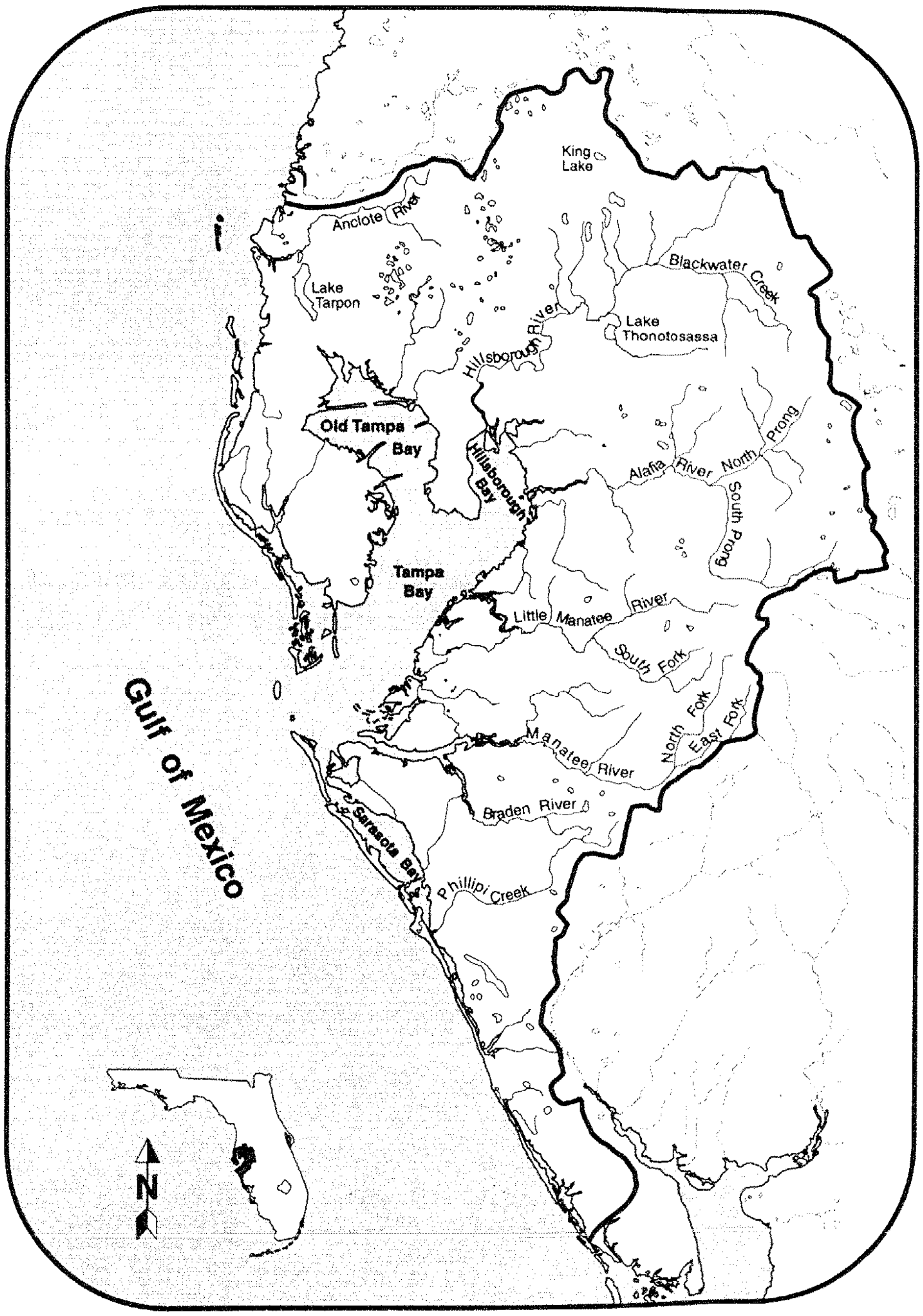
Biological Report 90(20)
December 1990

An Ecological Characterization of the Tampa Bay Watershed



Fish and Wildlife Service and
Minerals Management Service

U.S. Department of the Interior

Biological Report 90(20)
December 1990

An Ecological Characterization
of the
Tampa Bay Watershed

edited by

Steven H. Wolfe
and
Richard D. Drew

State of Florida
Department of Environmental Regulation
2600 Blairstone Road
Tallahassee, Florida 32301

Project Officer
Larry Handley
U.S. Fish and Wildlife Service
National Wetlands Research Center
1010 Gause Boulevard
Slidell, Louisiana 70458

Performed for

U.S. Department of the Interior
Fish and Wildlife Service
Research and Development
National Wetlands Research Center
Washington, D.C. 20240

and

Minerals Management Service
Gulf of Mexico Outer Continental Shelf Office
1201 Wholesalers Parkway
New Orleans, Louisiana 70123-2394

DISCLAIMER

The opinions, findings, conclusions, or recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the U.S Fish and Wildlife Service unless so designated by other authorized documents.

This report may be cited:

Wolfe, S.H., and R.D. Drew, eds. 1990. An ecological characterization of the Tampa Bay watershed. U.S. Fish Wildl. Serv. Biol. Rep. 90(20). 334 pp.

PREFACE

This report is one in a series that provides an ecological description of Florida's gulf coasts. The watersheds described herein, with their myriad subtropical communities, produce many benefits. The maintenance of this productivity through enlightened resource management is a major goal of this series. This report will be useful to the many people who have to make decisions regarding the use of the natural resources of the area.

Any questions or comments about or requests for this publication should be directed to:

Information Transfer Specialist
U.S. Fish and Wildlife Service
National Wetlands Research Center
NASA Slidell Computer Complex
1010 Gause Boulevard
Slidell, Louisiana 70458

CONTENTS

Page

PREFACE iii
FIGURES vii
TABLES x
CONVERSION FACTORS xii
ACKNOWLEDGMENTS xiii
AUTHORS xiv
Chapter 1. Introduction
1.1 Purpose and Organization 1
1.2 The Tampa Bay Watershed 1
Chapter 2. Geology and Physiography
2.1 Structure and Geologic Setting 3
2.2 Tertiary Stratigraphy 6
2.3 Pleistocene Marine Terraces 6
2.4 Physiography 8
2.4.1 Central Lake District 8
2.4.2 Ocala Uplift District 11
2.4.3 Southwestern Flatwoods 11
2.5 Recent Sediments and Soils 13
Chapter 3. Climate
3.1 Introduction 25
3.2 Rainfall 26
3.3 Winds 34
3.4 Temperature 38
3.5 Relative Humidity 39
3.6 Solar Radiation 40
3.7 Evapotranspiration 41
3.8 Hurricanes 45
3.9 Air Pollution 48
Chapter 4. Hydrology and Water Quality
4.1 Introduction 56
4.2 Ground Water 57
4.3 Surface Water 70
4.3.1 Anclote River Basin 73
4.3.2 Western Pinellas Peninsula 74
4.3.3 Old Tampa Bay and Southeastern Pinellas County Peninsula 78
4.3.4 Hillsborough River Basin 85
4.3.5 Alafia River Watershed 103
4.3.6 Manatee and Little Manatee River Basins 109
4.3.7 Manasota Coastal Area 117
4.3.8 Tampa Bay 126
Chapter 5. Vegetation Communities (Habitats)
5.1 Introduction 134

Page
5.2 Terrestrial Habitats 134
5.2.1 Pine-Oak Woodlands 136
5.2.2 Pine Flatwoods (Typical Flatwoods) 137
5.2.3 Prairies 138
5.2.4 Hammocks 139
5.3 Freshwater Wetland Habitats 140
5.3.1 Swamp Forests 140
5.3.2 Wet Prairies and Marshes 143
5.3.3 Lakes, Ponds, and Rivers 147
5.4 Estuarine, Saltwater Wetland, and Coastal Habitats 154
5.4.1 Salt Prairies and Marshes 154
5.4.2 Mangrove Forests 155
5.4.3 Oscillating-Salinity Open Waters 162
5.4.4 Beach, Dune and Coastal Strand 179
5.5 Disturbed Communities 184
5.5.1 Exotic Plant Communities 186
5.5.2 Agricultural Communities 191
5.5.3 Urban–Industrial Communities 194
5.5.4 Canals and Other Artificial Structures 195
5.5.5 Phosphate-Mined Lands 196
5.5.6 Spoil Islands 206
5.6 Endangered and Threatened Plant Communities. 214
Chapter 6. Fauna
6.1 Introduction 216
6.2 Invertebrates 216
6.2.1 Freshwater Invertebrates 216
6.2.2 Estuarine Invertebrates 218
6.3 Fishes 222
6.3.1 Freshwater Fishes 222
6.3.2 Estuarine and Marine Fishes 229
6.4 Amphibians and Reptiles 234
6.5 Birds 238
6.5.1 Forest (Arboreal) Birds 238
6.5.2 Wading Birds 242
6.5.3 Floating and Diving Water Birds 243
6.5.4 Birds of Prey 245
6.5.5 Probing Shorebirds 246
6.5.6 Aerially Searching Birds 247
6.6 Mammals 249
Literature Cited 254
Appendix
Table A-1. Cenozoic units and formations underlying the Tampa Bay watershed. 280
Table A-2. Point-source emission summary for west-central Florida. 282
Table A-3. Summary of point- and areal-source emissions in west-central Florida 283
Table A-4. Areal source emissions of particulates and SO_2 in west-central Florida,. 284

Appendix Page
Table A-5. Municipal, domestic, and industrial dischargers in the lower Hillsborough River watershed. 286
Table A-6. Domestic and industrial dischargers in the Tampa Bypass Canal drainage system. 286
Table A-7. Industrial dischargers in the Alafia River watershed. 287
Table A-8. Summary of 1982 and 1983 Tampa Bay water-quality characteristics. 288
Table A-9. Aquatic macrophytes collected from the Alafia and Little Manatee Rivers. 289
Table A-10. Bloom species of algae detected in Tampa Bay during 1981. 291
Table A-11. Rare, threatened, and endangered plant species in the Tampa Bay watershed; their status and distribution among major habitats. 293
Table A-12. Habitat distribution and relative abundance of freshwater fish in the Tampa Bay watershed. 299
Table A-13. Composite list of fish species reported from Tampa Bay. 302
Table A-14. Habitat distribution and relative abundance of terrestrial reptiles in the Tampa Bay watershed. 306
Table A-15. Wetland and aquatic habitat distribution and relative abundance of reptiles in the Tampa Bay watershed. 308
Table A-16. Terrestrial habitat distribution and relative abundance of amphibians in the Tampa Bay watershed. 310
Table A-17. Wetland and aquatic habitat distribution and relative abundance of amphibians in the Tampa Bay watershed. 311
Table A-18. Terrestrial habitats in which forest (arboreal) birds in the Tampa Bay watershed are found, including distribution, relative abundance, and seasonal occurrence. 312
Table A-19. Wetland habitats in which forest (arboreal) birds are found in the Tampa Bay watershed, including relative abundance and seasonal occurrence. 317
Table A-20. Aquatic habitats in which forest (arboreal) birds are found in the Tampa Bay watershed, including relative abundance and seasonal occurrence. 321
Table A-21. Habitat distribution, relative abundance, and seasonal occurrence of wading birds in the Tampa Bay watershed. 322
Table A-22. Habitat distribution, relative abundance, and seasonal occurrence of floating and diving water birds in the Tampa Bay watershed. 324
Table A-23. Aquatic habitat distribution, relative abundance, and seasonal occurrence of birds of prey in the Tampa Bay watershed. 325
Table A-24. Wetland habitat distribution, relative abundance, and seasonal occurrence of birds of prey in the Tampa Bay watershed. 326
Table A-25. Terrestrial habitat distribution, relative abundance, and seasonal occurrence of birds of prey in the Tampa Bay watershed. 327
Table A-26. Habitat distribution, relative abundance, and seasonal occurrence of probing shorebirds in the Tampa Bay watershed. 328
Table A-27. Habitat distribution, relative abundance, and seasonal occurrence of aerially searching birds in the Tampa Bay watershed. 330
Table A-28. Terrestrial habitat distribution and relative abundance of mammals known or expected to occur in the Tampa Bay watershed. 331
Table A-29. Wetland habitat distribution and relative abundance of mammals known or expected to occur in the Tampa Bay watershed. 333
Table A-30. Aquatic habitat distribution and relative abundance of mammals known or expected to occur in the Tampa Bay watershed. 334

FIGURES

Figure Page
1. Tampa Bay watershed. 2
2. Stratigraphic nomenclature of Florida. 4
3. Major structural features of southeastern Coastal Plain. 5
4. Glacial eustatic sea-level chronology for Florida. 7
5. Terraces of west-central Florida. 9
6. Physiographic division of the Tampa Bay watershed. 10
7. Tampa Bay estuary physiographic divisions. 13
8. Distribution of the major soil orders in Florida. 15
9. Recent sediment cross section of Sanibel Island 17
10. Soil associations in the Tampa Bay watershed. 19
11. Bathymetry of Tampa Bay. 22
12. Texture of bottom sediments in Tampa Bay. 23
13. Calcium carbonate content of bottom sediments (%) in Tampa Bay. 24
14. Florida climatic divisions. 25
15. Average annual precipitation in the Tampa Bay watershed, 1941–70. 28
16. March and November average rainfall in the Tampa Bay watershed. 29
17. Average July rainfall in the Tampa Bay watershed 31
18. Average number of days when rainfall exceeds 0.025 cm (0.01 in) and average number of monthly thunderstorms. 32
19. Average monthly rainfall in the Tampa Bay watershed. 33
20. Average number of days per month when rainfall exceeds 0.25 cm (0.1 in). 33
21. Frequency distribution of rainfall in southwest Florida over a 5-year period. 33
22. Thirty-year annual rainfall for Lakeland. 34
23. Rainfall deviation from normal over 30 years at Lakeland 35
24. Seasonal wind directions and speed at the 950-mbar level in Florida, 1957-67. 36
25. Average monthly divergence curves for June, July, and August 1963, over the Florida Peninsula. . 37
26. Prevailing wind speed and direction. 38
27. Annual, January, and August average temperatures in south-central Florida. 39
28. Average number of days per year in Florida when air temperatures exceed 32°C. 40
29. Average monthly relative humidity at different times of the day. 40
30. Percent of possible sunshine, daytime sky cover, and solar insolation in southwest Florida. 42
31. Average seasonal cloudiness in southwest Florida 43
32. Average number of days with heavy fog in southwest Florida. 44
33. Estimated evapotranspiration patterns in Florida. 44
34. Average monthly evaporation and solar radiation in eastern Tampa Bay watershed. 45
35. Comparative average potential evapotranspiration in the middle Gulf area as calculated by four models. 46
36. Paths of hurricanes striking the Tampa Bay area 1885 to 1990. 47
37. One-hundred-year hurricane flood surge in Little Manatee River (assuming mean annual river-discharge rate). 48
38. Seasonal average nutrient concentrations in rainwater at Tamiami Trail and Forty-Mile Bend. 50
39. Average daily concentrations of airborne sulfur dioxide in the rural and urban Tampa area for the years 1970–83. 53
40. Annual suspended-particulate emissions in the Tampa area during 1973–83. 53
41. Number of days each year on which ozone concentration exceeded 80 ppb and 120 ppb in the Tampa area during 1971–83. 55
42. Generalized hydrogeology in the Southwest Florida Management District. 58

Figure	Page

43. Generalized hydrogeologic relation between surficial and Floridan aquifers. 59
44. Hydrographs of wells open to the surficial aquifer in the Tampa Bay watershed. 60
45. Potentiometric surface of Floridan aquifer. 62
46. Water levels at the Mullet Key tide station and in a southwest St. Petersburg well open to the lower part of the Floridan aquifer. 63
47. Groundwater levels, irrigation pumpage, and rainfall in the central Tampa Bay watershed. 64
48. Generalized conceptual model of groundwater flow in the Tampa Bay watershed. 66
49. Hydrochemical facies in the Floridan aquifer's upper permeable zone. 67
50. Median water quality in the surficial aquifer and upper and lower units of the Floridan aquifer. 68
51. Chloride concentration in groundwater from the upper and lower Floridan aquifer. 69
52. Section through Floridan aquifer showing chloride concentrations in the coastal margin of Pinellas and central Hillsborough County. 70
53. Major drainage basins of the Tampa Bay watershed. 71
54. Ten-year average monthly flows of major rivers and streams in the Tampa Bay watershed. 72
55. Anclote River basin. 73
56. West Pinellas peninsula basin. 75
57. East Pinellas Peninsula and Old Tampa Bay basin. 79
58. Dissolved oxygen values in Tanglewood Estates canals, northeast St. Petersburg. 81
59. Hillsborough River and Tampa Bypass Canal drainage basins. 86
60. Discharge hydrographs for two gauging stations on the Hillsborough River. 88
61. Flow, current velocity, and residence times for the Tampa Reservoir. 95
62. Salinity (ppt) in the lower Hillsborough River. 96
63. Dissolved oxygen in lower Hillsborough River. 98
64. Fecal coliform in the lower Hillsborough River. 99
65. Orthophosphate in the lower Hillsborough River 100
66. Alafia River drainage basin and Alafia River to Little Manatee River coastal area basin. 104
67. Ammonia concentrations in the North Prong Alafia River, February 2, 1982. 106
68. Dissolved phosphorus trends in Hillsborough Bay and the Alafia River. 107
69. Seasonal water-quality conditions in the lower Alafia River. 108
70. Conductivity, stage, and streamflow stations on Lower Alafia River and Bullfrog Creek. 109
71. Conductivity profiles (µmhos/cm) in the lower Alafia River. 110
72. Little Manatee River basin and Terra Ceia and Cockroach Bays coastal area drainage basins. 111
73. Seasonal water quality conditions in the Little Manatee River. 112
74. Manatee River drainage basin. 115
75. Wet- and dry-season salinity variation in the Lower Manatee River. 117
76. Upper Manasota coastal area drainage basin. 119
77. Lower Manasota coastal area drainage basin. 120
78. Blackburn, Lyons, Dona, and Roberts Bays and their tributaries. 121
79. Dry season hydrography in Dona, Roberts, and Lyons Bays 122
80. Wet season hydrography in Dona, Roberts, and Lyons Bays. 123
81. Average monthly concentrations of total phosphorus and color in Phillippi Creek. 125
82. Circulation pattern in Tampa Bay. 127
83. Location of evenly distributed particles after 30 days of mixing in Tampa Bay. 127
84. General water quality index of Tampa Bay for 1982. 129
85. General water quality index of Tampa Bay for 1983. 130
86. Total phosphate concentrations in the Tampa Bay estuary, 1974–83. 131
87. Biochemical oxygen demand (BOD) in the Tampa Bay estuary, 1974–83. 131

Figure		Page
88.	Maximum surface and minimum bottom DO concentrations in Tampa Bay, 1974–83.	132
89.	Turbidity in the Tampa Bay estuary, 1974–83.	132
90.	Chlorophyll a concentrations, light penetration, and color in the Tampa Bay estuary, 1974–83.	133
91.	Vegetation and land use in the Tampa Bay drainage basin.	135
92.	Typical cypress dome with associated plants.	142
93.	Typical wet prairie with associated plants.	145
94.	Typical freshwater marsh with associated plants.	146
95.	Typical freshwater aquatic plant habitat.	148
96.	Seasonal variation of periphytic algal genera in Lake Tarpon, 1973–1977.	151
97.	Distribution of fish farms in the Tampa Bay watershed.	152
98.	Vertical distribution of selected algae and invertebrates on red mangrove prop roots.	156
99.	Successional relations of mangrove communities and some associated plant communities in relation to approximate tide levels.	157
100.	Mangrove forest types represented in the Tampa Bay watershed.	158
101.	Leaf-litter production rates in mangrove forest categories.	161
102.	Diagrammatic representation of the principle of protein enrichment of red mangrove debris during degradation.	161
103.	Distribution of major seagrass species in Tampa, Florida during July 1983 survey.	163
104.	Generalized schematic of species zonation among seagrasses in Tampa Bay relative to depth and salinity.	164
105.	Seasonal growth pattern for *Thalassia* in Tampa Bay.	167
106.	Five types of seagrass beds identified for Tampa Bay.	168
107.	Seagrass distribution in 1943.	170
108.	Seagrass distribution in 1983.	171
109.	Average levels of chlorophyll a in the Tampa Bay system 1981.	178
110.	Yearly trends in chlorophyll a concentrations in four areas of Tampa Bay.	179
111.	Monthly trends in chlorophyll a concentrations in four areas of Tampa Bay during 1982-83.	180
112.	High energy beach community showing major zones relating to sand motion.	181
113.	Two patterns of spatial succession of vegetation community types on west coast barrier islands.	185
114.	Schematic of effect of canal development on hydrology and habitat structure.	197
115.	Location of central Florida phosphate district in relation to Tampa Bay watershed.	198
116.	Stratigraphic units of concern in phosphate mining.	199
117.	Generalized flowsheet of Florida phosphate-mining plants.	200
118.	Generalized habitat succession on dredged material islands in Florida.	208
119.	Generalized vegetation map of a dredged disposal island in Tampa Bay.	211
120.	Plant community succession on filled land, Boca Ciega Bay.	213
121.	Seasonal distribution of selected juvenile fishes within the nursery areas of Tampa Bay.	230
122.	Estuarine fish communities.	232
123.	Relative abundance of amphibian and reptile species in various habitat categories within the Tampa Bay watershed.	236
124.	Number of species of breeding land birds in the Florida Peninsula.	240
125.	Nesting patterns of colonial shorebirds on Florida spoil islands.	249

TABLES

Tables	Page
1. Deep strata of Florida.	3
2. Tertiary strata of the Tampa Bay watershed.	6
3. Morphometric features of Tampa Bay estuary and some of its bays.	14
4. Soil Conservation Service soil orders.	15
5. Typical soil types on west-central Florida coastal barrier islands .	18
6. Plant community and soil series associations in the Tampa Bay watershed.	20
7. Wet-season, dry-season, and total annual rainfall in the Tampa Bay watershed.	27
8. Major hurricane storm tides in the Tampa Bay watershed.	48
9. Coastal areas most vulnerable to hurricane flooding in the Tampa Bay watershed.	49
10. Maximum winds reported in the Tampa Bay watershed.	49
11. Major air pollutants in the Tampa Bay watershed and their probable sources.	52
12. Summary of fluoride point-source and areal-source (pond) emissions in Polk, Hillsborough, and Manatee counties.	54
13. Ground-water and surface-water use by county in 1978.	65
14. Ground-water withdrawal rates and predicted rates for major users in Hillsborough, Manatee, and Sarasota counties, 1975, 1985, and 2000.	65
15. Point sources discharging to eastern Old Tampa Bay and Upper Tampa Bay.	80
16. Point-source dischargers in the western Old Tampa Bay drainage area.	87
17. Description and water-quantity data for four continuous-record gauging stations in the Hillsborough River.	94
18. Summary statistics for dissolved oxygen levels in the lower Hillsborough River.	97
19. Stormwater and baseline flow water quality data from three drainage basins to the lower Hillsborough River.	101
20. Primary productivity and chlorophyll a concentrations in the lower Manatee River.	118
21. Typical lentic aquatic vascular plants in the Tampa Bay watershed.	150
22. Typical lotic aquatic vascular plants in the Tampa Bay watershed.	150
23. Phytoplankton genera collected in the Alafia and Little Manatee Rivers.	153
24. Reproductive strategy differences between three species of mangrove found in the Tampa Bay watershed.	159
25. A comparison of nutritive values for various plant parts of turtlegrass in the Tampa Bay area.	166
26. Biomass values for seagrasses in the Tampa Bay area.	166
27. Changes in seagrass distribution in the Tampa Bay system from ca. 1940 to 1983, based on aerial mapping.	172
28. Changes in seagrass distribution in Sarasota County bay systems between 1948 and 1974.	173
29. Net primary production (NPP) of major estuarine habitat components	175
30. Major vegetational changes from savannah to cabbage palm forests on a coastal barrier island.	182
31. Characteristic species of the tropical hammock association on a coastal barrier island.	184
32. Species composition of the wetland subassociations on a coastal barrier island.	184
33. Water bodies containing *Hydrilla* within the Tampa Bay watershed.	192
34. Previous community associations of major or representative urban centers in the Tampa Bay watershed.	195
35. Structural and functional changes in natural communities in response to gross changes brought about by urbanization.	196
36. Revegetation and land-use possibilities for various landfill types.	201

Tables | Page
37. Occurrence of plant species in phosphate-mined areas of Florida. 202
38. Types of reclamation recently completed or approved for implementation in the central Florida phosphate district. 205
39. Major plant species associated with the generalized plant succession pattern on dredged material islands in Florida. 209
40. Summary of physiochemical soil parameters associated with vegetated community types on dredge spoil islands. 210
41. Dominant fish species, in order of abundance, collected in selected areas of Tampa Bay and the percentage of the catch represented by those species. 234
42. Amphibians and reptiles of biological significance. 239
43. Species and feeding strategies of forest birds using flatwoods in the Tampa Bay area 241
44. Number of wading bird nests by county in the Tampa Bay watershed from 1976 to 1978. 243
45. Birds designated as endangered, threatened, rare, or of special concern. 250
46. Marine mammals sighted or stranded in Tampa Bay and in Gulf of Mexico coastal waters between Pasco and Sarasota counties. 252
47. Mammals of special concern in the Tampa Bay watershed. 253

CONVERSION FACTORS

Metric to U.S. Customary

Multiply	by	To Obtain
millimeters (mm)	0.03937	inches (in.)
centimeters (cm)	0.3937	inches (in.)
meters (m)	3.281	feet (ft)
kilometers (km)	0.6214	miles (mi)
square meters (m^2)	10.76	square feet (ft^2)
square kilometers (km^2)	0.3861	square miles(mi^2)
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons (gal)
cubic meters (m^3)	35.31	cubic feet (ft^3)
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces (oz)
grams (g)	0.03527	ounces (oz)
kilograms (kg)	2.205	pounds (lb)
metric tons (t)	2205.0	pounds (lb)
metric tons (t)	1.102	short tons
kilocalories (kcal)	3.968	British thermal units (BTU)
Celsius degrees (°C)	1.8(°C) + 32	Fahrenheit degrees (°F)

U.S. Customary to Metric

Multiply	by	To Obtain
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet	0.0929	square meters
acres	0.4047	hectares
square miles	2.590	square kilometers
gallons	3.785	liters
cubic feet	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
short tons (ton)	0.9072	metric tons
British thermal units	0.2520	kilocalories
Fahrenheit degrees	0.5556(°F −32)	Celsius degrees

ACKNOWLEDGMENTS

The authors and editor wish to acknowledge the assistance of a number of people who contributed to the preparation of this document. Many public and private agency representatives cooperated with our search for published and unpublished data sources. Noteworthy among these were the staffs of Southwest Florida Water Management District, Hillsborough County Environmental Protection Commission, Tampa Bay Regional Planning Council, Marine Research Laboratory and Bureaus of Geology and Mine Reclamation in the Florida Department of Natural Resources, University of South Florida, New College at Sarasota, Florida Institute of Oceanography at St. Petersburg, the University of Florida's Center for Wetlands, Archbold Biological Research Station, Mote Marine Laboratory, and Sarasota County Environmental Services Laboratory.

We would also like to thank Robin R. Lewis of Mangrove Systems, Inc. for access to data and figures from their studies, and Ken Haddad, Bureau of Marine Resources of the Florida Department of Natural Resources; Eric Shaw and Mark Friedemann, Florida Department of Environmental Regulation; Robert R ogers, Mineral Management Service; Tom Kunneke, Martel Labs, Inc.; Lorna Patrick, Channing Bennett, and Beth Vairin of the U.S. Fish and Wildlife Service; as well as Loretta Wolfe and Bonnie Boynton for review and editing. Thanks also to Sue Lauritzen for review of and assistance with graphics.

We would especially like to thank Lawrence Handley and the late Millicent Quammen of the U.S. Fish and Wildlife Service for review, review coordination, and general assistance...and persistence.

Conventional graphics by Carol Knox

Computer graphics and layout by Steve Wolfe

AUTHORS

Richard D. Drew
State of Florida
Department of Environmental Regulation
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

N. Scott Schomer
107 Strawberry Patch
Chapel Hill, North Carolina 27514

Paul Johnson
State of Florida
Office of the Governor
Tallahassee, Florida 32399

Chapter 1. Introduction

1.1 Purpose and Organization

In recent years, development in west-central Florida has accelerated at an unprecedented pace, precipitating a rapid change in the environmental conditions that characterize the area. Widespread habitat destruction, sewage and industrial effluent discharge, ground and surface water diversion, and urban and agricultural runoff are but a few of the inevitable by-products of economic expansion that alter the regional ecology.

In the highly developed and rapidly changing coastal zone of west-central Florida, a fine line is emerging between vigorous economic growth and the preservation of the natural environment. Often, in deciding where this line is to be drawn, there is considerable uncertainty about the composition, interactions, and value of the living resources in an area. This report attempts to resolve some of the uncertainty and to assist in future resource development and management by providing an extensive review and synthesis of available literature on the ecology of the Tampa Bay drainage basin. In contrast to conventional literature reviews and syntheses, the report deliberately crosses disciplinary boundaries to focus on the manner in which the drainage basin functions as an integrated ecological system.

Chapters 2 through 4 describe the geology and physiography of the study area, the climate, and the characteristics of ground and surface waters. Chapter 5 describes plant communities and their succession. Chapter 6 deals with fish and wildlife, their habits, and their habitat preferences.

1.2 The Tampa Bay Watershed

This area (Figure 1) consists of the drainage basins and estuaries of Hillsborough, Tampa, Old Tampa, and Sarasota Bays, and the coastal provinces from the Anclote River south to and including the Manasota Peninsula. These drainage basins and their corresponding United States Geological Survey hydrologic units are as follows:

Hydrologic Unit	Geographic Areas
03100201	Sarasota Bay, Manasota Peninsula
03100202	Manatee River basin
03100203	Little Manatee River basin
03100204	Alafia River basin
03100205	Hillsborough River basin
03100206	Tampa Bay and coastal areas
03100207	Coastal Pinellas County and Anclote River basin (southern portion).

The drainage basin encompasses over 176 km of coastline and 7,700 km^2 of west central Florida.

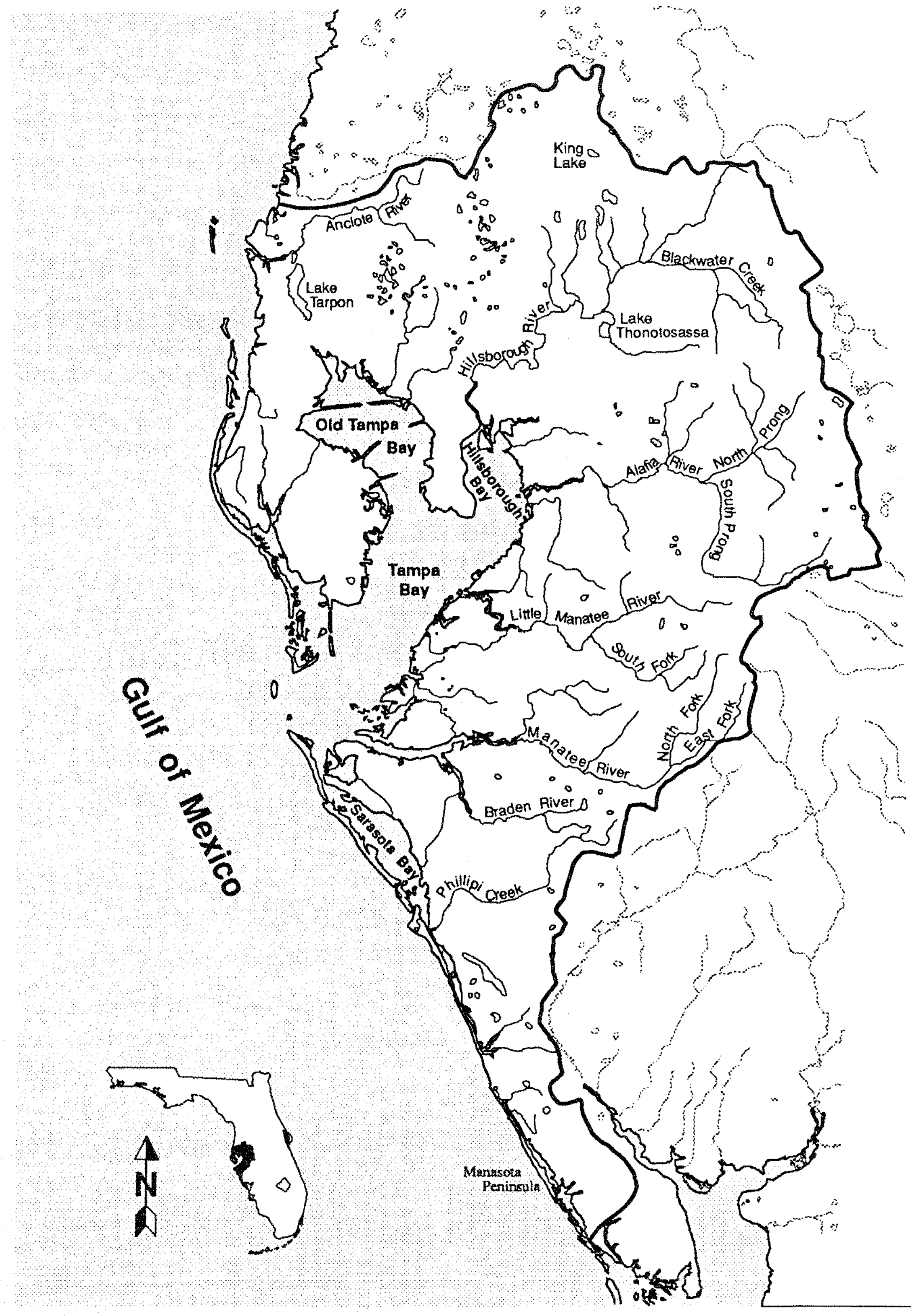


Figure 1. Tampa Bay watershed.

Chapter 2. Geology and Physiography

Richard D. Drew

2.1 Structure and Geologic Setting

The Tampa Bay watershed is underlain by 1,200 m (north-central Pasco County) to 4,000 m (southwest Sarasota County) of sedimentary rocks that overlie a pre-Mesozoic basement complex of crystalline, igneous, and metamorphic rock (Rainwater 1960; Hickey 1981a; Deuerling and MacGill 1981). The sedimentary rock consists of sandstone, anhydrite, and dolomite of Mesozoic age, and underlies limestone, dolomite, clay, and sand strata of the Cenozoic age (Menke et al. 1961; Lane 1980; Lane et al. 1980). The deep strata of Florida (Table 1) consist of sedimentary rock over the pre-Mesozoic basement rock. A thick and relatively homogeneous layer of carbonate materials found in the deep stratigraphy reflects a relatively long, stable period that was conducive to the formation and growth of a massive carbonate bank between the Gulf of Mexico and the Atlantic Ocean. Reefs formed near old shorelines, carbonate sediments were deposited in shallow coastal waters, and marine, brackish, and freshwater habitats contributed to the beds of marl, limerock, sands, and organics such as peats and mucks. When eustatic sea-level changes occurred, the accumulated sediment masses subsided to produce three major structural features that dominated the subsequent geology of the peninsula. These are the Suwannee Channel (Chen 1965), the South Florida Basin (Applin and Applin 1964), and the Peninsula Arch and Ocala Uplift (Puri and Vernon 1964). Figure 2 summarizes the stratigraphic relationships of the pre-Cenozoic Florida Peninsula. More detailed analyses of Florida's pre-Cenozoic strata may be found in Cooke (1945), Puri and Vernon (1964), Chen (1965), and Brooks (1973).

Table 1. Deep strata of Florida (after Rainwater 1960).

Division		Composition
Cedar Keys (lower)		Dolomite, anhydrite, limestone
Navarro		Dolomite, limestone, chalk
Taylor		Chalk, dolomite, limestone
Austin		Chalk and argillaceous limestone
Eagleford-Tuscaloosa		Shale, argillaceous limestone
Washita-Fredricksburg		Anhydrite dolomite and dolomite limestone
Glen Rose	(upper)	Dolomite, limestone and anhydrite
	(middle)	Anhydrite, some limestone and dolomite
	(lower)	Limestone, dolomite, anhydrite, some shale

From the late Cretaceous to upper Eocene, the Suwannee Channel (Figure 3) was a narrow waterway extending from southeast Georgia to Apalachicola Bay. For the entire Tertiary period, the channel represented a natural biological and sedimentological barrier that caused the development of a southern sedimentary province quite distinct from its northern continental counterpart. Northwest and north of the channel, a clastic facies composed of sandstone, shale, and limestone developed; south and southeast of the channel, the Florida Peninsula sedimentary province formed as a nonclastic facies consisting of

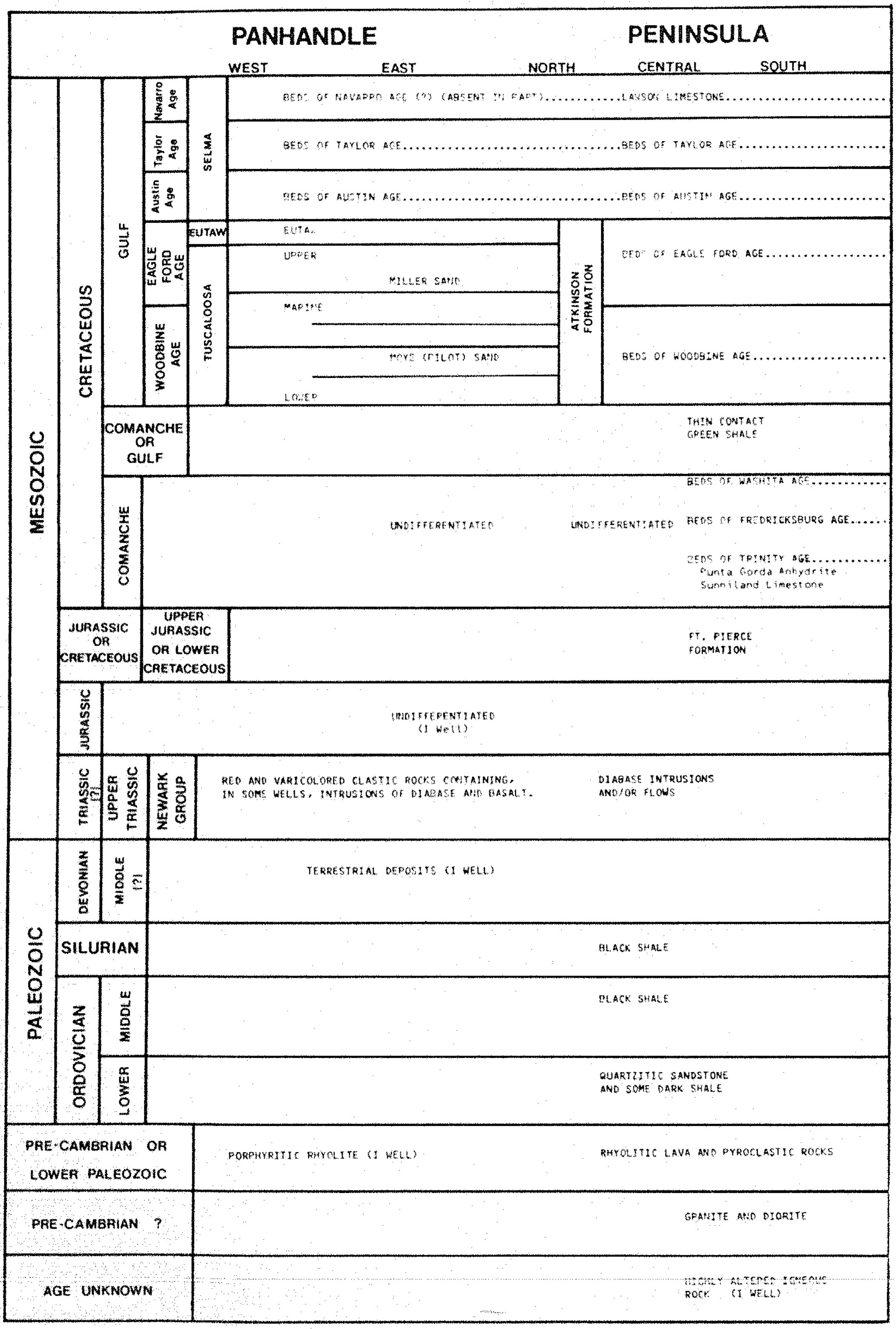


Figure 2. Stratigraphic nomenclature of Florida (after Puri and Vernon 1964).

