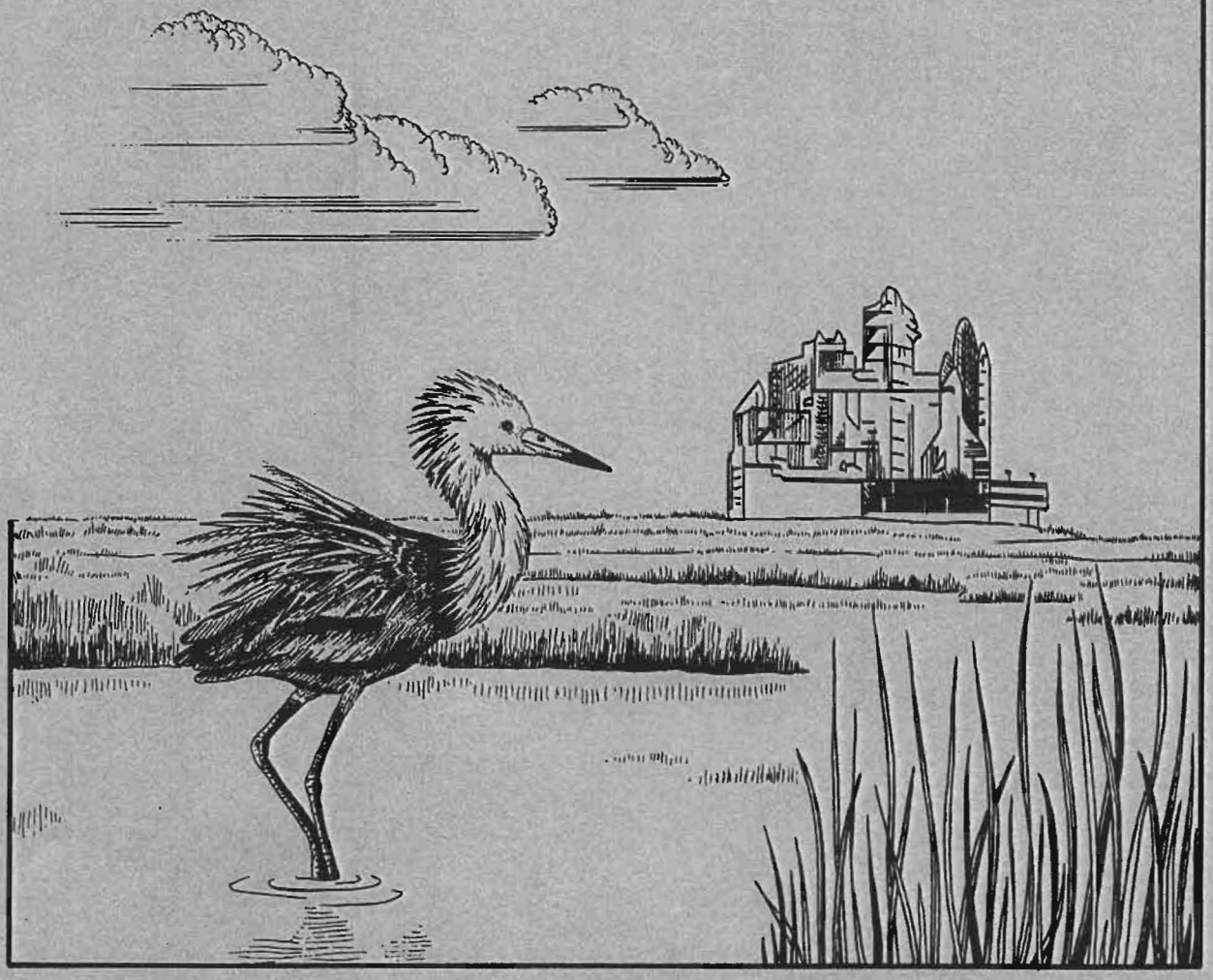
WELUT-85/W05
FEBRUARY 1985

ENVIRONMENTAL SYSTEMS AND MANAGEMENT ACTIVITIES ON THE KENNEDY SPACE CENTER, MERRITT ISLAND, FLORIDA: RESULTS OF A MODELING WORKSHOP



Fish and Wildlife Service

U.S. Department of the Interior

WELUT-85/W05
February 1985

ENVIRONMENTAL SYSTEMS AND MANAGEMENT ACTIVITIES ON THE KENNEDY SPACE CENTER, MERRITT ISLAND, FLORIDA: RESULTS OF A MODELING WORKSHOP

by

David B. Hamilton
Austin K. Andrews
Gregor T. Auble
Richard A. Ellison
Adrian H. Farmer
and
James E. Roelle
Western Energy and Land Use Team
U.S. Fish and Wildlife Service
2627 Redwing Road
Fort Collins, Colorado 80526-2899

Performed for
Environmental Sciences Branch
John F. Kennedy Space Center
National Aeronautics and Space Administration
Kennedy Space Center, Florida 32899

Western Energy and Land Use Team
Division of Biological Services
Research and Development
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

This report should be cited as:

Hamilton, D. B., A. K. Andrews, G. T. Auble, R. A. Ellison, A. H. Farmer, and J. E. Roelle. 1985. Environmental systems and management activities on the Kennedy Space Center, Merritt Island, Florida: results of a modeling workshop. U.S. Fish Wildl. Serv., Western Energy and Land Use Team, Ft. Collins, CO. WELUT-85/W05. 130 pp.

EXECUTIVE SUMMARY

In the early 1960's, the National Aeronautics and Space Administration (NASA) began purchasing 140,000 acres on Merritt Island, Florida, in order to develop a center for space exploration. Most of this land was acquired to provide a safety and security buffer around NASA facilities. NASA, as the managing agency for the Kennedy Space Center (KSC), is responsible for preventing or controlling environmental pollution from the Federal facilities and activities at the Space Center and is committed to use all practicable means to protect and enhance the quality of the surrounding environment. The Merritt Island National Wildlife Refuge was established in 1963 when management authority for undeveloped lands at KSC was transferred to the U.S. Fish and Wildlife Service.

In addition to managing for 11 Federally-listed threatened and endangered species and other resident and migratory fish and wildlife populations, the Refuge has comanagement responsibility for 19,000 acres of mosquito control impoundments and 2,500 acres of citrus groves. The Canaveral National Seashore was developed in 1975 when management of a portion of the coastal lands was transferred from NASA to the National Park Service. This multiagency jurisdiction on Merritt Island has resulted in a complex management environment.

The modeling workshop described in this report was conducted May 21-25, 1984, at the Kennedy Space Center to: (1) enhance communication among the agencies with management responsibilities on Merritt Island; (2) integrate available information concerning the development, management, and ecology of Merritt Island; and (3) identify key research and monitoring needs associated with the management and use of the island's resources. The workshop was

structured around the formulation of a model that would simulate primary management and use activities on Merritt Island and their effects on upland, impoundment, and estuarine vegetation and associated wildlife.

The simulation model is composed of four connected submodels. The Uplands submodel calculates changes in acres and structural components of vegetation communities resulting from succession, fire, facilities development, and shuttle launch depositions, as well as the quantity and quality of surface runoff and aquifer input to an impoundment and an estuary. The Impoundment submodel next determines water quality and quantity and changes in vegetation resulting from water level manipulation and prescribed burning. The Estuary submodel then determines water quality parameters and acres of seagrass beds. Finally, the Wildlife submodel calculates habitat suitability indices for key species of interest, based on vegetation conditions in the uplands and impoundments and on several hydrologic parameters. The model represents a hypothetical management unit with 2,500 acres of uplands, a 600-acre impoundment, and a 1,500-acre section of estuary. Two management scenarios were run to analyze model behavior. The scenarios differ in the frequency of shuttle launches and prescribed burning, the extent of facilities development, the amount of land disposed waste material applied, and the nature and timing of impoundment water level control.

Early in a model development project, the <u>process</u> of building the model is usually of greater benefit than the model itself. The model building process stimulates interaction among agencies, assists in integrating existing information, and helps identify research needs. These benefits usually accrue even in the absence of real predictive power in the resulting model. Open communication occurs among the Federal, State, and local agencies involved with activities on Merritt Island and the agencies have a cooperative working relationship. The workshop provided an opportunity for all of these agencies to meet at one time and have focused discussions on the key environmental and multiagency resource management issues. The workshop framework helped to integrate information and assumptions from a number of disciplines and

agencies. This integration occurred in the computer simulation model and among workshop participants as submodel linkages were developed and scenario results discussed.

A number of research needs were identified at the workshop during the model building and testing exercises and associated discussions. These needs were based on the informed judgement of researchers and managers familiar with Merritt Island or similar areas, rather than on a comprehensive literature review or sensitivity analysis of the preliminary model developed at the workshop. Some of the needs can be addressed by interpreting the results of completed studies from similar geographic areas as they relate to Merritt Island, while others will require additional research studies on Merritt Island. Major research needs associated with the Upland submodel include behavior of the near-surface aquifer, factors limiting slash pine regeneration, frequency and effects of natural fire on various cover types, cumulative effects of shuttle launches, and fate in upland soils of nitrogen and phosphorus from land applied waste material. Key Impoundment submodel needs include documentation of vegetation changes in response to altered water depth, salinity, and nutrient concentrations and better specification of the functional characteristics of impoundments as chemical filters. Important information gaps identified in the Estuary submodel include a more complete analysis of factors contributing to phytoplankton abundance, evaluation of sources of turbidity other than phytoplankton, and identification and quantification of factors limiting seagrass distribution. Primary research needs associated with the Wildlife submodel include a survey of breeding habitat, production data, and harvest data for mottled ducks; data on the emigration and immigration of juvenile mullet (and other transient fish) in the impoundment; the contribution of various seagrasses to habitat requirements of sea trout; and the effects of dissolved oxygen on survival of juvenile sea trout.

Ideally, the modeling workshop process is iterative in nature. Periods between workshops are used for research, data collection, and model refinement. Each workshop integrates information collected since the last workshop and produces a more credible model that is more useful in evaluating management

alternatives. Participants felt that continued application of this process would help provide ongoing integration and communication among agencies and would allow each agency's planning and management activities to be viewed within the context of an overall assessment.

CONTENTS

	Page
EXECUTIVE SUMMARY	iii
FIGURES	viii
TABLES	xii
ACKNOWLEDGMENTS	xiii
INTRODUCTION	1
Objectives	2
Facilitated Modeling Workshops	3
BOUNDING THE WORKSHOP MODEL	5
Actions and Indicators	6
Space and Time	6
MODEL DESCRIPTION	10
Overview	10
Upland Submodel	18
Impoundment Submodel	43
Estuary Submodel	64
Wildlife Submodel	76
MODEL BEHAVIOR	92
Scenario I	93
Scenario II	107
WORKSHOP RESULTS	121
Communication	121
Information Integration	121
Research Needs	122
REFERENCES	129

FIGURES

Number		Page
1	Looking Outward Matrix constructed at the Merritt Island workshop	12
2	General flow of information to and from each submodel	14
3	Overall structure and order of calculation for the Merritt Island model	14
4	Hypothetical management unit	16
5	Percent cover of oaks as a function of time since last fire	36
6	Mean shrub height as a function of time since last fire	37
7	Percent open area and cover of vegetation less than 6 inches tall as a function of time since last fire	38
8	Percent tree canopy closure in slash pine flatwoods as a function of time since last fire	39
9	Proportional decrease in percent cover of oaks in mixed oak scrub as a function of the number of shuttle launches per year that result in deposition on the management unit	40
10	Diagrammatic cross section of impoundment	45
11	Relative elevations used in Impoundment submodel calculations	46
12	Relationship of water depth to storage volume for the 600-acre impoundment	47
13	Components of impoundment water budget	48
14	Cases of surface water exchange between impoundment and estuary	51
15	Location of cover type optima in salinity-water depth state space	59

FIGURES (continued)

Number		Page
16	Graphic representation of Euclidean distance calculations for one point in system's trajectory through salinity-water depth state space	59
17	Stylized representation of estuary considered in the Estuary submodel	65
18	Cross-sectional view of stylized esutary considered in the Estuary submodel	66
19	Chlorophyll-a concentration as a function of total phosphorus concentration	70
20	Average turbidity as a function of average chlorophyll-a concentration	72
21	Maximum depth at which sea grass can exist as a function of turbidity	74
22	Maximum distance from shore at which sea grass can exist as a function of maximum depth at which seagrass can exist	74
23	Scrub jay density as a function of vegetation structure for four different variables	79
24	Gopher tortoise suitability indices as a function of vegetation, water table depth, and time since last fire	82
25	Mosquito production indices as a function of both hydrology and vegetation structure	84
26	Striped mullet density by month in estuarine areas contiguous with Merritt Island	88
27	Mottled duck brood habitat suitability as a function of vegetation cover	90
28	Acres of slash pine flatwood and saw palmetto scrub - Scenario I	96
29	Acres of xeric oak hammock and mixed oak scrub - Scenario I	96

FIGURES (continued)

Number		Page
30	Acres of developed land and citrus groves - Scenario I	97
31	Percent cover of oaks in mixed oak scrub, saw palmetto scrub, and slash pine flatwood - Scenario I	98
32	Average water depth and salinity in the impoundment - Scenario I	99
33	Acres of mangrove-halophyte and salt marsh - Scenario I	99
34	Acres of cattail-mixed freshwater marsh and willow swamp-marsh - Scenario I	100
35	Acres of open water - Scenario I	100
36	Storage of available total phosphorus and aluminum in the impoundment - Scenario I	102
37	Loading of total phosphorus to the estuary from the impoundment and from runoff and precipitation - Scenario I	102
38	Average chlorophyll-a concentration and extent of sea grass beds - Scenario I	103
39	Number of scrub jays and scrub jay suitability index for mixed oak scrub - Scenario I	103
40	Index of gopher tortoise carrying capacity - Scenario 1	105
41	Salt marsh mosquito production - Scenario I	105
42	Mullet-days per year - Scenario I	106
43	Acres of slash pine flatwood and saw palmetto scrub - Scenario II	110
44	Acres of xeric oak hammock and mixed oak scrub - Scenario II ..	110
45	Acres of developed land and citrus groves - Scenario II	111

FIGURES (concluded)

Number		Page
46	Percent cover of oaks in mixed oak scrub, saw palmetto scrub, and slash pine flatwood - Scenario II	111
47	Average water depth and salinity in impoundment - Scenario II	112
48	Acres of mangrove-halophyte and salt marsh - Scenario II	112
49	Acres of cattail-mixed freshwater marsh and willow swamp-marsh - Scenario II	113
50	Acres of open water - Scenario II	113
51	Storage of available total phosphorus and aluminum in impoundment - Scenario II	115
52	Loading of total phosphorus to the estuary from the impoundment and from runoff and precipitation - Scenario II	115
53	Average chlorophyll-a concentration and extent of sea grass beds - Scenario II	116
54	Number of scrub jays and scrub jay suitability index for mixed oak scrub - Scenario II	116
55	Index of gopher tortoise carrying capacity - Scenario II	117
56	Salt marsh mosquito production - Scenario II	117
57	Wading bird-days per year - Scenario II	118
58	Mullet-days per year - Scenario II	119
59	Mottled duck broods per year - Scenario II	119

TABLES

Number		Page
1	Management actions identified at the Merritt Island workshop	7
2	Performance indicators identified at the Merritt Island workshop	8
3	Successional transitions and time constants for upland vegetation cover types	31
4	Minimum time between fires in upland cover types	33
5	Fire conversion factors for slash pine flatwood age classes	34
6	Monthly water quantity and quality variables - Scenario I	94
7	Monthly water quantity and quality variables - Scenario II	108

ACKNOWLEDGMENTS

This report summarizes the activities, discussions, and conclusions of a modeling workshop concerning the environmental systems and managment activities on the NASA Kennedy Space Center. The following individuals participated in the workshop:

Fred Adrian
Merritt Island NWR
Fish and Wildlife Service
P.O. Box 6504
Titusville, FL 32780
(305) 867-4820

G. Ronnie Best
Ecologist & Associate Director
Center for Wetlands
Phelps Laboratory
University of Florida
Gainesville, FL 32611
(904) 392-2424

John Breen
National Park Service
Canaveral National Seashore
Titusville, FL
(305) 867-4675

David R. Breininger
Bionetics Corp.
BIO-2
Kennedy Space Center, FL 32899
(305) 853-3281

Jonathan Brown
Clark Engineers-Scientist
7520 Southwest 57 Avenue
Miami, FL 33143
or
Box 21167
Kennedy Space Center, FL 32815
(305) 867-2000

Mario Busacca
Environmental Management Staff
DF-EMS
Kennedy Space Center, FL 32899
(305) 867-7509

Charles Chambers
Executive Director
American Institute of
Biological Sciences
1401 Wilson Boulevard
Arlington, VA 22209
(703) 527-6776

Steven P. Christman
U.S. Fish & Wildlife Service
Denver Wildlife Research Center
412 NE 16th Avenue
Gainesville, FL 32601
(904) 372-2571

Mary Davis
Tall Timbers Research Station
Rt. 1, Box 160
Tallahassee, FL 32312
(904) 893-4153

David Dwornik
Black Hall
Department of Environmental
Engineering
University of Florida
Gainesville, FL 32611
(904) 392-0834

Jim Frazee
St. Johns River Water
Management District
P.O. Box 1429
Palatka, FL 32077
(904) 328-8321

R. Grant Gilmore
Assistant Research Scientist
Harbor Branch Foundation, Inc.
Link Port
RR 1, Box 196
Fort Pierce, FL 33450
(305) 465-2400

Carlton Hall
Bionetics Corp.
BIO-2
Kennedy Space Center, FL 32899
(305) 853-3281

Ross Hinkle
Bionetics Corp.
BIO-2
Kennedy Space Center, FL 32899
(305) 853-3281

John Hutton
Brevard Mosquito Control District
P.O. Box 728
Titusville, FL 32780
(305) 636-6062

Herbert W. Kale II
Florida Audubon Society
11-1 Audubon Way
Maitland, FL 32751
(305) 843-5796

William M. Knott
Biological Sciences Officer
MD-ENV
Kennedy Space Center, FL 32899
(305) 867-3152

Albert M. Koller, Jr.
KSC Environmental Health Officer
MD-ENV
Kennedy Space Center, FL 32899
(305) 867-3152

Dennis Kuenzel
National Park Service
Kennedy Space Center, FL 32899
(305) 867-4674

Willard Leenhouts
P.O. Box 6504
Merritt Island National
Wildlife Refuge
Titusville, FL 32780
(305) 867-4826

Clay L. Montague
Assistant Professor
Department of Environmental
Engineering Sciences
A. P. Black Hall
University of Florida
Gainesville, FL 32611
(904) 392-0836

Paul Schmalzer
Bionetics Corp.
BIO-2
Kennedy Space Center, FL 32899
(305) 853-3281

Frank Snelson
Department of Biological Sciences
Box 25000
University of Central Florida
Orlando, FL 32816
(305) 275-2141

Wilson Timmons
Water Resources
Merritt Island Courthouse
2775 N. Courtney Pkwy.
Merritt Island, FL 32953
(305) 453-9550

Stephen R. Vehrs
Merritt Island National
Wildlife Refuge
P.O. Box 6504
Titusville, FL 32780
(305) 867-4820

Michael Willard
Environmental Engineering
Merritt Island Courthouse
2575 N. Courtney Pkwy.
Merritt Island, FL 32953
(305) 453-9550

Al Zale
School of Forest Resources
and Conservation
Cooperative Fish & Wildlife
Research Unit
117 Newins-Ziegler
University of Florida
Gainesville, FL 32611
(904) 392-1861

As workshop facilitators, the authors of this report are indebted to all of these individuals for their contributions. In particular, we wish to thank Al Koller and Bill Knott of the Environmental Sciences Branch at the Kennedy Space Center for giving us the opportunity to facilitate the workshop. In addition, opening presentations by Bill Knott, Steve Vehrs, and Bill Leenhouts and permission to use descriptions of the activities and management responsibilities of the Federal agencies on Merritt Island were extremely useful and greatly appreciated.

Despite the quality of the contributions by the participants listed above, errors of fact or interpretation may remain. For these, the authors take full responsibility.

INTRODUCTION

In the early 1960's, the National Aeronautics and Space Administration (NASA) began purchasing most of the northern portion of Merritt Island, Florida, in order to establish a center for space exploration. Sufficient land was acquired to provide an adequate safety and security buffer for launching chemically-fueled rockets. Currently, 140,000 acres are owned by NASA and administered as the Kennedy Space Center (KSC).

In 1963, Merritt Island National Wildlife Refuge (MINWR) was established when NASA transferred management authority for part of its wildlands to the U.S. Fish and Wildlife Service. By cooperative agreement, this authority was expanded in 1972 to include all of the KSC except areas with NASA facilities and other property related to the space program. Because all of the MINWR is owned by NASA, it is considered an overlay refuge. Among the acquisition terms for the Refuge was the comanagement of 19,000 acres of mosquito control impoundments (with the Brevard Mosquito Control District) and 2,500 acres of citrus croplands. The MINWR provides habitat for 11 Federally-listed endangered and threatened species. Prescribed burning and water level manipulation are the primary techniques used to manage habitats for these and other species inhabiting Merritt Island.

In 1975, management of a portion of the coastal lands was transferred to the National Park Service (NPS). However, when the Canaveral National Seashore was established, primary management authority for most of the undeveloped lands was retained by the MINWR.

NASA, as the managing agency for the KSC, is responsible, under Executive Order 12088, "... for ensuring that all necessary actions are taken for the prevention, control, and abatement of environmental pollution with respect to Federal facilities and activities under the control of the agency." In addition, NASA, in its Procedures for Implementing the National Environmental Policy Act (NEPA), as published in 14 CFR 1216, is committed to "... use all practicable means, consistent with NASA's statutory authority, available resources, and the National policy, to protect and enhance the quality of the environment."

At the KSC, the Biomedical Office in the Environmental Sciences Branch has been charged with investigating, interpreting, and predicting physical, chemical, and biological impacts on the surrounding environment from all KSC operations. Accordingly, the Biomedical Office has, over the past decade, conducted baseline environmental monitoring and ecological studies and has recently implemented a long term monitoring plan. The monitoring activites will provide information on the environmental effects of all KSC operations, including facility development, industrial operations, system support operations, and space vehicle launches and landings. This information will provide a basis for NASA policy and operational decisions to ensure the protection and enhancement of the KSC environment.

OBJECTIVES

A simulation modeling workshop was held May 21-25, 1984, at the KSC to focus available expertise and knowledge concerning the environmental systems and various management activities on Merritt Island. Specific objectives of the workshop were to:

(1) Enhance communication among the Federal, State, and local agencies involved with activities on Merritt Island;

(2) Integrate existing information concerning development, management, and ecology of Merritt Island; and

(3) Identify key research and monitoring needs associated with management and use of the island's resources.

The workshop was sponsored by the Kennedy Space Center and coordinated with the Merritt Island National Wildlife Refuge and the Canaveral National Seashore. It was facilitated by staff from the Western Energy and Land Use Team, U.S. Fish and Wildlife Service, and attended by participants representing Federal, State, and local government agencies and academic institutions. This report is a summary of the workshop activities and results.

FACILITATED MODELING WORKSHOPS

The workshop modeling approach (Holling 1978) was developed by environmental scientists and systems analysts at the University of British Columbia and the International Institute for Applied Systems Analysis in Austria. The approach is organized around a series of 3- to 5-day workshops that define information needs and promote a common understanding of the issues. These workshops are followed by periods of information collection, analysis, and synthesis. The workshops are attended by participants from key agencies and interests, who collectively represent a range of scientific expertise, management responsibility, and decisionmaking authority. These individuals are both involved in the workshops and undertake some of the key tasks of information collection, analysis, and guidance that occur between workshops.

The focus of modeling workshops is the construction and refinement of a quantitative, dynamic simulation model of the system under study. Early in a particular application, the process of building the model is usually of greater benefit than the model itself. Benefits of the model building approach include:

(1) The development of a simulation model enables participants to view their expertise in the context of the whole system, thereby promoting interdisciplinary and interagency communication, understanding, and collaboration.

(2) The model building process focuses attention on the interrelationships and indirect connections between components of the resource system. 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.

(3) Model building forces a clear statement of the assumptions being made, both stated and subconscious, in day-to-day management and decisionmaking activities. A clear statement of assumptions and their implications to other workshop participants provides better understanding, and perhaps better support, of management decisions and represents a set of clearly stated questions or hypotheses for analysis.

(4) The simulation model provides a logical framework for synthesizing a variety of existing information.

(5) Finally, the attempt to quantify environmental, economic, and social processes associated with the resource issue quickly and objectively identifies gaps in data or our conceptual understanding of the system, which can be translated into research priorities.

With sufficient refinement, models sometimes can provide a reasonable representation of future consequences of various management or decision alternatives. The involvement of managers and decisionmakers in the model building process helps ensure that potential users understand the strengths and weaknesses of the resulting tool.

BOUNDING THE WORKSHOP MODEL

Combined operational, development, and resource management issues, such as those on Merritt Island, typically involve complex interactions among a variety of economic, social, and environmental factors. Although some individual components of such a system may be well understood, the complexity of component interactions generally results in poor understanding of the system as a whole. Simple representations of poorly understood systems often provide valuable insight into system behavior under different management or development alternatives, although they may not provide sufficient detail and credibility for actual decisionmaking. The representation used in a simulation model must, therefore, be sufficiently detailed and flexible to address all concerns adequately, yet must remain simple enough to be understandable. Problem simplification for better understanding is stressed in the early phases of the workshop modeling process; addition of realistic complexity is stressed in later phases to provide a level of detail consistent with management and decision needs.

The workshop modeling process approaches the bounding problem through a group discussion of actions (those activities that management can undertake to manipulate the system toward some desired end) and indicators (those performance measures used to evaluate the response of the system). Because indicators are the links between the simulation model and participants' perceptions of the system, it is important to compile a comprehensive list that represents the concerns of all interests. The discussion subsequently turns to consideration of the spatial and temporal resolution necessary to represent the components and processes implied by this set of actions and indicators. Spatial resolution concerns the geographic extent of the model, as well as the degree to which that geographic area needs to be subdivided into smaller units

in order to represent the dynamics of the processes involved. Temporal resolution refers to the basic time step of model calculations and the number of iterations needed to cover the time horizon of interest.

ACTIONS AND INDICATORS

The actions and indicators initially identified at the workshop are shown in Tables 1 and 2. For the purposes of this report, they are organized into the groups that became major components (submodels) of the simulation model. Management actions are listed only under the submodel that contains the computer code implementing that action; however, the actions may affect indicators in more than one submodel. The actions and indicators represent the participants' initial definition of the system and its primary components and are organized by submodels. The items in these lists have been edited and combined in order to avoid the duplication and confusion that inevitably occur during a workshop. Hopefully, all the ideas expressed during the workshop have been retained.

SPACE AND TIME

On the basis of these actions and indicators and discussions of fire and water management on the MINWR, it was decided that the workshop model should consider a hypothetical management unit. The unit was subdivided into an upland area, an impoundment, and an estuary. This relatively simple representation allowed subsequent discussions to focus on the functional effects of management and development on vegetation and wildlife, rather than becoming bogged down in spatial complexities of particular management units or locations. If desired, the model can use site-specific data (e.g., acres of cover types, size of impoundments, size of watersheds draining into the impoundment and the estuary, cover types and water depths in the impoundment) to approximate a particular management unit. Subsequent modeling activities could refine the model to include multiple impoundments and aerial ignition units if such detail is required for management and decisionmaking.

Table 1. Management actions identified at the Merritt Island workshop.

Submodel	Action
Upland	- Shuttle launch - Construction of new facilities - Solid/liquid waste management - Prescribed burning - Storm water management - Control of exotic plants* - Reforestation* - Citrus management* - Facility maintenance - roads*
Impoundment	- Water level manipulation/ mosquito control - Opening/building dikes - Prescribed burning - Dike maintenance*
Estuary	- Dredging and disposal* - Opening/building causeways* - Control of boat traffic*
Wildlife	- Management for threatened and endangered species - Sport and commercial fishing regulation* - Control of exotic animals*
Other	- Visitor use regulation*

*Indicates that the action was identified but not incorporated into the model due to lack of time or information.

Table 2. Performance indicators identified at the Merritt Island workshop.

Submodel	Indicator
Upland	Acres of various cover types Percent coverage of dominant species Height of shrub layer Depth to groundwater Fuel loading* Reproduction* Species composition of each cover type*
Impoundment	Surface water depth Surface water quality salinity aluminum zinc phosphorus nitrogen dissolved oxygen* pH* temperature* Acres of various cover types
Estuary	Acres of seagrass beds
Wildlife	Scrub jays Gopher tortoises Mosquitos Mullet Mottled ducks Piscivorous wading birds Eagles* Woodstorks* Palm warblers* Yellow-rumped warblers* Nesting shore birds* Mosquito fish* Flag fish* Spotted sea trout* Sea turtles* Manatees*
Other	Visitor use-days*

*Indicates that the indicator was identified but not incorporated into the model due to lack of time or information.

The time horizon for the model was set at 30 to 50 years so that the effects of management and development activities on vegetation communities and subsequent recovery could be simulated. The incremental time step for the model proved to be troublesome because of the very different time scales at which the relevant processes operate. For example, changes in chemical concentrations in the water column or changes in mosquito populations are best represented with a time step of several hours to several days. On the other hand, changes in some wildlife populations and vegetation communities are appropriately modeled with time steps of a year to several years. Because of this disparity, a monthly time step was chosen for water balance calculations within the Upland, Impoundment, and Estuary submodels, and an annual time step was chosen for all other calculations.

MODEL DESCRIPTION

OVERVIEW

Submodel Definition

The system defined by the actions, indicators, spatial scale, and temporal framework described above was divided into four subsystems. The criteria for useful division of a model into submodels at a workshop are:

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

(2) Allocating participant expertise efficiently (each submodel represents the concerns and expertise of a particular set of participants); and

(3) Partitioning the workload equally among facilitators so that participants have an opportunity to incorporate an appropriate amount of depth in their area of expertise.

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

(1) Upland - acres and structural characteristics of cover types; the quantity and quality of water running off into the impoundment and estuary; and the effects of prescribed burning, facilities development, launch deposition, and land application of waste materials.

(2) Impoundment - acres of cover types; water depth, acres inundated, and water quality; and effects of water level manipulation and prescribed burning.

(3) Estuary - acres of seagrass beds and water quality.

(4) Wildlife - habitat suitability indices for key fish and wildlife species.

During initial planning, it was anticipated that the model developed at the workshop would focus on management actions (e.g., fire management or water level manipulations) relevant to the upland and impoundment components of the Merritt Island ecosystem. While the importance of the open estuary was recognized in a general way, it was not envisioned as a separate component of the model. As a result, only a few people with expertise in estuarine ecology were invited, and they were not alerted to the possible need at the workshop for data and/or models pertaining to the estuary. During the initial phases of the workshop, however, it became apparent that there was general interest in the impacts of management activities in the estuaries surrounding Merrit Island. The estuary was, therefore, included as a model component, and a small group of participants constructed a very simple estuarine model (see ESTUARY SUBMODEL section). Additional time and information would, no doubt, have resulted in a more credible model.

Submodel Interactions

Following submodel definition, workshop participants defined the linkages or information transfers between the submodels. The mechanism for identifying these linkages is referred to as a Looking Outward Matrix. The Looking Outward Matrix presented in Figure 1 has been edited to reflect discussions and decisions that occurred among subgroups throughout the workshop. The submodels or components are arrayed as both the row and column headings of the matrix. For each of the matrix elements representing an interaction between two components, the following question is asked: "In order to represent the

...FROM THIS SUBMODEL	INFORMATION REQUIRED BY THIS SUBMODEL... UPLAND	IMPOUNDMENT	ESTUARY	WILDLIFE
UPLAND		Volume of surface water runoff from uplands (acre-inches) Volume of surficial groundwater input (acre-inches) Precipitation (inches) Loadings of Al, Zn, total nitrogen, total phosphorus, and salt in precipitation, surface runoff, and surficial groundwater	Volume of surface water runoff from uplands (acre-inches) Volume of surficial groundwater input (acre-inches) Precipitation (inches) Loading of total phosphorus in precipitation, surface runoff, and surficial groundwater	Percent cover of oak in mixed oak scrub, saw palmetto scrub, and slash pine flatwood cover types Mean shrub height (meters) in mixed oak scrub, saw palmetto scrub, and slash pine flatwood cover types Percent of open area or with vegetation less than 6 inches in mixed oak scrub, saw palmetto scrub, and slash pine flatwood cover types Percent tree canopy closure in slash pine flatwood cover type Acres of each cover type Time since last fire for all cover types (years) Depth to water table (meters) in mixed oak scrub, saw palmetto scrub, and slash pine flatwood cover types
IMPOUNDMENT	Water level (feet above mean sea level) Total area of impoundment (acres)		Volume of water flowing to or from impoundment (acre-inches) Total phosphorus in water flowing from impoundment (lbs) Evapotranspiration (inches)	Number of 2-week dry periods from May through September Connection of impoundment to estuary each month (open or closed) Total acres inundated each month Acres of marsh vegetation Acres of marsh vegetation inundated each month
ESTUARY	Water level (feet above mean sea level) Surface area of estuary (acres)	Water level (feet above mean sea level) Concentration of Al, Zn, total nitrogen, total phosphorus, and salt in estuary (lbs/acre-inch)		Acres of seagrass beds
WILDLIFE				

Figure 1. Looking Outward Matrix constructed at the Merritt Island workshop.

dynamics of the submodel in this column, what information is required from the submodel in this row?" In addition to identifying linkages between the model components, constructing such a matrix is extremely useful in promoting interdisciplinary communication and understanding. Workshop participants are forced to look carefully at the kinds of information that they can reasonably expect to obtain from other disciplines (i.e., how their submodel dynamics are influenced by other submodels) and the kinds of information other disciplines expect from them (i.e., how their submodel influences the dynamics of the other submodels). Note that the question asked in this exercise (What information is needed from other disciplines?) is qualitatively different from the more common one that asks what information each discipline can provide.

