system. Obviously, that doesn't tell you what's going to happen if you have many of these, but it will tell you what will happen in that one case with the kind of fidelity you're willing to accept. You tell me what kind of differences you're looking for and we can give you some idea of what kind of program is needed to answer that question.

61. I would like to ask a question of all of you. How much of the wealth of literature, German and Dutch dealing with polder soils, German literature dealing with pond culture and the various physical and chemical reactions of pond soils, etc., have we assimilated and utilized effectively? It seems to me that there is some information in soil science that we might effectively utilize in enhancing our own background knowledge. Would you tend to agree? I would like to offer this as a suggestion. The other point is somewhat related. There is, in my opinion, a wealth of literature on the process of how to design

experiments to answer questions where you've got, not only major effects, but all kinds of complicated interactions. I feel that the principles of experimental design, particularly in places like marshes, where you can physically lay out these experimental designs, will permit you to assess first-, second-, and third-order interactions, if you're interested in them, and also major effects. I think if you look at a system purely from a univariate point of view and the law of the minimum still applies, then you may have a very biased picture of reality because some other factor may be limiting rather than the one you happen to be attempting to use as a treatment variable. Again, I offer purely as a suggestion that a book like Sir Ronald Fisher's, Experimental Design, although written a long time ago, may still have some virtue in terms of helping you essentially plan multifactorial experiments. One can test all the major nutrients, minor nutrients, organics, inorganics, etc. It seems to me that this might provide some of the input data for building the kinds of conceptual models that have been talked about. Although Dr. O'Connor has left the meeting, I think he certainly impressed me with the fact, and in fact yesterday's talks also impressed me with the fact, that the mathematicians are ahead of us. It's time that we gained a little more accuracy and precision in some of the coefficients that we try to put into models. I feel that the methodology for doing this is available. All we have to do is specify the kind of accuracy and precision that we're looking for.

John Lunz (Waterways Experiment Station):

62. In response to the question on how we access the European literature, I believe that there are certain persons, at least in the Corps and among contractors doing work for the Corps, that are interested in trace metal transport systems specifically and that make some modern use of some of that literature. A lot of them also are benefited by our access to agricultural literature; application of cadmium and contaminated sewage sludge to crop systems has relevance to the application of dredged material in wetlands or use of dredged material in creating wetlands. But the other question, I have a basic fear of models I guess because I sometimes think ecosystem modelers begin to believe the output of their

computers when some of the output is not verifiable. If our objective is mostly to understand how a particular set of processes affects the fishery and our final decision is based on the impact of an operation on a fishery, then how do we verify it when the techniques do not exist in which to come up with the quantifiable characterization of a fishery in the first place. I'm questioning the objectives of the workshop in this discussion. Is it to outline those courses of scientific investigation that should be used, that should allow us to build better models, or is it to identify the situations where models can be effectively used now? If it's the latter, then perhaps some of the ideas that we're throwing around are not relevant. I also question whether we have a lot of the techniques that we need to conduct the investigations. Do the techniques developed for aquatic chemistry and agricultural soils science apply to these systems, or do we have to develop better ones? Do different techniques exist with which to effectively census fish communities within the system? I think not.

Saila:

63. I argue with you about the latter case. A competent fishery scientist can estimate the magnitude of a population with the kind of accuracy and precision which will tell you if a perturbation occurs. I think this can be done for at least all life history stages beyond that of the larvae. I think that we do have techniques in the case of single species, and in the case of fish I think we have historically demonstrated that there are effective single species management models. They've been used for some time. These are not models which are integrated with the whole system. We're looking exclusively at a population and man's interaction with that population. We can tell you what man's effect will be whether it's the entrainment of a power station or the effect of a given mesh size of a net.

Don Robey (Waterways Experiment Station):

64. As you know, my group at the Waterways Experiment Station sponsored this workshop through a contract with SAI. First of all, we're here to listen and learn. We picked the subject areas of the invited papers and selected topic areas. Our purpose for having this workshop is

twofold: the first to assess through the invited and contributed papers where we are right now; and, secondly, through the session this afternoon to provide input into our future research at the Waterways Experiment Station. We want to address in our research efforts only high priority problems. I would like to see us continue with the panel giving their feelings as to where we are right now, what we can do, what we can't do, and then next I would like to see all of you contribute in the area concerned with what major questions are remaining. I would like to leave here with some recommendations in this area. Let me provide you with a little more background. Concerning the manner in which we conducted the contract with SAI, first of all we asked them to visit each of our Corps coastal offices. At each office, they spent a day with a team of two and sometimes three people talking with Corps personnel. The purpose of this was to identify the priority problems within the Corps, what questions are being asked, and which ones can't they answer. From this input we structured the workshop. Now what I want to be able to do, given limitations of time and money, is to address the highest priority problems through using existing techniques and, where required, through additional research. With this brief background, maybe we can continue with the panel members giving their thoughts.

Ray Krone (University of California at Davis):

65. I'd like to present some thoughts that accumulated during the conference and that might be useful to meeting Don Robey's objectives.

66. Modeling might be motivated from the standpoint of two objectives. One is from the management objective, that is decisionmaking related to management of estuary and water quality; the other is from the development of understanding of interactions between water and marshes, and water and organisms, water and sediment, and so forth. Those might be two motivations, but they actually go hand in hand as I'll explain in a minute.

67. There are two kinds of modeling that have been described here. There were some references, two references in fact, to empirical modeling; that is, regression analysis. I squirm, I think a lot of people squirm, when they hear regression analysis mentioned. It's the kind

of thing that you do when you don't know anything else to do or when the costs of doing anything else are prohibitive and you feel called upon to stick your neck out. I don't think that many people recommend the use of mindless correlations without some understanding of what the actual processes are.

68. The other end of the modeling techniques that have been described is simulation of natural systems. I think that's where most of our sentiments lie. In order to simulate the natural system, it's necessary to have accurate descriptions of the component processes; that is, the processes that you're synthesizing into a description of a whole system. In fact, the accuracy of a prediction of any kind of a change in a system depends on the accuracy of the descriptions of the component processes. I would like just to enumerate a few to point out the importance and to perhaps recommend a hierarchy of importance that might be useful for modeling. The first has to do with describing the flow. It's already been referred to by this panel, but I can't help but emphasize it further. All the transport processes that we've been discussing are affected by water movements. Material either moves directly with the water movement or diffuses due to mixing of the waters in an estuary. Estuarial water movements are among the most complex hydraulic systems in the universe, not just in the world but anywhere. Stop and think about it a minute. Estuaries are bounded by waters having different densities, waters with entirely different motions at the boundaries, tidal saline waters at one boundary, unidirectional but highly varying freshwater flows on the other boundary. There are free surface flows, surface area changes with time, and, as pointed out here, there are mudflats exposed part of the time and not exposed part of the time. The flows are highly variable and the densities of the flows are highly variable; that is, they tend to be stable (but not always) as the more dense waters are near the bottom. Densities vary throughout the system with time. In fact, they vary not only due to salinity but due to suspended solids content and temperature. If you add on to these variabilities hot discharges from power plants, or water intakes for various purposes and diversions (sorry Dr. O'Connor left so early), diversions of freshwater

flows at the upper end of an estuary so as to drastically change the hydrodynamics of the system, you can see that describing the water motions, nekton, algae production, almost anything else, it's essential that there be an adequate description of those water motions. When you think about the gravity circulations that result from the differences in densities at the two ends, you can see that just that is a major factor in algae production or sediment transport.