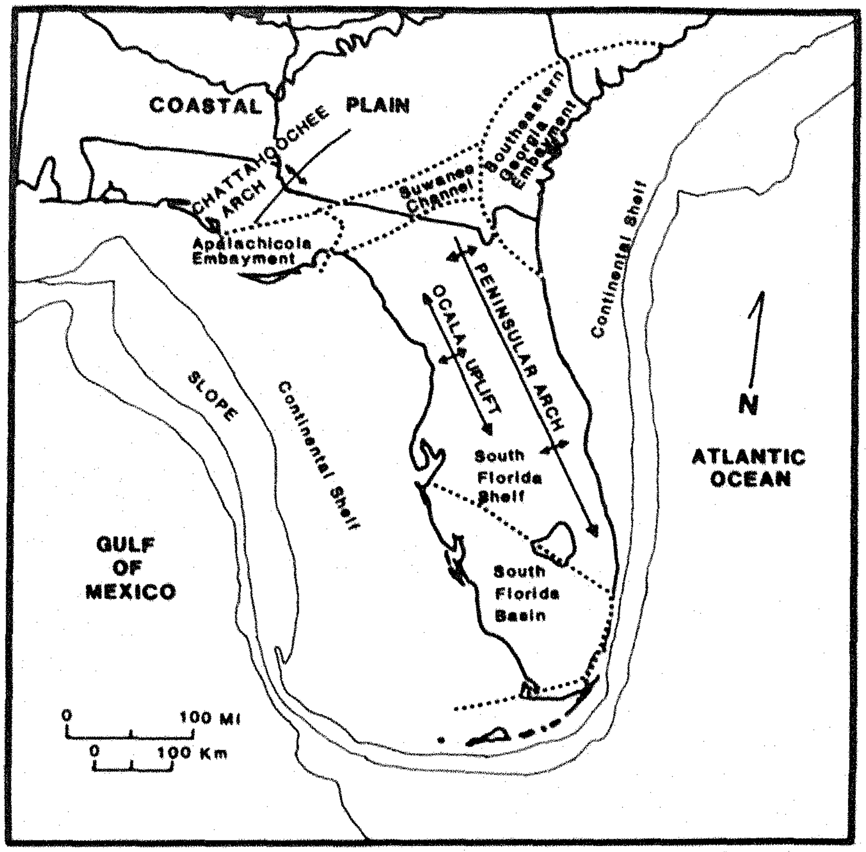


Figure 3. Major structural features of southeastern Coastal Plain (after Chen 1965).

carbonate, evaporites, and anhydrides (nonclastic sediments are those formed from biological and/or chemical actions, while erosion of preexisting rocks forms clastic sediments). The barrier effect of the Suwannee Channel gradually disappeared near the end of the Eocene epoch (Chen 1965).

During this time interval from the late Cretaceous to the upper Eocene, a downwarping took place in south-central Florida, forming the shallow structural South Florida Basin (Figure 3). The downwarping resulted from differential compaction within the basin throughout the Tertiary, and a late Tertiary tectonic uplift along the east and northeast margins of the basin to further tilt the basin in a northwesterly direction. This resulted in a subsequent thickening of the tertiary carbonate strata in a southwest direction into the basin (Menke et al. 1961; Applin and Applin 1965).

The Peninsular Arch, formed by regional tectonism and differential sediment compaction, "trends south-southeast and extends from southeastern Georgia through Florida into the Great Bahamas" (Chen 1965). Murray (1963) suggested that "the Arch is a mobile 'swell or welt' in the developing Gulf-Atlantic Coastal geosynclinal province." The Ocala Uplift is the late Tertiary flexure in central peninsular Florida, centered around the upper Eocene (Ocala) and the late middle Eocene (Avon Park) group (Chen 1965). Applin (1951) found no close structural relation between the Cenozoic Uplift and Paleozoic Arch.

Because of the downdipping of the South Florida Basin and the uplifting of the central peninsular anticline, Tertiary and Quaternary rocks that are several hundred meters deep in the Charlotte Harbor area are found as exposed surface sediments less than 150 km north in central Florida (Gorelick 1975). The Peninsula Arch, the "backbone of the Florida Platform" (Chen 1965), and the Ocala uplift are responsible for higher midstate elevations or ridges.

Pressler (1947) believed that anticlinal folds are the most prevalent structures in the South Florida Shelf. Although identified as secondary structural features, faults are prevalent within this area. Based on configuration of the surface of the submerged areas, Pressler and others have concluded that the Florida Peninsula is bounded on the south and east by major fault zones. These faults are probably due to continental plate movements, in addition to settling, compacting, and continuous downwarping of the sedimentary fill.

Tampa Bay sits on the southwest flank of the Peninsular Arch and just southwest of the Ocala Uplift. Fracture patterns in carbonate rock associated with the Ocala Uplift show preferred fracture orientation with azimuths from 301 to 325 just north of Tampa Bay (Hickey 1981a). Also, fracture patterns are found in the northern part of Pinellas County but absent in the southern part. They are also found in reduced numbers in southern Hillsborough County (Vernon 1951).

2.2 Tertiary Stratigraphy

Tertiary strata in the Tampa Bay watershed are illustrated in Table 2 and described in Appendix Table A–1.

2.3 Pleistocene Marine Terraces

In the Quaternary (Recent) Period, there were at least five major intervals of worldwide climatic cooling (glacial) and four warming (interglacial) periods, with many less pronounced climatic changes superimposed on each of the major periods. The majority of these climatic fluctuations (Figure 4) took place in the Pleistocene Epoch or "Great Ice Age," primarily from 2 million to 40,000 years B.P. (before present). Each interglacial period brought sea levels up as high as 60 m above present-day mean sea level (m.s.l.), and created a warm, tropical and subtropical marine environment conducive to sediment accumulation from resident biota (nonclastic) and weathered and eroded materials (clastic). With the onset of glacial periods, the sea levels receded. The accompanying aridity of terrestrial environments created episodes of erosion,

Table 2. Tertiary strata of the Tampa Bay watershed (after Hickey 1981a).

Erathem	System	Series		Formation
	Quaternary	Pleistocene		Surficial Sand
		Pliocene		Tamiami Formation
				Bone Valley Formation
		Miocene	Middle	Hawthorne Formation
			Lower	Tampa Limestone
	Tertiary	Oligocene		Suwannee Limestone
			Upper	Ocala Limestone
		Eocene	Middle	Avon Park Limestone
			Lower	Oldsmar Limestone
		Paleocene		Cedar Keys Limestone
Mesozoic	Cretaceous	Undifferentiated for this report		
Pre-Mesozoic		Undifferentiated for this report		

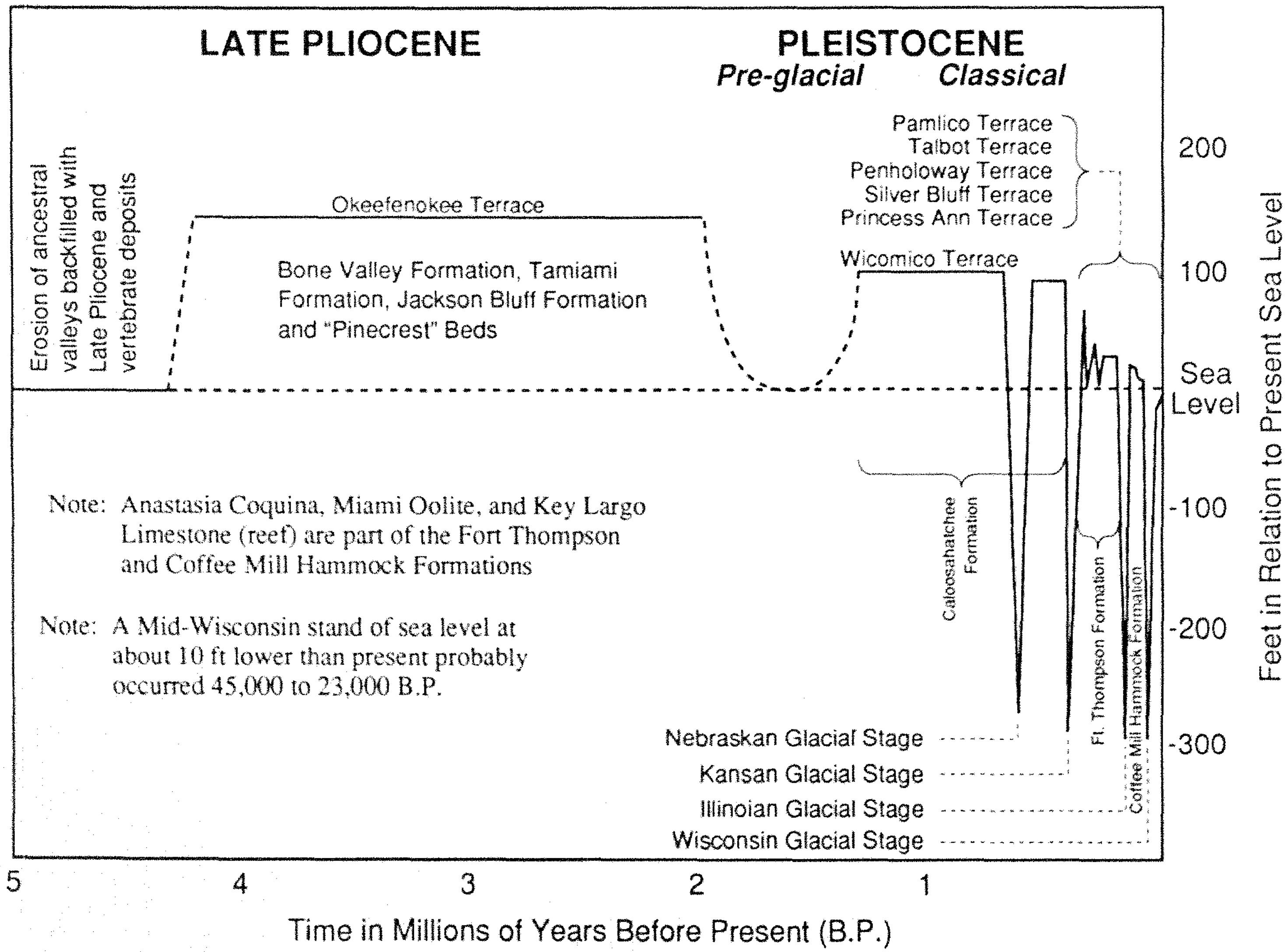


Figure 4. Glacial eustatic sea-level chronology for Florida (after Brooks 1968).

weathering, and the reworking of sediments of the Suwannee, Tampa, Hawthorne, and Bone Valley Formations, along shorelines of previously deposited materials (Roush 1985). The end result of these depositional, erosional, and reworking processes was the series of terraces and ancient shorelines that today typify the state's geomorphology. Each terrace represents (at least initially) a level plain having a slight seaward dip. The landward margin is the abandoned shoreline, which is generally marked by a low scarp line (Heath and Smith 1954). Belts of ancient terrace and shoreline sands occur in steplike formation typically running parallel to and rising inland from the Florida coastline. The highest represents the oldest deposit. The actual number and origin of terraces in Florida are the subject of much debate. Healy (1975) summarizes the history of terrace classification and origin and adopts for illustration the terrace terminology used by Cooke (1939, 1945).

Of the eight terraces and shorelines Cooke (1945) identified in Florida, six occur in the Tampa Bay watershed (Figure 5) (Healy 1975; Roush 1985). Altschuler and Young (1960) question the Pleistocene marine terrace origin of the surface sands in the central Florida uplands (more than 30 m above m.s.l.), particularly those associated with the Bone Valley Formation in eastern Hillsborough and Manatee counties and western Polk County. Instead, they suggest that the sands are a residual weathered product of the underlying Bone Valley Formation. This "residual" hypothesis is supported by later work indicating that much of the higher terrain (30–50 m) in Florida represents older Pliocene and upper Miocene age deposits and not terrace deposits associated with the advance of Pleistocene seas (Healy 1975).

The terrace-sand lithology and thickness vary slightly from one terrace to the next. The greatest difference is between the younger deposits (Pamlico) and the older, more inland deposits (Peek 1959; Altschuler et al. 1964; Knapp 1980). Generally, the sands are quartose, fine to medium grained (fine to coarse north of Seminole and NW of Largo), subangular to subrounded, well sorted, white to light tan or buff, and hardened to sandstone in places (Heath and Smith 1954; Peek 1959; King and Wright 1979; Knapp 1980; Sinclair 1982). The younger Pamlico deposits, found along the Tampa Bay shores and near coastal areas, consist of shell and limestone and range in thickness from zero to 6 m. Older deposits consist of quartz sand and some clay, and range in thickness from 0 to 20 m (Peek 1959; Knapp 1980). Terrace sands may contain organic debris, 1%–3% phosphate, silts (particularly in older deposits), iron oxides as stain, and clay in minor amounts (King and Wright 1979; Sinclair 1982).

2.4 Physiography

Tampa Bay and its drainage system lie within the sand-rich central or midpeninsular zone of Florida. The watershed is characterized by the following three physiographic districts and nine divisions (Figure 6) (Brooks 1982b) based on rock and soil type, geologic structure of the underlying rocks, geomorphic processes that constructed or sculptured the landscape, and relief.

A. Central Lake District
   1. Lakeland Ridge (Lakeland Ridge)

B. Ocala Uplift District
   1. Webster Limestone Plains (Western Valley)
   2. Dade City Hills (Brooksville Ridge)
   3. Hillsborough Valley (Zephyrhills Gap)
   4. Tampa Plain (Gulf Coastal Lowlands)

C. Southwestern Flatwoods District
   1. Bone Valley Uplands (Polk Uplands)
   2. De Soto Slope (De Soto Plain)
   3. Pinellas Peninsula (Gulf Coastal Lowlands)
   4. Barrier Island Coastal Strip (Gulf Coastal Lowlands, Lagoons and Barrier Chain)

The names in parentheses denote similar physiographic divisions described by Cooke (1939) and White (1970), who based their divisions primarily on features associated with higher stands of sea level.

2.4.1 Central Lake District

Sandhills that form the Lakeland Ridge extend from just southeast of Bartow to approximately 16 km north of Lakeland. This ridge lies along the northeastern edge of the watershed, reaches a maximum

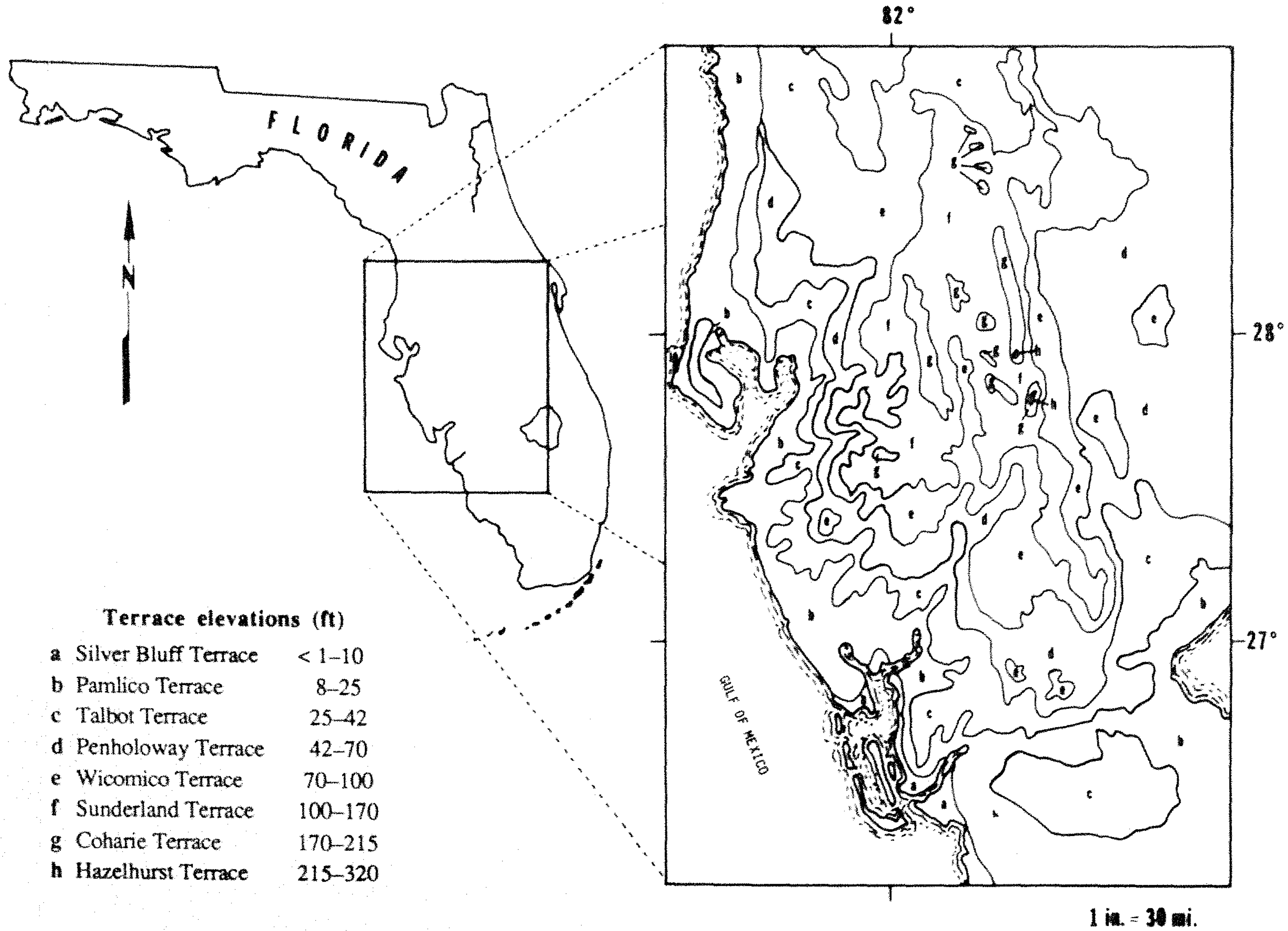


Figure 5. Terraces of west-central Florida (after Healy 1975).

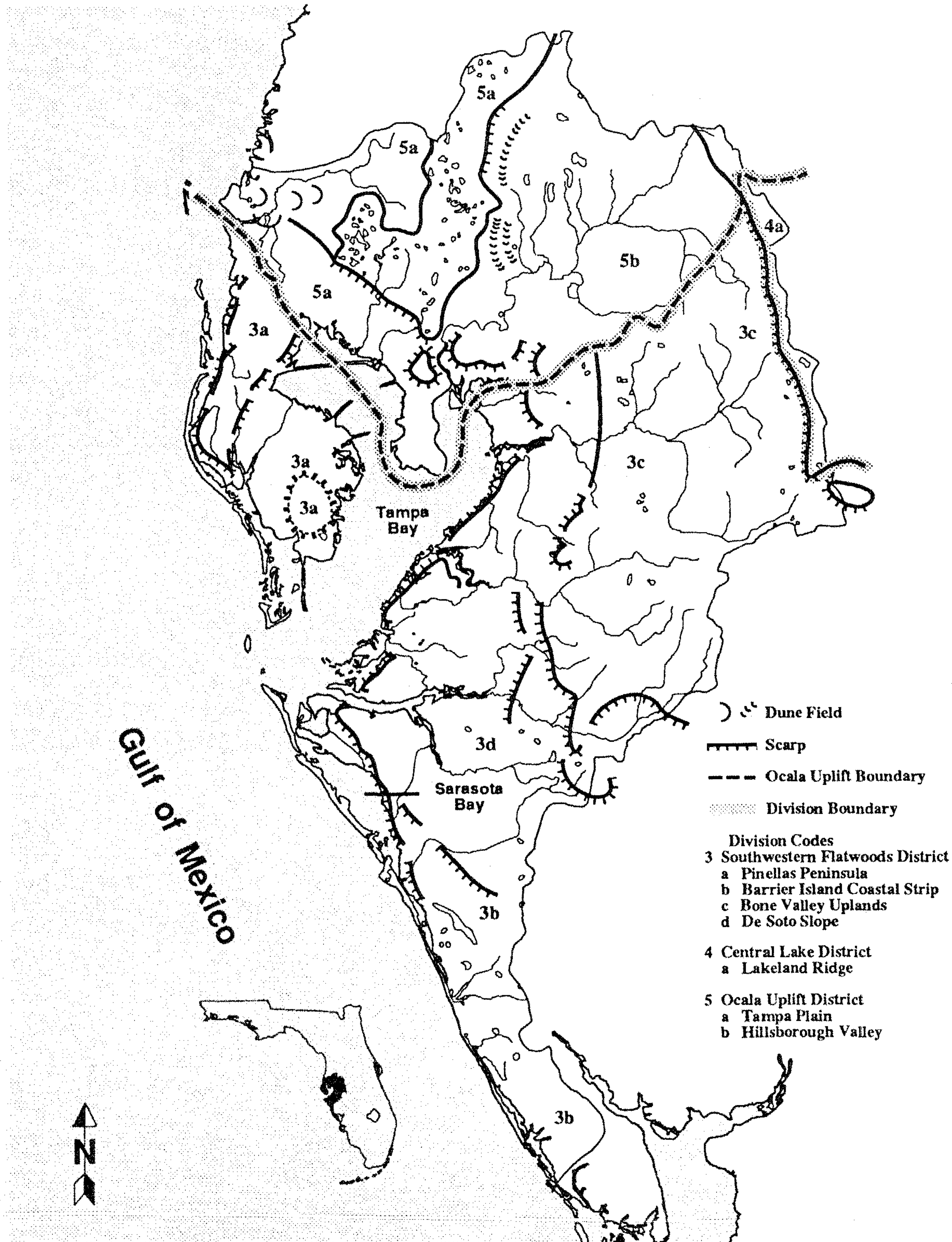


Figure 6. Physiographic division of the Tampa Bay watershed (after Brooks 1982b).

elevation (m.s.l.) of 80 m, and averages about 60 m. Very deep weathering of phosphatic silty sands has resulted in a thick, residual sand soil. The Lakeland Ridge is part of the Central Lake District of Florida and consists of uplifted limestones of the Floridan aquifer lying uncomformably below surficial sands. This region is sandhill karst with solution basins and is Florida's most active region for new sinkhole development. Internal drainage within the sandy hills serves as an important recharge route for the Floridan aquifer.

2.4.2 Ocala Uplift District

a. Dade City Hills. Only a small portion of the Dade City Hills extends into the northern Hillsborough River watershed, while most of this feature lies north of the study area. Dade City Hills is a spectacular ridge of high hills dissected from upper Miocene and silty sands. It is an active recharge and karst region where deep weathering has produced thick sand soils. Elevations range from 53 to 60 m and are quite irregular, with the highest areas to the south and west. Despite the height of the ridge, the irregular topography prevents the formation of persistent valleys; hence, the surface drainage pattern is not well defined.

The position of the ridge correlates well with outcrops of Bone Valley and Alachua Formations and exhibits relatively greater resistance to solution than the limestones that lie to the east and west. The Dade City Hills is part of the Ocala Uplift District, which encompasses all of the Big Bend area of Florida from Tampa Bay to Tallahassee and into south Georgia. Known as the "Lime Sink Region," the structure of the area is a broad uplift of early Tertiary limestones that occurred during the middle and late Tertiary. Much of the limestone is near or at the surface in the region.

b. Webster Limestone Plains. West of the Dade City Hills is an erosional plain of low relief, less than 30 m in elevation, and consisting of a northern dry plain and a southern wet plain. The wet plain is distinguished by a water table at or above the land surface and exhibits a landscape of swamps and wet pine flatwoods. The headwaters of both the Withlacoochee River and the Hillsborough River are formed in this region.

c. The Hillsborough Valley. The Hillsborough River watershed is an erosional basin where sluggish surface drainage is still dominant, but where there are many karst features from which much of the surficial clastic sediment has been removed. The greatest relief in the "plain" is found in the headwaters, where elevations reach 43 m above m.s.l.

d. The Tampa Plain. Along with the Hillsborough Valley, the Tampa Plain is the southernmost extension of the Ocala Uplift District. The plain covers much of western Hillsborough, northern Pinellas, and central and western Pasco Counties, and is characterized by lowland karst features related to the Tampa Limestone Formation (Figure 6).

Land-O-Lakes encompasses a plain at 15 to 25 m above m.s.l., with many small lakes, despite the presence of a moderately thick silty sand layer over the limestone. The area lies directly north of Tampa and extends into central Pasco County and then west to the gulf coast, taking on a crescent shape. The crescent's two cusps define the northern, eastern, and southeastern borders of the Odessa Flats or the Anclote River watershed. Flatwoods dominate the poorly dissected low sand plain of the Odessa Flats except near the coast, where some paleodunes persist.

South of both the Odessa Flats and the Land-O-Lakes lies the Lake Tarpon Basin, an erosional basin less than 10 m in elevation. This basin, which is partially backfilled with late Pleistocene sediments, extends along the northern shore of Old Tampa Bay from Tampa to Lake Tarpon.

2.4.3 Southwestern Flatwoods

a. De Soto Slope. This feature, along with the Bone Valley Uplands, Pinellas Peninsula, and Barrier Island Coastal Strip, is a member of the Southwestern Flatwoods District. The district is distinguished by Miocene and Pliocene sedimentary rock and sediments with nonexistent or thin Quaternary deposits. Wetlands and flatwoods characterize the area.

Brooks (1982b) defines the De Soto Slope as a plain that gradually slopes from a maximum of 30 m (Wicomico Terrace) to 9 m (Talbot Terrace). Surface drainage within this plain is frequently interrupted by cypress swamps underlain by clay deposits. The De Soto Slope gradually narrows in width from north to south. To the north, particularly northwest, the slope dramatically pinches to a narrow belt running parallel to the eastern Tampa Bay shoreline. Along this belt, terracing is more evident, as is the slope, and is best observed in the Alafia River watershed.

b. The Bone Valley Uplands. The headwaters of the Alafia, Little Manatee, and Manatee Rivers are contained in the Bone Valley Uplands, a poorly drained plateau underlain by deeply weathered sand and clayey sand of the Bone Valley Formation. Flatwoods with cypress heads and strands are common. The upland margin, which generally exceeds 40 m m.s.l. contains excessively drained thick white sands.

c. The Pinellas Peninsula. The peninsular foreland between the limestone coast to the north and the middle-Miocene to Recent clastic sediments southward along the coast is called the Pinellas Peninsula. Residual deeply weathered sandhills occur in the northern portion of the peninsula, and sand and shell of Plio-Pleistocene age underlie the central and southern lower terraces.

d. The Barrier Island Coastal Strip. The coastal strip is bordered to the west by lagoons and islands of Recent origin, and inland, to an elevation of approximately 6 m, by coastal flatwoods. The coastal areas, particularly islands and inlets, are very dynamic and prone to shifts in position, size, and shape.

In the southern half of the watershed, drainage to the coastal lagoons of Lemon Bay, Dona Bay, and Little Sarasota Bay is ill-defined and originates entirely from gently sloping lowlands. These lowlands roughly correspond to terraces of the Pamlico and Talbot shorelines. Cow Pen Slough to Dona Bay is the most distinct freshwater drainage system in this area. A number of low-lying lakes are found upland of these lagoons. Drainage from Phillippi Creek into Roberts Bay and the Bracken River into Sarasota Bay is restricted to a narrow belt of lowlands adjacent to the estuarine embayments.

Proceeding north, the Manatee, Little Manatee, and Alafia Rivers traverse a steeper and narrowing coastal strip. Still farther north, the Coastal Strip grades into the Hillsborough Valley.

Seaward of the mainland from Marco Island to Anclote Key is the Gulf Barrier Island Chain, which is a product of a plentiful terrigenous sand supply and sufficient wave energy to transport sand to and from the coastline. Miocene siliclastic rocks provide the local supply of sand for the high-energy coastal processes. The area's protruding coastline and steeper slope allow more of the Gulf of Mexico's wave energy to be expended on the shoreline and not dampened by extended shallow flats characteristic of low-energy coasts (e.g., Big Bend, Ten Thousand Islands). However, a great deal of the coastline has been stabilized during development.

e. Gulf-coastal estuaries and lagoons. A significant fraction of the watershed behind the barrier island chain is made up of submerged lands that are drowned river valleys and relict lagoons. Together, these form the Tampa Bay estuary and the narrow line of nearly continuous lagoons, including (from north to south) Palma Sola, Sarasota, Roberts, Little Sarasota, Dona, and Lemon Bays.

The Tampa Bay estuary is a roughly Y-shaped system 55 km long and 15 km wide, covering approximately 900 km^2 and having a shoreline 340 km long (Olson and Morrill 1955). The estuary (Figure 7) is divided into Old Tampa, Hillsborough, Middle Tampa, Lower Tampa, Boca Ciega, and Terra Ceia Bays, the Manatee River, and Anna Maria Sound (Olson and Morrill 1955; Simon 1974; Lewis and Whitman 1985). The Tampa estuarine system is crisscrossed and modified by four major causeways and an extensive network of dredged channels (Figure 7). The disposal of dredged materials over the years has resulted in the formation of numerous spoil "islands" in the estuary. Table 3 presents a summary of morphometric features of the Tampa Bay estuary.

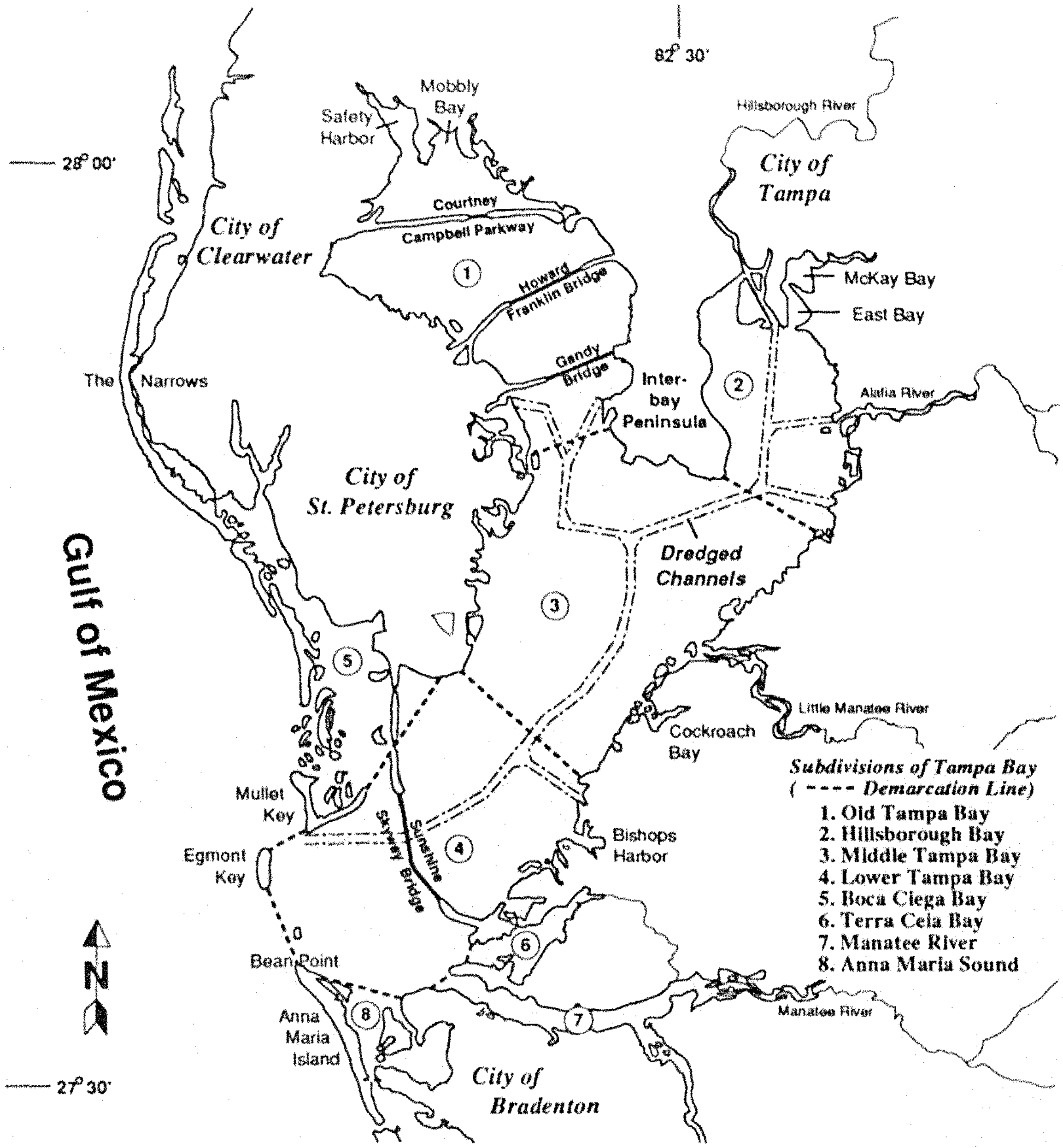


Figure 7. Tampa Bay estuary physiographic divisions (after Lewis and Whitman 1985).

2.5 Recent Sediments and Soils

Soils are described and classified based on measurable and visible differences in surficial soil profile characteristics down to a depth of 2 m (Carlisle 1982a). The profile is composed of one or more soil horizons and is characterized by the nature of the parent rock, weathering processes, the transport mechanisms involved, biology, and stage of decomposition. In central and south Florida, the soils or uppermost sediments are geologically young and are surficial (Estevez 1981); that is, the soil profiles

Table 3. Morphometric features of Tampa Bay estuary and some of its bays (after Simon 1974).

Morphometric feature	Old Tampa Bay	Hillsborough Bay	Tampa Bay	Boca Ciega Bay	Tampa Bay Estuary
Length (km)	21	14.5	—	—	56
Average width (km)	3-10	7	11-16	—	16
Area (km^2)	203	105	519	56	882
Volume (km^3)	—	—	—	—	2.862
Maximum depth (m)	11	5.5	12.8	—	17.4
Mean depth (m)	—	—	—	—	3.4
Modal depth (m)	2.4	2.1	4.3	0.6	3
Length of shoreline (km)	87	59	159	—	—
% of total system (area)	23	12	59	6	100

reflect changes in sediment types rather than development of chemically or mechanically produced horizons. For example, one is more likely to observe sands layered over marsh-produced calcareous marl, particularly in the coastal regions. Apart from the common quality of "newness" of Florida's peninsular soils, each soil is a unique fingerprint of the preexisting conditions; i.e., parent materials. Soils are organized into a taxonomic classification system by the U.S. Soil Conservation Service (SCS) in which each soil is categorized by order, suborder, great group, subgroup, family, and soil series (Collins and Caldwell 1982). Nationwide, there are 10 orders of soil, of which 7 are found in Florida. Entisols, Spodosols, Ultisols and Histosols dominate the State's landscape. Table 4 presents a general description for each of the 10 orders and their relative abundance in Florida. The distribution of four major soil orders in Florida is illustrated in Figure 8. The figure indicates only the dominance of a soil order in an area. For example, Histosols (peats and mucks) dominate the regional soil groups only in an area south of Lake Okeechobee, but are found in 42 of 67 Florida counties.

Soil information in the Tampa Bay watershed is available in the *Florida General Soil Atlas* and the County Soil Survey. The *Florida General Soil Atlas* presents a soil-association map for each county in the State (DSP 1975a,b). A soil association is a group of one or more major soils and at least one minor soil that are found naturally together to form a distinctive landscape. These soil association maps provide a statewide coverage of soil types, but lack the detail required for site-specific work, as only the dominant soil types are reported. However, for some areas of the State, the atlas may be the only current and areally comprehensive soil data base available (Carlisle 1982b). The other, more detailed, source of soil data is the SCS County Soil Surveys. These are at various stages of completion in the State. Soils, at the soil series level, are delineated on 1:20,000-scale photomosaics. A description of each soil series is provided, as well as associated soil types, flora, drainage characteristics, and suitability for various land uses (Carlisle 1982b).

In the Tampa Bay watershed, all six counties have published surveys, the latest, Polk County, in 1986 (USDA 1981). Although these surveys appear to provide an excellent soil data base, two of the five published surveys (Hillsborough and Sarasota Counties) were completed during the late 1950's (USDA 1958, 1959). Since that time, the survey methodology has been changed significantly to modify the taxonomic structure and soil series names, include previously undescribed soil series for wetland areas, and describe alteration of existing soils by development.

Table 4. Soil Conservation Service soil orders (after Collins and Caldwell 1982).

Order name	Principal diagnostic property(ies) (simplified definitions)
Alfisols[a]	Mineral soils, relatively low in organic matter, relatively high base saturation; an illuvial horizon of silicate clays; moisture available to mature a crop.
Aridisols[b]	Mineral soils, relatively low in organic matter; inadequate moisture to mature a crop without irrigation in most years, some pedogenic horizons.
Entisols	Mineral soils, weak or no pedogenic horizons, no deep wide cracks in most years.
Histosols	Organic in more than half of upper 80 cm.
Inceptisols[c]	Mineral soils, some pedogenic horizons and some weatherable minerals, moisture available to mature a crop in most years, no horizon of illuvial clays, relatively low in either organic matter or base saturation, or in both.
Mollisols[c]	Mineral soils, thick dark surface horizon, relatively rich in organic matter, high base saturation throughout, no deep wide cracks in most years.
Oxisols[b]	Mineral soils, no weatherable minerals; inactive clays; no illuvial horizon of silicate clays.
Spodosols	Mineral soils, an illuvial horizon of amorphous aluminum and organic matter, with or without amorphous iron.
Ultisols	Mineral soils, an illuvial horizon of silicate clays; low base saturation, moisture available to mature a crop in most years.
Vertisols[b]	Clayey soils; deep wide cracks at some time in most years.

[a] Widely interspersed areas; [b] None recognized in Florida; [c] Minor occurrence.

Even in the 1972 Pinellas County soil survey, the wetland soils were generally classed as swamp or marsh. Only Pasco and Manatee (revised) County surveys provide a current and complete inventory and analysis of the soils. Revision of some of the older surveys is under way, including remapping of Hillsborough County. Another valuable informational source on regional soils is an annual publication, *Proceedings of the Soil and Crop Society of Florida*, which provides a scientific forum for the most recent soil research in the State.

