RESULTS OF A MODELING WORKSHOP CONCERNING ECONOMIC AND ENVIRONMENTAL TRENDS AND CONCOMITANT RESOURCE MANAGEMENT ISSUES IN THE MOBILE BAY AREA

David B. Hamilton
Austin K. Andrews
Gregor T. Auble
Richard A. Ellison
Richard A. Johnson
James E. Roelle

U.S. Fish and Wildlife Service
Fort Collins, Colorado

and

Michael J. Staley

Environmental and Social Systems Analysts Ltd.
Vancouver, B.C. Canada V5Z 1G6

Western Energy and Land Use Team
Office of Biological Services
U.S. Fish and Wildlife Service
2625 Redwing Road
Fort Collins, Colorado 80526

EXECUTIVE SUMMARY

During the past decade, the southern regions of the U.S. have experienced rapid change which is expected to continue into the foreseeable future. Growth in population, industry, and resource development has been attributed to a variety of advantages such as an abundant and inexpensive labor force, a mild climate, and the availability of energy, water, land, and other natural resources. While this growth has many benefits for the region, it also creates the potential for increased air, water, and solid waste pollution, and modification of natural habitats.

A workshop was convened to consider the Mobile Bay area as a site-specific case of growth and its environmental consequences in the southern region. The objectives of the modeling workshop were to: (1) identify major factors of economic development as they relate to growth in the area over the immediate and longer term; (2) identify major environmental and resource management issues associated with this expected growth; and (3) identify and characterize the complex interrelationships among economic and environmental factors. This report summarizes the activities and results of a modeling workshop concerning economic growth and concomitant resource management issues in the Mobile Bay area.

The workshop was organized around construction of a simulation model representing the relationships between a series of actions and indicators identified by participants. The workshop model had five major components. An Industry Submodel generated scenarios of growth in several industrial and transportation sectors. A Human Population/Economy Submodel calculated human population and economic variables in response to employment opportunities. A Land Use/Air Quality Submodel tabulated changes in land use, shoreline use, and air quality. A Water Submodel calculated indicators of water quality and quantity for fresh surface water, ground water, and Mobile Bay based on discharge information provided by the Industry and Human Population/Economy Submodels. Finally, a Fish Submodel calculated indicators of habitat quality for finfish and shellfish, utilizing information on water quality and wetlands acreage.

The workshop was successful in identifying many of the critical interrelations between components of the Mobile area system. Not all of these interactions, such as the feedback of air quality as a limitation on development, could be incorporated in the workshop model because of the model's broad spatial scale and because of uncertainties or data gaps. Thus, the value of the modeling workshop was in the areas outlined below, rather than in the predictive power of the initial model developed at the workshop.

First, participants developed a holistic perspective on the interactions which will determine future economic and environmental trends within the Mobile Bay area. Potential environmental consequences and limitations to growth identified at the workshop included: shoreline and water access; water quality of Mobile Bay; finfish and shellfish habitat quality with respect to dissolved oxygen and coliforms; air quality; and acreage of critical wetland habitat. Second, the model's requirements for specific, quantitative information stimulated supporting analyses, such as economic input-output calculations, which provide additional insight into the Mobile Bay area system. Third, the perspective of the Mobile area as an interacting system was developed in an open, cooperative forum which may provide a foundation for conflict resolution based on common understanding. Finally, the identification of model limitations and uncertainties should be useful in guiding the efficient allocation of future research effort.

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Benson, Norman
National Coastal Ecosystems Team
USFWS, NASA/Slidell Computer Center
1010 Gause Blvd.
Slidell, LA 70458
(504) 255-6511 FTS 685-6511

Blancher, Don
Marine Environmental Sciences Consortium
P.O. Box 369-370
Dauphin Island, AL 36528
(205) 861-2141

Blood, Jeffrey H.
Director of Development
Baldwin County Commission
P.O. Box 148
Bay Minette, AL 36507
(205) 937-9561

Bradley, Paul
ATTN: PD-EE
U.S. Army Corps of Engineers
Mobile District
P.O. Box 2288
Mobile, AL 36628

Burns, Jerry
Alabama Coastal Area Board
P.O. Box 755
Daphne, AL 36526
(205) 626-1880

Crozier, George
Director
Marine Environmental Sciences Consortium
P.O. Box 369-370
Dauphin Island, AL 36528
(205) 861-2141

Duncan, Joseph R.
Environmental Engineering Consultant
White, Lynn, Duncan and Assoc., Inc.
219 W. Alabama Street
Florence, AL 35630
(205) 766-1051

Friend, John H.
Management Consultant
Suite 2212
First National Bank Bldg.
Mobile, AL 36602
(205) 432-3158

Hackney, Ted
Mobile Area Chamber of Commerce
P.O. Box 2187
Mobile, AL 36652
(205) 433-6951

Hammer, Richard M.
Continental Shelf Associates, Inc.
P.O. Box 3609
Tequesta, FL 33458
(305) 746-7946

Helis, James
MOEPSI
1250 Poydras Building
New Orleans, LA 70113
(504) 566-5244

Hosking, William
Sea Grant Advisory Service
3940 Government Blvd., Suite #5
Mobile, AL 36609
(205) 661-5004

Jones, Myrt
President, Mobile Bay Audubon Society
724 Brannon Court
Mobile, AL 36609
(205) 666-2476

Kirkwood, James B.
Coastal Ecosystems Activity Leader
USFWS
75 Spring Street SW
Atlanta, GA 30319
(404) 221-6343

Klotz, Paul
Regional Environmental Coordinator
Betz•Converse•Murdock•Inc.
P.O. Box 1784
Mobile, AL 36633
(205) 433-3981

McDonald, Cameron
Assistant Director for Project Development
Alabama Department of Energy
25 Washington Avenue
Montgomery, AL 36130
(205) 832-5010

McErlean, Andy
Deputy Director
USEPA Environ. Res. Lab
Gulf Breeze, FL 32561
(904) 932-5311

McPhearson, Merrill
USPHS/FDA
Dauphin Island, AL 36528
(205) 861-2962

Merrihew, Larry
Merchants National Bank
P.O. Box 2527
Mobile, AL 36622
(205) 690-1594

Pearson, Joe
Mobile United
P.O. Box 1243
Mobile, AL 36633
(205) 432-1638

Roth, Robert
USEPA - Region IV
345 Courtland St., NE
Atlanta, GA 30365
(404) 881-3776

Savage, Tim
Alabama Coastal Area Board
P.O. Box 755
Daphne, AL 36528
(205) 626-1880

Sheppard, Gene
Environmental Manager
Degussa Corp.
P.O. Box 606
Theodore, AL 36590
(205) 653-7933

Smith, Everett
Geological Survey of Alabama
P.O. Drawer O
University, AL 35486
(205) 349-2852

Smith, Hattie L.
Exec. Vice President
So. Baldwin Chamber of Commerce
P.O. Box 1117
Foley, AL 36536
(205) 943-3291

Smith, John H.
Mayor
City of Prichard
Prichard, AL 36610
(205) 457-7605

Tatum, Walter M.
Chief Marine Biologist
Department of Conservation
and Natural Resources
P.O. Drawer 458
Gulf Shores, AL 36542
(205) 968-7575

Thornhill, Tom
USFWS
NSTL Station, MS 39529
(601) 688-3500

Willis, William
Director, Environmental Health
Admin.
State Health Office
State Office Bldg.
Montgomery, AL 36130
(205) 832-3176

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INTRODUCTION

During the past decade, the southern region of the U.S. has experienced rapid growth which is expected to continue into the foreseeable future. To help identify and assess long-term economic and environmental trends and concomitant resource management issues likely to face this region, the U.S. Environmental Protection Agency (EPA) funded the Southern Regional Environmental Assessment (SREA) through their Office of Strategic Assessment and Special Studies. Conducted by the Science and Public Policy Program, University of Oklahoma, the SREA is intended to provide information for both short-term policymaking and long-term research and development planning through a series of regional and representative site-specific analyses. One of these site-specific analyses concerns the Mobile Bay area of Alabama.

The Mobile Bay area has played a prominent role in the history, growth, and economic development of the Northern Gulf Coast. The bay serves coastal area residents and inland areas in a variety of ways. The Port of Mobile provides major commerce on a world-wide basis and is rapidly expanding and modernizing port facilities to prepare for anticipated demand. Its geographical position provides easy access to the sea, and a potential new access to the U.S. interior upon completion of the Tennessee-Tombigbee Waterway. The developed lands adjacent to the bay and the lower Mobile River and its tributaries serve as the location for economically important industrial, commercial, and urban development. In addition, navigation, sport and commercial fishing, and recreational boating are important uses of Mobile Bay.

The bay, through its natural function and the design of man, also serves as a repository for municipal and industrial effluents and urban and agricultural runoff. As growth and economic development continue, competing uses of the water resources, associated wetlands, and adjacent lands may cause ever-increasing stresses on the bay's environment. Effective management should delineate these competing economic and environmental forces, assess the demands and needs for this water resource, and formulate plans which will, to the maximum extent feasible, protect the natural qualities of the area while responding to the needs and problems related to economic growth.

OBJECTIVES

The purpose of the Mobile Bay workshop was to bring together a balanced group of experts, representing a broad range of interests, to address the following objectives:

(1) identify major factors of economic development as they relate to growth in the area over the immediate and longer term;

(2) identify major environmental and resource management issues associated with this expected growth; and

(3) identify and characterize the complex interrelationships among economic and environmental factors.

The workshop, held November 2-6, 1981 in Gulf Shores, Alabama, was facilitated by staff of the Adaptive Environmental Assessment Group of the Western Energy and Land Use Team, U.S. Fish and Wildlife Service. Workshop participants included representatives from Federal, State, and local government agencies as well as industrial, commercial, and environmental interest groups. This report is a synthesis of workshop activities and results.

THE ADAPTIVE ENVIRONMENTAL ASSESSMENT METHODOLOGY

The Adaptive Environmental Assessment (AEA) process is a systems analysis tool for cooperative assessment of complex resource issues. It promotes integrated, balanced, front-end planning and management with direct participation of Federal, State, and local agencies and public interest groups. Developed by the International Institute for Applied Systems Analysis (IIASA), in Laxenburg, Austria, and the Institute of Animal Resource Ecology at the University of British Columbia, the AEA approach is organized around a series of highly structured modeling workshops alternating with periods of research and analysis.

AEA is based on three principles addressing the problems encountered with other environmental assessment techniques. First, participants drawn from key agencies and interest groups, who collectively represent a relevant range of scientific expertise, management responsibility, and decisionmaking authority, are brought together in interdisciplinary workshops during the early stages of planning. Representation of all interest groups insures balanced consideration of issues relevant to all affected interests and produces analysis results which are responsive to policymakers' needs. In addition, potential conflicts between groups can be identified at an early stage in planning, thus increasing opportunities for their resolution well before deadlines for important decisions. Second, computer simulation modeling and other systems analysis techniques are used to promote communication and coordination among workshop participants, to limit the scope of the environmental assessment to relevant factors affecting the target decision, to synthesize existing information to identify important gaps in data and conceptual understanding of the resource system necessary for making an informed decision, and to assist in predicting potential consequences of various management alternatives as a basis for designing balanced management strategies. Third, monitoring programs can be designed and analysis of results continued so that actual impacts are tracked and management strategies adjusted as unexpected impacts occur.

The focus of an initial AEA workshop, such as the one described in this report, is the construction of a quantitative, dynamic simulation model of the system under study. Early in an assessment the process of building a model is usually of greater benefit than the model itself. Development of a simulation model provides a framework for integrated discussion of a resource issue which enables participants to view their expertise in the context of the whole system, thereby promoting interdisciplinary communication and understanding. The fundamental value of focusing attention on the interrelationships and indirect connections between components of a resource system is that these connections often represent the points at which various agencies and interests must interface in their attempts to deal with the complexities of the resource issue. Also, in building a simulation model, participants are forced to be precise about their assumptions. Conceptual uncertainties about system

behavior are objectively exposed, and questions that must be addressed in order to understand system responses to resource development projects are identified.

An initial modeling workshop thus provides a good beginning to an environmental and economic development analysis. If appropriate, subsequent workshops and research periods can be used to develop a technically refined simulation model useful for exploring potential impacts of various resource development or management alternatives.

BOUNDING THE WORKSHOP MODEL

Resource development issues often involve complex interactions among a variety of economic, social, and environmental factors. While some individual components of such a resource system may be well understood, the complexity of component interactions generally results in poor understanding of the system as a whole. Simple representations of resource systems can provide valuable insight and understanding of system behavior under different management or development alternatives; they may not provide sufficient detail and credibility for actual resource development decisions. The representation of the resource system used in an analysis must therefore be sufficiently detailed and flexible to address all concerns adequately, yet must remain simple enough to be understandable. Problem simplification is stressed in the early phases of the AEA process to provide better understanding; addition of realistic complexity is stressed in later phases to provide a level of detail consistent with management and decision needs.

The process of simplificaton, or bounding, was initiated in the workshop by describing management alternatives (actions), identifying performance measures (indicators) used to evaluate the effects of those actions, and putting the actions and indicators in a manageable spatial and temporal framework.

ACTIONS

Actions identified at the Mobile Bay workshop were organized into the groups that eventually became the major components of the simulation model (Table 1). The majority of these actions describe potential industrial developments and land use changes.

Table 1. Actions identified at the Mobile Bay workshop.

Model component	Action
INDUSTRY	Dredging and spoil disposal Port construction Oil and gas development Theodore Industrial outfall Tennessee/Tombigbee Waterway Mobile Harbor Project Build off-shore port[a] Recycle solid wastes[a] Construct pipelines Deep well injection[a] Construct marsh/wetlands Sewage treatment facilities Increase coal handling facilities Hazardous waste transport and disposal[a] Build power plants[a]
HUMAN POPULATION/ECONOMY	Housing development Increase services Control non-point source runoff
LAND USE/AIR QUALITY	Change land use regulations Change air quality regulations Better control of solid waste disposal[a] Protect prime farmland Increase waterfront access[a] Purchase wetlands (e.g., Dauphin Island) Control non-point source pollution
WATER	Line drainage ditches Straighten river channel
FISH[b]	Regulate commercial harvest[a] Regulate recreational harvest[a]
OTHER ACTIONS	Implement conflict resolution forum for permitting[a]

[a]Not addressed in model because of lack of information, lack of time, or because it was deemed of only minor importance.

[b]Includes both finfish and shellfish.

INDICATORS

Indicators are defined as those measurements used to evaluate the performance of a system. They are the links between the simulation model and the participants' perceptions of the system. It is important to compile a comprehensive set of indicators representing the interests of all participating agencies and groups because individuals have different perceptions as to what is important in the system. A comprehensive list ensures that the model is relevant to the concerns of all participants. Most of the indicators identified at the workshop represent potential effects of development on the local economy, population, and aquatic resources (Table 2).

SPACE

Two aspects of space are usually defined for the purposes of simulation modeling. First, the boundaries of the total area to be represented in the model must be specified, and second, the degree of resolution or number of smaller subunits to be considered within the overall boundaries.

It was decided that the total area to be represented would include Mobile and Baldwin counties, and Mobile Bay (Fig. 1). The terrestrial portion of this area was subdivided into the two counties because participants were interested in differences in development and effects between the counties and because most of the relevant data were on a county basis. Mobile Bay and the Mobile-Tensaw Delta were subdivided into seven areas (Fig. 1), as a first approximation, to represent water quality differences in the bay. East-west dividing lines were placed at the city of Mobile, the mouth of the Dog River, and the mouth of the Magnolia River. The north-south dividing line followed the dredge spoil bank on the east side of the navigation channel. Participants agreed that a much finer spatial resolution would be required for detailed water quality modeling but felt the seven-subunit resolution was adequate for purposes of an initial workshop.

Table 2. Indicators identified at the Mobile Bay workshop.

Model component	Indicator
INDUSTRY	Dredge spoil land disposal and relative amount of current capacity used
	Capital investment
	Capital costs of permitting delays
	Industrial expansion due to Theodore outfall (addressed within total Mobile Company development)
	Coal and grain exports[a]
HUMAN POPULATION/ECONOMY	Human population size and density
	Level of employment
	Size of service industry
	Human health[a]
	Disposition of bay revenues[a]
	Recreational use
	Tourist dollars
	Flow of soft and hard goods[a]
	Housing starts
	Number of jobs by sector and type
	Number of new jobs
	Per capita income
	Income distribution[a]
	Crime and vandalism rates
LAND USE/AIR QUALITY	Acres of dunes, beaches, sensitive areas, wetlands
	Air quality
	Amount of construction in coastal areas
	Beach erosion[a]
	Land ownership[a]
	Historic sites preserved[a]
WATER	Water quality (salinity, temperature, dissolved oxygen, coliform, trace metals,[a] pesticides,[a] hydrocarbons,[a] suspended solids[a])
	Ground water quantity and quality
	Water use

Table 2. (continued)

Model component	Indicator
FISH[b]	Population sizes Benthic community structure[a] Commercial species Recreational species Threatened and endangered species[a] Harvest Contaminant levels Acres of grass beds, bay bottoms[a] Catch/unit effort
OTHER INDICATORS	Time required for permitting Permits granted Permits denied Industrial inquiries[a] Number of corporations moving into area[a]

[a]Not addressed in model because of lack of information, lack of time, or because it was deemed of only minor importance.

[b]Includes both finfish and shellfish.