69. Well, I can't help but emphasize the need for a better description for hydraulics and there seems to be two reasons that we don't have adequate descriptions. First we need the field data. The next thing is the dissolved material transport. Many of the things that we're concerned about are sensitive to the concentration of dissolved materials. Of course, the hydraulic model itself is sensitive to salt because it affects density, but biota, sediments, and most things we're concerned with are also affected by dissolved material concentration; of course, the dissolved materials themselves are often the object of a model study. So I put them second in the hierarchy of required models following hydrodynamic models and they require an additional collection of data in addition to good hydraulic model output. The third level is modeling sediment transport, which requires information on sediment inputs and sediment properties to describe suspended solids concentrations. You can see that if the dissolved materials that you're concerned with suffer absorption-desorption processes, then it's necessary to go back one loop and include the sediments in that description. In any case, I would certainly put them third. Finally, if you're interested in algae production, comes primary productivity. You really need all three of the previous ones to just make a start; light penetration is affected by suspended solids, often the limiting factor in algae multiplication. The algae aggregate with suspended particles and are transported with them. You need that information. The nutrient supplies are determined by dissolved material transport and of course the hydraulics either dilutes them or provides the necessary conditions for them. I'd list that hierarchy as being the way to go if you want a complete estuary model. Then, of course, if you're brave or foolish, I don't know which, you can

model fish transport, but I think we have the technology available to do a pretty good job on all four of those levels of modeling. Let me re-emphasize, in order to make reliable models it is necessary to know all the important constituent mechanisms that are relevant to your model, and hopefully we will eventually know which ones are more important than others. In other words, which models are more sensitive than others.

70. Questions from the audience concerning the four levels of modeling follow:

Krone:

71. We could do a job with four. I'm not competent to say anything about fish. There have been enough algae models so that I'm beginning to have some belief that they can be done. That doesn't mean that I agree with all the algae models we've seen. Well, I've mentioned the need for adequate input data, and I'd like to say something else about that. We've talked about modeling and the simulation and prediction for management purposes or for understanding. In the actual management activity, of which modeling is a part, the biggest part is collecting the field data. Field data are needed for both descriptions of the mechanisms or the coefficients to put into the model and then to verify the model after it's been put together and to evaluate its performance under a wide variety of conditions. I would guess that gathering field data would cost about five times as much as running the model in a typical case. If you're budgeting $100,000 for modeling, you'd better budget a half million dollars for getting the field data. I'm probably a little light at that from my experience.

72. Another thing about the modeling that struck me, and we haven't talked about it at all for some reason, is how you operate the model for the decisionmaking or for understanding the system. I strongly prefer time-dependent models. When you average out conditions over long periods of time, you're averaging out a lot of things simultaneously, and you can't really evaluate them. Time-dependent models are expensive to operate. You can't really run through a year's time in an estuary. So for practical purposes, and actually even if it weren't practical otherwise from the standpoint of cost, it would be most desirable to select

the conditions under which you want to run the model that will lead you to a decision. Now what kind of conditions might they be? Storm events might be appropriate in some cases where you're worried about transport. Minimum freshwater inflows for another, to see what the impact of that extreme condition might be if you're interested in diverting water. High flows, low flows, changing flows from high to low flows where the mixing zone is moving upstream—that's when we have our fish kills in San Francisco Bay. In any case, it's necessary early in the modeling effort to identify the kinds of conditions that are of interest so that the model will be the most appropriate for those conditions. A corollary to that observation is that once you've built the model, you've only started; you've got to run a lot of experiments before you come up with the information necessary to make the decisions, which means that early in the game it's necessary to couple the modeling activity with a decisionmaking activity. The people who have to make the decisions need to get their input in early in the modeling and field studies design in order to make an effective, reliable kind of model.

73. I've been talking largely from the standpoint of decisionmaking. I should say something about understanding the system. If a modeling activity is to be really successful, the competence of the modelers and the decisionmakers should continually grow. That is, the information that comes out of the model should tell how to make a better model or how to make a better sampling program in the field to get better understanding. I think that ought to be programmed in at the outset. There ought to be an extra 10% of the budget available for making improvements at the end of one modeling effort so that the next one is better. Sometimes that's happened and, where it has in the past, it has been very useful. It usually, however, happens within the Corps or in private consulting firms, and it's usually hidden somewhere in the overhead. I think the time has arrived that it's taken out of the overhead and put up front as an important objective.

Ken Fucik (SAI):

74. At what point do we begin to believe models? Where is that point?

Krone:

75. Well, I'm from Missouri, figuratively, so probably I may be a little bit on the skeptic side. I feel very strongly that a model should include coefficients that are independently determined insofar as possible. Every reaction rate, diffusion coefficient, settling velocities for sediments, etc., should be determined separately from the modeling activity and inserted into the modeling activity. You can't do it 100%, there are things that we can't yet describe and one of those is longitudinal and vertical diffusion coefficients from purely hydraulic data. So it's almost always necessary to make some adjustments, but the values that you find when you adjust it should be within reason. If you have two orders of magnitude higher diffusion coefficient, you know you're fudging somewhere. That's one way you can tell. The second way is to look at the processes that are described in the modeling activity and see if they represent the system as you understand it. There should be no exceptions. If there is an exception, there should be a red light flashing, and it should be investigated further. The third way, and a way that I think should be required in every model, is that after having developed the model you see how it fits a wide range of conditions. You'll hear people separate it into verification and proof or calibration, verification, and substantiation. You'll hear all these fancy terms, but it doesn't make any difference which you call which. It should fit a range of conditions and as nearly as possible include the range that you are seeking. Now usually that doesn't happen. Models are made to extrapolate to new conditions, but the verification should include conditions as close to it as you can. If it does fit everything that you see, there's still some doubt that it'll fit the extrapolation, but it's a very small doubt, and the chances that you take using the model are much smaller than the chances that you take doing it without it. Models generally pay very handsomely.

Wiegert:

76. You're describing the process of scientific attempts to disprove hypotheses. I agree. When does the hypothesis turn into theory. I tend to be careful about this. Usually a modeling activity is

undertaken because the results are important, and if the results are really important, then you want to examine all the assumptions and all the relations that you use making sure that those that are known to be relevant to the process are included. For those that aren't relevant to the process, or that the process is insensitive to if they're excluded, we must have some idea of what the effect of the exclusion is.

77. Don't you think that you probably ought to emphasize that, as far as the management decisions are concerned, you have to take into account the consequences of believing models.

Krone:

78. Usually you learn.

Wiegert:

79. The consequences of believing it possibly vary; detrimentally if you are wrong and depending on whether it's type one or type two error.

Nixon:

80. It seems to me from recent experience that one problem is that when management agencies let a contract, particularly to consulting companies, the final report is written based on a model. I'm thinking of ecological system models. I don't know how it works with fisheries models. A report is written and presented to the agency with certain recommendations based on the model output. I think in dealing with the reality of human nature there is a tendency to put somewhere in the fine print that, of course, the results are subject to the uncertainties of the coefficients. It's very difficult for a company to write a thing and say, "Well, here are the results, and they've got about 10% chance of really being worth a damn." It's really hard to put that up front. It kind of filters in. It's hard to draw that band of gray which is thicker than the axis. I think that you have people in the management agencies who are not competent to look at that report carefully. After all, if they had the expertise in-house, they would probably not have let the contract in the first place. So you have somebody looking at it, and maybe he's a very fine sedimentologist, but he's looking at the algal growth dynamics. He says, "Well, this is a reputable guy, and they appear to be good, and they've done the model, and we'll make a decision."