Sands and organics dominate the soils in the watershed and much of the coastal-plain region of Florida. Such soils are a product of the wet, semitropical climate; the flat terrain; and the short geologic time the parent materials (sands) have been exposed to the soil development processes (USDA 1983). High rainfall, short, mild winters, and high summer temperatures encourage rapid oxidation and leaching of deposited

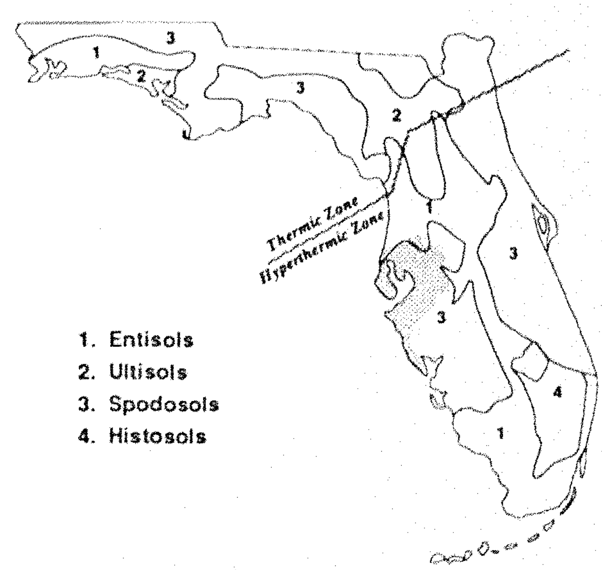


Figure 8. Distribution of the major soil orders in Florida (after Goodins et al. 1982).

organic materials in the poorly drained sandy soils. In partially or completely inundated wetland areas, leaching is reduced and the high productivity of a subtropical climate causes rapid generation of organic materials and a buildup of peat and/or muck. The relatively short time surface sediments have been exposed to soil-making processes has generally resulted in an absence of developed soil horizons in the watershed and a predominance of relatively poorly developed and/or geologically young soils, such as Spodosols, Entisols, and Histosols (DSP 1975a,b; USDA 1982, 1983).

The Tampa Bay watershed is dominated by Entisols along the more elevated eastern and northern margins, and by Spodosols elsewhere. Entisols are mineral soils that have not formed definite soil horizons, or have only rudimentary horizons. These soils are typically sandy, acidic, very poorly to excessively drained (depending on water-table depth), and have a low cation-exchange capacity (CEC). The CEC affects soil ability to retain various ions, including needed plant nutrients. The higher the CEC the greater the soil's capacity to retain ions. Soils with low CEC (e.g., sands) limit productivity unless storage sites such as organic topsoils (e.g., peats and mucks) or a low permeable horizon (e.g., a spodic horizon which "catches" the leached ionic materials) develop to reduce the loss of nutrients and minerals.

Spodosols, the dominant soil order in the watershed, exhibit a spodic horizon or subsurface layer that contains an accumulation of organic matter and precipitated oxides of aluminum and iron. Soils overlying this organic layer are generally well-leached sands that exhibit a low CEC and base saturation and are moderately to strongly acidic. The low pH is a result of the neutrality and poor buffering characteristics of the parent material (terrace sands), the presence of surficially decomposed organic materials, and the natural acidity of rain. Pine flatwoods are well suited for these soils; their litter is low in metallic ions and has a low neutralization potential. Both characteristics promote soil acidity. Spodic soils range from well drained to very poorly drained, dependent on water depth and the degree of organic pan (hardpan) development at the spodic horizon. A well-developed hardpan substantially slows or blocks the downward movement of water, forcing the water to move laterally. Because these soils are typically found in areas with little or no slope, lateral movement is slow, and the waters back up, causing seasonal ponding. Intensive drainage networks are constructed in these areas to make them suitable for a variety of agricultural purposes. Soils of this order are found in every county in the watershed and dominate in all but Polk County (DSP 1975a,b).

Histosols are peat and muck organic substrates formed of partially decomposed plant material and a mixture of inorganic sand, clay, and silt. While this soil order is not a dominant substrate in the watershed, it frequently occurs in wetlands. Water inundating the wetlands creates an anaerobic layer at the sediment-water interface that promotes an accumulation of partially decomposed organic materials.

The difference between the two organic forms, peat and muck, is the degree of decomposition. Peat is a fibrous organic substrate only slightly altered from the original plant structure and retains identifiable plant parts (e.g., leaves, stems, seeds, and roots). The parent material is local (autochthonous), and the ash and inorganic content is typically low. In contrast, muck is a thoroughly decomposed, fine-grained, nonfibrous, organically rich substrate that is high in ash content and is often mixed with inorganic sedimentary material. Source material for muck may be autochthonous or allochthonous (transported from outside the decomposition site).

The origin, structure, chemical qualities, decomposition rates, environments, and patterns, as well as other characteristics of organics are well studied, particularly in south Florida. Davis (1946) provides an extensive review of peat deposits in Florida including information on their nature, origin, type, and composition. This work is supplemented by Cohen and Spackman's (1974) description of south Florida peats and Stone and Gleason's (1976) and Kropp's (1976) work in the Corkscrew Swamp Sanctuary.

The major peat deposits in the watershed are located in the riverine swamps of the Bracken, Manatee, Anclote, Little Manatee, and Hillsborough Rivers; Lake Thonotosassa; and the coastal mangroves and saltwater marshes (Davis 1946; Reynolds 1976; Herwitz 1977; USDA 1958, 1982, 1983).

Some small deposits are typically found in the numerous swamps, marshes, ponds, and sloughs, and along some stream margins. Regionally, organic deposits range in depth from a few centimeters to 3 m and are high in carbon and nitrogen, but low in other nutrient forms (e.g., phosphorus) (Davis 1946). The type and condition of peat is dependent on water depth, pH, hydroperiod, parent vegetation, topography, thickness, degree of decomposition, characteristics of the underlying sediment, inorganic content, and presence of incorporated layers such as marl, shell, limerock, or sand. Peats are most often classified by their parent material, e.g., mangrove peat, *Conocarpus* (buttonwood) peat, *Spartina* peat, and others (Cohen and Spackman 1974). Mangrove peat, which forms in the southwestern coast's tidal area, usually retains much more of the original plant structure than its freshwater and brackish-water counterparts. It also exhibits a greater ash content caused by the intermixing of shells and sands transported into the swamps by tides and storm waves.

Soils associated with the barrier island group of the Tampa Bay watershed are commonly mixtures of the region's three dominant soil orders, with the sandy Entisols dominating the group. Sediment from the Pleistocene terraces, mostly Pamlico sands and reworked marine sediments, have been molded into the existing islands by erosion and deposition (Brooks 1973; Missimer 1973; Herwitz 1977; Morrill and Harvey 1980; Estevez 1981). The characteristics of sediments common to the barrier islands of the region are illustrated in Figure 9. Beach and dune sand and

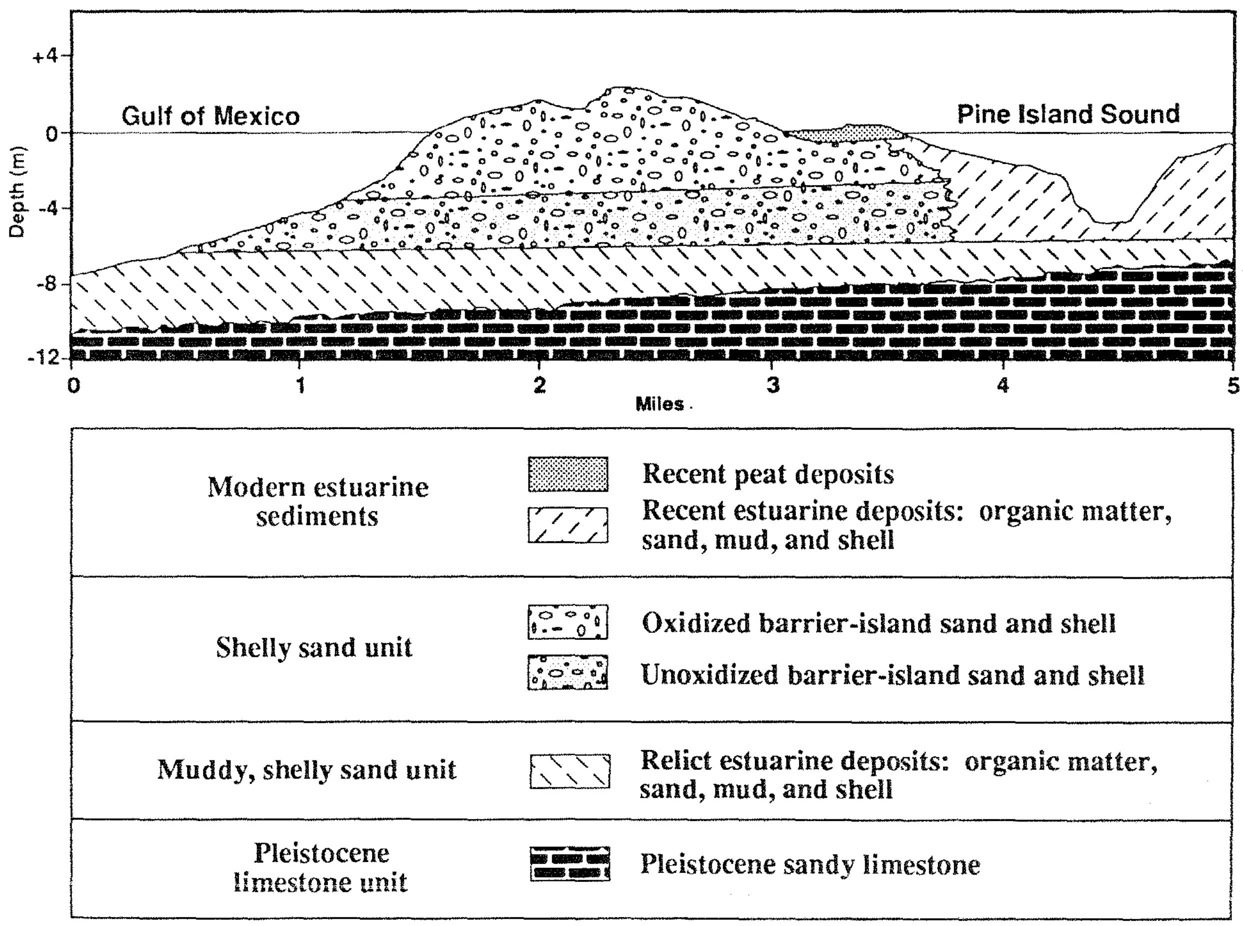


Figure 9. Recent sediment cross section of Sanibel Island (after Missimer 1973).

shell normally prevail on the western island faces, where greater tidal, wind, and current forces are exerted. These tan-colored, well-oxidized sediments are composed of mixed carbonate shell material and fine to medium-grained quartz sand. Sands include heavy minerals, phosphorite, shell materials, and organics. South of Tampa Bay, sand, shell, and clay content increases lagoonward and only the gulf-facing side has relatively thick sequences of sand. Gulf beaches south of Sarasota, particularly near Venice, contain appreciable phosphorite in sizes up to gravels (Knapp 1980). On the eastern side, a quieter environment encourages the deposition of mangrove forest and *Spartina* marsh peats. In the sheltered bays, lagoons, and harbors, a muddy-shelly sand is found that varies in its composition (fine-grained quartz sand, silt,clay, shell material, and organic matter), depth, and thickness (Missimer 1973; Estevez 1981). Lagoons are bounded by a medium to fine sand and silt lithology north of Tampa Bay and by sand, shell, and clay to the south (Knapp 1980).

Soil types on the barrier islands are known largely through the work of Herwitz (1977)—Cayo Costa, Morril and Harvey (1980)—North Captiva, and the U.S. Department of Agriculture, SCS (1983)—Manatee County. Soils series that are generally representative of barrier island soils in the watershed are presented in Table 5 and are further described by Reynolds (1976).

Florida soils have generally developed from a mantle of noncalcareous sands and clays overlying limestone deposits. The sand and clay mantle varies in thickness, but, in the watershed, generally thins in the coastal lowlands and wetlands. Soil series found in close association with underlying marls or limestone often exhibit alkaline qualities even under anaerobic conditions (e.g., Kesson, Parkwood Variant, Manatee, and Felda [USDA 1983]). Common or representative soil associations in the watershed are presented in Figure 10 (Caldwell and Johnson 1982). The lowland and inland flatwood soils are dominated

Table 5. Typical soil types on west-central Florida coastal barrier islands (adapted from Herwitz 1977; Morrill and Harvey 1980; Estevez 1981; USDA 1982, 1983).

Soil type	Local soil series	Characteristics
Quartzipsamments[a]	Canaveral Fine	Most abundant, moist mineral soils, sand and shell fragments with thin accumulation of organic materials at or near the surface; moderate to well drained; coastal strand, savannah, cabbage-palm forest, tropical hammock, Australian-pine forest; beach soil is similar but has higher shell content and is disturbed by wave action.
Psammaquents[a]	Captiva	Poorly drained, but very permeable; sandy texture, gray; associated with shallow sloughs and seasonally wet depressions; marshes, wetlands in general, cabbage-palm forests (in depressions).
Sulfaquents[a]	Kesson	Poorly drained mineral soils, like Captiva but has sulfidic horizon (associated with salt-water intrusion) close to surface; found on bay fringes associated with salt flat and mangrove communities; *Batis maritima* and *Sesuvium portulacastrum* indicator plants.
Sulfihemists[b]	Wulfert	Organic soil; muck, decomposed roots; associated with flat, tidally-flooded mangrove forests along shallow backwaters on island baysides.
Medisaprists[b]	Terra Ceia	Organic soil, muck, associated with hardwood swamps.
Various	Arents	Well-drained, human-disturbed soils without discernible horizons, e.g., Indian shell mounds.

[a] Entisols—Mineral soils lacking pedogenic horizons (see Table 4).
[b] Histosols—Organic soils saturated most of the year (see table 4).

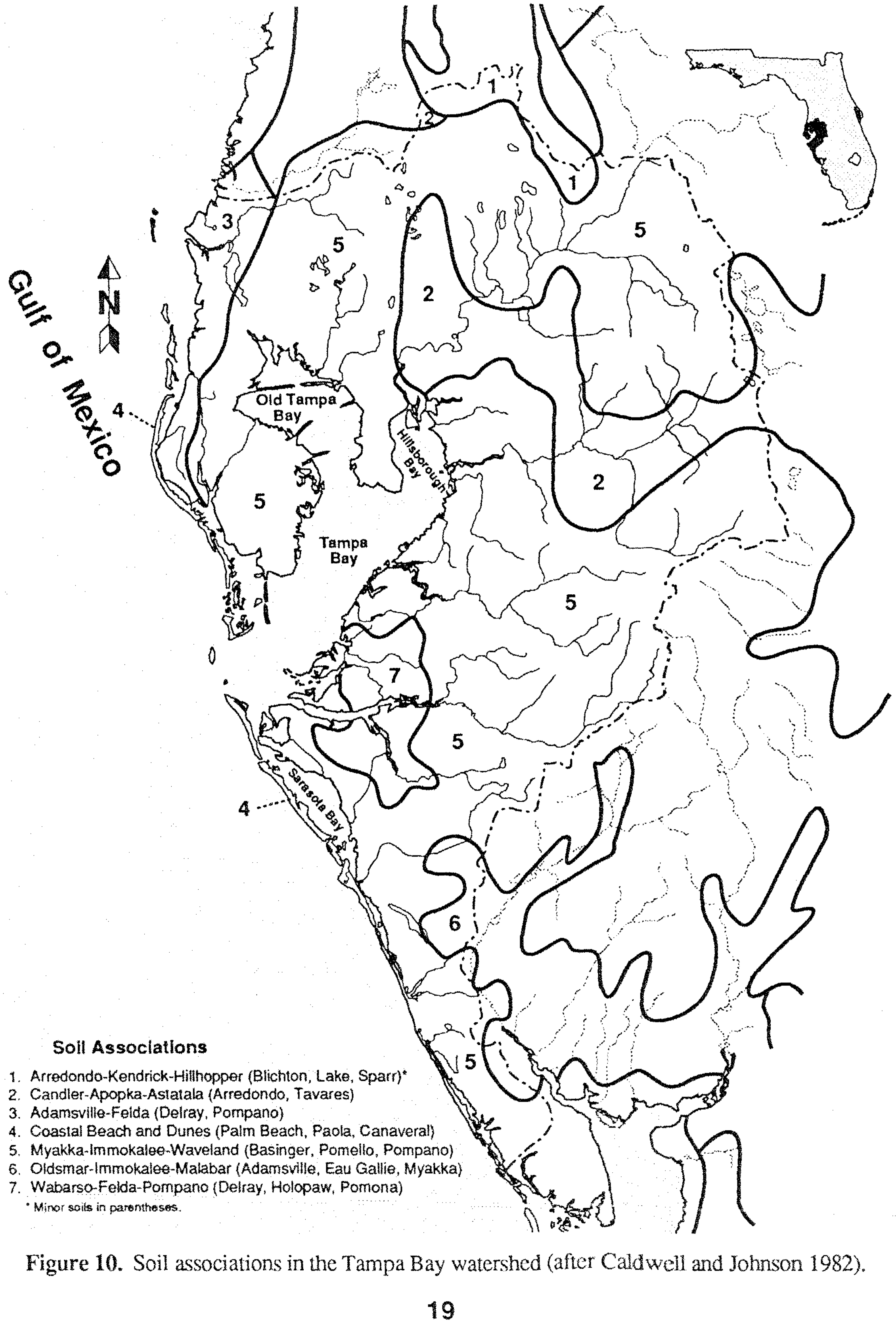


Figure 10. Soil associations in the Tampa Bay watershed (after Caldwell and Johnson 1982).

by Spodosols and Entisols soil orders. The single spodic soil association of Myakka–Waveland–Cassia, for example, represents 33% of Manatee County soils. Ridge, knoll, and hill soils are generally sandy and well-drained Entisols, often associated with regional terraces and prehistoric dune ridges.

An individual soil series can be associated with one or more plant communities, since plant communities reflect several factors, including drainage conditions, chemical and mineral composition, and climate. Table 6 presents common plant–soil series relationships for the watershed.

Arent soils (i.e., soils disturbed by human activity to a point of altering the soil profile) are found in association with mine pits, dredge-and-fill activities, and other urban developments. Phosphate mining in

Table 6. Plant community and soil series associations in the Tampa Bay watershed (after USDA 1958, 1972, 1981, 1983; Eco Impact, Inc. 1979; Carlisle et al. 1981; Carlisle and Brown 1982).

Plant community	Soil series associations
Pine flatwoods	Myakka, Eau Gallie, Waveland, Immokalee, Pomona, Ona, St. Johns, Wabasso, Zolfo, Wauchula.
Pine and cabbage palm forests	Adamsville, Felda, Pinellas, Bradenton, Hallandale, Parkwood Variant, Aripeka.
Prairies	
A. Saw palmetto	Myakka, Immokalee.
B. Seasonally wet	Pompano, Delray, Basinger, Placid, Sellars.
Scrub forests	
A. Sand pine scrub	Cassia, Duette, Orsino, Pomello, Astatula, Paola, St. Lucie.
B. Longleaf pine and turkey oak hills	Orlando, Tavares, Candler.
Hammock forests	Felda-Palmetto, Bradenton, Parkwood Variant, Aripeka (along elevated margins), Paisley (Variant Sand), Arredondo.
Freshwater hardwood and cypress swamps	Chobee, Tomoka, Okeelanta, Terra Ceia, Aripeka (along elevated margins), Sellars, Canova, Anclote.
Freshwater marshes	Delray, Floridana, Gator, Manatee, Tomoka, Okeelanta, Terra Ceia, Sellars, Zephyr.
Tidal marshes	Myakka (tidal), Okeelanta (tidal), Gator, Homosassa, Weekiwachee, Lacoochee, Pahokee, Tisonia, Aripeka (along elevated margins).
Mangrove swamps	Estero, Wulfert, Kesson, Bessie, Weekiwachee, Hallandale (variant), Peckish.
Coastal beaches/dunes	Canaveral, Satellite.
Floodplains and sloughs	Delray, Felda, Palmetto, Pineda, Basinger, Pompano, Anclote, Canova, Okeelanta, Chobee.
Cypress domes and small grassed ponds	Delray, Floridana, Gator, Tomoka, Basinger, Anclote, Placid, Sellars, Zephyr, Okeelanta-Terra Ceia.

western Polk, eastern Hillsborough, and northeastern Manatee Counties has created and continues to create large areas of arent soils. The disturbed soils occur as mixed overburden (substrate overlying the phosphate matrix), quartz sand tailings used as pit fill or to cap clay settling areas, and, the most pervasive, consolidated clay slimes (Schnoes and Humphrey 1980; U.S. Bureau of Mines 1982). Urban activities, particularly those requiring extensive dredging and filling, have altered much of the coastal lowland soil in Pinellas, Hillsborough, Manatee, and Sarasota counties (Estevez 1981; USDA 1983). In 1973, approximately 15% of Pinellas County soils were classed as made land or urban land (DSP 1975a). About 730 ha of Manatee County barrier islands are arent soils classed as Canaveral sand—filled or organic substratum created from dredged sand and shells deposited on tidal swamp or marshes (USDA 1983).

Estuarine sediments of the Tampa Bay watershed consist primarily of quartz sand and calcareous shell material (Pyle et al. 1972; Brooks 1973; Mote Marine Lab 1975). The sands, and to some extent, the calcareous material, result from a backfilling of offshore sediments that began about 8,000 years ago. The offshore sediments were, in turn, an earlier product of erosion from the Tampa Bay watershed river valleys, exposed during a lower sea-level stand (Stahl 1970; Brooks 1973). Pliocene and Miocene marl, limestone, and sand underlie unconsolidated Holocene deposits that are generally 12 to 15 m thick in Tampa Bay, but increase to as much as 30 m in channels. Shallow (less than 1.8 m deep) sand flats gradually slope to channels which exceed 5 m near the bay axis (Figure 11). The scoured Egmont Channel at the mouth of Tampa Bay reaches an 18 m depth (Brooks 1973). In the last century people have made numerous alterations in the smooth bottom topography, including enlargement of natural channels and creation of new channels, spoil areas, turning basins, and causeways. Sand-sized particles dominate the estuary bottom sediments, except in Hillsborough Bay, where silt is abundant, and in high velocity channels, where coarser sediments are found (Figure 12). Silts and other fines also increase significantly in association with human modifications. For example, silt and clay fractions in the Anclote River estuary rarely exceed 1%, but in the adjacent Port Tarpon Marina, silts alone account for more than 3% of the sediment composition (Pyle et al. 1972). The typically homogeneous vertical composition of the sediment's top 0.5 m in Tampa Bay is caused by mixing by currents (tidal and wind driven) and benthic fauna bioturbation. Sediments of the shallow flats along bay margins are composed of an almost pure fine quartz sand. Calcium carbonate content, mainly fragments of mollusk shells, increases along the slope bordering the channels near the bay mouth (Figure 13). Kyanite, staurolite, and sillimanite are the more commonly observed heavy minerals. Clay minerals such as kaolinite and montmorillonite are rare (Goodell and Gorsline 1961; Pyle et al.1972).

Stormwater discharge from areas of intense urban development contribute large quantities of suspended solids and significantly increase the nearshore sediment's percentage of organic matter. The increase is most pronounced in areas without significant tributaries (e.g., creeks, sloughs, rivers), such as the Intracoastal Waterway, Dona and Roberts Bay, eastern portions of Sarasota Bay, Old Tampa Bay, and southeast Pinellas County. Waterway sediment composition is affected by instream hydrologic modifications (e.g., channelization, saltwater barriers, control structures, reservoirs) and the upland land uses (Lopez and Michaelis 1979; Lopez and Giovannelli 1984). Cow Pen Slough, for instance, exhibits a low level of organic matter except where it runs near a county landfill (Mote Marine Lab 1975).

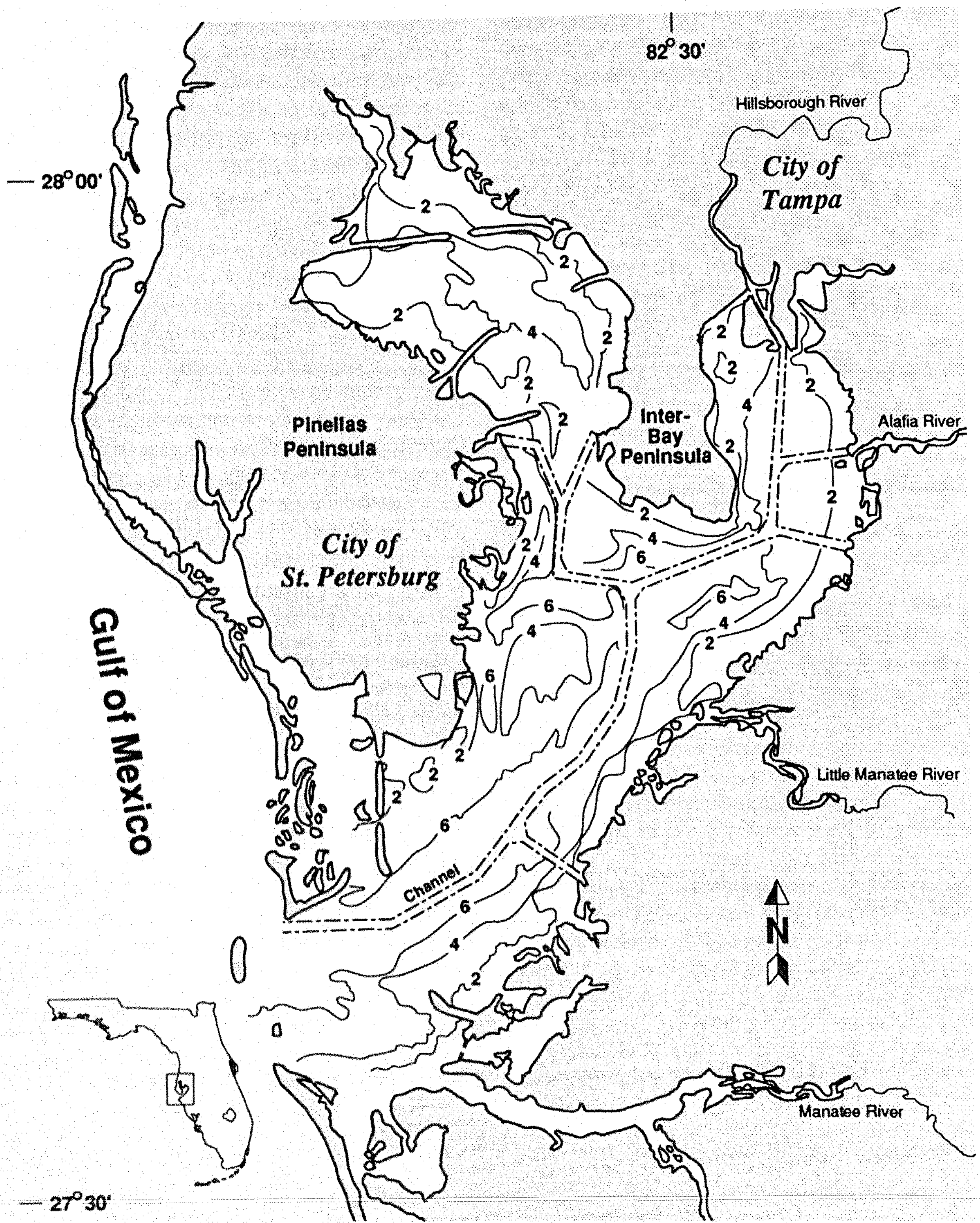


Figure 11. Bathymetry of Tampa Bay (ft) (from NOAA National Ocean Survey chart #11412).

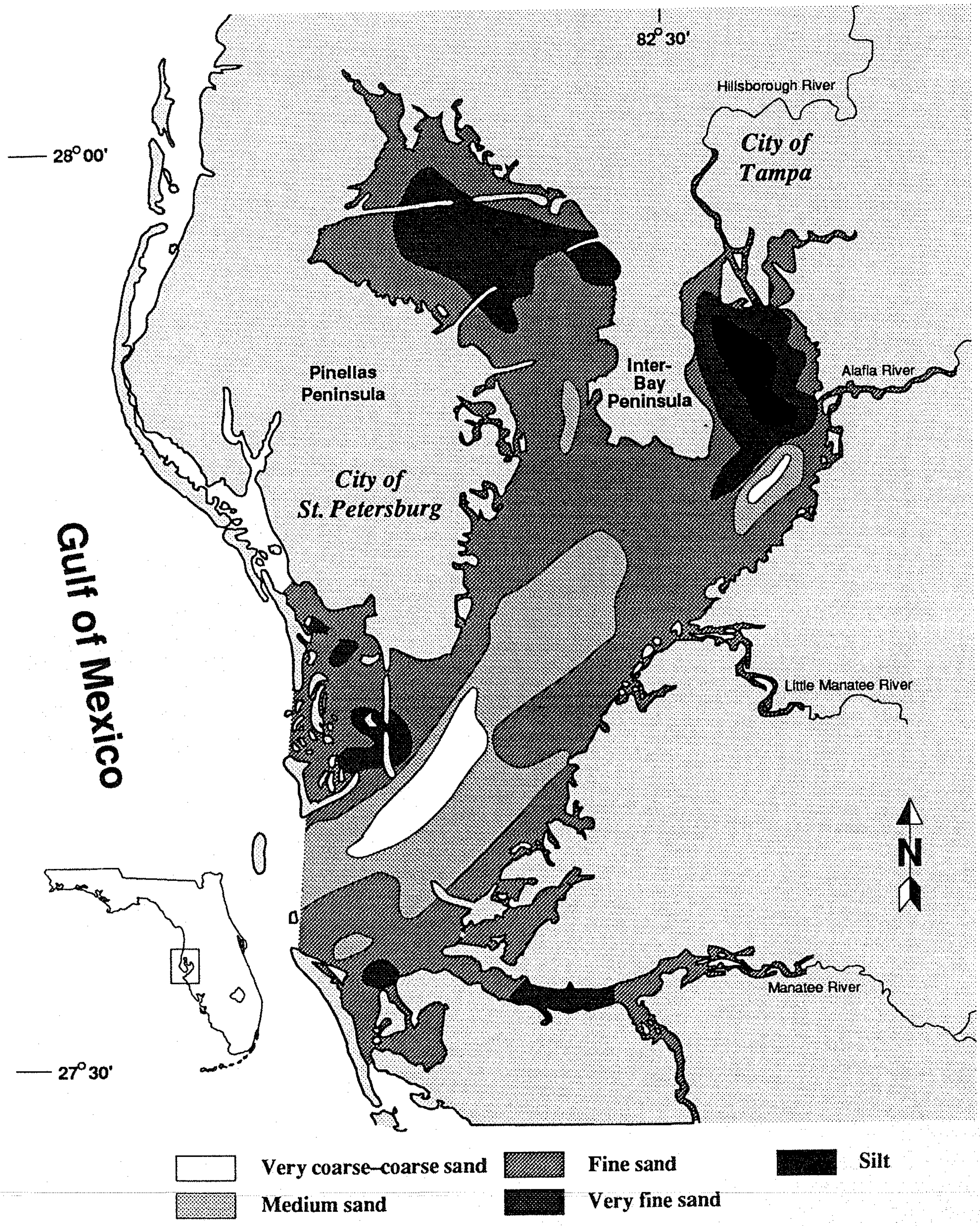


Figure 12. Texture of bottom sediments in Tampa Bay (after Goodell and Gorsline 1961).

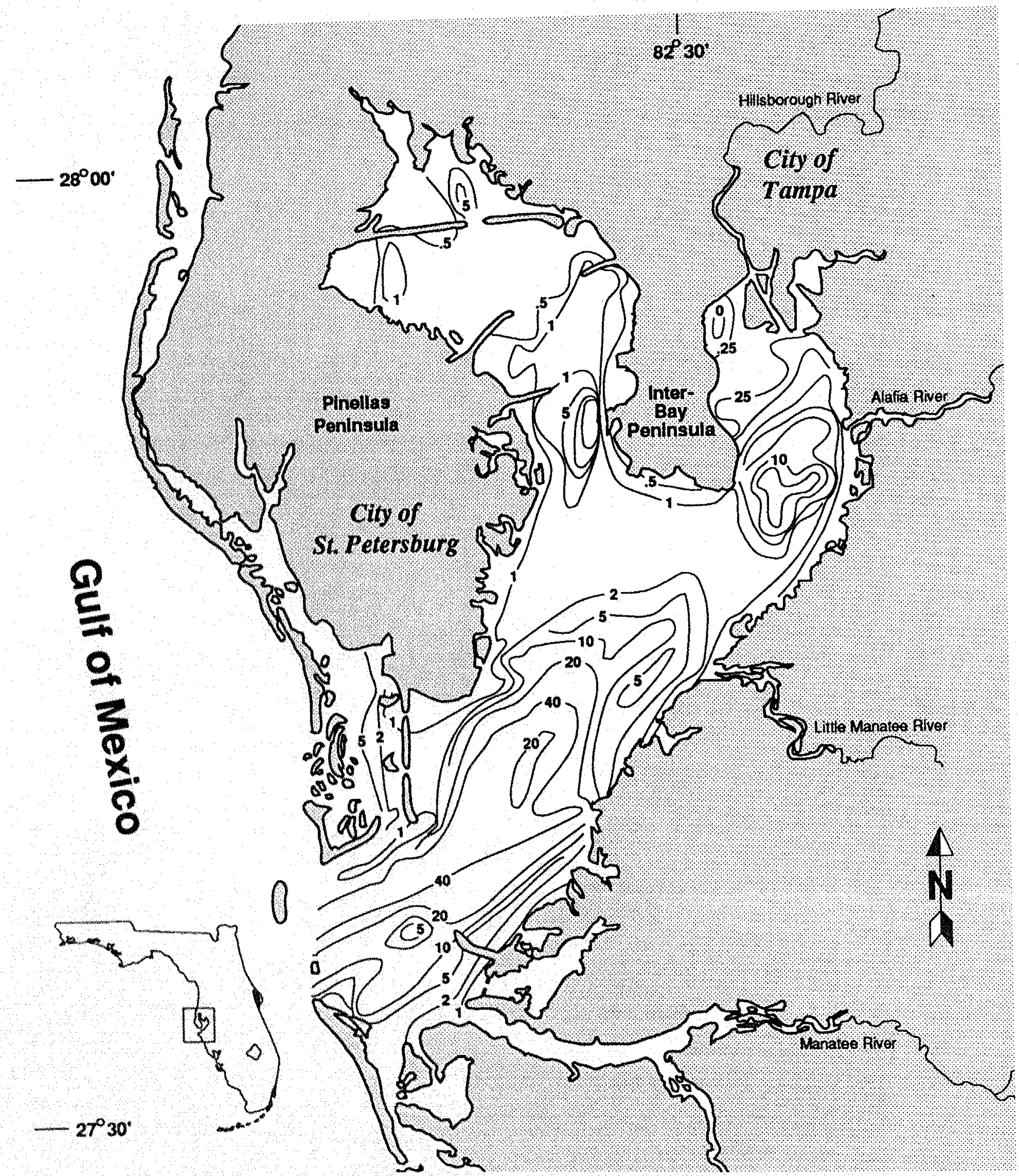


Figure 13. Calcium carbonate content of bottom sediments (%) in Tampa Bay (after Goodell and Gorsline 1961).

Chapter 3. Climate

Richard D. Drew

3.1 Introduction

The National Weather Service classification system divides Florida into seven climatic divisions. Each division encompasses an area in which basic climatic variables, primarily temperature and rainfall, are generally consistent when averaged over extended periods of record. Obviously, the boundary lines between the climatic divisions approximate general lines of change. Sometimes station-to-station differences within a division exceed divisional variation, particularly between coastal and inland areas. Despite these differences, climatic divisions are a means of organizing watershed and statewide climatic indicators. Most of the Tampa Bay watershed is in the south central division, with a small part in the north central division (Figure 14). The locations of first-order weather stations operated by the National Weather Service in Florida are also shown in Figure 14. Each station provides the most complete weather data base available, including statistics on temperature, rainfall, cloud cover, relative humidity, wind, barometric pressure, and solar radiation. For the watershed, only the Tampa Station provides this level of detail, while first-order station data from Lakeland and Fort Myers provide information on the inland and southwestern coastal areas, respectively, for the general region. This data base is supplemented by cooperative and research stations that provide weather data of a more limited nature (e.g., rainfall and air temperature). These secondary weather stations monitor the climate for a variety of applications; water management, agriculture, and aviation are three of the most important. For a more complete review of the weather stations adjacent to and in the watershed, refer to the publications of USDC (1953, 1964), FBC (1954), Thomas (1970, 1974), Palmer and Miller (1976), Whalen (1977, 1979), Wyllie (1981), and Heath and Conover (1981).

In general terms, the mild subtropical climate of the watershed is a product of its low topography, its proximity to the Gulf of Mexico and the Atlantic Ocean, and its relatively low latitude (Bradley 1972; USDC 1981). The slight relief allows uninterrupted movement of winds and rains across the terrain. The adjacent waters moderate temperatures, acting as a heat source in winter and a heat sink in summer, and provide a source of moisture for clouds and rain. The temperature differential between the water and the

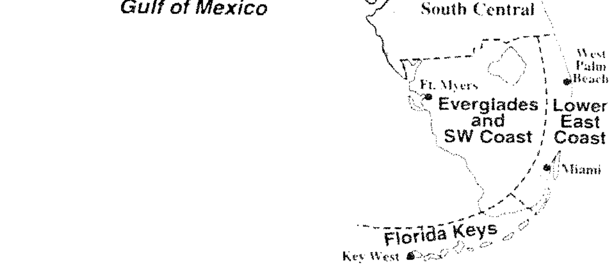


Figure 14. Florida climatic divisions (after Bradley 1972).

land also drives the land and sea breezes. The inland areas are typically cooler in winter and warmer in summer than the adjacent coastal regions. The low latitude provides for moderate winter temperatures (Palmer 1978). Rainfall in the area is characteristic of a humid mesothermal climate with a warm, wet summer dominated by thundershowers and a moderate to slight dry season during the winter (Hela 1952; USDC 1981).

3.2 Rainfall

Mean annual precipitation for the Tampa Bay watershed is approximately 140 cm (Heath and Conover 1981). The entire region is characterized by a relatively long period (6 to 8 months) of low rainfall and a shorter period (4 to 6 months) of heavy rains. Dry-season rains vary from 5 to 6.5 cm per month. Wet-season rainfall is much more variable, both spatially and temporally, and ranges from about 13 to over 20 cm per month (Palmer 1978). From November to April, the dry season provides 24% to 34% of the annual rainfall, derived primarily from middle-latitude cyclonic or frontal rainfall systems (Thomas 1974; Echternacht 1975; Palmer 1978). The wet-season rains are a daily phenomenon caused by convective rainfall systems (e.g., cumulonimbus thundershowers) that, in the summer months alone (June to September), account for over 60% of the watershed's annual rainfall. Wet-season, dry-season, and total annual rainfall for individual stations in and adjacent to the watershed are given in Table 7. Annual average rainfall isohyets for the watershed are illustrated in Figure 15. Rainfall exceeds 140 cm in the eastern half of Pasco and Hillsborough Counties and most of the Manatee River watershed in Manatee County.

A 5-year cyclic rainfall pattern observed in south Florida (e.g., Florida Keys or along the southeast coastal ridge) is not evident in the Tampa Bay watershed (Thomas 1970). The only long-term rainfall pattern apparent in this area is a recent (1960–75) period of deficit rainfall when monthly rainfall was consistently lower than normal (Palmer 1978; TI 1978a).

The weather over much of the eastern United States is dominated by a succession of low- (cyclone) and high- (anticyclone) pressure systems that move generally west to east and collectively result in winds known as the prevailing westerlies (Palmer 1978; U.S. Air Force 1982). The zones of contact between these pressure systems are called fronts. Rare during the wet season in the Tampa Bay area, fronts dominate south and central Florida's dry season in response to the general atmospheric circulatory system's shift southward over the state (Blair and Fite 1965; Palmer 1978). The fronts, also called synoptic-scale systems, pass over the region an average of once a week and exhibit rainfall patterns quite distinct from the wet-season convection storms (Echternacht 1975; Palmer 1978; Bamberg 1980). Synoptic rains typically fall over a more uniform area of the front and depend only on the temporal passage of the system (Gruber 1969; Echternacht 1975; Palmer 1978). Frontal rainfall usually extends along a line from northeast to southwest over the Florida peninsula and sweeps south to southeast. Convergence of warm, humid air masses to the south and the cooler, drier air carried with the front generates rainfall along the frontal path. Rainfall intensities depend on the strength of the interacting air masses and motions of individual precipitation "pockets" within the front. Occasionally, large amounts of rain will fall in a narrow band when the front becomes stationary.