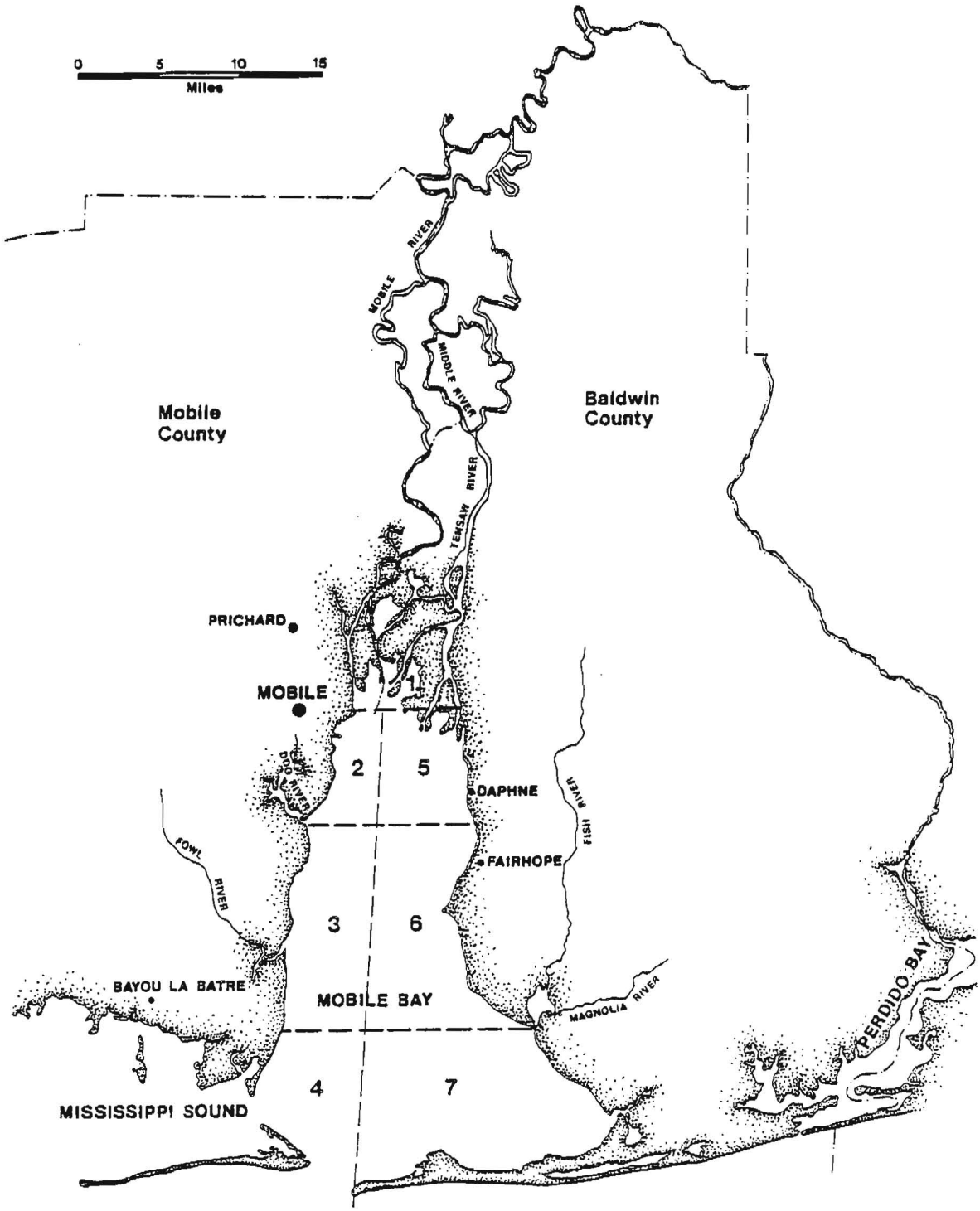

FIGURE 1. Geographic area considered in the Mobile Bay workshop model.

TIME

Two aspects of time must be considered in a simulation model: the time horizon or length of time for which model projections are desired, and the time step or interval between successive values throughout a given simulation.

A time horizon of 30 years was selected for the model. This time horizon was chosen because it corresponded to the EPA Southern Regional Environmental Assessment time horizon and because some projections of potential growth and development in the Mobile Bay area were available for this time period. The incremental time step proved to be more troublesome because relevant processes and data were at very different time scales. For example, human population growth and industrial development are often recorded as average annual growth or based on 5- or 10-year censuses and surveys, while water quality in Mobile Bay can change over a period of a few hours to a few days. An annual time step was eventually chosen for the workshop model; however, water quality calculations were made on a monthly basis corresponding to monthly data available at the workshop. Again, a finer resolution would be required for detailed water quality modeling but participants felt monthly calculations would provide a reasonable first approximation.

SUBMODEL DEFINITION

Based on the discussions of key actions and indicators, the Mobile Bay resource system was divided into five subsystems for more detailed discussion by subgroups of participants. Criteria for useful division of a system model into submodels at a workshop include:

(1) minimizing information transfers between submodels (each subgroup considers a relatively isolated part of the whole system);

(2) efficient allocation of participant expertise so that each submodel represents the concerns and expertise of a group of participants; and

(3) the purely practical consideration of fairly equal workloads for workshop facilitators so that participants have the opportunity to incorporate an appropriate amount of depth in their area of expertise.

After considerable discussion, the following major components (submodels) were selected:

(1) Industry - industrial development (and its consequences) and channel dredging;

(2) Human Population/Economy - human population growth and changes in local economy;

(3) Land Use/Air Quality - changes in land use and air pollution;

(4) Water - water quality and quantity of fresh surface water and groundwater, and Mobile Bay water quality; and

(5) Fish - indicators of finfish and shellfish habitat quality.

SUBMODEL INTERACTIONS

Following submodel definition, workshop participants discussed the interactions between major components of the resource system by constructing a Looking Outward Matrix (Fig. 2). The submodels described above were arrayed as both row and column headings of a matrix. For each column of the matrix (i.e., for each component or submodel), participants were asked what they needed to know about all of the other components (i.e., row elements within that column) in order to predict how their component would behave under various development or preservation alternatives. In other words, they were asked to look outward at the ways in which other biological, social, and economic parts of the system affect their area of expertise. Note that this is a qualitatively different question than that which is usually posed in analyses where

From \ To	INDUSTRY	HUMAN POPULATION/ECONOMY	LAND USE/AIR QUALITY	WATER	FISH
INDUSTRY		Number of new jobs by industrial sector - management - skilled - semi-skilled - unskilled Wages paid Capital investment Dollars of output Sewage treatment capacity needed Freshwater requirements Volume of solid wastes produced	Acres of each land use type required for development Acres of wetlands required for dock expansion Acres of wetlands created Air pollutant emissions - NO_x - SO_x - TSP - hydrocarbons - photochemical	Volume of surface and groundwater withdrawals Volume of discharges to surface and groundwater Pollutant discharges to surface and groundwater - BOD - COD - trace metals Barge traffic on Tennessee-Tombigbee	Volume of dredged material Site of shipping channel
HUMAN POPULATION/ECONOMY	Workers available Time to process permits		Acres of each land use type required for development Air pollutant emissions - NO_x - SO_x - TSP - hydrocarbons - photochemical	Volume of surface and groundwater withdrawals Volume of discharges to surface and groundwater Pollutant discharges to surface and groundwater - BOD - COD - coliform	Human population size Demand for fish by species - commercial - recreational
LAND USE/AIR QUALITY				Runoff water quality - coliform	Acres of wetlands
WATER	Surface and groundwater available for withdrawal 7Q10 for major rivers Groundwater quality - salinity Annual sediment depth increment in bay	Surface freshwater quality - DO Groundwater quality - salinity - coliform Height of water table	Groundwater quality - salinity		Mobile Bay water quality - DO - fecal coliform - trace metals - hydrocarbons - salinity - pesticides
FISH	Location of oyster reefs	Number of commercial jobs Catch per trip Pleasure boat licenses	Acres developed for processing plants Acres developed for docks Acres of wetlands required to maintain fish production		

FIGURE 2. Workshop Looking Outward Matrix of information transfers between submodels.

experts are asked what information they can provide, rather than what information is needed.

Discussion of component interactions and identification of the information transfers in a Looking Outward Matrix is valuable in several ways. First, the exercise promotes interdisciplinary communication and broadens participants' understanding of the resource system of interest. Second, the Looking Outward Matrix lays the foundation for building a simulation model. Submodel construction is a process of quantifying how the information requested in the matrix affects the variables of a particular submodel. If sufficient information exists, such relationships can usually be formulated. If not, an information gap or research need is identified. Third, the resulting simulation model can be used to test the sensitivity of information transfers. Sensitive transfers can be noted for further, more detailed, investigation.

Specific information transfers within the workshop model are presented in the Looking Outward Matrix (Fig. 2). Elements on the main diagonal of the matrix in Figure 2 are crossed out because they represent the internal dynamics of the subsystems, which are described in subsequent sections on submodel structures.

SUBMODEL STRUCTURES

INDUSTRY SUBMODEL

Responsibilities

The Industry Subgroup was responsible for providing the structure and mechanisms to generate two types of information. One dealt with industry needs that must be met before development could occur. The remaining submodel output dealt with the results of industrial development. "Industry" for the purposes of this submodel referred to the following activities: chemical and petro-chemical production, oil and gas processing, ship building, dock expansion, power plants[1], and offshore port facilities[1].

The information requested by other subgroups to determine whether or not development could occur was facility site size (acres) and location, and amount of surface and groundwater (million gallons/day, mgd) needed by the operation[2]. Consequences of implementing the development used either by other submodels or by the workshop participants as indicators included: process water discharged (mgd); chemical oxygen demand (COD), biological oxygen demands (BOD), and trace metals[3] (tons/year) in discharged process water; air emissions (SO_x, NO_x, particulates, and hydrocarbons in tons/year); number of workers required for construction and operation[2]; size of shipping channel (length, width, depth in feet); number of barge trips/day[3]; dredge spoil site requirements (by habitat type and number of acres); amount of dredge spoil (million cubic yards/year); acres of wetlands created with dredge spoil; screening efficiency of water intake structures[2]; amount of solid wastes (million cubic yards/year)[2]; capital expenditures (cost of each facility and total costs); and the total costs of permitting delays.

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[1]Subgroup concensus was that this activity would not occur within the area of interest.

[2]Not used by requesting submodel, not included.

[3]Insufficient information available at workshop, not included.

The specific responsibilities listed above were designed to provide sufficient flexibility to simulate a broad range of development strategies. The three main features of the development scenarios were the type of development (port expansion, oil and gas processing, etc.), the amount of expansion of each type of development, and the timing of the developments.

Structure

If a facility was scheduled for development in the current year, the number of acres needed for a particular facility site was calculated by:

$$\text{NUMBER OF ACRES} = \begin{matrix}\text{ACRES REQUIRED BY}\\ \text{SMALLEST FACILITY}\end{matrix} \times \begin{matrix}\text{RELATIVE}\\ \text{SIZE}\end{matrix} \qquad (1)$$

The Land Use/Air Quality Submodel checked to see if there were sufficient acres available for the facility and returned a yes-no indicator. If the Land Use/Air Quality Submodel indicated that the facility could be developed; capital expenditures, numbers of construction and operations workers, amount of discharge water, and air and water emissions were calculated using the same approach described in equation (1). Values used to make these calculations are contained in Table 3. Capital costs of permitting delays were calculated by:

$$\text{COST} = \begin{matrix}\text{FACILITY CAPITAL}\\ \text{COSTS}\end{matrix} \times \begin{matrix}\text{NUMBER OF YEARS}\\ \text{DELAYED}\end{matrix} \times \text{PENALTY} \qquad (2)$$

The penalty was set at 0.15 for all model runs. The subgroup members estimated that 18 acres for roads would be required for each facility regardless of type. In addition, they estimated that each facility would need either 6 acres (Mobile County) or 4.5 acres (Baldwin County) for railroad right-of-way.

The submodel generated four types of dredge spoil depending on the development scenario. These were: maintenance spoil from the present 40-foot

Table 3. Industrial development characteristics used in the Mobile Bay workshop model.

Activity	Attributes for Small Facility												Ratio of Large to Small Facility
	Acres/ facility	Workers		Capital expenditures ($ x 10^6)	Emissions (tons/day)						Water (mg/d)		
		Construction	Operations		BOD	COD	SO_x	Particulates	NO_x	Hydrocarbons	Withdrawn	Discharged	
Chemical/petro-chemical	50	400	60	20	.038	.38	500	100	100	100	.75	.15	7
Ship building	10	15	25	.125	NA[a]	NA	NA	NA	NA	NA	0	0	4
Oil and gas processing	50	1000	70	500	NA	NA	900	0	900	0	.1872	0	1.36
Dock expansion (Tenn./Tom.)	200	200	1200	100	NA	NA	NA	NA	NA	NA	0	0	1
Dock expansion (55' channel)	1050	400	3000	175	NA	NA	NA	NA	NA	NA	0	0	1

[a] NA indicates not available.

channel, maintenance spoil from an expanded 40-foot channel, spoil from deepening the channel to 55-foot, and maintenance spoil from the 55-foot channel. Spoil was disposed of either by dumping in existing disposal sites and in the gulf, or by creating land fill for dock expansion and creating some wetlands (55-foot channel deepening only). No attempt was made to dispose of the dredge spoil in other habitat types when existing disposal sites were full. However, a record was maintained of the total spoil so that it could be compared with existing spoil disposal capacity.

Limitations. The major limitations of the Industry Submodel fall into three general categories: spatial resolution, water and air quality feedbacks, and water budgets. Although reasonable estimates of the type, characteristics, and timing of industrial growth are available, the fact that the growth will probably be limited because of diminishing suitable sites is poorly represented in the model because the selected spatial scale is too large. In spite of the fact that portions of Mobile County are currently unable to meet air quality standards, there was insufficient information available at the workshop (partially due to the spatial scale) to determine the impact of these criteria on additional industrial growth of any of the types represented in the model. Therefore, there was no feedback in the form of either denial of permission to build or a cost representation of required additional treatment of stack emmissions.

The problem of increased BOD and COD contributions from new industry was more complex. First, there was insufficient information at the workshop to estimate the cost of treating the additional load. Secondly, because of the spatial scale, it is unknown if local biological effects of discharges that meet existing standards would be serious enough to cause siting limitations. The subgroup participants recognized that solid waste disposal sites may eventually be a significant factor in determining the extent of industrial growth; however, this factor is not represented in the model because of uncertainty in how this would operate to limit industrial growth. The consensus of the subgroup was that there is currently a sufficient subsurface water supply for the projected growth in the Mobile area. However, concern was expressed

about increased saltwater intrusion into these aquifers. The subgroup participants decided that this was an area needing additional study, possibly on a site-specific basis. Water discharged from industrial operations would, at best, overload existing and proposed treatment facilities and, at worst, have unknown environmental effects if discharged into adjacent water bodies.

HUMAN POPULATION/ECONOMY SUBMODEL

Responsibilities

The Human Population/Economy Submodel was responsible for the calculation of the following variables: human population levels; employment rates; regional economics; government services; urban and recreational land use requirements; urban waste disposal; and indicators of the "quality of life". Unfortunately, not all of these calculations were included in the computer model. Some were left out due to constraints of time, data, and conceptual development.

The computer submodel did include population changes, employment rates, land uses, and waste disposal. Also, to a minor degree, some components of quality of life were calculated. Many economic indicators and government services (other than waste disposal) were not included in the model.

Structure

Human population dynamics. The major assumption of the human population model was that the number of primary jobs (industrial and tourist) in the Mobile Bay region determines all population processes. There are many difficulties with this assumption. However, this limited view of population dynamics was sufficient to predict a reasonably accurate trend in population, particularly under the conditions of significant industrial development which was the primary focus of the workshop.

In each year of simulation, the Industry Submodel calculated the number of primary jobs by county (Mobile and Baldwin) and by industrial sector. Each primary job in these industrial sectors generated additional employment in other industrial and service sectors of the two-county economy. An input-output technique was used to trace the industrial growth through the rest of the economy, and to estimate the multiplier effects associated with these primary jobs (Table 4). Total employment used in the simulation model was calculated by applying an employment multiplier to the number of jobs in the various sectors. Primary employment in other sectors was estimated initially and held constant, with a multiplier of 1.0, throughout the simulation. The input-output methods used in this exercise are described in more detail in the WORKSHOP RESULTS section of this report.

Table 4. Employment multipliers used in the Mobile Bay workshop model.

Industrial Sector	Employment multiplier
New construction	2.13
Chemical and petro-chemical	2.96
Shipbuilding	1.87
Oil and gas	3.25
Ten-Tom docks	3.02
Channel docks	3.02
Offshore terminal	3.10
Tourism	*
All other sectors	1.00

*Primary and indirect tourism jobs were calculated directly from tourist days.

Tourist jobs were estimated from tourism as a proportion of the number of tourist days:

$$\text{TOTAL JOBS DUE TO TOURISM} = 0.0037 \times \text{NUMBER OF TOURIST DAYS} \qquad (3)$$

The total jobs were then divided into skilled and unskilled categories. Data on these proportions were not available at the workshop so it was assumed that 85% of all jobs were for skilled workers.

Calculations of population growth and employment rates were done simultaneously. The number of skilled and unskilled jobs in the two counties was compared to the available labor force in the two counties and the following calculations were made:

(1) If the number of skilled jobs was fewer than the number of skilled workers then the workers were assumed to emigrate from the region.

(2) If the number of unskilled workers exceeded the number of unskilled jobs the workers were assumed to remain in the region and contribute to unemployment.

(3) If the number of skilled jobs exceeded the skilled labor force then the deficit was made up from two sources: immigration of skilled workers and/or training of local unskilled workers. (A parameter representing the proportion of the deficit to come from training was included in the model to represent policies affecting training programs.)

(4) If the number of unskilled jobs exceeded the unskilled labor force then unskilled workers were assumed to immigrate to the region to fill the jobs. The total population was then calculated by assuming an average labor force participation rate of 0.35.

Land use. All non-industrial land requirements were assumed to be proportional to the number of housing units, which in turn was proportional to population (3.7 people per unit). The land use requirements were calculated according to the following equations:

ACRES FOR HOUSING	=	0.400	x	NUMBER OF HOUSING UNITS	(4)
ACRES FOR COMMERCIAL AND SERVICE	=	0.043	x	NUMBER OF HOUSING UNITS	(5)
ACRES FOR RECREATION	=	0.650	x	NUMBER OF HOUSING UNITS	(6)
MILES OF SHORELINE FOR HOUSING	=	0.002	x	ACRES FOR HOUSING	(7)
MILES OF SHORELINE FOR RECREATION	=	NUMBER OF PEOPLE / 5280			(8)

There were no feedback mechanisms between land requirements and availability built into the model. It was assumed that population growth would not be constrained by the available land. If sufficient land was not available then the average density of people on the land would increase.

Wastes. Several types of urban waste were discussed in the workshop. However, only sewage was included in the model. It was assumed most sewage was treated and the plants operated "properly". Failures of the treatment plants due to accidents or flooding were handled by design of scenarios with altered discharge parameters.