It seems to me that before any management agency does that, whether it be from a model or a field study for that matter, they ought to go through the same sort of thing that the journals go through in terms of peer review. You take that report from the consulting company and you put some money in the kitty to hire three people to sit down and tear the damn thing apart and then come back to you. If you're going to spend millions of dollars building a sewage treatment plant and you spend $150,000 with company X to model it, the least you can do is give about three good people around the country a $1000 apiece to sit down and look at the report and tell you whether it looks any good or not. I can think of one particular case where that wasn't done, and lots of people who know something about the thing think the report is a bunch of junk.

81. As you say, it's all hypothesis, and we're all trying to get the truth, but still in human nature there is a tendency to sweep a lot under the rug. If you have people who are really pressed—they're monitoring five other projects at the same time—and a reputable report in a nice binding comes through, with all the fancy plastic on the front, and it's reputable people—things get done that ought not to be done. I think we have the problem in science, that as we get more and more sophisticated, the public view gets to be bewildered. If there is a lot of uncertainty, and we get experts disagreeing with each other, then people feel that science has nothing to do with it. Decisions become purely political.

Wiegert:

82. I agree they feel that way, but I don't know why it's always tacked onto biology and ecology. The same thing is true of the physical sciences.

Nixon:

83. As soon as you start working with chemists and physicists you realize that.

Wiegert:

84. For example, who was the geologist that said nothing would leak from the salt domes into the Mississippi.

Krone:

85. There are a lot of obvious things that you can do, if you have a model that averages over a week--I think we saw some. The average is over a week and you have algae blooms the last three days. You might suspect whether the algae blooms are predicted by that model. I think time-dependent models are the way to go.

Wiegert:

86. I think what Scott said was that it is very good to have these reports referred.

Norman Benson (U. S. Fish and Wildlife Service):

87. I know that there is a correlation between fish production and shellfish in marshes; however, we don't exactly know the boxes and so forth that connect it. I know that in streams 60 to 70% of the change takes place during the storm event. In other words, that's when scouring and deposition take place. I suspect that when you interface marshes with some of these other areas, this is also a storm event phenomena. In other words you can get a very small export or import as measured, but what do hurricanes do. The question is, how do you model these things? I expect that is probably one of the prime ways or methods by which some of these marshes contribute nutrients and organic matter to the estuaries. But the question is, how do you model this? This might be the whole key to the relationship.

Nixon:

88. When I started out reviewing the data on nutrient fluxes, I figured that since I was doing this for modelers, people were really interested in the estuary. What you would really like to do is have some physical forcing function that you can plug in to take account of the marsh, such as some function of temperature and tide height or something that would give you a nice predictive equation, in some mechanistic fashion, for interactions between the marsh and the estuary. You could force temperature, you could force the seasonal tidal cycle, and you could put in a storm here and there. The tide level would flush the marsh depending on how much was stored, which would depend on the decomposition rate, temperature, and all those sorts of first-order decay

kinetics. It would be wonderful. You could put it all together in your mind in about half an hour. You could write the equations, draw the flow diagrams, do a wonderful model for estuary-marshes. The problem is that because we know so little about most of these things, the exercise is futile. We're not ready to do it yet. You may be quite right that the storm events are when detritus moves, but in terms of modeling it, I don't think its going to have any credibility.

Wiegert:

89. I think catastrophic physical events are actually much easier to model than catastrophic biological events because you can measure during some of these physical events as they happen. You can actually find out where it's transported out. Then the question is, how often on the average will they happen? You certainly can't say that on the 17th of August this is going to happen.

Nixon:

90. But you can't bring forward, yet, any data which show definitely that a big storm moves this stuff into the estuaries. So far, you can only make a model that says that it goes with the tide height.

Wiegert:

91. During catastrophic rainfall we know what happens.

Krone:

92. We can describe sediment suspension by storms.

Robert Reid (Texas A&M University):

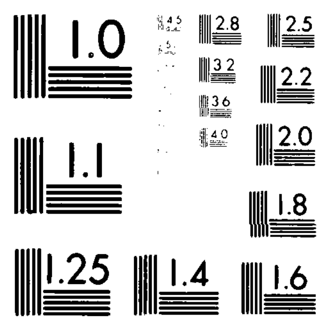
93. I'd like to address some questions related to the physical modeling. It has been alluded to several times in the conference that everything is so sophisticated with the physical model that we have the most confidence in it. I would like to emphasize that all the problems are not solved in this area. We've mentioned one of the problems already with respect to the physical aspect of marsh regions: How do we treat water flowing over a marsh grass? Another and perhaps one of the foremost problems with regard to the physical modeling is in regard to the turbulance closure problem.

94. This is a classical problem that we have approached in the past with ad hoc parameterization of both the bottom friction, surface

AD-A089 961 SCIENCE APPLICATIONS INC RALEIGH NC F/G 13/2
MARINE WETLAND AND ESTUARINE PROCESSES AND WATER QUALITY MODELI--ETC(U)
SEP 80 P HAMILTON DACW39-78-C-0087
UNCLASSIFIED WES/MP/EL-80-3

2 of 2
AD A
089961

END
DATE
FILMED
11-80
DTIC



MICROCOPY RESOLUTION TEST CHART

friction, wind stress, and the way that momentum gets communicated to both the mean flow and to waves, i.e. how it's partitioned. We're still pretty much dealing with ad hoc ways of doing this. There are some beginnings of the state of the art with respect to higher levels of turbulence closure, and this has to do with the vertical transfer of momentum. It relates to trying to predict some of the things that were brought out very early in this conference with regard to measurements of turbulence. These are the turbulence intensity and how it is related to the transfer coefficients in the vertical. We know probably less about the horizontal transfer except that the exchange coefficients are undoubtedly related to scale and that scale has got to be related in turn to the scale of the model grid. That's a problem. It is being worked on. It needs more application particularly to cases where we do have data and to verify new methods of higher order closure in the turbulence problem. We have gotten by with ad hoc types of friction models for modeling things like tides and storm tides. Where we know pretty well what the forcing is, we can get by with vertically integrated models; that is, two-dimensional models in which we can relate the vertically integrated velocity to the bottom stress in shallow water and get reasonable predictions of water level variations. When it comes to velocity prediction, that's another matter. If you compound the problem by going to two layers or "n" layers and add in the baroclinic component, then the problem gets even more complex in respect to the effects of stratification. How do you handle these in a kinematic sense with respect to the velocity in the various layers, via interlayer turbulence, and so on? These are some problems that do exist.