Following the Looking Outward exercise, the workshop participants met in smaller subgroups, one for each major component, to construct a conceptual model representing the internal dynamics of that component. The basic charge of each subgroup is summarized in Figure 2, which is interpreted as follows: given a set of actions (identified in the bounding exercise) that you must represent in the model and a set of inputs provided by other subgroups (Looking Outward Matrix), describe the mechanisms and processes (rules for change) that occur in your component to produce the set of indicators (from bounding exercise) you must represent and the outputs that other subgroups require from you (Looking Outward Matrix).

Model Structure

The overall structure of the Merritt Island model is summarized in Figure 3. For each month in a simulation year, the Upland submodel first calculates surface water runoff, direct precipitation, aquifer input, and chemical loadings to the impoundment and the estuary. Aquifer input is based on water level elevations in the impoundment and estuary, calculated for the previous month. The Impoundment submodel next calculates a new water level and water quality based on surface water and aquifer inputs from the upland, direct precipitation, evapotranspiration, and exchange with the estuary. The

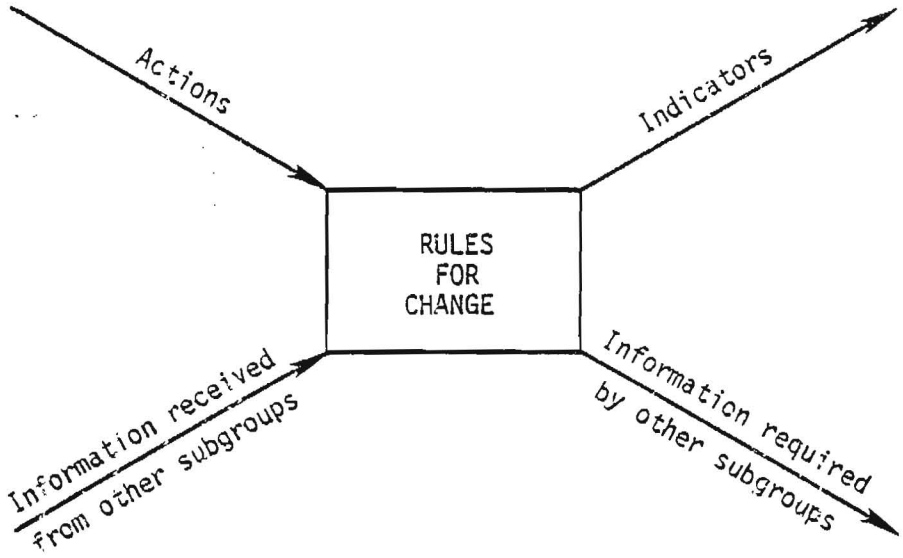


Figure 2. General flow of information to and from each submodel.

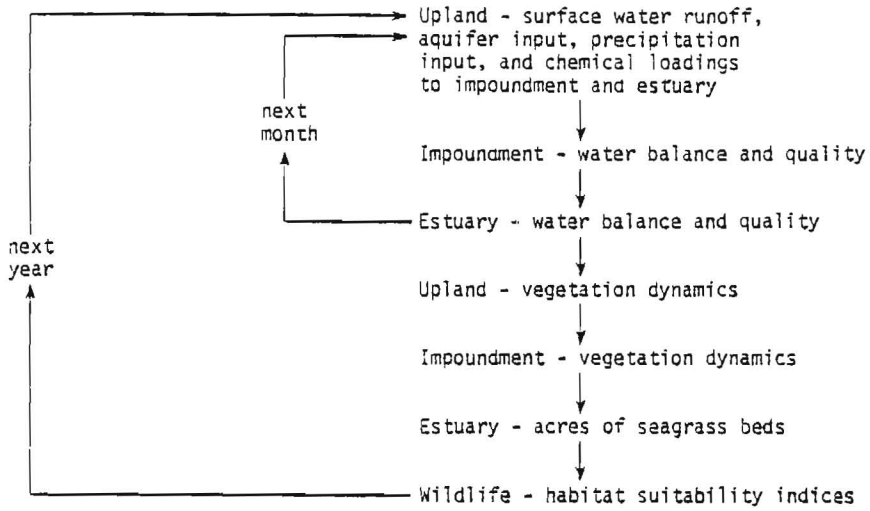


Figure 3. Overall structure and order of calculation for the Merritt Island model.

Estuary submodel then calculates a new water level and water quality based on surface water and aquifer inputs from the uplands, exchange with the impoundment, and variations in sea level. This set of calculations is repeated for each month of the year. After the annual hydrologic and water quality cycle is simulated, resulting vegetation and associated wildlife changes are calculated. The Upland submodel calculates changes in areas of each cover type and in several structural parameters of vegetation communities, based on succession, occurrence of fire, development activities, and shuttle launches. The Impoundment submodel next calculates changes in vegetation based on the simulated hydrologic cycle for the year and associated water quality. The Estuary submodel then calculates the change in acres of seagrass beds based on water quality. Finally, the Wildlife submodel calculates habitat suitability indices for scrub jays, gopher tortoises, mullet, mottled ducks, and wading birds and a production estimate for mosquitos based on the previously calculated vegetation conditions in the uplands and impoundment at the end of the simulation year and on several monthly hydrologic parameters. The entire annual calculation sequence is repeated for as many yearly iterations as desired.

For purposes of the workshop and this report, a hypothetical management unit containing an upland area, an impoundment, and a section of an estuary was used (Figure 4). The management unit was assumed to be near-field to a launch pad and to contain 2,500 acres of uplands (approximately the size of MINWR management unit 5.2, adjacent to launch pad B). All upland cover types were assumed to be present in this unit in proportion to their mapped coverage on Merritt Island. The impoundment was specified as 600 acres by assuming that the ratio of the impoundment to its upland drainage area should be approximately 1:4. From a map of Merritt Island, it was determined that the area at the upper end of Banana River and Banana Creek is approximately one-third estuary and two-thirds uplands and impoundments. The estuary was, therefore, specified as 1,500 acres. More detailed discussions of these areas are provided in each submodel description in the MODEL DESCRIPTION section of this report.

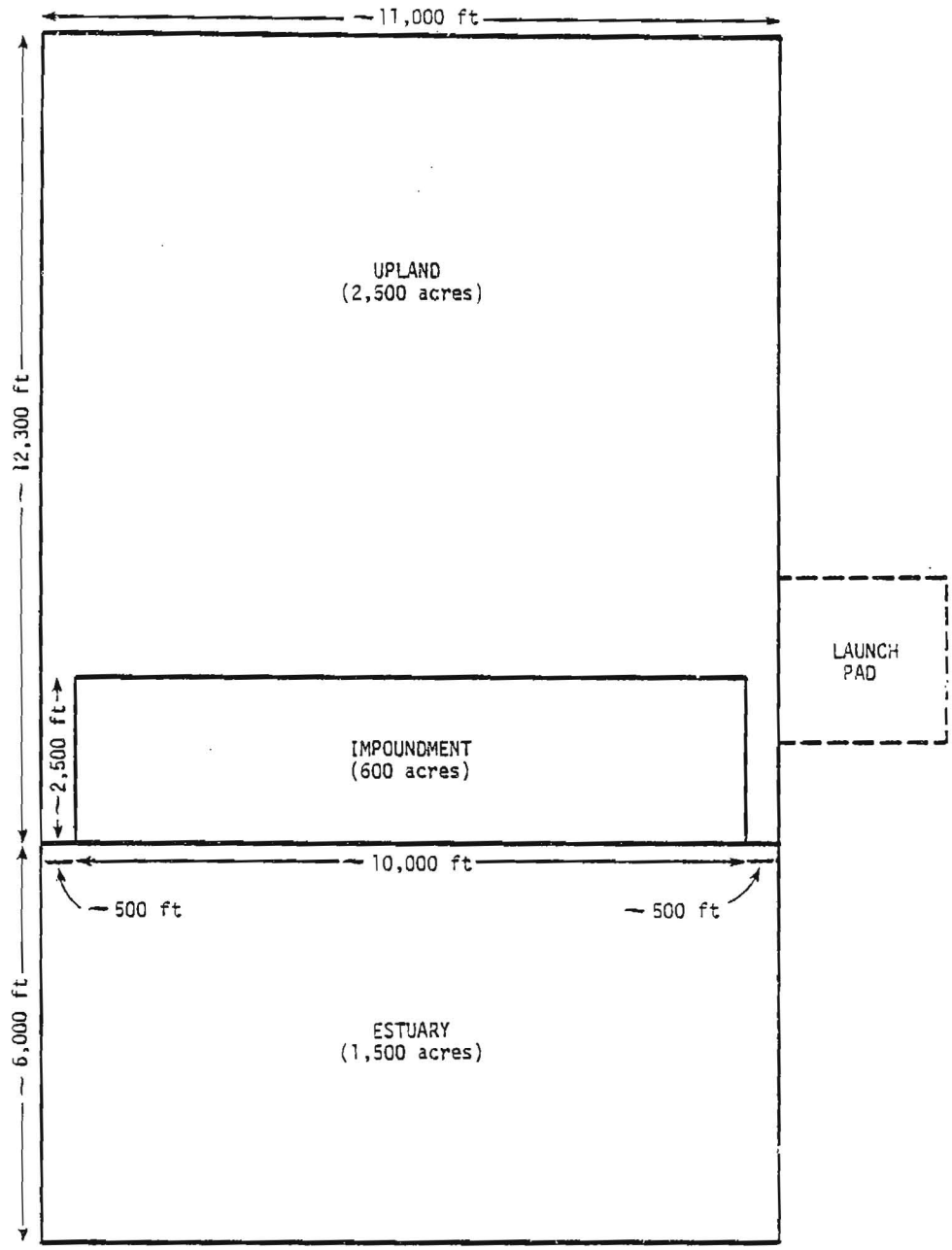


Figure 4. Hypothetical management unit.

Detailed descriptions of the calculations performed in each submodel are presented in the following sections of this report. The submodels are written in standard FORTRAN and executed within a general simulation control package called SIMCON (Hilborn 1973). Variable names used in equations in the following text are generally the same as in the FORTRAN code. Unless otherwise noted, the following subscript conventions apply to the variables:

IM = 1,12 refers to months where IM = 1 = January

IV = 1,12 refers to cover types where
- IV = 1 = dune/strand
- IV = 2 = mixed oak scrub
- IV = 3 = saw palmetto scrub
- IV = 4 = slash pine flatwood
- IV = 5 = xeric oak hammock
- IV = 6 = oak-cabbage palm and cabbage palm hammocks
- IV = 7 = cabbage palm savanna
- IV = 8 = developed
- IV = 9 = ruderal
- IV = 10 = active citrus groves
- IV = 11 = abandoned citrus groves succeeding to oak-cabbage palm hammock
- IV = 12 = abandoned citrus groves succeeding to mixed oak scrub

IC = 1,6 refers to chemical constituents in runoff and surface water where
- IC = 1 = aluminum
- IC = 2 = zinc
- IC = 3 = total nitrogen
- IC = 4 = total phosphorus
- IC = 5 = salt
- IC = 6 = total suspended solds (TSS)

IS = 1,5 refers to steps or elevations within the impoundment, and

IT = 1,5 refers to impoundment cover types where
- IT = 1 = mangrove-halophyte
- IT = 2 = salt marsh
- IT = 3 = cattail-mixed freshwater marsh
- IT = 4 = willow swamp-marsh
- IT = 5 = open water

Some of the potential limitations associated with each submodel are presented in the following sections of this report. These limitations represent areas where simplifying assumptions may depart significantly from the processes they represent or where there is limited data (or at least where

there was limited data during the workshop). The identification of a potential limitation does not necessarily imply the need for additional research. Although the representation of a particular process or phenomenon may be simplistic, it may be sufficient for making many management decisions.

UPLAND SUBMODEL

Responsibilities

The Upland subgroup was responsible for developing the rules for change to represent changes in the acres and structural parameters of upland vegetation communities resulting from succession, prescribed burning, facilities development, shuttle launches, and citrus grove management. These vegetation characteristics are used by the Wildlife submodel to calculate habitat suitability indices for several indicator species. In addition, the Upland subgroup was responsible for calculating the volume of water and associated constituent loadings (aluminum, zinc, total nitrogen, total phosphorus, salt, and total suspended solids) to the impoundment and estuary resulting from direct precipitation, deposition from shuttle launches, surface water runoff, and surficial groundwater flow. These values are subsequently used as inputs to water balance and constituent mass balance calculations in the Impoundment and Estuary submodels.

The Upland submodel can be parameterized to represent management units of different sizes, with different compositions and acreages of cover types, with different lengths of contact with the impoundment and the estuary, and at different distances and orientations from a shuttle launch pad. For purposes of the workshop, a hypothetical 2,500-acre management unit adjacent to the launch pad was chosen, with all cover types represented in proportion to their occurrence on Merritt Island.

Structure

The Upland submodel is divided into two sections. Volumes of surface water runoff, surficial groundwater flow, direct precipitation, and associated constituent loadings to the impoundment and estuary are calculated monthly. Changes in acres of cover types and associated structural parameters are calculated annually.

Monthly calculations - precipitation, runoff, and groundwater input. Precipitation for a given month is chosen as a normally distributed random number from a distribution with a mean and standard deviation calculated from a 40-year precipitation record for that month. The value is constrained by a monthly minimum and maximum observed precipitation from the same 40-year record.

Loadings of aluminum, zinc, total nitrogen, total phosphorus, salt, and total suspended solids to the impoundment and estuary are calculated from average monthly concentrations of constituents as:

PL(IM,IC) = P(IM) * PCONC(IM,IC) * WTOT and

PLE(IM,IC) = P(IM) * PCONC(IM,IC) * ETOT

where PL(IM,IC) = precipitation loading to the impoundment in month IM of constituent IC (lb)

PLE(IM,IC) = precipitation loading to the estuary in month IM of constituent IC (lb)

P(IM) = precipitation in month IM (inches)

PCONC(IM,IC) = average concentration of constituent IC in precipitation in month IM (lb/acre-inch)

WTOT = surface area of the impoundment (acres)

ETOT = surface area of the estuary (acres)

Monthly average concentrations are used because total nitrogen and total phosphorus concentrations can vary by several orders of magnitude throughout the year.

Direct deposition of constituents to the impoundment and estuary from the shuttle launch cloud is added to the precipitation loadings as:

PL(IM,IC) = PL(IM,IC) + [DSTS(IC) * LPM(IM) * PDW] and

PLE(IM,IC) = PLE(IM,IC) + [DSTS(IC) * LPM(IM) * PDE]

where PL(IM,IC) = precipitation loading to the impoundment in month IM of constituent IC (lb)

PLE(IM,IC) = precipitation loading to the estuary in month IM of constituent IC (lb)

DSTS(IC) = amount of constituent IC deposited from the cloud per launch (lb)

LPM(IM) = launches per month for month IM

PDW = proportion of material from the launch cloud deposited in the impoundment

PDE = proportion of material from the launch cloud deposited in the estuary

Aluminum and total phosphorus are the only constituents currently considered in the submodel for launch cloud deposition. While deposition of hydrochloric acid is not explicitly included in the model, some effects of this acid deposition are calculated for upland vegetation cover types (described below).

The amount of material deposited [DSTS(IC)] depends, in a very general way, on the distance of the management unit from the launch pad. If the unit is adjacent to the pad, all of the aluminum and total phosphorus is assumed to be deposited in the unit (including the impoundment and estuary). If the management unit is specified as far-field (0.6-15.0 miles away), then material is assumed to be deposited in a 1-mile wide path whenever the cloud blows across the unit. The frequency with which the cloud is blown over the unit is

specified as input to the model, based on the assumed direction of the unit from the pad. For computational simplicity, the submodel assumes that the unit is approximately square and calculates the acres over which deposition occurs based on the proportion of the unit covered by the 1-mile wide path of the cloud. The amount of material deposited is then calculated as:

DSTS(IC) = DCONC(IC) * ADEPF

where DSTS(IC) = amount of constituent IC deposited from the cloud per launch (lb)

DCONC(IC) = predictions of deposition of constituent IC from NASA's REEDM model (lb/acre)

ADEPF = area over which deposition occurs far-field (acres)

Currently, the submodel utilizes a constant cloud width and deposition concentration. If depositions from launch clouds are thought to have a large influence on certain environmental parameters or if the model is particularly sensitive to this variable, then far-field launch depositions should be reformulated as a function of distance from the launch pad.

The volume of surface water runoff from precipitation to the impoundment and estuary is calculated as:

USWIN(IM) = TRUN * WPCT

USWINE(IM) = TRUN * (1.0 - WPCT)

where USWIN(IM) = volume of upland surface water runoff to the impoundment in month IM (acre-inches)

USWINE(IM) = volume of upland surface water runoff to the estuary in month IM (acre-inches)

WPCT = proportion of total surface water runoff that flows into the impoundment

TRUN = total surface water runoff from precipitation for the month (acre-inches)

Surface water runoff due to land application of waste material and from shuttle launches is added later because some of the following calculations for constituent loadings are based on precipitation runoff.

The total surface water runoff from precipitation for the month is determined as a fraction of the average annual runoff, which has been adjusted to reflect the amount of precipitation in the month relative to the average precipitation for that month:

$$TRUN = RTOT * RPCT(IM) * [P(IM)/PMEAN(IM)] * UTOT$$

where TRUN = total surface runoff for the month (acre-inches)

RTOT = average annual runoff per acre (inches)

RPCT(IM) = the proportion of annual runoff that, on the average, occurs in month IM

P(IM) = precipitation in month IM (inches)

PMEAN(IM) = average precipitation for month IM (inches)

UTOT = total area of upland in the management unit (acres)

The Upland subgroup originally intended to calculate runoff based on monthly rainfall intensity, acres of each cover type, and runoff coefficients, which varied by month for each cover type. However, there was insufficient time at the workshop to determine all the runoff coefficients, so the simpler approach described above was used. If the dynamics of either the Impoundment or Estuary submodels are sensitive to surface water input, the more detailed approach could be incorporated.

Constituent loadings in surface water runoff resulting from precipitation and land application of waste material are calculated simply as products of volumes of water and associated constituent concentration:

$$USWL(IM,IC) = [USWIN(IM) * PCONC(IM,IC)] + [(WVOL/27154.) * WCONC(IC) * PLAW] \text{ and}$$

$$USWLE(IM,IC) = [USWINE(IM) * PCONC(IM,IC)] + [(WVOL/27154.) * WCONC(IC) * PLAE]$$

where USWL(IM,IC) = runoff loading to the impoundment in month IM of constituent IC (lb)

USWLE(IM,IC) = runoff loading to the estuary in month IM of constituent IC (lb)

USWIN(IM) = volume of upland surface water runoff to the impoundment in month IM (acre-inches)

USWINE(IM) = volume of upland surface water runoff to the estuary in month IM (acre-inches)

PCONC(IM,IC) = average concentration of constituent IC in precipitation in month IM (lb/acre-inch)

WVOL = volume of land-applied waste material (gal)

WCONC(IC) = concentration of constituent IC in the land-applied waste material (lb/acre-inch)

PLAW = proportion of land-applied waste material that runs into the impoundment

PLAE = proportion of land-applied waste material that runs into the estuary

The model assumes that land application of waste material will saturate soil binding sites very quickly so that all of the nitrogen and phosphorus in applied material will be available in surface runoff. In reality, some of the applied material will likely percolate to surficial ground water. It was believed that virtually all applied liquid would end up in the estuary or impoundment through either surface runoff or surficial ground water. Therefore, these inputs were combined for conceptutional simplicity. The amount of aluminum resulting from shuttle launch deposition on the uplands that is added to surface runoff was assumed to be proportional to the amount of total monthly precipitation that runs off:

$$USWL(IM,1) = USWL(IM,1) + [(DSTS(1) * LPM(IM) * PDU) * USWIN(IM)/P(IM) * UTOT)] \text{ and}$$

$$USWLE(IM,1) = USWLE(IM,1) + [(DSTS(1) * LPM(IM) * PDU) * USWINE(IM)/(P(IM) * UTOT)]$$

where USWL(IM,1) = runoff loading of aluminum (lb) to the impoundment in month IM

USWLE(IM,1) = runoff loading of aluminum (lb) to the estuary in month IM

DSTS(1) = amount of aluminum deposited per launch (lb)

LPM(IM) = number of shuttle launches in month IM

PDU = proportion of material from the launch cloud deposited on the uplands

USWIN(IM) = volume of upland surface water runoff to the impoundment in month IM (acre-inches)

USWINE(IM) = volume of upland surface water runoff to the estuary in month IM (acre-inches)

P(IM) = precipitation in month IM (inches)

UTOT = total area of upland in the management unit (acres)

Most of the zinc from shuttle launches is associated with the water released from the holding tanks following each launch. In the submodel, this zinc is added to zinc in surface water runoff as:

$$USWL(IM,2) = USWL(IM,2) + [DSTS(2) * LPM(IM) * PZNW] \text{ and}$$

$$USWLE(IM,2) = USWLE(IM,2) + [DSTS(2) * LPM(IM) * PZNE]$$

where USWL(IM,2) = runoff loading of zinc (lb) to the impoundment in month IM

USWLE(IM,2) = runoff loading of zinc (lb) to the estuary in month IM

DSTS(2) = amount of zinc in the holding tanks following each launch (lb)

LPM(IM) = number of shuttle launches in month IM

PZNW = proportion of zinc and water released after each launch that flows into the impoundment

PZNE = proportion of zinc and water released after each launch that flows into the estuary

Although some phosphorus is deposited from the launch cloud, it was assumed that upland soils would bind deposited phosphorus sufficiently so that none of it would be leached in surface runoff.

Total suspended solids in surface runoff were assumed to come primarily from developed areas and are added to previously calculated TSS loadings as:

USWL(IM,6) = USWL(IM,6) + [TRUN * UACRE(8)/UTOT] * (TSSW * TSS) and

USWLE(IM,6) = USWLE(IM,6) + [TRUN * UACRE(8)/UTOT] * (TSSE * TSS)

where USWL(IM,6) = runoff loading of TSS (lb) to the impoundment in month IM

USWLE(IM,6) = runoff loading of TSS (lb) to the estuary in month IM

UACRE(8) = area of developed land in the management unit (acres)

UTOT = total upland area in the management unit (acres)

TSSW = proportion of developed area draining into the impoundment

TSSE = proportion of developed area draining into the estuary

TSS = concentration of TSS in runoff from developed areas (lb/acre-inch)

TRUN = total surface water runoff from precipitation for the month (acre-inches)

Although runoff from vegetated areas contains some suspended solids, information on these smaller loadings was not available during the workshop and, thus, was not included in this version of the model.

The total surface runoff from the uplands is calculated by adding runoff from land application of waste material and release of water from the holding tanks following launches to precipitation runoff calculated earlier:

$$USWIN(IM) = USWIN(IM) + [(WVOL/27154.) * PLAW] + [(SVOL/27154.) * LPM(IM) * PZNW] \text{ and}$$

$$USWINE(IM) = USWINE(IM) + [(WVOL/27154.) * PLAE] + [(SVOL/27154.) * LPM(IM) * PZNE]$$

where USWIN(IM) = volume of surface water runoff to the impoundment in month IM (acre-inches) (previously calculated as precipitation runoff only)

USWINE(IM) = volume of surface water runoff to the estuary in month IM (acre-inches) (previously calculated as precipitation runoff only)

WVOL = volume of land-applied waste material (gal)

PLAW = proportion of land-applied waste that runs into the impoundment

PLAE = proportion of land-applied waste that runs into the estuary

SVOL = volume of water released after each shuttle launch (gal)

LPM(IM) = number of shuttle launches in month IM

PZNW = proportion of zinc or water released after each shuttle launch that flows into the impoundment

PZNE = proportion of zinc or water released after each shuttle launch that flows into the estuary

Surficial ground water flow into the impoundment and estuary is a function of the difference in head between the upland water table and the water levels in the impoundment and estuary:

```
UGWIN(IM) = ([HYDC * ([(BASESA + UHEAD) ** 2.0] - [BASESA +
            (WDEPTH(IM)/12.0) ** 2.0])/(2.0 * UDIST)] *
             UFRW) * (30.0/27154.0)  and

UGWINE(IM) = ([HYDC * ([(BASESA + UHEAD) ** 2.0] - [BASESA +
             (ELEVEL(IM)/12.0) ** 2.0])/(2.0 * UDIST)] *
              UFRE) * (30.0/27154.0)
```

where UGWIN(IM) = volume of surficial ground water flow into the impoundment in month IM (acre-inches)

UGWINE(IM) = volume of surficial ground water flow into the estuary in month IM (acre-inches)

HYDC = a representative hydraulic conductivity (gal/day/ft^2)

BASESA = depth of the base of the surficial aquifer from mean sea level (ft)

UHEAD = a representative height of the water table in the uplands above mean sea level (ft)

WDEPTH(IM) = elevation of water in the impoundment above mean sea level in month IM (inches)

ELEVEL(IM) = elevation of water in the estuary above mean sea level in month IM (inches)

UDIST = average distance of travel for surficial ground water (ft)

UFRW = length of contact between uplands and the impoundment (ft)

UFRE = length of contact between uplands and the estuary (ft)

The above equation factors into the product of the hydraulic conductivity, the hydraulic gradient (upland head - impoundment head)/distance of travel), the average cross sectional area per linear foot of contact (upland head - impoundment head/2), and the length of contact. Constituent loadings in ground water are calculated as the product of surficial ground water flow and representative ground water concentrations:

```
UGWL(IM,IC) = UGWIN(IM) * GWCONC(IC)  and

UGWLE(IM,IC) = UGWINE(IM) * GWCONC(IC)
```

where UGWL(IM,IC) = ground water loading to the impoundment in month IM of constituent IC (lb)

UGWLE(IM,IC) = ground water loading to the estuary in month IM of constituent IC (lb)

UGWIN(IM) = volume of surficial ground water flow into the impoundment in month IM (acre-inches)

UGWINE(IM) = volume of surficial ground water flow into the estuary in month IM (acre-inches)

GWCONC(IC) = a representative ground water concentration of constituent IC

Annual calculations - upland vegetation acres and indicators. The area in each cover type is adjusted annually to reflect changes due to facilities development, succession, and prescribed or wild fires. Changes due to water level fluctuations in the impoundment were considered by the group but not incorporated into the model because of the relatively small area potentially affected. Structural parameters in the mixed oak scrub, saw palmetto scrub, and slash pine flatwood cover types also can change annually in the model as a result of fires, natural community development, and shuttle launches.

Facilities development activities in the model remove acres from various cover types and place them in a general development category (e.g., buildings, parking lots, launch pads, and roads). The acres of each cover type to be developed each year are specified as inputs to the model. The resulting acres in each cover type are calculated as:

UACRE(IV) = UACRE(IV) + DACRE(IV)

where UACRE(IV) = area of upland vegetation in cover type IV (acres)

DACRE(IV) = area of upland vegetation cover type IV to be developed (acres)

The sign convention for DACRE(IV) indicates that acres of vegetation to be developed or acres of citrus to be abandoned are specified as negative numbers,

while the total number of acres to be added to the developed category and the acres to be added to the abandoned citrus grove categories are specified as positive numbers. With this convention, the sum of all elements in DACRE should always be zero, providing a check on development specifications in management scenarios (see MODEL BEHAVIOR section). If there are insufficient acres in a particular vegetation cover type to develop as specified, the total number of acres developed is reduced accordingly. In reality, a decision would probably be made to take those acres out of another cover type. However, time was not available during the workshop to permit these types of decision rules to be developed for the submodel. The values for DACRE(11) and DACRE(12) are calculated by assuming that, when citrus groves are abandoned [DACRE(10)], a specified proportion of those acres (CGMOS) will eventually succeed to mixed oak scrub and the remaining proportion (CGCPH) to cabbage palm hammock.

There was some debate during the workshop on how to best model succession of the various vegetation communities. A promising approach that was ultimately rejected involved modeling individual trees and their interactions within a relatively small (e.g., 0.25 acre) stand (e.g., Botkin et al. 1972; Ek and Monserud 1974). While this approach would have provided very good resolution of species composition and structural changes in the stand, it was not practical at the workshop to model (or specify data for) all the stands of all the vegetation types in a typically patchy 2,500-acre management unit. The approach that was eventually used for this submodel (Shugart et al. 1973) is based on the analytical solution to a linear differential equation model that considers stand dynamics and sylvics to determine successional losses from forested cover types over large regions ($2.5 * 10^6$ to $2.5 * 10^8$ acres):

$$\text{acres}_{\text{time } t} = \text{acres}_{\text{time } t-1} * e^{-\text{ transfer rate}}$$

While this approach sacrifices detail within stands, it accounts for the behavior of a set of heterogeneous stands classified as the same cover type without the need to make calculations for all stands individually. The resolution of this approach could be improved by breaking each cover type into 2 to 4 age or size classes and representing successional transitions through age classes, as well as transitions among different cover types.

The number of acres succeeding out of a given cover type each year is calculated as:

ACREL(IV) = UACRE(IV) * (1.0 - [EXP(-1.0/[TTIME(IV)/TTFAC])])

where ACREL(IV) = area succeeding out of cover type IV (acres)

UACRE(IV) = area in cover type IV (acres)

EXP = the natural antilogarithm function

(-1.0/[TTIME(IV)/TTFAC]) = the transfer rate coefficient for cover type IV

TTIME(IV) = time constant representing the longevity of the dominant species after it has reached maturity (yr)

TTFAC = a user-specified factor to convert TTIME(IV) to a multiple-stand transition time

The time constant TTIME(IV) can be easily estimated from the literature. However, the longevity of individual trees of a particular species is inadequate to represent successional transition times of a hetergeneous set of stands for several reasons. First, the time constant does not include the time required for the dominant species to become established and mature. The transition time for a stand should, therefore, be longer than the estimate of dominant species longevity. Second, site environmental conditions (e.g., edaphic and microclimate factors) could increase or decrease maturation times and longevity from values reported in the literature. Third, even if a stand transition time is derived by adjusting TTIME(IV) for the first two factors, the transition time for an individual stand is likely to be shorter than the

transition time for a set of heterogenous, multiple-aged stands. The model currently uses a single parameter, TTFAC, to account for these factors and generate a multiple-stand transition time from the literature value for species longevity.

The resulting acres in each cover type are then calculated as:

UACRE(IV) = UACRE(IV) + SUCC(I,IV) * ACREL(I)

where UACRE(IV) = area in cover type IV (acres)

SUCC(I,IV) = a matrix containing 1's, 0's, and -1's that qualitatively specifies the successional transitions from cover state I to state IV, as presented in Table 3

ACREL(IV) = area succeeding out of cover state IV (acres)

Table 3. Successional transitions and time constants for upland vegetation cover types.

Succession from:	to:	in years
mixed oak scrub	xeric oak hammock	40
slash pine flatwood	saw palmetto scrub	150
cabbage palm savanna	cabbage palm hammock	30
abandoned citrus groves	mixed oak scrub	100
abandoned citrus groves	cabbage palm hammock	30

Fires affect vegetation in several ways. Light to moderate fires can eliminate or reduce understory vegetation and, thus, retard succession, while more severe fires can cause shifts from one cover type to another. Transitions

between cover types and changes in understory vegetation in selected cover types are represented reasonably well in the model; effects of fires on succession probably are poorly represented.

For each simulation year, the model determines if a fire occurs in the management unit as a function of the prescribed fire and wildfire suppression policies implemented in the scenario being run and the time since the last fire in each cover type. Because the Merritt Island area is subject to as many as six lightning strikes/km^2/month during the summer (Leenhouts 1982), the model assumes that sufficient lightning strikes occur each year to potentially start a wildfire in the management unit. However, if the scenario being run specifies a fire prevention policy, no effects are calculated. If no wildfire suppression is specified or if a prescribed burn is specified in the scenario, the fire is sustained and effects calculated for cover types with sufficient fuel loadings. Fuel loadings are treated implicitly in the model by specifying the minimum amount of time between fires required for each cover type to build up sufficient fuels to sustain a fire (Table 4).

The effects of fires on succession are not well incorporated in the current model. Light to moderate fires can delay succession or cause successional regression within a cover type by damaging or destroying the understory, including seedlings and saplings of "later" successional species. If fires are frequent enough, a fire subclimax can be maintained. The model currently skips successional calculations for cover types burned the previous year. In other words, succession of that cover type is delayed only a year. While the conceptual approach of blocking succession following a fire may be adequate for purposes of this model, the number of years that succession is blocked should be a function of the vegetation cover type. Another possible approach is to subdivide cover types into age classes (as discussed previously with respect to succession). With this approach, effects of fires could be conceptualized to include regression to an earlier age class within a vegetation cover type. This sort of approach is used only for slash pine flatwoods in the current model.

Table 4. Minimum time between fires in upland cover types.

Cover type	Minimum time between fires (yr)
Dune/strand	3
Mixed oak scrub	10
Saw palmetto scrub	3
Slash pine flatwood	3
Xeric oak hammock	10
Oak-cabbage palm or cabbage palm hammock	10
Cabbage palm savanna	3
Developed	a
Ruderal	a
Citrus groves	a
Abandoned citrus groves succeeding to cabbage palm hammock	10
Abandoned citrus groves succeeding to mixed oak scrub	10

[a]Would not generally burn in wild or prescribed fires.

In the model, severe fires can result in transitions from xeric oak hammock to mixed oak scrub and from slash pine flatwoods to saw palmetto scrub. Xeric oak hammocks only burn if both sufficient time has elapsed since the last fire and drought conditions exist (annual precipitation less than 30 inches). Under these circumstances, a user-specified proportion of the acres (currently 0.8) is converted to mixed oak scrub. The representation of fire effects in slash pine flatwoods required a somewhat more detailed approach. The acres of flatwoods are subdivided into three age classes (5 years or less, 6 to 19 years, and 20 years or older). The number of acres in each age class is updated each year. In years when the slash pine flatwoods burn, user-specified proportions of the acres in each age class are converted according to Table 5.

Table 5. Fire conversion factors for slash pine flatwood age classes.