The sewage treatment parameters assumed for the model were:

(1) 100 gallons per person per day total discharge;

(2) a BOD loading of 0.167 pounds per person per day; and

(3) coliform counts (MPN) of 200 cells per 100 ml at the treatment plant outfall.

Crime rate. One of the major social components of "quality of life" is the rate of crime. In the model it was assumed that the major determinent of crime was unemployment. A preliminary analysis of the relationship between crime and unemployment in Mobile County provided the basis for the hypothesis presented in Figure 3. It was clear that a more careful analysis of these data and an expansion of the determinants that affect crime are needed. For example, income distribution, the level of government services, and the occupational distribution of employment are all known to affect the rate of crime.

Limitations

Given the level of detail attempted in the workshop there are three main areas where the human population model is weak and further modeling work would be useful: regional income; government revenue and services; and indicators of the quality of life.

Regional income. If the Industry Submodel produced expenditures and wages by industry type then an income "input-output multiplier" similar to the employment multiplier could be used to calculate regional income. Furthermore, by combining the effects of employment and income an attempt could be made to predict income distribution, an indicator considered of important social consequence.

Government revenues. By making some simple assumptions about the contributions of industrial and urban development to regional income it might be possible to estimate changes in revenues to governments under different development scenarios and tax regimes.

Government services. It might also be possible to calculate the costs of services, such as safety, transportation, or utilities (water, sewage treatment) by assuming per capita requirements for each of these services.

Indicators of the quality of life. Much progress has been made recently on analytical methods for identifying and measuring the importance of specific elements of the quality of life. Population density, occupational categories, human health, recreational opportunities including public access to the Gulf

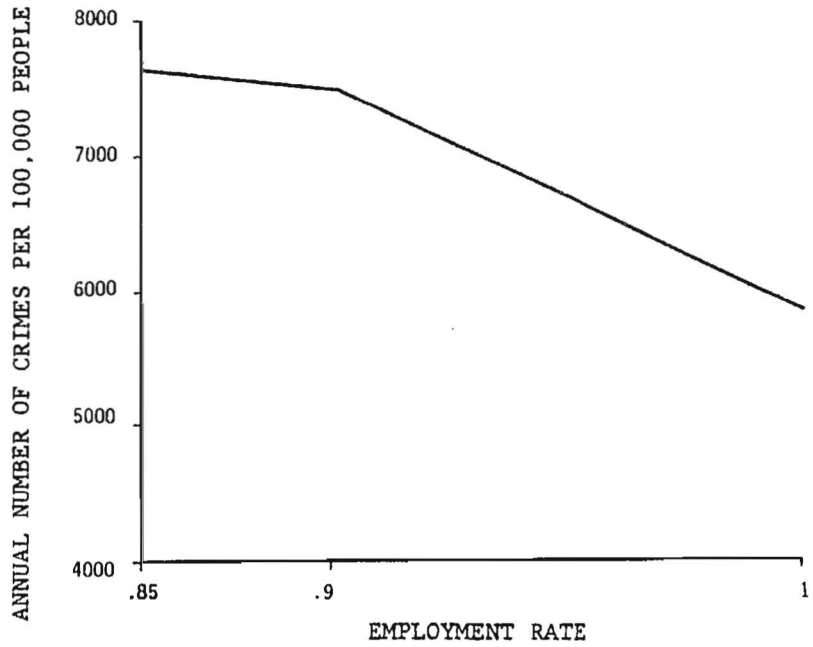

FIGURE 3. Assumed relationship between crime rate and employment rate.

and Bay, educational opportunities, income levels and income distribution, home ownership and new housing starts, and the availability of Government services have all been analyzed for the Mobile Bay area. More effort is needed to link these elements with other economic and ecological indicators so they can play a more meaningful and realistic role in simulation models intended to describe environmental and socioeconomic systems.

LAND USE/AIR QUALITY SUBMODEL

Responsibilities

This subgroup was broadly charged with representing changes in land use and habitat types, wildlife populations, and air quality. Time constraints limited what could be addressed at the workshop. The Looking Outward Matrix (Fig. 2) indicates that most of the information requested by other submodels from the Land Use/Air Quality Submodel concerned acres of land, either the current acreage in various land classification types or the acreage available for conversion to a new use. Thus, the subgroup focused on developing a land classification system and a set of rules to change the acreage in each land class in response to demands for land from the Industry and Human Population/ Economy Submodels. Because many of the land use problems and conflicts in the Mobile Bay area involve the coastal zone and access to water, a shoreline classification system was also developed. Demands for various shoreline types were evaluated in concert with demands for acreage to determine changes in land and shoreline.

Wildlife populations were not directly addressed. The changes in land and shoreline, which were modeled, represent broad changes in wildlife habitat. The translation of such changes to wildlife population dynamics would require a finer spatial resolution of habitat as well as an explicit treatment of mortality and reproduction for each population. This effort was not feasible at the workshop itself.

Air quality is a serious problem in the Mobile Bay area; all of Mobile County has been designated as a Primary Nonattainment Area for Photochemical Oxidants and portions of eastern Mobile County have been designated as Primary Nonattainment Areas for Particulates (Alabama Coastal Area Board 1980). Air quality is thus a potential limitation on growth in the Mobile Bay area, both through the general environmental quality and desirability of the area and, specifically, through administration of the Clean Air Act. The subgroup decided, however, that reasonable incorporation of ambient air quality indicators and the feedback effects of air quality on various types of growth was not possible within the scope of the workshop model. In large part this was

due to the spatial and legal complexities of air quality and air quality control. The approach taken was to simulate various loadings or emissions (SO_x, NO_x, particulates, hydrocarbons) over the broad geographical scale of the model. The broad air quality consequences - in terms of loadings - could thus be examined for a variety of growth scenarios. The role of air quality limitations in shaping various growth scenarios was not addressed.

Structure

Land classification. Land was classified as one of nine types. The types identified were mutually exclusive and exhaustive; any parcel of land would be included in one and only one classification type. The initial classification and subsequent changes considered Mobile and Baldwin Counties separately.

Industrial land was defined as acreage in industrial use including fish processing and ship building. The state docks were also included in this category. Swamp was defined as forested wetland. Marsh included all non-forested wetlands - fresh, brackish, and salt water. Agriculture/Forestry was land being used for agriculture or forestry.

Housing included the land associated with private dwellings, apartments, and condominiums. Commercial was land devoted to retail, wholesale, and financial activities. Services/Recreation was a diverse category including roads and railroads, communication facilities, utilities, government (excluding wetlands and state docks), cultural, entertainment, and recreational facilities (excluding wetlands). Businesses which were primarily a recreational service, such as a private marina, were classed as Service/Recreational. Vacant was private, undeveloped land (excluding Agriculture/Forestry and wetlands). Water was inland water bodies.

Initial conditions for the various land classes (Table 5) were estimated from a variety of reports and maps representing land use and type during the period 1975-1980. They should not be considered precise estimates; the

emphasis in the workshop was on consideration of the relationships which will determine changes over the next 20-30 years, not on a precise current description.

Shoreline classification. Much of the concern over potential environmental consequences of growth in the Mobile Bay area, and the competition for resources which will shape the pattern and direction of that growth, is concentrated in the coastal area itself. Land use conflicts among industrial, recreational, and housing demands are likely to be much sharper in the more desirable areas that provide access to the bay.

Table 5. Initial conditions of land classification in acres.

Type	Mobile County	Baldwin County
Industrial	4,800	600
Wetlands		
Swamp	7,400	164,500
Marsh	4,200	9,600
Agriculture/Forestry	530,300	722,100
Housing	35,200	9,700
Commercial	4,000	1,200
Services/Recreational	51,800	27,400
Undeveloped	66,900	74,900
Inland Water Bodies	22,300	46,500
Total	726,900	1,056,500

In order to represent this situation at the spatial scale of the workshop model, a shoreline classification system was developed. Shoreline was separated into Beach and Waterfront (all other shoreline). Five uses were then delineated in both counties. No distinction was made between public and private ownership within each use type although the problem of limited public access is important, especially in Mobile county. The initial conditions for the shoreline classification (Table 6) were determined by visual examination of maps in conjunction with subgroup participants' knowledge of the area.

Table 6. Initial conditions of shoreline classification in miles.

Use	Mobile County		Baldwin County	
	Beach	Waterfront	Beach	Waterfront
Housing	3	44	20	87
Commercial	1	8	2	6
Industrial/dredge disposal	0	13	0	0
Recreational development	1	0	5	7
Undeveloped	10	44	3	43
Total	15	109	30	143

Changes in land and shoreline. Demands for land and shoreline conversion were made each year by the Industry and Human Population/Economy Submodels. Demands for land and shoreline conversions by the Human Population/Economy Submodel were met from the undeveloped category, if possible. If insufficient land was available in the undeveloped category to meet total demand from both the Human Population/Economy and Industry Submodels, land was transferred from Agricultural/Forestry to undeveloped to allow the demand to be met. The amount transferred was 1.5 times the demand, accounting for a somewhat greater amount of land taken out of active production in a given year than would be effectively converted to land uses such as Housing or Industry in that same

year. Demands for shoreline conversions (Beach and Waterfront) from the Human Population/Economy Submodel were met from the respective undeveloped categories, if possible. If no Undeveloped Beach or Waterfront shoreline remained, demands were not met and no conversions took place. Demands for land and shoreline conversions from the Human Population/Economy Submodel were evaluated independently; the assumption was that if additional housing, for example, could not be located along the shoreline it would be located elsewhere.

Demands for land and shoreline from the Industry Submodel in a given year were evaluated in the same manner as demands from the Human Population/Economy Submodel, with the following exceptions:

(1) Land and shoreline requests were formulated for each of the industrial and transportation expansions considered. Sufficient land and shoreline had to be available to meet both the requests or neither of the requests was met for that activity in that year.

(2) Waterfront (non-Beach) was the only class of shoreline requested.

Subgroup participants felt that the best projection of future wetland losses (conversions from this type to another) was a small, constant annual loss rate. Marshes were thus converted to Undeveloped (which was assumed to be quickly converted to other uses in response to demands from the Human Population/Economy and Industry Submodels) at an annual rate of 0.83% in Mobile County and 0.16% in Baldwin County. Provisions were also made to allow any type of direct land and shoreline conversions in any year so that other scenarios, such as a large destruction or creation of wetlands associated with a specific project, could be simulated.

Air quality. Loadings (tons/year) of SO_x, NO_x, particulates, and hydrocarbons were calculated separately for Mobile and Baldwin Counties as the sum of an industrial emission of each type, as provided by the Industry Submodel, and a loading representing population-related and non-point source emissions. The population-related loadings were calculated by assuming they were directly proportional to population size. The proportions were estimated from current loadings and population sizes. This approach is obviously a very crude

representation of air quality dynamics; however, subgroup participants felt a more detailed representation of air quality, and its feedback limitations on additional growth and emissions, was not feasible at the spatial and temporal resolution of the workshop model.

Limitations

There are several major limitations of the Land Use/Air Quality Submodel as a representation of these aspects of the Mobile Bay area. Wildlife populations were not directly represented; air quality was superficially treated on the basis of annual loadings, rather than ambient concentrations, with no feedback on the factors producing the emissions; and the processes by which competition among various potential land uses is resolved were not represented at the level of detail at which such decisions are actually made.

A much finer spatial scale would be required to develop more realistic representations of many of these processes. As noted in the Industry Submodel description, decisions about land use and, to some extent, atmospheric emissions are made on a very restricted, site-specific basis. Land use changes are determined by a spatially complex set of zoning regulations, site characteristics, and relative costs. Currently, air quality characteristics are an important factor for some industrial uses. Incorporation of this complexity was beyond the scope of the workshop model and could, in fact, obscure the broader environmental consequences of and constraints on general patterns of potential economic growth by focusing on detail. The importance of these spatial factors suggests, however, that a detailed, computerized geographic information system would be a valuable planning aid for the Mobile Bay area.

WATER SUBMODEL

Responsibilities

The Water Submodel was responsible for representing the potential effects of industrial and urban growth on the quantity of fresh surface and groundwater and the water quality of Mobile Bay. Basic information available from other submodels included amount of water withdrawn from freshwater supplies and quantity and concentration of various constituents in discharges into rivers, groundwater, and Mobile Bay. The task of the Water subgroup was to formulate mathematical expressions describing how these withdrawals and discharges might affect local water quality as reflected by indicators such as dissolved oxygen (DO), coliforms (MPN), and salinity.

Structure

Hydrodynamic and water quality models, for both surface and groundwater, typically require large sets of complex physical and chemical equations which need to be solved simultaneously at fairly detailed spatial and temporal resolutions. The U.S. Army Corps of Engineers Waterways Experiment Station in Vicksburg, Mississippi maintains such a hydrodynamic model which can be used to study circulation in Mobile Bay, and other hydrodynamic and water quality models have been developed for the bay (e.g., Pitts and Farmer 1976; April and Raney 1979; Brady 1979). The complexity of these models precluded their incorporation into the workshop model during the time available. In addition, attempts to incorporate these models would have focused discussions on details of the models rather than on linkages or interactions with other workshop submodels. It was therefore decided to build a simple water quantity and quality submodel during the workshop. In order to reduce the task to something manageable in the time available, several initial assumptions were made based on discussions within the subgroup and with other subgroups:

(1) Calculations would be made on a monthly basis for seven subdivisions of Mobile Bay and associated surface freshwater inflows (Fig. 1) and for the primary groundwater aquifer which underlies most of Mobile and Baldwin Counties. Participants felt this temporal and spatial resolution was inadequate for impact analysis and management decisions, but adequate for purposes of the workshop.

(2) Adequate supplies of fresh surface water would not be a limiting factor for future development nor would these supplies be drastically altered by future development. The quantity of withdrawals and discharges to rivers was therefore not explicitly modeled.

(3) Groundwater hydrology and quality could not be modeled in detail but calculations would be made to indicate groundwater depletion and possible salt water intrusion.

(4) Only water quality constituents of primary concern to the Fish, Human Population/Economy, and Industry Subgroups would be modeled initially. These constituents were salinity, dissolved oxygen, and fecal coliforms.

(5) Water quality in each segment of the bay would be calculated from current conditions and changes in freshwater input and pollutant loadings to that segment associated with various future scenarios of interest. This approach provided a reasonable first approximation to spatial differences in water quality while avoiding complex water circulation modeling.

Based on these assumptions, Water Submodel calculations were divided into five components: indicators of groundwater depletion and saltwater intrusion; freshwater inflows; and salinity, DO, and coliforms in Mobile Bay. The following sections discuss formulations for each of these components.

Groundwater. Most of the Mobile and Baldwin County area is underlain by the Miocene-Pliocene aquifer which has a total storage of approximately 61,000 billion gallons and an approximate perennial yield of 1040 million gallons per

day (Alabama Coastal Area Borad 1980). The Water Submodel merely summed total urban and industrial groundwater pumping, as calculated by the Human Population/Economy and Industry Submodels respectively, and set a flag indicating overpumping and possible saltwater intrusion if more than 1040 mgd was being used. Areas around Bayou La Batre and Gulf Shores utilize separate alluvial aquifers or terrace deposits for many domestic and a few public wells. These sources have perennial yields of only one to several hundred mgd. Potential effects of development on these smaller aquifers and potential limitations on development by these low perennial yields were not explicitly included in the model because of the spatial resolution chosen. However, these factors would have to be considered when evaluating the feasibility and desirability of continued development in these areas.

Freshwater inflows. Calculation of freshwater inflows to Mobile Bay were based on 25-year average flows for major contributing rivers. For each year in a model simulation, this average (39,500 mgd x 365 days) was modified by a normally distributed random factor which approximated historical variability in river flows due to wet and dry years. The annual freshwater inflow was then partitioned into inflows for each month based on the average proportion of annual flow which historically occurred in each month. This representation assumes that the volume and variability in natural river flows in the future will be similar to that occurring in the past. If the Tennessee-Tombigbee Waterway is completed, additional freshwater inflow will result from opening and closing locks upstream. In the Water Submodel, this additional flow was calculated from projected lockages per day at Bay Springs (Fig. 4). With an average freshwater inflow of 39,500 mgd and a 7-day, 10-year low flow of approximately 5,200 mgd, the maximum added inflow due to the Tennesee-Tombigbee (800 mgd) is not expected to be very significant. While the effects of the Tennessee-Tombigbee on freshwater inflows is not expected to be significant, the effects of associated industrial and urban expansion on water quality may be.

Mobile Bay salinity. Salinity in Mobile Bay is determined primarily by freshwater inflows, tidal movements, and resulting circulation patterns. Because of limited time during the workshop, an empirical approach was taken to calculating salinity. Calculations for spatial subdivisions west of the

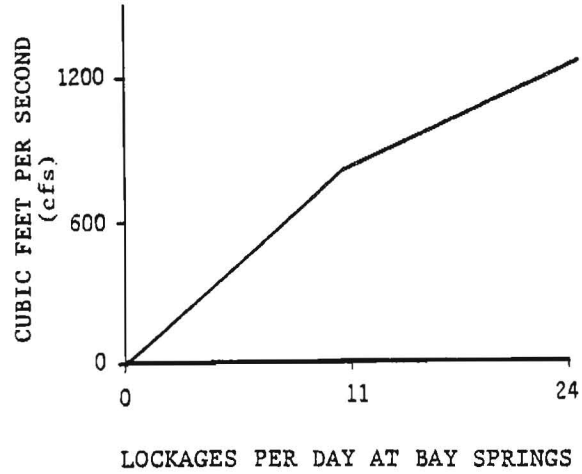

FIGURE 4. Increase in Mobile River flow due to barge traffic on Tennessee-Tombigbee Waterway.

navigation channel (Fig. 1) were based on average salinities of 4, 16, 20, and 26 parts per thousand (ppt) for areas 1, 2, 3, and 4 respectively. These salinities were decreased if freshwater inflow (calculated earlier) was greater than historical averages and increased if inflow was less than average. Salinity changes were calculated as:

$$\text{SALINITY CHANGE} = \left(\frac{\text{CALCULATED INFLOW}}{\text{AVERAGE FLOW}}\right) \times \text{SEGMENT SALINITY FACTOR} \qquad (9)$$

where SEGMENT SALINITY FACTOR = 1.0, 1.2, 1.4, and 1.6 ppt for areas 1, 2, 3, and 4 respectively

Salinities were assumed to increase 5% if the main navigation channel was enlarged. Salinities for spatial segments east of the navigation channel were initially conceptualized as 5% higher than the corresponding segment west of the channel. This was a crude attempt to represent the generally higher salinities east of the channel which result because the dredge spoil bank associated with the channel limits the influence of Mobile River inflows on these eastern segments. Average segment salinities, segment salinity factors, and the 5% factor for eastern segments were derived from Chermock (1974).