95. With respect to scale consideration, we talked about different kinds of models. One can classify them the way they're set up, the way they work, and what physical phenomena are put into the model. For a lot of the models we have used the term box models versus others. The only kind of model, that I know of, <u>is</u> the box model. It's purely a matter of scale, and no matter what scale you take, it's finite. Also, we have a pretty good handle on how you handle the physics among the boxes and how you put momentum and heat into the boxes from other boxes, from

the atmosphere, from the bottom, and so on. What we don't have a good handle on is what's going on within the boxes and how you parameterize that. I've mentioned one of these problems and that's turbulence. In the higher order turbulence closure schemes, what you do is add another prediction equation for the turbulent energy in the box and if you don't like that, then you go to a higher level where you look at the variance of the turbulence within the box and so on. With respect to parameterization of things going on within the box, there's another example besides turbulence. We have the problem of dealing with a canopy over a marsh. How do you parameterize the vegetation? If there are fixed pieces of material as in a physical model, you can probably do a pretty good job. If it's marsh grass that's waving around, how you treat that as far as its hydraulic characteristics and its effect on turbulence within the water is something else. The problem has been approached; the most developed work on canopy flows is in the atmospheric problem—flow through orchards, for example. There are analogies to the methods that have been used for marsh grass situations.

96. Another subgrid scale problem is the presence of channels that you can't resolve, for example, subgrid scale channels in a marsh. There are approaches to that problem. They haven't been fully exploited. Barriers and other subgrid scale effects have been used in ad hoc systems; they seem to work. Some verification exists, more verification is needed. Sources and sinks is another example of subgrid scale effects. We heard a discussion of analytical models applied to small-scale sources and sinks; I think to really deal with that problem you have to deal with a hybrid model in which you imbed quasi-analytic solutions at subgrid scale size within the finite mesoscale grid.

97. With respect to scale considerations, certainly when you set up a model the grid scale that you adopt ought to be such that (vertically or horizontally) you resolve the most energetic scales in the system. We don't always do that. We particularly don't always do it in the blue water oceanography models. Another consideration is not only do we want to resolve the most energetic scale in the system (and that demands some empirical knowledge with respect to any estuary that you're

looking at), but also what are some of the natural scales that exist. Horizontally, these are the radii of deformation and particularly the so-called baroclinic radii of deformation. They're essentially a wave speed (a gravity wave speed, internal in the case of baroclinic wave) divided by the Coriolis parameter. These scales, the baroclinic scales, range from about 50 km down. As you go to higher order baroclinic or internal wave effects, these horizontal scales get smaller. In an estuary, these scales probably start at 10 km and go down. The higher order ones may be 1 km. If you want to resolve those and if they are really important in an estuary, your grid scale has to be suitably small. Again, I'd like to draw analogies to the blue water problem. There is a coupling between the problem of vertical resolution and the problem of horizontal resolution. If you model an internal wave in which you are resolving it horizontally with a 10-km grid, then it's foolish to go to 10 levels or to 10 layers because you are looking then at baroclinic wave phenomena, internal waves, whose horizontal scale is maybe 1 km. So it's better to back off and say, let's put more resolution into the horizontal and less into the vertical as a compromise. The same situation may exist in the estuary, but we do know that friction is a much more important problem there in contrast to Coriolis effect. When we talk about the radii of deformation, we're saying that Coriolis is much more important than friction. In an estuary this is probably not the case, and this question still needs to be addressed. There are frictional scales, both vertical and horizontal, that one needs to look at.

98. Next is the problem of forcing. Of course, there is tidal forcing, usually at the boundaries. For an estuary, certainly, it would be at the boundaries. There is also wind forcing, both locally and at the boundaries. For example, we heard early in the workshop here, from studies from the Chesapeake Bay, about long-range effects of nonlocal wind. You force the shelf waters and that gets transmitted through the opening of the estuary into the system and, in the case of Chesapeake Bay, could be relatively energetic compared to local forcing. Those kinds of problems need to be looked at for estuaries where this remote forcing does exist. Thermal forcing we haven't said much about. In the

deepwater problem, the wind forcing and tidal forcing seem to be the dominant forcing, although there are some thermal effects. Certainly, thermal effects are important with respect to the mixed layer. The problem of the mixed layer and how the thermocline is eroded by energetics within the mixed layer, by wind, waves, and by convective circulation is an important one. The problem of the upper mixed layer has not received as much attention in estuaries as in the deep water.

99. The last thing I would like to mention with respect to forcing is on forcing wind waves. We have heard some discussion of wind waves and we know that it is vital in respect to the sediment modeling because it is significant in determining the bottom stress—at least a portion of the bottom stress. Of course, it's the total current that does it. But since, by and large, in many cases in shallow water the wave part—which is the oscillatory part of the current—can constitute a good portion, if not a major part, of the total current at the bottom. In that sediment problem, one has to consider the wind waves.

100. What about the hydrodynamic problem? In the hydrodynamic problem for storm surges the bottom friction is a secondary thing; you can get by with a very ad hoc model. You can get pretty good results for storm surges and tides. When you're dealing with the circulation problem (the average circulation over a tidal cycle or over weeks and so on), the bottom friction is the break that keeps things more or less in equilibrium against the wind and against the residual tidal effects; it is of first-order importance. It is essential that you model that bottom friction correctly; the correct way is to add the wind waves to the problem. Otherwise, you're not going to get the right bottom friction.

101. The last thing that I would like to mention is sensitivity analysis. I think that we could exploit these models much better if we could subject our models to a much greater scrutiny with respect to sensitivity of all the different parameters that we have imbedded in these models with respect to forcing, bottom friction, the different physics we've got involved (nonlinearity), and the whole works. What we usually do once we've found that the model conserves mass and energy in the

absence of friction and doesn't blow up on us, etc., we tend to become secure or comfortable with the model. The more comfortable we get with the model, the more dangerous it is, the more apt we are to really believe the results. We've got to put these under more and more severe scrutiny, as has already been pointed out, before you can really believe them. We could do more sensitivity analysis, not necessarily comparing against data, although this is nice when you've got the data. How sensitive is the model to small change of this and that parameter? We also could exploit these models more using them in a sort of quasi-diagnostic manner like the meteorologists do. Their diagnostic method, or objective analysis as they call it, is to take all existing data and blend it into a consistent picture via a model. In their case, it's actually a steady-state model, or quasi-steady-state. One could do this sort of thing with estuarine data to help fill in the gaps; i.e., do the interpolation between where you've got the data and where you would like data but don't have it. Along that line I think one could exploit the use of models to answer questions that have been brought up here in relation to error bounds on fluxes of things through a cross section. If we've got these models and if they have pretty good resolution in the vertical and across the channel, we could use these to compute fluxes and their sensitivity to variations in certain parameters.

Wiegert:

102. I have just one comment about one of your later statements. When you run these models, I strongly recommend a graphic output, not only of the time changes in the state variables, but also of the changes in the fluxes themselves because often you get some good clues to things that are really radically wrong whereas in the net result if the fluxes are bad the compartment behavior might be pretty good.

Nixon:

103. Are there any last minute questions?

Unknown:

104. Models have the advantage of helping with decisionmaking. Would it be possible to develop a scheme for rating the quality of a model? There's a scheme called risk analysis that is applied in

operations management which takes a set of operations leading up to the production of an airplane or spaceship and allows you to identify the various points along the course of production as having a relative criticality value. This leads to determining the success of a mission as having a relative probability of failure values based on the risk associated with that operation. If you have a given set of assumptions, or a given set of values we use to make a model, you could rate each of those assumptions or values according to the data available to produce that value, as well as the relative criticality of that assumption in producing the model's final output. At the end, you would have a model that might have a real high probability of being accurate. Of course, with a model that had a much lower probability of being accurate, you'd tend to make a lot of professional judgments along the line. In any case, the decisionmaker would be able to use it with the knowledge that you're taking a chance.