Age classes of slash pine flatwoods	Proportion of acres "converted" to:		
	≤ 5 years slash pine flatwood	Same age slash pine flatwood	saw palmetto scrub
≤ 5 years	0.00	0.00	1.00
6-19 years	0.05	0.75	0.20
≥ 20 years	0.05	0.90	0.05

The structural vegetation indicators required by the Wildlife submodel include the percent cover of oaks, the percent cover of vegetation less than 6 inches tall and open areas, and the mean shrub height in the mixed oak scrub, saw palmetto scrub, and slash pine flatwood cover types. In slash pine flatwoods, the percent tree canopy closure also is needed. All of these indicators are calculated similarly, based on the proportion of the acres that burned in the last fire, development of the community since that fire, and development of the unburned portion since the previous fire:

$$Indicator_{IV} = PBURN(IV) * f[TFIRE(IV)] + [1.0 - PBURN(IV)] * f[TFIRE2(IV)]$$

where $Indicator_{IV}$ = the value of the indicator for cover type IV

PBURN(IV) = proportion of cover type IV burned in the last fire

TFIRE(IV) = time elapsed since the most recent fire in cover type IV (yr)

TFIRE2(IV) = time elapsed since the fire that occurred prior to the most recent fire in cover type IV (yr)

f[TFIRE(IV)] and f[TFIRE2(IV)] = the piecewise linear functions illustrated in Figures 5-8

The only effect of shuttle launches on vegetation indicators incorporated in the model is a reduction in the percent cover of oaks in the mixed oak scrub cover type in near-field management units. The primary cause of this reduction is assumed to be the low pH of "rainfall" from the launch cloud. Deposition of aluminum oxide and hydrochloric acid occurs in far-field management units but has resulted only in some spotting of leaves, not defoliation. Therefore, it was assumed that no reduction in percent cover of oaks would occur. For near-field units, the area potentially affected is specified as input (ADEPN, currently 30 acres). The acreage of mixed oak scrub affected is calculated as:

$$DAREA = ADEPN * PDU * [UACRE(2)/UTOT]$$

where DAREA = the area of mixed oak scrub affected by deposition from the shuttle launch (acres)

ADEPN = total area of deposition in the near-field management unit (acres)

PDU = proportion of deposition from the launch cloud occurring over the uplands

UACRE(2) = total area of mixed oak scrub in the management unit (acres)

UTOT = total upland area (acres)

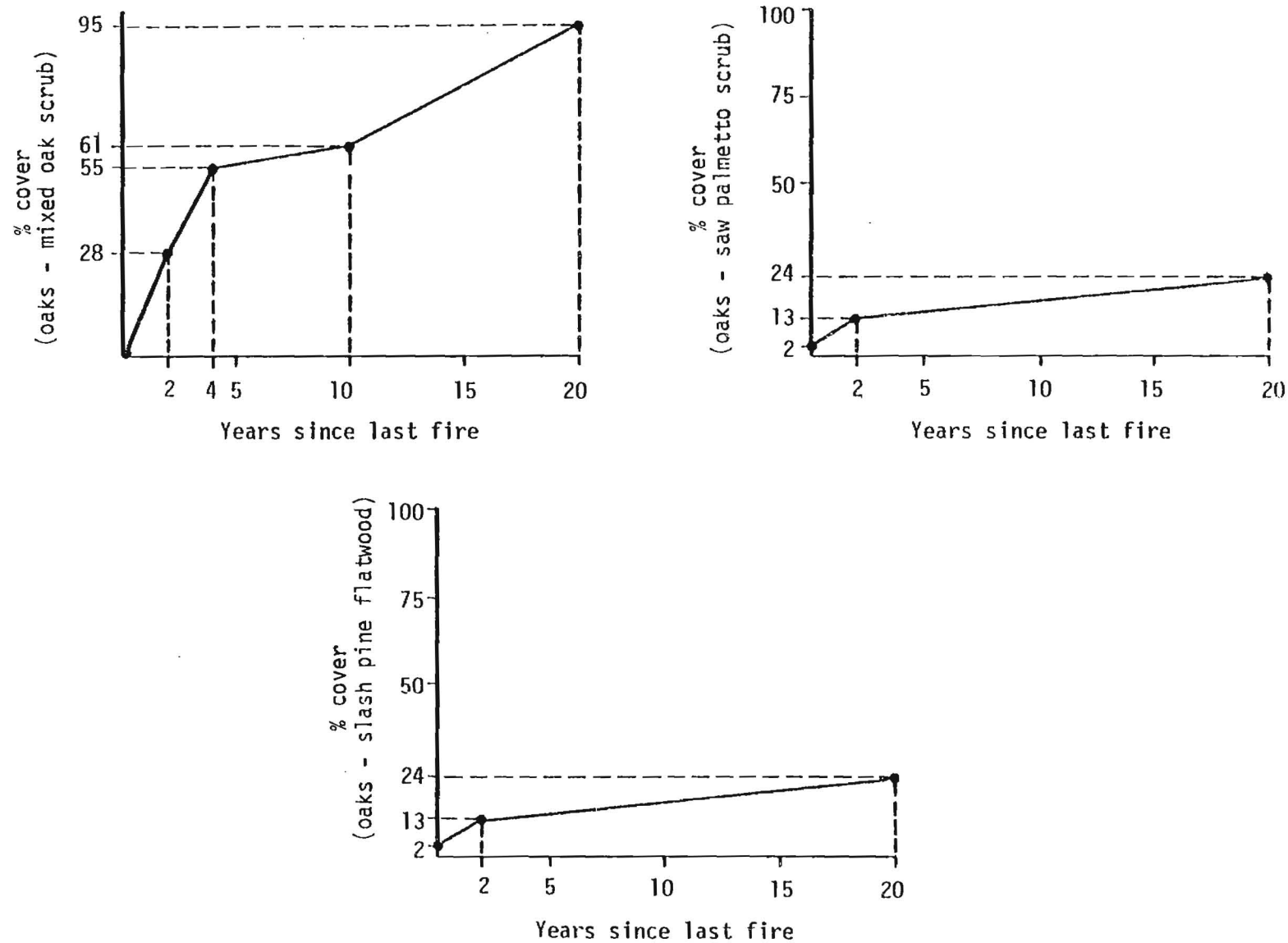


Figure 5. Percent cover of oaks as a function of time since last fire.

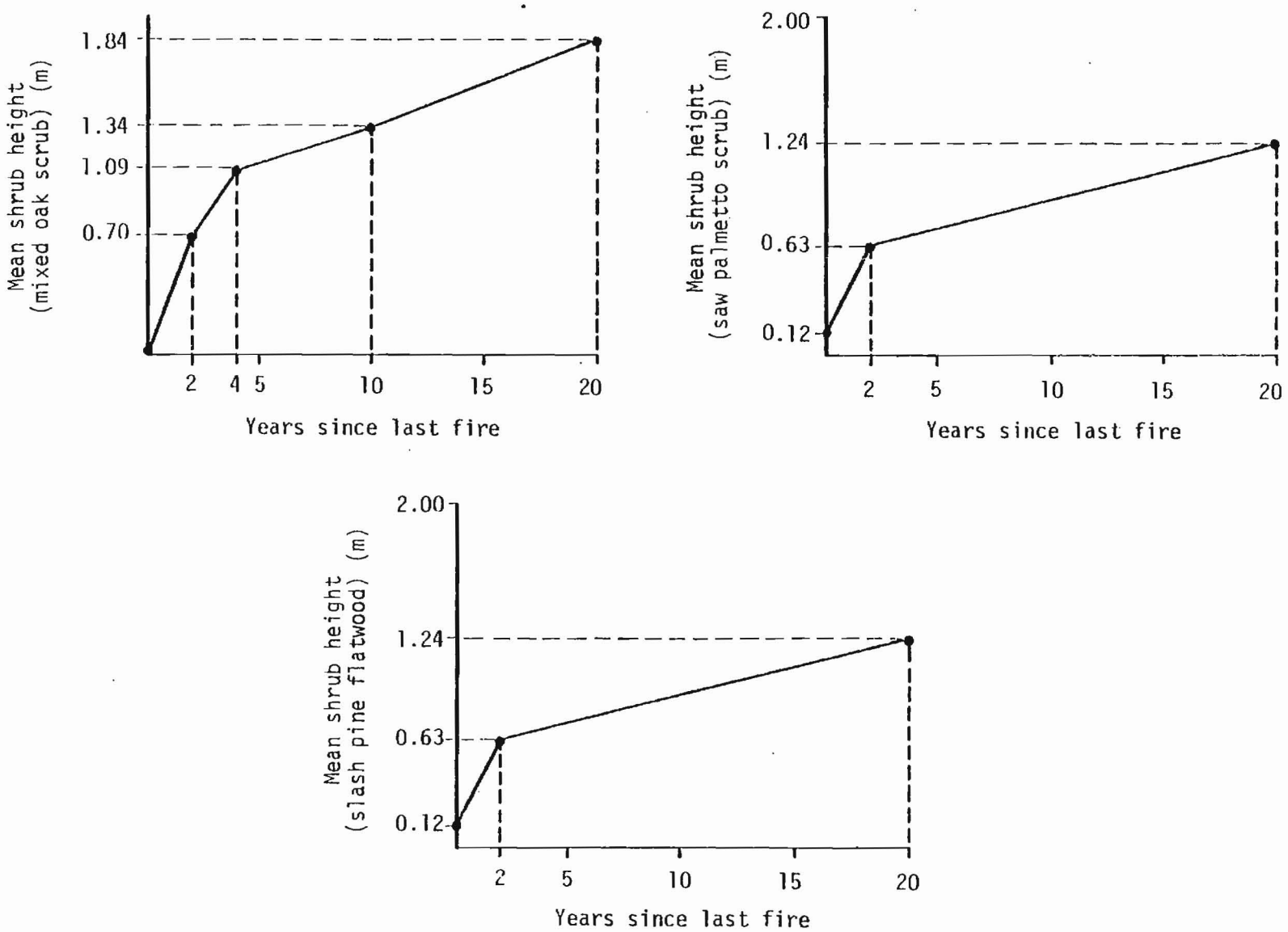


Figure 6. Mean shrub height as a function of time since last fire.

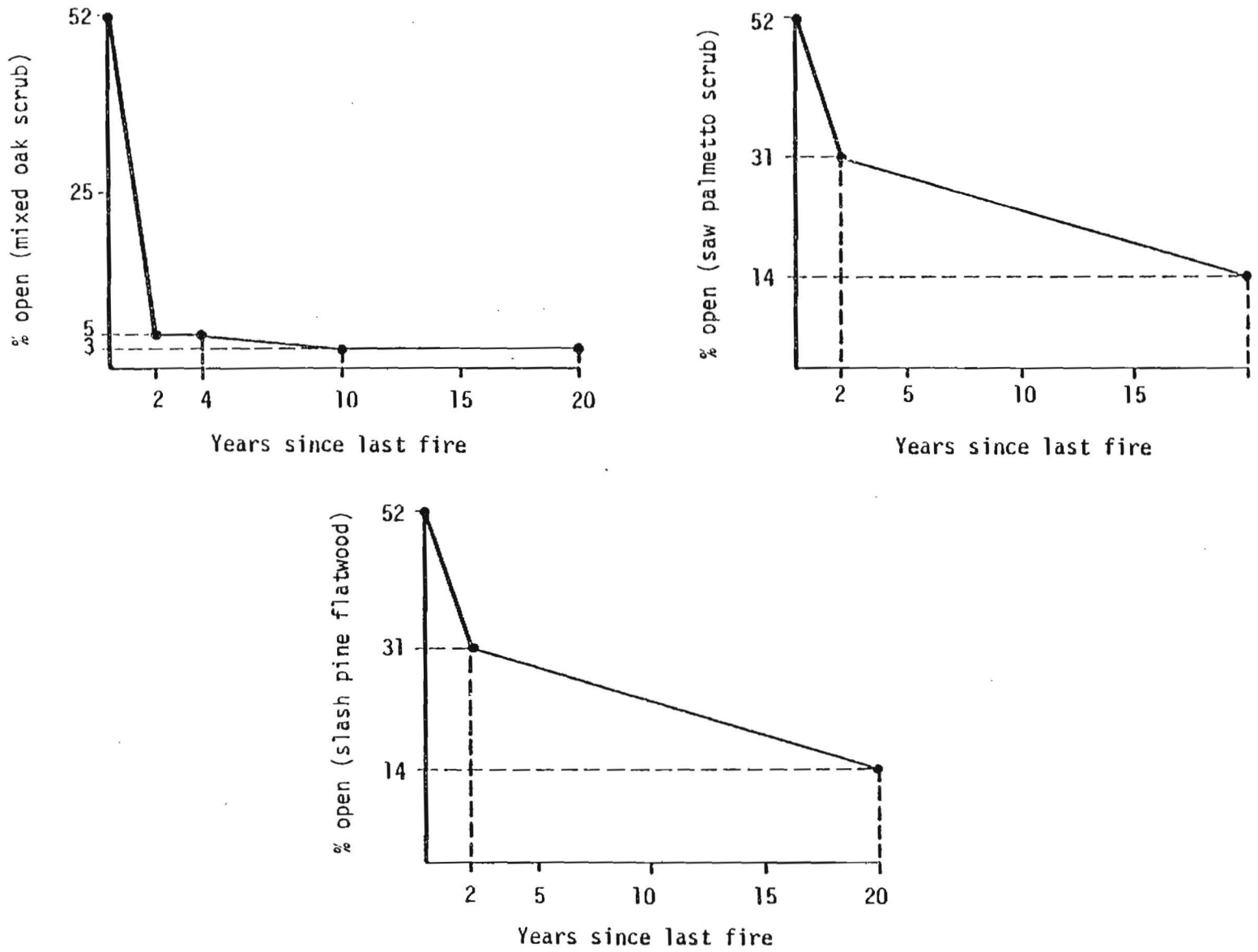


Figure 7. Percent open area and cover of vegetation less than 6 inches tall as a function of time since last fire.

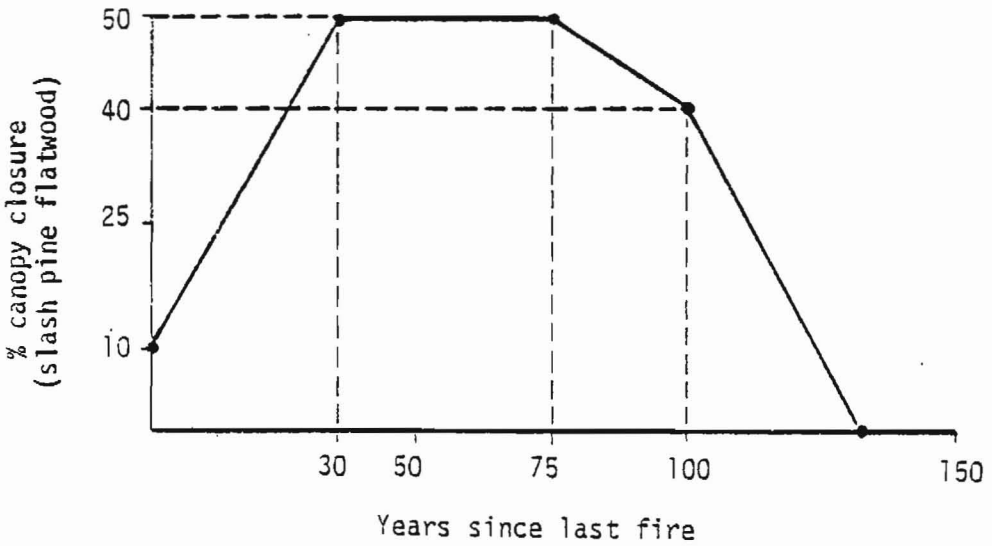


Figure 8. Percent tree canopy closure in slash pine flatwoods as a function of time since last fire.

The decrease in percent cover in affected areas is calculated as:

DPCMOS = f(RLPY)

where DPCMOC = decrease in percent cover of oaks in mixed oak scrub due to shuttle launches

RLPY = total shuttle launches during the year which result in deposition in the management unit

f(RLPY) = the piecewise linear function illustrated in Figure 9

While there was little data at the workshop to support the actual numbers used in the function in Figure 9, participants felt it was important to attempt to incorporate these kinds of effects in the model for purposes of discussion. The percent cover of oaks indicator for the entire management unit is the weighted average of the percent cover in areas subject to deposition and in those areas not affected:

PCMOS = (PCMOS * (UACRE(2) - DAREA) + (PCMOS * (1.0 - DPCMOS) * DAREA))/UACRE(2)

where PCMOS = percent cover of oaks in mixed oak scrub

UACRE(2) = total area of mixed oak scrub in the management unit (acres)

DAREA = the area of mixed oak scrub affected by deposition from the shuttle (acres)

DPCMOS = the decrease in percent cover of oaks in mixed oak scrub due to shuttle launches

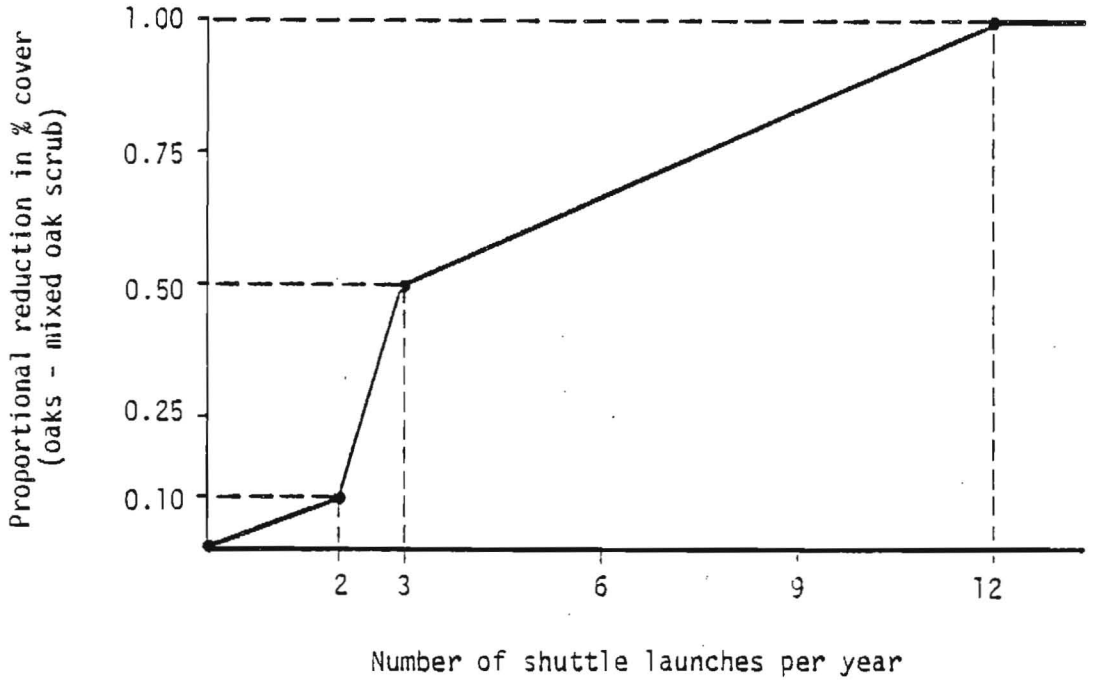


Figure 9. Proportional decrease in percent cover of oaks in mixed oak scrub as a function of the number of shuttle launches per year that result in deposition on the management unit.

Limitations

The amount of water and constituent loadings in precipitation, surface runoff, and surficial ground water flow can have major effects on water quality and vegetation in the impoundment and estuary. Several limitations of the Upland submodel could affect the representation of impoundment and estuarine dynamics. The current approach for calculating precipitation volume results in less variability in annual rainfall than has actually been observed, because calculations each month are independent of other months. As such, long term droughts or wet periods are unlikely to be produced by the model. Fewer long term droughts in the model result in underestimation of the frequency of burning in xeric oak hammocks. Because these fires generally increase the number of acres of suitable scrub jay habitat, it is likely that the number of scrub jays is also underestimated. Less variability in the model's precipitation record also reduces the variability of impoundment depth and, therefore, affects vegetation dynamics. As a result, the occasional reproductive failure of some fish and wildlife species due to prolonged droughts or wet periods may not be adequately represented. These problems could be easily remedied by reading 40 years of monthly precipitation data as input to the model rather than using statistical distributions.

Little is known about surficial ground water movement. However, initial estimates indicate that the volume of water moving from ground water to the impoundments and estuary is relatively small compared to direct precipitation and runoff. As such, it may not be necessary to refine the representation of ground water in the model at this time. As currently conceptualized, surface runoff from the uplands is not affected by changes in the acreages of upland cover types even though the associated runoff coefficients actually vary both by cover type and by month. Scenarios run to date do not involve large shifts in acreages among cover types; therefore, this problem has not been a serious limitation. The representation of surface runoff should probably be refined to make runoff coefficients specific to various cover types and to incorporate monthly variation for additional scenarios that involve massive development or changes in cover types due to habitat management.

Treatment of the results of shuttle depositions and land application of waste material could be improved in several ways. The area of deposition and concentration of material deposited for far-field management units are independent of distance from the pad. Analysis of results from NASA's modified REEDM model might provide the basis for a better representation. Very crude assumptions were made concerning the fate of aluminum and phosphorus deposited on the uplands (aluminum is leached relative to the proportion of precipitation that runs off, and all deposited phosphorus is bound to soil particles). These assumptions should be re-examined because of their potential effect on impoundment and estuarine water quality. The assumption concerning quick saturation of soil binding sites by nitrogen and phosphorus in land-applied waste material should also be re-examined because of the large volume of material considered and the sensitivity of the Estuary submodel to phosphorus loadings.

The effects of development may not be adequately represented in the current model. If sufficient acres are not available for development in a specified cover type, the acres to be developed are reduced accordingly. In actuality, the development would probably occur but in a different area. Scenarios run to date do not include large development projects, so this limitation has not been a problem.

The general approach used to represent succession in the Upland submodel is probably appropriate for the spatial scale and resolution of this model. However, subdividing the vegetation cover types into 2 to 4 age or size classes would allow a more detailed representation of succession and a more appropriate representation of fire effects on succession. If a much more detailed (spatially and temporally) approach for modeling fire spread and its effects is required, models used by the U.S. Forest Service (e.g., Albini 1976; Main et al. 1982) or the gradient modeling approach implemented in Glacier National Park should be considered. The gradient modeling approach (Kessell 1976) links a computerized data base of terrestrial site inventories (10-m resolution from aerial photographs), gradient models of vegetation and fuel that use qualitative information from the data base, fuel moisture and microclimate models that extrapolate base station weather data to remote sites based on

information in the data base, and fire behavior and fire ecology models that integrate information from the data base and the other models to calculate real-time fire behavior and ecological succession following a fire.

IMPOUNDMENT SUBMODEL

Responsibilities

The subgroup constructing the Impoundment submodel was responsible for representing the following actions: water level manipulation/mosquito control; opening/building dikes; prescribed burning; and dike maintenance (Table 1). All of these actions, except dike maintenance, are represented in the submodel. General indicators desired from the Impoundment submodel were surface water depth, surface water quality (salinity, aluminum, zinc, total phosphorus, total nitrogen, dissolved oxygen, pH, and temperature), and acres of various cover types (Table 1). All of these general indicators are represented in the submodel, except for the surface water quality parameters of dissolved oxygen, pH, and temperature.

Several outputs were requested by other submodels (Figure 1). The volume of water flowing between the impoundment and the estuary (acre-inches), the total phosphorus in water flowing from the impoundment to the estuary (lbs), and evapotranspiration (inches) are calculated for the Estuary submodel. Water level (feet above mean sea level) and the total area of the impoundment are used by the Upland submodel. The number of 2-week dry periods from May to September, the total area of impoundment inundated (acres), the area of marsh cover type (acres), the area of marsh cover type inundated (acres), and an indicator of the existence of a surface water connection between the impoundment and the estuary (yes/no) are calculated for the Wildlife submodel.

Structure

The Impoundment submodel consists of three basic types of interconnected calculations:

(1) A water budget updating storage volume and water levels in the impoundment based on an accounting of inflows and outflows of water;

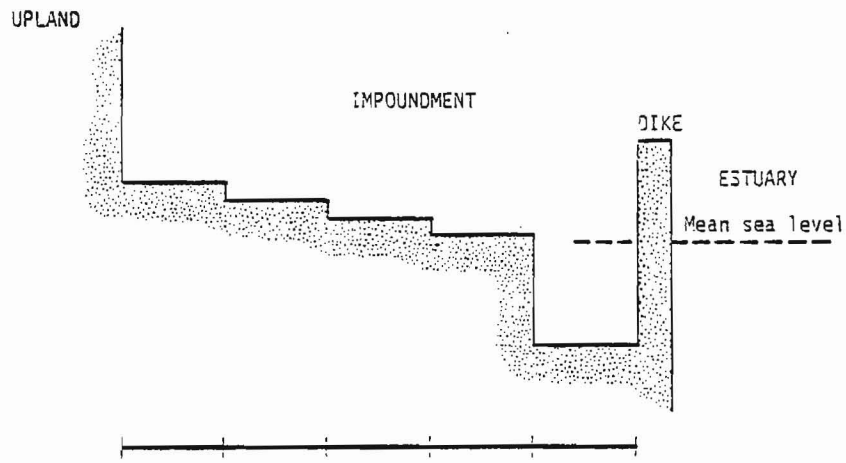
(2) Mass balance calculations for various constituents (salt, total phosphorus, total nitrogen, zinc, and aluminum), tracing their movement and storage in various flows and storages of water; and

(3) Changes in the areal extent of various cover types based on the environmental driving variables of water depth, salinity, and fire.

The water budget and mass balance calculations are done monthly and the cover type changes are done annually. Secondary indicators, such as the area of marsh vegetation inundated, are then derived from the results of these basic calculations.

The general shape and relationship of the impoundment to the upland and estuary are depicted in Figure 4. The impoundment itself is depicted in Figure 10. Variation in topography within the impoundment is represented by five discrete elevations, each comprising a specified fraction of the total area of the impoundment. The impoundment is separated from the estuary by a dike with a stop log structure. The elevation of the stop log structure, and, thus, the elevation of water at which surface water flow occurs, is an input parameter that is varied to simulate different management actions. The total area of the impoundment is assumed to be 600 acres with step elevations and proportions as indicated in Figure 10. The number of feet of edge between the impoundment and the estuary (approximately 10,000 ft for one side of a 600-acre impoundment) and the number of feet of edge between the impoundment and the uplands (approximately 15,000 ft for the other three sides of a 600-acre impoundment) are calculated from the total area of the impoundment, assuming

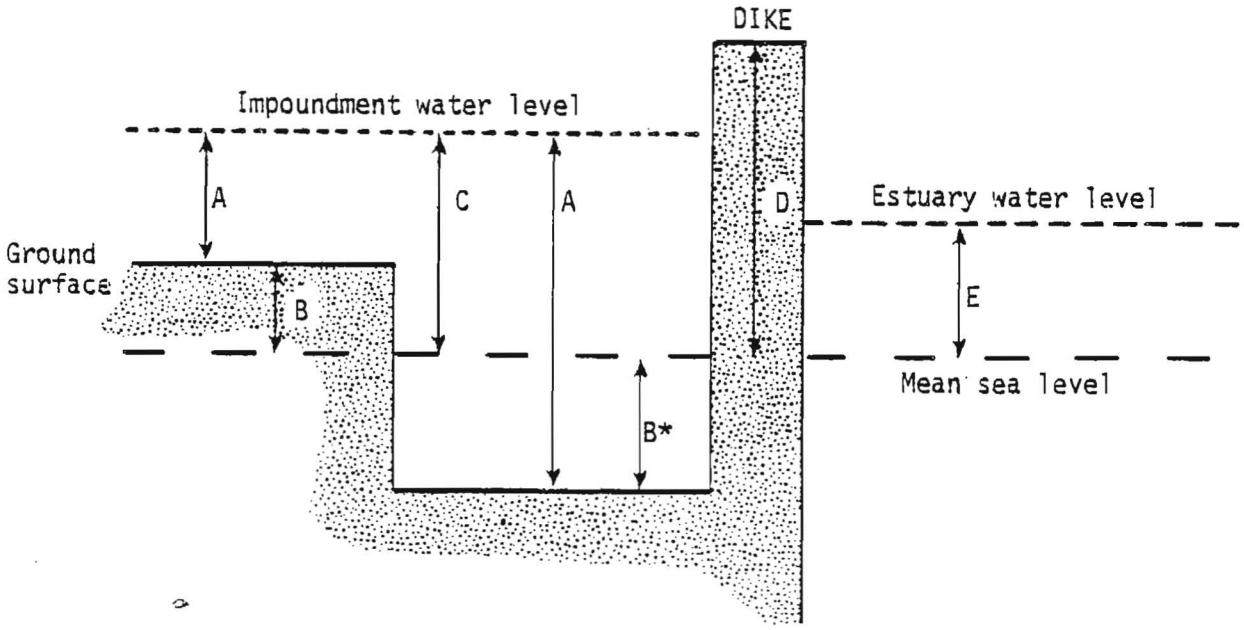
a rectangular impoundment with a ratio of length to width of 4:1 and the configuration depicted in Figure 4. The impoundment shape and total area, the step elevations, the proportion of the impoundment in various steps, and, in principle, the number of different steps can be varied to represent different types of impoundments.



5	4	3	2	1	Step Index (IS)
4	25	50	20	1	% of total area in step
21	15	8	3	-36	Elevation of step above mean sea level in inches

Figure 10. Diagramatic cross section of impoundment.

Computationally, the calculations of water budget and changes in cover type require a number of variables representing elevations of water and land relative to other elevations of water and land. The most important of these relative elevations are depicted in Figure 11. Water level in the impoundment is related to storage volume in the impoundment based on DIM, water depth at the lowest step (the deepest point in the impoundment). This relationship (Figure 12) is also used in inverse to calculate the storage volumes associated with various water depths. This relationship is dependent on the total area and the relative proportions and elevations of each step and thus needs to be re-specified if these parameters are altered.



A. STEPD(IS) - Water depth at each impoundment step; maximum value (i.e., for lowest step) is DIM. Values depicted are positive.

B. STEPEL(IS) - Height of each step above mean sea level. As depicted, B is positive and B* is negative.

C. WDEPTH(IM) - Height of water in impoundment above mean sea level. Value depicted is positive.

D. DIKE(IM) - Height of dike (top stop log) above mean sea level. Value depicted is positive.

E. ELEVEL(IM) - Height of water in estuary above mean sea level. Value depicted is positive.

Figure 11. Relative elevations used in Impoundment submodel calculations.

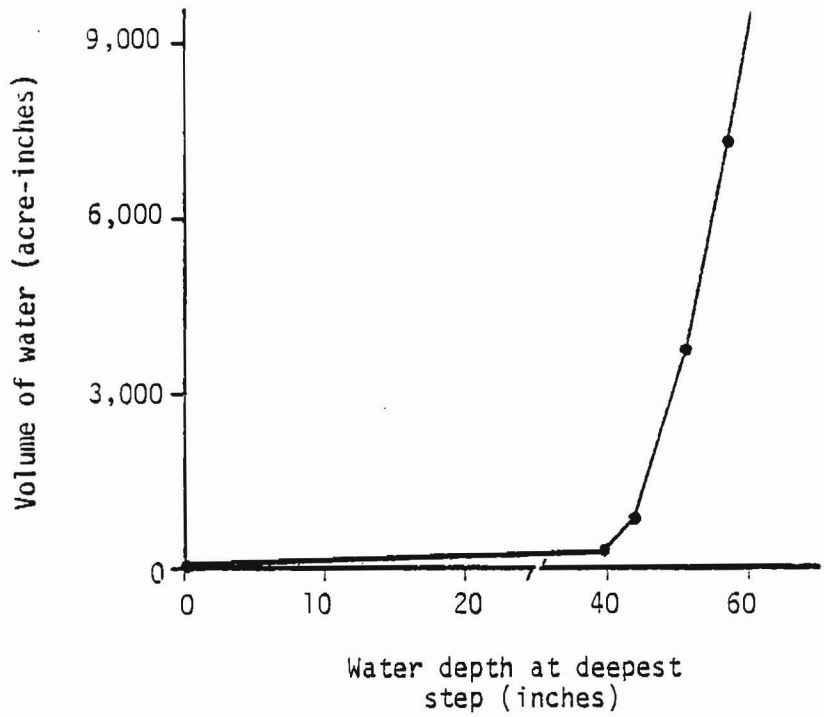
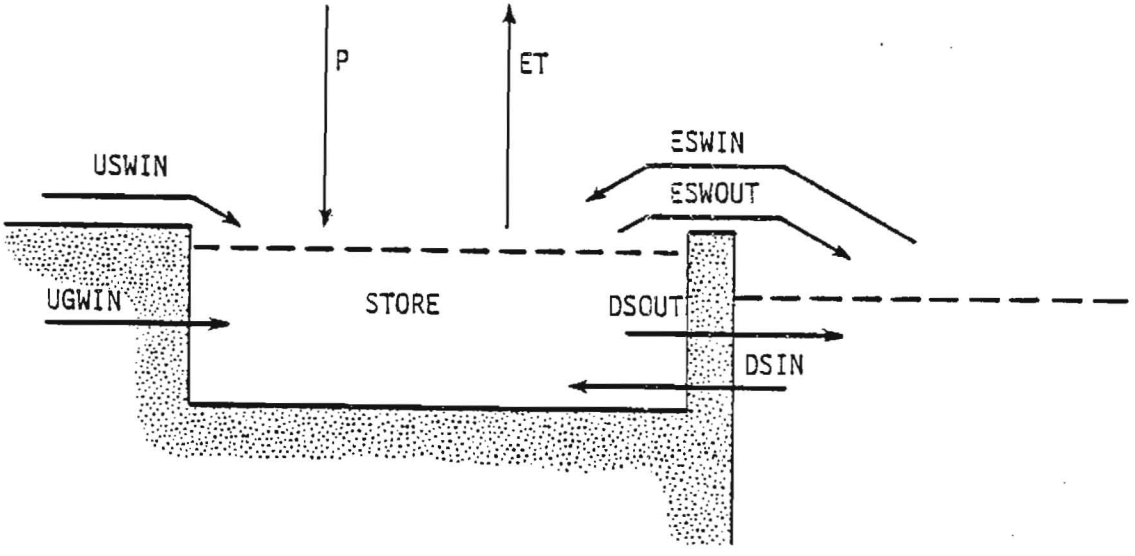


Figure 12. Relationship of water depth to storage volume for the 600-acre impoundment. The relationship is assumed to be linear above 57 inches of water depth.