Mobile Bay dissolved oxygen. Very little information is available concerning past dissolved oxygen (DO) dynamics in Mobile Bay (Schroeder 1979) or potential effects on DO of increased growth and development in the area. Yet low DO concentrations in the bay, from both natural and anthropogenic causes, have periodically violated water quality standards and have been implicated in many fish kills over the past 10 years. In an attempt to represent DO concentrations (in parts per million, ppm) in Mobile Bay empirically, the 100% oxygen solubility concentrations for each spatial segment were calculated based on salinity, water temperature, and the vapor pressure of seawater (Don Blancher, personal communication). Actual saturations were calculated by multiplying these concentrations by average monthly percent DO saturations for each segment given current industrial and domestic loadings of biological oxygen demand (BOD) and chemical oxygen demand (COD). The monthly percent saturations were derived during the workshop from Loyacano and Smith (1979) and Marine Environmental Sciences Consortum (1979). Potential future increases in industrial and domestic loadings of BOD and COD were calculated by the Industry and Human Population/Economy Submodels and used in the Water Submodel to calculate additional oxygen demand as follows:

$$\text{ADDITIONAL OXYGEN DEMAND} = .01 \times e^{(\text{INCREASE in BOD and COD})} \qquad (10)$$

where e = 2.71828

This formulation assumes that the effect of BOD and COD on DO will increase with increased loadings. DO concentrations for each segment for each month were calculated as:

$$\text{DO} = \text{ACTUAL SATURATION} - \text{ADDITIONAL OXYGEN DEMAND} \qquad (11)$$

Mobile Bay coliforms. Although coliform bacteria are not pathogenic, they are used to indicate the potential presence of pathogenic organisms with which they are often associated. Direct tests for the pathogenic organisms are too varied and time consuming to be of practical use, while water samples

can be quickly analyzed for coliforms. Coliform counts in various parts of Mobile Bay have periodically violated water quality standards thereby closing these waters to shellfish harvest.

Coliform counts in Mobile Bay result primarily from local municipal and industrial discharges and upstream discharges which enter the bay from the Mobile River. Coliform loadings from municipal and industrial discharges in each county were calculated by the Human Population/Economy and Industry Submodels. The Water Submodel partitioned these discharges into the various spatial segments of the bay based on estimates of the proportion of total discharges into each area. Coliform inputs from the Mobile River were calculated based on river flow (Fig. 5).

Limitations

The Water Submodel developed during the workshop provides a very simplistic representation of a few water quality constitutents in Mobile Bay. Much of the simplicity in this submodel arises from the limited temporal and spatial resolution which could be dealt with during the workshop. For example, water quality changes occur in Mobile Bay on the order of hours while the submodel uses only monthly averages. Spatially, the submodel treats Mobile Bay as seven areas with water quality characterisitcs homogeneous within each segment. However, ciruclation patterns in Mobile Bay are relatively complex and vertical stratification is evident. While this submodel was adequate for purposes of the first workshop, future activities would require a much more detailed hydrodynamic and material transport model such as the one developed by April and Raney (1979).

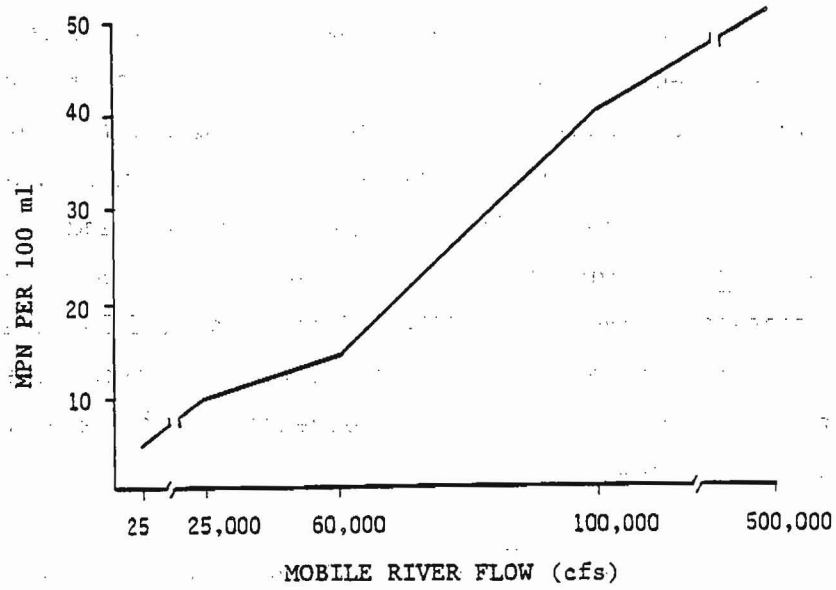

FIGURE 5. Coliform input to Mobile Bay from Mobile River.

FISH SUBMODEL

Responsibilities

Growth and development in the Mobile Bay area may potentially impact aquatic resources through: alteration of wetlands; changes in water quality (e.g., salinity, dissolved oxygen concentrations, coliform counts); changes in the magnitude of activities such as dredging and spoil disposal; and changes in the demand for recreational and commercial fishing opportunities (Fig. 2). The task of the Fish Subgroup was to formulate, insofar as possible, relationships describing the impacts of these changes on aquatic habitats (e.g., open water, wetlands, submerged grassbeds, bay bottoms), the fish (both finfish and shellfish) utilizing those habitats, and the recreational and commercial fishing industries.

Structure

Early in the subgroup discussions, participants realized that the impacts of growth and development on particular tracts of habitats such as submerged grassbeds would be very dependent on site-specific decisions (e.g., locations of shipping channels and dredge spoil disposal areas) that could not be

addressed in the broad spatial framework chosen for the workshop modeling exercise. A preliminary decision was therefore made to concentrate subgroup efforts on wetlands, the open water, fish resources, and the fishing industry. Three species were initially chosen for representation in the model: brown shrimp (Penaeus aztecus), oysters (Crassostrea virginica), and spotted sea trout (Cynoscion nebulosus). Shrimp and oysters were chosen because of their importance to the commercial and recreational fisheries, and because of their very different life histories and habitat requirements. Spotted seatrout were chosen because of their importance to the recreational fishery and their potential importance as a predator on shrimp.

Shrimp. Brown shrimp spawn in the Gulf of Mexico, principally during December and January, and immigrate into Mobile Bay as postlarvae from February through May or June (Heath 1979). Marshes surrounding Mobile Bay serve as nursery areas for the postlarvae, which feed largely on detritus. Juveniles move back into the bay before emigrating to the Gulf of Mexico. During the time they are in the bay they reach sexual maturity and are harvested. Those that escape the harvest return to the Gulf of Mexico to spawn.

Heath (1979) reported no apparent relationship between the shrimp spawning stock in Mobile Bay and recruitment the following year at present levels of exploitation. While the commercial catch in Mobile Bay has declined in the last 15 years (Fig. 6), fishing effort has also declined (Fig. 7), and catch per unit effort (CPUE) has remained relatively constant (Fig. 8). The decline in total catch is thus attributed to a shift in the fishery toward offshore areas, rather than to a reduction in the population. Overfishing the shrimp stock to the point where the ability of the population to maintain itself is impaired does not appear to be economically feasible. Year to year variations in shrimp populations thus appear to be more closely related to environmental factors than to rates of exploitation or size of the spawning stock escaping to the Gulf of Mexico.

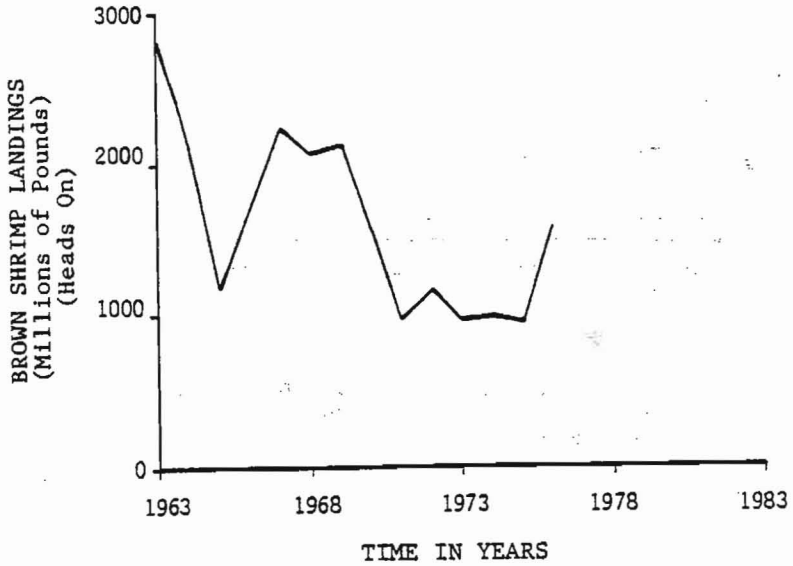

FIGURE 6. Historical trend in brown shrimp landings in Mobile Bay.

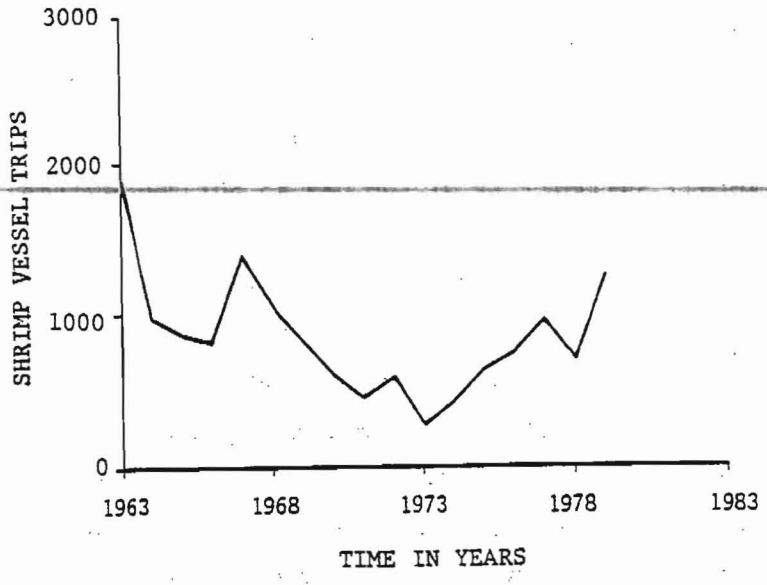

FIGURE 7. Historical trend in shrimp fishing effort in Mobile Bay (data from Heath 1979).

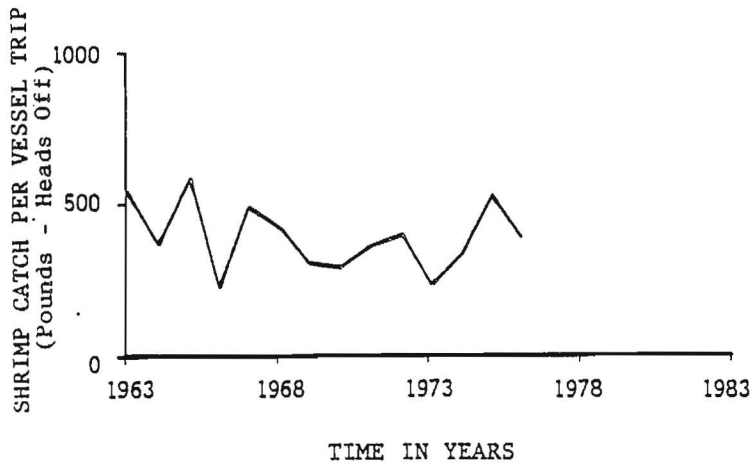

FIGURE 8. Historical trend in catch/unit effort for the shrimp fishery in Mobile Bay (data from Heath 1979).

Since the size of the spawning stock apparently bears little direct relationship to the size of the shrimp population in the following year, it was not possible to model shrimp population dynamics explicitly. In lieu of a population dynamics approach, participants attempted to construct simple indices that would reflect the impact of changing environmental conditions (e.g., salinity, dissolved oxygen concentration, wetlands available for nursery areas) that might result from growth and development on the catch of shrimp in Mobile Bay and on the overall suitability of the bay as shrimp habitat.

Participants suggested that the number of postlarvae entering Mobile Bay in the spring, and hence the population available for harvest in the following summer and fall, is strongly related to salinity conditions, particularly in February. Regression analysis of the small amount of data available at the workshop tended to support this hypothesis (Figs. 9 and 10). The resulting regression equations were thus used in the model to predict potential catch and potential CPUE under the February salinity conditions generated by the Water Submodel. Potential values for catch and CPUE were then modified to reflect the impacts of two other factors: wetland acreage available for nursery areas (generated by the Land Use/Air Quality Submodel) and the proportion of the bay having dissolved oxygen levels (generated by the Water Submodel) suitable for shrimp.

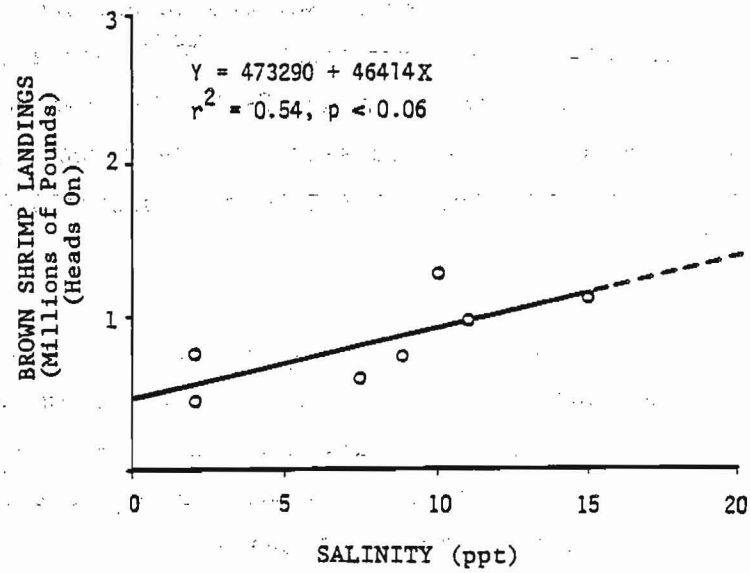

FIGURE 9. Relationship between brown shrimp landings and mean February salinity in Mobile Bay.

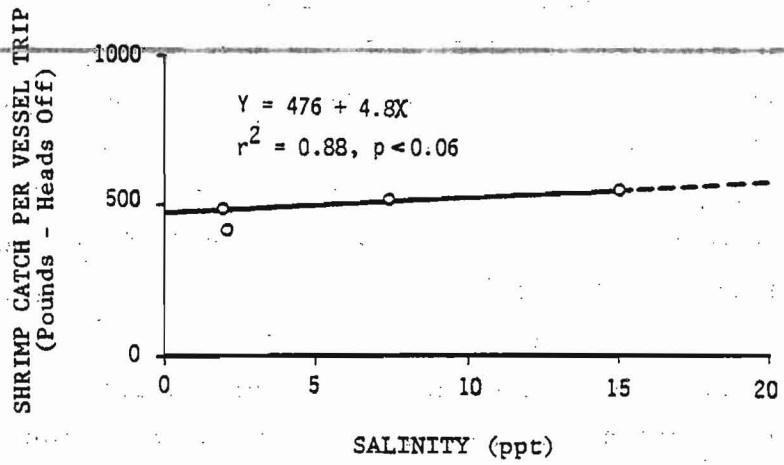

FIGURE 10. Relationship between shrimp catch/unit effort and mean February salinity in Mobile Bay (catch/unit effort data from Heath 1979).

Changes in the number of wetland acres were accounted for by expressing the predicted number of wetland acres (from the Land Use/Air Quality Submodel) as a proportion of the current (1981) number of wetland acres, and mutiplying the result times the potential catch and the potential CPUE generated from the regression equations. Final values for catch and CPUE were then computed by multiplying by a volume-weighted average representing the proportion of the bay having DO levels (as generated by the Water Submodel) acceptable to shrimp (> 2 ppm).

One difficulty with this approach, of course, is that shrimp immigration to the bay is not solely a function of salinity conditions in February. Shrimp encountering salinity barriers in February may simply wait and immigrate when (and if) conditions improve. An attempt was made to overcome this difficulty by constructing a volume-weighted index of the suitability of salinity conditions for shrimp immigration for the period from February through June. For each of these months, for each of the areas 2-7 of the bay (Fig. 1), Figure 11 was used to compute an index of habitat suitability. The resulting values were weighted according to the volume of the bay sections and averaged to provide a composite index of the suitability of salinity conditions for shrimp immigration in a given year.

Oysters. While the total area of productive oyster reefs in and around Mobile Bay has remained relatively constant over the past 80-90 years, centers of productivity have tended to shift toward the south and west (Eckmayer 1979). The most productive reefs are presently located between Mississippi Sound and Mobile Bay. Certain of these reefs (e.g., Cedar Point Reef) are apparently being overharvested, while others (e.g., Sand Reef and Buoy Reef) are underharvested due to more difficult access and deeper water (Eckmayer 1979). Overharvesting tends to reduce the amount of cultch available for future spat fall. Unfortunately, there was no information available at the workshop concerning the relationships between harvest, suitable habitat, and spat fall. Consequently, as with shrimp, it was not possible to model oyster population dynamics explicitly, and a habitat suitability approach was necessary.

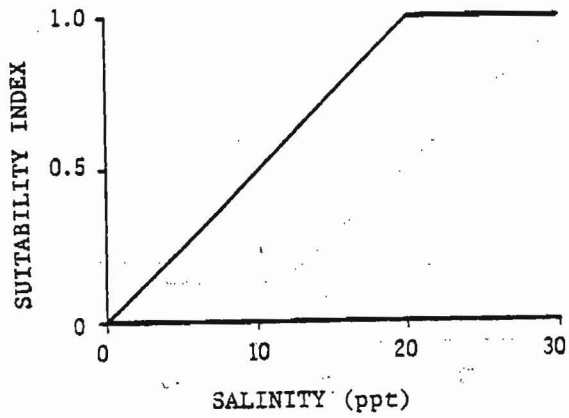

FIGURE 11. Relationship between salinity and suitability of Mobile Bay for immigration of shrimp postlarvae.