Don Robey (WES):

105. Bob (Reid), I think you brought up the time and length scale type problem. I wanted to address that from the standpoint that most likely there are different time and length scales in the physical, biological, and chemical processes of estuaries. I don't think anybody has looked at that in the estuary. We've looked at it in the reservoir. In fact, this question was on top of my list after the first workshop session. I think we need to take a hard look at that and, as I think Ray (Krone) suggested, we might need to go to three different models: hydrodynamics, transport, and quality, separate them out.

Nixon:

106. Do you want any response to these as you bring them up?

Robey:

107. Let's say, as far as the heirarchy of models, should we have separate hydrodynamics? I think we're still going to have temperature and salinity and, depending upon the sediment concentrations which affect density, we may have to include these to accurately model the hydrodynamics.

Nixon:

108. What you're saying is that because things are happening on a short time scale for the biological events, do we want time dependency there?

Robey:

109. No. The real interest in the biological factors, I believe, is mainly in the longer term effects. In hydrodynamics, we're making shorter interval computations than I think you would ever attempt in the biological end. Possibly as short as 15 sec, depending upon the solution technique used.

Nixon:

110. That's tricky. One of the lessons in biology, I think, if we've been learning anything in the last 10 years or so, is that things are happening faster than anybody ever thought and that the turnovers are extremely fast, at least in the water column.

Robey:

111. True, some of Dick Park's work shows that in the lakes.

Nixon:

112. We're going to have to look with a very short time scale especially at high temperatures in terms of what are the turnovers of the various compartments. I don't know about 15 sec, but certainly on the hour, or something like that. On the other hand, the thing that often saves the biology and makes it relatively inexpensive is that we don't need the spatial resolution that the physical oceanographers do. If you go out to an estuary you often don't really care whether the phytoplankton are a whole lot different a quarter of a mile away than they are over here, unless there's some particular reason for it. But you can't just leave out chunks of the circulation like that. You can't leave holes in it and calculate the estuarine circulation every 5 miles down the estuary. We don't usually have any kind of verification data for the biology on a really fine scale anyway. There's more spatial independence in the biology than in the circulation, perhaps.

Wiegert:

113. I think the point here is that it does not depend on the

solution time of the model to use one model on short solution time and another one on long time, or whatever the rates are. A lot of times biological rates aren't happening much faster than any of the advective exchange or the diffusion rates. If that's true, then this means that we have to take biological gradients into account. Things may be growing and declining purely as a result of biological interactions without being greatly affected by the hydraulics.

Robey:

114. I guess what I'm hearing is that we need to be cautious about going to full-blown ecological models in the estuaries. We want them in the one-dimensional reservoir models, and I think we've done a pretty good job with them from the standpoint of having comparable time scales in the hydrology, chemistry, and biology. Dick Park's work has emphasized the biological/chemical versus hydrodynamics. What I am hearing here is that to think about an ecological model right now is probably somewhat premature. The questions we seem to be asked center around circulation type problems and possible changes in salinity and dissolved oxygen. Sediment transport is definitely a problem area, and, as we all know, you can't model the transport of pollutants without modeling sediment movement. Ray Krone presented a list, a general modeling heirarchy, which seemed reasonable. I was wondering if there was a general agreement in that.

Nixon:

115. Recognizing that the people here who do biological modeling may feel differently, it seems to me that in a sense I'm tempted to agree with you on that. However, we develop this "thing" about model builders and nonmodel builders. That's a false dichotomy to start with. We all make models; any good scientist builds models. They may be conceptual or on a computer. What you're trying to do all the time is put the pieces back together and see if they fit and see what the consequences of any one measurement are. The literature is full of individual measurements, little pieces of this and little pieces of that. People usually don't make the effort to take their number, that rate that they're measuring so carefully in the laboratory, and ask what the

consequences of that number are. If that is the rate, what does it mean for some other processes involved. You're doing a lot of that with a model. You're saying if the number is good, what does it mean about what's happening to the things that are involved in this process, and does it make any sense or not? Does it fit in with what I know about the rest of the world? We all ought to be doing that. We should be doing ecological modeling even if our state of ignorance is very high. Maybe that's even more reason for doing it. But the other thing is, we ought to broaden the definition of what an ecological model is. We're limiting it here to being a numerical ecological model, but I think the other thing that we've got a lot to learn from is living ecological models, or microcosm models. They are especially useful for doing pollution work. If you want to do pertubation studies using a numerical model, you use a model of the system in the state it's in now and try to see if it's going to change state if you do something to it. That's pretty difficult to handle in the numerical model. If you let nature design itself, and you can conduct the experiment on it, then it seems to me that you've got a better chance of finding out what's going to happen, particularly, for a lot of trace metals and trace organic chemicals. If we want to find out the routes, rates, and reservoirs for these kinds of things, we're more likely to get the answers out of experimental ecosystem work than we are out of numerical models at this point in the game. I think we need both kinds of models.

<u>Robey</u>:

116. That suggests a response to John Lunz's question--at least my response. One thing we're doing in our one-dimensional reservoir models is applying Monte Carlo techniques to the various coefficients that must be provided as input. For example, let's take the growth rate of an aggregation of algae. You can go through the literature and, depending upon who's paper you read, obtain different growth rates. We, like others, have found that you can put distributions on these. At any time step within a numerical computation we go into the distribution and randomly pull out a value to use. With this approach, you can produce a band of "results" upon which you can put some statistical limits, you're

not just putting out one deterministic result. Whether it's the best approach--I don't know. It's good for a decisionmaker. You hate to give him one line--at least we do.

(Question on Monte Carlo technique)

117. The only thing that the Monte Carlo simulation does is, if you assume all the assumptions and equations in the model are valid, it gives you a statistical range on the model output. That's what it boils down to.

Wiegert:

118. I think it's important to realize that we never make a model of the whole system. Neither all the physical variables nor anywhere near all the species are included. So we're always dealing with a vast simplification. It becomes a question of what the objectives of the model are. If you just want to deal with management of a particular game species or fisheries population and the only thing you're concerned with is varying a well-known source of mortality, use a simple model. You certainly wouldn't consider putting all the other species in there because they really don't have any relevance. If you want to ask questions on trophic level interactions, then you have to have a more complex model, but again you're forced, even if you don't like it, to try to pick just those parts of the system that are being most severely affected and sometimes you're obviously going to be wrong. That's where I think a model can help you learn to recognize if you're getting ridiculous results or results that are wrong.

Lunz:

119. Bernie Patten says that the greatest value of modeling is that it forces you to sit down and conceptualize relationships for purposes of designing experiments. I agree with it but I'm not sure everyone does.

Wiegert:

120. In decisionmaking the use of a reasonable model that's been reasonably and critically looked at is certainly better than a decision made without that.