Figure 16 illustrates the average monthly rainfall for the wettest dry-season month, March, and the driest dry-season month, November. The disappearance of summer convection systems, frontal systems that remain to the north, and the shift in tropical storm movement to the west of Florida create an environment conducive to November's low rainfall. In November, the average rainfall in the watershed varies from less than 2.5 cm to just over 3 cm, and generally increases from south to north. Monthly average rainfall tends to increase gradually through March, when there is maximum development of frontal rainfall. Average rainfall ranges from less than 5 cm near Venice to the south to greater than 7.5 cm in the extreme northwest around Lakeland.

In midspring, the frontal systems move north of west-central Florida and local sea-breeze/convection circulation becomes the dominant force controlling wet-season rainfall (Echternacht 1975; Palmer 1978;

Table 7. Wet-season, dry-season, and total annual rainfall in the Tampa Bay watershed.

Station location	(N)[a]	Dry season Nov. to Apr (cm)	%[b]	Wet season May to Oct (cm)	%	Annual average (cm)	Ref.[c]
Alafia River							
Lakeland WB City	54	38.48	30	91.21	70	129.69	1
Lakeland	37	38.40	31	87.15	69	125.55	2
Pierce	30	35.84	26	104.11	74	139.95	3
Plant City	74	39.60	28	100.66	72	140.26	1
Hillsborough River							
Hillsborough St. Park	23	41.78	29	101.32	71	143.10	1
St. Leo	69	41.71	29	101.17	71	165.74	1
Manatee River							
Bradenton	77	36.80	26	102.90	74	139.70	1
Bradenton Exp. Stat.	78	37.52	27	102.18	73	139.70	4
Ft. Green	14	40.67	28	103.23	72	143.89	1
Parrish	14	42.16	28	108.31	72	150.47	1
Sarasota Bay							
Long Boat Key	15	56.67	34	109.02	66	165.68	1
Sarasota S.E.	16	32.92	24	105.66	76	138.58	1
Venice	20	34.67	29	86.03	71	120.70	1
Phillippi Creek							
Sarasota	26	39.42	29	95.76	71	135.18	1
Tampa Bay							
Bay Lake	16	45.34	32	98.60	68	143.94	1
Pinellas Park	25	38.38	27	104.44	73	142.82	1
St. Petersburg	55	39.42	29	96.27	71	135.69	1
Tampa	93	35.56	28	93.27	72	128.83	1
Tampa Airport	29	38.51	31	86.92	69	125.43	5
Tampa AFB	31	34.29	30	78.49	70	112.78	6

[a] (N) = Years of record.
[b] % = Percent of total annual rainfall.
[c] References: 1) Thomas 1974 2) USDC 1978 3) FBC 1954 4) USDC 1964 5) USDC 1981 6) USAFETAC 1974

Bamberg 1980). Convection rainfall is a product of the sea-breeze system and the direction and intensity of the general wind system. The pattern of shower formation in the region is described by Palmer (1978) as follows:

> During the course of a summer day the land in a coastal area warms up more rapidly than adjacent water bodies. The warm land heats the overlying air which, in turn, becomes light and buoyant relative to the air over the water. In terms of atmospheric pressure, a low pressure area develops over the land with relative high pressure over the water. Since winds are the result of atmospheric pressure differences, an onshore wind develops, commonly called the sea breeze. Development of the sea breeze begins a few hours after sunrise and continues to mid or late afternoon. At the time of maximum development, the front (landward edge) of the sea breeze may have pushed 30–40 km inland and is marked by cumulus clouds. Under favorable conditions these may develop into cumulonimbus clouds producing shower activity.

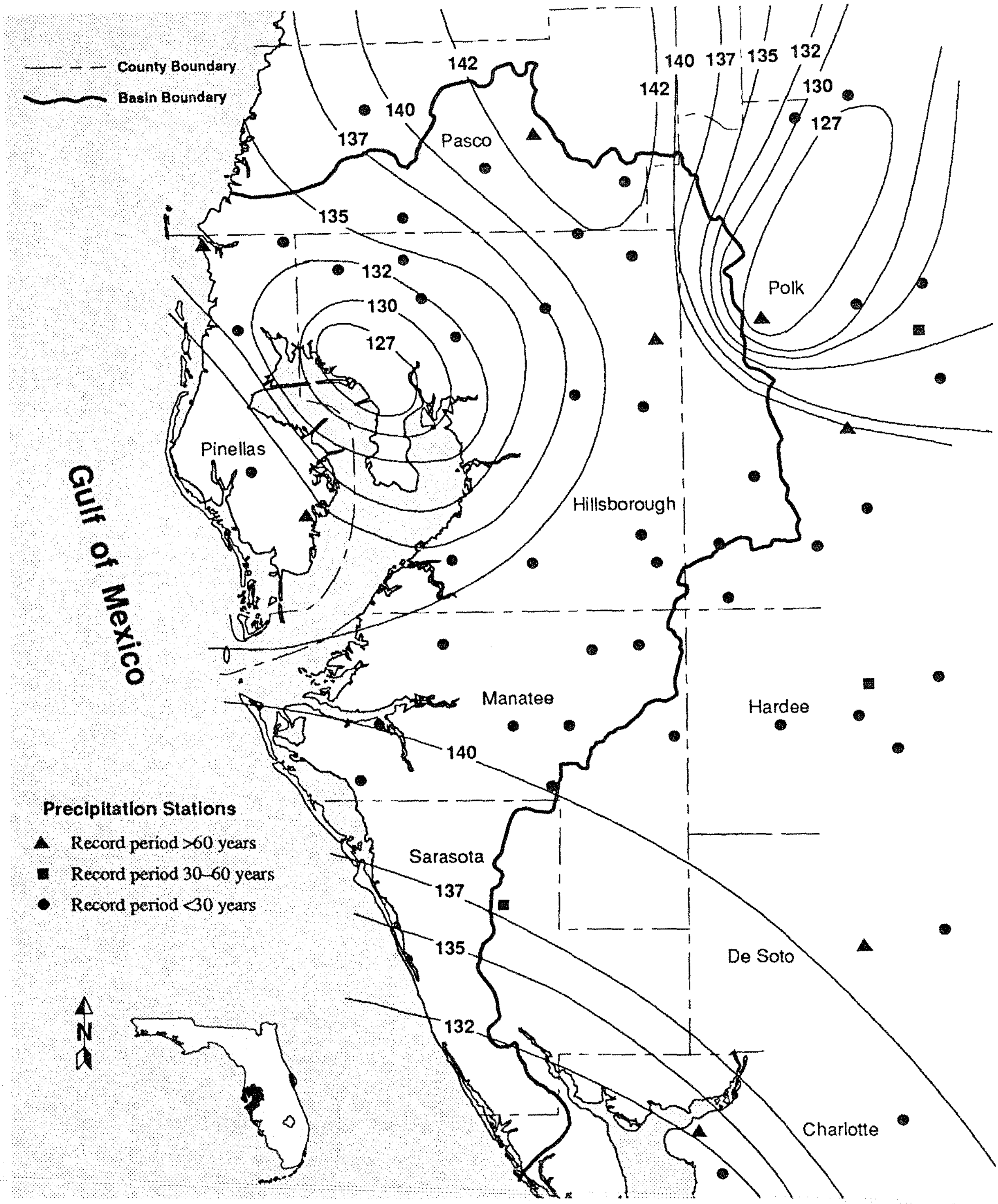


Figure 15. Average annual precipitation (cm) in the Tampa Bay watershed, 1941–70 (cm/yr) (after Palmer 1978).

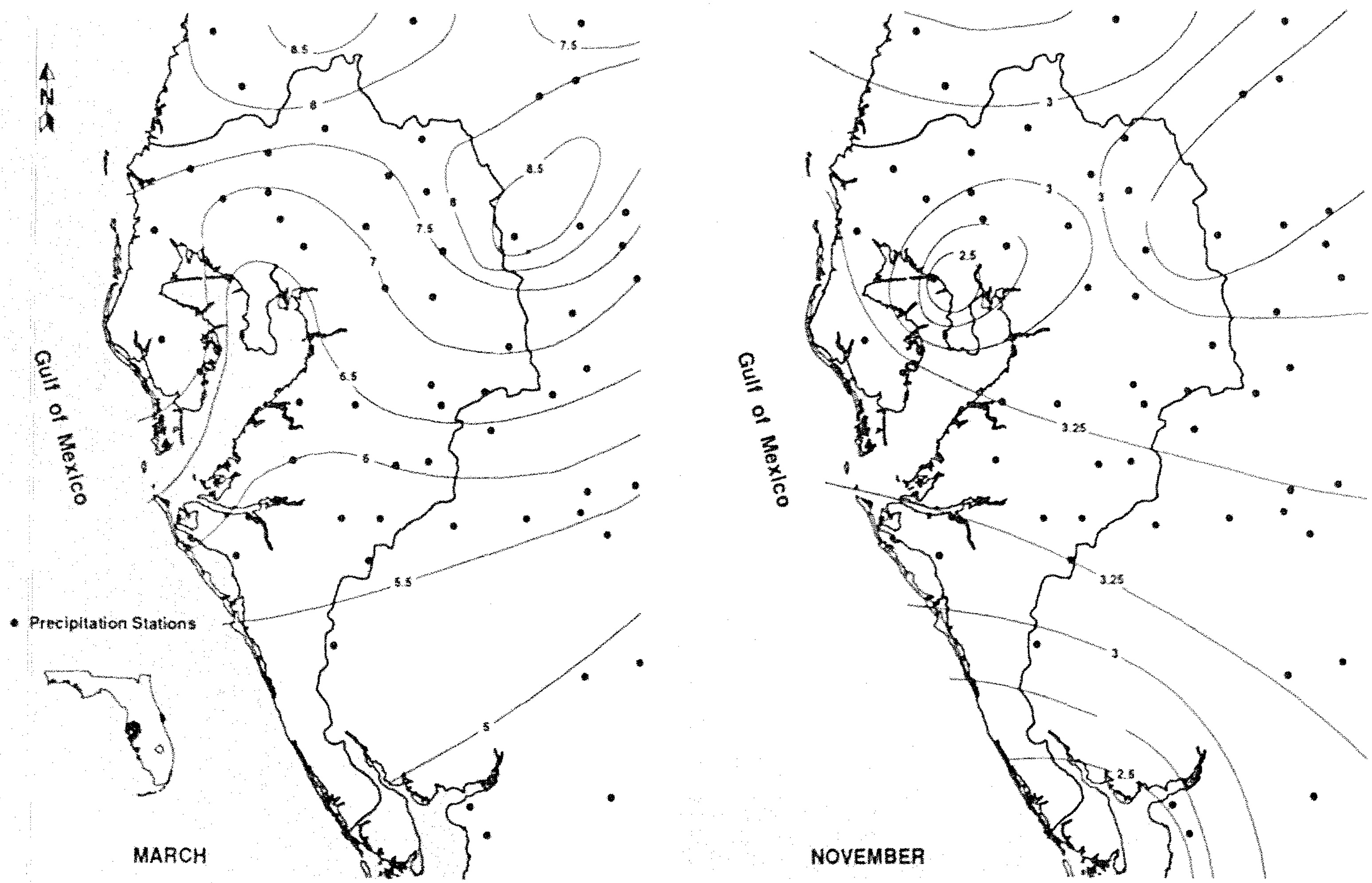


Figure 16. March and November average rainfall (cm) in the Tampa Bay watershed (after Palmer 1978).

The local sea breezes interact with large-scale (synoptic) airflow (prevailing southeasterlies and southwesterlies) to form lines of convergence where rainstorm development is greatest (Frank et al. 1967; Gruber 1968; Pielke 1973). While the dry-season rainfall tends to increase from south to north, the wet-season rainfall exhibits (from north to south) a ridge-and-trough pattern of higher and lower areas of rainfall (Figure 17). A ridge of seasonally and monthly high rainfall values extends from the Bradenton area eastward to encompass southern Polk County and northern Hardee County (Figure 17). "Troughs" or areas of minimal rainfall characterize the southern (Charlotte Harbor) and northern (Tampa) portions of the watershed (Palmer 1978).

Convective wet-season storms exhibit the greatest spatial and temporal variations of any rainfall regime. Extreme differences in annual rainfall of as much as 10 cm in 1.5 km and 35 cm in 6.5 km have been reported in the region (Woodley et al. 1974). Monthly variations of more than 13 cm occur in areas situated only a few kilometers apart (Duever et al. 1975; Palmer 1978; Buono et al. 1978). The difference in rainfall is related not only to the physical placement of the clouds but also to moisture content and size of individual storm clouds. The natural variability of rainfall from a single cumulonimbus cloud in south and central Florida ranges from 200 to 2,000 acre-ft (Woodley 1970).

A predominant form of the convective wet-season storm is the thundershower. These storms are brief (1–2 h), usually intense, and occasionally attended by strong winds or hail (Bradley 1972). Thunderstorms in the Tampa Bay watershed are more frequent (87 to over 100 days per year) than any other section of the continental United States, and most frequent (about 75%) during the summer months (Jordan 1973; Palmer 1978). Wet-season storms lasting more than a few hours are infrequent and generally associated with tropical disturbances. The short-duration, high-intensity thundershowers are related to cyclic, land/sea-breeze convective processes. Rain from these storms generally falls during the late afternoon or early evening hours, a period of maximum atmospheric convergence (Gruber 1969; Echternacht 1975; Gannon 1978). Figure 18 shows the average number of days when rainfall exceeds 0.025 cm and the average number of thunderstorms per month as reported by the area's three first-order weather stations.

Distribution of rainfall over west-central and southwest Florida during the year exhibits a bimodal pattern (Figure 19). The first and smaller of two peaks is in February or March and the second in July and August (Thomas 1974). This bimodal seasonal distribution of rainfall is associated with times of maximum frontal (March) and thunderstorm (July) activity (Palmer 1978).

A commonly reported precipitation statistic of interest for air pollution and ecological studies is the number of days on which certain amounts of rainfall are reported, i.e., rainfall greater than or equal to 0.25 cm. A summary of the mean number of days per month with rainfall exceeding 0.025 cm and 0.25 cm, respectively, is given in Figures 18 and 20 (Bradley 1974; Gutfreund 1978; TI 1978a). The monthly and seasonal distribution of rainfall is relatively uniform. Storm events exceeding or equal to 1.3 and 2.5 cm exhibit the same temporal patterns shown in Figure 20 for smaller threshold storms (Gutfreund 1978).

Rainfall frequency distributions developed from 5 years of record (1975–1979) for Fort Myers, Orlando, and Tampa are illustrated in Figure 21. This figure shows that approximately 75% of the rainfall events in the watershed contribute less than 1.5 cm per event.

Drought is occasionally experienced even in the "wet" season (Bradley 1972). The effect of drought is aggravated or ameliorated by variations of temperature that affect transpiration, evaporation, and soil moisture. One of the more noteworthy studies of this situation is that of Gannon (1978), whose model of the daily sea-breeze circulation over the south Florida peninsula showed that developments on the land surface, such as urbanization and wetland drainage, inadvertently redistribute rainfall by changing the overall daily heat budget. Soil moisture and surface albedo (the ratio of reflected radiation to total radiation) are the two most important factors influencing the strength of the daily sea-breeze circulation in

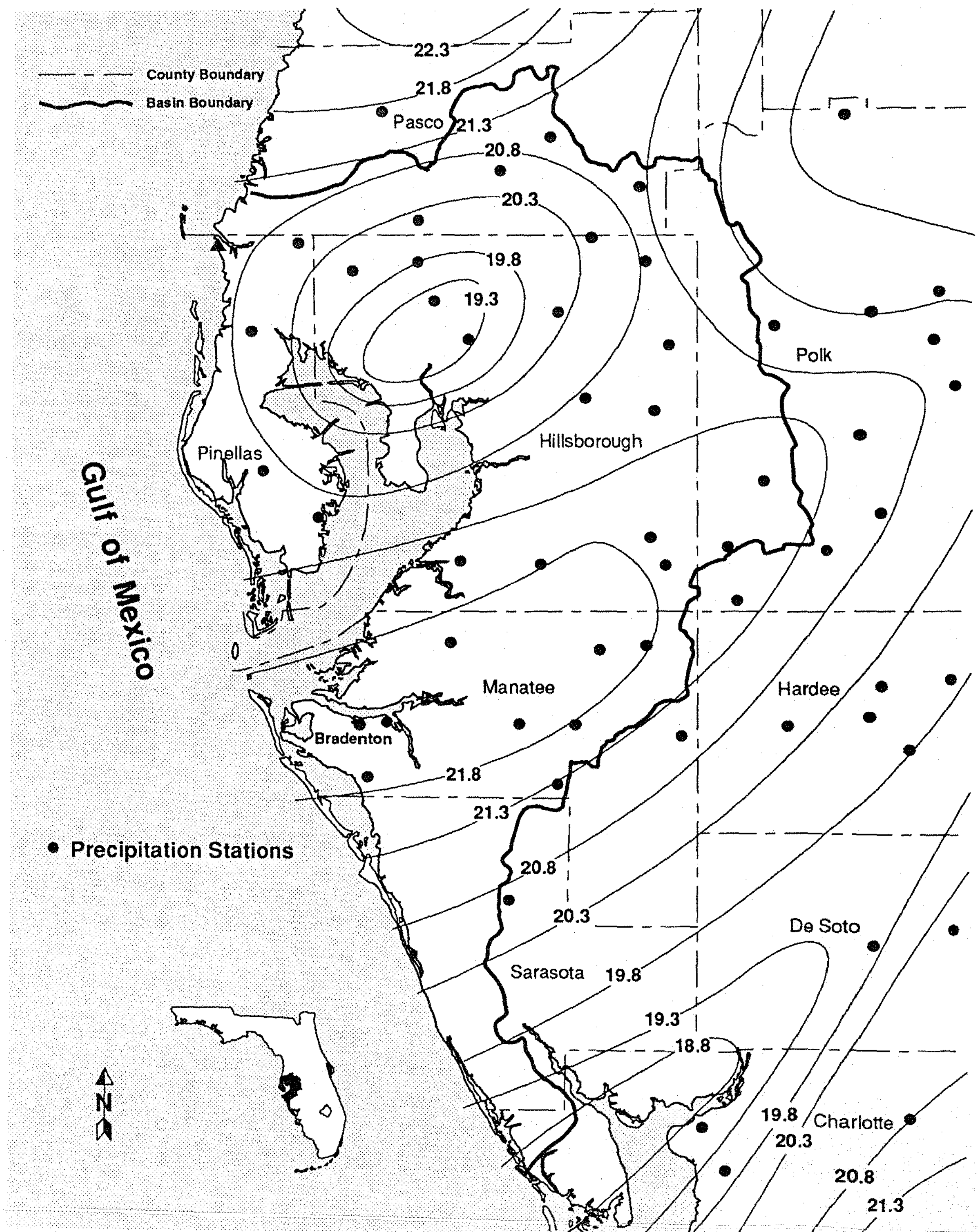


Figure 17. Average July rainfall (cm) in the Tampa Bay watershed (after Palmer 1978).

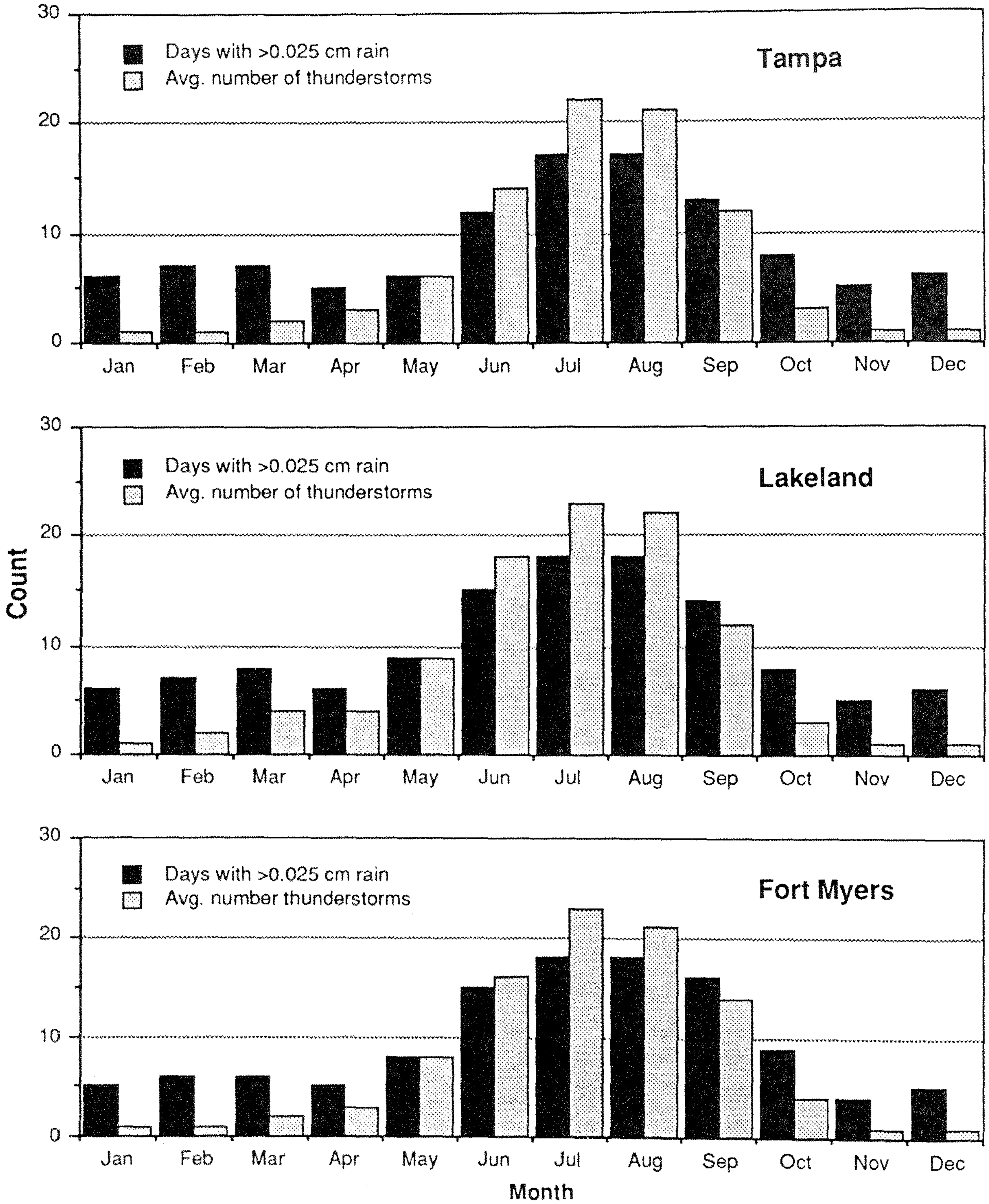


Figure 18. Average number of days when rainfall exceeds 0.025 cm (0.01 in) and average number of monthly thunderstorms (data from Bradley 1974; TI 1978a).

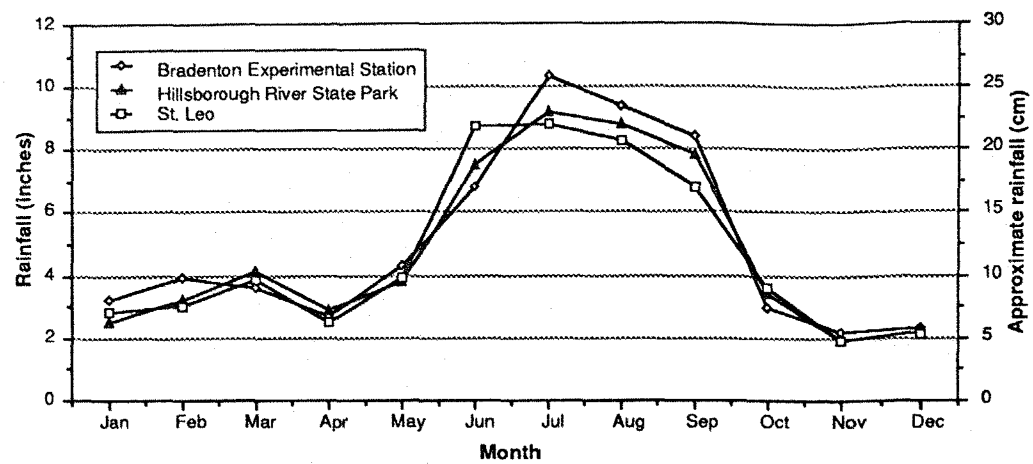


Figure 19. Average monthly rainfall in the Tampa Bay watershed (after Thomas 1974).

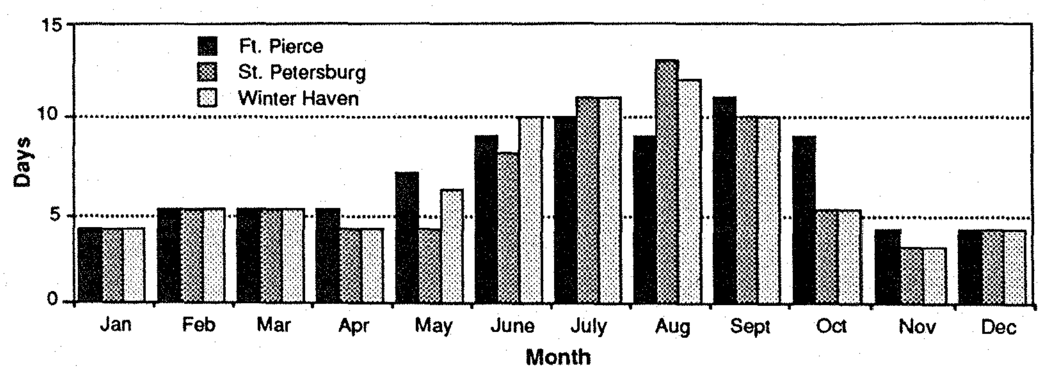


Figure 20. Average number of days per month when rainfall exceeds 0.25 cm (0.1 in) (after Gutfreund 1978).

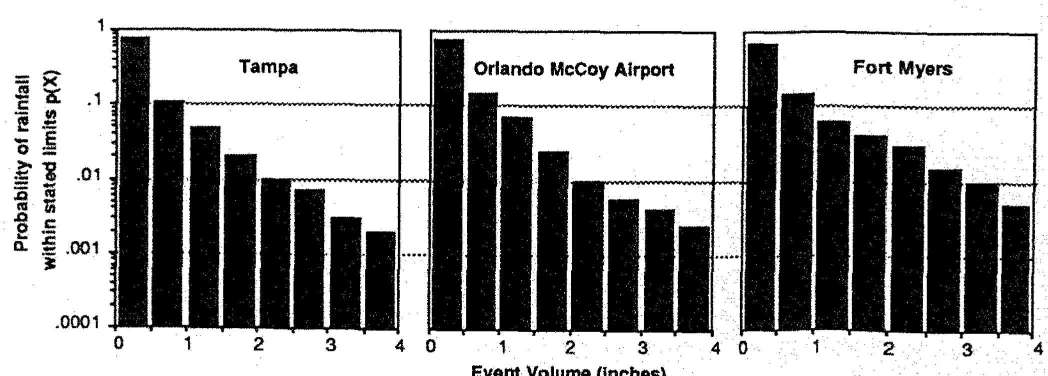


Figure 21. Frequency distribution of rainfall in southwest Florida over a 5-year period (after Anderson 1982).

Gannon's model. Surface albedo is inversely related to soil moisture; consequently, wetland drainage may exert something of a self-accelerating effect on the daily hydrologic cycle by lowering soil moisture (which itself changes the heat budget), by providing less moisture for evapotranspiration, and by increasing surface albedo (which increases daytime heating). The total removal of wetlands from the weather cycle through asphalt and concrete paving and other urban development further amplifies the shift toward higher temperatures.

The implications of temperature change for fish and wildlife, as well as for the human population of south Florida, have recently been noted by Marshall (described in Boyle and Mechum 1982). His hypothesis is that development and drainage have slowly replaced Florida's wet season "rain machine" with a relatively drier "heat machine" during summer months. The wet-season rains that are so vital to south Florida's ecosystems are less frequent because of massive changes in the daily heat budget.

Rainfall has been deficient in west-central Florida since 1961 (Palmer and Bone 1977). The drought is most severe in an area that runs from Tampa eastward through Bartow and northeast to Orlando; within this region, the 16-year cumulative deficits range as high as 218 cm. Southward, the cumulative deficit decreases to less than 25 cm at Fort Myers. The deficit is attributed to the urbanization between Tampa and Orlando, which reduces soil moisture; the absence of "normal" hurricane activity during the 16-year period; and a permanent climatic change (Palmer 1978). A 30-year annual rainfall profile for Lakeland is presented in Figures 22 and 23. This figure clearly shows the recent shift of annual rainfall from an even distribution of wet to dry years before 1961 to a lopsided distribution of dry to normal years since that time.

3.3 Winds

Wind patterns in the Tampa Bay watershed are determined by the interaction of wind forces of a long- and short-term temporal nature. Seasonal large-scale (synoptic) atmospheric patterns represent the long-term phenomenon, such as the Atlantic anticyclone, whose western edge influences the lower-altitude winds of the Florida peninsula during the summer months. In this position, the anticyclone causes southeasterly winds in the southern part of the watershed and southerly winds in the northern

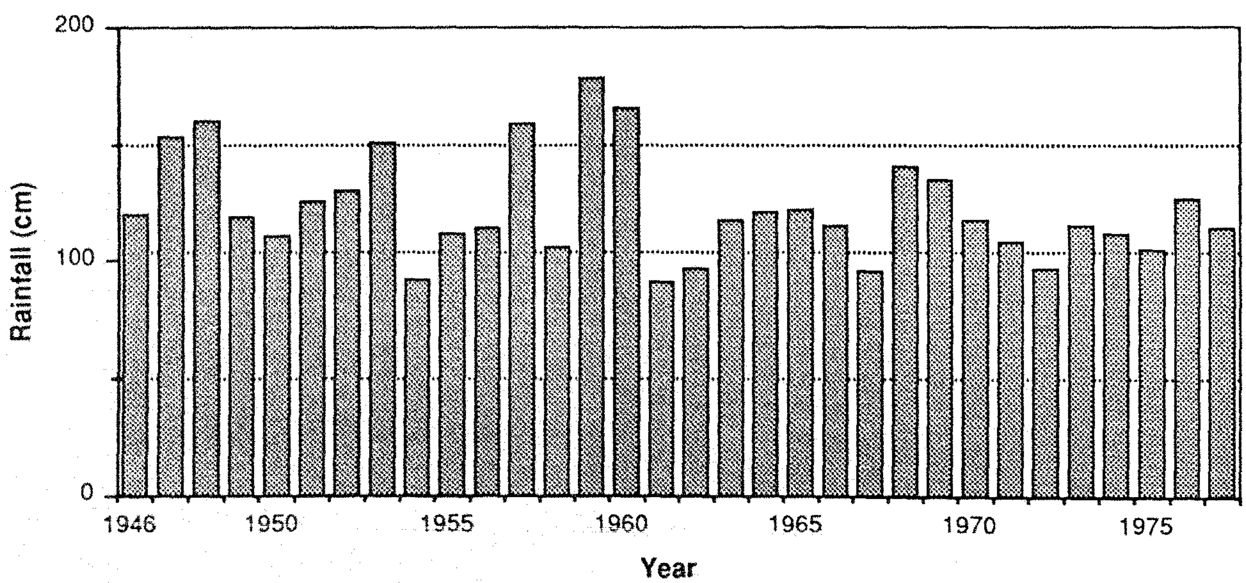


Figure 22. Thirty-year annual rainfall for Lakeland (data from Palmer 1978).

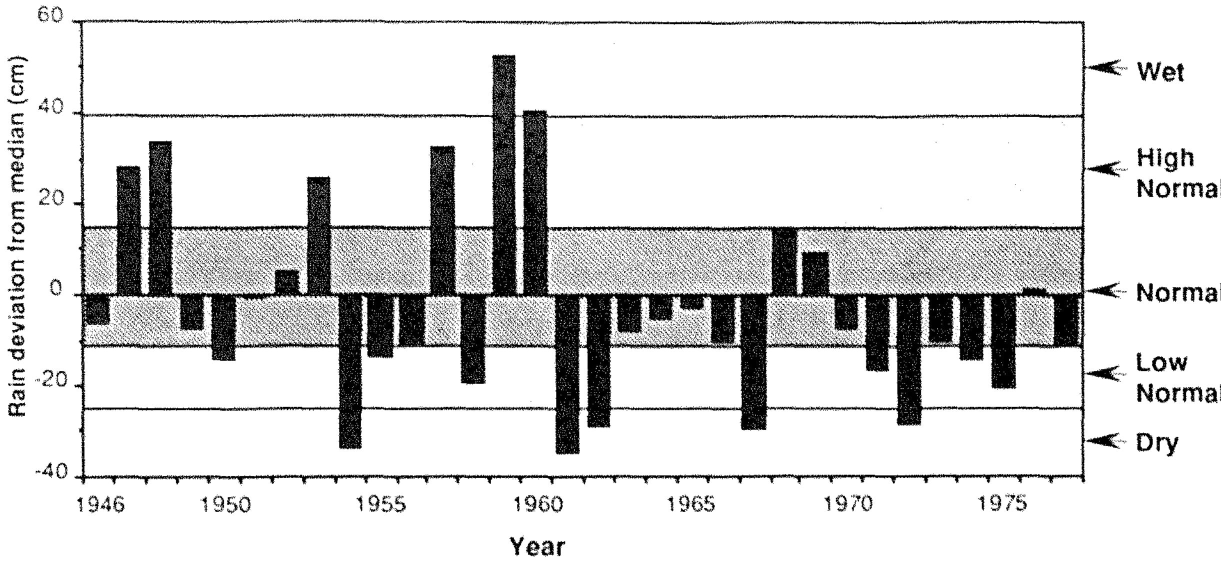


Figure 23. Rainfall deviation from normal over 30 years at Lakeland (data from Palmer 1978).

watershed (Figure 24). In the winter months (Figure 24), prevailing easterly trade winds dominate the region south of latitude 27°N, while its counterpart, the westerlies, influence the area north of latitude 29°N. The region between is quite varied (Gruber 1969).

Short-term atmospheric phenomena include localized diurnal land/sea breeze convective processes during the wet season and synoptic-scale frontal systems during the dry season (Echternacht 1975; Fernandez-Partagas and Mooers 1975; Palmer 1978). In a comprehensive examination of seasonal differences in the large-scale wind fields for the Florida peninsula, Gruber (1969) described the seasonal streamlines at three vertical levels: 950 millibars (mbar) at 0 to 600 m; 500 mbar at 5,500 to 6,000 m; and 200 mbar at approximately 12,000 m. His work was summarized by Echternacht (1975), who uses the wind-field patterns to describe potential air pollution problems affecting south Florida. The four seasonal wind-field patterns adapted by Echternacht (1975) at the 950-mbar level (i.e., for low-level winds) are illustrated in Figure 24. The Tampa Bay watershed is in a transition area of changing wind directions, especially in winter, when winds vary from southeasterly to the south and southwesterly to the north. Spring and summer generally exhibit more southerly winds, and fall is characterized by east or northeasterly winds. The prevailing winds interact with the wet- and dry-season short-term system processes (e.g., convective and frontal) to produce the day-to-day wind patterns over the watershed.

In the wet season (May to October), convective-scale winds (initiated by thermal gradients at the land-sea interface) mix with the prevailing southeasterly winds (Pielke 1973). The recurrent wind-cycle and maritime influence (discussed under the rainfall section) is significant to the watershed's wet-season climate because of the flat terrain and proximity to the water (Bradley 1972; Echternacht 1975). The daily changes in divergence (in this case, a measure of surface airflow away from a sinking column of air) over the Florida peninsula for June, July, and August were monitored by Frank et al. (1967). A pronounced diurnal pattern shows very strong convergence (negative divergence, indicating surface winds flowing towards an upwelling—in this instance likely to be a convective updraft) peaking around 1200 to 1400 hours (Figure 25). This pattern demonstrates that the convective scale is the fundamental scale of motion in the watershed during the wet season (Echternacht 1975).

In the dry season (November to April), the influence of convection diminishes as the sun's angle of

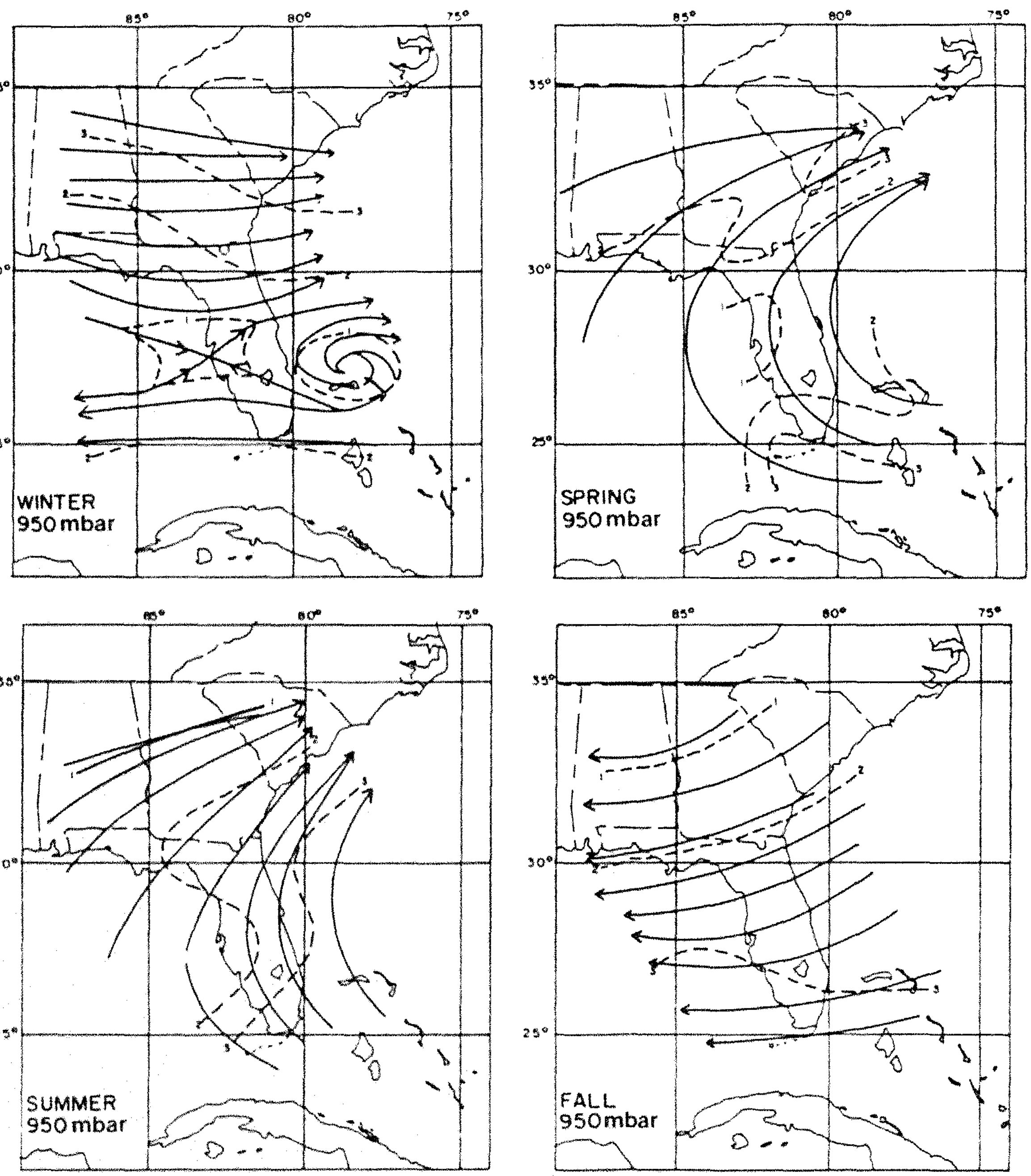


Figure 24. Seasonal wind directions and speed at the 950-mbar level in Florida, 1957-67 (after Echternacht 1975).