Participants felt that two environmental factors, salinity and coliform counts, were most important in determining the suitability of Mobile Bay as oyster habitat and the availability of oysters for harvest. Simple indices for these two factors were constructed as follows. For each month, salinity (as computed by the Water Submodel) in area 4 of the bay (Fig. 1) was used to generate an oyster habitat suitability index from Figure 12. The shape of Figure 12 reflects the fact that salinity around 15 parts per thousand (ppt) represents a good compromise between the requirements of oysters and the requirements of their chief predator, the oyster drill (Thais haemostoma). An annual index was calculated simply by averaging the monthly values. A second index, representing the proportion of the year that the oyster fishing season would be open, was calculated by summing the number of months having coliform counts (computed by the Water Submodel) less than some number allowable from a public health point of view (14/100 ml), and expressing the total as a fraction of the year.

Spotted seatrout. There was insufficient time available at the workshop to permit incorporation of spotted seatrout in the simulation model.

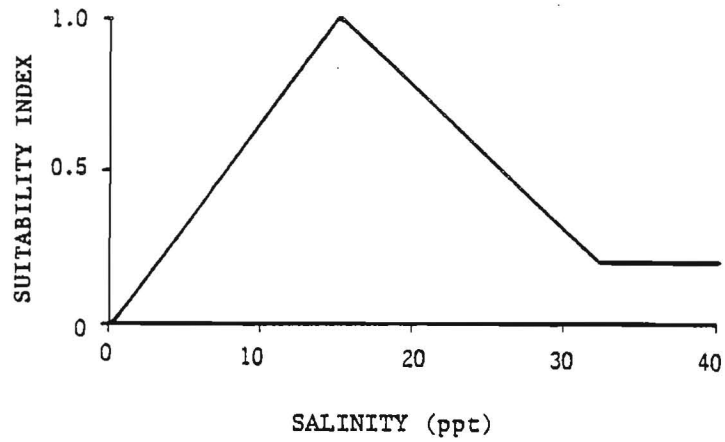

FIGURE 12. Relationship between salinity in area 4 of Mobile Bay (see Figure 1) and suitability for oyster habitat.

Limitations

Limitations of the Fish Submodel can be generally grouped into two categories: those resulting from the broad spatial and temporal scale chosen for the workshop model, and those resulting from a habitat index approach.

The first of these limitations has already been mentioned briefly. The broad spatial scale meant that site-specific decisions, which will no doubt be very important in Mobile Bay, concerning the proximity of development activities to important habitats could not be adequately considered in the model framework. Similarly, use of monthly average salinities to represent what are actually more short-term phenomena is undoubtedly an oversimplification.

Perhaps more important, however, are the limitations inherent in using a habitat index approach instead of explicit modeling of population dynamics. First, the model contains no mechanism for carrying the results of one year's conditions forward to future years. While this may not be important for shrimp, oyster harvesting activities in one year certainly have implications for oyster populations in future years (Eckmayer 1979). The second limitation, which is closely related to the first, is that the model contains no explicit representation of the impact of harvest on population or the reverse. It was

thus not possible to consider such factors as the implications of different fishing regulations, or the contribution of the fishing industry to the local economy. Finally, the habitat index approach makes it extremely difficult to consider interactions between species. Thus, even if there had been time to consider spotted seatrout, the habitat index approach would not have allowed consideration of their impact as predators on shrimp.

SYSTEM MODEL

STRUCTURE

The system model was composed of the five submodels linked together through the interactions identified in the Looking Outward Matrix (Fig. 2). Each year's calculations were initiated by the Industry Submodel, which determined land and shoreline requests, development activities, and direct consequences of development and operations in terms of primary jobs, emissions, water use and discharges, spoil disposal, and capital expenditures. The Human Population/Economy Submodel then calculated population and economic variables, including demand for land and shoreline, based on industrial activities and tourism growth. Next, the Land Use/Air Quality Submodel allocated land and shoreline for the following year based on requests from the preceding submodels. Air pollution emissions were also totaled based on variables supplied by the preceding submodels.

The Water Submodel then calculated water flow and quality for each month in the year, utilizing discharge information provided by the Industry and Human Population/Economy Submodels. Finally, the Fish Submodel calculated several annual aquatic habitat indices and catch variables based on wetland acreage and monthly water quality information. The sequence of calculations was then repeated for each succeeding year of the simulation.

BEHAVIOR

In this section we present sample output generated with the workshop model. The output is organized into two scenarios. The first scenario represents a nominal or reference projection of development and its effects in the Mobile Bay area. Results from this scenario are presented in some detail to establish the basic model behavior. The second scenario projects larger and more rapid industrial growth. Discussion of the second scenario focuses on those variables that show large differences from the first scenario.

The scenario results are presented in terms of absolute quantities (acres, tons/year, parts per million). In so doing, we run the risk of imputing greater accuracy to this initial model than is justified. We present the results in this form not because we necessarily believe them to be accurate, but rather in the hope of promoting constructive discussion. Models cannot be validated; like hypotheses, they can only be invalidated. Only by subjecting the model and its results to criticism can we establish the limits of its credibility. In comparing scenarios, it should therefore be remembered that general trends - and what they suggest about the representations of various interactions - have greater importance than actual numbers. The numbers are included only as points of reference and discussion.

Scenario I

Development activities in this scenario included: completion of the Tennessee-Tombigbee project, which was activated in the 6th year of the simulation; dock expansion, which began in the first year and took 5 years to complete; and channel enlargement to 55 feet, which was initiated in the 5th year and completed in the 10th year. Fourteen Chemical/Petrochemical facilities were scheduled for construction within the first 24 years of simulation, nine small plants and three large plants in Mobile County and two large plants in Baldwin County. Five small Shipbuilding facilities were scheduled for construction in Baldwin County; ten small and two large Shipbuilding facilities were scheduled for Mobile County. The new Oil and Gas Exploration/Extraction support facilities were all scheduled for Mobile County. One small, two medium, and two large facilities were planned. These activities are described in more detail in the Industry Submodel description.

The annual tourism growth rate was set at 1% in this scenario. Basic marsh loss rates were set at 0.8% annually in Mobile County and 0.16% annually in Baldwin County. In addition, dock expansion was assumed to take place in such a way as to destroy 10 acres of marsh in the first year and create 132.6 acres per year in each of the 5 years of construction, yielding a net gain of 122.6 acres in year 1 and 132.6 acres in years 2 through 5.

The effect of permit and other administrative or legal delays was examined in this scenario by assuming a 2-year additional delay in Chemical/ Petrochemical activities scheduled in the first 10 years and a 3-year delay in Oil/Gas activities scheduled in the first 10 years. Costs of these delays were calculated as described in the Industry Submodel.

Human population reached maxima of about 95,000 in Baldwin County and 450,000 in Mobile County (Fig. 13). Populations fluctuated more strongly in earlier years in response to higher annual variation in the number of jobs during this period because of construction starts and completions. Undeveloped land and shore (the sum of Beach and Waterfront) declined in both Mobile and Baldwin Counties in response to development requests from the Industry and Human Population/Economy Submodels (Figs. 14 and 15). Marsh acreage declined at the preset annual loss rates after an initial period of increase in Mobile County resulting from wetland creation associated with dock expansion (Fig. 16).

Total capital expenditures for the implemented development activities reached maxima of about $4.55 billion in Mobile County and $323 million in Baldwin County (Fig. 17). Delays that were introduced in Chemical/ Petrochemical and Oil/Gas projects during the first 10 years of the simulation added to the total cost of projects scheduled during this period (Fig. 18). Dredge spoil disposal exceeded current capacity after approximately 15 years (Fig. 19). The rate of spoil production increased after the first 5 years as the result of enlargement to the 55-foot channel.

The Water Quality Submodel produced monthly patterns of flow and concentration variables for each year of the simulation. Monthly output from the first year of the simulation is presented here to illustrate representative seasonal patterns of these variables. Mobile River flow varied from less than 60 to nearly 300 billion gallons per month (Fig. 20) in the first year of the simulation. Coliform counts were strongly related to Mobile River flow and followed the same seasonal pattern (Fig. 21). Salinity was inversely related to river flow, with lower freshwater input producing less dilution from ocean levels (Fig. 22). Dissolved oxygen (DO) levels were lowest in the summer

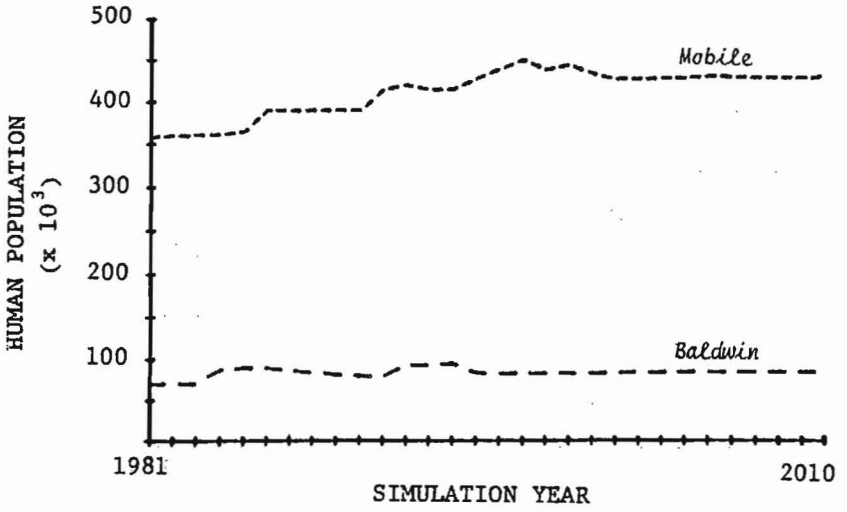

FIGURE 13. Scenario I: Human population in Mobile and Baldwin Counties.

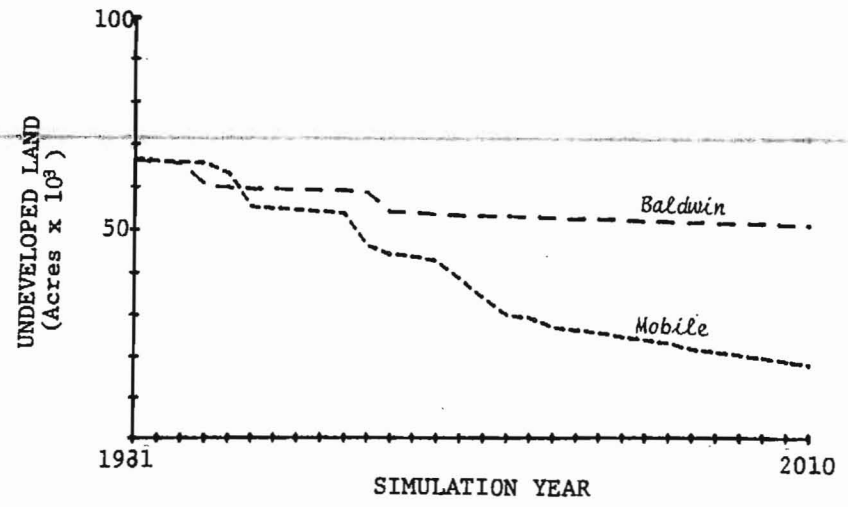

FIGURE 14. Scenario I: Acreage in undeveloped land category in Mobile and Baldwin Counties.

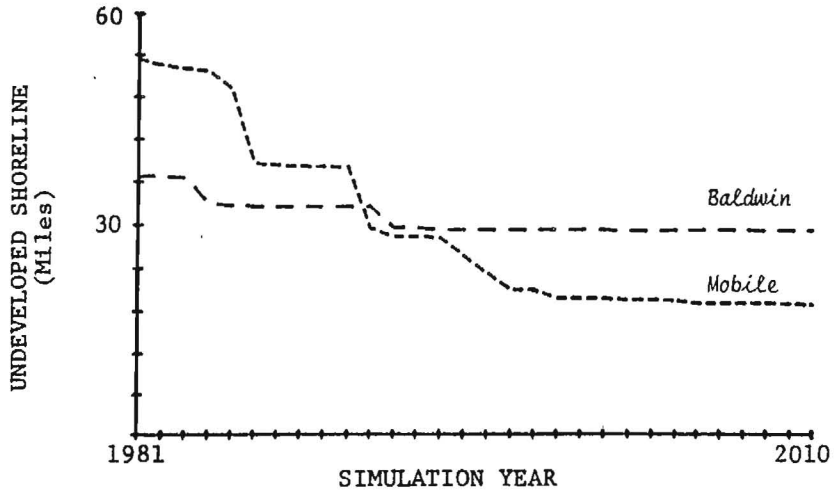

FIGURE 15. Scenario I: Total shoreline in undeveloped category for Mobile and Baldwin Counties.

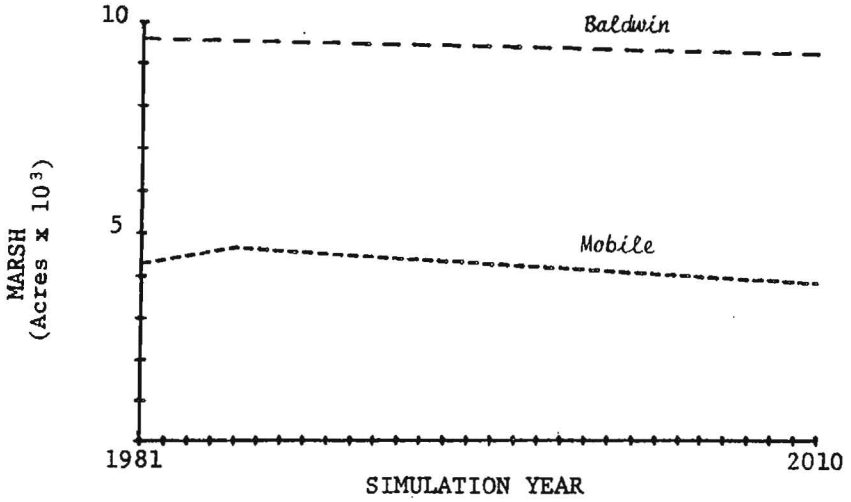

FIGURE 16. Scenario I: Marsh acreage in Mobile and Baldwin Counties.

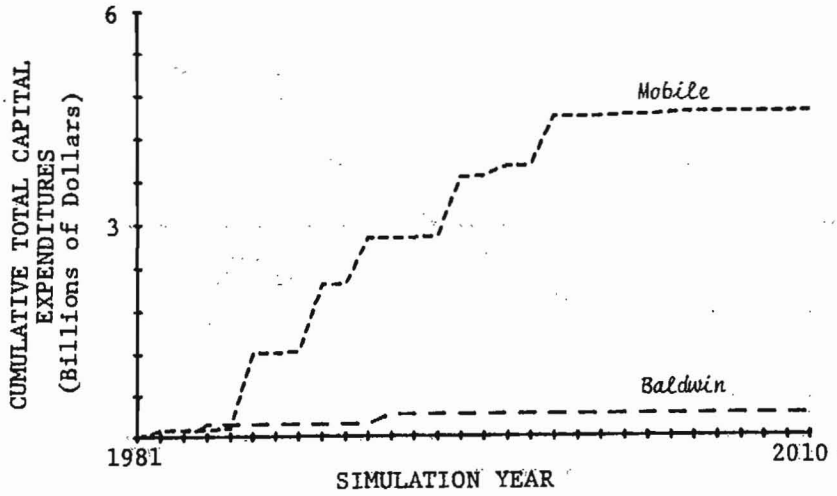

FIGURE 17. Scenario I: Cumulative total capital expenditures on implemented projects in Mobile and Baldwin Counties.

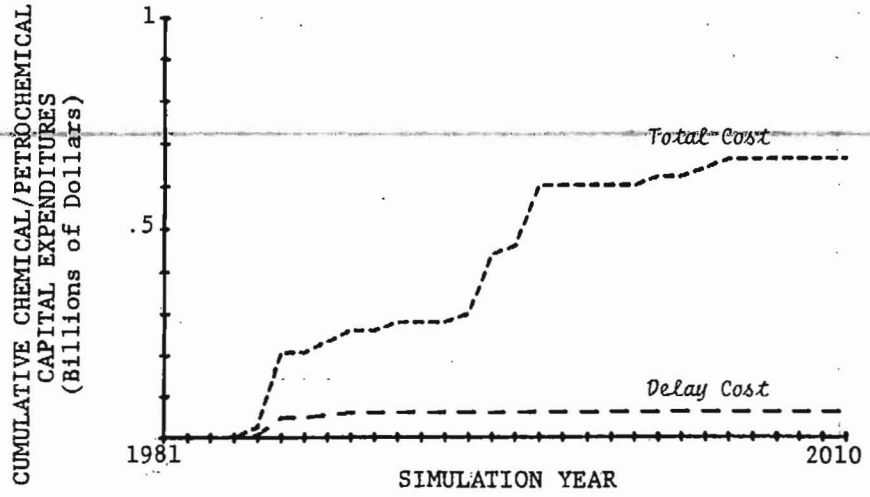

FIGURE 18. Scenario I: Cumulative capital expenditures and delay costs for Chemical/Petrochemical projects implemented in Mobile County.

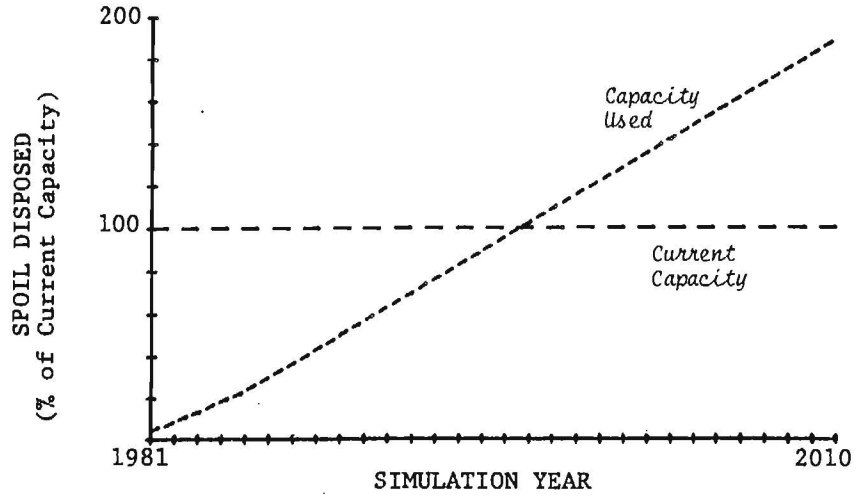

FIGURE 19. Scenario I: Cumulative dredge spoil disposed on land in the Mobile Bay area as a percent of the capacity of current disposal sites.