Unknown:

121. I would like to make a comment on the way a "model," by way of example, is very different from the type of things we tend to think of. In this case a problem was faced by National Marine Fisheries on George's Bank. Now a lot of us might think in terms of going in and developing very, very complex ecosystem models; this might be very tempting because of the backlog of information that exists on George's Bank. This particular work was given last summer; it's in press. This particular individual took a conceptual model and divided the major fisheries populations into eight categories: important fisheries populations and commercial fish species. A last category included most of the prey species that these various things were feeding upon. They then developed a plain structure of the system. They didn't even put arrows on the transfers. By using a very, very simple transformation from graph theory, they reduced the dimensionality of that graph to a single dimension which means they took out all of the secondary transfers leaving only the primary transfers in that system. From that, they were able to develop a system, this was several years ago, by which they predicted that by licensing a higher catch during a certain time of year on a threadfin shad, they could increase the catch of bluefish during the regular fishing season. It was tried out and it worked. Here's a case of a very, very simple technique based on nothing but a simple conceptual model. It was simplified further to attack that direct problem without all the inherent complexities of energy flow models. I work with complex energy flow models, but I have no objections with attacking a problem in the simplest possible way, and the most effective from a managing point of view.

Robey:

122. I'll concur in that. We use modifications of the Vollenweider type models in reservoirs just like everybody else. I'm not saying that we should not build ecosystems models; what I am saying is maybe it is premature at this time.

Fucik:

123. We're presently working on a model in which they collected the data and now they say go build us a model. Maybe your approach,

Don (Robey), should be to say that we're going to build an ecosystems model of the estuary, or the marsh, now what do we need to develop the model and set up the program to develop the model.

Ivan Show (SAI):

124. The model that Ken (Fucik) is referring to, the specific task description, says, "Tell us what the structure of the system looks like." We're not building the model for the model's sake. If there was an easier way to do it, we'd do it. It turns out there's not. There are some very difficult problems in defining the structure of the system. We're attacking that problem. The ultimate result is to bring that back now and add the last step, which so many people forget to do, which is to interpret the results and define the real structure of the system and what the implications of the system and perturbations on that system are.

Wiegert:

125. Why is it that you seem to be talking about the separation. I don't think Ray's comments, while very good, were directed towards trying to separate hydraulic models from ecological models. An ecological model, if it's a system like an estuary, has to include hydrodynamics.

Robey:

126. Yes, it would be in there; the output of one is the input of the other.

Wiegert:

127. I'm not even sure it has to be that much separated.

Robey:

128. I'm pretty sure it would have to be, considering computer constraints.

Wiegert:

129. For example, I have things that are crude hydrodynamics in the model we've run, but in no sense of the word are they explicit; in other words we're not modeling water movement.

Robey:

130. Okay, that's what I'd be talking about doing or suggesting maybe the way to go.

Wiegert:

131. I'm not sure I'd really agree with that.

Robey:

132. The reason why I say that is because you probably would run various scenarios on the hydrodynamics just to see what's going on.

Robey:

133. In order to do sediment transport you have to have water movement, there's no doubt about that. From our standpoint, we need to do a good job defining circulation. I think we've got to do at least the full-blown route on the two-dimensional hydrodynamics. I believe we need both two-dimensional vertically integrated models and two-dimensional laterally integrated models; I can't imagine anyone studying the Savannah, especially the lower Savannah, without a two-dimensional laterally integrated model.

Reid:

134. These exist in a certain form. I would like to see us develop three-dimensional models that might be used in a two-dimensional mode. The reason I say that is that some of the physical phenomena that one would like to parameterize can only be properly handled in the three-dimensional sense. This again relates to the turbulence closure problem. One can still do quite a bit of good modeling with the two-dimensional model.

Lee Butler (WES):

135. As far as the three-dimensional modeling is concerned, at least from what I've seen in the literature, the problem we face right now is that we really don't have a computer that exists for you to do a practical three-dimensional problem in the brute force manner. I think if you have an infinite speed computer or something like that, one that's quite a bit faster, you can probably come up with a brute force way to solve the equations. Whether or not you can give it all the proper input and boundary conditions, that's another matter. I don't think it was clear in Peter Sheng's paper because of the short presentation time but he had one approach in terms of trying to limit the amount of time that is spent. In his hydrodynamics, he actually handles quite a bit of it

in an analytical way: in the sense of defining a potential function or stream function over the water body and then trying to analytically express the velocities in the horizontal and the vertical. So there may be ways that mathematicians come up with that may handle these kinds of problems, to do it right now with the equipment we have, a little more efficiently. In dealing with the two-dimensional models, I really see a limitation. You cannot handle the problem properly.

Reid:

136. I'd like to add some comments on that. Of course, there have been three-dimensional models run and it's a matter of degree as to how far you can go. You can go two layers, you can resolve it so much in the lateral and longitudinal, and you can do the deepwater work; the biggest model that I know about is 15 levels in the vertical with a 200-mile resolution over the whole northern hemisphere. This kind of thing (simulations for 200 years) has actually been run; if they can do this at the GFDL laboratory in Princeton, we ought to be able to do some minor scaled-down version of this for an estuary. But, the thing that I tried to point out earlier that we're beginning to recognize now in ocean modeling is that this may have been just an interesting academic exercise. The horizontal resolution was not sufficient to resolve the eddies that we know now have to be present to properly model what does go on. We're now turning to more horizontal resolution and less resolution in the vertical. You treat the vertical structure in at least three different ways. You can take "n" fixed levels, with dependent variables such as density or temperature and salinity and velocity, of course. Secondly, you can take "n" layers; this is inherently Lagrangian in the sense that you're looking at the layer thickness variation. There are some arguments to say that if you have limited resolution such as two levels or two layers, you ought to go to two layers. There are arguments both for and against saying that the fixed level model or the Lagranian model is better. I tend to prefer the Lagranian model. Thirdly, much more recently, although the concept has been around since Heap's work in England, you can take "n" modes in the vertical. Currently, people like Blumberg and Spaulding and others are using this sort

of approach in principle. What you're doing is solving for the barotropic mode, the first baroclinic mode, and perhaps the second baroclinic mode, and you use structure functions in the vertical to resolve the vertical distributions of variables.

Wanstrath:

137. One of the things that impressed me, whether it be two-dimensional in the vertical or two-dimensional in the horizontal, was that there was a great deal of structure and that you had to make some assumptions, whether it be an x-z or an x-y kind of simulation, where you automatically threw out the other dimension. The thing that struck me throughout the presentations on the physical field experiments was that the areas where you would think it would be homogeneous with a nominal amount of wind, where you might say I could use two-dimensional theory here, you could never prove it. You can never go out in the field and verify it; you'd just likely go ahead. But, there was detail structure there (that didn't seem overlooked) in either application. It goes back to wind scales again, your very opening remark, the length and time scales. It doesn't appear that in the headlands where you would think river, no matter how poor the flow, would be so dominant that there would not be a reversal at slack water between the flood and the ebb. But it was clearly in most of the pictures of the presentations that, where the tide reversed, the system just continuously took a multi-level approach. Just one example, that it would be totally overlooked and would give erroneous results if you put in some kind of a chemical constituent at the top and one that would propagate throughout the water column, it would be hopelessly in error. You would have spent a lot of money in designing the experiments and trying to do testing and you would never get close to the proper decisionmaking answer. I think it goes back to looking at windscales again. I don't think we've ever addressed the basic residence time.