Monthly calculations - water budget and mass balance of constituents. The components of the monthly water budget for the impoundment are illustrated in Figure 13. Inputs of upland surface and aquifer water [USWIN(IM) and UGWIN(IM) in acre-inches] are calculated by the Upland submodel. Precipitation [P(IM) in inches] is provided by the Upland submodel, and a pattern of evapotranspiration [ET(IM) in inches] is provided as input data to the Impoundment submodel. Dike seepage [DSIN(IM) or DSOUT(IM), depending on direction] is calculated based on relative water levels in the impoundment and estuary as follows:

DS = GRAD * K * A * WFRE * DCON



USWIN(IM) - Upland surface water input

UGWIN(IM) - Upland aquifer input

P(IM) - Precipitation

ET(IM) - Evapotranspiration

ESWIN(IM) - Input (flow or pumped) from estuary

ESWOUT(IM) - Outflow to estuary

DSIN(IM) - Dike seepage from estuary

DSOUT(IM) - Dike seepage to estuary

Figure 13. Components of impoundment water budget.

where DS = monthly dike seepage, DSOUT(IM) if positive, DSIN(IM) if negative (acre-inches)

GRAD = dimensionless gradient = [(WDEPTH(IM)/12.] - [ELEVEL(IM)/12.)]/WIDTH

WDEPTH(IM) = monthly water level in impoundment (inches above mean sea level)

ELEVEL(IM) = monthly water level in estuary (inches above mean sea level)

WIDTH = distance over which seepage occurs (ft)

K = permeability of dike sediments (300 ft/mo)

A = cross-sectional area through which seepage occurs (10 ft^2/ft of dike)

WFRE = length of dike in contact with estuary (ft)

DCON = dimensional conversion from ft^3 to acre-inches (1/3630)

If DS is positive (i.e., flow is from impoundment to estuary), the value of DS is assigned to DSOUT(IM). If DS is negative (i.e., flow is from the estuary to the impoundment), the value of DS is assigned to DSIN(IM).

Exchange of surface water with the estuary can involve pumping to fill the impoundment to a defined level. Thus, a preliminary update of the storage in the impoundment is performed in order to be able to calculate the desired volume of pumping. The preliminary storage update is calculated based on all the monthly inflows and outflows, except the surface water exchange (ESWIN or ESWOUT), as follows:

```
PST = STM + USWIN(IM) + UGWIN(IM) + ((P(IM) - ET(IM)) * WTOT] +
      DSIN(IM) - DSOUT(IM)
```

where PST = preliminary storage in current month (acre-inches)

STM = storage in previous month (acre-inches)

USWIN(IM) = monthly upland surface water input (acre-inches)

UGWIN(IM) = monthly upland aquifer input (acre-inches)

P(IM) = monthly precipitation (inches)

ET(IM) = monthly evapotranspiration (inches)

WTOT = total area of impoundment (acres)

DSIN(IM) = monthly dike seepage input (acre-inches)

DSOUT(IM) = monthly dike seepage output (acre-inches)

The preliminary storage volume is then converted to a preliminary maximum water depth (DIM) and a preliminary height above mean sea level [WDEPTH(IM)] in the impoundment from the water depth to storage volume relationship (Figure 12).

The calculation of surface water exchange with the estuary is done by case, where the four possible cases represent different relationships of preliminary impoundment and estuary water levels to the elevation of the top stop log in the dike (Figure 14). In Case 1, the preliminary water level in the impoundment is higher than the dike (top stop log), and the water level in the estuary is below the dike elevation. Thus, a volume of water [ESWOUT(IM)] flows out of the impoundment such that the water level in the impoundment equals the dike elevation.

In Case 2, water levels in both the impoundment and estuary are higher than the dike elevation (Figure 14). If the preliminary impoundment level is higher than the estuary, a volume of water [ESWOUT(IM)] flows out of the impoundment such that the level in the impoundment is lowered to the estuary level. If the estuary level is higher than the preliminary impoundment level, a volume of water [ESWIN(IM)] flows into the impoundment such that the level in the impoundment is raised to the estuary level.

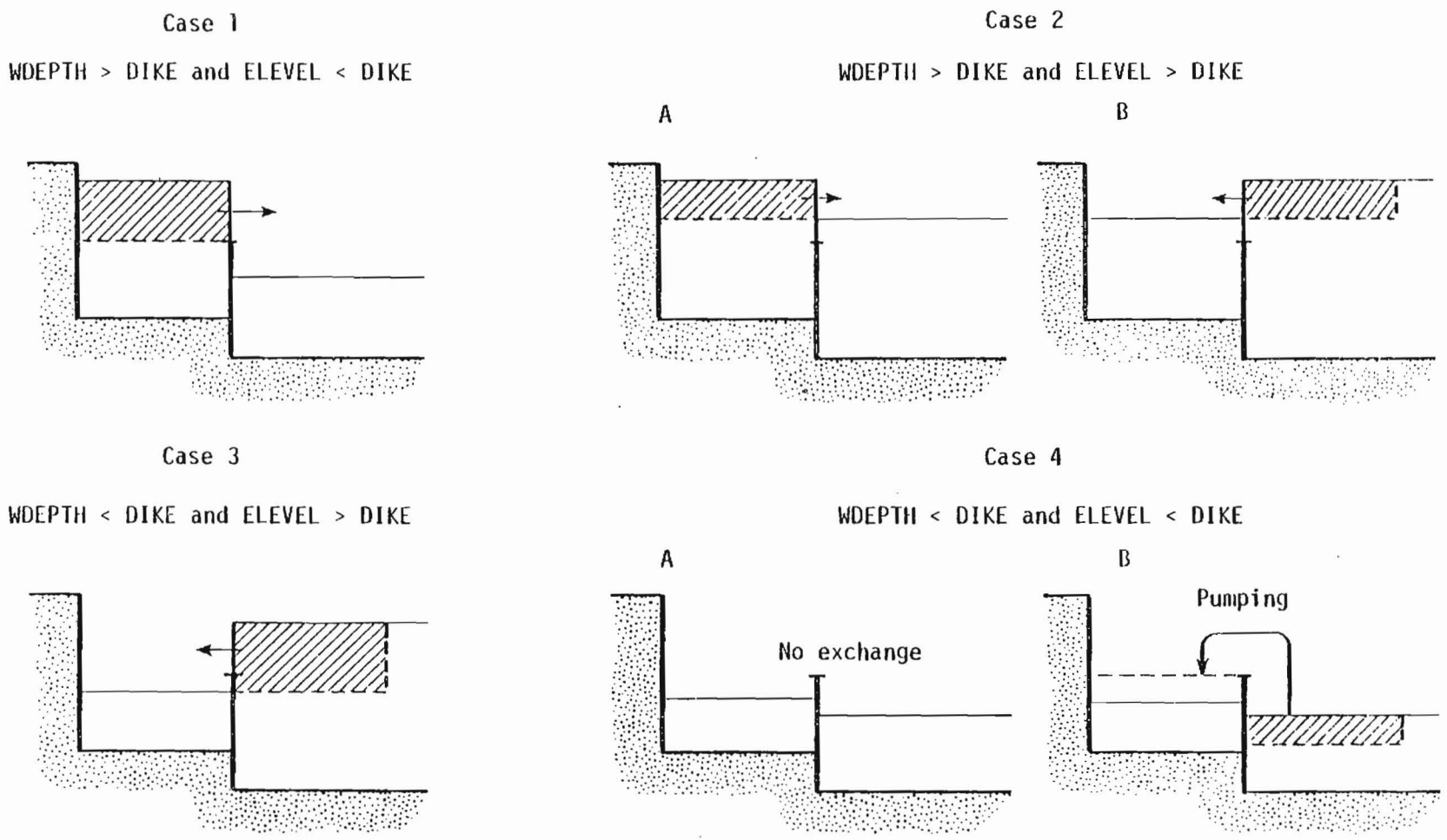


Figure 14. Cases of surface water exchange between impoundment and estuary.

In Case 3, water level in the estuary is higher than the dike elevation, and the preliminary water level in the impoundment is below the dike elevation (Figure 14). Thus, a volume of water [ESWIN(IM)] flows into the impoundment from the estuary such that the level in the impoundment is raised to the estuary level.

In Case 4, both the estuary and preliminary impoundment water levels are below the dike elevation (Figure 14). If no pumping is allowed [IPUMP(IM) = 0], then no exchange occurs [i.e., ESWIN(IM) and ESWOUT(IM) = 0]. If pumping is allowed, a volume of water [ESWIN(IM)] is pumped from the estuary into the impoundment such that the water level in the impoundment is equal to the dike elevation. In all the cases involving a calculation of the volume of water required to produce a change in the water level in the impoundment, the necessary volumes are calculated using the storage volume to water depth relationship of Figure 12 applied to the respective initial and final volumes.

The Wildlife submodel utilizes an indicator of whether or not there is a surface water connection between the impoundment and the estuary. A connection is assumed to exist in Cases 1, 2, and 3, and the variable OPEN is set to 1 for months meeting the conditions of any of these cases. If the conditions are those of Case 4 (i.e., pumping or no surface water exchange), the variable OPEN is set to 0, representing no effective connection for that month.

After the calculation of surface water exchange with the estuary, the monthly water budget is completed by updating the preliminary storage value as follows:

$$STM = PST + ESWIN(IM) - ESWOUT(IM)$$

where STM = storage at end of current month (acre-inches)

PST = preliminary storage for current month (acre-inches)

ESWIN(IM) = monthly flow of water from estuary to impoundment (acre-inches)

ESWOUT(IM) = monthly flow of water from impoundment to estuary (acre-inches)

The new storage volume is converted to a new water depth at the deepest step (DIM) by the relationship in Figure 12. This maximum depth is then used to calculate the new thickness of water overlying each step [STEPD(IS), where IS = step index] and a new elevation of water relative to mean sea level, WDEPTH(IM).

A mass balance of salt is calculated by updating a storage value of salt in the impoundment, considering all the inputs and outputs of salt associated with components of the water budget (Figure 13), as follows:

$$\begin{aligned} SMASS(5)_2 = {} & SMASS(5)_1 + USWL(IM,5) + UGWL(IM,5) + PL(IM,5) \\ & + ([ESWIN(IM) + DSIN(IM)] * ECONC(IM,5)) \\ & - ([ESWOUT(IM) * DSOUT(IM)] * [SMASS(5)_1/STM]) \end{aligned}$$

where $SMASS(5)_2$ = salt storage in impoundment at end of month (lb)

$SMASS(5)_1$ = salt storage in impoundment at beginning of month (lb)

USWL(IM,5) = monthly salt input in surface water from upland (lb)

USGL(IM,5) = monthly salt input in aquifer water from upland (lb)

PL(IM,5) = monthly salt input in precipitation (lb)

ESWIN(IM) = monthly surface water input from estuary (acre-inches)

DSIN(IM) = monthly dike seepage input from estuary (acre-inches)

ECONC(IM,5) = monthly salt concentration in estuary (lb/acre-inch)

ESWOUT(IM) = monthly surface water output to estuary (acre-inches)

DSOUT(IM) = monthly dike seepage output to estuary (acre-inches)

STM = impoundment storage volume at beginning of month (acre-inches)

This updated salt storage information is used with the storage volume at the end of the month to calculate salinity, or concentration, in the impoundment in parts per thousand.

Mass balances of total phosphorus and total nitrogen are calculated by the approach of separating each of these elements into "trapped" and "available" (or highly mobile) pools to represent the filtering function of vegetation in the impoundment. A multiplicative coefficient, FF, is applied to inputs of total phosphorus and total nitrogen each month to determine the fraction that will go into the respective "available" pools. This coefficient is equal to the fraction of the total impoundment that is unvegetated (i.e., in the open water cover type). If all the impoundment is unvegetated, all the inputs of total phosphorus and total nitrogen go into the "available" pools. If half the impoundment is unvegetated, half the inputs go into the "available" pool. If none of the impoundment is unvegetated, none of the inputs go into the "available" pool. This approach is clearly a simplification of the complex processes of biotic and abiotic uptake and release that determine the relationships between impacts and outputs of elements for impoundments. In particular, workshop participants have commented that submerged aquatic vegetation in the open water cover type (e.g., Chara spp) may have substantial filtering capacity for some time scales.

Outputs of total nitrogen and total phosphorus to the estuary are from the "available" pools as follows:

$$OUTN(IM) = SMASS(3) * [ESWOUT(IM) + DSOUT(IM)]/STM$$

and

$$OUTP(IM) = SMASS(4) * [ESWOUT(IM) + DSOUT(IM)]/STM$$

where OUTN(IM) = monthly transfer of total nitrogen from impoundment to estuary (lb)

OUTP(IM) = monthly transfer of total phosphorus from impoundment to estuary (lb)

SMASS(3) = impoundment storage of "available" total nitrogen at beginning of month (lb)

SMASS(4) = impoundment storage of "available" total phosphorus at beginning of month (lb)

ESWOUT(IM) = monthly surface water flow from impoundment to estuary (acre-inches)

DSOUT(IM) = monthly dike seepage flow from impoundment to estuary (acre-inches)

STM = impoundment water storage at beginning of month (acre-inches)

The storage of "available" total phosphorus in the impoundment is updated as follows: ,mod_equ 1_,end

$$SMASS(4)_2 = SMASS(4)_1 - OUTP(IM) + FF * [USWL(IM,4) + UGWL(IM,4) + PL(IM,4) + [[ESWIN(IM) + DSIN(IM)] * ECONC(IM,4))]$$

where $SMASS(4)_2$ = impoundment storage of "available" total phosphorus at end of month (lb)

$SMASS(4)_1$ = impoundment storage of "available" total phosphorus at beginning of month (lb)

OUTP(IM) = monthly transfer of total phosphorus from impoundment to estuary (lb)

FF = fraction of total phosphorus input that is "available"

USWL(IM,4) = monthly input of total phosphorus to impoundment in upland surface water (lb)

UGWL(IM,4) = monthly input of total phosphorus to impoundment in upland aquifer water (lb)

PL(IM,4) = monthly input of total phosphorus to impoundment in precipitation (lb)

ESWIN(IM) = monthly flow of surface water from estuary to impoundment (acre-inches)

DSIN(IM) = monthly dike seepage flow of water from estuary to impoundment (acre-inches)

ECONC(IM,4) = monthly concentration of total phosphorus in estuary (lb/acre-inch)

A similar update in storage is calculated for "available" total nitrogen. "Unavailable" or "trapped" total nitrogen and phosphorus (i.e., the 1.0 - FF fractions of input) are not explicitly accounted.

The mass balances of zinc and aluminum consist of merely accumulating all the inputs. No calculation of output is made, under the assumption that "filtering" of these elements by the impoundment is essentially complete. The storages for these elements, thus, represent only the accumulated loadings. The assumption of complete filtering is clearly an approximation. However, subgroup participants believed that this approximation was considerably better for zinc and aluminum than for nitrogen and phosphorus and that total accumulated loadings of these elements would provide a useful indicator. The calculation for aluminum is as follows:

$$SMASS(1)_2 = SMASS(1)_1 + [ESWIN(IM) + DSIN(IM)] * ECONC(IM,1) + USWL(IM,1) + UGWL(IM,1) + PL(IM,1)$$

where $SMASS(1)_2$ = impoundment storage of aluminum at end of month (lb)

$SMASS(1)_1$ = impoundment storage of aluminum at beginning of month (lb)

ESWIN(IM) = monthly surface water flow from estuary to impoundment (acre-inches)

DSIN(IM) = monthly dike seepage water flow from estuary to impoundment (acre-inches)

ECONC(IM,1) = monthly concentration of aluminum in estuary (lb/acre-inch)

USWL(IM,1) = monthly input of aluminum in upland surface water (lb)

UGWL(IM,1) = monthly input of aluminum in upland aquifer water (lb)

PL(IM,1) = monthly input of aluminum in precipitation (lb)

A similar calculation is made for zinc each month.

Annual calculations - vegetation changes. Vegetation, or lack thereof, in the impoundment is represented by the areal extent of the following five cover types: mangrove-halophyte; salt marsh; cattail-mixed freshwater marsh; willow swamp-marsh; and open water. The general approach taken in representing vegetation dynamics is that the community composition at any point in time reflects a long-term average of environmental driving variables. Two primary environmental variables are used, depth of inundation and salinity. Thus, with two exceptions (fire and excessive water depth), the fractions of various cover types at a given elevation, or step, within the impoundment reflect the similarity of a long-term running average of water depth and salinity at that elevation to the "optimum" water depths and salinities of various cover types. These optimum values are depicted in Figure 15. The open water cover type is given a salinity coordinate of zero in order to simplify the calculations. Open water might be more appropriately denoted by a line in Figure 15, reflecting a dependence only on water depth. The use of a running average (3 years for the model runs presented in this report) of environmental variables functions as a surrogate for the "response time" of the biological communities in order to avoid having open water converted to mature forest in 1 year.

Computationally, the first annual calculation is to update the running averages of water depth and salinity for each step. The model currently uses a 3-year running average with a separate water depth calculated for each elevation or step and one salinity average calculated for the entire impoundment. The differences (or Euclidean distances) between the current running averages for each step and the optimum values for each cover type are then calculated as follows:

$$DIST(IT) = [DSAL(IT) ** 2.0 + DDEP(IT) ** 2.0] ** 0.5$$

where DIST(IT) = normalized, Euclidean distance to cover type IT

DSAL(IT) = [SOPT(IT) - RAVS] * SCALES

DDEP(IT) = [DOPT(IT) - RAVD] * SCALED

SOPT(IT) = salinity optimum for cover type IT, see Figure 15 (ppt)

DOPT(IT) = optimum depth of inundation for cover type IT, see Figure 15 (inches of water above ground surface)

RAVS = 3-year running average of salinity (ppt)

RAVD = 3-year running average of water depth (inches of water above ground surface)

SCALES = scaling factor for salinity

SCALED = scaling factor for water depth

This calculation can be considered graphically as the distance from the current state of the system to other coordinates as the system moves through a state space of average salinity and water depth (Figure 16). Scaling factors (SCALES and SCALED) are necessary to adjust the relative importance of salinity and water depth (i.e., to avoid having their importance related to the units of measure). The scaling factors were set so that the differences between the maximum and minimum cover type optima for both salinity and water depth are 10 units. Other scaling factors (e.g., factors that maximize the relative distances between cover types) could be used.

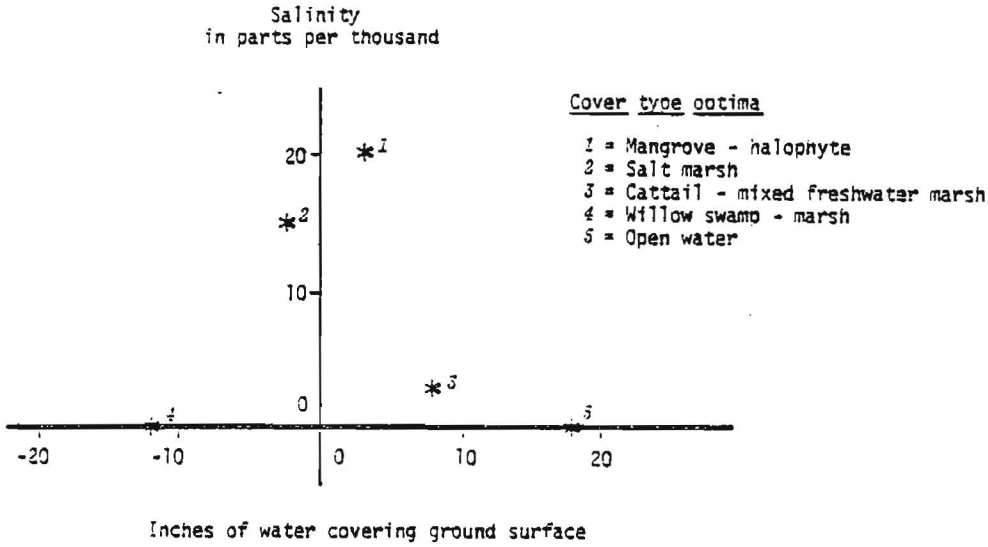


Figure 15. Location of cover type optima in salinity-water depth state space.

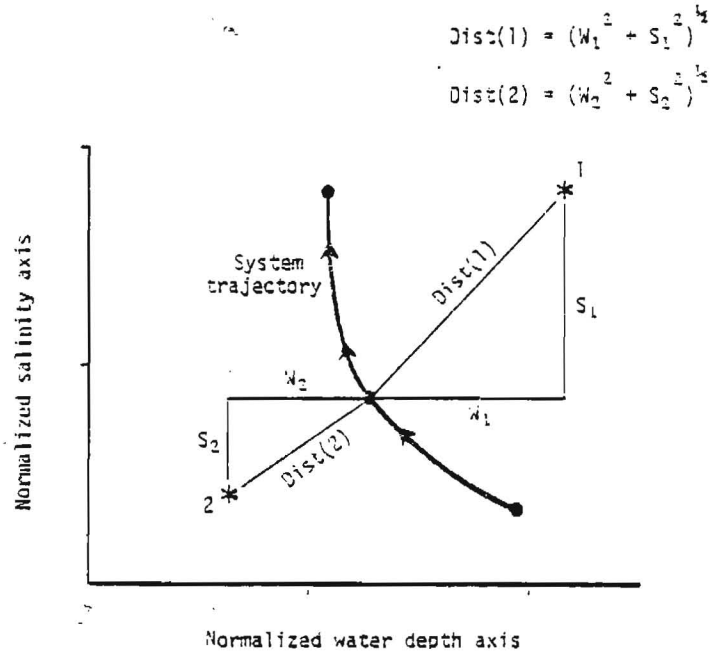


Figure 16. Graphic representation of Euclidean distance calculations for one point in system's trajectory through salinity-water depth state space. Each point in the trajectory represents a running average of past salinity and water depth for a given year. Asterisks represent optima for two hypothetical cover types.

At this point, two special cases are considered. The first case is excessive water depth. If the current year's water depth at a particular elevation, or step, is greater than or equal to 36 inches, then all of that step is assumed to be in the open water cover type. The second special case is fire. In the year in which a fire occurs and for 2 years following a fire, the Euclidean distance, DIST(IT), to selected community types is multiplied by a factor, FMULT(IT), increasing the distance to those cover types. This simulates the effects of fire in suppressing the representation of certain communities and favoring other communities. Currently, FMULT(IT) is set to 1.5 for the mangrove-halophyte and willow swamp-marsh cover types, thus decreasing the proportional representation of these communities for a 3-year period associated with each fire. Fires are introduced in the model by specifying a rotation interval in years, representing either regular natural starts or prescribed starts. A calculated start results in a fire only if the marsh cover types (salt marsh and cattail-mixed freshwater marsh) represent more than 25% of the impoundment area. This constraint is intended to simulate the role of these communities in enhancing fire potential in the other cover types.

Following incorporation of fire effects in the normalized, Euclidean distances, fractions in each cover type are calculated for each elevation, or step, as follows:

```
WFRAC(IS,IT) = DINV(IT)/TDINV
```

where WFRAC(IS,IT) = fraction of each step in cover type IT

DINV(IT) = 1.0/D2(IT)

D2(IT) = DIST(IT) ** 2.0

DIST(IT) = normalized, Euclidean distance to cover type IT

TDINV = sum of DINV(IT) over cover types

The normalized, Euclidean distances are squared before calculating fractions of each cover type in order tc decrease the relative representation of "remote" cover types. This is computationally simpler than introducing a large number of outer bounds or environmental limits for various cover types. Areas of each cover type at each elevation are then calculated by multiplying the fractions in each cover type at a given step, WFRAC(IS,IT), by the area of each step, STEPA(IS). Total areas of each cover type in the impoundment, WACRE(IT), are then obtained by summing over steps.

Several additional indicator variables are required by the Wildlife submodel. The variable DRY(IM,IS) represents the number of 2-week dry periods in each month for each step. This is set equal to 2.0 if the step is dry in a given month [i.e., STEPD(IS) is less than 0] and equal to 0 if the step is wet in a given month [i.e., STEPD(IS) is greater than or equal to 0]. The total area of the impoundment that is inundated in each month, WWET(IM), is calculated by summing the areas of all steps, STEPA(IS), that are inundated in a given month [as determined by values of STEPD(IS) greater than or equal to 0]. Finally, the area of marsh cover types (salt marsh and cattail-mixed freshwater marsh) that is inundated each month, DCOVER(IM), is calculated by summing the areas of these cover types across all the steps that are inundated in a given month, as determined above.

Limitations

Resolution. Water budget and mass balance calculations in the Impoundment submodel are done monthly, based on an impoundment consisting of five discrete elevations. A daily time step is a much more "natural" resolution for many of the physical processes and management decisions determining the water budget in the impoundment. One example is that, in reality, pumping may be required for mosquito control at one point in a month, while the impoundment may overtop the stop log structure because of rainfall and runoff at another point in the month. Another source of error associated with a monthly time step is that, in some months, some components of the water budget are large relative to the storage volume. Thus, using storage volume at the beginning of the month to

calculate proportional fluxes (i.e., those based on elevation or head) may result in numerical error. This error would be reduced by using a shorter time interval.

The internal topography could be easily refined by utilizing a large number of discrete elevations or steps. As currently conceptualized, the submodel "floods" and "drains" various elevations purely based on total volume and average water level in the impoundment. It would be more complicated, but perhaps useful, to incorporate isolated, local depressions that could trap water and, thus, remain inundated as average water levels declined due to surface drainage.

Water budget. Aside from the limitations of temporal resolution described above, the most important limitation in the water budget calculations probably involves the exchange of surface water with the estuary. The logic of a simple stop log structure with comparisons of monthly water elevations and decisions to pump or not pump a volume of water sufficient to raise water level to the top stop log is complex. However, this logic is simple compared to that required to represent structures, such as flap gates, that would allow a one-way "capture" of water from the estuary at high tide.

Mass balance of water constituents. The mass balance calculations of total nitrogen, total phosphorus, zinc, aluminum, and, to a lesser extent, salinity are crude. They really represent more of a "What if it worked like this?" exercise, than a comprehensive simulation of the biogeochemical processes in an impoundment. Much more is known about the biogeochemistry of these elements in wetlands than could be incorporated in the model during the limited time available at the workshop. However, the complexities resulting from incorporating additional detail may not result in substantially improved model performance, especially if critical processes, such as denitrification, can not be well represented.

Vegetation dynamics. The approach taken to vegetation dynamics is an interesting hybrid of simulation modeling and traditional ordination approaches

to describing patterns in community composition. There are a number of other approaches to simulating vegetation dynamics that might be profitably applied to impoundments (see West et al. 1981 for an overview of current models and approaches for woody vegetation).

A number of modifications might be considered in the current approach, including the following:

- The "response-time" or length of the running average could be varied. This is a simple parameter change for the number of years if all cover types are considered to respond identically. Incorporating different "response-times" for different cover types would be more complicated.

- The "shape" of the environmental state space could be altered by changing the scaling factors or using a different function to calculate "distance" in the space.

- Additional variables (e.g., pH or nutrients) could be incorporated in the environmental state space or different relationships could be used to weight the values of those variables over time (e.g., maximum annual salinity rather than average salinity).

- Cover types could be characterized by their environmental limits (e.g., maximum water depth) as well as, or instead of, their optimum values.

- Additional or transitional cover types could be included.

Before any of these modifications are implemented, it would be appropriate to compare the model output with some observed cover type distributions and sequences of vegetation change in the impoundments.

ESTUARY SUBMODEL

Responsibilities

As indicated in Figure 1, the primary responsibilities of the Estuary submodel were to produce estimates of water level (relative to mean sea level), for use by both the Impoundment and Upland submodels; the surface area of the estuary, for use by the Upland submodel; and concentrations of aluminum, zinc, total nitrogen, total phosphorus, and salt in estuarine water, for use by the Impoundment submodel. In addition, although it is not presently used by the Wildlife submodel, the Estuary submodel was responsible for producing an estimate of the area occupied by sea grass beds, which was considered an indicator of the amount of habitat available for sea trout. As intermediate products, the Estuary submodel also generates estimates of the chlorophyll content in the water column (an indicator of phytoplankton biomass and, hence, eutrophication) and turbidity.

In formulating an approach to producing these estimates, the Estuary submodel had available to it a variety of information from other submodels. This information included: water input to the estuary from precipitation, surface water runoff, and ground water discharge, as well as total phosphorus loadings in these inputs (from the Upland submodel); and evapotranspiration, the volume of water flowing to or from the estuary (including surface flow and dike seepage), and the amount of total phosphorus contained in water moving to the estuary (from the Impoundment submodel).

Structure

The Estuary submodel is a stylized representation of a section of estuary that is connected hydrologically to an upland, an impoundment, and the remainder of the surrounding estuary (Figure 17). The degree of hydrologic connection with the upland is determined, in large part, by the length of its boundary with the estuary (in this case, approximately 1,000 ft). The degree of connection with the impoundment is determined by the length of its boundary

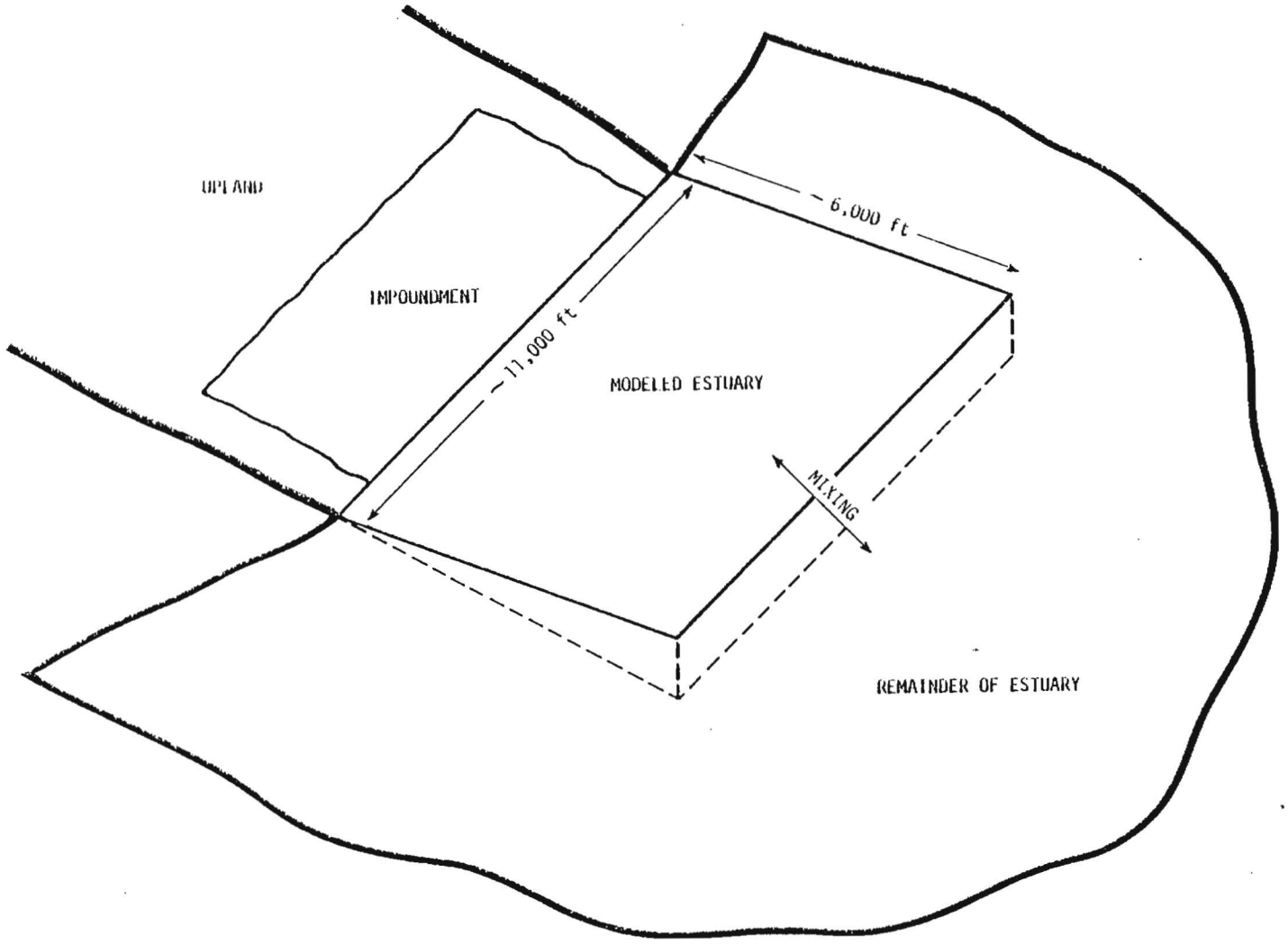


Figure 17. Stylized representation of estuary considered in the Estuary submodel.

with the estuary (in this case approximately 10,000 ft) and other factors, such as height of the impoundment dike, permeability of the dike, elevation of stop logs in the dike, and water level in the estuary. Mixing with the surrounding estuary is controlled by a simple coefficient representing the fraction of water in the modeled estuary that is replaced each month by water from the surrounding estuary.

The dimensions of the modeled estuary were determined in the following way (Figure 18). It was estimated, from a map of Merritt Island, that the area around the upper end of Banana River and Banana Creek consists of about one-third estuary and two-thirds uplands and impoundments. The area represented by the Upland submodel is approximately 2,500 acres, and the area represented by the Impoundment submodel is approximately 600 acres. The surface area of the modeled estuary was, therefore, estimated to be 1,500 acres. Given a shoreline border of 11,000 ft with the impoundment and upland (Figure 17), the modeled estuary must extend approximately 6,000 ft from shore (Figure 18) to provide a surface area of 1,500 acres.

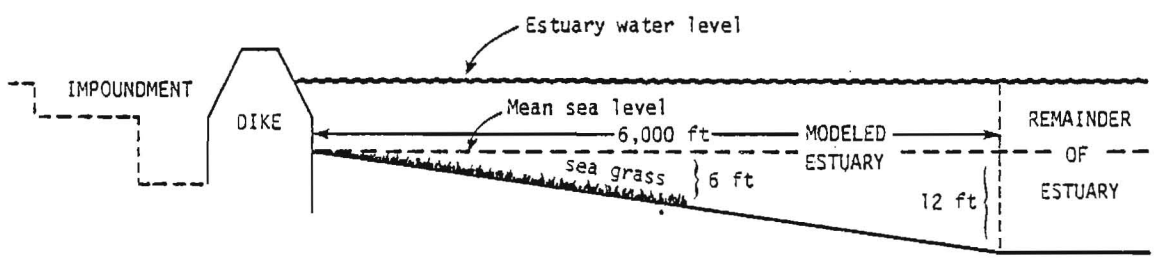


Figure 18. Cross-sectional view of stylized estuary considered in the Estuary submodel.