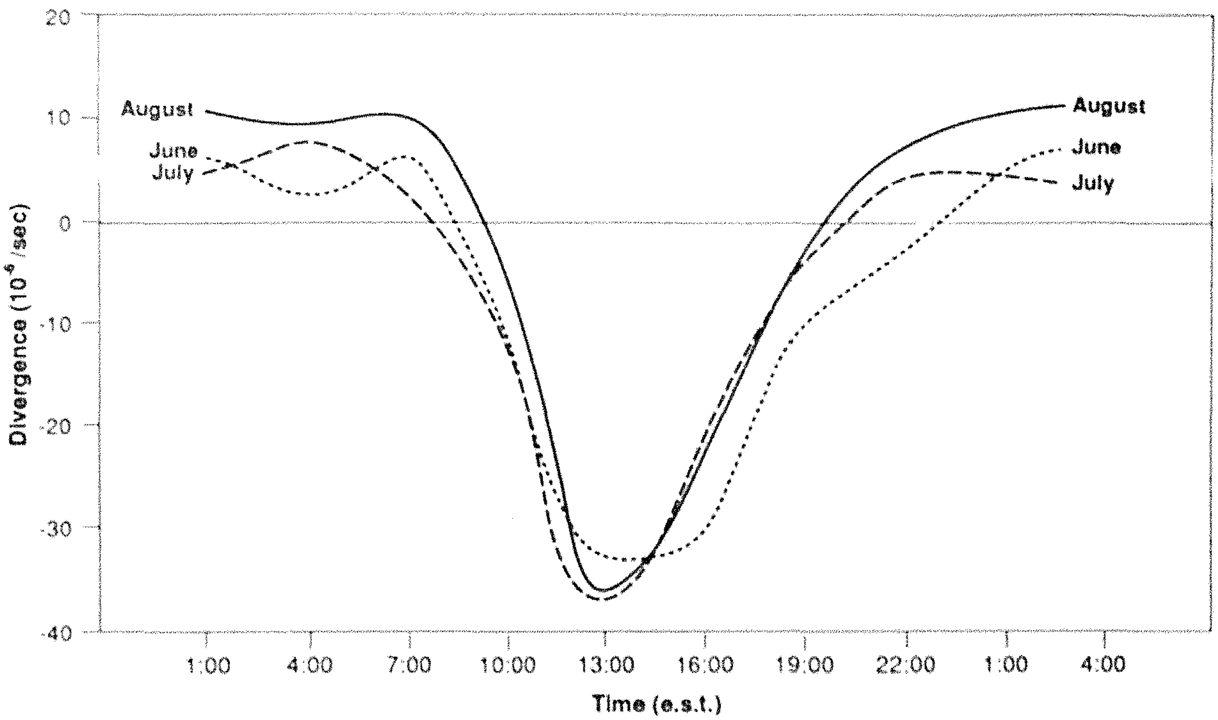


Figure 25. Average monthly divergence curves for June, July, and August 1963, over the Florida Peninsula (after Frank et al. 1967).

incidence decreases. This reduces the daytime radiant heating of the land and minimizes the thermal gradient between the land and sea surfaces (Blair and Fite 1965; Donn 1975). Dry-season wind patterns are influenced by synoptic-scale systems or winter frontals moving cold air masses southward. Although the watershed lies far enough to the south to remain affected by the easterlies year round (see Figure 24, winter), a northerly component related to the synoptic-scale systems affects the daily weather pattern (Echternacht 1975). Winter cold fronts typically pass over the watershed approximately once a week (Palmer 1978). An average cold front affects wind patterns for 4 to 5 days, involving a slow 360° clockwise rotation of wind direction (direction from which the wind is blowing). Winds rise above ambient throughout this period, reaching maxima roughly half a day before and after passage of the front. Maximum winds preceding the front are from the southwest and reach about 8 m/s. Maximum winds from an exceptional cold front may reach 20 to 26 m/s (Warzeski 1976).

Prevailing monthly wind speed and direction for first-order weather stations in or adjacent to the watershed are summarized in Figure 26. Although the concept of "prevailing" winds does not take into account diurnal shifts in wind direction and speed caused by differential heating of air and water surfaces or the passage of winter frontal systems, it does indicate the predominant seasonal factors that control wind.

Seasonally, highest average wind speeds are likely in late winter and early spring, and lowest speeds are most likely in summer. Winds near the coast, dominated by stronger land/sea breezes, are generally stronger than winds farther inland. Localized high winds of short duration (35–50 km/h) are generated by summer thundershowers and cold fronts (Bradley 1972). Wind speeds associated with convective systems follow a diurnal pattern. On a typical day, wind speeds are lowest at night, increase during daylight to a peak (which seldom exceeds 8–10 m/s) in the late afternoon, and then decrease in the evening (Mooers et al. 1975; Gutfreund 1978).

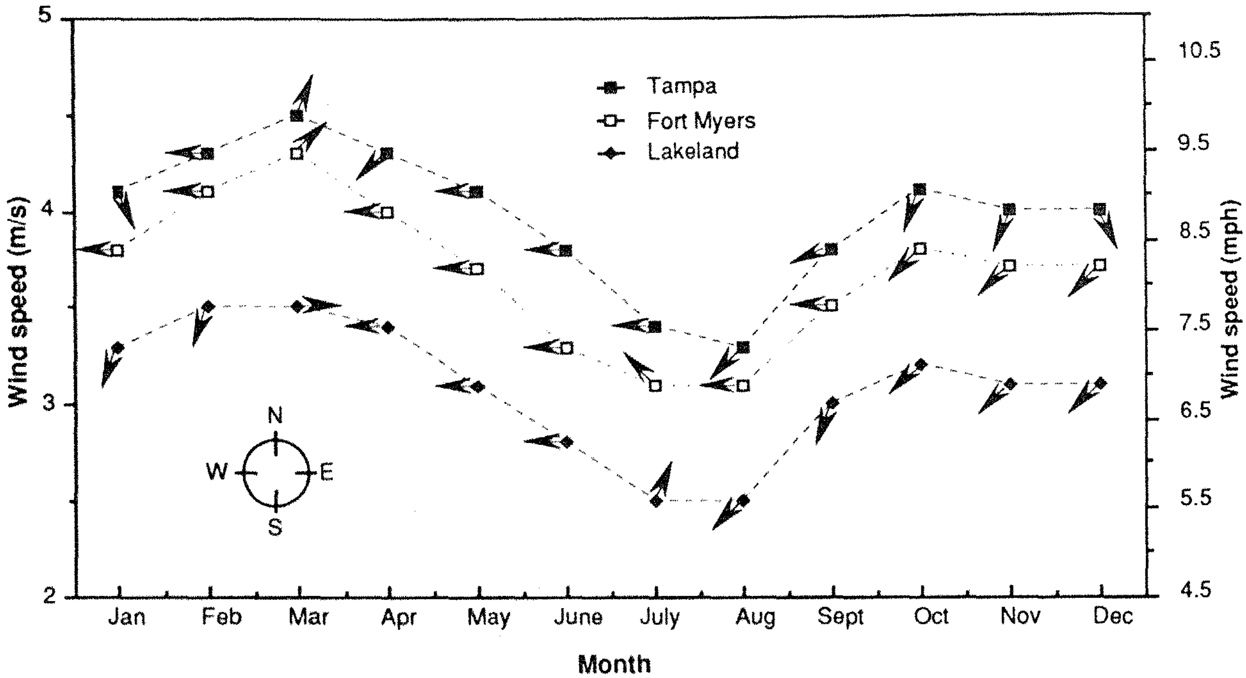


Figure 26. Prevailing wind speed and direction (data from Bradley 1974; TI 1978a).

Synoptic-scale influences are associated with the passage of the front, as previously described, rather than with diurnal patterns (Warzeski 1976). The influence of synoptic-scale systems on prevailing wind direction is evidenced by the northerly component of the prevailing wind directions for the months of October through January (Figure 26).

Wind direction and speed tend to vary with height above the ground. The variation of wind direction with height is not always uniform, but wind speed generally increases with height over the relatively flat terrain of the Tampa Bay watershed (Gutfreund 1978).

3.4 Temperature

The southern latitude and the moderating influence of the Gulf of Mexico control the air temperature regime in the Tampa Bay watershed. The climate is subtropical marine, characterized by long, warm summers and mild, moderately dry winters (Bradley 1972).

Isotherms for the average annual temperatures and for the coolest month (January) and the warmest month (August) in south-central Florida are given in Figure 27. Differences between coastal and inland areas are highlighted by isotherm contours that follow the coastline. Along coastal areas the maritime influence causes low daily fluctuations of air temperature and rapid warming of cold air masses that pass to the south and east of the state (USDC 1981). Inland areas generally display a greater range of temperatures because of more rapid heating and cooling of ground surfaces (Gerrish 1973; Gutfreund 1978; TI 1978a).

In winter, advective and radiational cooling processes following the passage of cold fronts cause sharp drops in temperature (Bamberg 1980). As rainfall diminishes with the passage of a front, cool, dry arctic air from Canada causes brisk northwesterly winds, which at maximum strength (velocity) cause the lowest daytime temperatures. Nighttime speeds cooling when large quantities of heat are radiated from land surfaces (water is a poor radiator), particularly in periods of clear skies and calm winds. Radiational cooling reaches a maximum a day or two

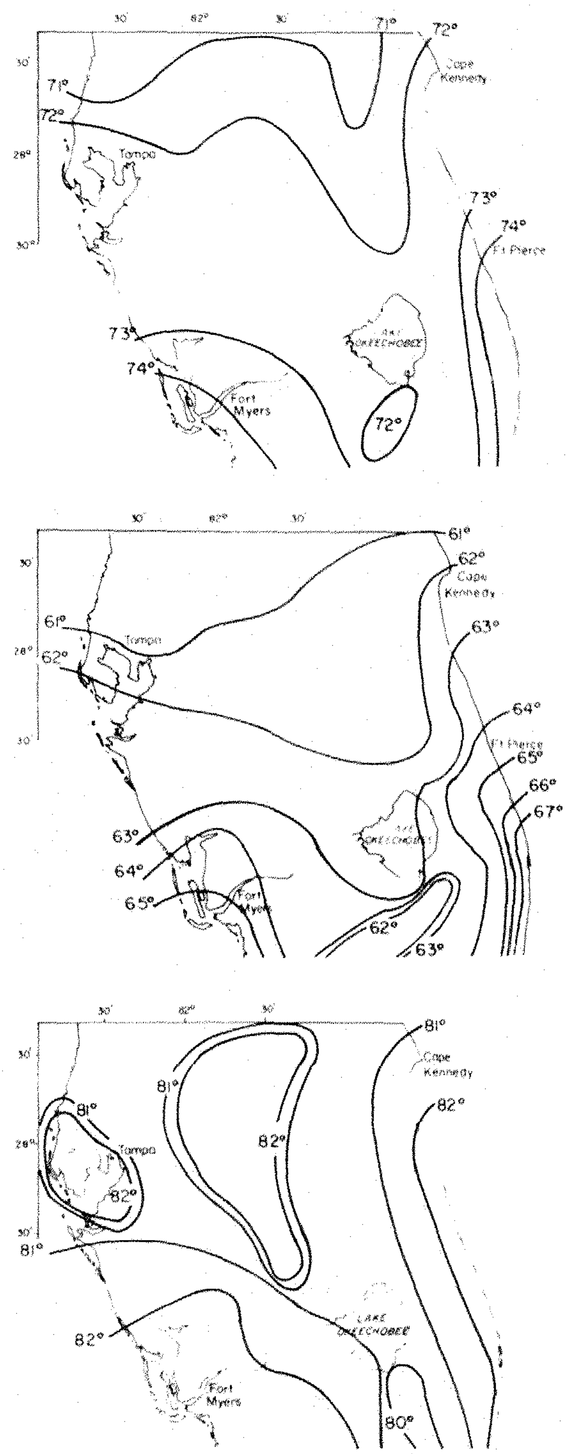


Figure 27. Annual, January, and August average temperatures (°F) in south-central Florida (after Thomas 1974).

after a front has passed, as the surface high-pressure system moves over or near Florida from the northwest. This cooling begins after sunset and results in the lowest temperatures for the entire front at dawn. Nighttime air-temperature gradients of 3°C to 8°C are common a few kilometers inland from the west-central Florida coastline with the passage of synoptic cold systems, as a result of radiational cooling. In addition to the coastal/inland air-temperature gradients, a similar gradient (3°C to 6°C) is found between relatively high, dry land and adjacent moist lowlands (Bamberg 1980). Another temperature gradient forms between urban and rural areas. Rural Lakeland, for example, typically experiences 2 days of freezing temperatures per year, while the city suburbs freeze an average of 11 days per year (USDC 1978).

The rare freeze, once or twice a year on calm, cold, clear nights (maximum radiational cooling), is generally not too destructive (TI 1978a). When sustained freezing temperatures are combined with strong northwest winds, the penetration of cold is near maximum and crop and citrus damage is most severe. A severe freeze is experienced about once every 20 years. Crops are most severely damaged if the freeze is followed by warm, dry weather. Water bodies act as natural heat sources during the freezes, moderating the surrounding air temperature by conduction.

Summer air-temperature gradients associated with wet-season convective processes develop more rapidly, are more frequent, and show greater spatial variation than the winter temperature changes associated with fronts. Air temperatures typically rise to the upper 90's in the vicinity of developing thundershowers, and drop 5°C–17°C when cool downdrafts generated from the thunderstorms precede a downpour (Bradley 1972; Bamberg 1980). In the Tampa Bay watershed, particularly the eastern edge, temperatures reach or exceed 32°C an average of 100 days per year (Gutfreund 1978). Temperatures along the coastal regions are more moderate (Figure 28).

3.5 Relative Humidity

A precise description of relative humidity is generally difficult because of large diurnal and seasonal

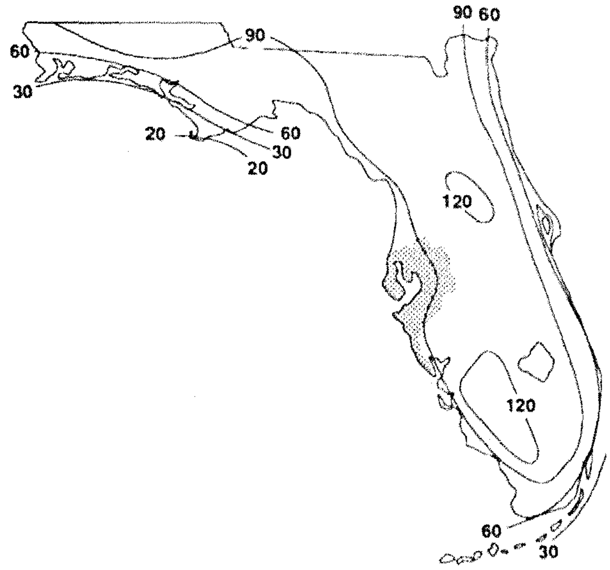


Figure 28. Average number of days per year in Florida when air temperatures exceed 32°C (after Gutfreund 1978).

variations (USDC 1981). Still, in Florida, and especially south Florida, the situation is less complex because of the abundance of moisture throughout the year (Gutfreund 1978). Average monthly relative humidities for 0100, 0700, 1300, and 1900 hours at the Tampa International Airport are summarized in Figure 29.

The mean annual relative humidity is quite uniform throughout the watershed, averaging about 75% (USDC 1981). Relative humidities are normally highest during the early morning hours, about 80%–90%, and lowest in the afternoon hours, about 50%–70%. Although seasonal differences are not great, mean relative humidities tend to be lowest in the spring (April and May) and highest in summer and fall.

3.6 Solar Radiation

Atmospheric solar radiation varies little across the Tampa Bay watershed (Gutfreund 1978). Factors that do vary are cloud cover, air pollution (particulate load

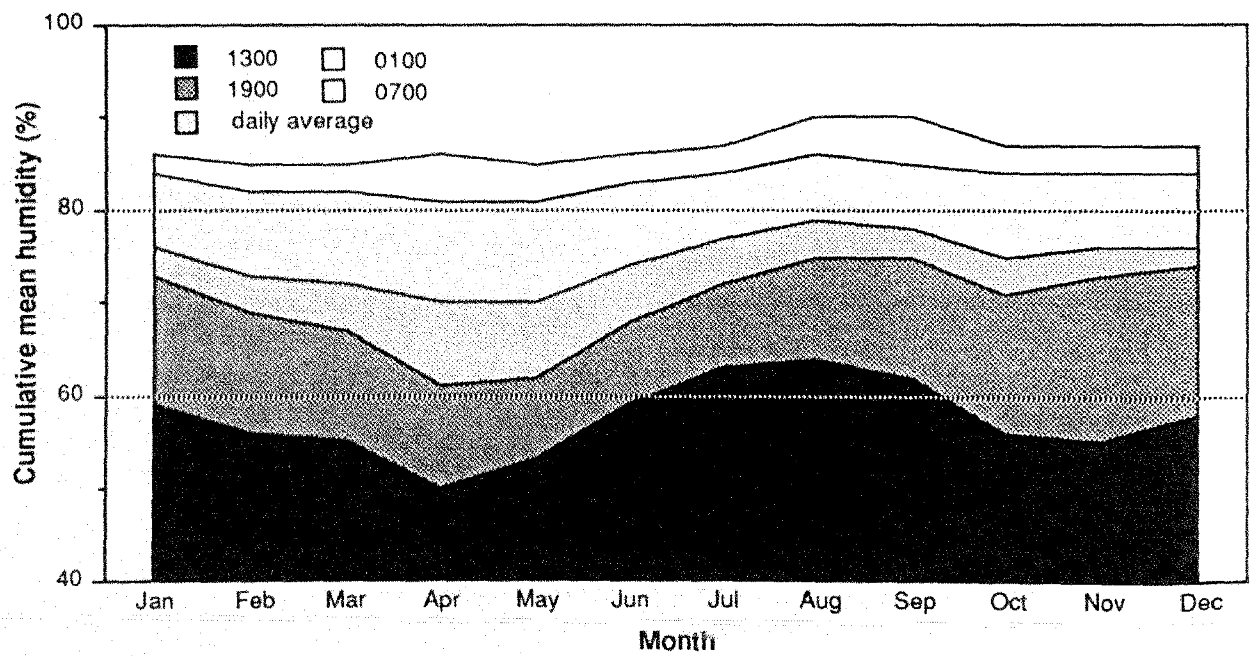


Figure 29. Average monthly relative humidity at different times of the day (USDC 1981 data).

or dustiness), and relative humidity. These factors modify the transmission, absorption, and reflection of solar energy (Blair and Fite 1965; Bamberg 1980), and largely determine the amount of solar radiation reaching the land and water surface. Solar radiation data collected at the Tampa and Lakeland first-order weather stations are presented in Figure 30 (Bradley 1972). The average daily solar radiation is 444 langleys (gram-calories per square centimeter). Monthly variations range from 293 langleys in January to 599 langleys in May (Bradley 1972). Higher values are reported in middle to late spring rather than during the summer solstice (when the angle of incidence is smallest) because of increased precipitation and cloud cover associated with the beginning of the south-central Florida wet season (Figures 19, 30 and 31). Information on the frequency of fog in the Tampa Bay area is presented in Figure 32.

3.7 *Evapotranspiration*

Evaporation and transpiration (evapotranspiration, ET) are two processes that move moisture, in the form of water vapor, into the atmosphere. Evaporation is defined as the passage of vapor to the atmosphere directly from the surface of water bodies, from surface and near-surface soils, or from impervious surfaces on which moisture has collected (Bamberg 1980). Transpiration is the movement of water vapor from a living body through membranes, pores, and/or cellular interstitial spaces by diffusion to the external surface and then to the atmosphere, or the evaporation of water from living surfaces directly into the atmosphere. Although all living surfaces transpire, vegetation is the primary source.

Two major factors that control evapotranspiration are solar energy and relative humidity. Solar energy provides the fuel necessary to transform liquid water into water vapor. The amount of solar energy reaching the earth's surface is modified by cloud cover, air pollution, and angle of incidence. Relative humidity is a measure of the air's moisture saturation. The relative humidity of fog, for example, usually is 100%, whereas that during rainfall may be less. Evapotranspiration is inversely related to relative humidity: as relative humidity increases, evapotranspiration decreases. Other factors controlling evapotranspiration are wind (velocity and duration), wave action, ground cover (type and density), shade, barometric pressure, temperatures (air and surface), soil type, soil-moisture content, and water-table depth (Parker et al. 1955; Dohrenwend 1977; Palmer 1978; Duever et al. 1979; Bamberg 1980; Wyllie 1981).

Evapotranspiration, especially when soils are saturated, becomes an important controller of sea-breeze intensity and, ultimately, the formation of convective storms. The heat consumption associated with high evaporation rates slightly increases temperature gradients between cooler inland areas and warmer coastal-urban strips (Gannon 1978; Bamberg 1980), especially for a day or two following a heavy rainfall. Because ET is a cooling phenomenon, land-water gradients are reduced, convective processes are reduced, and the recently rained-on area receives less rainfall. The overall effect is the creation of a natural feedback mechanism that tends to even the spatial distribution of seasonal rainfall (Bamberg 1980).

Estimates of evapotranspiration in west-central Florida range from 75 cm to 120 cm per year (Dohrenwend 1977; Palmer 1978). Predicted evapotranspiration patterns for Florida are given in Figure 33. Estimated annual values range from more than 100 cm in the southern part of the watershed to less than 90 cm in the north (Dohrenwend 1977). Although this is a first-order approximation, it closely agrees with the areawide 100 cm per year generally used by the Southwest Florida Water Management District (SWFWMD) in regional water-use calculations (Palmer 1978; Seaburn and Robertson, Inc. 1980). Both values are rough estimates for a region whose physical environment exhibits high spatial variability. Palmer (1978) categorized the geographic variation into four major evapotranspiration surface environments: lakes and open surface water bodies, wetlands, well-drained upland areas, and urban areas. Open surface waters exhibit evaporation rates that range from 120 cm in the northern watershed to 130 cm in the south. Wetlands show the greatest potential for moisture loss of any of the surface environments, with qualities that maximize both

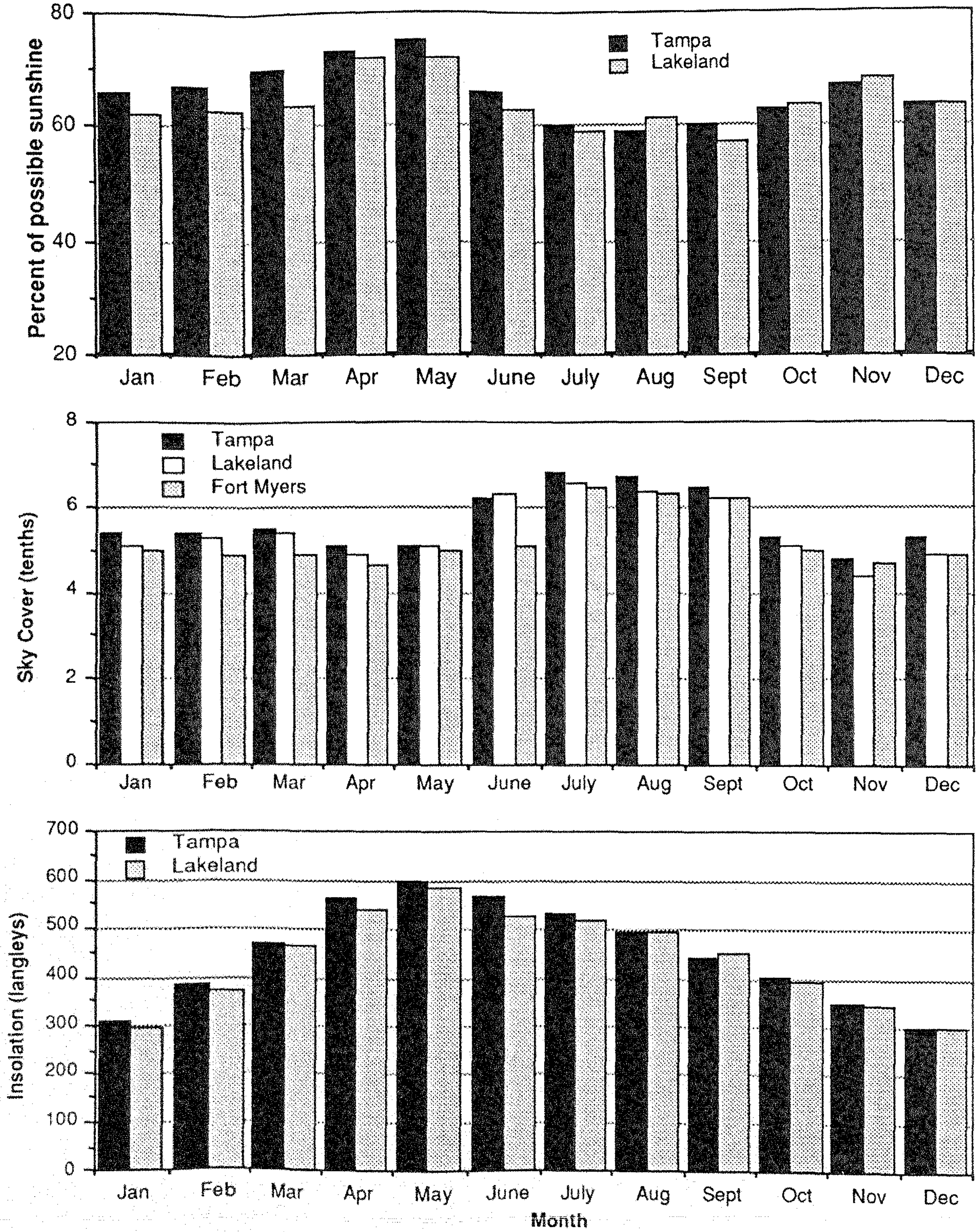


Figure 30. Percent of possible sunshine, daytime sky cover, and solar insolation in southwest Florida (after Bradley 1972; USDC 1978, 1981).

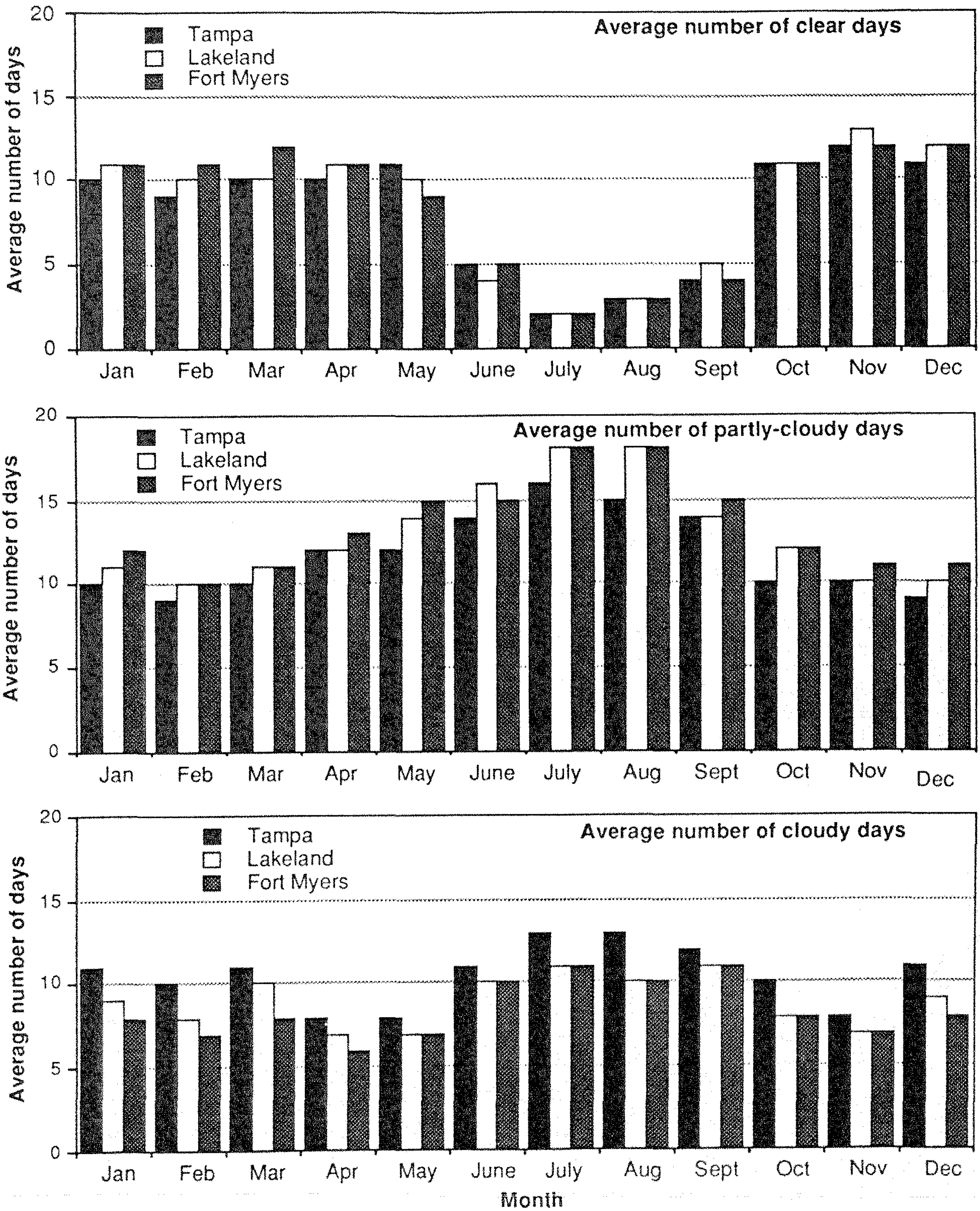


Figure 31. Average seasonal cloudiness in southwest Florida (after Bradley 1972; USDC 1978, 1981).

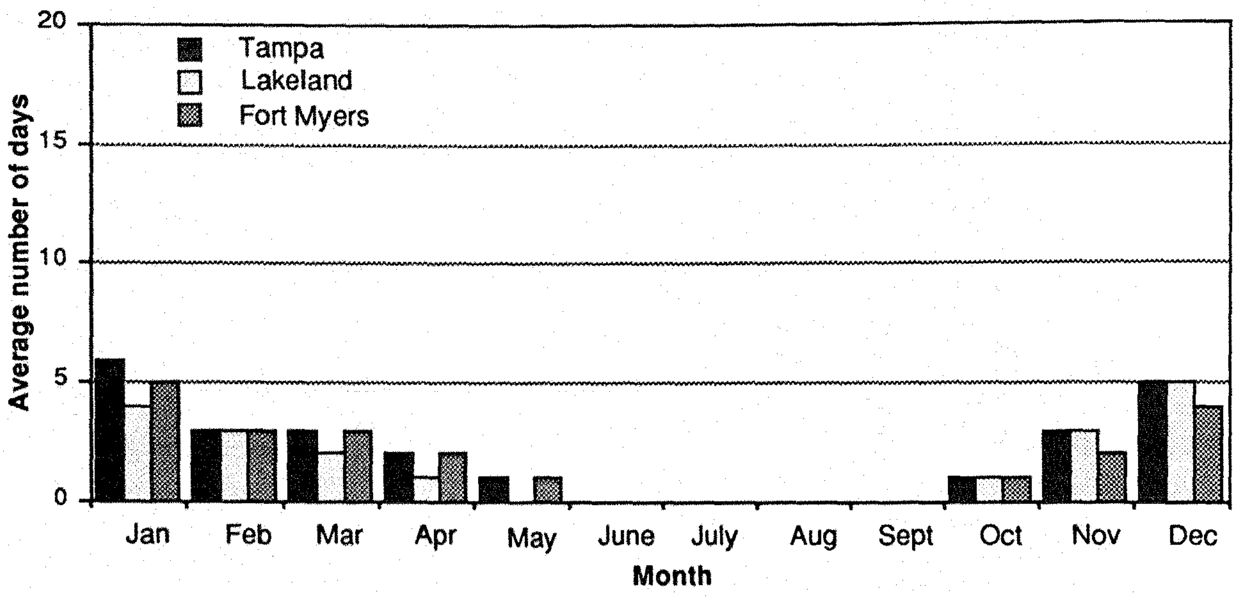


Figure 32. Average number of days with heavy fog in southwest Florida (after Bradley 1972; USDC 1978, 1981).

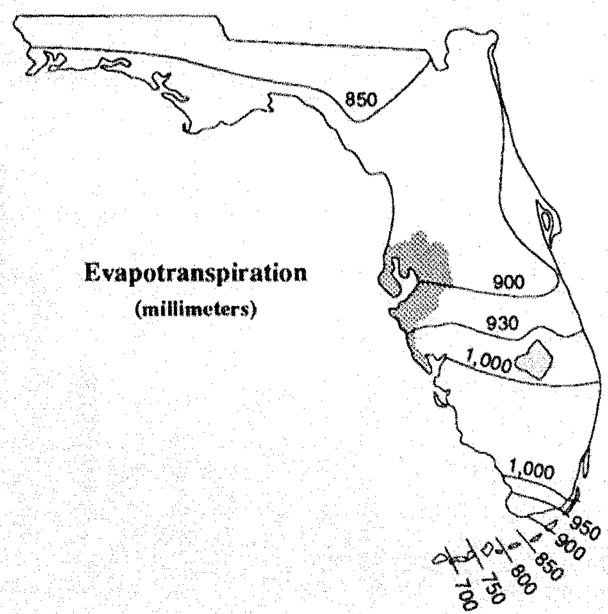


Figure 33. Estimated evapotranspiration patterns in Florida (after Dohrenwend 1977).

evaporation and transpiration (e.g., shallow surface waters and abundant aquatic vegetation). Well-drained uplands exhibit the most variable evapotranspiration rates in response to the variety of vegetative covers, soil types, and water-table depths. Urban areas, in which water is removed through stormwater-drainage systems, retain less water for evapotranspiration than any of the other surface environments.

The monthly pan evaporation at the Lake Alfred Experimental Station in the extreme northern watershed is shown in Figure 34. The pan evaporation is measured using a ventilated pan that is representative of evaporative losses from small, isolated natural shallow pools in the general vicinity of the pan where similar exposure conditions prevail (Parker et al. 1955). The seasonal variation shown in Figure 34 closely follows the monthly solar radiation reported at the Lakeland National Weather Station. A slight lag is probably related to the seasonal availability of moisture. Maximum pan evaporation is in May when the sun approaches summer solstice, spring winds are still strong, cloud cover is still minimal, heavy morning fogs are infrequent, and the relative humidity is near the yearly minimum.

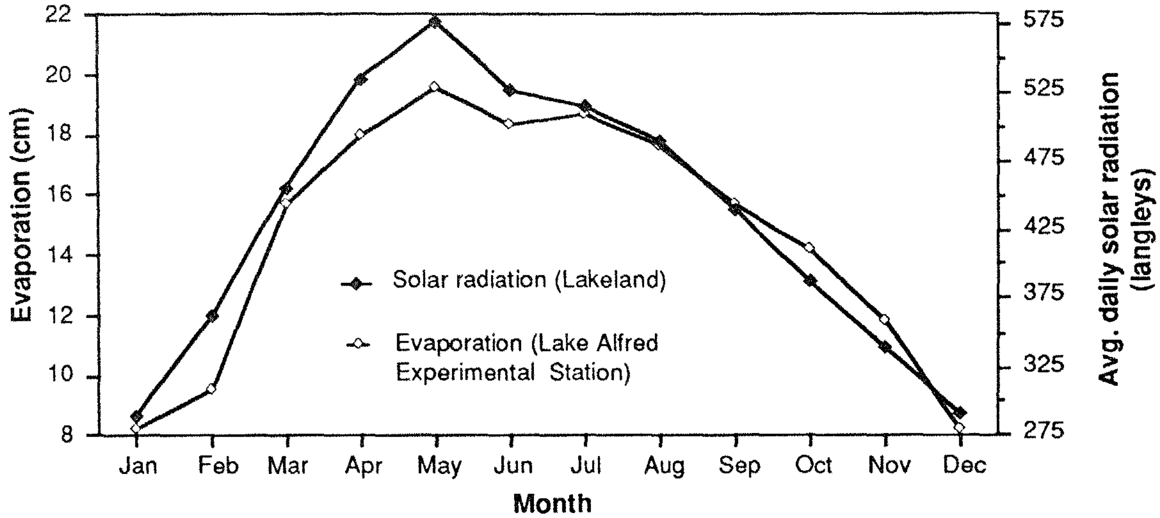


Figure 34. Average monthly evaporation and solar radiation in eastern Tampa Bay watershed (adapted from Parker et al. 1955; USDC 1978).

To estimate localized evapotranspiration rates, the SWFWMD has developed a model that is sensitive to spatial and climatic variations within the district boundaries (Palmer 1978). The model uses four existing evapotranspiration-predictive equations, those of Thornthwaite (1948), Blaney and Criddle (1962), Christiansen (1966), and Penman (1948). The Penman equation considers solar radiation, cloud cover, relative humidity, and wind, and appears most suited for the watershed. However, all four equations are used to estimate areally averaged values of both potential and actual evapotranspiration on a square-kilometer grid-cell level (Wyllie 1981; Bob Evans, SWFWMD; personal commmunication). This approach enables the user to choose one or a combination of the four values predicted. The data are incorporated into a monthly water-balance calculation for each cell (Wyllie 1981). The average monthly potential evapotranspiration for the gulf-coast area from Tampa Bay to Crystal River for each of the equations is illustrated in Figure 35. The Penman and modified Christiansen equations predict an earlier seasonal rise in potential evapotranspiration rates that corresponds to Lake Alfred pan evaporation data (Figure 34) and to evapotranspiration data from Tampa (Seaburn and Robertson, Inc. 1980). It was concluded that these two equations most accurately reflect conditions typical of southwest Florida (Wyllie 1981).

3.8 Hurricanes

The climatic conditions of south Florida may be divided into three energy levels or intensities (Warzeski 1976): prevailing mild easterly winds, winter cold fronts, and tropical storms and hurricanes. The first two were discussed in the sections on wind and rainfall. Tropical storms and hurricanes, because of their relative rarity, their importance as an ecological force, and their unique climatic characteristics, are treated as a separate climatic element.

In summer and fall, low-pressure areas originate in the warm, moist air of the equatorial trough. In these areas, the winds are light and usually drift from east to west. Atmospheric waves form in the easterly flow between 5°N and 20°N and proceed westward at 15 to 25 km/h (Blair and Fite 1965). From this point, the easterly wave development may go through one to four stages of a tropical cyclone (formative, immature, mature, decaying) as described by Riehl (1954).