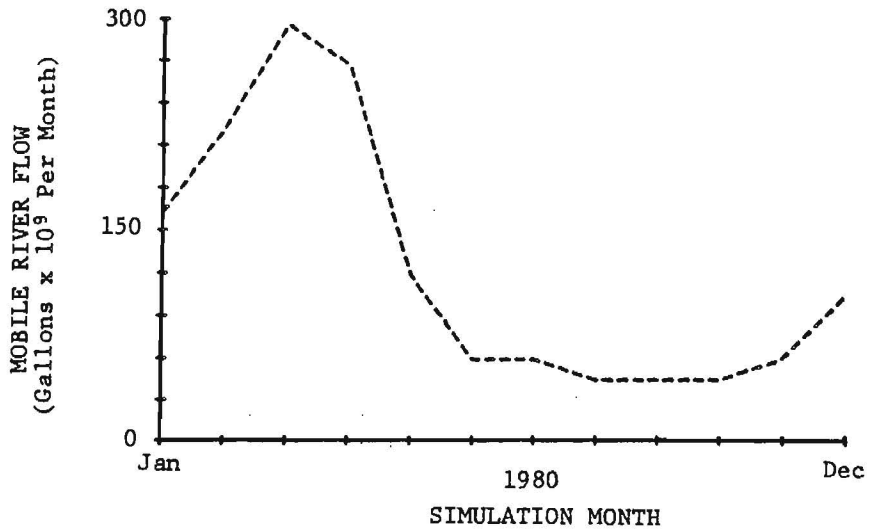

FIGURE 20. Scenario I: Mobile River flow during the first year of simulation.

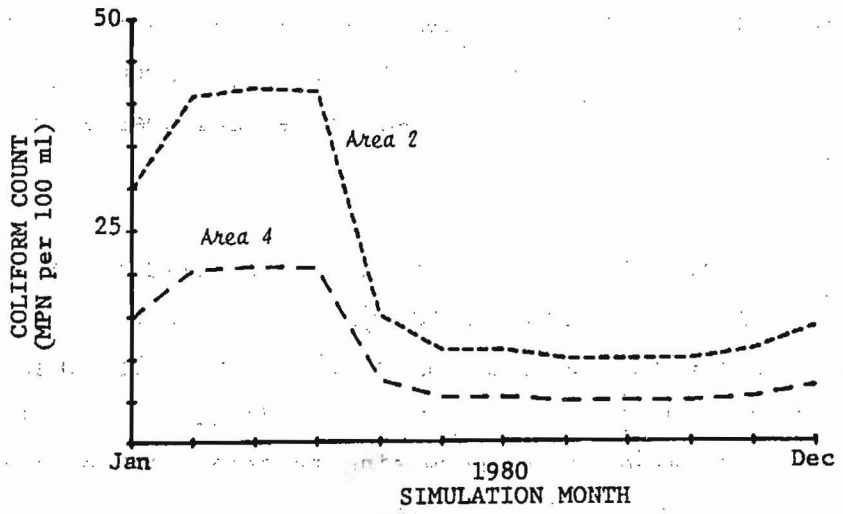

FIGURE 21. Scenario I: Coliform count in MPN (most probable number) per 100 ml for areas 2 and 4 of Mobile Bay during the first year of simulation.

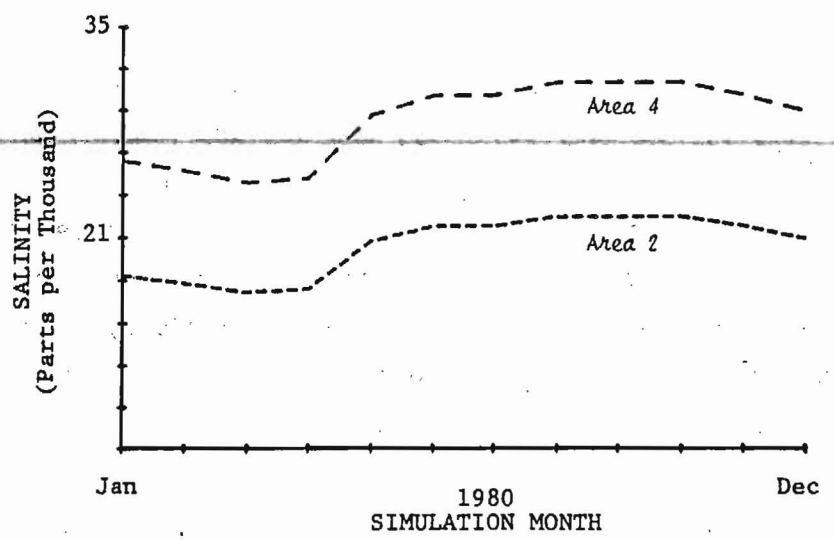

FIGURE 22. Scenario I: Salinity in areas 2 and 4 of Mobile Bay during the first year of simulation.

months (Fig. 23) reflecting the effect of water temperature on oxygen solubility (higher temperatures lead to lower oxygen saturation values). Area 2 had more seasonal variation in dissolved oxygen. DO was lower in area 2 than area 4 in the summer months, when water temperatures were similar, because of higher BOD and COD loadings (from Mobile). Area 2 had generally higher DO than area 4 in the rest of the year when water temperatures were lower in area 2 than area 4.

Air pollution loadings of total particulates increased in both Mobile and Baldwin Counties (Figs. 24 and 25). Loadings were considerably higher in Mobile County, with a maximum value of about 87,000 tons per year versus a maximum value of about 6,700 tons per year in Baldwin County. Emissions from the Industry Submodel represented an increasing fraction of the total in both counties. This trend was especially dramatic in Baldwin County. Industrial point emissions of total particulates first exceeded other sources in the fifth year of simulation and reached maximum values almost five times greater than emissions from other sources. Crime rate in the Mobile Bay area was represented in the model as a function of the level of unemployment. Unemployment, however, was relatively constant due to model assumptions about how population size was determined by the number of jobs.

Brown shrimp landings (Fig. 26) were calculated in the model based on dissolved oxygen levels, February salinity, and wetland (marsh) acreage. None of these factors had much annual variation in the simulation run. Marsh acreage increased slightly early in the simulation and then declined slowly (Fig. 16), which is reflected in the long-term trend in brown shrimp landings (Fig. 26). Shorter term variation was related to February salinity. The effect of salinity on shrimp is also evident in the small variation in salinity related habitat suitability, plotted on a scale of 0 to 1, with 1 representing optimum conditions (Fig. 27).

The suitability of oyster habitat with respect to salinity and coliforms did not have any clear trend in the simulation (Fig. 27). Coliform-related habitat suitability for oysters varied from about 0.65 to 0.75, corresponding to the simulated fraction of the year in which oyster beds would be open for harvest.

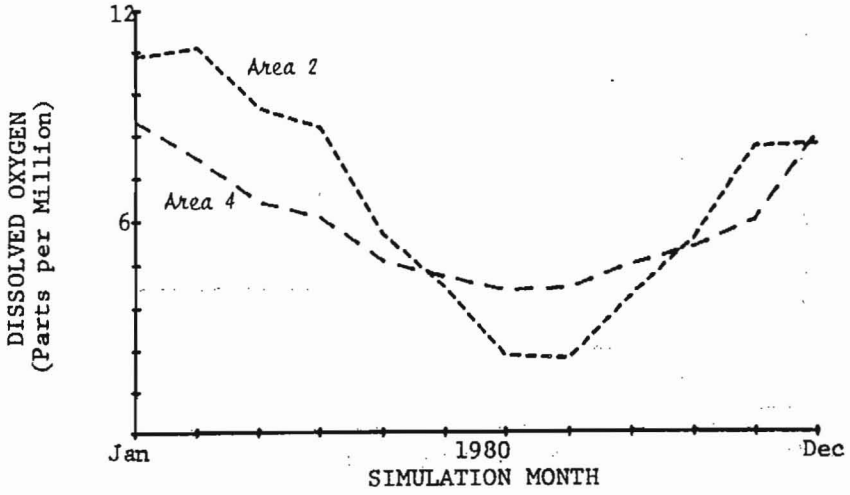

FIGURE 23. Scenario I: Dissolved oxygen in areas 2 and 4 of Mobile Bay during the first year of simulation.

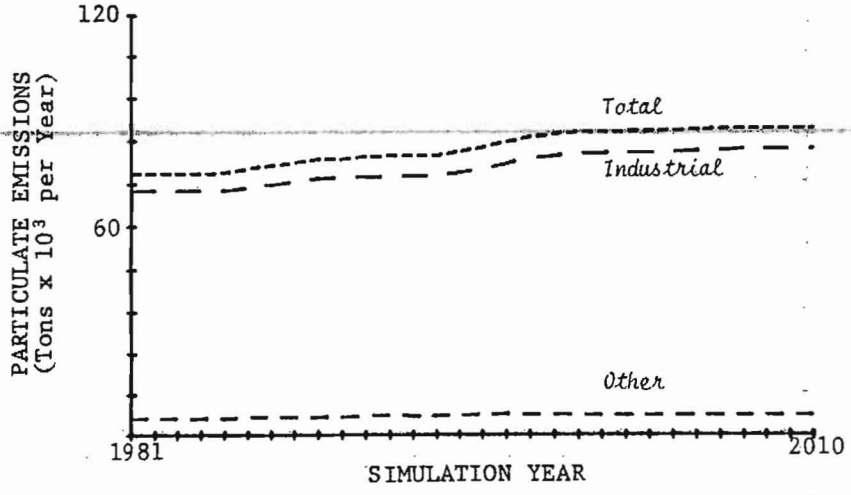

FIGURE 24. Scenario I: Particulate emissions in Mobile County.

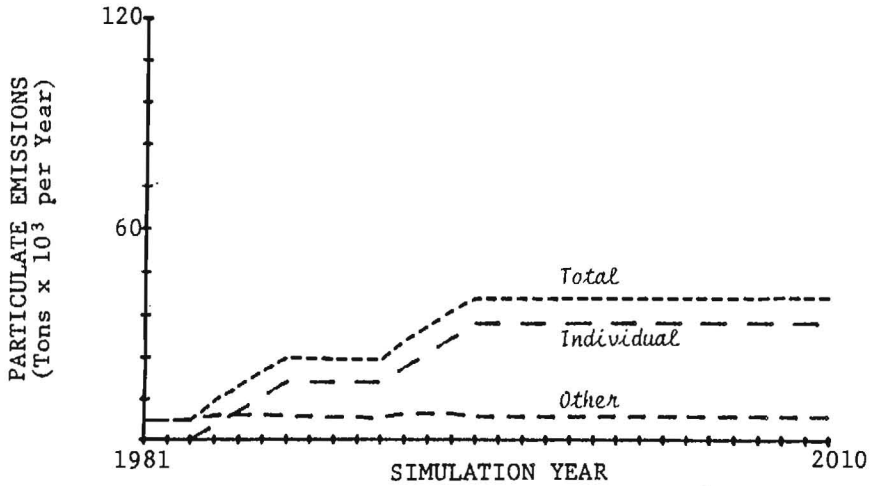

FIGURE 25. Scenario I: Particulate emissions in Baldwin County.

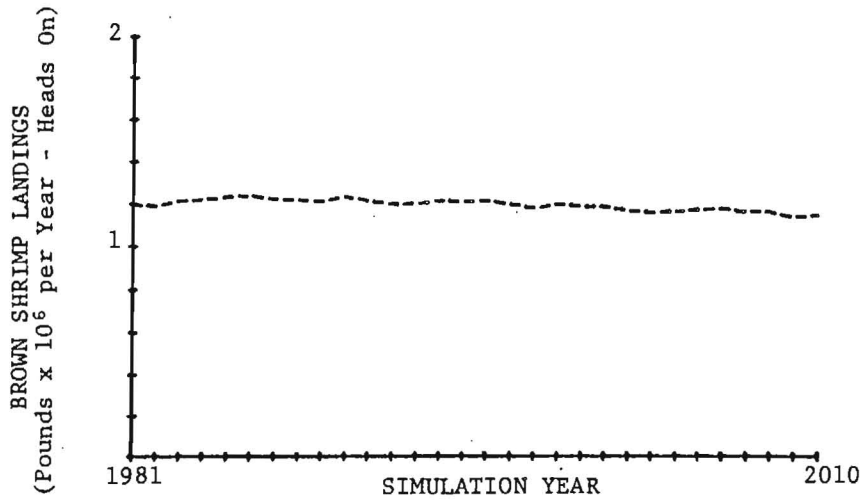

FIGURE 26. Scenario I: Annual known shrimp landings (heads on) in the Mobile Bay area.

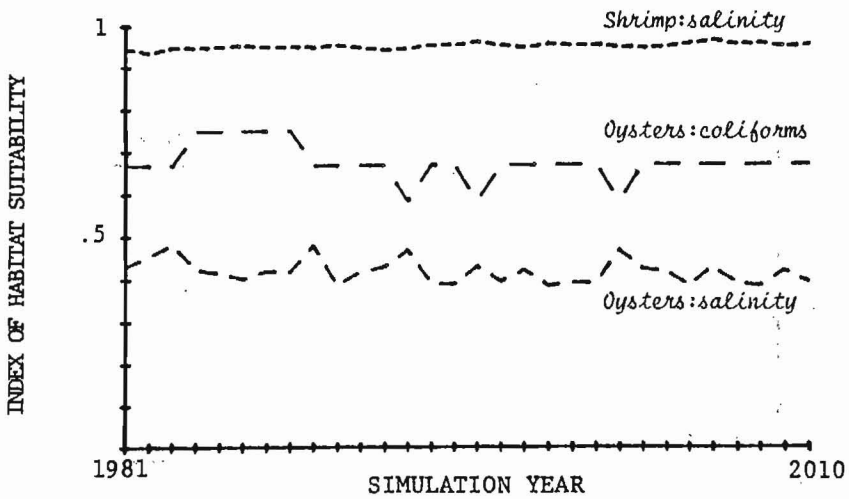

FIGURE 27. Scenario I: Suitability of Mobile Bay shrimp habitat with respect to salinity, and suitability of oyster habitat with respect to salinity and coliforms.

Scenario II

In this scenario, the conditions of Scenario I were altered to represent a projection of higher growth. There were no delays of industrial activities beyond their scheduled initiation. Chemical/Petrochemical development was increased to twenty large facilities, fifteen in Mobile County and five in Baldwin County. Shipbuilding development was increased to twenty large facilities, thirteen in Mobile County and seven in Baldwin County. Expansion to the 55-foot channel was initiated in year 1 rather than year 5. Annual marsh loss rates were doubled from those used in Scenario I and no wetlands creation resulted from the dock expansion. Finally, shoreline availability did not limit industrial activity; if adequate shoreline was not available, it was assumed that development would proceed without additional water access.

Human population growth was greater in this scenario, reaching maxima of about 507,000 in Mobile County and 127,000 in Baldwin County (Fig. 28). Total capital expenditures were also larger than in Scenario I (Figs. 17 and 29). The larger population growth and industrial development of this Scenario II resulted in more rapid declines in undeveloped land and shoreline (Figs. 14 and 30).

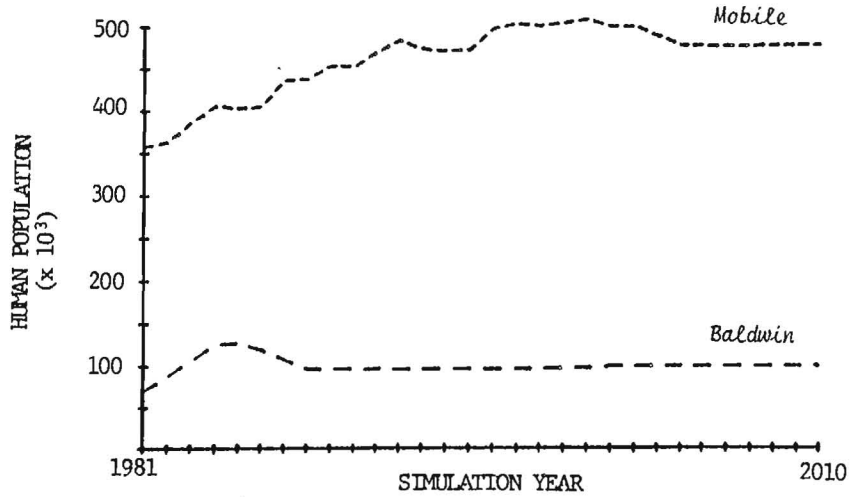

FIGURE 28. Scenario II: Human population in Mobile and Baldwin Counties.

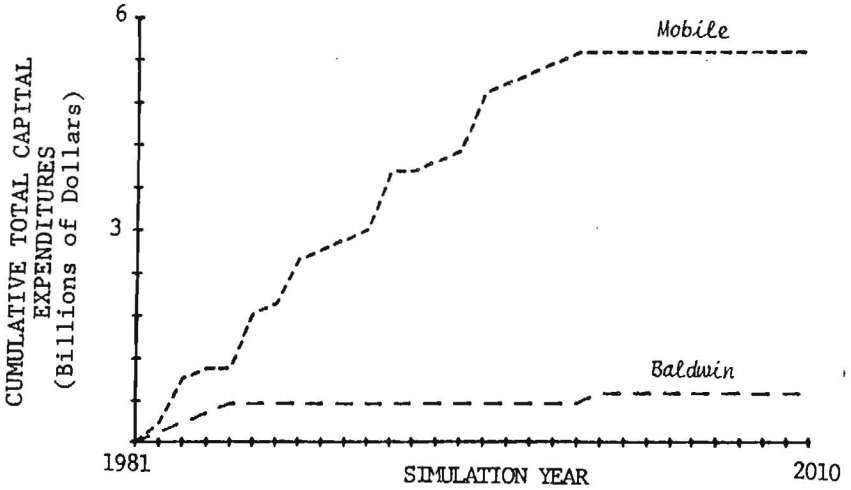

FIGURE 29. Scenario II: Cumulative total capital expenditures on implemented projects in Mobile and Baldwin Counties.