The bottom of the estuary is assumed to slope constantly away from the shore. While this assumption is not entirely correct, it does capture the idea that waters farther from shore tend to be deeper. The slope was determined from observations that sea grasses presently occupy waters as deep as 6 ft and that this depth is sometimes reached approximately 3,000 ft from shore. Extending this slope to a distance of 6,000 ft from shore produces a depth of 12 ft, which is in the neighborhood of the maximum depths found in the Banana River. In most places, however, depths of 12 ft exist only in periodically maintained barge canals. This representation may, therefore, overestimate the volume of water in the stylized estuary.

If the estuary water level is at mean sea level, the volume of water present is represented as a wedge with the dimensions 12 ft x 6,000 ft x 11,000 ft (Figures 17 and 18). This volume may be increased or decreased if the estuary water level is above or below mean sea level (Figure 18).

Calculations in the Estuary submodel are divided into two sections. The first section, which is executed for each month of simulation, calculates a mass balance on water and total phosphorus in the modeled estuary, considering inputs from, and outputs to, the other submodels and mixing with the remaining part of the estuary. It also estimates the chlorophyll-a content of the water column as a function of total phosphorus concentration. The second section, which is executed at the end of each year of simulation, calculates the turbidity of the water column, the maximum depth at which sea grass can live, and the area occupied by sea grass.

Monthly calculations. Monthly calculations begin with a volume of water (acre-ft) and loading of total phosphorus (lb) remaining from the previous month. For the first month of simulation, values representing the condition at the end of the previous month (9,000 acre-ft of water and a total phosphorous loading equivalent to 0.06 ppm) are provided as input.

The volume of water and phosphate loading in the estuary are then adjusted according to the total inputs to, and outputs from, the other submodels. Water losses include evaporation (which is assumed to be equivalent to the evapotranspiration rates used by the Impoundment submodel) and, in some months, seepage through the impoundment dike and flow into the impoundment. If seepage and flow into the impoundment occur, the loading of phosphorus is reduced in direct proportion to the amount of water lost. Additions to the water volume include direct precipitation, surface water runoff from the uplands, ground water flow from the uplands, and, in some months, seepage through the impoundment dike and flow from the impoundment. Each of these additions has an associated phosphate loading. Following all additions and subtractions, the adjusted volume of water and phosphate loading are preserved for later use.

The volume of the estuary in the current month is then calculated as a function of an input value for the height of the estuary relative to mean sea level:

$$EVOL = [ELEVEL(IM) * ETOT/12.] + [0.5 * DEPMAX * ETOT]$$

where EVOL = volume of water in estuary (acre-ft)

ELEVEL(IM) = height of estuary above mean sea level (inches)

ETOT = surface area of estuary (acres)

DEPMAX = maximum depth of estuary (ft)

The first expression on the right side of the equation is the volume of a box that varies in size as the level of the estuary changes monthly. The second expression is the volume of the wedge between mean sea level and the bottom of the estuary. It remains constant for any given configuration of the estuary.

The new estuary volume is then compared to the previously calculated adjusted volume. If the adjusted volume, computed from the volume for the previous month plus additions and subtractions, is greater than the new estuary

volume (EVOL), water is removed so that the adjusted volume is equal to the new volume. The phosphorus loading is also reduced in direct proportion to the amount of water removed. If the adjusted volume is less than the new volume computed (EVOL), water and phosphate are added from the surrounding estuary so that the adjusted volume is equal to the new volume. The phosphorus concentration in the water added from the surrounding estuary is assumed to be 0.06 ppm.

Following these calculations, water in the modeled portion of the estuary is mixed with water from the surrounding estuary. The amount of mixing is controlled by a coefficient ranging between 0.0 and 1.0. If the coefficient has a value of 0.0, no mixing occurs. If it has a value of 1.0, water in the modeled portion of the estuary is completely replaced by water from the surrounding estuary. The mixing coefficient is presently set at 0.5 for all months. A new phosphate loading is calculated in direct proportion to the volume of water remaining in the modeled estuary and the volume replaced from the surrounding estuary. The concentration in water from the surrounding estuary is again assumed to be 0.06 ppm.

The final step in the monthly calculations of the Estuary submodel estimates the concentration of chlorophyll-a in the water column as a function of total phosphorus concentration:

$$CHL(IM) = f[EPC(IM)]$$

where CHL(IM) = concentration of chlorophyll-a (mg/m^3)

EPC(IM) = concentration of total phosphorus (ppm)

f(EPC(IM)) = the piecewise linear function illustrated in Figure 19

Chlorophyll-a is used as an indicator of phytoplankton biomass. At the workshop, preliminary inspection of data from the upper Banana River revealed higher than balanced nitrogen/phosphorus ratios in the water column. This was interpreted as an indication that phosphorus concentrations could be limiting

phytoplankton abundance. Phytoplankton abundance, as represented by chlorophyll-a, was, therefore, assumed to be a function of total phosphorus concentration. The data points on Figure 19 were estimated from a 4-year set of monthly data from the upper Banana River in the following way. Because phosphorus is necessary for phytoplankton growth, it was assumed that a phosphorus concentration of 0.0 ppm would lead to a chlorphyll-a content of 0.0 mg/m³. The average phosphorus concentration measured was approximately 0.06 ppm. The average chlorophyll-a concentration corresponding to these phosphorus concentrations was approximately 10 mg/m³. The highest phosphorus concentration measured in the upper Banana River was approximately 0.15 ppm, and the highest chlorophyll-a concentration was approximately 35 mg/m³. An arbitrary upper limit (350 mg/m³), ten-fold greater than the maximum observed chlorophyll-a concentration, was established. The total phosphorus concentration corresponding to this chlorophyll-a concentration was estimated by extrapolating the slope of the line connecting the previous two data points.

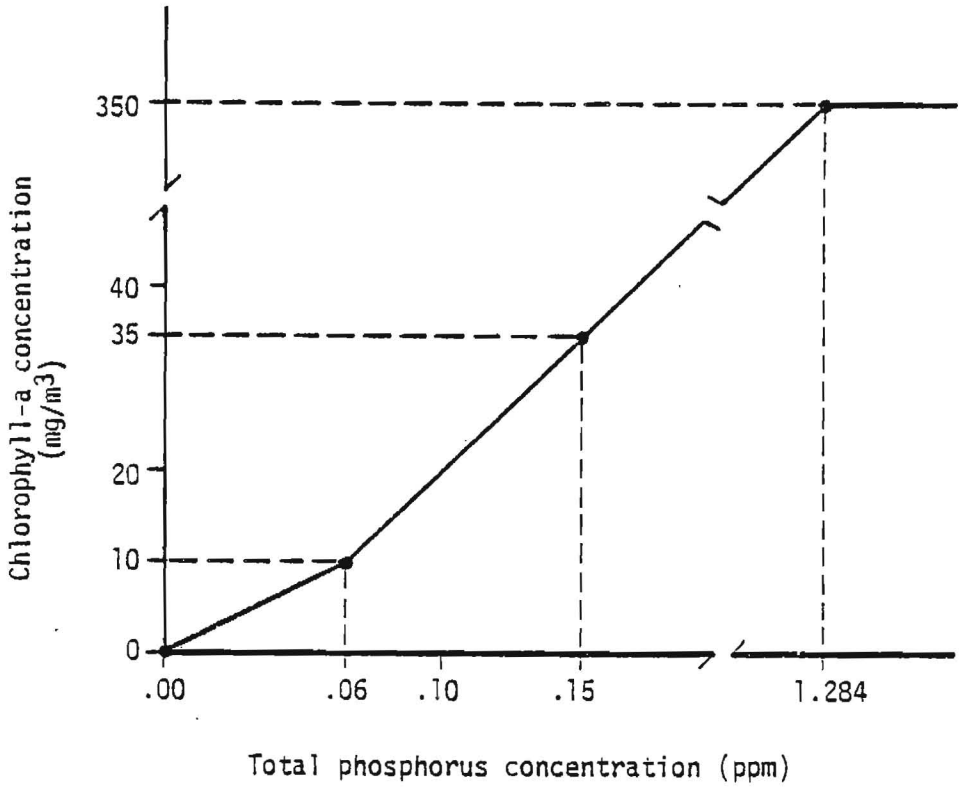


Figure 19. Chlorophyll-a concentration as a function of total phosphorus concentration.

Available time and information at the workshop did not permit detailed consideration of water quality constituents other than phosphorus. Concentrations of the other constituents (aluminum, zinc, total nitrogen, salt, and total suspended solids) in the estuary are, therefore, provided as input data.

Annual calculations. The ultimate purpose of the annual calculations is to estimate the area of sea grass beds in the modeled estuary. Based on general knowledge of other estuarine systems, it was assumed that sea grass distribution is limited by light penetration, which is, in turn, a function of turbidity in the water column. Turbidity was assumed to be a function of phytoplankton abundance, or chlorophyll-a concentration. While these assumptions are obviously very simplistic, it was thought that they might represent, to a first approximation, the major factors determining sea grass distribution.

In the annual calculations, monthly chlorophyll-a concentrations are first averaged to produce a mean annual value. This mean annual chlorophyll-a concentration is then used to estimate an average turbidity:

$$TURB = f(AVCHL)$$

where TURB = average turbidity (NTU)

AVCHL = average chlorophyll-a concentration (mg/m^3)

f(AVCHL) = the piecewise linear function illustrated in Figure 20

The data points on Figure 20 were estimated in the following way. It was assumed that all of the measured turbidity is associated with phytoplankton abundance. Other sources of turbidity (e.g., suspended solids) were ignored simply due to time constraints. Thus, a chlorophyll-a concentration of 0.0 mg/m^3 implies turbidity of 0.0 NTU. The average chlorophyll-a concentration measured in the upper Banana River was approximately 10 mg/m^3. The average turbidity associated with these chlorophyll-a measurements was approximately 4.2 NTU. Extrapolating the straight line connecting these two points, a chlorophyll-a concentration of 350 mg/m^3 implies a turbidity of 147 NTU.

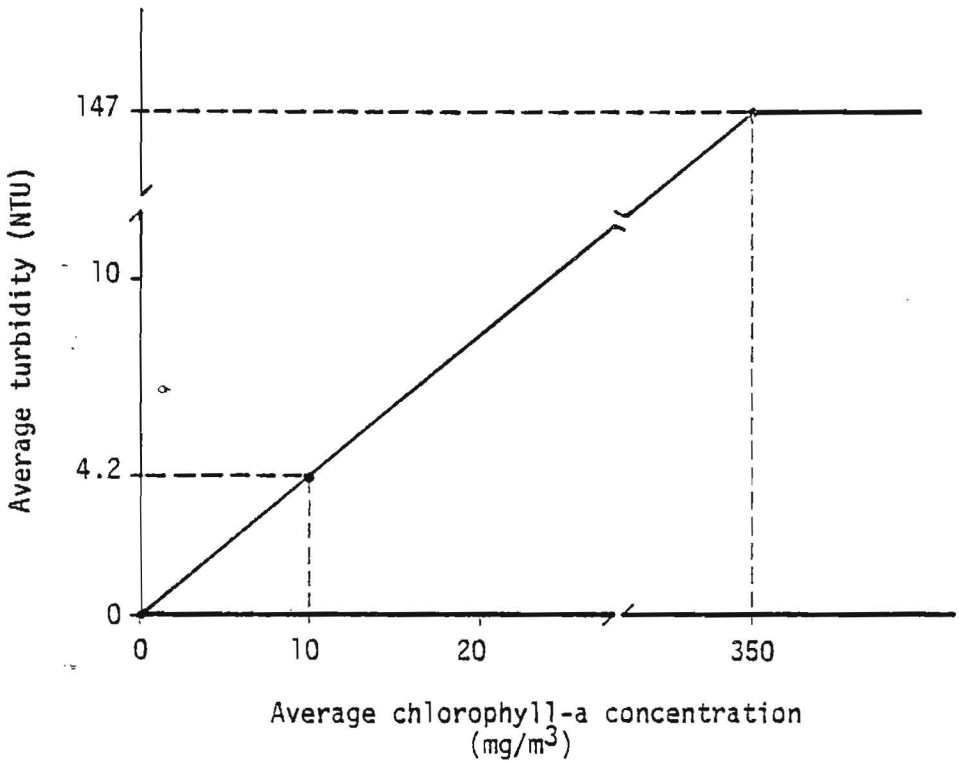


Figure 20. Average turbidity as a function of average chlorophyll-a concentration.

The Estuary submodel considers only changes in the areal extent of sea grass. Density of the stand is not considered. Based on experience, it was assumed that the primary factor limiting the areal extent of sea grass distribution is light penetration (i.e., turbidity). The average turbidity is, therefore, used to estimate a maximum depth at which sea grass can exist:

$$CRIT = f(TURB)$$

where CRIT = maximum depth at which sea grass can exist (ft)

TURB = average turbidity (NTU)

f(TURB) = the piecewise linear function illustrated in Figure 21

Data points in Figure 21 were estimated as follows. It was assumed that, in the absence of turbidity, sea grass could exist at the maximum depth of the estuary (12 ft). At current average turbidity (about 4.2 NTU), sea grass exists at depths up to 6 ft. Extrapolating the line between these two points implies that sea grass could not exist at any depth with turbidity greater than 8.4 NTU. Note that the choice of 12 ft as the maximum depth at which sea grass can exist in the absence of turbidity is a minimum estimate. Sea grasses are known to exist at greater depths in other locations. In the approach used, selection of a greater depth would result in a steeper slope for Figure 21 and, hence, greater sensitivity of sea grass to turbidity. In addition, the relationship depicted in Figure 21 ignores the fact that light penetration is a function of depth as well as turbidity. Thus, a given turbidity may limit sea grass distribution at a depth of, say, 30 ft, but have no effect at 10 ft.

The maximum depth is converted to an areal estimate of sea grass distribution in a straightforward manner. Sea grass is assumed not to respond to short-term changes in turbidity, but rather to long-term variations. A 10-year running average of the maximum depth at which sea grass can exist is, therefore, computed. At the start of the simulation, the elements of this array are all set to a depth of 6 ft. The maximum distance from shore at which sea grass can exist is estimated as:

$$GDIS = f(ACRIT)$$

where GDIS = maximum distance from shore at which sea grass can exist (ft)

ACRIT = 10-year running average of maximum depth at which sea grass can exist (ft)

f(ACRIT) = the piecewise linear function illustrated in Figure 22

The data points for Figure 22 were estimated from the geometry of the stylized estuary, as shown in Figure 18.

Finally, the areal extent of sea grass distribution is calculated by multiplying the maximum distance from shore by the shoreline distance (Figure 17).

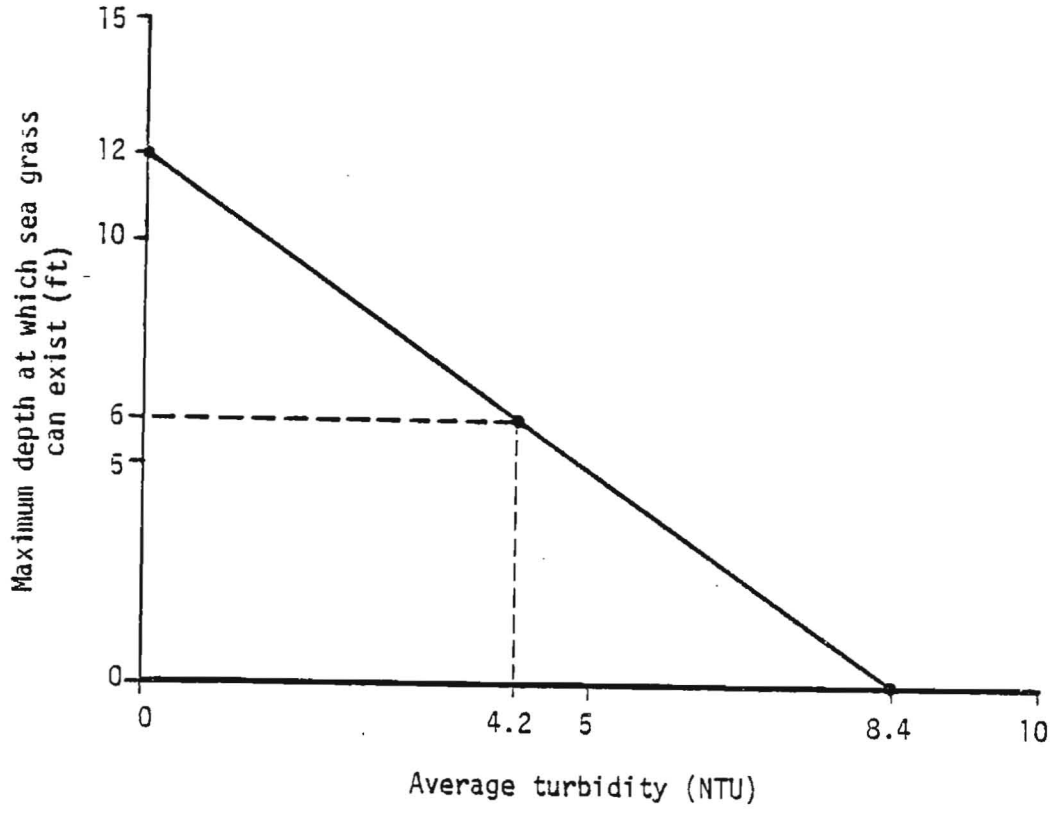


Figure 21. Maximum depth at which sea grass can exist as a function of turbidity.

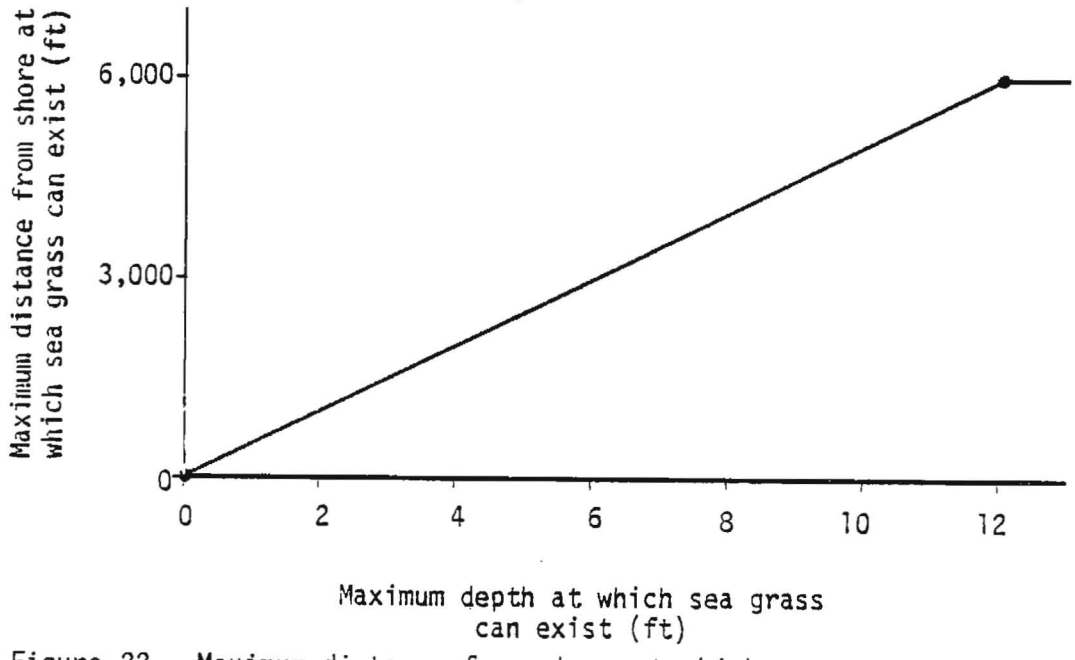


Figure 22. Maximum distance from shore at which sea grass can exist as a function of maximum depth at which sea grass can exist.

Limitations

Construction of the Estuary submodel was hampered by insufficient time, information, and expertise available at the workshop. The submodel that resulted is essentially a crude set of hypotheses concerning one causal pathway in the estuarine system. Its principal limitation may be that it does not consider many of the complex physical, chemical, and biological interactions that make estuaries important communities. From a physical perspective, the concept of a mixing coefficient is probably a poor substitute for detailed understanding of the action of winds, tides, and currents. From a chemical perspective, omission of water quality constituents, other than phosphorus, may be a gross oversimplification. From a biological perspective, failure to consider other components of the estuarine community (e.g., benthic macroalgae and invertebrates and zooplankton) likely means that many important relationships between fish and wildlife species, their habitats, and their food supplies are lacking.

Even for those components of the estuarine community that are considered, the assumptions used are questionable. For example, phytoplankton abundance was assumed to be solely a function of phosphorus concentration. This may or may not be true; there was little information available at the workshop that could be brought to bear on the subject. Similarly, it was assumed that turbidity is solely a function of phytoplankton biomass. Other sources of turbidity (e.g., total suspended solids resulting from dredging or wave action) were assumed to be of little importance. In addition, light penetration was assumed to be a function only of turbidity. Interactions between turbidity and depth were ignored. Finally, it was assumed that sea grass distribution is limited only by light penetration. Other factors (e.g., substrate and temperature) known to be important in determining the distribution of sea grass in other locations are not considered. Furthermore, variations in the density and species composition of sea grass, which may be important determinants of their suitability as habitat, are ignored.

And last, even if the assumptions outlined above are correct in a qualitative sense, there was little information available at the workshop to quantify them. With the parameters presently used, the areal extent of sea grass is very sensitive to small changes in phosphorus concentrations acting through chlorophyll-a concentrations and turbidity. Figure 21 indicates that the average turbidity need only double (from its present average value of 4.2 NTU to 8.4 NTU) to eliminate sea grass from the modeled estuary. An average turbidity of 8.4 NTU is produced by an average chlorophyll-a concentration of 20 mg/m^3 (Figure 20), which is within the range currently observed in single samples. An average chlorophyll-a concentration of 20 mg/m^3 is produced by a phosphorus concentration of 0.096 ppm (Figure 19), which is an increase of about 50% above the current average value of 0.06 ppm. While sea grass is known to be sensitive to light penetration, the information available is insufficient to evaluate whether or not the degree of sensitivity illustrated by these calculations is appropriate.

WILDLIFE SUBMODEL

Responsibilities

The Wildlife subgroup was charged with developing a submodel to explore the consequences of management actions to the faunal assemblage of Merritt Island. The principal management actions that guided the thinking of subgroup participants were fire management in the uplands and water management in the mosquito control impoundments.

The wildlife species potentially affected by fire and water management represent a large and diverse set of organisms, including several threatened or endangered species and many migratory birds for which there are established management priorities on the Merritt Island National Wildlife Refuge. There was insufficient time during the workshop to consider all important species and their interactions. In addition, the purpose of the workshop was to use the model building process as a means to foster communication, integrate information, and identify research needs, rather than build a model for

managing wildlife on the Refuge. Thus, the subgroup agreed initially to identify, for purposes of modeling, a small subset of indicator species representing communities most commonly associated with fire and water management.

The subgroup was presented with two extreme alternatives for a modeling approach. The first alternative was to explicitly model population growth processes (i.e., births minus deaths) in such a way that management actions could be related to temporal changes in the actual number of individuals (or biomass) in a population. The second alternative was to model the wildlife habitat using suitability index relationships. Using this approach, animals are related to their habitat based on empirical evidence that population variations can be at least partly explained by differences in vegetation patterns, land form, water, or other environmental variables. The subgroup opted for the habitat suitability approach because a larger number of indicator species could be included in the Wildlife submodel. Habitat suitability relationships were developed for: (1) scrub jays; (2) gopher tortoises; (3) piscivorous wading birds; (4) striped mullet; (5) salt-marsh mosquitos; and (6) mottled ducks. Habitat suitability relationships also were developed for the spotted sea trout but were not included in the submodel due to lack of information about response of sea trout to changes in environmental conditions.

The Wildlife submodel, comprised of suitability relationships for six species, is totally dependent on inputs from the other submodels. In essence, the suitability relationships transform vegetation and water variables generated by other submodels into dimensionless indices of carrying capacity.

The suitability indices may mimic temporal variation in vegetation and water more closely than would the actual population levels of the wildlife species because population growth rates often do not respond instantaneously to changes in the environment. Thus, suitability indices should be interpreted with respect to how quickly a wildlife population might respond to environmental changes. As a general rule, species with relatively short generation times, like the mosquito, are expected to follow annual trends in environmental conditions. Conversely, species with relatively long generation times, like the gopher tortoise, may not closely follow annual variations in suitability indices.

Structure

Scrub jay. The scrub jay was selected as an indicator for the following upland vegetation types: (1) mixed-oak scrub; (2) saw palmetto scrub; and (3) slash pine flatwoods. The suitability model for scrub jays was heavily influenced by information from Breininger (1978).

Scrub jay populations, as measured by habitat (TJAY), are calculated at each time step using the following function:

TJAY = [DJAYM * UACRE(2)] + [DJAYSF * UACRE(4)] + [DJAYSP * UACRE(3)]

where TJAY = index of carrying capacity for scrub jays (number of jays)

DJAYM = the suitability index for mixed-oak scrub (jays/acre)

DJAYSF = the suitability index for slash-pine flatwood (jays/acre)

DJAYSP = the suitability index for saw palmetto scrub (jays/acre)

UACRE(2) = area of mixed-oak scrub (acres)

UACRE(3) = area of saw palmetto scrub (acres)

UACRE(4) = area of slash pine flatwoods (acres)

The area variables are calculated in the Upland submodel for each time step. The suitability indices DJAYM, DJAYSF, and DJAYSP are calculated as the minimum or limiting condition by the following functions:

DJAYM = min {DJCOV, DJOS, DJHT, DJCAM}

DJAYSF = min {DJCOV, DJOS, DJHT, DJCAM}

DJAYSP = min {DJCOV, DJOS, DJHT, DJCAM}

where DJAYM = the suitability index for mixed-oak scrub (jays/acre)

DJAYSF = the suitability index for slash pine flatwood (jays/acre)

DJAYSP = the suitability index for saw palmetto scrub (jays/acre)

DJCOV, DJOS, DJHT, DJCAM = index values obtained from the piecewise linear functions illustrated in Figure 23

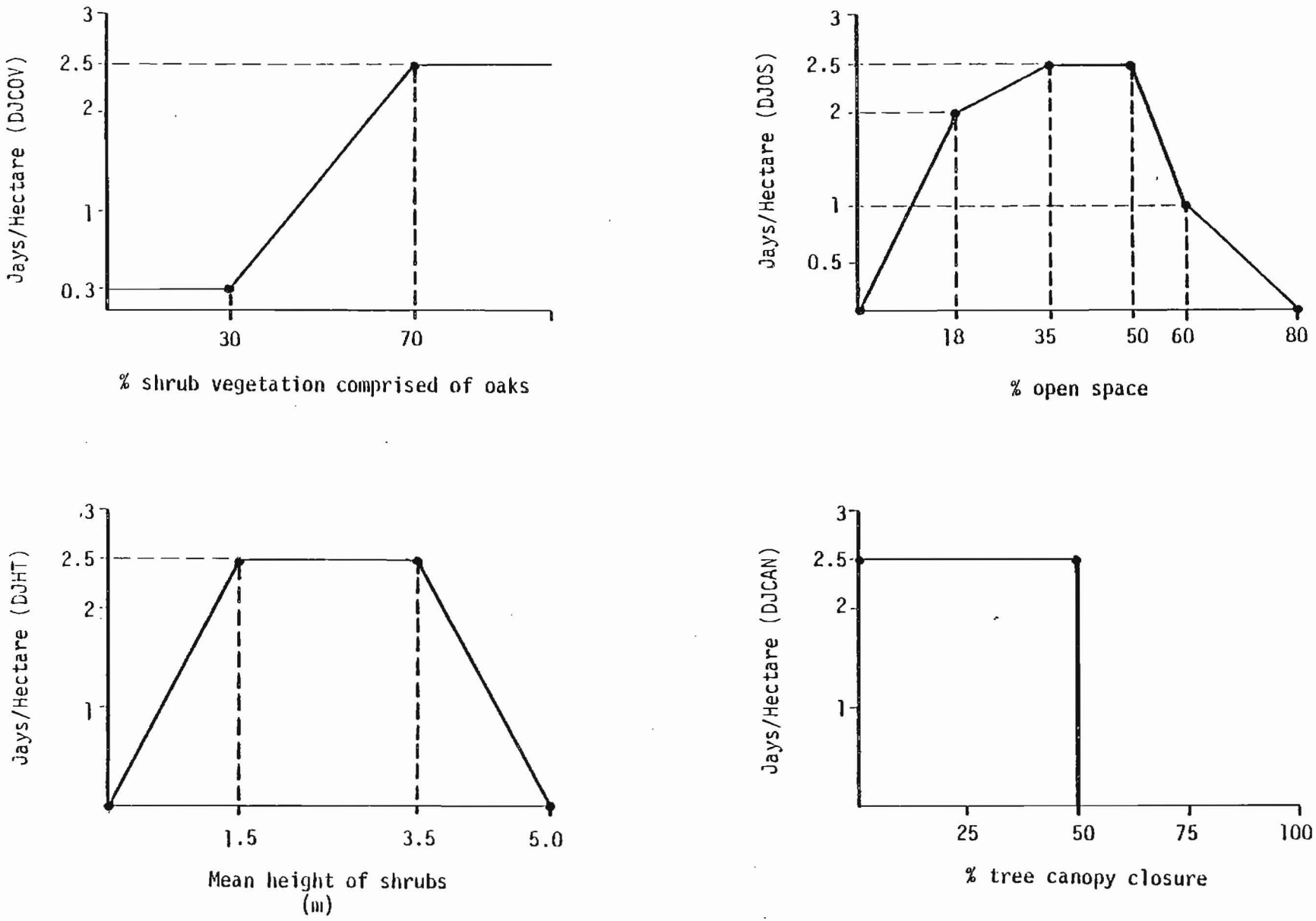


Figure 23. Scrub jay density as a function of vegetation structure for four different variables. Data for density vs. percent open space are from Breininger (1978).

Gopher tortoise. The information used to construct the gopher tortoise model was obtained from David Breininger, Bionetics Corporation, Kennedy Space Center, FL. Gopher tortoise habitat conditions at each time step are calculated by the following function:

$$TTORT = GTORTM * UACRE(2) + GTORTS * UACRE(3) + GTORTD * UACRE(1)$$

where TTORT = index of carrying capacity for gopher tortoises (acres)

GTORTM = suitability index for mixed-oak scrub (dimensionless)

GTORTS = suitability index for saw palmetto scrub (dimensionless)

GTORTD = suitability index for dune/strand (dimensionless)

UACRE(1) = area of dune strand (acres)

UACRE(2) = area of mixed-oak scrub (acres)

UACRE(3) = area of saw palmetto scrub (acres)

The suitability index for each of the vegetation cover types is defined as the minimum of a food availability index and a burrowing index:

$$GTORTM = \min \{GFOOD, GTSOIL\}$$

$$GTORTS = \min \{GFOOD, GTSOIL\}$$

$$GTORTD = \min \{GFOOD, GTSOIL\}$$

where GTORTM = suitability index for mixed-oak scrub (dimensionless)

GTORTS = suitability index for saw palmetto scrub (dimensionless)

GTORTD = suitability index for dune/strand (dimensionless)

GFOOD = the index of food availability for each appropriate cover type (dimensionless)

GTSOIL = the index of burrow potential (dimensionless), based on the depth to water table and obtained from the piecewise linear functions in Figure 24

The food availability index for each cover type is, in turn, related to vegetation conditions (i.e., the amount of open grazing area available) and time since the last burn. The food index for each cover type is as follows:

$$GFOOD = (GTCOV * GBURN) ** 0.5$$

where GFOOD = the index of food availability for each cover type (dimensionless)

GTCOV = the index of food availability obtained from the piecewise linear function in Figure 24

GTBURN = the index of time since the last burn, obtained from the piecewise linear function in Figure 24

Salt marsh mosquitos. The mosquito model produces an index of annual mosquito production for the entire impoundment area. The information used to construct the model was obtained from John Hutton, Brevard Mosquito Control District, Titusville, FL.