In the immature and mature stages, the systems generally move westward at 15 to 50 km/h with winds ranging from 61 km/h (38 mph) (tropical depression)

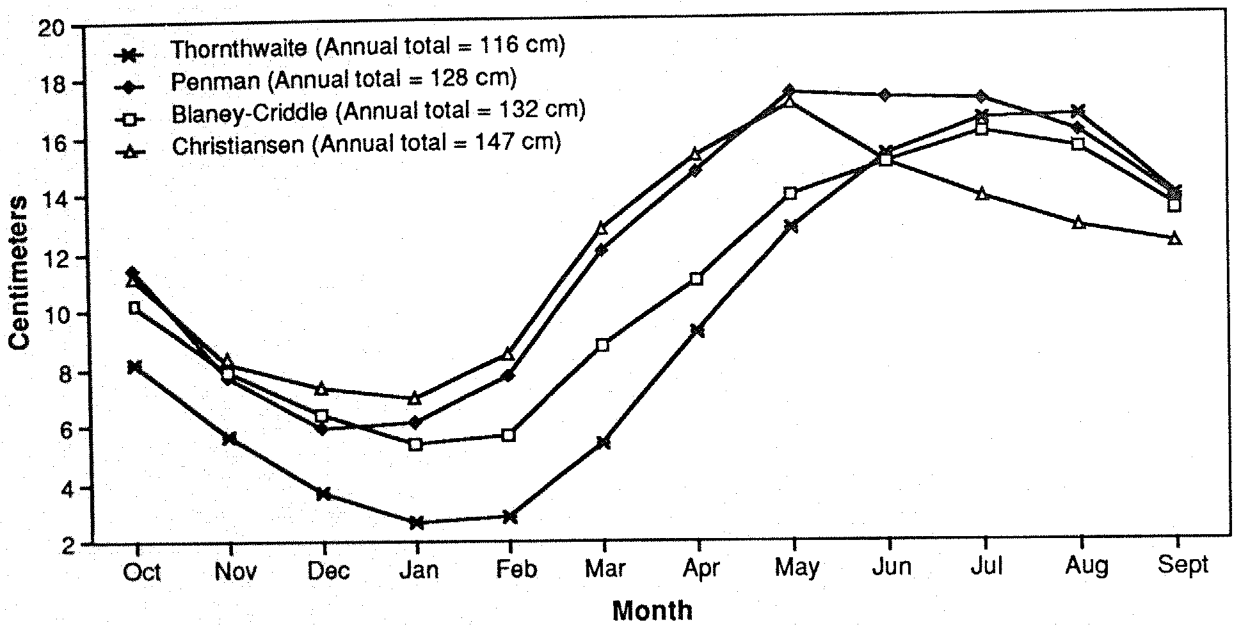


Figure 35. Comparative average potential evapotranspiration in the middle Gulf area as calculated by four models (after Wyllie 1981).

to more than 400 km/h (great hurricane). The typical path is parabolic, although the actual path of any given storm is governed by the winds above it, which cause a multitude of speed and directional changes (Riehl 1954; Blair and Fite 1965; Gentry 1974). Blair and Fite (1965) provide a concise description of the passage of a hurricane over south Florida.

As such a storm approaches, the barometer begins falling, slowly at first and then more and more rapidly, while the wind increases from a gentle breeze to hurricane force, and the clouds thicken from cirrus and cirrostratus to dense cumulonimbus, attended by thunder and lightning and excessive rain. These conditions continue for several hours, spreading destruction in their course. Then suddenly the eye of the storm arrives, the wind and the rain cease, the sky clears, or partly so, and the pressure stabilizes at its lowest value. This phase may last 30 minutes or longer, and then the storm begins again in all its severity, as before, except that the wind is from the opposite direction and the pressure rises rapidly. As this continues, the wind gradually decreases in violence until the tempest passes and the tropical oceans resume their normal repose. The violent portion of the storm may last 12–24 hours.

South Florida has been visited more often by hurricanes and tropical storms than any other equal-sized area of the United States (Gentry 1974). The Tampa Bay watershed is exposed to both Atlantic and Caribbean hurricanes, but is more vulnerable to late-season tropical cyclones moving northeasterly after recurvature (Cry 1965; Bradley 1972; Ho et al. 1975). Points of entry of hurricanes are shown in Figure 36. The Tampa Bay watershed is most often hit in the latter part of the hurricane season, usually September and October. The probability of hurricane-force winds in any year decreases from 1 in 11 at Fort Myers to 1 in 25 at Tampa (TI 1978a). Only 10 or 11 storms of hurricane intensity in 87 years of record have passed inland on the west coast of Florida from Cedar Key to Fort Myers (Heath and Conover 1981). The average forward speed for hurricanes affecting the watershed is 10 knots, with a radius of maximum winds extending an average of 20 nmi from the center (Ho et al. 1975). Detailed descriptions of the passage of specific hurricanes and tropical storms through the

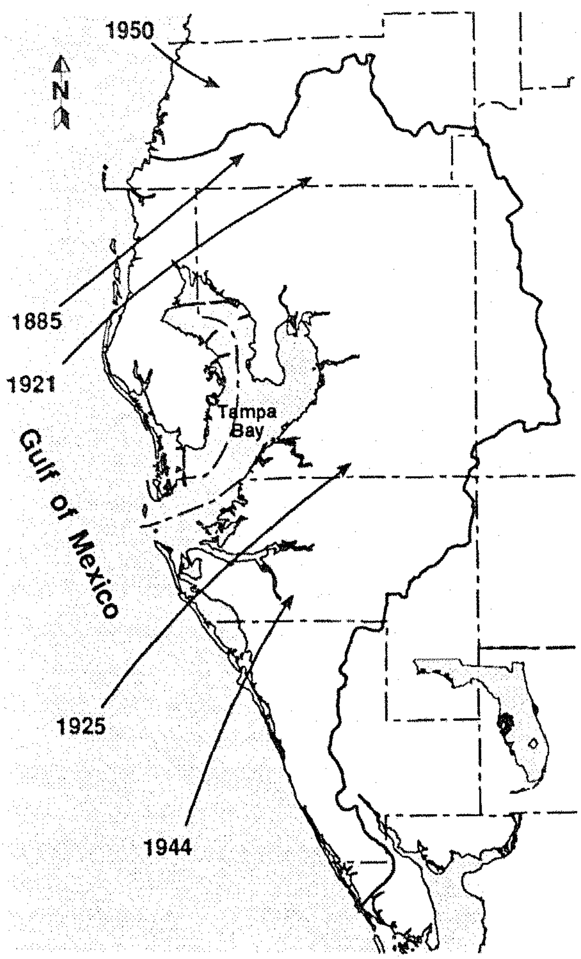


Figure 36. Paths of hurricanes striking the Tampa Bay area 1885 to 1990 (after Jordan 1984; *Monthly Weather Review* 1980–1991).

watershed (as well as the rest of the country) are published in the journal *Monthly Weather Review.*

The primary forces associated with hurricanes are wind, storm surge, and rain. Sustained winds higher than 120 km/h are necessary for a tropical storm to qualify as a hurricane. Sustained winds over 200 km/h put a hurricane into the "Great Hurricane" category. Winds over 200 km/h have been reported in central and south Florida on several occasions in the last century (Sugg et al. 1971). The most notable was the Labor Day hurricane in 1935, which passed over the Florida Keys with high sustained winds estimated at 320–400 km/h according to Bradley (1972).

The ecological significance of hurricanes is clear when one considers that wind force increases by the square of the wind speed. In other words, 150-km/h wind exerts four times as much force as a 75-km/h wind. When hurricane winds exceed 400 km/h, as was estimated for the Labor Day hurricane, their strength becomes almost inconceivable (Gentry 1974). Ball et al. (1967), Pray (1966), and Perkins and Enos (1968) describe the passages of two recent Great Hurricanes, Donna (September 1960) and Betsy (September 1965), through the Florida Keys and how they affected the ecology.

A storm surge is a meteorologically induced tide produced by a combination of high storm winds and low barometric pressure. The low pressure at the storm center or eye creates a vacuum that lifts the waters about 0.3 m for every 2.5 cm of pressure difference or 0.6–1 m for a major hurricane (Bruun et al. 1962). Winds generated by a hurricane cause heavy seas that travel as swell waves in all directions from the eye. Waves to the right of the storm center and running in the direction of the storm movement are generally the highest. As these waves encounter shallow coastal waters, they peak, break, and add to the overall water level toward the coast (referred to as the wave setup). Winds also act on the water surface (shear stress and normal pressure) to push the surface-water layers forward. In deeper offshore waters, this force is balanced by return flow in deeper layers, but in shallower coastal areas, the waters tend to pile up toward the shore. This pileup effect is most significant in the shallow inland lakes and broad continental-shelf bays, and more pronounced when the storm moves directly onshore (right angle to the shoreline). Other factors, such as the offshore slope of the bottom, storm speed and size, and shoreline configuration (e.g., bays, embayments, river estuaries), affect the size and duration of the storm surge (Jelesnianski 1972).

The total storm tide is a combination of the storm surge and the astronomical tide. Added to the top of the storm tide are storm waves, whose pounding forces severely damage coastal structures (Gentry 1974). In Florida, about 75% of all damage related to tropical storms is caused by tidal flooding, with the remaining 25% attributed to winds and rainfall

(Bruun et al. 1962). The U. S. Fish and Wildlife Service has maps showing maximum areas subject to flooding in southwest Florida (Kunneke 1983). Some of the higher storm tides reported along the central Florida gulf coast are presented in Table 8.

One of the highest recorded storm tides along the Florida gulf coast occurred on September 25, 1848, when a 4.5-m tide struck Tampa, destroying much of the port, but causing no loss of life. Seventeen days later a second hurricane caused a 3.0-m storm tide. The first of these two storms was the 100-year hurricane and has been used to estimate potential hurricane flooding in the watershed (Figure 37). A worst-case scenario (a storm the size and intensity of the 1935 Labor Day Hurricane) predicted a coastal storm surge of about 8 m for coastal Pinellas County (Seijo et al. 1979). The most vulnerable coastline areas in the watershed are given in Table 9.

The amount of rainfall from tropical storms varies according to the rate of ascent in the storm circulation, the forward movement, the temperature and lapse rates in the storm, and the moisture content of the air, which must be continuously renewed. Because of the violent nature of the storm, the error in the rainfall measurements may be as high as 50% (Dunn 1967). Usually, 12 to 25 cm of rain are recorded at any one point during the passage of a tropical storm (Gentry 1974). One of the wetter hurricanes to affect Tampa was Brenda (1960) which dropped more than 30 cm of rain within 24 hours (Dames and Moore 1975). Although Great Hurricane Donna (1960) passed over this coastline, it was a comparatively "dry" hurricane. Precipitation was only 5 to 8 cm. Great Hurricane Donna's winds, however, reached 240 km/h at Everglades City and caused extensive storm surge damage along the southwest coast (Bamberg 1980). Maximum winds reported in the watershed during hurricane conditions are given in Table 10.

Table 8. Major hurricane storm tides in the Tampa Bay watershed.

Location	Storm tide height[a] (m)	Date	Reference[b]
Tarpon Springs	3.0	Oct. 1921	1
Caladesi Island	1.9	Oct. 1921	2
Clearwater	2.9	Oct. 1921	2
St. Petersburg	2.3	Oct. 1921	2
St. Petersburg	2.2	Sept.1950	3
Tampa	4.3	Sept.1848	2
Tampa	3.0	Oct. 1848	2
Bradenton	2.1	Oct. 1921	2
Sarasota	2.1	Oct. 1921	2

[a]Storm tide height = Astronomical tide and storm surge.
[b]References: (1) USDC 1957; (2) Bruun et al. 1962; (3) Jelesnianski 1972.

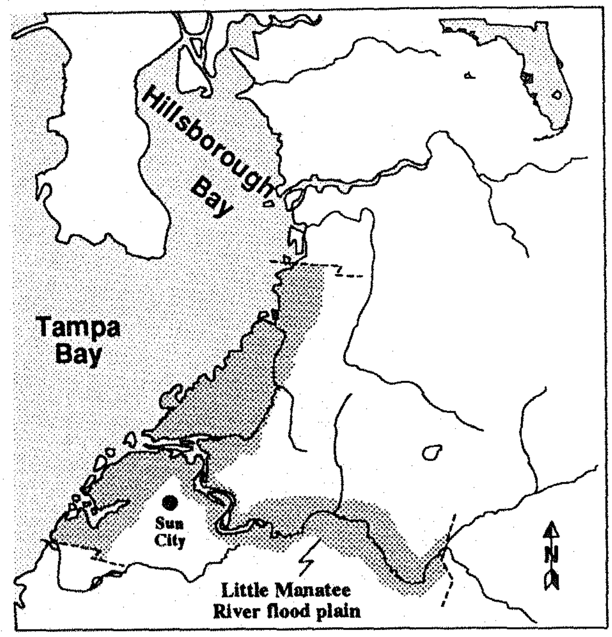


Figure 37. One-hundred-year hurricane flood surge in Little Manatee River (assuming mean annual river-discharge rate) (after Dames and Moore 1975).

3.9 Air Pollution

The sea breeze, moderate inland winds, abundance of sunshine (driving convective processes), and relatively high morning and afternoon mixing heights provide the Tampa Bay watershed with climatic characteristics that enhance the dispersion of pollutants and generally result in good air quality (ESE 1975; TI 1978a). However, portions of the watershed, particularly Hillsborough, northern Pinellas, and western

Table 9. Coastal areas most vulnerable to hurricane flooding in the Tampa Bay watershed (after Bruun et al. 1962).

Coastal region	Specific area(s)	Maximum elevation(s) (m)
South of Sarasota	Siesta Key	Generally <1.5
Sarasota to Tampa Bay	Lido Key[a]	1.2–1.8
	Longboat Key	0.9–1.5
	Anna Maria Key	0.6–1.5
Tampa Bay area	Areas bordering Tampa, Old Tampa, and Hillsborough Bay (e.g., Shell Isle and Davis Island). MacDill Air Force Base, and shore area north of Ballast Point to Hillsborough River.	Most <2.4 Much <1.5
Egmont Channel to Anclote Keys	Long Key	1.7–1.8
	Treasure Island	1.7
	Clearwater Beach Island	1.5

[a]New Pass formed from 1848 hurricane breakthrough.

Polk Counties, have consistently shown high levels of air pollutants that violate State and Federal air quality standards (EPA 1972; Ped Co. 1976; Bowman 1977; Urone and Chadbourne 1977; FDER 1978, 1979a,b; Gutfreund 1978; TI 1978a; HCEPC 1984). Elsewhere in the watershed, local or transient air-pollution problems associated with intense urbanization (e.g., construction, vehicular traffic, and fossil-fuel power plants) cause localized poor air quality, but not at the levels observed in the industrialized areas of Hillsborough, Pinellas, and Polk Counties.

Table 10. Maximum winds reported in the Tampa Bay watershed (after USDC 1957; Bruun et al. 1962; Seijo et al. 1979).

Location	Wind speed (km/h)	Date
Tampa	130	Oct. 18, 1910
	135	Oct. 19, 1944
	138	Sept. 4, 1935
Tarpon Springs	129 (129–160)	Oct. 25, 1921
Sarasota	124	Oct. 19, 1944

The atmospheric emission-transport mechanisms that convey contaminants from the air to the earth's surface depend on the nature of the substance and the regional weather patterns. Atmospheric contaminants take three forms: small particulate matter that can form condensation nuclei, suspended particulate matter or liquid aerosols that can be scavenged by falling raindrops, and solutes dissolved in condensation particles or cloud droplets (Echternacht 1975; Brezonik et al. 1982; ESE 1984). The sources for the three forms and their geographic distribution depend on weather patterns.

Large-scale synoptic (or pressure) systems that pass over the watershed in the dry season (November to April) may contain pollutants from sources far removed from the State (Echternacht 1975), in addition to localized sources (Holle 1971; TI 1978a; Edgerton 1981). Wet-season diurnal land/sea breezes carry atmospheric contaminants, primarily from local sources such as automobile emissions; stack gases; road, fertilizer, and pesticide dusts; and phosphate mining, transport, and processing emissions (Holle 1971; Echternacht 1975; TI 1978a; HCEPC 1984).

Airborne contaminants from the atmosphere are carried to the land and water surface by either wet or dry fallout (Irwin and Kirkland 1980). Materials subject to dry fallout are in a continuous flux of suspension and deposition (e.g., wind generated dust, bacteria, spores, pollens, car emissions) (HCEPC 1984). Materials deposited during wet fallout or rainfall, in either a dissolved or particulate form, are affected by two processes referred to as rainout and washout (Echternacht 1975). Semonim and Adams (1971) describe rainout as the removal of aerosols in the rainmaking process, and washout as the process of falling rain scavenging airborne particulates. In central and south Florida, phosphate (PO_4) in particulate form is subject to washout as well as to dry fallout year round (Echternacht 1975; Brezonik et al. 1982). In contrast, nitrogen as NO_x is primarily a soluble gas and is, therefore, removed in the rainout process. Edgerton (1981) found NO_x to be a significant airborne contaminant in the Tampa area, and levels of NO_3^-, NH_4^+, and SO_4^{2-} were observed to decrease with distance from the urban-industrial center. Total atmospheric fallout is commonly reported as bulk precipitation and includes all soluble and insoluble materials (Irwin and Kirkland 1980). Highest rates of total atmospheric fallout are commonly observed in agricultural areas and near major point sources; i.e., fossil-fuel power plants (Brezonik et al. 1982; HCEPC 1984). Lowest nutrient fallout amounts are reported in undeveloped coasts and forested areas.

Although most of the total annual bulk-precipitation load is deposited in the wet season, pollutant concentrations in rainfall are highest in the dry season (Echternacht 1975; Waller and Earle 1975). The South Florida Water Management District's rainwater chemistry data illustrate this seasonal difference of nitrogen and phosphorous concentrations. Peak concentrations in the spring months, characterized by high winds and low rainfall, are representative of high dry-fallout conditions (Figure 38). Fire is also believed to be a factor in inhancing the concentration of dry fallout in the dry season (Holle 1971; Waller

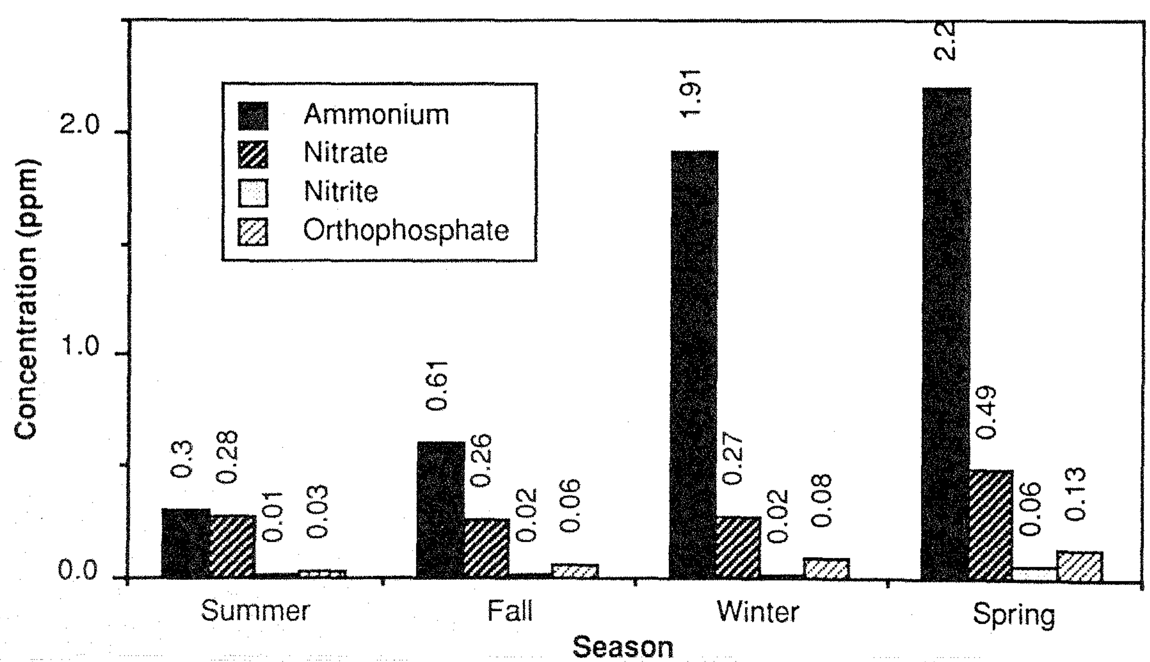


Figure 38. Seasonal average nutrient concentrations in rainwater at Tamiami Trail and Forty-Mile Bend (after Echternacht 1975).

and Earle 1975). Summer months, during peak rainfall and maximum dilution, show the lowest concentrations of dry fallout.

An important factor controlling the ecosystem's exposure to air pollutants is the frequency and duration of atmospheric inversions. The temperatures normally decrease with increasing altitude, but occasionally the reverse is true; that is, the temperature increases with height in a given atmospheric layer or between layers. This phenomenon is called an inversion of temperature or simply an inversion, and is common on calm, clear nights when the surface cools rapidly by radiant heat loss. The near-surface air is cooled by conduction and radiation faster than the air above it, creating an inversion—a stable equilibrium in the air column with cooler air at the surface. When air temperatures decrease with height (a condition favorable to convection), the air column is unstable (Blair and Fite 1965). The significance of inversions to air quality is that they reduce mixing, dilution, and dispersion of air pollutants, because air within an inversion is trapped. The near-ground pollutants, such as vehicle emissions, can build up to levels that constitute a health hazard (Gutfreund 1978).

Low-level inversions are least frequent and shortest in the southern part of the watershed, increasing in duration and frequency from the coast inland (Hosler 1961; Gutfreund 1978). Inversion frequency typically decreases with height and is observed most often in the surface-to-26-m layer. Seasonally, they are more common in winter and fall and least common in spring. They frequently form between 2200 and 0700 hours, with minimum frequency at 1000 hours. Land/sea breezes generally prevent the significant buildup of atmospheric pollutants in the watershed (Gutfreund 1978; TI 1978a).

Several studies, including the Hillsborough County Environmental Protection Commission (HCEPC) biannual reports, the State of Florida air quality statistical reports, and several privately and publicly funded studies (i.e., TI 1978a,b,c areawide impact assessment program) focus on air pollution in the Tampa Bay watershed. Although not as current as the State or local program reports, the EPA-funded TI (1978a) study is the most comprehensive. It is a compilation of the major air-pollutant sources, monitoring sites, and dispersion characteristics of west-central Florida (excluding Pinellas County). The following information is largely drawn from this report, and is supplemented by more current and site-specific data (e.g., HCEPC 1982, 1984).

The air pollutants of primary concern in the Tampa bay watershed and their probable sources are listed in Table 11. The sources are generally reported as point sources (e.g., exhaust stacks), or areal sources (e.g., forest fires, dust from unpaved roads). As shown in Appendix Table A-2, fossil fuel power plants and the phosphate industry are the most important SO_2 and total suspended particulates (TSP) point-sources, accounting for 97% of the SO_2 emissions and 80% of the TSP emissions (TI 1978a).

Power plants in 1976, particularly in Hillsborough County, accounted for 77% of the SO_2 point-source emissions (Appendix Table A-2), and 76% of the total (point- and areal-source) emissions in the region (Appendix Table A-3). The only SO_2 nonattainment area in Florida is situated in northern Pinellas County, where 22 violations were reported from July 1977 to April 1978 (FDER 1978). Probable point sources are a phosphate-processing plant, a fossil-fuel power plant, and an asphalt batch plant. Many of the 3-hour violations were observed in evening and early morning (1700 to 0600) when inversion frequency is the greatest. Annual sulfate load in Hillsborough County decreased from 1974 to 1978, and from 1978 to 1983 has stabilized in spite of an increase in the number of point sources (TI 1978a; HCEPC 1984). The decrease in loading was caused by implementation of air pollution abatement practices (e.g., higher stack heights, lower sulfur fuels), particularly from 1974 to 1976 (Appendix Table A-2, Figure 39). No violations of Federal or State standards were reported in Hillsborough County in 1982 and 1983 (HCEPC 1984).

Additional sources of SO_2 not addressed in the TI (1978) study include imported atmospheric sulfur from both continental and maritime areas, and natural biogenic sources of sulfur within the region. These may represent significant inputs into an area's total sulfur budget, particularly in nonindustrialized, rural regions (Adams et al. 1980; Edgerton 1981; ESE 1982a,b, 1984; Brezonik et al. 1982).

Table 11. Major air pollutants in the Tampa Bay watershed and their probable sources (after TI 1978a).

Pollutant	Probable source	Activity	References[a]
Sulfur dioxide	Fossil fuel power plants	Burning of sulfur containing fossil fuels.	1,10,12.
	Phosphate industry	Burning sulfur-containing fossil fuels.	2,10.
		Manufacture of sulfuric acid (an acid mist is also generated).	9.
	Other	Mobile emissions, stationary fuel combustion, incineration, citrus heaters, cement producers.	1,3,10,12 .
Dust [b]	Fossil fuel power plants	Fuel burning.	1,3,10.
	Phosphate industry	Fuel burning, drying, grinding, and material transport; other stages of mining.	8,10.
	Other	Small single-family or apartment heaters and incinerators, mobile sources, citrus heaters, bacteria, soil and meteoritic dust, spores and pollen, salt, cement processing, factory dust, and traffic.	10,11.
Fluorides	Phosphate industry	Various chemical processes, drying and calcining, fluoride removal for feed preparation, gypsum, and cooling-water ponds.	4,5,6,10.
^{222}Radon	Phosphate industry	Ground disturbance associated with strip mining leads to a redistribution of uranium-238 and its decay products.	7.
Lead	Industry	Lead smelting and refining, scrap-metal recovery, and battery manufacture.	10.
	Other	Burning of leaded gasoline.	10.
Nitrogen oxides and carbon monoxide	Fossil fuel power plants	Fuel burning	10,12.
	Other	Mobile emissions, any industrial process burning fuels.	10,12
Ozone	Product of reaction between hydrocarbons and nitrogen oxides	Autos, gas stations, gas terminals, gas tankers, car-undercoating operations, paint manufacturers, dry cleaners, auto refinishers.	10.

[a] References:

(1) Ped Co. 1976	(5) Tessitore 1975	(9) USEPA 1976
(2) USEPA 1977	(6) Tessitore 1976	(10) HCEPC 1982, 1984
(3) Ped Co. 1975	(7) Guimond and Windham 1975	(11) TI 1978a
(4) ESE 1977a	(8) FDER 1977	(12) ESE 1982b

[b] as total suspended particulates (TSP).

Although in 1976 the phosphate industry dominated the TSP point-source emissions (54%) in west-central Florida (Table 11), it contributes only about 17% of the total TSP loading to the watershed (Tables 11 and Appendix Table A-2). Vehicular emissions, dust from paved and unpaved roads, trash and garbage incineration, agricultural burning, and forest fires are areal sources that account for the largest part (56%) of the TSP emissions (Appendix Tables A-2 – A-4). Hillsborough County is one of the two Florida counties designated as a TSP nonattainment area by the U.S. Environmental Protection Agency (FDER 1978). Several stations located in the Hillsborough Bay area have reported primary (Federal) and secondary (State) 24-hour and annual geometric mean value violations in 1982 and 1983 (HCEPC 1984). The primary sources that contribute to these violations are National Sea Products, Hookers Point, and Gardinier Park, and to a lesser extent, fugitive dust from traffic and dust-producing industries (e.g., General Portland Cement, Florida Steel Corporation). Implementation of pollutant-control devices between 1974 and 1976 significantly reduced TSP and SO_2 point-source emissions (Appendix Table A-2, Figure 39 and 40) (TI 1978a; Gutfreund 1978; HCEPC 1984). Fluoride emissions in the watershed are confined to mining

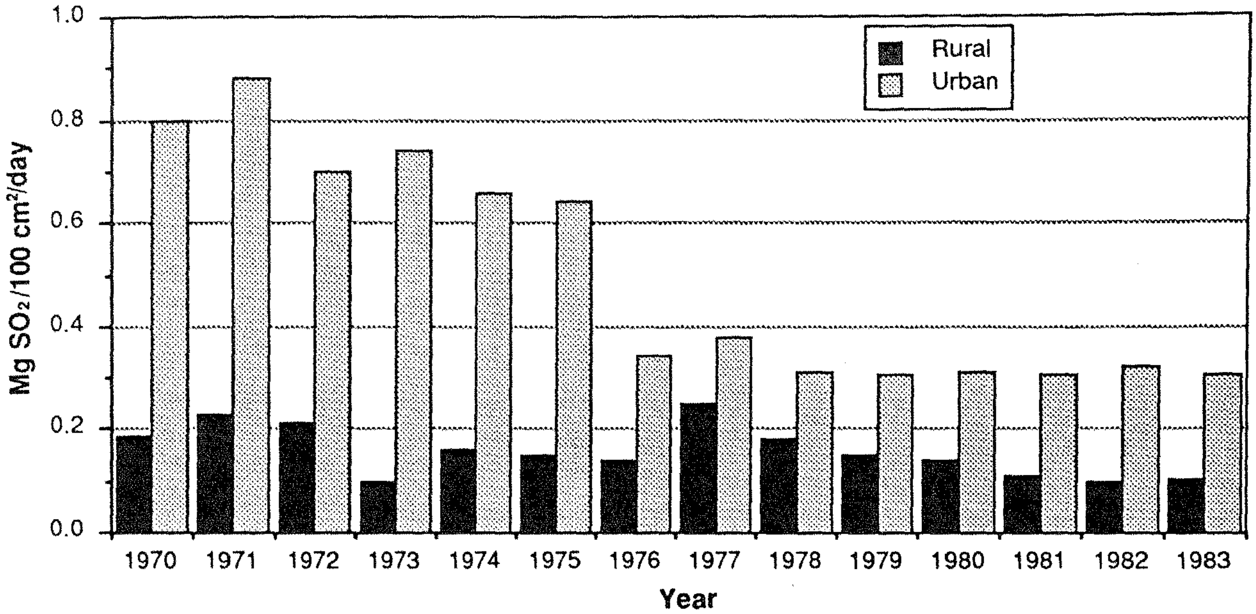


Figure 39. Average daily concentrations of airborne sulfur dioxide in the rural and urban Tampa area for the years 1970–83 (after HCEPC 1984).

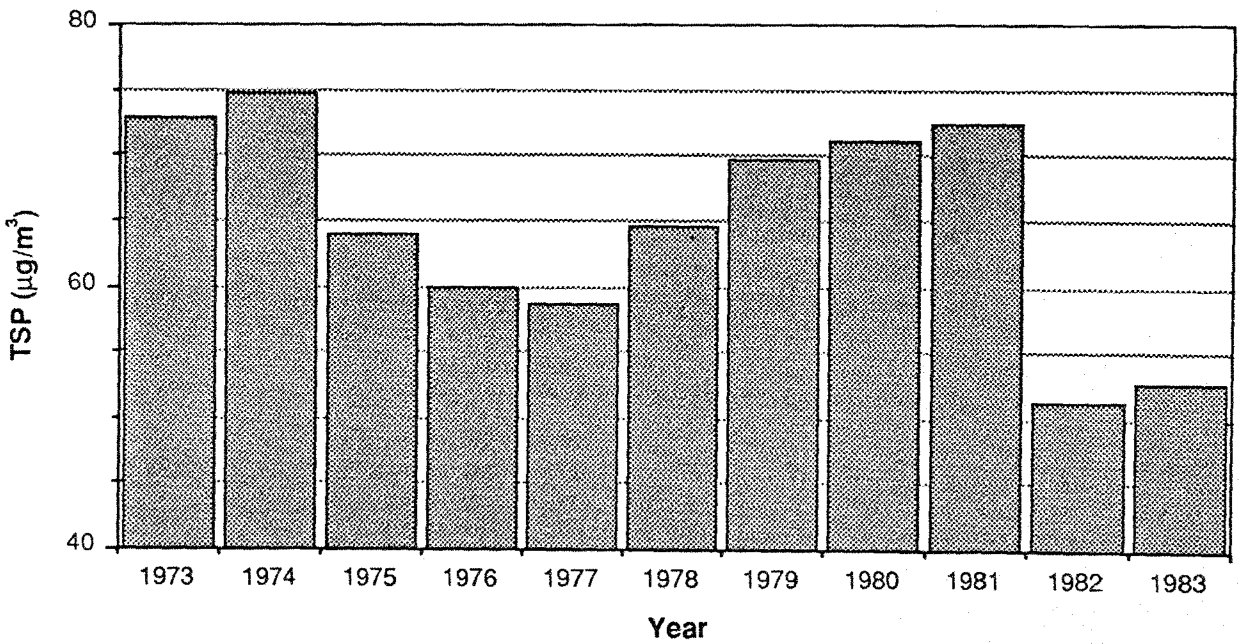


Figure 40. Annual suspended-particulate emissions in the Tampa area during 1973–83 (after HCEPC 1984).

activities, principally in eastern Hillsborough County and western Polk County (Table 12). The areal-source emissions (from holding ponds) are approximately five times as great as reported for point-source emissions. These emissions have, in some areas, increased pasture-grass fluoride content to levels exceeding 45 ppm (level considered to be hazardous to foraging cattle) (TI 1978a; HCEPC 1984).

Ozone (0_3) production at ground level is related primarily to a photochemical atmospheric reaction between reactive volatile organic compounds (RVOC), nitrogen oxides, and sunlight (HCEPC 1984). Reactive volatile organic compounds, which vaporize into the atmosphere as reactive hydrocarbons, are emitted from such stationary sources as gasoline storage and transfer operations and industries that use solvents and surface coatings containing organic compounds. Most reactive hydrocarbons, however, come from motor-vehicle exhaust systems. Nitrogen oxides result almost entirely from combustion in electric-power generation units or gasoline, diesel, and jet engines (FDER 1979b). Hillsborough, Pinellas, and seven other Florida counties were identified as photochemical-oxidant nonattainment areas by EPA (FDER 1979b). From January 1977 to October 1977, Pinellas County had 11 violation periods.

After September 7, 1982, the 1-hour ozone standard in the State was increased from 80 to 120 ppb, matching the Federal standard. Even with the laxer standard, several sites in the Hillsborough Bay area reported violations (e.g., Davis Island in 1983, [HCEPC 1984]). From 1973 to 1983 the number of days each year that exceeded 80 ppb in Hillsborough County remained fairly constant; slightly fewer days have exceeded the new standard of 120 ppb (Figure 41) (HCEPC 1984). Ozone levels show a strong diurnal pattern corresponding to increases in sunlight and vehicular traffic. Hourly ozone averages generally peak between 1200 and 1800 hours.

Table 12. Summary of fluoride point-source and areal-source (pond) emissions in Polk, Hillsborough, and Manatee counties (after TI 1978a).

	Total emissions (t/yr)		
	Pond emissions		Point sources
County	1974	1976	1976
Polk[a]	1,120	1,211	244
Hillsborough[a]	320	346	69
Manatee	15	15	2
Total	1,455	1,573	315

[a] Fluoride product recovery at one plant in Polk County and two plants in Hillsborough County tend to reduce pond emissions. Since no quantitative data exist on the extent of the reduction, it is not reflected in the numbers tabulated.

Additional air pollutants whose concentrations are tied to the diurnal pattern of vehicular traffic in the area are lead, carbon monoxide, and the nitrogen oxides. All these pollutants have decreased since 1973, apparently the result of the use of catalytic burners and lead-free gasoline in automobiles, and the implementation of air-pollution abatement practices at fossil-fueled power plants (HCEPC 1984). Although higher levels of all three pollutants correspond to the areas within the Tampa Bay watershed with higher populations and more traffic, no violations were reported in 1982 or 1983 (HCEPC 1984).

The pH of "pure" rain is controlled by the dissolution of atmospheric CO_2, forming a weak carbonic acid (H_2CO_3) with a pH of about 5.6. When factors such as alkaline dust and ocean spray that are characteristic of the Tampa Bay watershed are taken into account, the pH of rain approaches 7.0 (Brezonik et al. 1982). However, with the release of sulfur and nitrogen acids to the atmosphere (forming H_2SO_4 and HNO_3) from anthropogenic sources, (e.g. fossil-fuel combustion) and from biogenic sources (e.g., salt marshes), rainwater pH (particularly in urban-industrial areas) is drastically lowered (Brezonik et al. 1982; ESE 1984). The resulting acidic rainfall increases soil- and surface-water acidity and alters the capacity of the soils and organic materials to retain nutrients, metals, and exotics such as organochlorinated hydrocarbons. Although a released nutrient may boost plant food supply, the effect is short-lived, for the released nutrients are also more susceptible to leaching. Thus, on a long-term basis, the shift in acidity and subsequent loss of nutrients mean use of more fertilizer to sustain crop yields. In addition, toxic

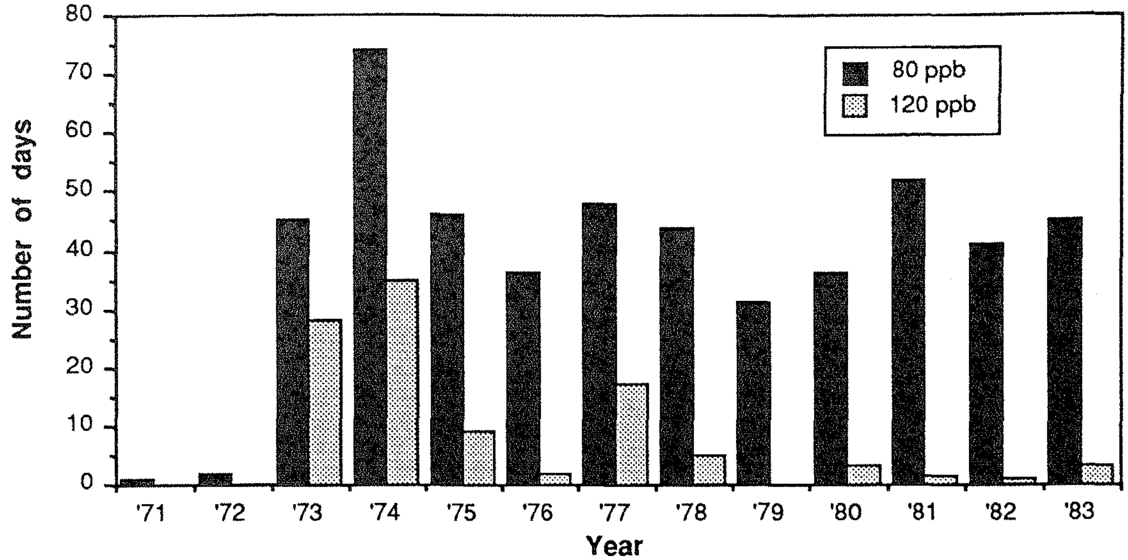


Figure 41. Number of days each year on which ozone concentration exceeded 80 ppb and 120 ppb in the Tampa area during 1971–83 (after HCEPC 1984).

metals and exotics become available to the hydrologic cycle, either by percolation into ground water or by dissolution back into the surface waters from bottom or suspended sediments (Brezonik et al. 1982). Edgerton (1981) studied the problem of atmospheric acid deposition in the Tampa Bay watershed by comparing sulfur, nitrogen, and acid fallout at seven sites in the area. Although all samples exhibited acidities higher than pure water in equilibrium with atmospheric CO_2, the area's rainfall was no more acidic than observed at most other locations in Florida (extreme south Florida was higher). However, the anions SO_4^{2-} and NO_3^- and cations Ca^{2+} and Mg^{2+} were reported in much higher concentrations in the Tampa area than elsewhere in the State. High levels of SO_4^{2-}, Ca^{2+}, and NH_4^+ in the area were tied back to the region's intensive industrial and surface activity (Edgerton 1981). These ions and others, e.g., NO_3^-, generally decreased a relatively short distance from the urban-industrial center, as, surprisingly, did the pH values. The decrease of pH in rainfall away from the industrial area was explained in the following manner (ESE 1982b):

> ...the mix of atmospheric emissions in the immediate area is such that the majority of acidity in Tampa area rain is neutralized by locally suspended particulate matter, principally calcium carbonate. Such particles, however, have significant deposition velocities and are redeposited close to Tampa, while the acid precursors (SO_2 and NO_x) may travel much greater distances."