Unknown:

138. You're talking about experimental work and that is indeed true. One thing I wanted to mention was that oftentimes when data are limited, modeling and laboratory experiments can make the results fairly

rapidly usable. For instance, if you find yourself in a situation where casualty can be associated with rain, or a particular variable, you go out in the field and measure it. You may not know what that means in relation to other parameters, biological or otherwise. One perfect example is the work that's been done in the Great Lakes area and the experimental work that has been done in the field. There is a lot of work that has been done experimentally in the laboratory, also, and they've worked with the system and normalized constants and a large number of factors, then observed the effects of variation on one parameter. You then readjust your baseline to see if there is interaction between the baseline parameters. I think there's a lot to be said for that method; that's the thing to go along with mathematical modeling techniques; the two really go hand-in-hand. One can look at possible relationships via the models and through experimental work to be able to calibrate your models to some extent. I don't think an ecological model can be used in a predictive mode right now in any system.

Nixon:

139. I agree with you completely. We ought to emphasize again here one of the things that I think Saul was saying before, that the purpose of the larger scale models is to go back and forth iteratively between the research and the models. This is what Dick has been emphasizing in the Georgia model. I'm not really sure what's become of the experimental aspect of the Georgia program with the diked marshes and all, but there was at least potentially a really nice opportunity for trying to put experimental things and manipulations together with the modeling work. We can take all the CLEANER models and all the ecosystem models of lakes in the world and put in the Michaelis-Menton kinetics for phosphorous dynamics in lakes and we could go around from now until doomsday arguing over whether phosphorus was limiting or not. It's sort of like lifting the sword out of the rock--you draw a curtain across the lake, as Dave Schindler did, and one side of the lake you throw in nitrogen and carbon and in the other side you add phosphorous. One side becomes bright green and the other side doesn't do anything. There's just no substitute for data. But the modeling is useful.

George Gardner (University of Washington):

140. Everything you've said about biological models is true. Every estuary is different both biologically and physically and I don't think you can ask what's the best general purpose biological model. You have to look at the specific question about the specific estuary and understand that these biological processes are important enough to affect the ecosystem and make a reasonable judgment based on what models are available, understanding of the physics of the model, and using what set of models can give the best answer. Go out and, with a limited budget on your field program, verify the model. In our work in the Duwamish, that's what we set out to do with our preconceived ideas on physical process. That turned out to be completely wrong. We found that there were processes there that no one had ever described, and there's no guarantee that that won't happen again. So even if you have inferences in physics to work from, we are still in the same boat as biologists when we try to model physical systems.

Saila:

141. The point that I would like to made is that there is an optimum way at least to gather your data in both space and time. If you define the accuracy and precision required, a statistician can tell you how to most effectively sample to get that data. I think perhaps we should keep that in mind, that if the data collection is five times more expensive than the modeling, let's do the data collection in some cost-effective way as well.

PART IV: RECOMMENDATIONS

142. To the reader who is familiar with recommendations put forward by other recent symposia on estuaries,*,** the conclusions of this section will not be surprising. The recommendations, given below, concentrate on the understanding of fundamental processes in estuaries and wetlands and advocate a multidisciplinary systems approach to research studies. Even though the conclusions arrived at during this study are similar to earlier studies, they should have additional weight because they are based, in part, on the practical problems experienced by the District Offices of the CE. It is apparent that lacking knowledge of how fundamental processes affect estuaries and wetlands hampers the CE from making predictions of the effects of various CE activities in the coastal zone. For example, it is difficult to predict, even qualitatively, the effect on an estuarine ecosystem of filling part of a bay with dredged material to create a salt marsh, without some knowledge of nutrient cycling between marsh and the estuary or the amount of detritus imported from the marsh during a tidal cycle or storm event. Monitoring programs are of little use if the processes which should be monitored are not properly defined in terms of their time scales and effects. This is not to say that some management problems cannot be tackled with existing techniques because experiments and models can be designed to give answers to some specific questions concerning the ecosystem at the present time. The main recommendations are for long-term research which eventually would put complex management decisions on firmer scientific footing. Specific recommendations arising from the survey of CE coastal offices and the workshop conclude this section.

---

* National Academy of Sciences. 1977. Estuaries, Geophysics and the Environment, Washington, D.C.

** Kjerfve, B. ed. 1978. Estuarine Transport Processes, University of South Carolina Press, Columbia, S.C.

Estuarine and Wetland Processes

143. The main recommendations can be divided into two basic, though interrelated, parts. The first basic recommendation concerns the importance of understanding the complex geophysical, geochemical, and biological processes which occur in wetlands and estuaries. The ultimate goal of applied research is the ability to predict changes which are a consequence of natural or man-induced perturbations to the system. For a model to make satisfactory predictions, it is necessary to model the processes correctly. A number of these processes require additional study and are noted below.

Turbulence

144. Perhaps the most difficult and, at the same time, most fundamental problem is that of understanding turbulent processes in estuaries. Mixing of mass and momentum due to turbulent eddies occurs on very small time and length scales. Turbulent mixing affects all substances in estuarine waters and recent studies have shown that complex channel topography and secondary circulations profoundly influence turbulent processes. The distribution of turbulent processes in the bottom boundary layers is fundamental to the transport, deposition, and resuspension of sediment. The movement of sediment grains in turbulent flows is a very difficult problem and has received relatively little study. The transport of sediment is important from a pollution point of view in that many heavy metals and other toxicants attach readily to sediment particles.

Transient events

145. Larger scale transport processes, as has been realized relatively recently, are greatly affected by transient events such as storms. For many systems, these events represent a primary cause of large transports and exchange of salt, sediment, nutrients, biomass, etc., in the wetland/estuary system. Much additional work is required to resolve the magnitude and frequency of these events and their resultant impacts. In this context, little study has been made of the hydrodynamics of very shallow creeks and irregularly inundated wetland areas. There is some

evidence that major exchanges between the marsh and the estuary occur during storms. The impact on biological and chemical processes of an influx of a large amount of detritus and organic load needs to be evaluated as does the effect of storm surges on wetland productivity.

Biochemical processes

146. The complex, highly dynamic nature of estuaries and wetlands means that understanding is needed of biological and chemical pathways, and rates of reaction and interaction need to be well defined if the structure of the ecosystem is to be elucidated. For example, the pathways of heavy metals in the system and the interactions with organic and inorganic material in the water column and in the sediments are not well understood. Pollution caused by toxic materials can have disastrous consequences for the ecosystem, particularly from the fishery point of view.

Multidisciplinary Systems Approach

147. The understanding of fundamental processes has been emphasized above. However, each process should not be considered in isolation, but considered in the context of the total ecosystem. This naturally leads to the systems approach to planning and executing long-term research programs. This is especially important if a modeling program for an estuary is to be initiated. Models of any system or part of a system should not be developed in isolation. They require appropriate field measurements for verification. More importantly, the interactive process of building models and executing field programs, which in turn leads to improvements in the models and will suggest more appropriate measurements and sampling schemes, leads to better understanding of the total system.

148. It is noted that the most scientifically significant modeling efforts in recent years have been conducted in places where there has been a coordinated, comprehensive program, directed at one particular ecosystem, carried out by a fairly large number of researchers. Two examples are Narragansett Bay and the Sappelo Island salt marshes.

149. These kinds of efforts are relatively rare, but similar

long-term, comprehensive studies should be planned so that a variety of different types of estuaries and wetlands are studied. Every effort should be made to develop interdisciplinary programs because nearly all the processes interact in some way, with physical processes and circulation being fundamental to the other disciplines.