The mosquito suitability index is measured in units of larvae-acres. It represents an extrapolation of a larval density index (larvae per dipper) to the total acres of suitable mosquito breeding habitat. The major mosquito breeding period lasts from approximately May 1st through October 30th each year. Decreased temperature and increased rainfall during September typically combine to severely curtail mosquito breeding in the impoundments. Mosquito breeding outside of the impoundments was judged to be relatively insignificant and was not modeled. The suitability index produced here is a sum of monthly production indices, as follows:

$$TBUGS = \sum_{IM=5}^{10} BUGS(IM)$$

where TBUGS = index of annual mosquito production (larvae-acres)

BUGS(IM) = the monthly production index across the entire impoundment (larvae-acres)

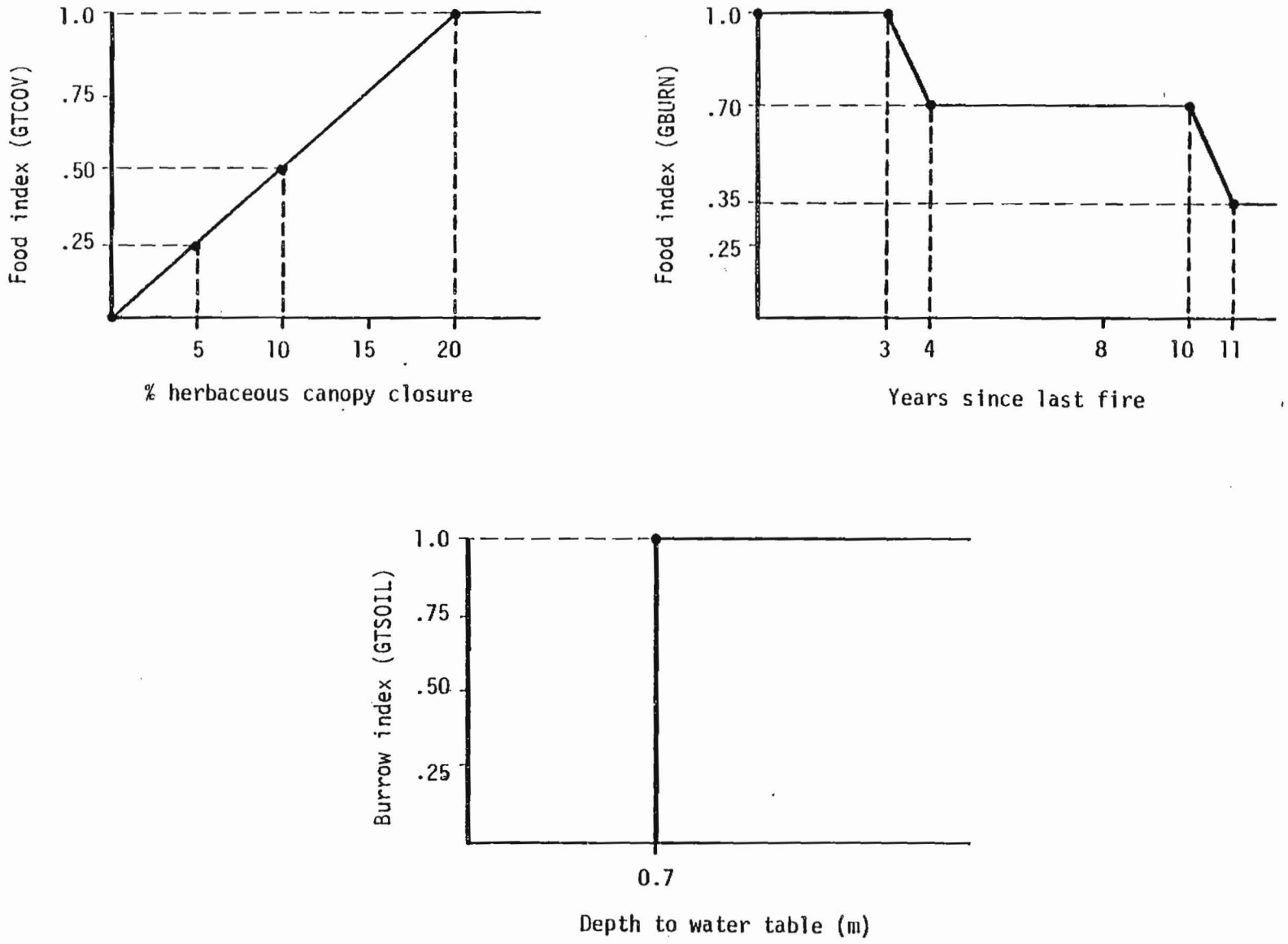


Figure 24. Gopher tortoise suitability indices as a function of vegetation, water depth, and time since last fire.

Because the Impoundment submodel considers the impoundment elevation gradient as five discrete elevation steps, the monthly mosquito production index [BUGS(IM)] is the sum of the production from each of the elevation steps:

$$BUGS(IM) = \sum_{IS=1}^{5} BBUGS(IS) * STEPA(IS)$$

where BUGS(IM) = the monthly production index across the entire impoundment (larvae-acres)

BBUGS(IS) = the monthly production index (larvae/dipper) for each elevation step (IS)

STEPA(IS) = the surface area for each elevation step (acres)

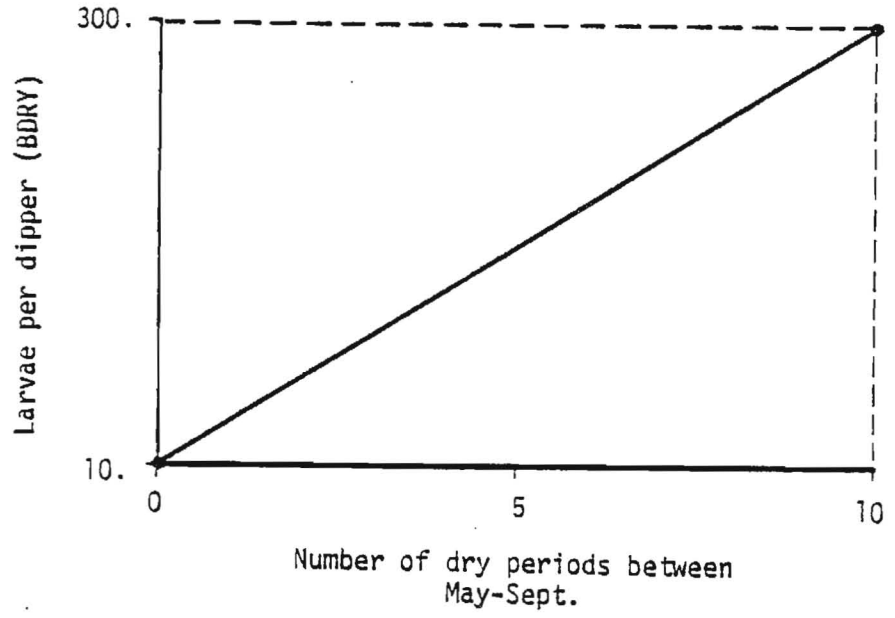
The preceding two functions are used simply to compute an overall production index by summing across the entire impoundment and across months within the entire mosquito breeding season. Within any one month (IM) and for any given elevation step (IS), mosquito production is related to two variables:

$$BBUGS(IS) = BCOV * BDRY$$

where BBUGS(IS) = the monthly production index (larvae/dipper) for each elevation step (IS)

BDRY = density of mosquito larvae (number of larvae) as a function of drought cycles, obtained from the piecewise linear function in Figure 25

BCOV = density modifier (dimensionless), based on vegetation cover and obtained from the piecewise linear function in Figure 25 (dimensionless)



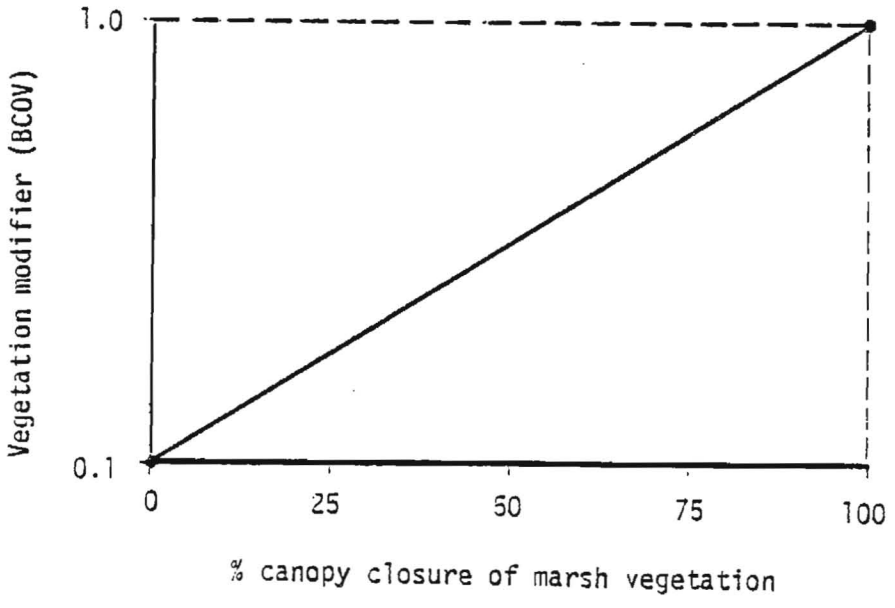


Figure 25. Mosquito production indices as a function of both hydrology and vegetation structure.

The value of BDRY is proportional to the number of 2-week drought periods during the mosquito breeding season. This function is based on several assumptions:

(1) A 2-week drought period is required in order for significant egg laying to occur.

(2) The maximum production per unit area of impoundment will occur if the impoundment was alternatively wet and then dry (i.e., 10 dry periods).

(3) The highest observed larval density was about 300 larvae per unit value approximately equal to that of a large spoon or "dipper".

The value of BCOV is used as a modifier of mosquito larval density. The basic assumption was that, all other conditions being equal, mosquito production is directly proportional to the amount of marsh vegetation present. Moreover, it was assumed that marsh vegetation can effect about a one order of magnitude difference in larval density. The underlying (but unsubstantiated) hypothesis is that the marsh vegetation provides a substrate on which female mosquitos perch while laying eggs; thus, higher density of substrate results in a higher incidence of egg laying.

Wading birds. On Merritt Island, the wetlands in general, and the impoundments in particular, provide highly suitable habitat for a diverse group of wading birds. The Wildlife subgroup designated an indicator guild to represent the wading bird assemblage. The wading bird guild was conceived as a group of species that rely heavily on small impoundment fishes for food.

The wading bird model produces an index of the number of bird-days (BADULT) in August that could be supported by food fish resources in the impoundment, based on the following assumptions:

(1) The typical wading bird guild member requires a mean of 100 gm/day of food fish on an annual basis. This figure is based on data presented by Kushlan (1978:274).

(2) August is the critical month because of the likelihood of insufficient food to meet brood and adult maintenance demands.

(3) The wading birds can crop 70% of the fish standing crop (subgroup concensus), as measured in August, on a sustained basis.

(4) The total crop of fish in August is solely a function of the impounded area in August.

Given these assumptions, the wading bird model is constructed as follows:

BADULT = [PFISH * FDENS * WWET(8) * 4046.8]/DFOOD

where BADULT = the suitability index for the wading bird guild (bird-days)

PFISH = the proportion of fish that can be cropped on a sustained annual basis; assumed to be equal to 0.7

FDENS = August density of food fish; assumed to be 6 gm/m^2 (this is an estimate that should be calculated in the future) (gm/m^2)

4046.8 = constant converting acres to m^2

WWET(8) = impounded area in August (acres)

DFOOD = the daily food requirements of a typical individual wading bird; assumed equal to 100 gm per day (gm/day/bird)

Striped mullet. Striped mullet were selected as an indicator of a group of fish species that utilize the impoundment areas only part of the year. In the case of striped mullet, the impoundments provide a nursery area for juveniles during fall and winter months.

The mullet model suitability index (TOTMUL) is based on the following equation:

$$TOTMUL = \sum_{IM=1}^{12} SMLET(IM)$$

where TOTMUL = the total mullet during the year (number of mullet)

SMLET(IM) = the total number of mullet in the impoundment during month IM (number of individuals)

The variable SMLET(IM) is computed one of two ways, depending on whether or not the impoundment is open to the estuary. The two cases are:

(1) The impoundment is open for a given month [i.e., OPEN(IM) = 1]. In this case, it is assumed that the mullet density within the impoundment equalizes to observed mean densities in the surrounding estuary [DMULL(IM)], obtained from Gillmore (1984) and displayed in Figure 26. Thus:

$$SMLET(IM) = DMULL(IM) * WWET(IM) * 4046.8$$

where SMLET(IM) = total number of mullet in the impoundment during month IM (number of individuals)

DMULL(IM) = observed mean mullet densities from Gillmore (1984) (numbers/m^2)

WWET(IM) = impounded area by month (acres)

4046.8 = constant converting acres to m^2

(2) The impoundment is closed for a given month [i.e., OPEN(IM) = 0]. In this case, the total mullet in the impoundment is equal to the number present during the month when the impoundment was last open to the estuary. Thus:

SMLET(IM) = SMLET(LO)

where SMLET(IM) = total mullet during the current month (number of mullet)

SMLET(LO) = the total mullet during previous month LO (number of mullet)

LO = month index from 1 (January) to 12 (December), where LO < IM and LO is set for the last month that the impoundment was open to the estuary [OPEN(IM) = 1]

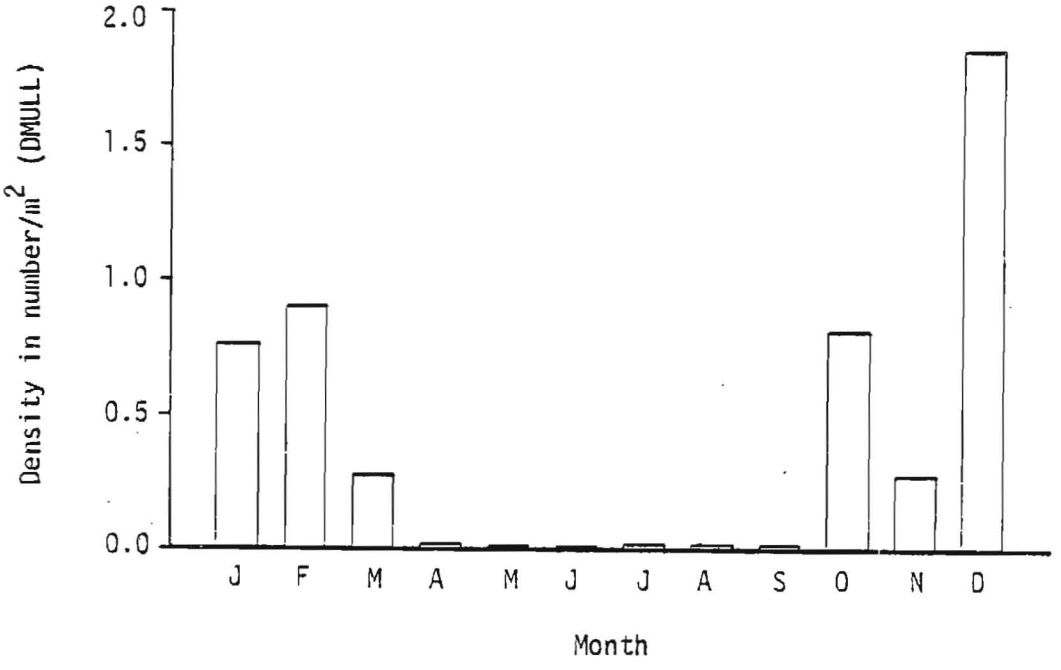


Figure 26. Striped mullet density by month in estuarine areas contiguous with Merritt Island. Data from Gillmore (1984).

Mottled duck. Functional relationships for the mottled duck were not developed during the subgroup meetings due to lack of time. The model described here was developed subsequent to the workshop by the subgroup programmer, based on information in Steiglitz and Wilson (1968). The following assumptions were made in developing the mottled duck model:

(1) Brood rearing habitat is the limiting habitat component.

(2) Nesting habitat is in abundant supply and includes numerous dredge spoil disposal islands (Stieglitz and Wilson 1968).

(3) The suitability of impoundments is a function of vegetation structure. A percent canopy closure of 40-60% will provide resources and space requirements for the maximum brood density.

Based on these assumptions, an index of brood habitat suitability (SBROOD) is calculated as follows:

$$SBROOD = \sum_{IM=4}^{8} BROOD(IM) * WWET(IM)$$

where SBROOD = an index of brood habitat availability (broods)

BROOD(IM) = the monthly index of brood density obtained from the piecewise linear function in Figure 27 (broods/acre)

WWET(IM) = the inundated area by month (acres)

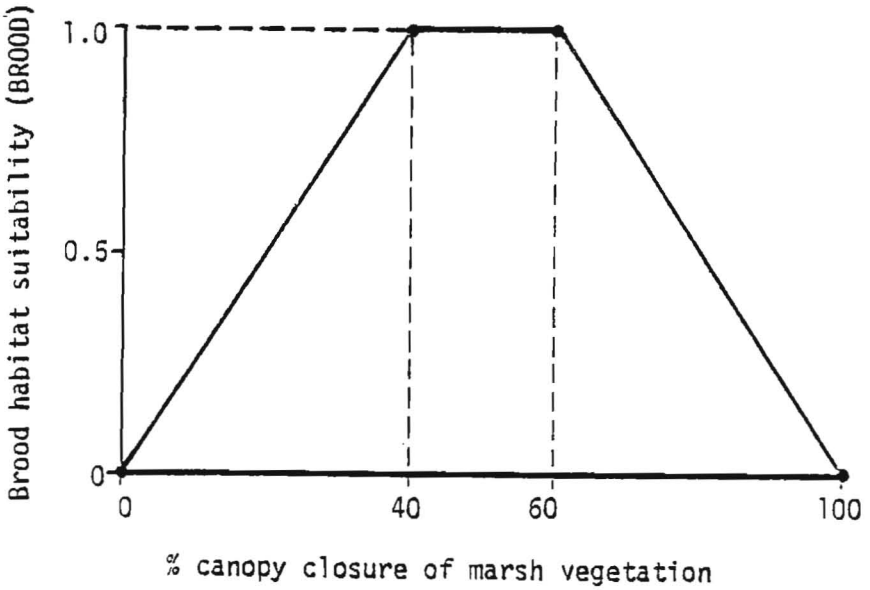


Figure 27. Mottled duck brood habitat suitability as a function of vegetation cover.

Limitations

Perhaps the most fundamental limitation of the Wildlife submodel is that the suitability relationships are largely comprised of untested hypotheses. While many variations in animal abundance can be explained by observed changes in habitat conditions, it is not known if the variables and relationships developed herein are appropriate for relating fire and water management to the affected wildlife populations.

The following specific limitations and modifications were suggested by subgroup participants during the model building exercise:

(1) The scrub jay model should be reconstructed on a higher resolution spatial scale. Specifically, the jay model needs to include information on patch size and interspersion of vegetation types.

(2) The wading bird relationships should be reformulated in several ways. Most important of these is that food fish production should be a function of variables other than the size of the impoundment in August.

(3) The success with which wading birds catch fish is dependent on the density of food fish. The submodel should incorporate a density-dependent success rate, because shrinking of the impounded area is an important factor in concentrating food fishes in some years.

(4) The wading bird submodel should be reconstructed to deal explicitly with production of wading bird young as it relates to food supplies within the impoundment.

(5) The striped mullet relationships, as presently constituted, ignore factors that affect recruitment from impoundment nursery areas. Specifically, it might be desirable to include both predation on mullet inside and outside the impoundment and some measure of the relative quality of the impoundment habitat.

MODEL BEHAVIOR

In the following section, we present sample output generated with the model conceptualized at the workshop. The output is organized into two scenarios, which differ in the frequency of shuttle launches, the frequency of prescribed burning in the uplands and in the impoundment, the extent of facilities development, the amount of land-disposed waste material, and the nature and timing of water level control in the impoundment. Results from the first scenario are presented in some detail to establish reference conditions. Variables that change significantly from these reference conditions are presented and discussed for the second scenario.

The scenario results are presented in terms of absolute quantities (e.g., acres of slash pine flatwoods, salinity in the impoundments, habitat suitability for scrub jays). 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 "correct", but in the hope of promoting constructive discussion. Only by opening the model and its results to criticism can we establish the limits of its credibility. In comparing scenarios, it should, therefore, be remembered that qualitative changes and general trends probably have greater significance than actual numbers. The numbers are included only as points of reference and discussion.

The hypothetical management unit presented in Figure 4 and described throughout the MODEL DESCRIPTION section of this report is assumed for both scenarios. In summary, this unit is near-field to a shuttle launch pad and has 2,500 acres of uplands, a 600-acre impoundment, and a 1,500-acre section of estuary.

SCENARIO I

Under conditions of Scenario I, the uplands in the management unit are burned every 3 years, while vegetation in the impoundment is never burned. Water is pumped from the estuary into the impoundment as needed from May to September for mosquito control. Stop logs in impoundment dikes are set at 36 inches above mean sea level. These conditions are maintained through the first 10 years of the simulation in order to show model behavior without the effects of development or shuttle launches. In year 10, two activities are initiated. First, 2 acres of slash pine flatwood and 1 acre each of mixed oak scrub and saw palmetto scrub are developed each year. This development continues throughout the remainder of the 40-year simulation run. In addition, 1 acre of citrus groves is abandoned each year and allowed to revert to natural vegetation. This policy is terminated in year 20. Second, five shuttle launches per year are initiated in year 10 and continue through the end of the model run. The launches are assumed to occur in February, April, June, August, and October. In year 20 of the simulation, the land application of waste material begins. Every month through the end of the run, 542,000 gallons of material are applied.

Water Budget and Quality

Monthly output depicting water quantities and quality is presented in Table 6. These results are from year 16, which is an average year in terms of total precipitation (51 inches). Input of water to the impoundment is dominated by direct precipitation. Surface water runoff and exchange with the estuary account for significantly less input, with a minimal contribution from surficial ground water. From January to March, water flows from the impoundment into the estuary because the impoundment water budget consists of moderate inputs of direct precipitation and runoff and low evapotranspiration. From May to September, evapotranspiration is higher relative to inputs, and water is pumped from the estuary into the impoundment to maintain water level for mosquito control. Variation in the amount of water pumped is due to monthly variation in precipitation, runoff, and evapotranspiration.

Table 6. Monthly water quantity and quality variables - Scenario I.

	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
Precipitation (inches)	5.0	3.0	3.2	0.1	7.3	4.6	7.2	5.1	4.3	3.5	6.2	1.8
Precipitation input to impoundment (acre-inches)	3,000	1,810	1,964	85	4,398	2,767	4,322	3,065	2,560	2,123	3,725	1,108
Surface runoff to impoundment (acre-inches)	512	329	334	33	753	487	733	583	434	383	630	187
Surficial ground water to impoundment (acre-inches)	33	33	33	34	33	33	33	33	33	33	33	33
Flow from impoundment to estuary (acre-inches)	2,200	644	120	-	-	-	-	-	-	531	3,164	51
Flow from estuary to impoundment (acre-inches)	-	-	-	-	441	621	587	828	730	-	-	-
Evapotranspiration (acre-inches)	600	780	1,500	2,100	2,580	3,300	5,100	3,900	3,180	1,500	780	600
Impoundment open to estuary	yes	yes	yes	no	no	no	no	no	no	yes	yes	yes
Aluminum input to impoundment from direct deposition (lb)	0	11,550	0	11,550	0	11,550	0	11,550	0	11,550	0	0
Aluminum input to impoundment from runoff (lb)	0	159	0	157	0	157	0	170	0	159	0	0
Total phosphorus input to estuary from precipitation (lb)	7.5	9.0	4.9	0.4	11.0	6.9	216.1	681.9	902.7	106.1	1,080.3	2.8
Total phosphorus input to estuary from runoff (lb) - without land application	0.5	0.6	0.3	0.0	0.8	0.5	14.7	50.3	61.2	7.3	73.1	0.2
Total phosphorus input to estuary from runoff (lb) - with land application	369	369	369	368	369	369	383	419	429	376	441	368
Total phosphorus input to estuary from impoundment (lb)	172	64	33	25	20	21	19	22	28	62	208	43

The model assumes there is an undetectable amount of aluminum in precipitation, ground water, and land-applied waste material. Thus, there is aluminum input only during months when there is a shuttle launch. The impoundment receives aluminum both through direct deposition from the launch cloud and from surface runoff, which carries some of the aluminum deposited in the uplands. Given the assumptions about the hypothetical management unit, no direct deposition of aluminum occurs in the estuary. The estuary receives all of its aluminum from surface runoff.

Without land application of waste material, the input of total phosphorus from precipitation to the impoundment and estuary is about five times as great as runoff input. However, when land application occurs, the input of total phosphorus in surface runoff is significantly higher except in July, August, September, and November, when the concentration of phosphorus in precipitation is naturally high.

Upland

The acreage of slash pine flatwoods declines continually throughout the scenario because of development, succession to saw palmetto scrub, and effects of prescribed fires every 3 years, which cause some conversion to saw palmetto scrub (Figure 28). The increase in saw palmetto scrub (Figure 28) is the net result of succession and fire-related conversions from slash pine flatwoods, succession from some of the abandoned citrus groves, and a small decrease each year (after year 10) due to development. Through the first 20 years, the acreage of xeric oak hammock slowly increases as a result of succession from mixed oak scrub (Figure 29). Although prescribed fires occur every 3 years, the xeric oak hammock is unaffected because a minimum of 10 years is required to build up enough fuel to sustain a fire. Even if fuel loadings are sufficient to sustain a fire, the xeric oak hammock is assumed to burn only if drought conditions exist. This combination of factors occurs in the 19th year of the simulation and most of the acres in xeric oak hammock revert back to mixed oak scrub. Xeric oak hammock subsequently recovers through succession. The acres in mixed oak scrub exhibit the opposite pattern (Figure 29). Through

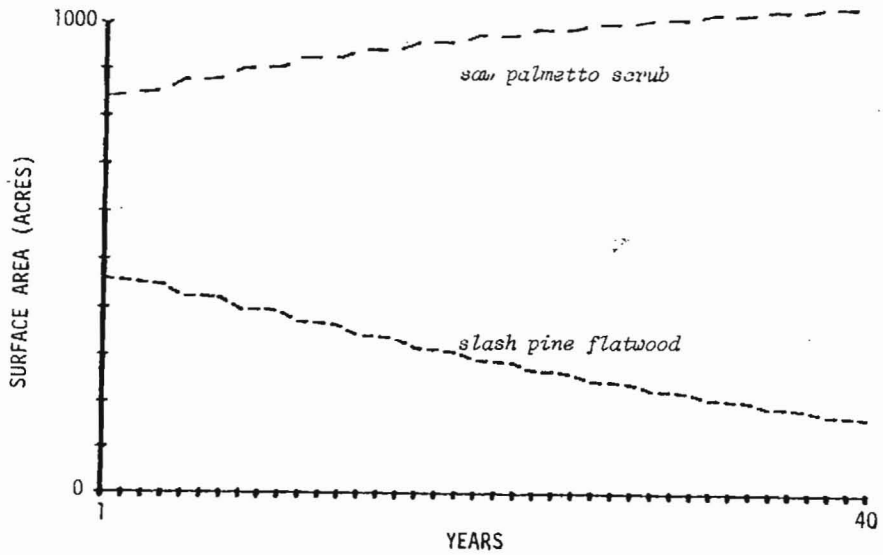


Figure 28. Acres of slash pine flatwood and saw palmetto scrub - Scenario I.

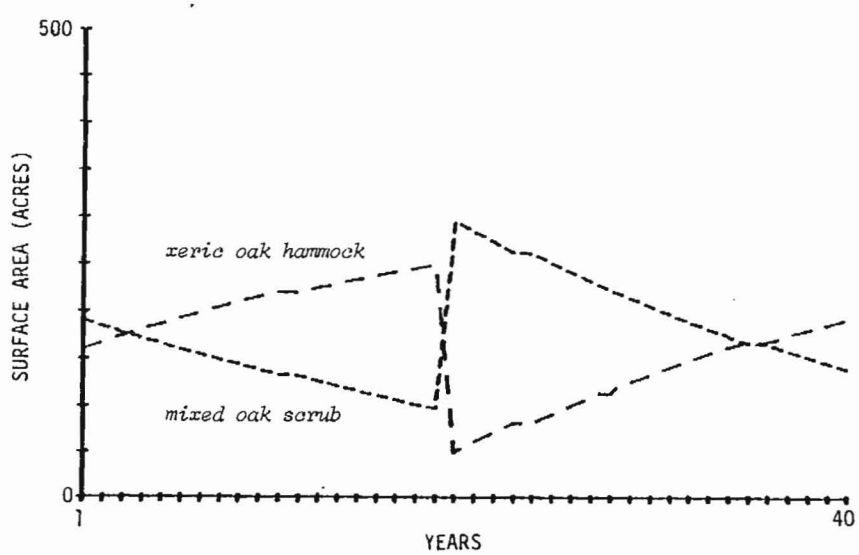


Figure 29. Acres of xeric oak hammock and mixed oak scrub - Scenario I.

the first 20 years, the gains due to succession from abandoned citrus groves are small compared to the losses to development and succession to xeric oak hammock. A substantial area of mixed oak scrub is re-established as a result of the fire in year 19. The increase in developed acres and the abandonment of some citrus groves are shown in Figure 30.

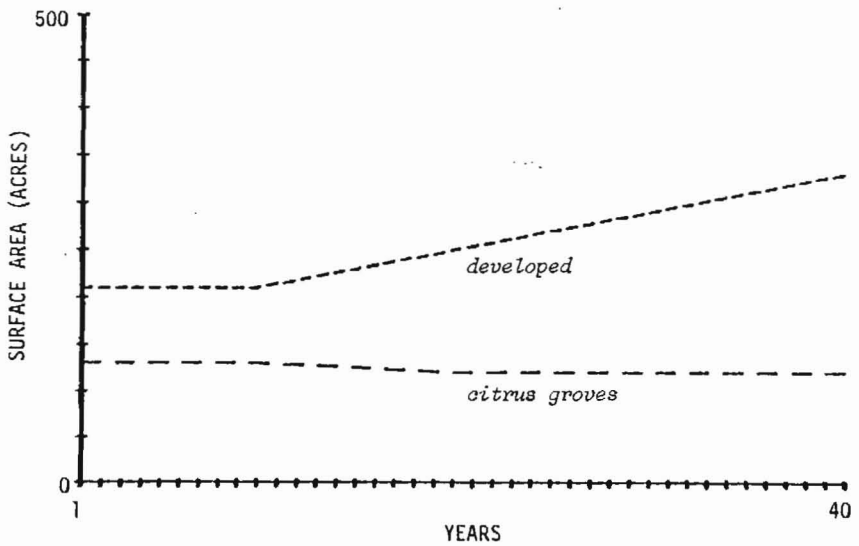


Figure 30. Acres of developed land and citrus groves - Scenario I.

The effects of fires on vegetation community structural parameters are illustrated in Figure 31. The variation in percent cover of oaks reflects fires every 3 years in slash pine flatwoods and saw palmetto scrub and every 10 years in mixed oak scrub. Mean shrub height exhibits a similar pattern, while percent open space exhibits the opposite pattern.

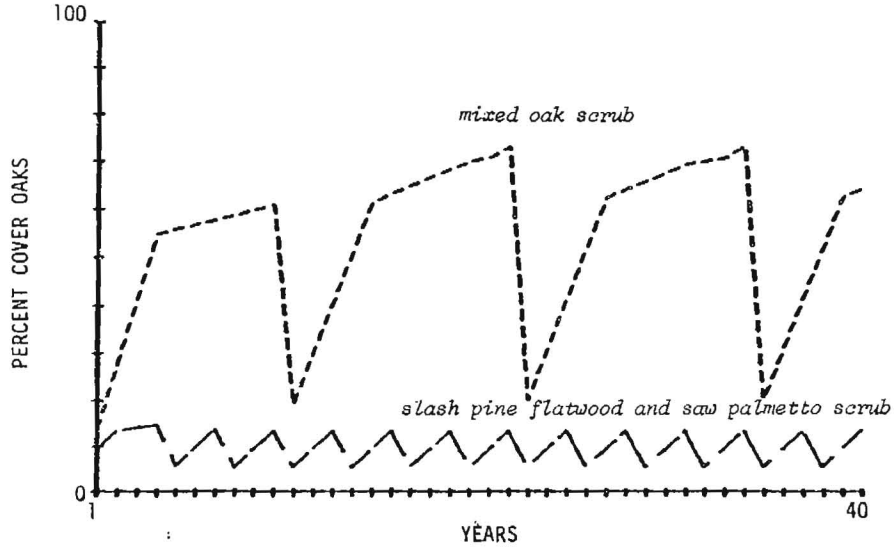


Figure 31. Percent cover of oaks in mixed oak scrub, saw palmetto scrub, and slash pine flatwood - Scenario I.

Impoundment

The 3-year running average water depth in the impoundment does not vary much from year to year because pumping is used as necessary to bring the water to a specified level for mosquito control (step 3 in the impoundment is depicted in Figure 32). However, the amount of pumping required in any year changes substantially due to the variability in precipitation. As a result, the 3-year running average of salinity in the impoundment is more variable (Figure 32). The areal extent of the mangrove-halophyte, salt marsh, and willow swamp-marsh cover types varies directly with changes in salinity (Figures 33 and 34). The area of cattail-mixed freshwater marsh is generally inversely related to salinity, although the patterns are not an exact inverse because of confounding changes in water depth (Figure 34). Pumping for mosquito control maintains open water as the predominant cover type (Figure 35).

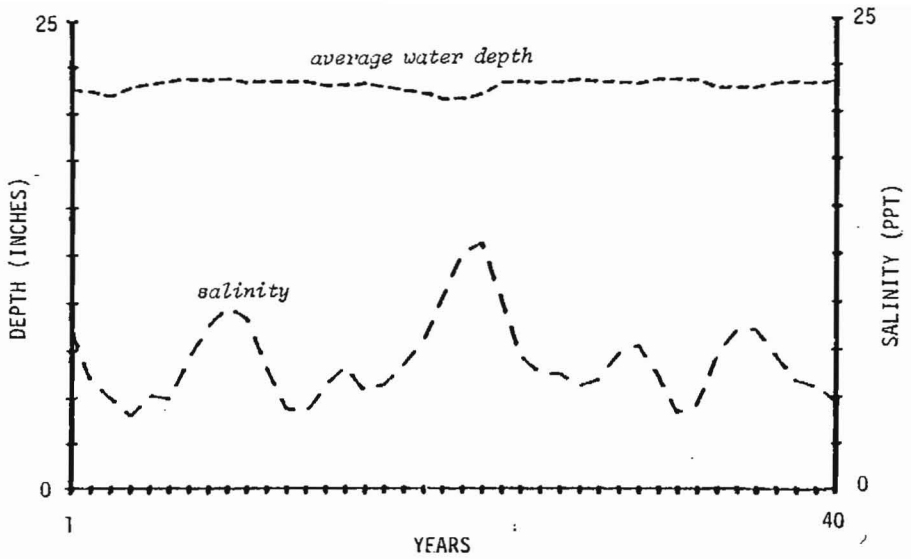


Figure 32. Average water depth and salinity in the impoundment - Scenario I.