Other studies (Brezonik et al. 1982; ESE 1982b, 1984) observed pH values from the Tampa Bay region to average less than 4.7. Summer rains were generally 0.2 to 0.3 pH units lower than winter precipitation. Sulfuric (H_2SO_4) and nitric (HNO_3) acids account for 70% and 30%, respectively, of the excess acidity (Brezonik et al. 1982).

Chapter 4. Hydrology and Water Quality

Richard D. Drew

4.1 Introduction

Perhaps nowhere else in Florida are conflicts over water supply and optimum use more sharply defined than in the west-central region. The large and rapidly growing urban populations of Tampa, St. Petersburg, Clearwater, and Sarasota place increasing demands on potable water resources and compete with water-intensive industrial and agricultural users for the regional water supply. The development of reservoirs and well fields to meet existing and projected demands alters the magnitude and timing of freshwater discharge to the estuarine environment. Shortfalls in local sources have inspired some investigators to propose importing water from as far north as the Suwannee River (Geraghty and Miller, Inc. 1977).

Once the water's immediate usefulness ends, it is disposed of in the form of sewage and industrial waste, urban runoff, mine processing waste, and agricultural runoff to the local surface and ground waters. For Tampa Bay, waste disposal has resulted in fish kills, algal blooms, phosphate slime pond spills, sewer overflows, closed shellfish areas, reduced seagrass meadows, and the loss of aesthetic appeal (Simon 1974; FDER 1980,1983; Metcalf and Eddy, Inc. 1980, 1983; HCEPC 1982, 1984).

In addition to upland urban, industrial, and agricultural development, the Bay itself has been physically modified to facilitate real estate development, traffic flow, and waterborne commerce. In 1974 a total of 65 km of dredged channels, ranging in depth from 6 to 11 m, cut across the Tampa Bay system (Simon 1974). The 60 km of causeways that cross the bay system reduce flushing of bay waters to a third of the natural rate. Shoreline real estate development has created extensive finger canals and seawalls where there were once mangroves and salt marshes. Old Tampa Bay, Hillsborough Bay, and Boca Ciega Bay are the areas most affected by these modifications (Getter et al. 1983).

The Tampa Bay system's ability to support and produce fish and wildlife is often reduced in this ongoing water supply and water-use struggle. Upstream water diversion, land development, and increased consumption alters the timing and magnitude of freshwater supply to the freshwater wetland and estuarine ecosystems, while urban and agricultural runoff and sewage and industrial discharge change its chemical nature. Dredging, filling, and shoreline modifications of the bay and its major tributaries chronically remove valuable breeding and nursery habitats, destroy bottom communities, and resuspend settled nutrients.

Describing water quality and quantity in the Tampa Bay watershed is very difficult, considering the wealth of past studies and the great number of ongoing or recently completed studies. This chapter attempts to summarize the available information by geographic divisions or major river and receiving water drainage areas. The Tampa Bay watershed, for this purpose, is divided into eight drainage areas, including the Anclote River; West Pinellas Peninsula; Eastern Pinellas Peninsula/Old Tampa Bay; Hillsborough River/Tampa Bypass Canal; Alafia, Manatee, and Little Manatee Rivers; and Manasota Coastal area. Tampa, Old Tampa, and Hillsborough Bays are discussed separately. Land use, point sources, and nonpoint sources are briefly described for each drainage area to provide an insight into what is entering the waters (either natural or of human origin), followed by a review of the area hydrology and water quality.

Ground water is treated from a general watershed perspective. It is included in the Tampa Bay watershed characterization because of its direct connection to the watershed surface waters via springs, seepage, sinkholes, water supply, and subsurface disposal. Information is presented vertically by aquifer and horizontally with changes in geologic strata and saline interaction.

4.2 Ground Water

Ground water in the Tampa Bay watershed is present in two aquifers, the surficial and the Floridan, generally separated by a confining bed of dense clay. The thickness, lithology, depth, and distribution of these units are spatially quite variable (Figure 42). The generalized hydrogeologic relationship among these units is illustrated in Figure 43.

The surficial aquifer is nonartesian and consists predominantly of fine to very fine sand and clayey sand interbedded with clay, marl, shell, limestone, and phosphorite of primarily Pliocene to Recent origin (Figure 42). Typically, it ranges from 6 to 12 m in thickness, but may reach 30 m under ridges near the northern and eastern boundaries of the watershed (Motz 1975; Wehle 1978; Wilson and Gerhart 1980; Brown 1982b; Henderson 1983). The surficial aquifer is absent where the limestone of the Floridan aquifer or the confining layer nears or reaches the surface.

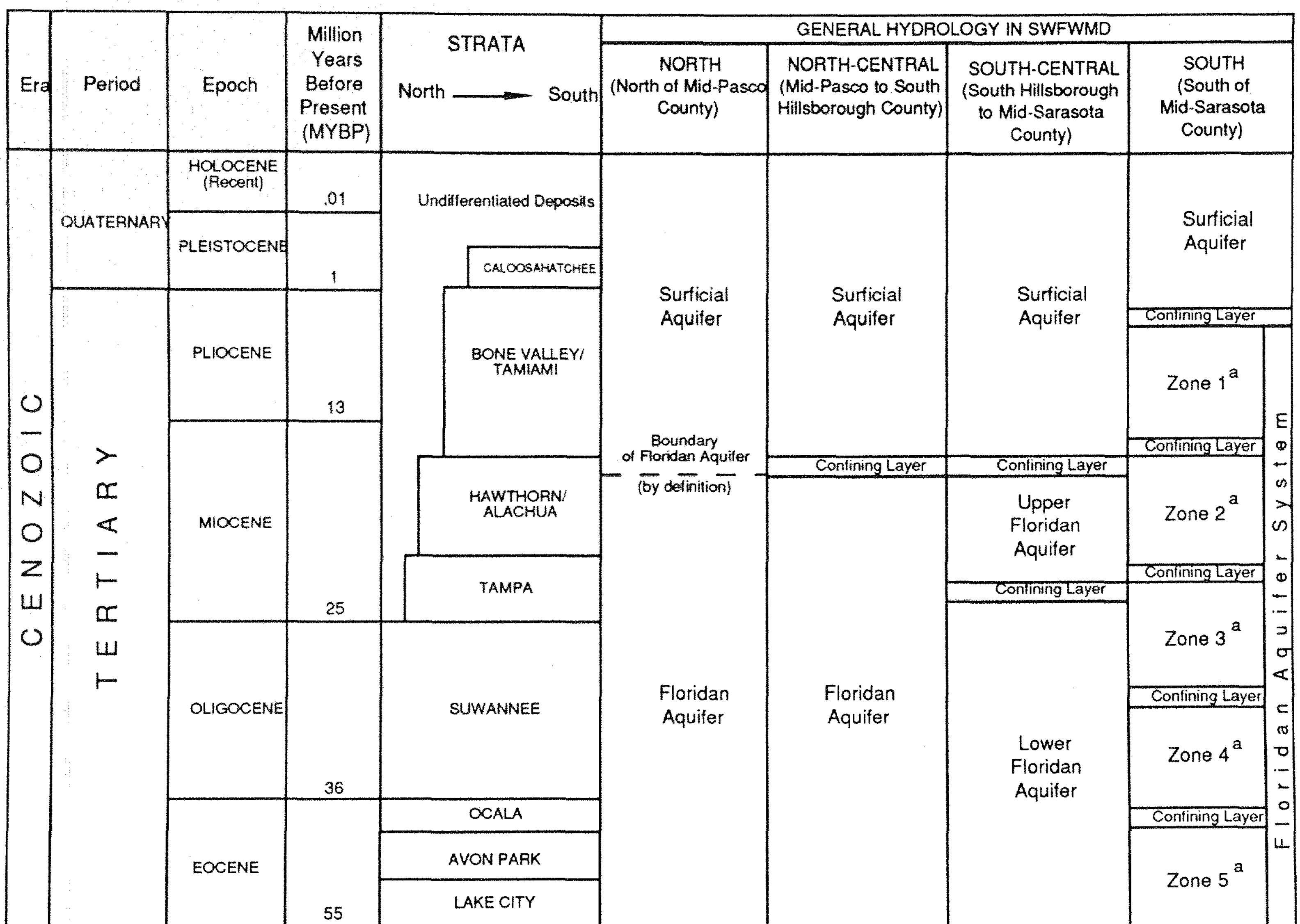
Yield from the aquifer is as variable as its thickness. Transmissivity is a measure of an aquifer's ability to have water pumped from a well without lowering the water table. Transmissivity for the water table (surficial) aquifer ranges from zero, where the thickness is less than a few meters, to about 2,000 m^2/day (Geraghty and Miller, Inc. 1976, 1977; Wilson and Gerhart 1980).

Water-table gradients and direction of flow usually conform to local topography, so that steeper gradients adjoin major stream courses and gentle gradients characterize the broad interstream areas (Wehle 1978; SWFWMD 1981). Water in the surficial aquifer flows laterally toward local points of discharge (e.g., lakes, streams, ditches, wells, sinks) grading down toward the Gulf of Mexico or Tampa Bay, and downward as leakage through the confining layer to recharge the Floridan aquifer (Stewart et al. 1978). In poorly drained areas, the water table is at or near the land surface (e.g., Cypress Creek, Green Swamp), but generally it lies 1.5–15 m below (Motz 1975; Wehle 1978; Hickey 1981a; Brown 1982a,b).

Seasonal changes in the height of the water table typically range from 0.5 to 1.5 m, with peak heights reached in the rainy season and midwinter. Lower levels correspond to the end of the dry season, commonly May (Tibbals et al. 1980; Hickey 1981a; SWFWMD 1981; Brown 1982a,b). Along coastal margins, daily fluctuations are caused by tides (Hickey 1981a). Two hydrographs, illustrated in Figure 44, show no significant trends in water levels from 1965 to 1976, other than that expected from annual rainfall variation.

In some areas of the Tampa Bay watershed, the surficial aquifer has been affected permanently by human activities. One example, the construction of the Tampa Bypass Canal from 1970 to 1982, diverted high-flow flood waters away from the middle Hillsborough River to the Six Mile Creek/Palm River system. The canal penetrated a ridge separating the two river systems and cut through a wet, flat upland area called Harney Flats. The lower water level in the canal has increased drainage from the surficial aquifer on lands adjacent to the canal, lowering the water table. The canal also broke through the confining layer, creating a new, larger outflow point for the artesian aquifer that reduced flow to Eureka Springs and seepage springs in Harney Flats. The net effect of the canal, even with control structures to maintain water-level heights in the canal, was a 0.5 to 1.5-m lowering of the surficial aquifer in Harney Flats and Eureka Springs area (Motz 1975; Duerr and Stewart 1980; USGS 1983).

The confining layer that separates the surficial from the Floridan aquifer is typically formed by a carbonate and clastic sequence composed of clay, silt,



[a] Zones 1 and 2 are considered by some authors to be intermediate aquifers, and Zones 3, 4, and 5 to represent the Floridan aquifer in Manatee and Sarasota counties (Brown 1982b; Sutcliffe and Thompson 1983; Wolansky et al. 1983).

Figure 42. Generalized hydrogeology in the Southwest Florida Management District (after Wehle 1978).

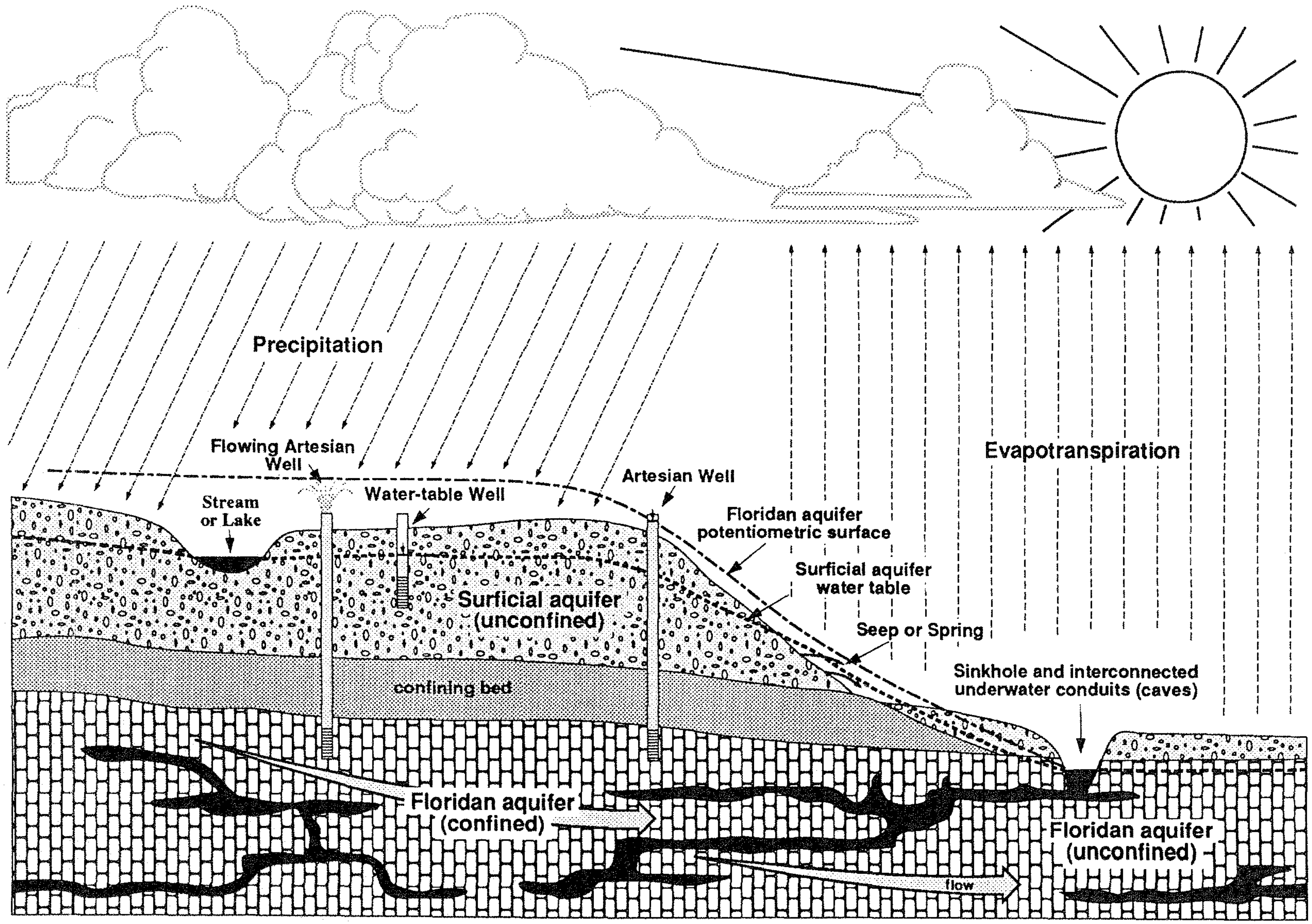


Figure 43. Generalized hydrogeologic relation between surficial and Floridan aquifers.

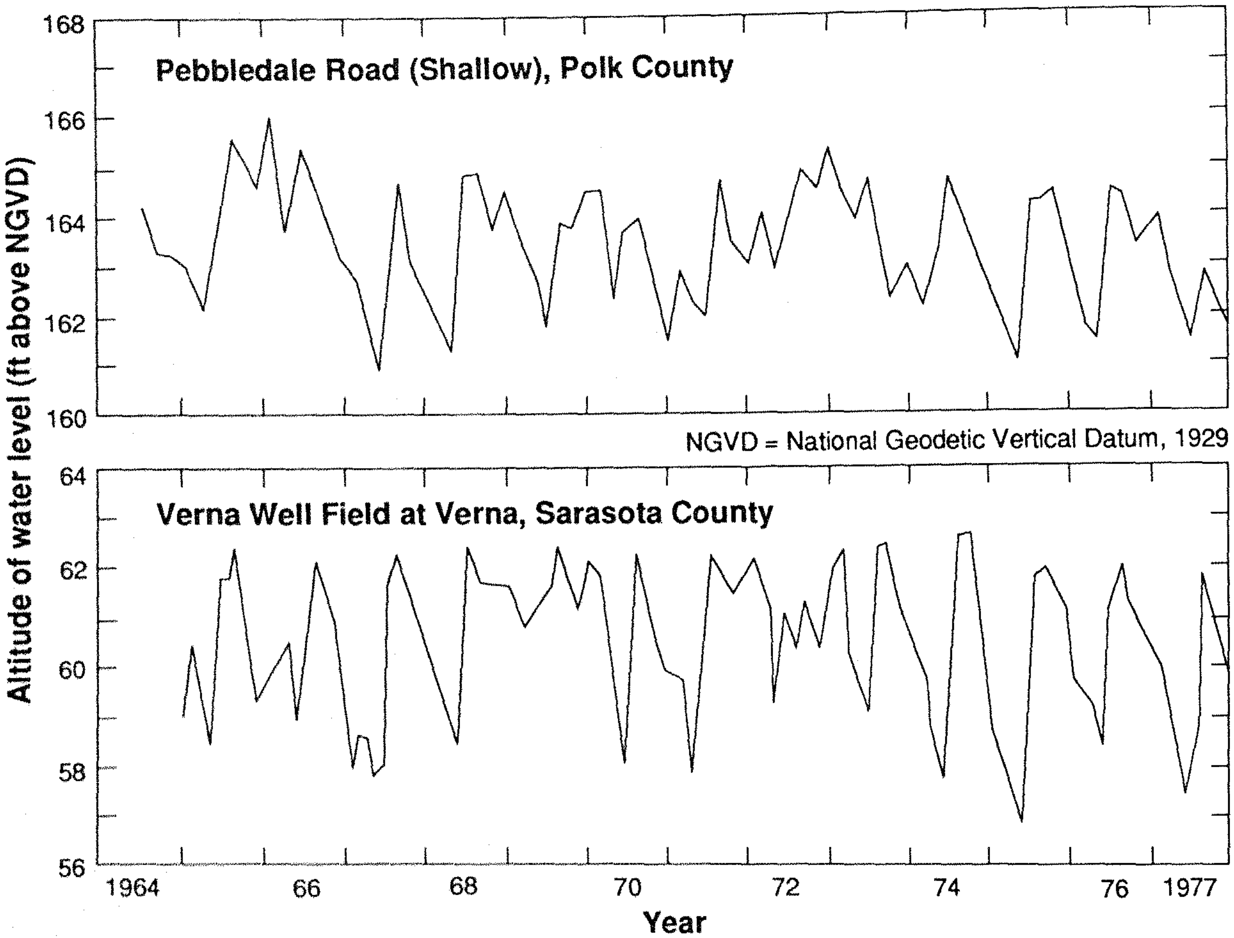


Figure 44. Hydrographs of wells open to the surficial aquifer in the Tampa Bay watershed (Wilson and Gerhart 1980).

marl, limestone, and dolomite of the upper Hawthorne Formation, and undifferentiated deposits that include all or parts of the Caloosahatchee Marl, Bone Valley Formation, and Tamiami Formation, and to the east, the sand and clay unit of the Tampa Limestone (Wehle 1978; Wilson and Gerhart 1980; Brown 1982a). Although quite variable, the thickness of the confining layer tends to increase toward the south (Buono et al. 1979). North of Tampa, it ranges from zero to 20 m, averaging 7.5–15 m (Hickey 1981a; Brown 1982b; Henderson 1983). The confining layer was absent at 12 of 59 test-well sites in northwest Hillsborough and south Pasco Counties (Sinclair 1974). South of Tampa Bay to southeast of Sarasota, the layer may reach a thickness of about 120 m (Hickey 1981a). In southern Hillsborough County and much of Manatee and Sarasota Counties, the confining layer contains intermediate aquifers that provide much of the area's domestic, home irrigation, and public water supply (Brown 1982b).

Penetration of the confining bed results in a direct linkage between the surficial and Floridan aquifers. This may be caused by sinkholes (Figure 43), uncased well holes, and hydrologic modifications such as the Tampa Bypass Canal (Motz 1975; Stewart et al. 1978). Typically, the confining layer restricts vertical hydraulic conductivities to about 1 mm/day (Hickey 1981a; Brown 1982a). In an area around Tarpon

Springs, conductivities ranged from 2 to 0.1 mm/day. This rate of exchange, however, varies greatly, temporally and spatially, and may be affected by height of the water table, potentiometric surface elevation, local lithology, and topography.

Beneath the confining layer, the Floridan aquifer consists of limestone and dolomite that extends from the Lake City Limestone (early Eocene) up through the permeable beds of the Hawthorn Formation. These strata contain solution-enlarged fractures and bedding planes that provide abundant water for the watershed's industrial, agricultural, and domestic needs.

The top of the Floridan aquifer lies near the surface in the northeastern portion of the watershed (Green Swamp) and gradually dips to about 120 m below the National Geodetic Vertical Datum (NGVD) of 1929 just south of Sarasota (Figure 45) (Buono and Rutledge 1979). The bottom ranges from 335 m below the NGVD in the north to about 550 m below the NGVD at Sarasota Bay, and generally corresponds to the beginning of vertically consistent intergranular evaporites that are in either the Avon Park, Lake City, or Oldsmar Limestones of Eocene age (Wolansky et al. 1979). Transmissivity for the aquifer is variable, ranging from an average of 3,700 m^2/day in the Cypress Creek watershed to an average of 9,300 m^2/day along southeast Hillsborough and eastern Manatee counties (Wilson and Gerhart 1980; Henderson 1983).

Potentiometric surface maps of the Floridan aquifer, showing water levels for most of the Tampa Bay watershed, have been produced since January 1964, and for all of the watershed since 1975 (Stewart et al. 1971; Mills and Laughlin 1976; Brown 1982b). Potentiometric surfaces of intermediate aquifers and water-table heights have been recorded since 1975 (Gombers 1975; Wolansky et al. 1978; Brown 1982b).

Potentiometric levels of the Floridan aquifer exhibit strong seasonal changes similar to those observed in the surficial aquifer, that is, high in the fall and low in the spring (Brown 1982b; Causseaux and Fretwell 1982). Changes are caused by seasonal water use, rainfall, tidal variations in the Gulf of Mexico and Tampa Bay, barometric changes, and earth tides (Wilson and Gerhart 1980; Hickey 1981a; Causseaux and Fretwell 1982).

Tides and barometric pressure changes are short-term phenomena that affect the surficial aquifer and the Floridan aquifer potentiometric altitude on a daily or weekly basis, as illustrated in Figure 46. Changes are generally restricted to coastal margins (Sinclair 1979; Hickey 1981a).

Water users (e.g., industry, agriculture, municipal) and rainfall are, by far, the most influential factors controlling changes in the Floridan's potentiometric surface in the watershed. Both affect levels on a seasonal and long-term (several-year) basis (Brown 1982b). Seasonally, spring low aquifer levels correspond to maximum irrigation pumpage and minimum rainfall, while maximum levels, reported in late summer and early fall, correspond to the end of the wet season when irrigation is minimal, as illustrated in Figure 47 (Robertson 1973; Reichenbaugh 1977; Tibbals et al. 1980; Wilson and Gerhart 1980; Causseaux and Fretwell 1982). Long-term declines in the Floridan aquifer have been reported from several wells, and have been attributed to increases in population, irrigation for agriculture, and the number and variety of industrial users (Duerr and Trommer 1981; Hickey 1981a,b; Rollins 1981; Brown 1982b; Yobbi 1982; Causseaux and Fretwell 1982). The introduction of deep turbine pumps in the early 1960's greatly accelerated water use in the watershed and has been singled out as a major cause for the drop in the potentiometric surface in the last 20 years (Wilson and Gerhart 1980; Hickey 1981a). Deficit annual rainfalls over this period (1960–1980) have also been blamed for the long-term drop in the Floridan aquifer (Palmer 1978; Wilson and Gerhart 1980).

Ground-water and surface-water use by county in the Tampa Bay watershed is presented in Table 13. Agricultural irrigation, mainly for citrus and vegetable crops, is the largest ground-water use in the watershed, followed by public supply and industry (Duerr and Trommer 1981). Public water use is greatest in Pinellas and Hillsborough Counties, where more than 90% of the total watershed's public supply needs are met (Henderson 1983). Potable water is

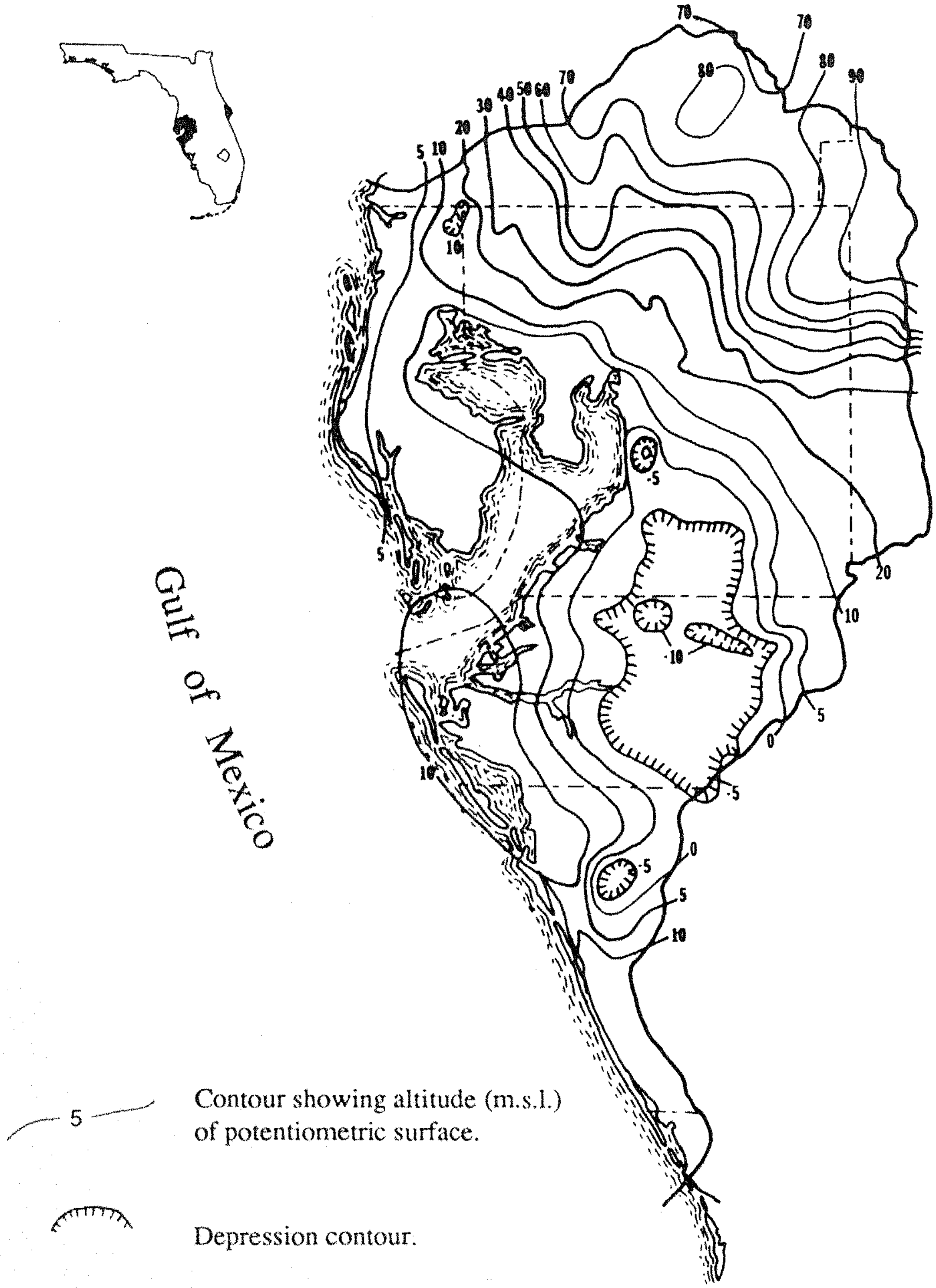


Figure 45. Potentiometric surface of Floridan aquifer (after Buono and Rutledge 1979).

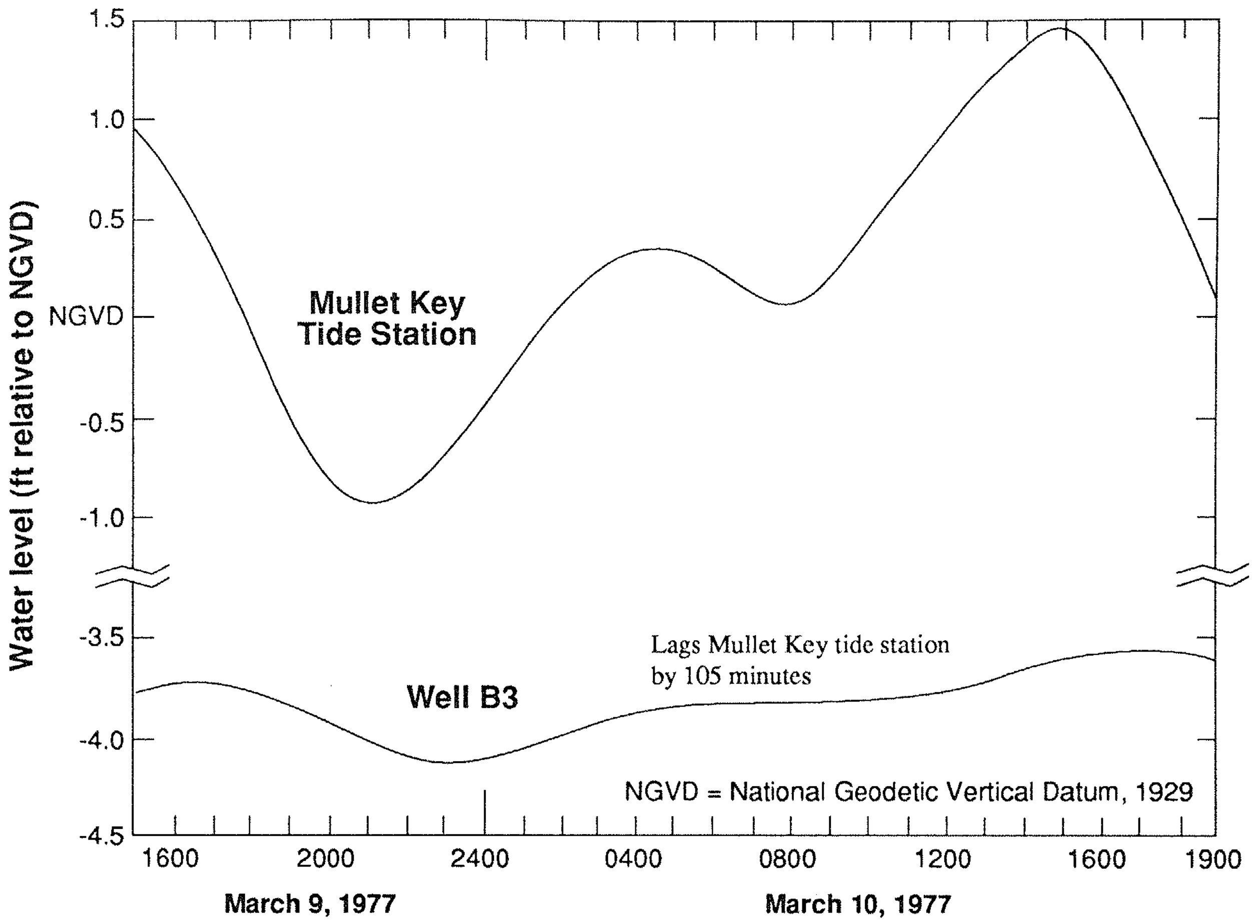


Figure 46. Water levels at the Mullet Key tide station and in a southwest St. Petersburg well open to the lower part of the Floridan aquifer (Hickey 1982).

increasingly being imported from other counties such as Pasco County, (e.g., Cypress Creek wellfield). Most significant of the industrial water users are phosphate mines; citrus, chemical, and food processing; and air conditioning (Causseaux and Fretwell 1982).

Future ground-water consumption in the Tampa watershed will increase significantly by the year 2000, as shown in Table 14 (Wilson and Gerhart 1980). Even these estimates appear to be very conservative when the values predicted for 1985 in Table 14 are compared to the actual levels reported in 1978 (Table 13). The most abrupt change is expected to be caused by expanded phosphate mining operations in eastern Hillsborough and Manatee counties. The net effect of the increased ground-water consumption is expected to decrease the Floridan's potentiometric surface by 1.5–3.0 m by the year 2000 (Wilson and Gerhart 1980).

Although the surficial aquifer is not widely used as a water supply, it is a major source of recharge for the Floridan aquifer. The rate of leakage and even its direction is dependent on the Floridan potentiometric surface, the surficial aquifer altitude, the land surface elevation, and the characteristics of the confining layer.

Downward leakage is common in most inland areas of the watershed, while upward leakage occurs along coastal areas and along the incised valleys of

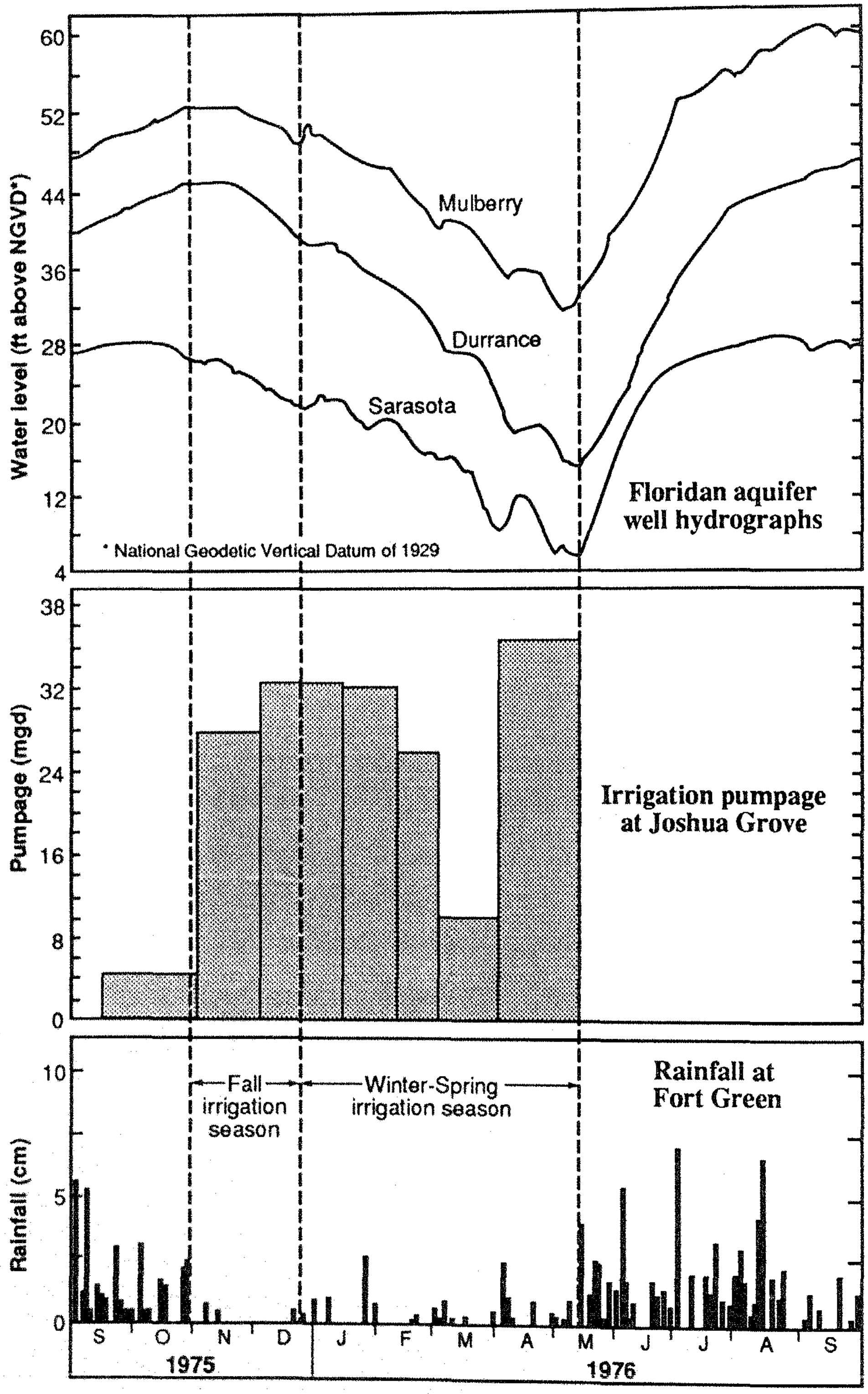


Figure 47. Ground-water levels, irrigation pumpage, and rainfall in the central Tampa Bay watershed (Wilson and Gerhart 1980).

Table 13. Ground-water and surface-water use by county in 1978 (after Rollins 1981).

County	Amount of water used for indicated purpose[a]												
	Public supply		Rural		Industrial		Irrigation		Thermo-electric		Subtotal		Total
	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	
Hillsborough	21	45	15	0	75	9	57	3	1	2,292[s]	169	2,349	2,518
Manatee	0	17	7	0	5	0	46	5	0	3	58	25	83
Pasco	4	0	13	0	15	0	26	0	0	670[s]	58	670	728
Pinellas	98	0	1	0	1	0	19	0	0	796[s]	119	796	915
Sarasota	9	8	6	0	0	0	31	3	0	0	46	11	57
Subtotal	132	70	42	<1	96	9	179	11	1	3,761	449	3,851	4,301
Total	202		42		105		190		3,762		4,301		

[a] GW - ground water; SW - surface water; all is freshwater except for 39.8 mgd of saline ground water used by industry in Hillsborough County. All measurements are in million gallons per day (mgd).

Table 14. Ground-water withdrawal rates and predicted rates for major users in Hillsborough, Manatee, and Sarasota counties, 1975, 1985, and 2000 (after Wilson and Gerhart 1980).

County	User	Withdrawal rate (mgd)		
		1975	1985	2000[a]
Hillsborough	Phosphate mines	0.8	20.0	26.0
	Municipal	11.9	13.9	14.4
	Irrigation	55.0	55.0	55.0
	Total	**67.7**	**88.9**	**95.4**
Manatee	Phosphate mines	0	34.2	41.7
	Municipal	0	1.5	3.8
	Irrigation	32.7	37.6	45.0
	Total	**32.7**	**73.3**	**90.5**
Sarasota	Phosphate mines	0	0	0
	Municipal	7.1	7.1	7.1
	Irrigation	4.6	5.6	7.0
	Total	**11.7**	**12.7**	**14.1**
3-county total		**112.1**	**174.9**	**200.0**

[a] extrapolated

major streams (Henderson 1983), or wherever the potentiometric surface is above the surficial aquifer (Figure 48). The rate of upward leakage is lower in May than September, corresponding to the seasonal fluctuations of the potentiometric surface (Wilson and Gerhart 1980). Locally, the leakage may be high due to an absence or thinning of the confining layer, or breaches in the layer caused by sinkholes (Figure 43) or other karst features common to the watershed (Motz 1975; Tibbals et al. 1980; Sinclair 1982; Henderson 1983). In the northern half of Pasco County, the confining layer is absent and the Floridan aquifer is nonartesian (Wehle 1978). In the southern half of the Tampa Bay watershed, the Floridan aquifer is more complex (Figure 42) and may be divided into as many as five distinct aquifers separated by confining layers and exhibiting different water pressures and water quality. The upper two of the five aquifers are considered by some authors to be intermediate aquifers, part of the overlying confining zone, and separate from the Floridan aquifer system (Brown 1982b; Sutcliffe and Thompson 1983; Wolansky et al. 1983).