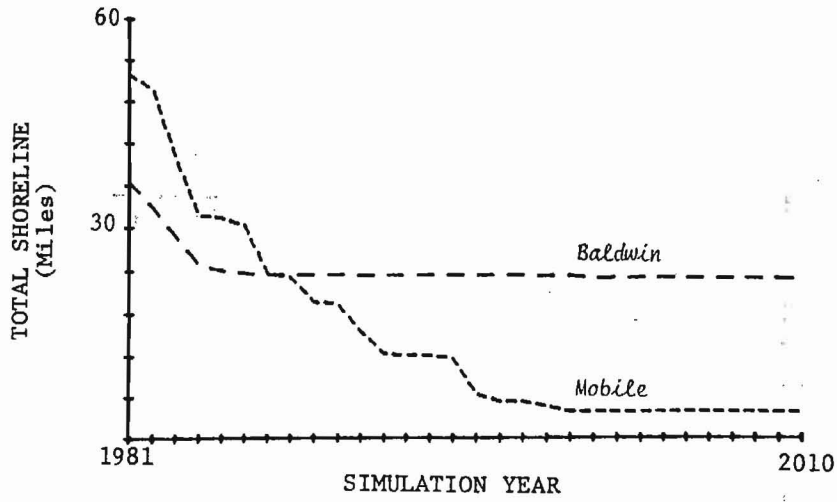

FIGURE 30. Scenario II: Total shoreline in undeveloped category for Mobile and Baldwin Counties.

Particulate emissions were much higher than for Scenario I in Mobile County (Figs. 24 and 31) and slightly higher than for Scenario I in Baldwin County (Figs. 25 and 32). Increases in total particulate emissions closely tracked increases in industrial loadings in both counties.

Annual shrimp catch declined slightly more in Scenario II than in Scenario I, due to slightly greater wetland losses (Figs. 26 and 33). Shrimp and oyster habitat suitabilities with respect to salinity were also slightly different in this scenario during the period in which salinity was altered by earlier completion of the 55-foot channel.

Summary

Population growth and environmental alterations were determined in the model by implementation of specific development projects. Jobs associated with these projects produced population increases of approximately 30% for Mobile County and 35% for Baldwin County in Scenario I, and 40% for Mobile County and 70% for Baldwin County in Scenario II. Population maxima occurred in the first 7 to 20 years of simulation reflecting the sequence of anticipated projects and the temporary nature of construction activities associated with the projects.

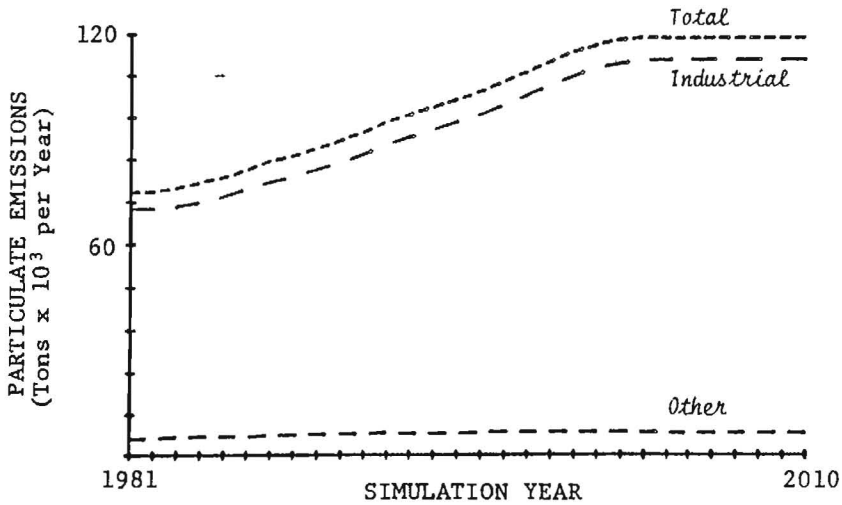

FIGURE 31. Scenario II: Particulate emissions in Mobile County.

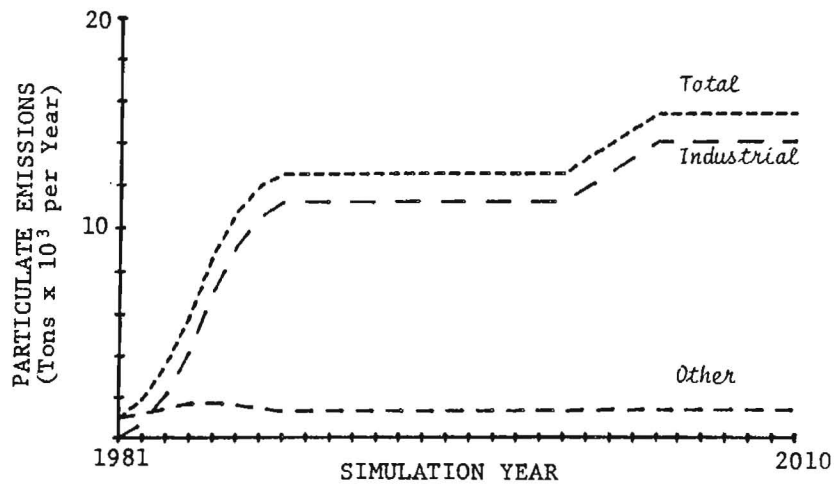

FIGURE 32. Scenario II: Particulate emissions in Baldwin County.

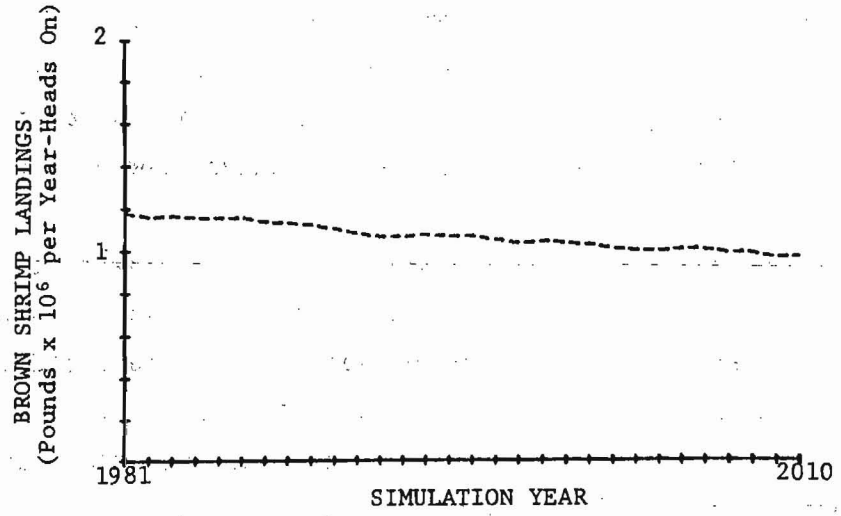

FIGURE 33. Scenario II. Annual brown shrimp landings (heads on) in the Mobile Bay area.

Air pollution loadings increased in the model as a result of this development. In the case of total particulates, the increase was substantial and primarily associated with industrial emissions. Undeveloped land and shoreline decreased in response to expansion in industrial and residential land uses. Water quality, finfish habitat quality, and shellfish habitat quality and catch were not appreciably affected by the projected development.

The results of the similation runs reflect the combined implications of the assumptions and relationships used to construct the model. The principal value from examining the behavior of an initial workshop model is that the model provides a structure for asking the questions: "Is this behavior reasonable?" and, if it is not, "What aspects of the real system were not adequately represented in the model?" The human population maxima for the 30-year simulation of Scenario I are somewhat higher (7% for Baldwin County and 10% for Mobile County) than the population projections of the Alabama Coastal Area Board (1980) for year 2000. Furthermore, the model assumed that all the population growth is a direct or indirect result of a set of specific projects in several economic sectors. Thus, intrinisic growth in other sectors, which could produce additional population growth, was not considered. A possible resolution of these discrepancies is that Scenario I may have overestimated the actual number of specific projects which will be implemented. It is

also unlikely that the increase in total particulate loadings will occur as simulated by the model. Feedback from air pollution regulation was not incorporated in the model and will likely act to limit increases in emissions. Likewise, land use changes will most likely also include shifts from agriculture and forestry rather than merely declines in undeveloped acreage.

Several factors contribute to the small projected effects of development activities on many of the environmental and social indicators. Many of these effects are very site-specific and are not apparent at the broad spatial scale of the model. For example, coliform content of Mobile Bay as a whole is much more strongly determined by the Mobile River and its upstream loadings than by discharges directly into the Bay. Water quality at a particular site, however, might be strongly influenced by a particular municipal discharge into the Bay. If certain sites or types of habitat, such as specific types of wetland, are critical, then the broad spatial scale may underestimate the effects of their alteration. Participants in the Land Use/Air Quality subgroup felt that wetland loss rates were likely to be relatively small in the future regardless of development activities, with the possible exception of dock expansion. This assumption was based on confidence in the effectiveness of wetlands protection activities and is one of the reasons shrimp habitat and catch did not change appreciably because both of these indicators were functions of marsh acreage in the model.

Unemployment and crime rate did not change appreciably in the model because of the ease with which the population was assumed to adjust to changes in the number of jobs. In fact, the geographic, educational, social, and ethnic factors which act to limit the extent to which people move from place to place and job to job are probably much more important than they were portrayed as being in the model. Again the value of the workshop simulations themselves lies more in identifying what has not been represented than it does in quantitative predictions.

WORKSHOP RESULTS

The workshop had three primary objectives: to identify major factors of economic development as they relate to growth in the Mobile Bay area; to identify the major associated environmental and resource management issues; and to characterize the relationships among those economic and environmental factors. These topics are discussed below in the context of interactions between the major components of the workshop model.

In the course of discussions at the workshop, it became apparent that an underlying motivation for many of the Mobile Bay area participants was to provide for a more effective resolution of conflicts related to various patterns of growth and their associated economic, human, and environmental consequences. The concluding section offers our ideas on some of the foundations required for effective resolution of the issues identified at the workshop.

RELATIONSHIPS AMONG MAJOR ECONOMIC AND ENVIRONMENTAL FACTORS

Conceptual Model

This general discussion of interactions among components of the Mobile Bay resource system represents a synthesis of participants' comments expressed during the Looking Outward Matrix exercise. Numbers noted in brackets below correspond to numbered interactions in Figure 34. As indicated in the preceding section on simulation results, not all of these interactions and relationships were adequately incorporated in the workshop simulation model. The intent of this discussion is to highlight key interactions among components of the resource system rather than to describe all aspects of the resource system. These interactions are highlighted because they often represent points at which various agencies and interests must interface in their attempts to deal with the complexities of a resource issue. More detailed descriptions of the natural resources of the Mobile Bay area and their use can be found in Loyacano and Smith (1979), U.S. Department of Commerce (1979), and Alabama Coastal Area Board (1980).

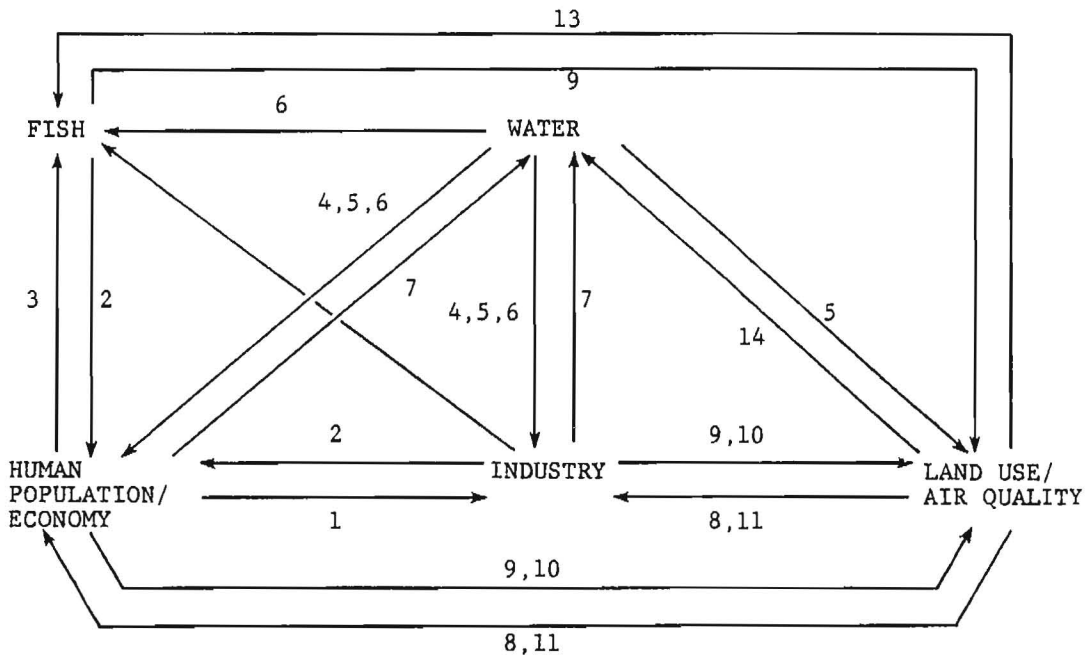

FIGURE 34. Major component interactions identified at the Mobile Bay workshop.

1. available workers, time to process permits
2. jobs, stimulation of local economy and population, demand for services
3. recreational and commercial harvest
4. withdrawals from surface or groundwater
5. fresh surface and groundwater quality
6. Mobile Bay water quality
7. discharges to surface or groundwater, saltwater intrusion into groundwater
8. land available for development
9. land developed
10. air pollutant emissions
11. air quality
12. dredge spoil disposal
13. wetlands
14. agricultural runoff

Rapid growth in population, industry, and resource development in southern regions of the United States over the past decade has been attributed to a variety of factors such as an abundant and inexpensive labor force [1], a mild climate, and the availability of energy, water [4,5], land [8], and other natural resources. This growth is projected to continue in the foreseeable future. As industry expands further, the local economy is stimulated through increased employment and tax revenues [2]. This favorable economic situation and prospect of jobs, as well as a mild climate, also stimulates a net immigration of people into the area [2], which results in urban expansion. This interaction was represented in the workshop simulation model by the creation of jobs both directly and indirectly from specific projects initiated by the Industry Submodel.

The combined industrial and urban expansion means greater withdrawals of surface and groundwater [4] for domestic, industrial cooling, and industrial process use. An eventual decline in groundwater supplies and saltwater intrusion into groundwater [7] could result from overpumping of groundwater. In fact, saltwater intrusion is currently occurring in the Mobile, Dauphin Island, and Gulf Shores areas (U.S. Department of Commerce 1979). Increased water utilization will result in increased discharges to surface and groundwater [7] with potentially higher levels of biological and chemical oxygen demand, chemicals such as trace metals and hydrocarbons, and domestic wastes as indicated by coliforms counts. Increased non-point source discharges (urban storm water runoff; septic tank, landfill, and dump seepage; agricultural runoff) may also adversely affect water quality. Increased dredging associated with industrial expansion may also increase suspended and deposited sediments in the bay.

The degradation of water quality [6] in Mobile Bay, which might result from increased pollutant loadings, could have several effects. A decline in commercial and recreational fish (finfish and shellfish) harvest may result from an increase in direct mortality, a loss of suitable habitat, or an increase in the frequency and duration of closure of certain fisheries (e.g., oysters) [6]. These potential effects were represented in the workshop model by brown shrimp catch and indices of habitat suitability for oysters and brown shrimp. None of these indicators showed large changes within the time horizon

of model simulation runs, however. Fish kills in the Mobile Delta associated with industrial and municipal discharges have occurred in the past (Tucker 1979). Degradation of water quality may also cause a decline in recreational use of the bay and associated development. Thus, while industrial and urban expansion may initially stimulate the local economy in general, expansion may eventually depress certain segments of the economy. On the other hand, degradation of fresh water quality [5] may eventually limit further expansion because of inadequate supplies of fresh water for domestic and industrial use or because of violations of water quality standards. In fact, water quality standards for several parameters (DO, BOD, coliform bacteria, trace metals, nitrate, phosphate) have been violated periodically in the recent past (Brady 1979; U.S. Department of Commerce 1979). At the very least, urban and industrial growth will require increased capital expenditures for additional water and sewage treatment facilities [8].

Increased population and industrial expansion may also result in increased air pollutant emissions [10]. Repeated violations of National Ambient Air Quality Standards may eventually constrain further development [11]. Portions of eastern Mobile County have already been designated as Areas of Primary Nonattainment and Secondary Nonattainment of Standards for Particulates. The entire county has been designated as a Primary Nonattainment Area for Photochemical Oxidants (U.S. Department of Commerce 1979).[1] In theory under the Clean Air Act, permits will not be issued in the future for proposed facilities which would increase particulate or photochemical oxidant levels in these areas. Even if permits are issued, long delays in this or other permitting processes may cause prospective industries to locate elsewhere to avoid costs associated with these delays [11].

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[1]Primary standards are those necessary for protection of public health; secondary standards are those necessary to protect public welfare (including soils, water, vegetation, wildlife). For a review of the Clean Air Act see Avery and Schreiber (1979).

Industrial and urban growth will result in land use changes in both Mobile and Baldwin counties [9]. These changes could adversely impact fishery resources [13] if wetlands are destroyed by developments such as dock expansion. Certain types of wetlands are used as nursery grounds for early life stages of some commercially important fish species. On the other hand, these fisheries might be favorably affected if dredge spoil disposal is conducted so as to create these types of wetlands. Changes in land use may also constrain further industrial expansion [8] because of limited land with the proper combination of attributes suitable for development (e.g., shoreline or navigation channel access, proper zoning, adequate air quality to allow permitting, adequate clean fresh water).

Economic Input-Output Analysis

The simulation model required estimates of the employment multipliers for various types of economic activity. These were obtained by an economic input-output (I-O) analysis, or model, which also addresses several other interesting aspects of economic activity in the area. The results of this analysis are presented here as an example of the type of understanding which is not dependent on the simulation model itself, but which is often gained through the activity of constructing a simulation model.