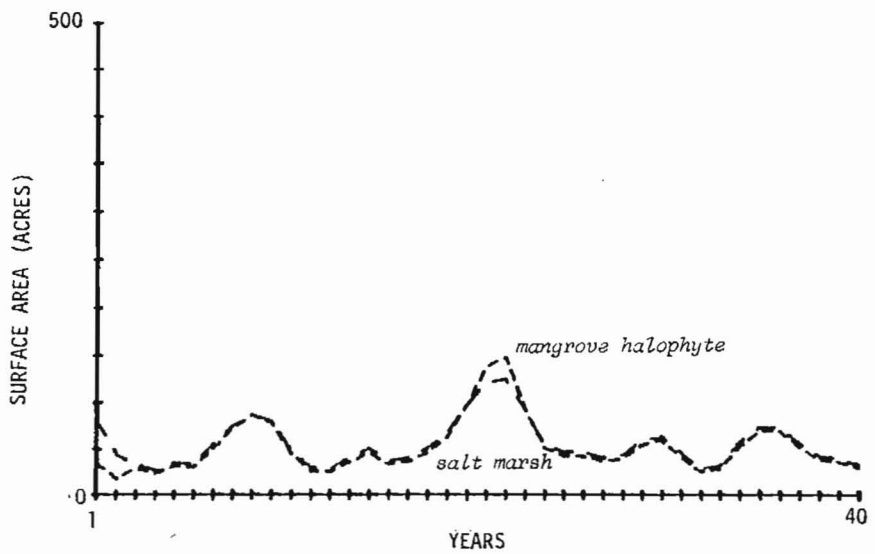


Figure 33. Acres of mangrove-halophyte and salt marsh - Scenario I.

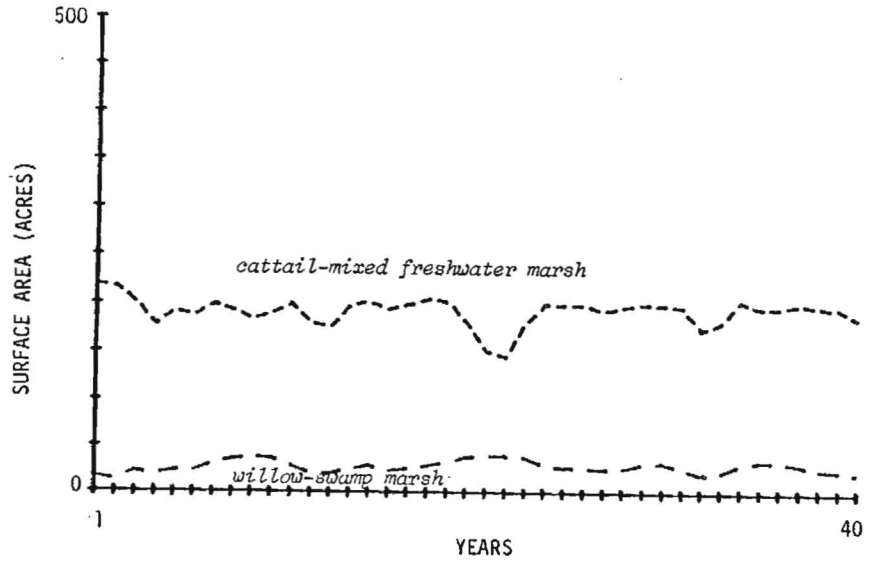


Figure 34. Acres of cattail-mixed freshwater marsh and willow swamp-marsh - Scenario I.

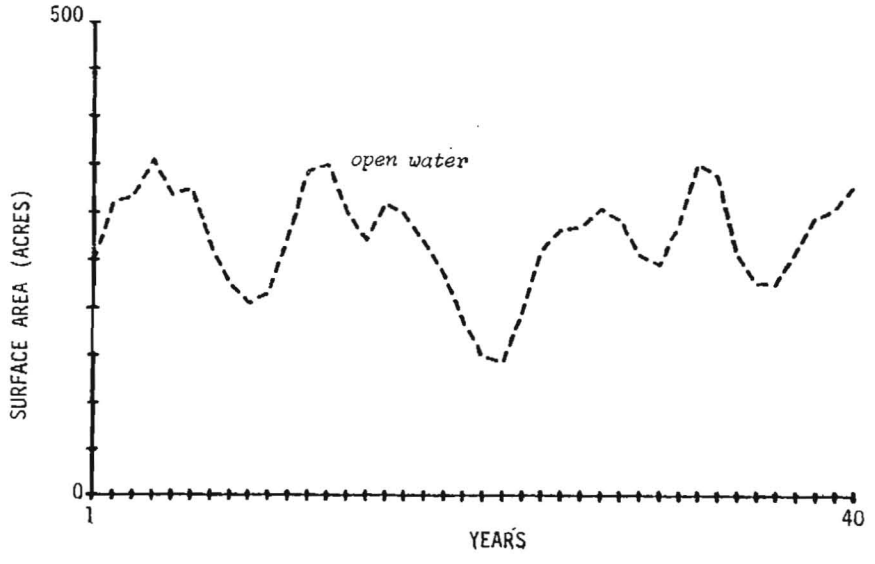


Figure 35. Acres of open water - Scenario I.

The storage of available total phosphorus in the impoundment (Figure 36) is a function of inputs from precipitation and runoff, the filtering ability of the impoundment vegetation, and exchange with the estuary. The increase in total phosphorus storage after year 20 is a result of the increased inputs from land-applied waste material. Aluminum is assumed to be totally trapped in the impoundment; therefore, the variable in Figure 36 represents the cumulative input from shuttle launches (direct deposition and upland runoff).

Estuary

Initially, the estuary receives about twice as much total phosphorus from the impoundment as from the uplands and direct precipitation (Figure 37). Although the concentration of total phosphorus is not as high in the water received from the impoundment, the volume of water exchanged is much larger than runoff and precipitation inputs. After land application of waste material begins, both runoff and impoundment inputs of total phosphorus increase; however, the input directly from the uplands dominates.

The increase in loadings of total phosphorus to the estuary after year 20 results in an increase in average chlorophyll-a concentration and a concomitant decline in the extent of seagrass (Figure 38). It should be remembered, however, that the extent of seagrass in the model is very sensitive to small changes in phosphorus concentration acting through average chlorophyll-a concentrations and turbidity.

Wildlife

Scrub jay. The slash pine flatwood and saw palmetto scrub cover types provide equally suitable habitat for scrub jays. Throughout the model run, the decrease in acres of flatwoods is approximately offset by the increase in saw palmetto scrub. As such, the behavior of scrub jays (Figure 39) is primarily a function of the acres and structural parameters of mixed oak scrub communities. Following fires, scrub jay suitability is depressed because of the reduction in the percent cover of oaks. Although the percent cover of

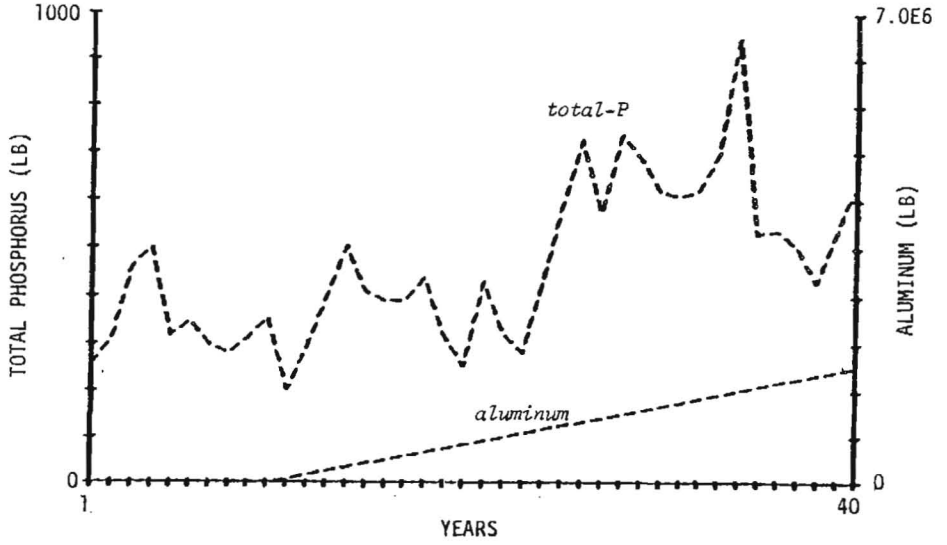


Figure 36. Storage of available total phosphorus and aluminum in the impoundment - Scenario I.

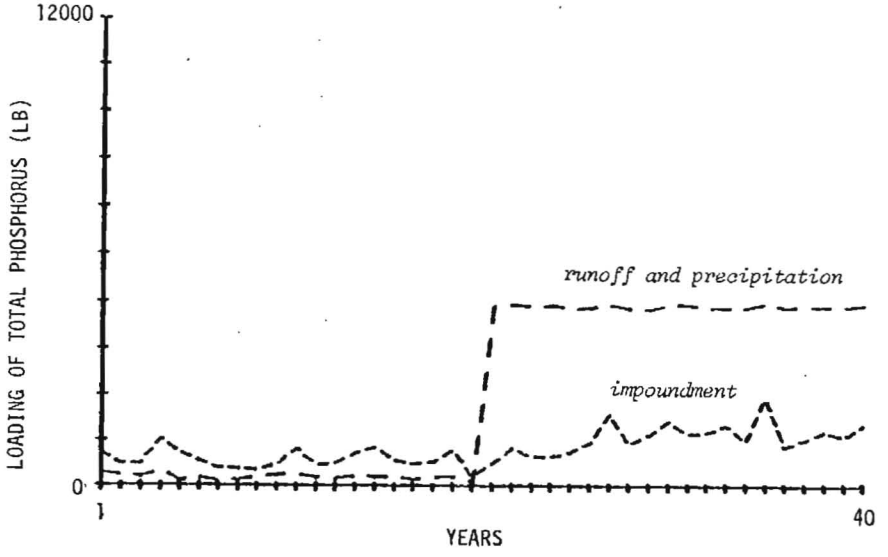


Figure 37. Loading of total phosphorus to the estuary from the impoundment and from runoff and precipitation - Scenario I.

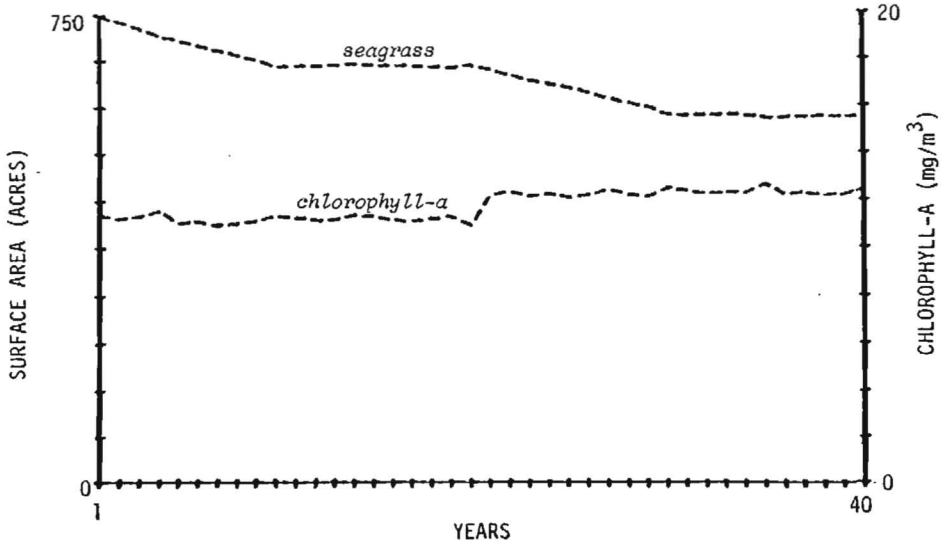


Figure 38. Average chlorophyll-a concentration and extent of seagrass beds - Scenario I.

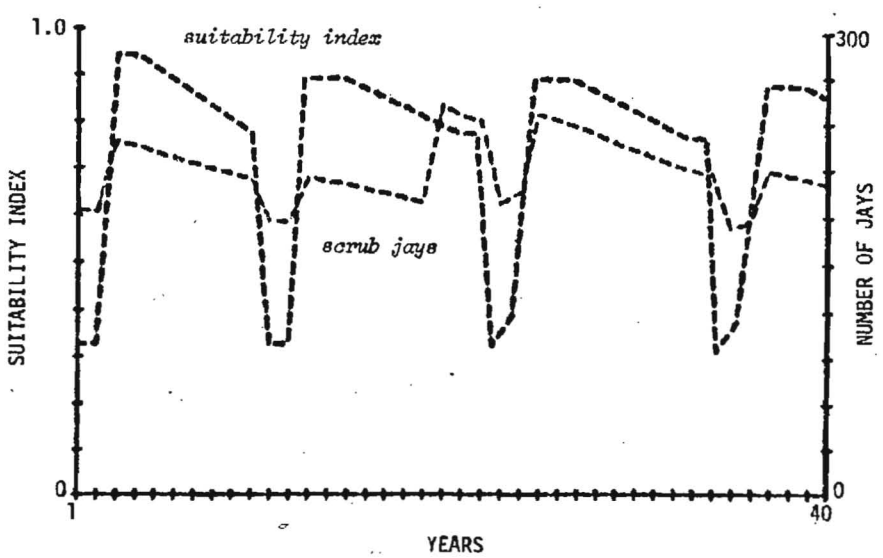


Figure 39. Number of scrub jays and scrub jay suitability index for mixed oak scrub - Scenario I.

oaks, and, therefore, scrub jay suitability, rapidly increases following a fire, the concomitant decrease in percent open space quickly becomes the limiting factor. The subsequent decrease in open space causes the suitability of mixed oak scrub to decline until the next fire (Figure 39). The overall decline of scrub jays in the first 18 years and in the last 21 years is due to the loss of acres of mixed oak scrub through succession and development. The increase at year 19 is the result of the fire in the xeric oak hammock cover type and the concomitant re-establishment of mixed oak scrub. This increase in scrub jays is probably more rapid than would actually be observed because of the low dispersal and the social system of the jays, which are not accounted for in the model.

Gopher tortoise. The behavior of gopher tortoise habitat conditions shows a similar overall decline due to the loss of acres through succession and development (Figure 40). The large increase in habitat after year 19 results from the re-establishment of mixed oak scrub due to fire in the xeric oak hammock cover type. Gopher tortoise habitat condition improves immediately following fires as herbaceous cover (food) quickly becomes established in open areas. This habitat improvement lasts for only a short period; as shrubs become established, herbaceous cover declines.

Mosquitos. Because pumping is used in this scenario to maintain impoundment water levels for mosquito control, changes in the salt marsh mosquito production index (Figure 41) are due solely to changes in canopy closure of salt marsh and cattail-mixed freshwater marsh (Figures 33 and 34).

Wading birds. The number of wading bird-days remains relatively constant throughout the model run at approximately 100,000.

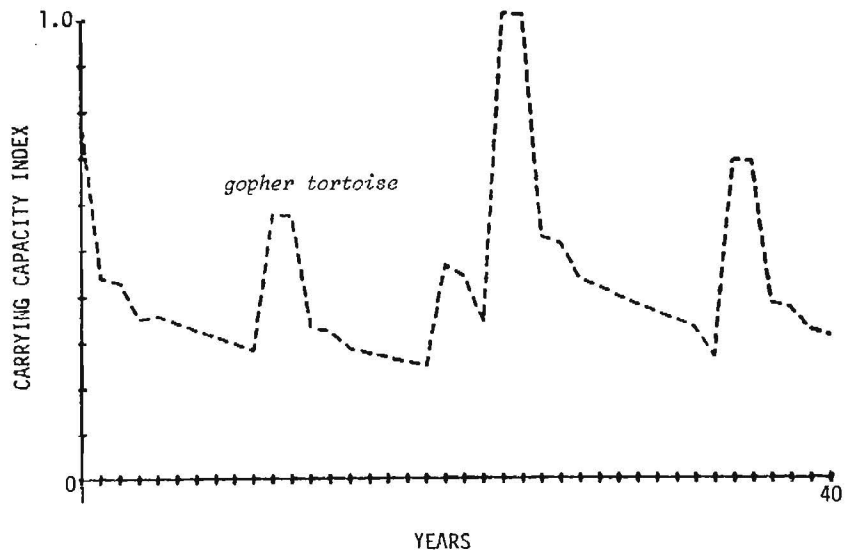


Figure 40. Index of gopher tortoise carrying capacity - Scenario I.

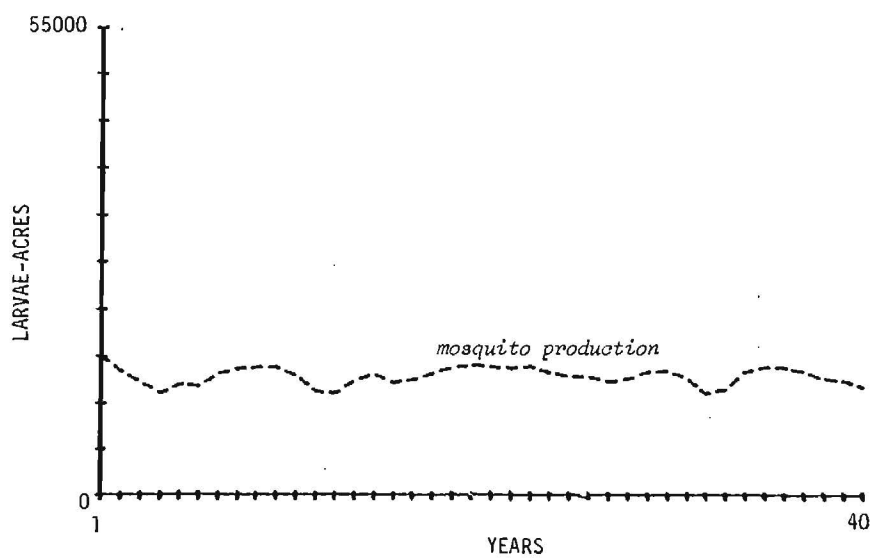


Figure 41. Salt marsh mosquito production - Scenario I.

Striped mullet. Striped mullet utilize the impoundment only part of the year for a nursery area. The number of mullet-days of use per year (Figure 42) is critically dependent on when, during the year, the impoundment is open to the estuary. Mullet-days are high in years when the impoundment is open to the estuary between October and February. Low years generally mean that the impoundment was open only when mullet densities in the estuary were relatively low.

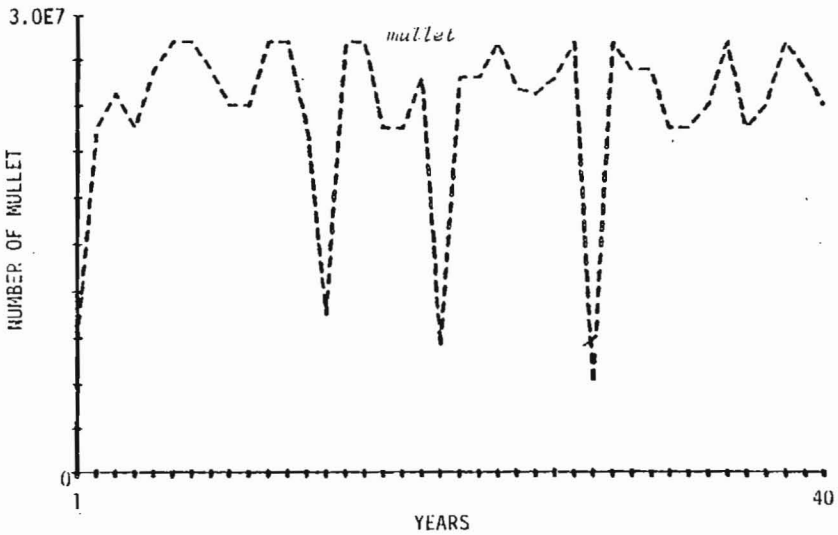


Figure 42. Mullet-days per year - Scenario I.

Mottled duck. The index of mottled duck broods is dependent on the amount of area inundated in the impoundment. Because pumping is utilized to control mosquitos, the area inundated remains relatively constant, and the number of broods, therefore, remains relatively constant at about 3,000.

SCENARIO II

Under Scenario II, the uplands in the management unit are prescribed burned only every 15 years, while vegetation in the impoundment is burned every 3 years. In year 10, shuttle launches and land development begin. Shuttle launches are increased to 20 per year. Development activities also are increased so that 1 acre of mixed oak scrub, 4 acres of saw palmetto scrub, and 5 acres of slash pine flatwoods are developed each year. In addition, 12.5 acres of new citrus groves are added each year for 4 years by converting 6.25 acres of slash pine flatwood and 6.25 acres of cabbage palm hammock. In year 10, pumping for mosquito control is terminated and, in year 15, the stop logs are lowered from 36 inches to 5 inches in impoundment dikes. Thus, the impoundment becomes more like a natural salt marsh. In year 20, land application of waste material begins at 542,000 gallons per month, but the amount is increased 10% each year for 10 years.

Water Budget and Quality

Monthly output depicting water budget and quality calculations under Scenario II is presented in Table 7. These results are from year 16. Input of water to the impoundment is still dominated by direct precipitation, although the amount of runoff has increased because of increased shuttle launches and the associated dumping of water used for sound suppression. Surficial ground water input is still low but somewhat more variable because of the increased variability of the head differential between the upland and the open impoundment. Flow between the impoundment and the estuary reflects a more natural water budget, dominated by the balance between precipitation input and evapotranspiration instead of pumping.

Aluminum input to the impoundment from both direct deposition and surface runoff is higher than in Scenario I due to the four-fold increase in shuttle launches. The input of total phosphorus to the estuary from runoff is initially the same as in Scenario I. However, when land application of waste material begins in year 20, the loading increases 10% per year until year 30.

Table 7. Monthly water quantity and quality variables - Scenario II.

	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
Precipitation (inches)[a]	5.0	3.0	3.2	0.1	7.3	4.6	7.2	5.1	4.3	3.5	6.2	1.8
Precipitation input to impoundment (acre-inches)[a]	3,000	1,810	1,964	85	4,398	2,767	4,322	3,065	2,560	2,123	3,725	1,108
Surface runoff to impoundment (acre-inches)	549	329	370	51	772	506	770	583	471	401	648	224
Surficial ground water to impoundment (acre-inches)	33	33	33	33	37	35	36	35	35	33	33	33
Flow from impoundment to estuary (acre-inches)	14,630	1,466	704	-	1,825	485	-	261	-	-	3,179	3,028
Flow from estuary to impoundment (acre-inches)	-	-	-	606	-	-	450	-	83	376	-	-
Evapotranspiration (acre-inches)[a]	600	780	1,500	2,100	2,580	3,300	5,100	3,900	3,180	1,500	780	600
Impoundment open to estuary	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Aluminum input to impoundment from direct deposition (lb)	23,100	11,550	23,100	23,100	11,550	23,100	23,100	11,550	23,100	23,100	11,550	23,100
Aluminum input to impoundment from runoff (lb)	315	159	314	314	158	313	313	170	313	317	156	312
Total phosphorus input to estuary from precipitation (lb)[a]	7.5	9.0	4.9	0.4	11.0	6.9	216.1	681.9	902.7	106.1	1,080.3	2.8
Total phosphorus input to estuary from runoff (lb) - without land application[a]	0.5	0.6	0.3	0.0	0.8	0.5	14.7	50.3	61.2	7.3	73.1	0.2
Total phosphorus input to estuary from runoff (lb) - with land application[b]	369	369	369	368	369	369	383	419	429	376	441	368
Total phosphorus input to estuary from impoundment (lb)	1,461	13	8	0	31	3	0	22	0	0	742	397

[a] Same as Scenario I.

[b] Initially the same as Scenario I but increases 10% per year starting in year 20.

Upland

The acreage of slash pine flatwood declines somewhat slower in the first 10 years than in Scenario I because there are no prescribed fires to cause the conversion to saw palmetto scrub (Figure 43). However, by the end of the model run, the acreage of slash pine flatwood is virtually the same as in Scenario I due to the increased development of flatwoods and conversion to citrus groves. The less frequent fires and the increased development also mean fewer acres in the saw palmetto scrub cover type (Figure 43). With a 15-year prescribed burning cycle, fires never occur in a drought year in this scenario. As such, mixed oak scrub is continually lost to development and succession with no fire-related re-establishment from xeric oak hammock (Figure 44). The increases in developed acres and citrus groves are shown in Figure 45.

The effects of fires on vegetation community structural parameters are illustrated in Figure 46. Although sufficient fuel loads build up after only 3 years in saw palmetto scrub and slash pine flatwoods and after 10 years in mixed oak scrub, the scenario assumes wild fire suppression. As a result, the variation in percent cover of oaks reflects prescribed fires every 15 years.

Impoundment

After year 15, the 3-year running average water depth in the impoundment at step 3 becomes very low because the stop logs are removed from the dikes and the water level is no longer artificially maintained during the summer months for mosquito control (step 3, shown in Figure 47). The average salinity in the impoundment becomes much more variable after it is opened to the estuary (Figure 47). As a result, the acres of all impoundment vegetation cover types become more variable than in Scenario I (Figures 48, 49, and 50). The increased fire frequency and decreased average water depth cause the acreage of salt marsh vegetation to increase dramatically. Open water decreases dramatically with a much smaller decrease in cattail-mixed freshwater marsh.

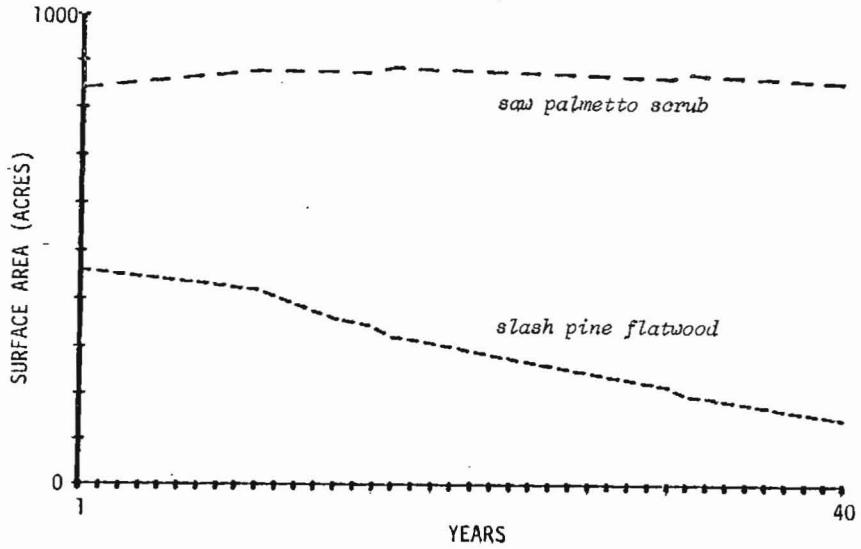


Figure 43. Acres of slash pine flatwood and saw palmetto scrub - Scenario II.

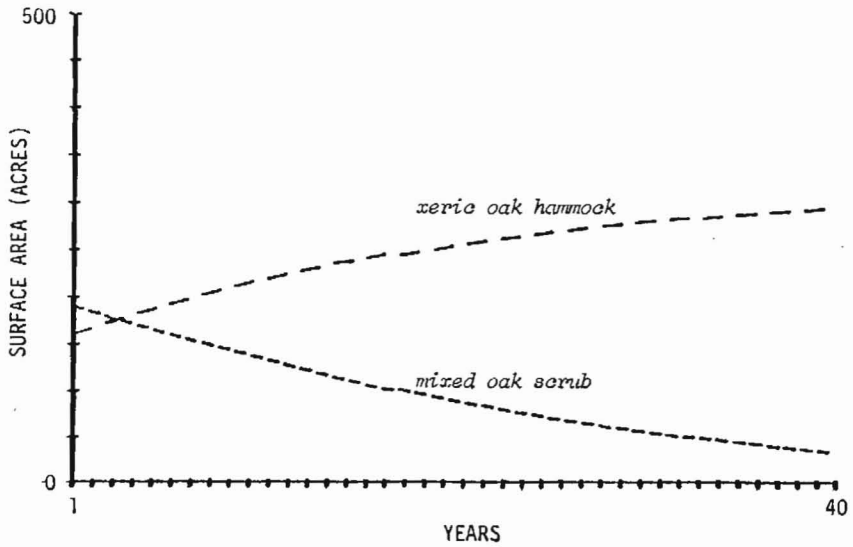


Figure 44. Acres of xeric oak hammock and mixed oak scrub - Scenario II.

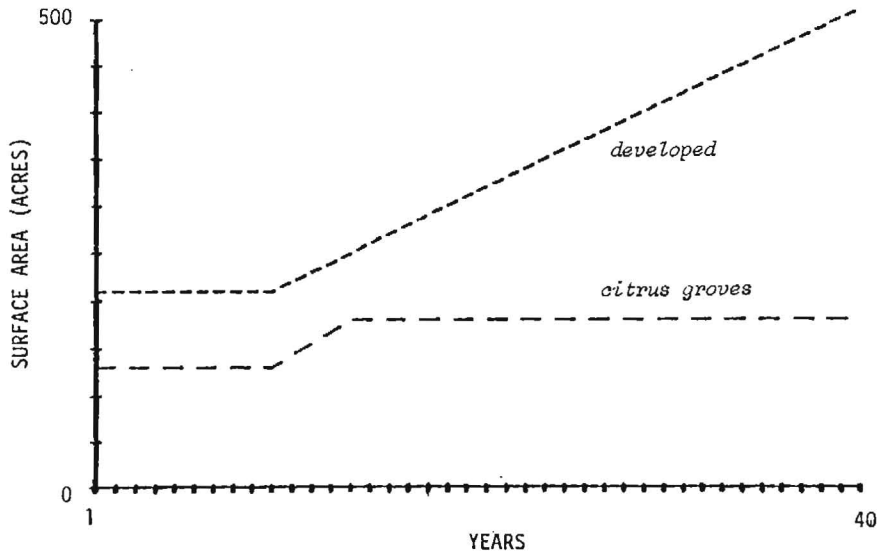


Figure 45. Acres of developed land and citrus groves - Scenario II.

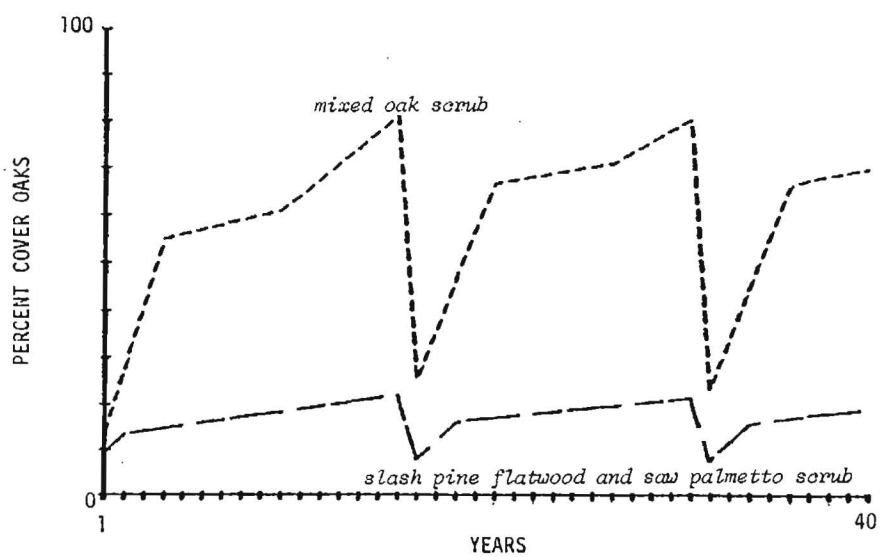


Figure 46. Percent cover of oaks in mixed oak scrub, saw palmetto scrub, and slash pine flatwood - Scenario II.

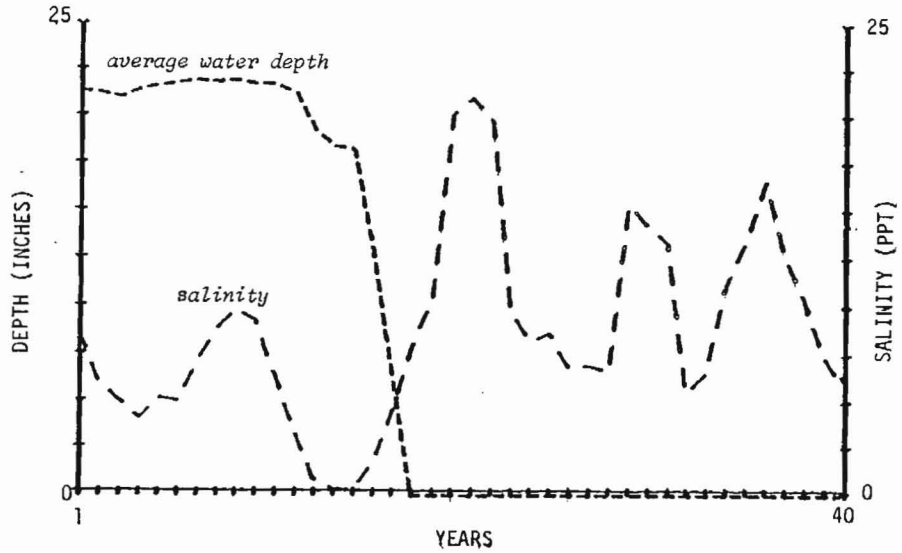


Figure 47. Average water depth and salinity in impoundment - Scenario II.

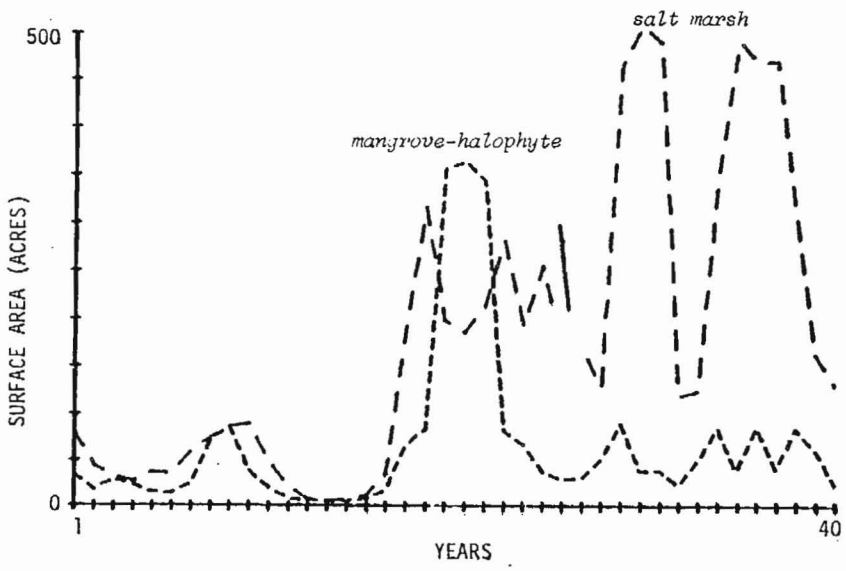


Figure 48. Acres of mangrove-halophyte and salt marsh - Scenario II.