150. Activities of the CE primarily alter the hydrodynamic system in estuaries and wetlands by altering freshwater inflow, dredging, channelization, construction of harbors and shore protection structures, and the creation of intertidal marsh. Prediction of the effects of these activities on the physical regime is of primary importance, and the techniques for doing this are the most advanced. However, since changes in the dynamics also may alter sediment transport, biological and chemical processes, and fisheries, it is evident that these areas must not be neglected in favor of hydrodynamic studies. This is the main reason why a multidisciplinary approach to long-term studies of fundamental processes is recommended.

Specific Recommendations

151. This final section is devoted to specific recommendations concerning CE activities in estuaries and wetlands. The survey of the coastal offices, the literature review, and the workshop have all been taken into account and the important problems, for which adequate techniques appear to be lacking, are noted below.

Wetlands

152. In certain parts of the country (the west coast, the northeast coast) certain types of wetland (infrequently flooded marshes and mangrove swamps) have had little study, and it is important that these areas be characterized in terms of physical, chemical, and biological structure and basic processes including primary productivity.

153. More specific problems are the need to assess (a) the impact of assimulation of effluent (from diked impoundments and dredged material disposal) on the salt marsh; (b) the role of buffer regions, such as saline flatlands in Texas, in maintaining the health of wetland ecosystems;

and (c) the effects of stresses in the wetlands such as platforms and highway bridges.

154. The use of experimental microcosms in conjunction with ecosystem models could provide much useful information on the complex biological and chemical processes which occur in wetlands. A microcosm can be subjected to experiments rather more easily than a natural marsh and thus may provide better tests of whether the processes are correctly modeled.

Marsh-estuarine coupling

155. To be able to assess the effects on estuarine water quality and ecosystems by creating marshes using dredged material or by promoting delta growth, it is necessary that import/export relationships between the marsh and the estuary be properly characterized. The importance of modeling the hydrodynamics of shallow creeks and marshes should be stressed and the impact of storm events and extremes of freshwater flow also should be investigated.

Estuaries

156. Most of the important research needs, including improved modeling, turbulent studies, and transient events, are part of the long-term recommendations above. Specific problems concern the cumulative impact of deadend canals, small boat harbors, and marinas on water quality of estuaries. Design techniques which aid the flushing of these small-scale systems are also needed. Models addressing the effects on water quality due to dredging and disposal of sediments, particularly if they are polluted, should be developed.

General

157. The CE should consider having contract reports, particularly if they involve complex models, externally reviewed, primarily to ensure that limitations and shortcomings of the studies are adequately spelled out. Contracts for the application of existing models to a system should include some funds for further development and improvement of the models based on the experience gained during the contract.

158. Finally, there is a need in some CE District Offices to modernize methods of storing and handling data and literature for environmental assessments.

Problem Summary and Recommended Studies

159. Problems identified during this study are summarized below:

- a. Techniques are needed to predict the effects of Corps of Engineers activities on the hydrodynamics, dissolved and particulate transport, biological and chemical processes, and biota in coastal environments. Corps of Engineers activities include construction, channel deepening and widening, island creation, and upstream projects leading to changes in freshwater flows.
- b. Selected marsh/estuarine areas need to be characterized in terms of physical, chemical, and biological structure and chemical and biological processes. Specific areas identified include the west and northeast coasts, infrequently flooded marshes, mangrove swamps, and buffer areas such as the saline flatlands of the western gulf. Included in the characterization would be a uniform methodology of classification and a means to assess the value of the wetland to the total ecosystem.
- c. The types and magnitudes of stresses the marsh/estuarine ecosystem may be subjected to in terms of structual stability and deviations in the rates of selected chemical and biological processes need to be determined. Included would be estimation of the assimulative capacity for effluents from diked impoundments, dredged material disposal sites, storm runoff, and agricultural runoff. Indices of structure and processes include fish and invertebrate nursery grounds, fish production, water quality, and import/export realtionships of nutrients and detritus.
- d. Techniques to evaluate the cummulative impacts of deadend canals, small boat harbors, and marinas on the adjacent coastal ecosystem need to be developed. Procedures are needed to assess the magnitude of perturbation of water quality due to point and nonpoint sources of contaminants entering the canals and small harbors. Design criteria to minimize adverse water quality degradation within the canals and harbors and in the adjacent ecosystem need to be formulated.

e. An increased understanding is needed of the process of marsh creation through deltaic growth including habitat creation and species succession.

160. Specific research studies are summarized below:

a. Turbulent processes in estuaries need increased understanding.

b. Wind and thermal forcing through boundaries and wind waves need additional study.

c. Modeling barriers and subgrid phenomena need increased development.

d. A more detailed understanding of the hydrodynamics of very shallow coastal waters including sheet flow in marshes, flow in very shallow channels, sediment transport, periodic inundation, and the relationships of residence time to winds, tides, and freshwater inflow and rainfall is needed.

e. Existing hydrodynamic models need to be extended by including selected water quality parameters in advection-dispersion equations. Priority of inclusion is salinity, temperature, dissolved oxygen, nutrients, phytoplankton, and toxicants.

f. Material budget analyses of irregularly flooded marshes need to be conducted.

g. Identification and quantification of biological and chemical pathways and reactions need more extensive study. Included is the evaluation of the effects of transient events such as storms, surges, and extreme freshwater flows on estuaries, wetlands, and their import/export relationships.

APPENDIX A: CALL FOR PAPERS

Call for Papers

WORKSHOP

WETLAND AND ESTUARINE PROCESSES AND WATER QUALITY MODELING

The U. S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, is sponsoring a workshop on wetland and estuarine processes and their relationship to mathematical water-quality modeling. The workshop will be held

June 18-20, 1979
New Orleans, Louisiana

The objective of the workshop is to assess our present understanding and ability to quantify important wetland and estuarine processes. Topics to be discussed include estuarine circulation, sediment, transport processes, and biological and chemical aspects of wetland-estuarine coupling. The ability to mathematically model these complex systems will be the workshop theme with emphasis on water quality.

Attendees will be limited in number in order to promote exchange of ideas in a workshop setting. Interested persons are invited to submit presentations of recent research, both theoretical and experimental, which fit the objective of the conference. Abstracts must be submitted for review by March 16. Notification of paper acceptance will be provided by April 6. Accepted papers will be allotted 20 minutes with an additional 10-minute discussion period. Proceedings of the workshop will be published. Manuscripts will be required to be submitted to the organizers by May 25. The workshop will include invited review papers by eminent specialists.

Abstracts of papers should be submitted to:

Dr. Peter Hamilton
SCIENCE APPLICATIONS, INC.
4900 Water's Edge Drive, Suite 255
Raleigh, NC 27606

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Hamilton, Peter
  Marine wetland and estuarine processes and water quality modeling; workshop report and recommendations / by Peter Hamilton, Science Applications, Inc., Raleigh, N. C. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.
  116, 2 p. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; EL-80-3)
  Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Contract No. DACW39-78-C-0087.
  Includes bibliographies.

1. Ecosystems. 2. Environmental effects. 3. Estuaries. 4. Marine wetlands. 5. Salt marshes. 6. Water quality models. 7. Wetlands. 8. Workshops. I. Science Applications, Inc. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; EL-80-3.
TA7.W34m no.EL-80-3