The Mobile Bay area economy is characterized by extensive interaction between industrial sectors. Each economic sector not only produces goods and services, but is also a consumer, purchasing other goods and services for use in the production process. The inputs needed by a particular industry (or sector) to produce the commodity it sells are outputs of other industries (or sectors). For example, if the shipbuilding industry is to build a new ship, it needs certain amounts of steel, welding materials, paint, and many other inputs that are produced by other industries. As these other industries engage in their own production process, they in turn purchase inputs from other producing sectors of the economy, thereby generating more economic activity.

Not all of the expenditures by industrial sectors for productive inputs are used to purchase raw materials or capital goods. Some money is also used

to hire labor. These workers spend their wages in somewhat predictable ways, giving rise to still further additions to economic activity. Input-output techniques are used to trace these "industrial interactions" through the economy and estimate how expansion in a particular industry will affect other individual sectors as well as the employment, income, output, and population of the total two-county economy.

The I-O model used at the Mobile Bay workshop was developed from a National I-O model that includes 466 industrial sectors. All of the counties in the country are represented in this National model, and the sum of all individual county activities is controlled to equal National totals for income, employment, and value added. Two hundred twenty of the 466 sectors in the National model are active in the Mobile and Baldwin County economies. These 220 sectors were aggregated into 47 sectors in the I-O model built for the Mobile Bay workshop. Results showing the most relevant sectors are listed in Tables 7 and 8.

Table 7 reflects the relative importance of several industries in generating employment in the 47 sector Mobile Bay area I-O model. The number of jobs reflects employment in the year 1977 as used in the National I-O model. The multipliers show how many additional jobs would be created for each new job generated by expansion of a particular industry. For example, there were 8,054 people directly employed in tourism in 1977, ranking tourism fifth among sectors providing employment. For each new job generated in the tourism secotr, about 1.39 additional jobs are created within other sectors of the two county economy.

Table 8 shows the relative importance of several sectors in contributing to the value of goods and services produced in the Mobile Bay area economy. For example, in 1977 $131.5 million was added to the value of the two-county product by the chemicals industry. If the chemical industry were to expand, $1.31 would be added to the value of products in other industries for each dollar added in the chemicals industry.

Table 7. Relative importance of Mobile area economic sectors in terms of employment.

Sector	Rank	Jobs	Multiplier
Retail trade	1	18,829	1.59
New construction	2	11,937	2.13
Wholesale trade	3	9,350	1.78
Health & social services	4	9,087	1.70
Tourism	5	8,054	2.39
Lodging & eating places	6	7,045	1.75
Financial & insurance	7	4,548	2.18
Non-profit organizations	8	4,147	1.58
Maintenance construction	9	3,937	1.95
Paper mills	10	3,869	2.71
Chemicals	11	3,541	3.03
Water transportation	12	3,323	3.02
Ship building & repair	13	2,131	1.87

Table 8. Relative importance of Mobile area economic sectors in terms of total value added.

Sector	Rank	Value added ($ million)	Multiplier
Real estate	1	437.9	1.27
Retail trade	2	267.5	1.89
Wholesale trade	3	215.1	1.70
New construction	4	192.1	2.39
Chemicals	5	131.5	2.31
Health & social services	6	123.9	2.05
Paper mills	7	116.9	2.22
Maintenance construction	8	92.7	1.80
Tourism	9	88.9	1.72
Financial & insurance	10	83.5	2.28
Water transportation	12	69.7	3.01
Ship building & repair	23	28.7	2.21
Petroleum refining	25	27.2	2.28

From this general discussion, it is apparent that the Mobile Bay resource system is highly complex. This complexity results from the high degree of interaction and feedback among system components. Hopefully, the workshop activities described in this report have contributed to an integrative framework for understanding this resource system and planning balanced development in the Mobile Bay area.

FOUNDATIONS OF EFFECTIVE CONFLICT RESOLUTION

Over the past decade, the number of environmental disputes has increased dramatically; often ending in protracted litigation. While environmental decisions made by the courts have contributed to valuable policies, the costs have been high (Baldwin 1978). Litigation typically involves large expenditures of public and private funds for legal fees and escalated costs of development after long court-imposed delays. The litigation process also tends to further polarize "environmentalists" and "developers". These problems have motivated development of new procedures for resolving environmental disputes.

Environmental mediation and other forms of consensual environmental conflict resolution have only recently been developed but have been useful in the limited instances in which they have been applied (Baldwin 1978). This new approach examines conflicts as problems to be mutually solved (not court cases to be won) and explores more integrative solutions which promote a balance among diverse interests thereby allowing all sides to "win" in some sense (Hill 1982; Mernitz 1980). The environmental mediation process is thus interactional and stresses understanding and communication of the complexities of the resource system and development alternatives under consideration. The goal is to achieve a common perspective of the issue (Hill 1982). A "third party" typically facilitates this communication process and subsequent collaborative solving of the environmental dispute.

Environmental mediation is based largely on labor-management negotiation procedures but differs in several important ways (Baldwin 1978). First, labor negotiations are usually iterative, providing and opportunity "to come back

next year for a better deal". Consequences of environmental decisions are often irrevocable. Second, effects of various wage and fringe benefit concessions on corporate profits are usually well known and predictable while complex ecosystems and environmental effects of development are often poorly understood. This uncertainty adds to the difficulty of resolving conflicts. Finally, labor-management negotiations typically involve two parties while environmental disputes often involve many parties, each with different interests at stake and different indicators of interest (e.g., Table 2). It is highly unlikely that all of these indicators can be simultaneously optimized to the satisfaction of all interests and the task of achieving acceptable trade-offs becomes more difficult as the number of affected parties increases. It is important, however, that the broadest spectrum of affected interests be included in the mediation process; the exclusion of one or more parties in a position to block implementation could negate a seemingly successful solution.

The complexities of the economic and environmental systems under consideration and the multiplicity of affected parties have several general implications for resolution of associated conflicts: clear communication and a common perspective are essential; development of effective trade-offs requires a thorough understanding of complex interactions; and, since uncertainty is unavoidable, the collaborative problem solving process should be adaptive. The AEA workshop discussed in this report provided a first step towards developing these foundations for effective conflict resolution.

Communication and Reperception

Conflict is primarily subjective; parties involved in past conflict resolution workshops have often been surprised "to learn the extent to which they differed in perception of the conflict" (Hill 1982). The process of communicating perceptions of the conflict, synthesizing what is known, and objectively developing a reperception of the conflict has been highly productive for parties discussing possible resolution strategies (Hill 1982). Building a common perspective of the problem, breaking down sterotypes, and developing a common sense of purpose among participants are necessary prerequisites for collaborative problem solving (Lee 1982).

The bounding exercise provided workshop participants with the opportunity to communicate their perceptions of the management and development actions which might be taken in the Mobile area and the way in which they felt those actions might influence indicators of interest to them. The preliminary representation of the Mobile Bay area as an interacting system helped develop a common, broader, more objective perspective (i.e., reperception) of the Mobile Bay area economic-environmental system. A major advantage of this representation is that it directs attention to relationships determining change as opposed to an inventory or description of current conditions.

The process of translating the general understanding of Figure 34 to the explicit mathematical form of a simulation model revealed a number of uncertainties. These ranged from questionable approaches or poorly substantiated assumptions used in the model, to issues which were identified as important, but which were not included in the model (see LIMITATIONS sections of SUBMODEL STRUCTURES, and APPENDIX). The areas where a need for better understanding was identified included potential problems related to hazardous waste transportation and disposal, including heavy metals; interactions between land use and water access; factors determining and representing economic and social conditions; and functional relationships determining fish and wildlife populations.

There was a consistent discussion at the workshop concerning appropriate spatial and temporal scales. Actual processes and resource decisions are often very site-specific and can thus require very detailed spatial and temporal scales. Conflict resolution will probably require such detailed information and analysis. This does not imply that the broad spatial and temporal scale of the workshop model was a mistake. Changes and interactions are occurring in the Mobile Bay area as a whole and they can easily be neglected by focusing on individual sites and decisions. Often, the cumulative impact of a large number of small decisions and changes - such as wetland alterations - is unacceptable, although the individual actions are reasonable when considered in isolation. Complimentary analyses are thus required at several spatial scales.

Development of shared purposes, undermining of stereotypes, and sharing of information among parties in environmental mediation situations can often be elicited by having participants work on specific tasks in small, heterogeneous groups (Lee 1982). The conceptualization and testing of submodels by small groups of participants at the AEA workshop represented an initial attempt to elicit these responses.

In order to deal with the immense complexity and overload of often conflicting data inherent in most environmental mediation processes, mediation facilitators are increasingly using computers and simulation modeling to manage and retrieve data and project consequences of alternative proposals (Strauss and Clark 1980; Johnson 1980). Computers can provide a consistent framework for communication among adversaries and enhance consensus-building capabilities of the process. While the simulation model developed at the first AEA workshop is not sufficiently technically refined or validated to support such an activity, the model does demonstrate the potential integration and communication which models can provide. Aspects of this are discussed in more detail in the following section (Trade-Off Analysis). The difficulties encountered at the workshop with the site-specific nature of many of the issues and, in particular, with water access and shoreline as critical resources, suggest that a computer-based, geographic information system would be a useful tool. Such systems can provide easily modified storage and portrayal of spatially complex data, and are available for a variety of spatial resolutions, costs, and computer systems. They are useful in themselves, as well as potentially contributing to a more detailed simulation model.

Trade-Off Analysis

Complex systems can exhibit complicated and non-linear behavior. This means that the trade-off relationships on which conflict resolution is based will not always be strictly proportional. This is especially true if the conflict involves complex biological phenomena, such as fish or wildlife populations which may exhibit thresholds and other non-linear responses. However, effective conflict resolution can take advantage of these

relationships - if they are understood and communicated - to identify promising areas of compromise, where a relatively large benefit can be produced in one indicator with relatively little cost in terms of another indicator.

For example, consider the trade-off generated by the workshop simulation model between annual municipal and industrial loading of coliform into area 4 of Mobile Bay (potentially influenced by discharges from the proposed Theodore Industrial outfall in area 3) and the fraction of the year oyster beds are closed to harvest (Fig. 35). For the portion of the curve to the right of a discharge of about 4.5×10^{14} coliform, if relatively small decreases in discharge (e.g., a to a') can be made then relatively large increases in the time oyster harvest is open (e.g., b to b') can result. Diminishing returns occur for discharge reductions to the left of 4.5×10^{14} coliform; these reductions result in only small increases in open oyster harvest. On the other hand, if small decreases in the time oyster beds are open is acceptable (e.g., c to c'), then relatively large increases in the coliform loading could be tolerated (e.g., d to d') with assumed concomittant decreases in capital expenditures for treatment facilities. Trade-off considerations such as this would, of course, also have to include the additional costs of treatment to attain discharge reductions and the value of the increased oyster harvest. Although the workshop model will not currently support this type of activity, Figure 35 demonstrates the way in which modeling of interactions of many factors (population growth, industrial development, sewage treatment, oyster habitat requirements) can be used to suggest potentially productive areas for compromise discussions.

Manage for Uncertainty

Uncertainty is an unavoidable aspect of decisions concerning complex economic-environmental systems. This uncertainty arises from an incomplete understanding of the systems involved and unexpected events (changing economic conditions, technological innovations, unpredicted impacts) which may occur in the future and influence these systems and decisions associated with them. Even when decisions are mutually achieved, problems with implementation or changing circumstances may subsequently renew the conflict (Lee 1982). To the

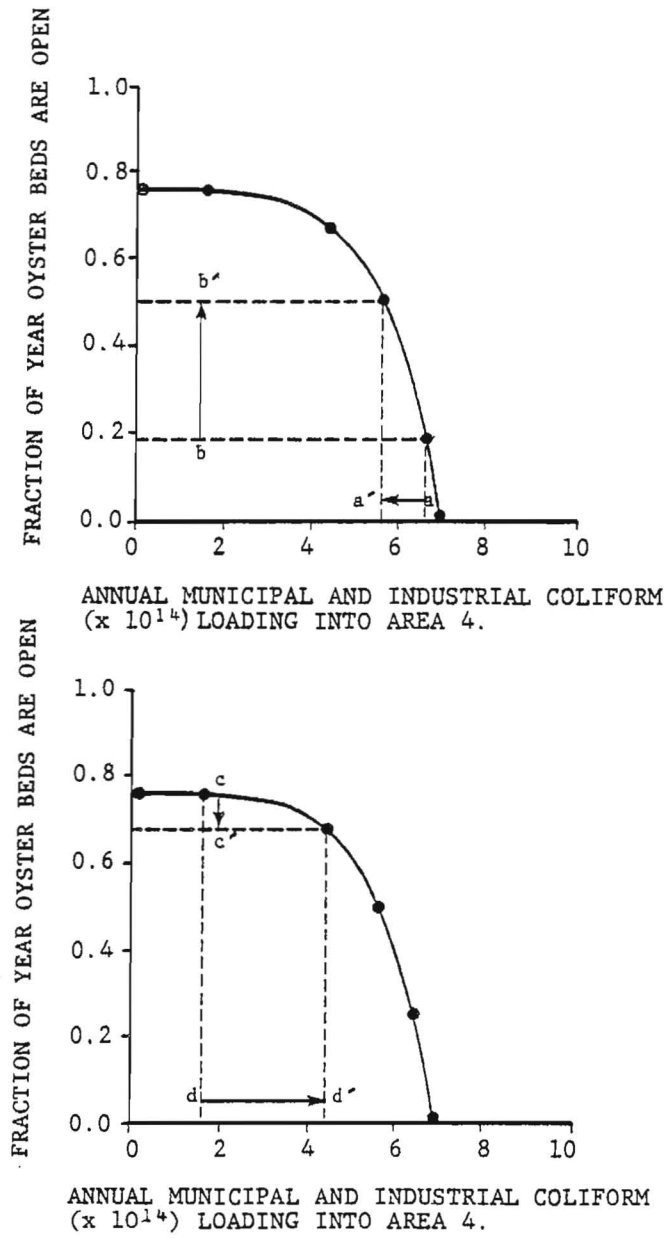

FIGURE 35. Potential trade-offs between coliform loading in area 4 and fraction of year oyster beds are open.

extent possible, environmental mediation should be an open-ended process (Lee 1982) approached from an adaptive management viewpoint (Hilborn 1978). The adaptive management philosophy holds that in such situations, management or utilization decisions should be made not only on the basis of their expected results, but also for their utility in producing information needed to better understand the system, and their probable flexibility in responding to unexpected events that inevitably occur. In addition, a continuing relationship among affected parties should be maintained to facilitate adjustments as circumstances change.

WORKSHOP CONCLUSIONS

Workshop participants felt that the workshop modeling process was a useful first step towards developing a mechanism for coordinated communication and planning among agencies and interest groups and a framework for addressing controversial issues in a rational, integrated manner. Participants expressed the need for such activities in the Mobile area and felt that continued model development and interaction of the various interests might be worthwhile for these reasons. In addition, participants suggested that the understanding of interactions among components of the Mobile Bay area system which was developed at the workshop be presented to managers and decisionmakers who were not at the workshop. Participants felt that this activity could further facilitate interagency planning. The primary value of this initial modeling exercise has been in its use as a communications tool, not as a final answer in itself. This perspective was well summarized by Don Blancher, a workshop participant, who commented: "Models are to be used, but not necessarily believed".

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APPENDIX

MODEL LIMITATIONS AND RESEARCH NEEDS

A discussion period at the workshop was devoted to identifying limitations of the simulation model and limitations of both data and understanding of relationships which were identified in the process of model construction. These are presented below, organized by the submodel areas, in a form very similar to that in which they were recorded at the workshop. Many of the items are phrased as suggestions for model improvement or topics on which information and understanding needs to be improved. Model limitations and information or research needs are also discussed in the SUBMODEL STRUCTURES and WORKSHOP RESULTS sections of the body of the report.

Industry

1. High resolution model to locate specific sites for dredge spoil disposal;

2. Specific port requirements (e.g., marshalling yards);

3. Potential for, and consequent effects of, off-shore mineral extraction;

4. More advance planning, and communcation of that planning, for off-shore facilities;

5. More information about the types of industrial development likely at specific sites;

6. A more specific and better developed proposal for off-shore port facilities as an alternative to some on-shore port expansion;

7. Careful investigation of the need for additional electrical generating capacity;

8. Better understanding of the potential of deep-well injection as a waste disposal alternative;

9. Better information on hazardous waste disposal and transportation;

10. More information on economic costs of permitting delays;

11. Clearer understanding of water access requirements of various industries; and

12. Additional information on industrial/transportation air pollutant emissions (e.g., heavy metals) due to both primary development and anticipated secondary growth.

Terrestrial - Land Use/Air Quality

1. Effects of various land use alternatives on specific wildlife species;

2. More detail spatial resolution;

3. Ability to track effects of institutional and legislative action on air quality; and

4. Better understanding of shoreline utilization, and access, and its dynamics in relation to industry, recreation, tourism, and critical habitat.

Water Quality

1. Hydrodynamic modeling of the Bay, including treatment of stratification;

2. Better understanding of whether heavy metals are a problem; and

3. Experiments and modeling to estimate the origins, relative loadings, and fates of coliform bacteria, especially with respect to how well coliform counts indicate water quality if coliforms associated with pulp and paper operations do not have as high a level of associated pathogens.

Fish

1. Effects of overfishing on population dynamics of Mobile Bay species;

2. Whether shrimp recruitment from the Gulf always adequate, and the variability in recruitment;

3. How catch per unit effort (CPUE) and total harvest in the Bay is changing over time for shrimp and crabs;

4. Consideration of other species (e.g., oysters and speckled trout) - what information is available and how important these species are; and

5. Effects on commercial fishing due to habitat destruction from pollution loadings and trace metals.

Human Population/Economics

1. Better understanding of solid waste disposal situation;

2. Quantitative methods to address "Other Services" such as police and fire protection;

3. Predictions including more economic indicators (e.g., Gross Regional Product and Personal Income);

4. Because it is difficult to aggregate variables into a single indicator "quality of life", some additional indicators needed include health, educational levels, crime, services (including recreational opportunities), and divorce rates.

5. Availability of recreational opportunities and services can affect crime rates;

6. Economic and social considerations have not been given adequate (balanced) consideration in the workshop model; and

7. People moving to Mobile Bay for retirement and unemployable portion of population need to be considered.