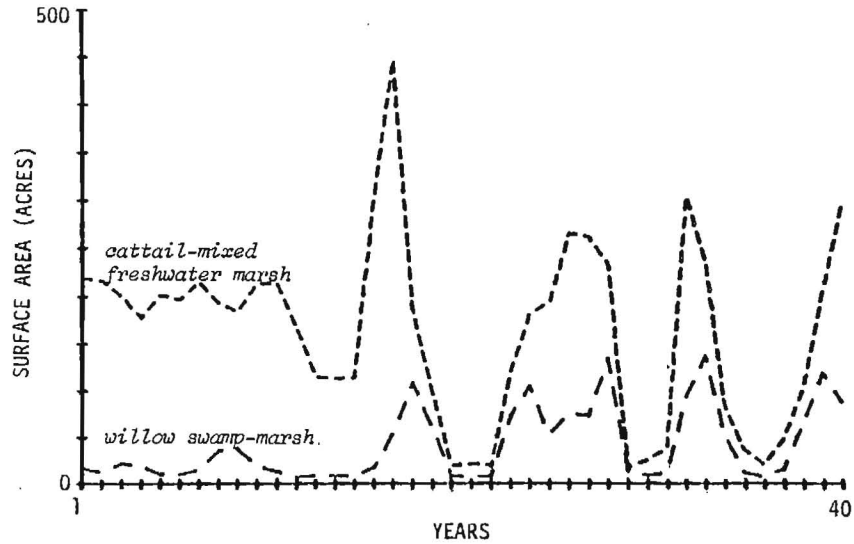


Figure 49. Acres of cattail-mixed freshwater marsh and willow swamp-marsh - Scenario II.

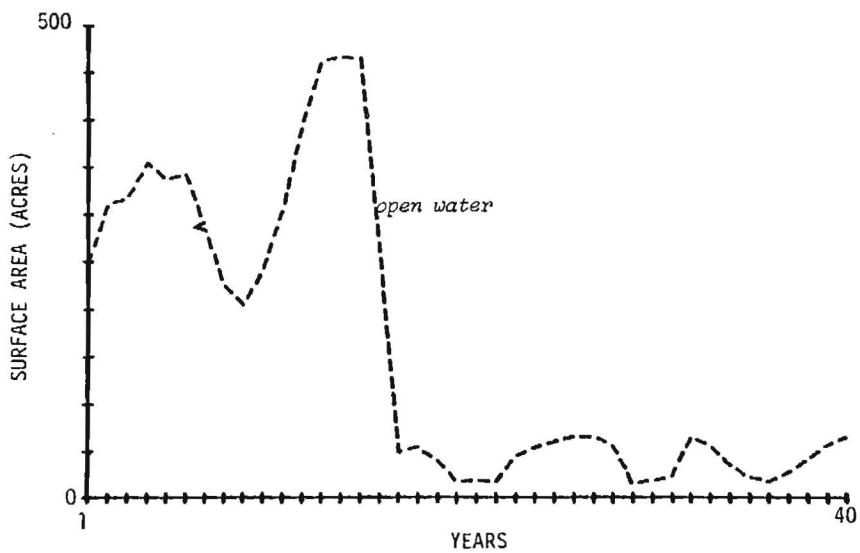


Figure 50. Acres of open water - Scenario II.

The decrease in storage of available total phosphorus after year 20 (Figure 51) is due to the drastically decreased storage of water in the impoundment. The increased cumulative input of aluminum to the impoundment (Figure 51) reflects the increase in shuttle launches.

Estuary

The increased loadings in total phosphorus from land application (Figure 52) cause the average chlorophyll-a concentration to be higher in this scenario (Figure 53). As a result, the decline in extent of seagrass beds is greater (Figure 53).

Wildlife

Scrub jay. The increased development of mixed oak scrub, saw palmetto scrub, and slash pine flatwoods and the fact that the xeric oak hammock does not burn in this scenario cause the index of scrub jays to decline substantially over the course of the model run (Figure 54). Habitat suitability increases for short periods following the less frequent fires but soon begins to decline as open space declines.

Gopher tortoise. Gopher tortoise habitat also declines substantially due to development and the lack of fire in xeric oak hammocks (Figure 55).

Mosquitos. As expected, salt marsh mosquito production increases dramatically as salt marsh vegetation increases after the impoundment is opened to the estuary (Figure 56).

Wading birds. When pumping for mosquito control is terminated and the impoundment is opened to the estuary, the area of the impoundment inundated in August decreases. As a result, fewer food fish are available for wading birds. This results in approximately 25% reduction in wading bird-days per year (Figure 57).

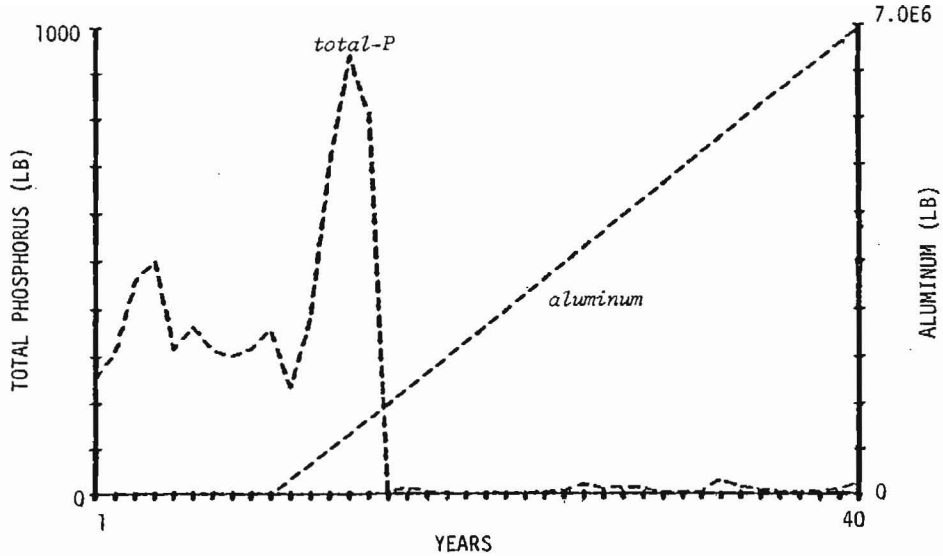


Figure 51. Storage of available total phosphorus and aluminum in impoundment - Scenario II.

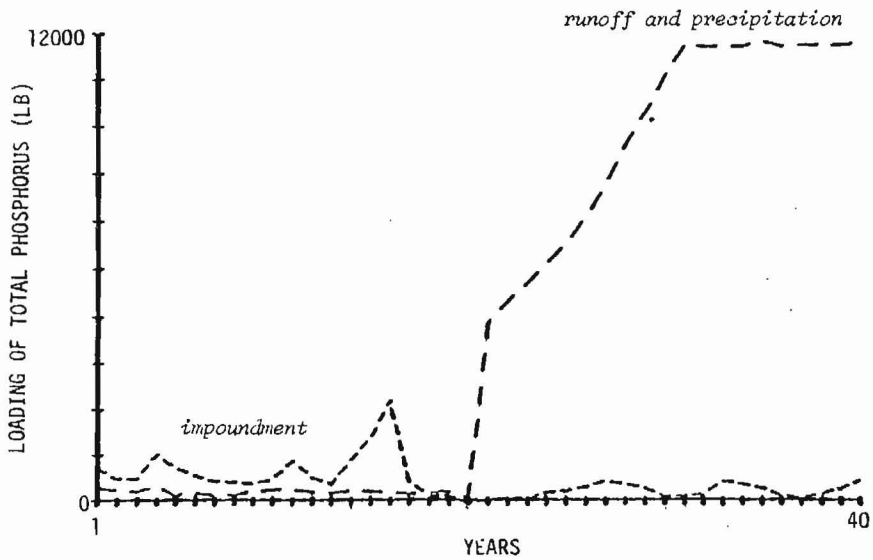


Figure 52. Loading of total phosphorus to the estuary from the impoundment and from runoff and precipitation - Scenario II.

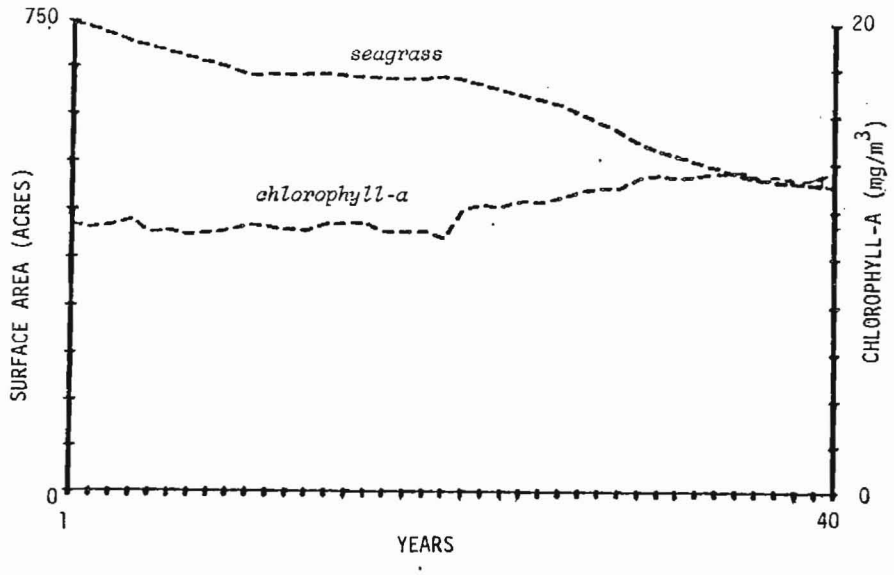


Figure 53. Average chlorophyll-a concentration and extent of seagrass beds - Scenario II.

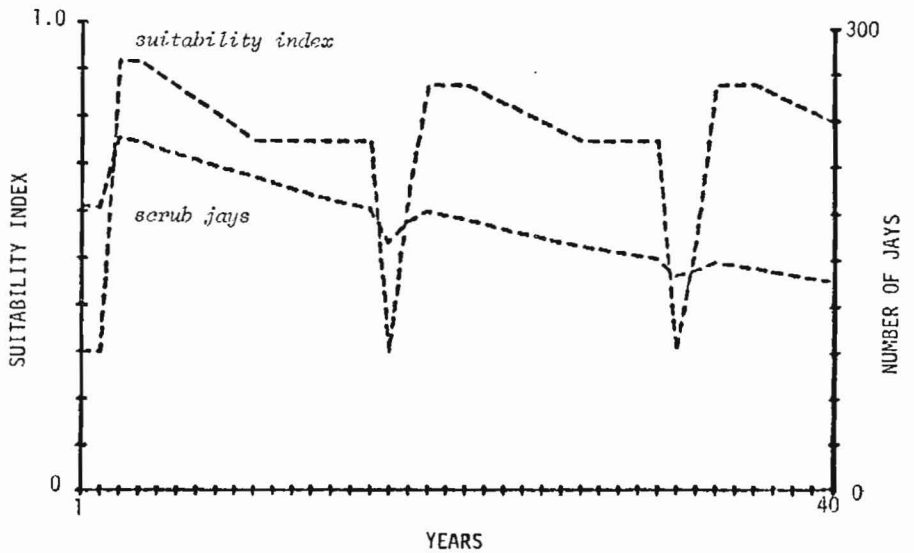


Figure 54. Number of scrub jays and scrub jay suitability index for mixed oak scrub - Scenario II.

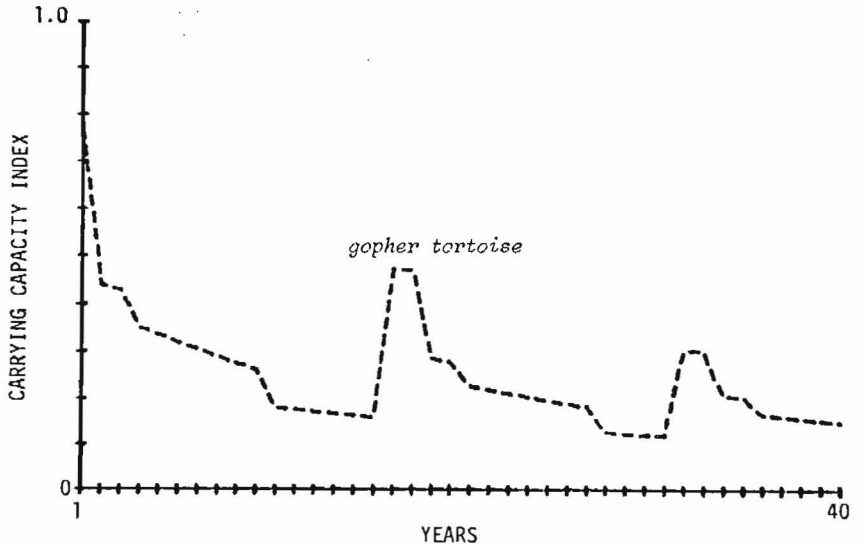


Figure 55. Index of gopher tortoise carrying capacity - Scenario II.

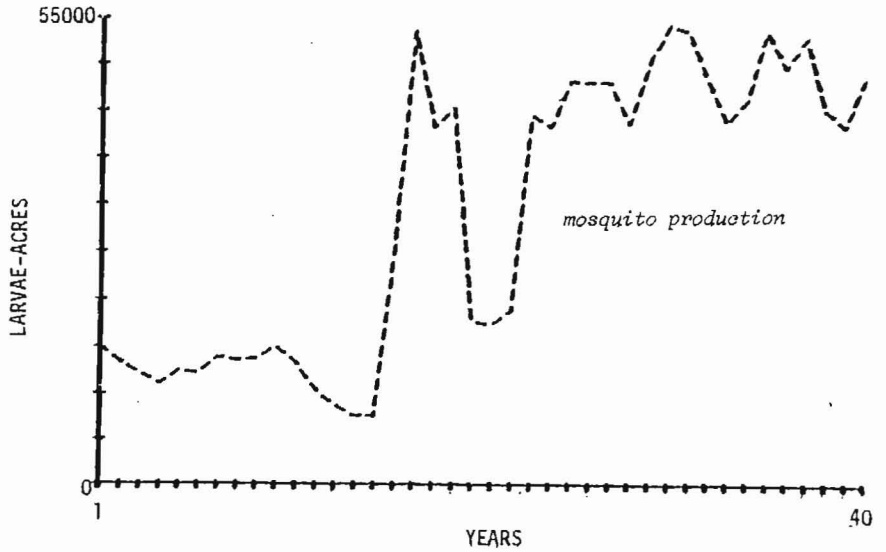


Figure 56. Salt marsh mosquito production - Scenario II.

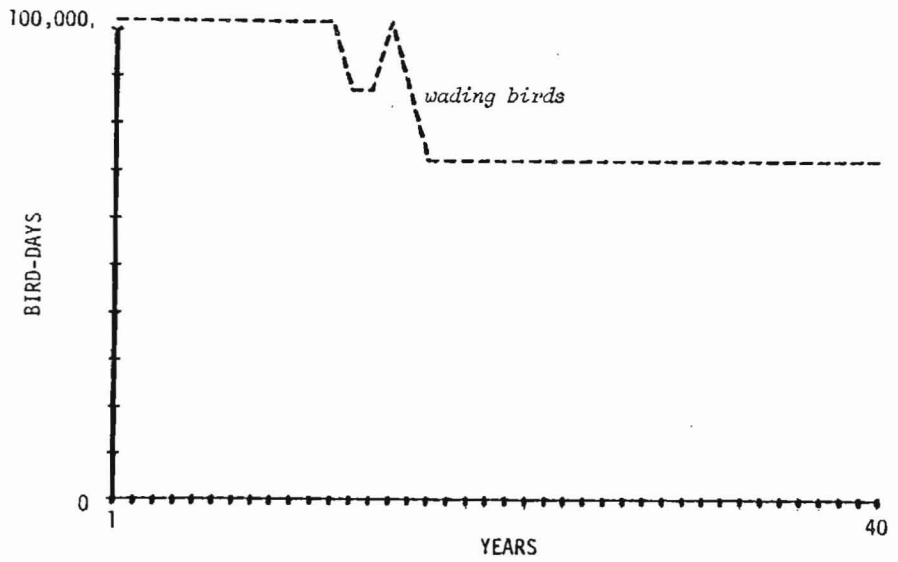


Figure 57. Wading bird-days per year - Scenario II.

Striped mullet. Although the impoundment is continually open to the estuary after year 15, the area inundated is generally less. This results in a 70% reduction in the index of mullet-days (Figure 58).

Mottled duck. The index of mottled duck broods is also dependent on the area of the impoundment inundated. Opening the dikes and eliminating pumping, therefore, results in a drastic reduction in the use of the impoundment by mottled ducks (Figure 59).

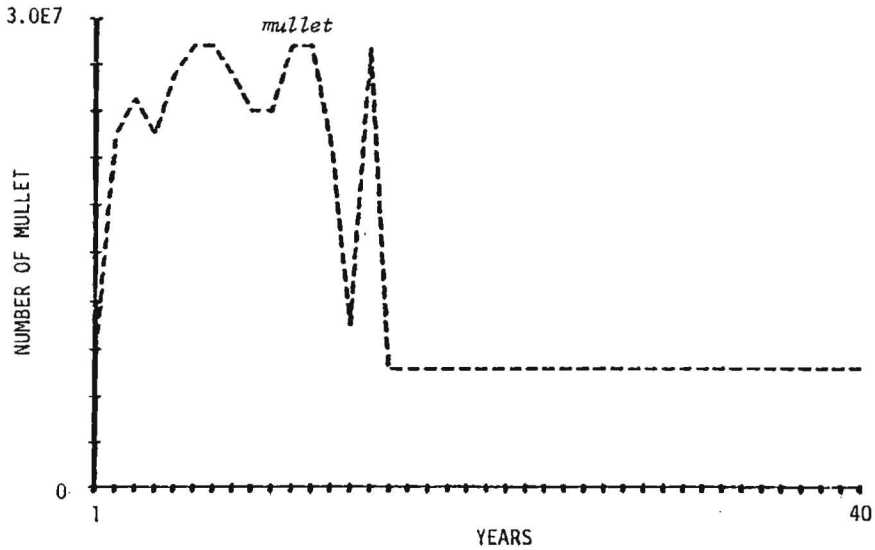


Figure 58. Mullet-days per year - Scenario II.

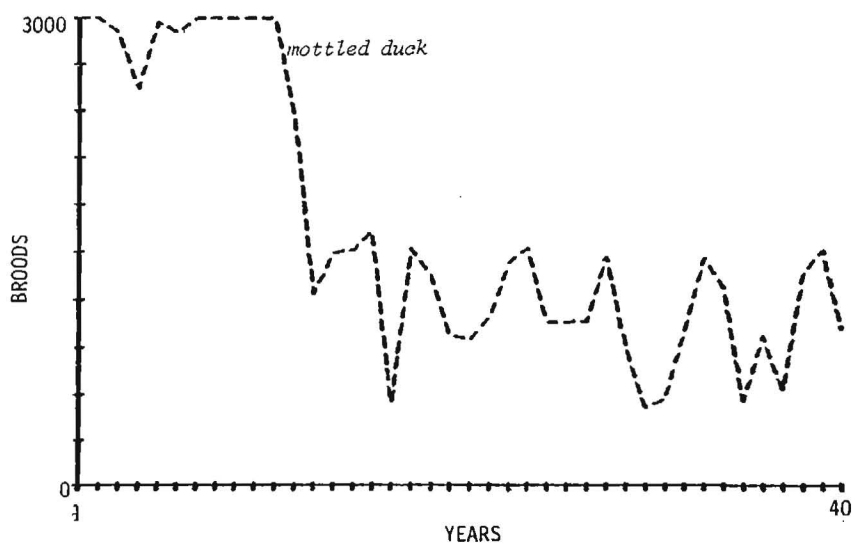


Figure 59. Mottle duck broods per year - Scenario II.

While re-establishing a more natural hydrologic regime in the impoundment causes all three associated fish and wildlife indicators to decline in the model, it should not be concluded that this is a generally poor management action. Some of the simplifying assumptions in the model may be causing erroneous behavior. In addition, there are many fish and wildlife species found on Merritt Island that would benefit from this action (R. Grant Gilmore, pers. comm.). For example, the effects described depend greatly on season and elevation of the marsh, which certainly varies greatly on Merritt Island. A natural hydrologic regime, meaning periodic dewatering of the impoundment due to natural water level fluctuations, will result in less breeding habitat available to resident fish species. However, a natural open hydrologic regime will have a quite positive effect on transient species. In addition, heavy fish use of completely vegetated marsh habitat has been well documented by various local research efforts during the past 30 years. Indigenous marsh fishes do not necessarily require open water. Impoundment utilization by transient species occurs principally during fall and winter larval and juvenile recruitment periods if the impounded marsh is open and under a natural hydrologic regime. If impoundments that are normally accessible to transient fish populations are closed from September to March, these habitats will be removed as juvenile nursery grounds, undoubtedly increasing natural juvenile mortality. The species most affected would be striped mullet, common snook, ladyfish, and spot, all of which support local commercial and sport fisheries.

WORKSHOP RESULTS

COMMUNICATION

Communication among Federal, State, and local agencies involved with activities on Merritt Island has been open in the past, and these agencies have a cooperative working relationship. While communication among various pairs of agencies has been effective, there have been few opportunities for all relevant agencies to meet together. The workshop provided an opportunity for these agencies to have focused, sustained discussions of key environmental and multiagency resource management issues. The participation, interest, expertise, and openness of individuals representing these agencies allowed a broader perspective and understanding of the Merritt Island resource system to be developed. While difficult to document, this aspect of a workshop is extremely valuable to the extent that participants represent a community of agencies that will continue to be involved with multiagency management and use of Merritt Island's resources.

INFORMATION INTEGRATION

A simulation model is a structure for representing the net result of a series of statements about how the Merritt Island system operates. Given the model framework defined by participants at the workshop, information and assumptions from a number of disciplines and agencies were integrated. This integration occurred not only in the computer simulation model itself, but also among participants as submodel linkages were developed and scenario results discussed.

There are two general ways in which the integration of information could be inadequate. First, some processes and linkages may have been poorly represented due to lack of time during the workshop. For example, volume of runoff from the uplands and the effect of interspersion of vegetation cover types on scrub jay habitat suitability. Second, some processes or linkages may have been excluded from the model because they were thought to be of only secondary importance or they were not well understood. For example, effects of variables other than salinity and water depth on impoundment vegetation (e.g., pH and nutrients) and sources of turbidity in the estuary other than phytoplankton. Some of these processes might be critical in the behavior of the real world system.

Ideally, the modeling workshop process is iterative in nature. Periods between workshops are used for research, data collection, and model refinement. Each workshop integrates information collected since the last workshop and produces a more credible model that is more useful in evaluating management alternatives. The iterative application of the process provides ongoing integration and communication among agencies and allows each agency's planning and management activities to be viewed within the context of an overall assessment.

RESEARCH NEEDS

A number of model limitations and information gaps were identified at the workshop in the process of constructing the simulation model and discussing scenario results. Some of these problems were the result of very limited time during the workshop to compile and incorporate relevant information; others were the result of a true lack of understanding and data. Thus, some of the information gaps may be addressed by interpreting existing studies from similar geographic areas as they relate to Merritt Island, while others can only be filled by conducting additional research and field studies on Merritt Island. Even if there is a true lack of knowledge in somes areas, as seems likely, the costs and benefits of acquiring the level of understanding required to develop a more detailed simulation model must be carefully considered. A more

empirical understanding developed from experience and the results of relatively simple experiments may be sufficient and more cost-effective for making many management decisions.

The research needs summarized below were compiled from participants' comments during the workshop. As such, they represent the informed judgement of researchers and managers familiar with Merritt Island or similar geographic areas, rather than the result of a comprehensive literature survey or model sensitivity analysis. In fact, given the very preliminary nature of the model, it probably is not yet appropriate to use model results and sensitivity analyses for identifying and prioritizing research needs.

Uplands

Hydrology-surficial ground water and surface runoff. Very little is known about the near surface stratigraphy and behavior of the near-surface aquifer at Merritt Island. At the scale of the workshop model, surficial ground water input to the impoundment and estuary is small compared to surface runoff and direct precipitation. However, the volume and constituent concentrations of surficial ground water may have a significant influence on water quality and vegetation on a site specific basis within impoundments or estuaries or in impoundments that have a small upland drainage and extensive contact with the near-surface aquifer relative to their volume. The ground water survey currently being conducted will begin to address this need.

Information on surface water runoff at Merritt Island is currently available for developed areas. Estimates of runoff or runoff coefficients for natural areas can probably be generated based on information from similar areas. While the volume of runoff to impoundments and estuaries is not as large as direct precipitation, runoff may have a more significant effect on water quality due to its loadings of metals and nutrients leached from the soil.

Succession. The greatest uncertainty with respect to succession concerns the factors limiting slash pine reproduction on Merritt Island. The workshop model currently has acres of slash pine flatwoods being lost both through natural succession and as a result of fire, with very little regeneration. Comparison of a small number of plots, with and without slash pine reproduction, currently being studied by Bionetics, Inc. and MINWR will hopefully identify some of these limiting factors.

Fire. Many of the vegetation communities on Merritt Island are thought to be fire-maintained subclimaxes. Upland habitat management by MINWR is based on the best estimates currently available for natural fire frequency. However, vegetation communities on Merritt Island are not very comparable to those in which fire frequency and effects studies have been conducted. Therefore, a study to determine the fire history of Merritt Island would be extremely valuable for refining the upland habitat and fire management plans. In addition, the effects of fire on nutrient release should be examined because of the potential effects on impoundment and estuarine water quality.

The workshop model currently treats the effects of fire empirically. While this approach is adequate given the spatial resolution chosen, current objectives, and other model limitations, participants discussed the possible need to represent fire effects in more detail at a later time. More detailed modeling of fire intensity, spread, and effects could be based on existing models used by the U.S. Forest Service (e.g., Albini 1976; Main et al. 1982) or by the U.S. National Park Service (Kessell 1976).

Launch effects. Little is known about the cumulative effects of shuttle launches on nearby vegetation communities and associated wildlife. The workshop model very crudely calculates deposition and movement of aluminum, phosphorus, and zinc from launches very crudely. Soil, sediment, and water column dynamics of these materials are not considered explicitly. A single effect of acid deposition on vegetation is included in the model primarily for purposes of discussion. Analysis of long-term monitoring data currently being collected by KSC should help define the fate and effects of key constituents

from shuttle launches. The decision to conduct additional studies should consider whether or not the extent of the area affected near-field or the frequency of exposure at any one site far-field justifies the additional expense.

Nutrient cycling. Little is known about the potential fate and effects of nitrogen and phosphorus introduced into the system from land-applied waste material. In particular, the model assumes that all phosphorus deposited on the uplands from launches would be bound in the soil while nitrogen and phosphorus in land-applied waste material would quickly saturate soil binding sites, thereby allowing all subsequently applied material to runoff into the impoundment and estuary. This hypothesis should be tested because the potential input of nitrogen and phosphorus is high even though the volume of water is low compared to direct precipitation and associated runoff.

Impoundments

Research needs were evident in two major areas: vegetation dynamics and the mass balance of constituents (i.e., the function of impoundments in filtering or contributing materials to the estuary).

Vegetation dynamics. The primary need in this area is for carefully documented analyses of observed vegetation changes in impoundments in response to altered environmental variables, such as water depth, salinity, and nutrient concentrations. This may not be a true "need" if historical analyses have been conducted but were not available at the workshop.

Mass balance of constituents. At the workshop, the subgroup was not able to adequately characterize the internal transformations and external exchanges of elements (including carbon) in quantified, mechanistic terms.

Wetlands, either natural or impounded, seem to be able to "capture" or absorb high proportions of certain loadings, at least in the short term. This function is represented in the model. However, a considerable amount of

additional understanding is required to define adequately the functional characteristics of these systems as filters:

- Capacity. The capacity of these systems is not infinite. What is the "capacity" or "useful-life" and how does efficiency change as the system becomes "saturated"?

- Release Characteristics. How are materials released or flushed from the system? To what extent is retention only a seasonal displacement with materials released at the end of a growing season? Are large quantities of materials flushed during irregular perturbations, such as hurricanes or fires?

- Wetland Biota. At what levels do retained materials substantially affect the biota (e.g., metal accumulation and eutrophication responses)? How are capacity, efficiency, and release characteristics related to cover types or the composition of wetland biota (e.g., do phytoplankton and algae in the open water cover type provide a large amount of filtering)?

In addition to the function of impoundments as filters of input to the estuary, impoundments may, to some degree, function as a source of energy or detrital material to the estuary. This function is not represented explicitly in the current model. There are interesting scientific questions in this area (e.g., What food chain does Spartina production support?). From a management perspective, one of the most important questions is what fraction of the contributions of coastal wetlands to estuaries and estuarine populations can be retained when selectively isolating coastal wetlands (e.g., impounding the wetlands for a period of time to achieve mosquito control or waterfowl utilization). Can a coastal wetland still provide important detrital inputs if it is only "open" to the estuary for 6 months of the year or for 1 year out of 3?

Estuaries

Phytoplankton abundance and turbidity. The Estuary submodel assumes that phytoplankton abundance is a function solely of phosphorus concentration. The model further assumes that the associated phytoplankton biomass is the primary factor influencing turbidity. Other factors that influence phytoplankton abundance and contribute to turbidity need to be evaluated. This is especially important given the currently conceptualized dependence of sea grass distribution on turbidity.

Sea grass distribution. The distribution of sea grass is assumed to be limited only by light penetration. Furthermore, the areal extent of sea grass is very sensitive to changes in phosphorus concentrations acting through chlorophyll-a concentrations and turbidity. Information concerning other factors determining sea grass distribution in similar geographic areas needs to be evaluated for its relevance to the Merritt Island situation. If possible, better quantified functional relationships should be developed to relate the key factors to sea grass density, as well as distribution.

Wildlife

Scrub jay. Field observations have led to the preliminary conclusion that scrub jay habitat suitability is dependent on the vegetation characteristics of species composition, height, and spatial/density parameters, including patchiness of scrub communities, plant spacing, and canopy closure. Study is needed to quantify these characteristics and to determine the relative importance of each as factors limiting scrub jay habitat suitability.

Gopher tortoise. Although data are spotty, gopher tortoises apparently find suitable burrowing conditions if the water table depth exceeds 0.7 m. The unresolved, and unmodeled, question is what role soil temperature plays in determining acceptable burrow sites. Both of these questions can probably be answered with a relatively small amount of effort. Of greater uncertainty is how the herbaceous food supply limits tortoises. The two main aspects of the

food supply question that need investigation are how to define adequate quantities (as possibly affected by quality consideration) and how far gopher tortoises will range from the burrow to obtain food.

Mottled duck. Early studies (Stieglitz and Wilson 1968) indicated that adequate nesting habitat for mottled ducks was available. However, this may be changing. The number of breeding pairs seems constant and limited to about 100, and it is uncertain if this is a habitat-imposed limit. An extensive survey of breeding habitat, production data, and fall/winter harvest data is needed in order to develop a strategy for the management of mottled ducks.

Striped mullet. Data are needed on the emigration and immigration of juvenile mullet (and other transient fish) relative to the impoundments in order to ascertain the contribution of impoundments to the populations of these fish. Information also is needed on production and survivorship within the impoundments.

Sea trout. The sea trout model was not included due to a lack of information pertaining to juveniles. In order to refine this model, information is needed on density of juveniles over sea grass beds and the effects of dissolved oxygen on survivorship of juveniles.

REFERENCES

Albini, F. A. 1976. Estimating wildfire behavior and effects. U.S. For. Serv., Intermountain For. Range Exp. Stn., Gen. Tech. Rep. INT-30. Ogden, UT. 92 p.

Botkin, D. B., J. F. Janak, and J. R. Wallis. 1972. Some ecological consequences of a computer model of forest growth. J. Ecol. 60:849-872.

Breininger, D. R. 1978. Habitat preference of the Florida scrub jay (Aphelocoma coerulescens coevulescens) on Merritt Island National Wildlife Refuge, Florida. M.S. Thesis, Florida Inst. Tech., Melbourne. 159 pp.

Ek, A. R., and R. A. Monserud. 1974. FOREST: A computer model for simulating the growth and reproduction of mixed forest stands. Res. Rep. A2635. Coll. Agric. Life Sciences, Univ. Wisconsin, Madison. 13 pp. + app.

Gillmore, G. R. 1984. Fish and macrocrustacean population dynamics in a tidally influenced impounded subtropical marsh. Harbor Branch Foundation, Inc. Rep. 36 pp.

Hilborn, R. 1973. A control system for FORTRAN simulation programming. Simulation 20:172-175.

Holling, C. S., ed. 1978. Adaptive environmental assessment and management. John Wiley and Sons, New York. 377 pp.

Kessell, S. R. 1976. Gradient modeling: A new approach to fire modeling and wilderness resource management. Environ. Manage. 1:39-48.

Kushlan, J. A. 1978. Feeding ecology of wading birds. Pages 249-298 in A. Sprunt IV, J. C. Ogden, and S. Winckler, eds. Wading birds. Natl. Audubon Soc., New York. 381 pp.

Leenhouts, W. 1982. Fire management plan, Merritt Island National Wildlife Refuge.

Main, W. A., R. J. Straub, and D. M. Paananen. 1982. FIREFAMILY: Fire planning with historic weather data. U.S. For. Serv., North Central For. Exp. Stn., Gen. Tech. Rep. NC-73. St. Paul, MN. 31 pp.

Shugart, H. H., T. R. Crow, and J. M. Hett. 1973. Forest succession models: A rationale and methodology for modeling forest succession over large regions. Forest Sci. 19:203-212.

Stieglitz, W. O, and C. T. Wilson. 1968. Breeding biology of the Florida duck. J. Wildl. Manage. 32(4):921-934.

West, D., H. Shugart, and D. Botkin. 1981. Forest succession: Concepts and application. Springer-Verlag, New York. 517 pp.