Ground-water quality is controlled by the composition and solubility of soil and rock through which the water passes, the residence time of the water, and the source of the water (Hutchinson 1978; Tibbals et al. 1980; Brown 1982b; Sprinkle 1982). In the Tampa Bay watershed, ground-water quality exhibits two general trends: one vertical from the surficial aquifer down to the lower confining bed of the Floridan aquifer, and the other lateral or east to west. Vertically, the major change is an increase in dissolved solids and specific conductivity with depth. In the surficial aquifer, the residence time is relatively short and the aquifer stratum is composed of minerals (i.e., insoluble quartz sand) that contribute low concentrations of ions, and clay particles that adsorb dissolved solids (Hutchinson 1978).

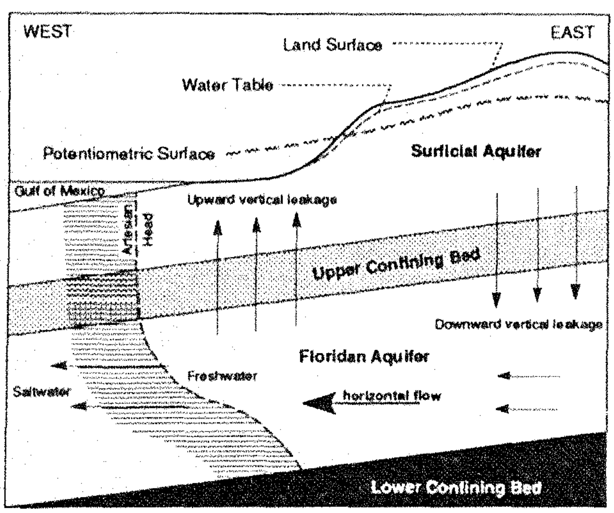


Figure 48. Generalized conceptual model of ground-water flow in the Tampa Bay watershed (after Wilson and Gerhart 1979, 1980).

In the upper layer of the Floridan aquifer, the residence time of the ground water increases, as does the solubility of the rock (limestone) through which the water passes. Dissolved calcium, magnesium, and bicarbonates dominate the increased dissolved-solid concentration reported from this major water supply for west-central Florida. Downward toward the lower confining layer of the Lake City Limestone, the ground-water residence time increases and the aquifer lithology reveals more dolomite and intergranular gypsum and anhydrites. These factors cause an increase in specific conductivity, dissolved solids, and sulfates (gypsum) to a concentration that exceeds acceptable levels for public water supply and agriculture.

In addition to a vertical pattern, an east-to-west or northeast-to-southwest gradient is present in the watershed (Figure 49). Most inland areas (eastern Pasco, Hillsborough, and Manatee Counties) are in a zone characterized hydrochemically as a calcium-bicarbonate facies. The previous vertical-profile description applies to the ground-water quality associated with this facies. Dissolved-solid concentrations in the surficial aquifer and parts of the Floridan aquifer from the eastern or upper Alafia River watershed are shown in Figure 50. In this facies, the dominant process that controls the concentration and form of dissolved solids in the ground water is chemical reaction between water and the aquifer limestone (Sprinkle 1982).

To the west and southwest of this zone is a mixed hydrochemical facies consisting of calcium, bicarbonate, magnesium, sodium, and chloride ions (Figure 49). It is a transitional area or zone of diffusion

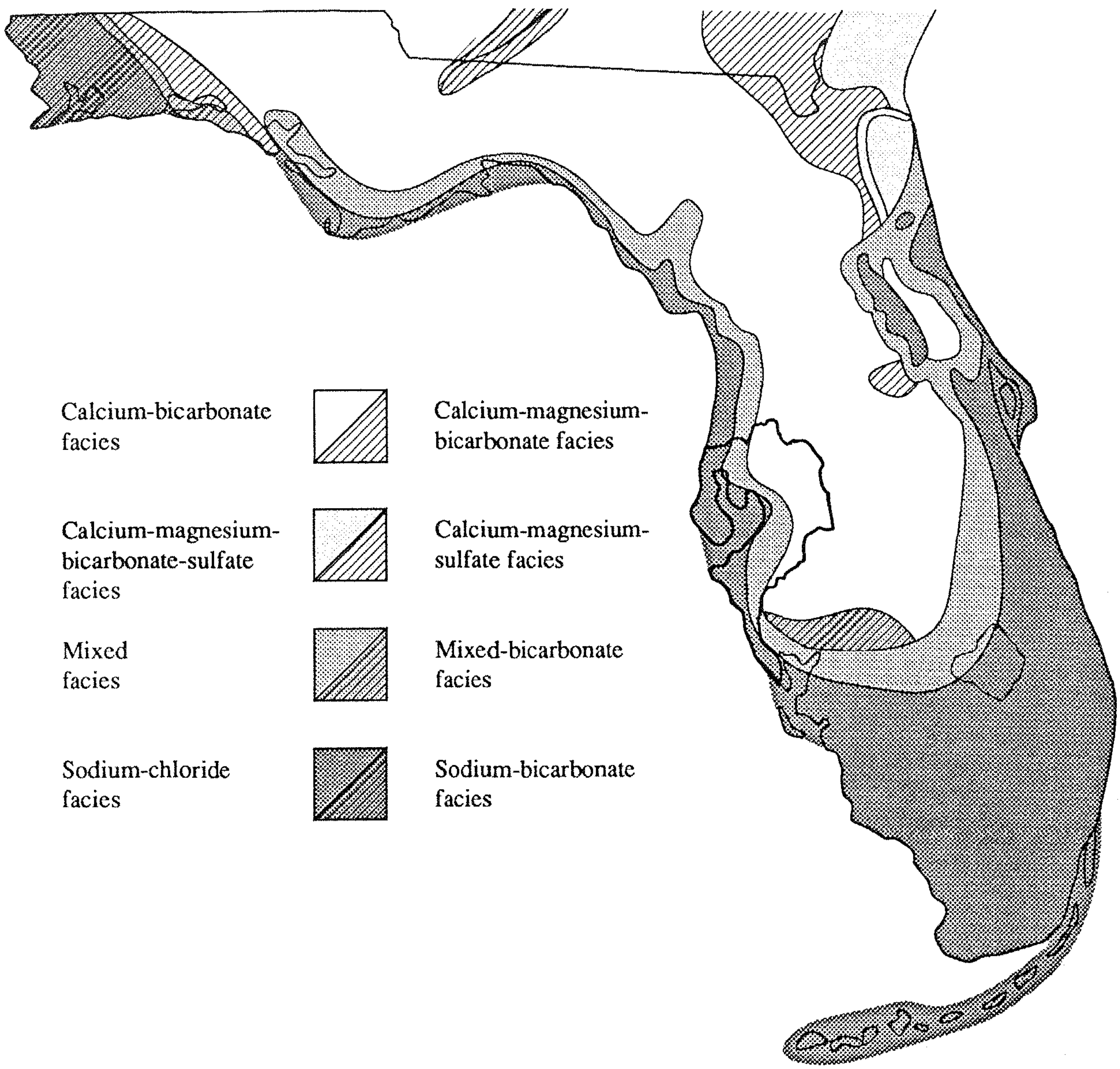


Figure 49. Hydrochemical facies in the Floridan aquifer's upper permeable zone (after Sprinkle 1982).

between saltwater and freshwater ground waters, and may also be a result of mixing freshwater with residual saline water, particularly in areas with long residence times (Sprinkle 1982). The influence of saltwater increases with depth because of density differences between saltwater and freshwater, as well as freshwater recharge from the surficial aquifer.

Along the coastal margin of the Tampa Bay watershed is a predominantly sodium chloride hydrochemical facies. The chloride concentrations typically range from 25 mg/L to 19,000 mg/L, with lower concentrations inland and in the upper part of the Floridan aquifer (Hickey 1982; Causseaux and Fretwell 1983). Chloride concentrations along the coastal margin of

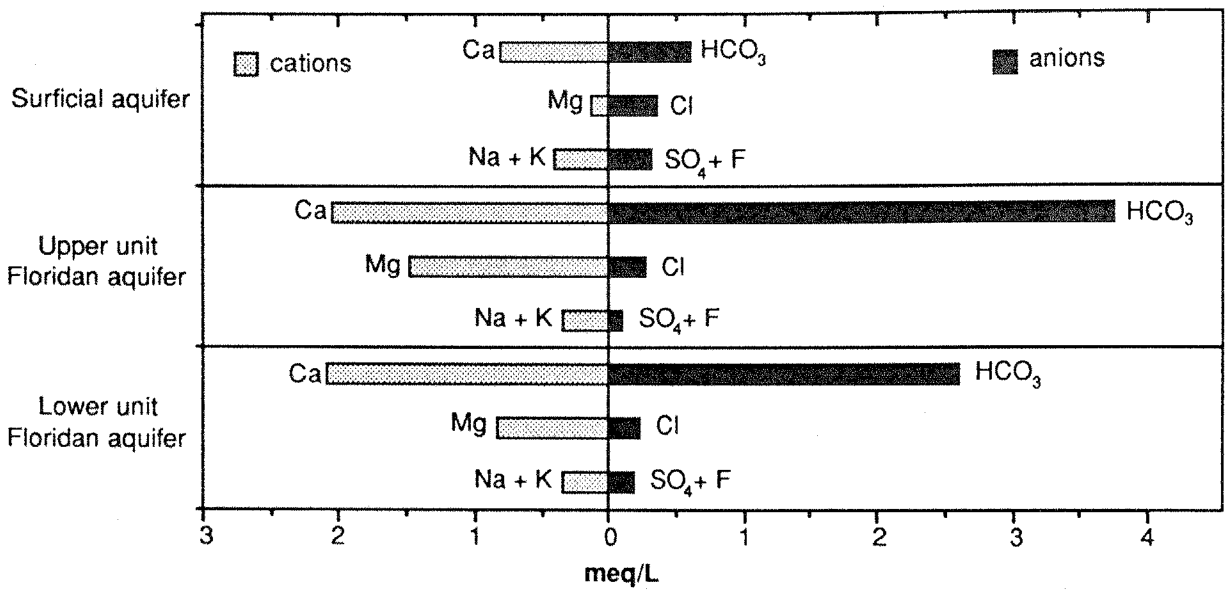


Figure 50. Median water quality in the surficial aquifer and upper and lower units of the Floridan aquifer (after Hutchinson 1978).

the Tampa Bay watershed from the upper and lower part of the Floridan aquifer are illustrated in Figure 51. Vertical profiles of chloride concentrations in ground water from the Gulf of Mexico inland and from Tampa Bay inland 15 km are shown in Figure 52.

Farther to the south, particularly in Sarasota County, chloride concentrations in the Floridan aquifer generally exceed 250 mg/L (Wilson and Gerhart 1980; Brown 1982b; Causseaux and Fretwell 1983; Sutcliffe and Thompson 1983). In these areas, public water supplies are drawn from inland reservoirs (Lake Manatee, Lake Ward) and intermediate aquifers located in the Tamiami and upper Hawthorn Formations (Brown 1982b; Sutcliffe and Thompson 1983).

Localized contamination of freshwater by dissolved solids (e.g., chlorides and sulfides) may result from upward leakage of mineralized waters through uncased or improperly cased wells or lateral contamination (e.g., saltwater intrusion); may be stimulated by overuse of local water supplies creating a cone of depression; or may arise from downward leakage of storm-driven tides (Tibbals et al. 1980; Causseaux and Fretwell 1983; Sutcliffe and Thompson 1983).

Other contaminants found in ground water are nutrients (ammonia, organic nitrogen, orthophosphate), organics (total and dissolved organic carbon, including tannins and lignins), metals and inorganics (iron, strontium, iodine, barium), pesticides, and bacteria (Stewart et al. 1978; Brown 1982a; Miller and Sutcliffe 1982). In addition to the processes previously described (i.e., dissolution of minerals, saltwater infiltration), several other mechanisms can contribute to ground-water contamination in the Tampa Bay watershed. North of Tampa where the aquifer lies near the surface, the structural faults and solution cavities provide direct access to the ground water by surface storm-water contamination, as illustrated in Figure 43 (Stewart et al. 1978; Sinclair 1982). Contamination of the surface aquifer, the intermediate aquifer, and the Floridan aquifer may also occur during subsurface injection of sewage wastes (Rosensheim and Hickey 1977; Hickey 1977a,b, 1981a, 1982; Hickey and Barr 1979; Hickey and Spechler 1979; Wilson et al. 1979; Hickey and Wilson 1982), land-surface spreading of treated and untreated wastes (Fernandez 1978; Franks 1981; Brown 1982a), waste disposal at landfills (Hutchinson and Stewart 1978; Fernandez 1978,1983;

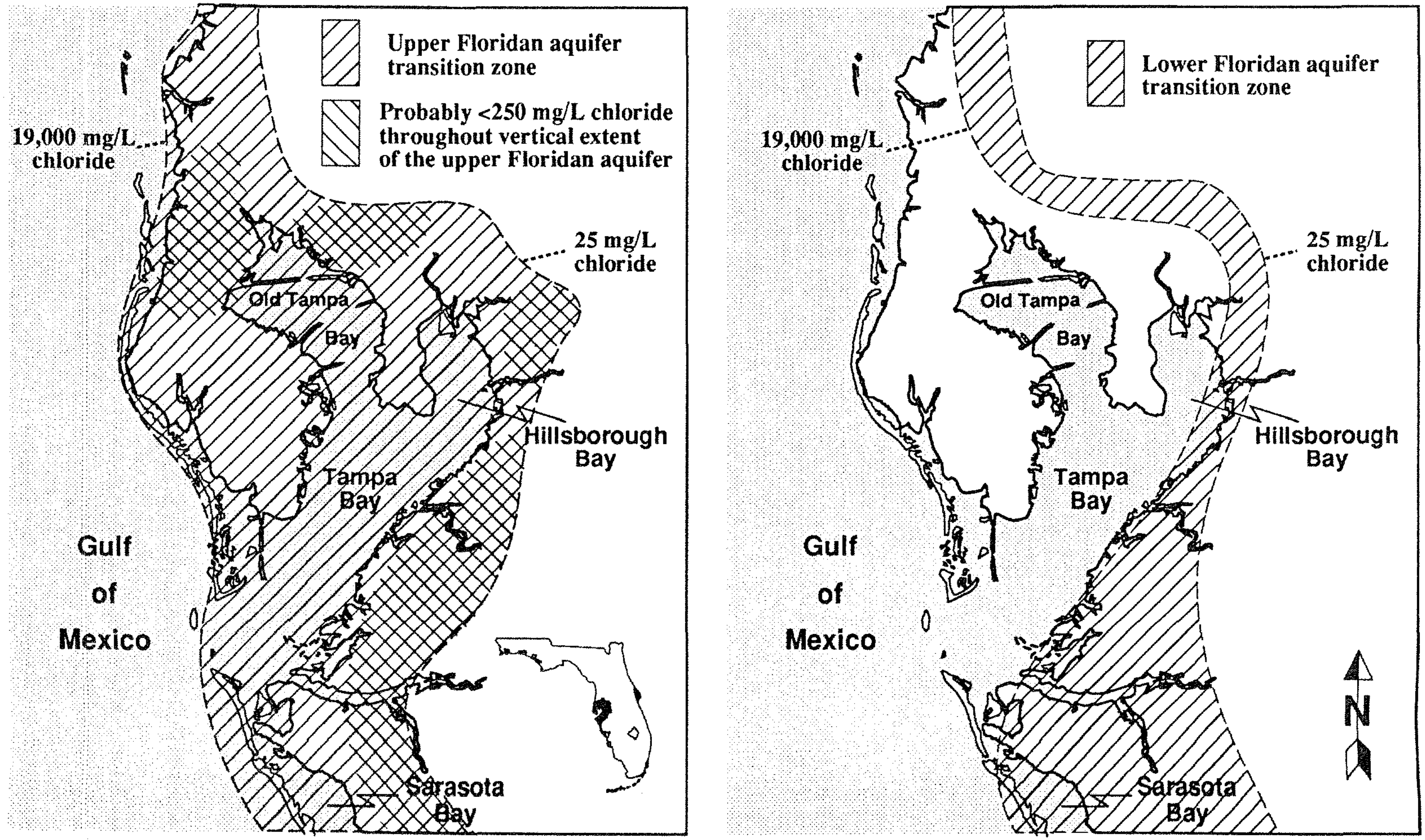


Figure 51. Chloride concentration in groundwater from the upper and lower Floridan aquifer (after Hickey 1982).

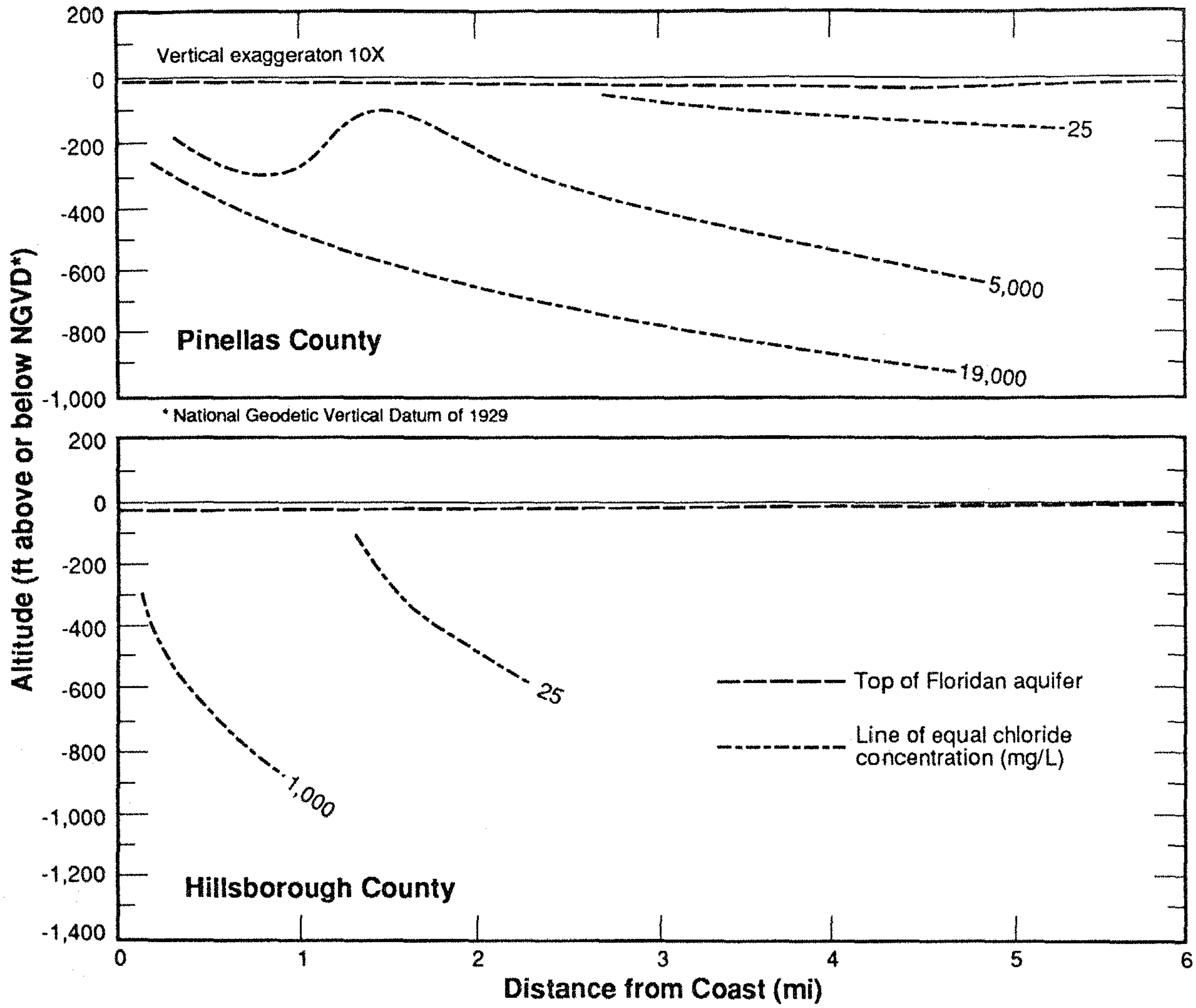


Figure 52. Section through Floridan aquifer showing chloride concentrations in the coastal margin of Pinellas and central Hillsborough County (after Causseaux and Fretwell 1983).

Fernandez and Hallbourg 1978; Duerr and Stewart 1980, 1981; Stewart et al. 1983), and disposal of phosphate mine waste products such as gypsum stacks and slime ponds (Miller and Sutcliffe 1982).

4.3 Surface Water

The Tampa Bay watershed encompasses eleven major river basins or drainage areas (Figure 53). From north to south these watersheds are the Anclote River, West Pinellas Peninsula, East Pinellas Peninsula-Old Tampa Bay, Hillsborough River, Tampa Bypass Canal-Palm River, Alafia River, coastal basin between the Alafia and Little Manatee Rivers, Little Manatee River, Terra Ceia and Cockroach Bays coastal basin, Manatee River, and the Manasota coastal basin.

The monthly 10-year-average flows at major stations in these river basins are shown in Figure 54. Seasonally, there tend to be two recurrent peaks in surface outflow, a small one in February and a larger one in the wet season (August to October). Variations

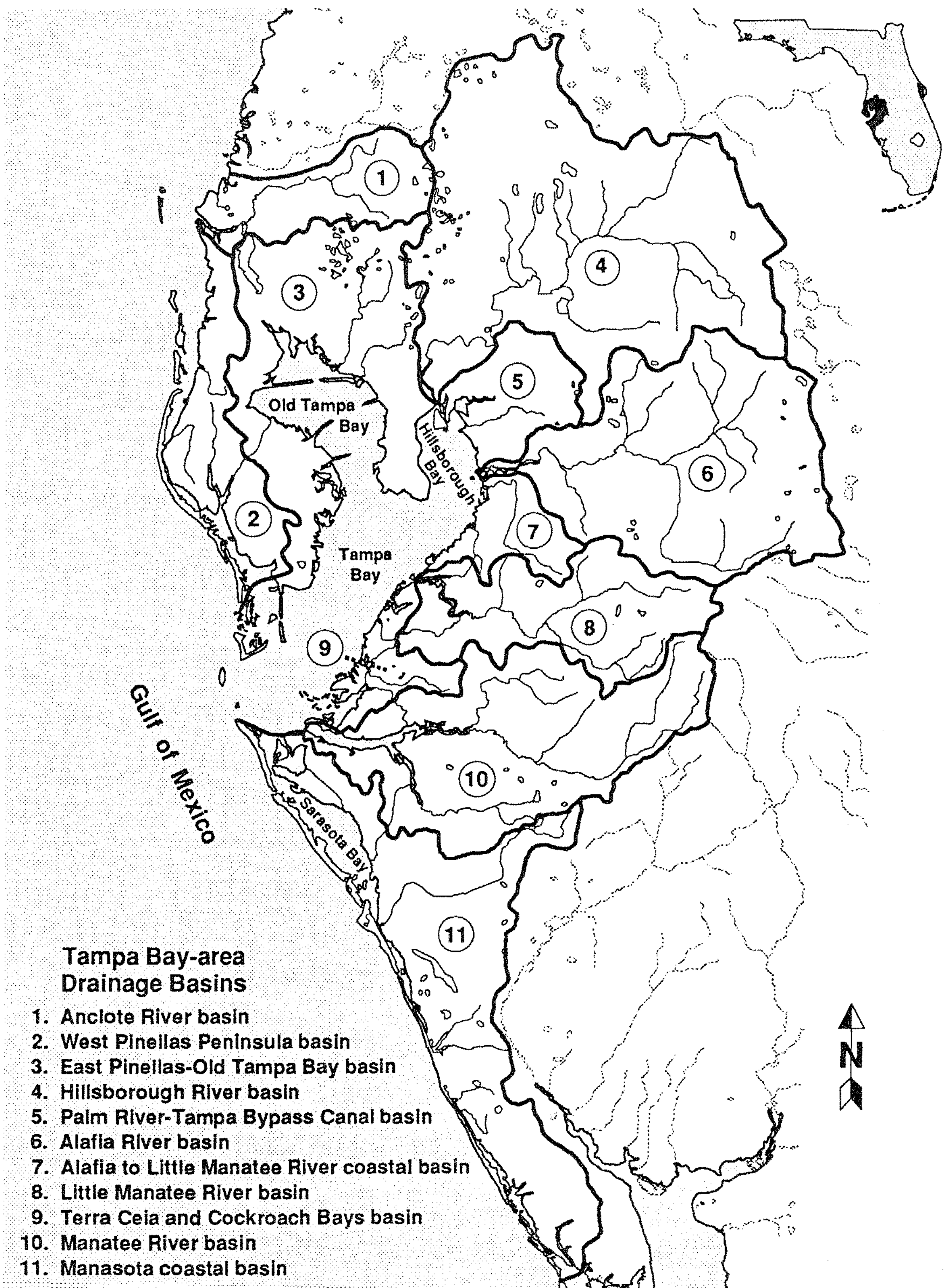


Figure 53. Major drainage basins of the Tampa Bay watershed (after Conover and Leach 1975).

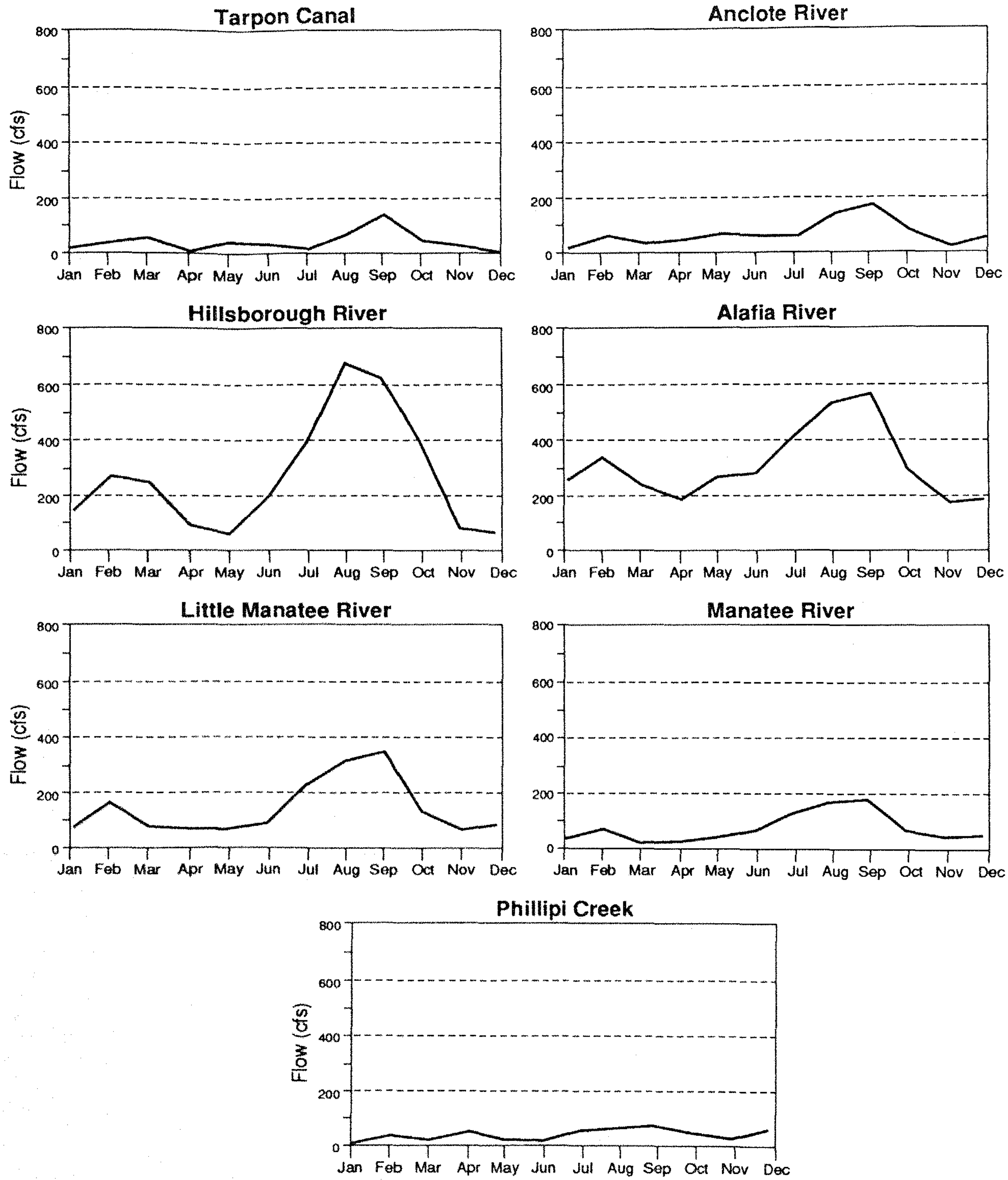


Figure 54. Ten-year average monthly flows of major rivers and streams in the Tampa Bay watershed (after USGS 1983).

in flow are greatest during these periods reflecting the combined effects of drought and flood years.

4.3.1 Anclote River Basin

The Anclote River originates near Drexel in Pasco County and flows about 30 km southwesterly through the northwest corner of Pinellas County to the Gulf of Mexico near the city of Tarpon Springs (Figure 55). From its headwaters downstream to the middle reaches, the river basin is rural, characterized primarily by pine flatwoods, citrus, pasture, and forested wetlands. The area is sparsely populated, although in the eastern and southern edge of the watershed, numerous lakes are ringed by residential development (Cherry et al. 1970; Turner 1979). In the lower reaches, the river meanders through swampy, tidally affected lowlands bordered by several large developments (e.g., Tarpon Springs). The residential development along the coastal margin has typically been built on filled-in salt marshes (ESE 1977b; Turner 1979).

Three main tributaries flow into the upper Anclote River. These are the South Branch, Cross Cypress Branch, and Sandy Branch. The streambeds of all three tributaries have largely retained their natural form. In this reach the main river channel is 3–15 m wide and 1–2 m deep. The river slope averages 0.66 m/km, ranging from 1 m/km at the headwaters to 0.4 m/km near Elfers (Cherry et al. 1970; Seijo et al. 1979).

Very little water-quality data exist for the upper river. Flow on several days each year is zero, and in most years the upper river dries up for a number of days (USGS 1982). Low dissolved-oxygen levels (<4.0 mg/L) are common, caused by a combination of low streamflow and decomposition of organic materials (leaf litter). High levels of organic carbon are probably contributed by wetlands adjacent to the river (ESE 1977b).

Downstream of the junction of the main and south branches, the Anclote River generally exhibits good water quality. Exceptions to this are occasional high levels of ammonia and phosphates, probably caused by livestock on adjacent pasturelands (ESE 1977b).

Near Elfers, where the area drained is approximately 188 km^2, flow averages 2.0 m^3/s, ranging

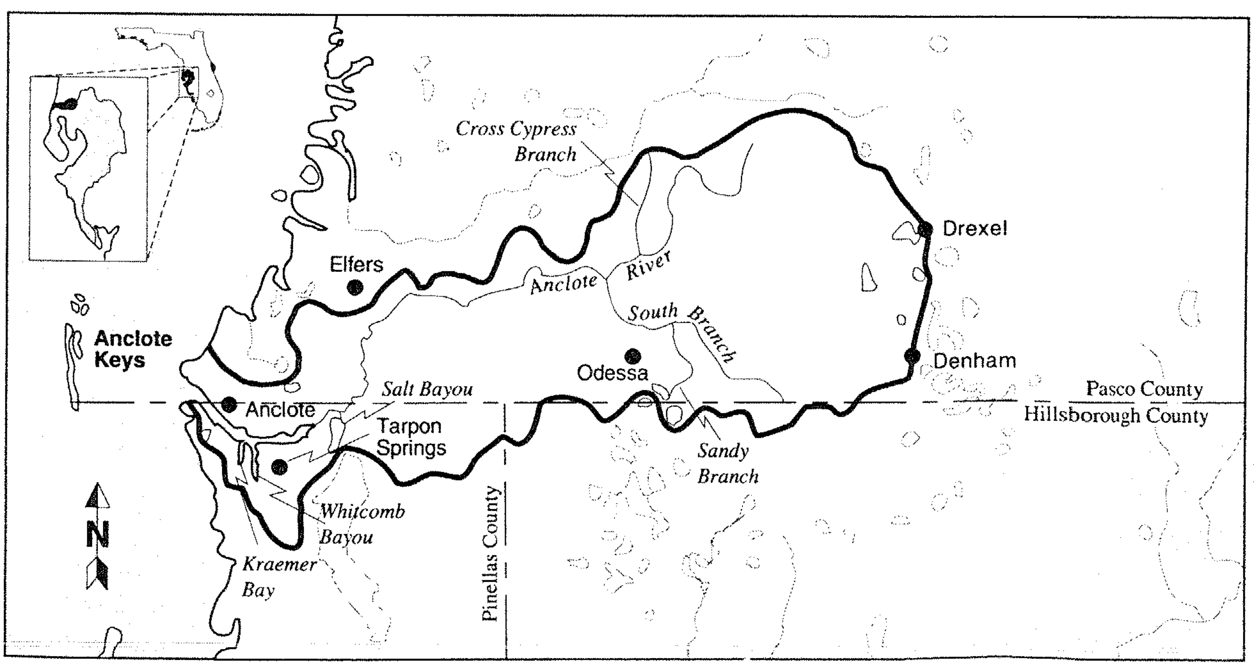


Figure 55. Anclote River basin.

from 142 to 0.01 m^3/s (USGS 1982; Foose 1983). Dissolved solids, mainly calcium bicarbonate, average 222 mg/L and are derived from ground-water seepage that annually contributes about 10% to the total river flow (Cherry et al. 1970; ESE 1977b).

The lower Anclote River is tidally influenced as far as 23 km upstream. Chloride concentrations range from 3,000 mg/L at a point 4 km upstream of Salt Lake, to 18,000 mg/L at the mouth of the river (Baird et al. 1973; Seaburn and Jennings 1976). Water quality in the lower Anclote River above Tarpon Springs is generally good. Dissolved oxygen is typically higher than 5 mg/L. An occasionally high total phosphorus level (0.39 mg/L) is thought to be a result of agricultural runoff from pastureland (ESE 1977b).

The river broadens to an average width of 460 m from Tarpon Springs to the Gulf of Mexico, and its mean depth, except for a dredged channel, remains about 1 m. A ship channel about 4.5 m deep has been dredged from the river mouth to the city of Tarpon Springs. Additional flow (about 2.8 m^3/s), primarily from ground-water seepage and springs, is contributed by Kreamer and Whitcomb Bayous just downstream of Tarpon Springs (Seaburn and Jennings 1976). There, the river also receives both urban runoff and point-source contributions. Point sources include the Tarpon Springs sewage treatment plant and a Stauffer Chemical plant engaged in work using elemental phosphorus and ferrophosphorous. High levels of total phosphorus (0.83 mg/L) and biochemical oxygen demand (BOD) (4.4 mg/L) have been reported in Whitcomb Bayou slightly downstream from the Tarpon Springs sewage treatment plant (ESE 1977b).

Considerable hydrology and water-quality information has been collected on the Anclote estuary and anchorage before and since construction of Florida Power Corporation's Anclote Plant at the mouth of the river (Humm et al. 1971; Baird et al. 1972,1973; FPC 1977).

The estuary and anchorage (behind Anclote Key) is shallow, ranging from 0.5 to 3.5 m deep. Within the anchorage, areas less than 0.5 m deep comprise about 35% of the total area. A bathymetric cross section of the anchorage from the mouth of the river to Anclote Key is roughly U-shaped with shallower plateaus toward the mainland and the key. A dredged channel runs from the deeper central portion of the anchorage to the mouth of the river.

Currents in the anchorage generally flow north during flood tides and south during ebb tides. Wind speed and direction exhibit strong influences on water currents when speeds reach 4.5 m/s or greater. Mean flood-tide velocities range between 5 and 40 cm/s, while ebb-tide velocities range from 5 to 34 cm/s. Calculated residence time (to 1% of initial concentration) for the anchorage is 56.75 days.

Salinities in the anchorage vary seasonally with rainfall and runoff and diurnally with the tides. Concentrations in the estuary range from 0.8 ppt in the freshwater side, to 32.7 ppt in the Gulf of Mexico. In the anchorage, salinities generally fall within the 14- to 31-ppt range. Salinities in the power-plant intake average only 2–4 ppt less than in the anchorage, because over a net tidal cycle considerably more of the intake water originates from the anchorage waters than from fresh river waters (FPC 1977).

Average temperatures in the anchorage range between 20 and 30°C. Heated water discharged from the Anclote Power Plant raises ambient temperatures more in winter than in other seasons. Seasonally average maximum increases above ambient were reported by FPC (1977) as follows: winter 4.7°C, spring 3.5°C, summer 3.0°C, and fall 3.6°C. The +1°C isotherm caused by the thermal effluent consistently covered about 15% of the total anchorage; the +2°C and +3°C isotherms covered 10% and 6%, respectively; and the +4°C, +5°C, and +6°C isotherms were not consistently present (FPC 1977).

Nutrients, organic color, chlorophyll *a*, silicates, and bacteria (total coliforms) decrease from the river to the anchorage. Concentrations of these materials are highest in late summer and early fall and are vertically well mixed except in the deep, open shipping channels (Baird et al. 1973).

4.3.2 Western Pinellas Peninsula

Seventy-two kilometers of keys or barrier islands lie between the mouth of the Anclote River and the main entrance to Tampa Bay (Egmont Channel). Surface water bodies are predominantly coastal bays, lagoons, and bayous; these receive drainage from the mainland via overland sheetflow, through stormwater drainage systems, and from a few relatively small streams. The barrier islands run generally northwest-southeast in the southern half of the Pinellas County coast, and almost north-south in the northern half of the county (Figure 56). The islands are closest to the mainland at Indian Rocks Beach on Sand Key, where the lagoon through the Narrows is only 60–90 m wide. The Narrows connect Boca Ciega Bay on the south with Clearwater Harbor and St. Joseph Sound on the north.

Water currents between the barrier islands and the Pinellas County mainland are mainly tidal (USACE 1966). Tides are mixed, fluctuating between semidiurnal and diurnal over the course of a month, and average 0.55 m in amplitude (USACE 1966). In very shallow areas, winds tend to dominate current speed and direction. Northern lagoons (St. Joseph Sound and Clearwater Harbor) are most affected by winter winds that come from the north and northeast, running parallel to the lagoons. Winds from the southeast, common in summer, are more influential on Boca Ciega Bay, a northwest-to-southeast oriented lagoon.

The St. Joseph Sound drainage area extends from just south of Tarpon Springs to just north of Clearwater in the northwest corner of the Pinellas Peninsula, and includes Honeymoon and Caladesi Islands. The eastern margin of the drainage area is approximately 1.5 km west of Lake Tarpon. Major land uses, from north to south, are Sutherland Bayou, citrus and urban; Smith Bayou, urban, residential, and agriculture; Curlew Creek, urban, agriculture, and open space; and Cedar Creek, residential and parks. Urban and residential Dunedin drains to the northern part of Clearwater Harbor by overland flow and a network of canals.

Much of the coastline from Anclote to Sutherland Bayou remains in the natural state, (i.e., mangrove and marsh community). However, south of Sutherland Bayou, seawalls, filled-sand and gravel beaches, and riprap have replaced the native shorelines (Getter et al. 1983).

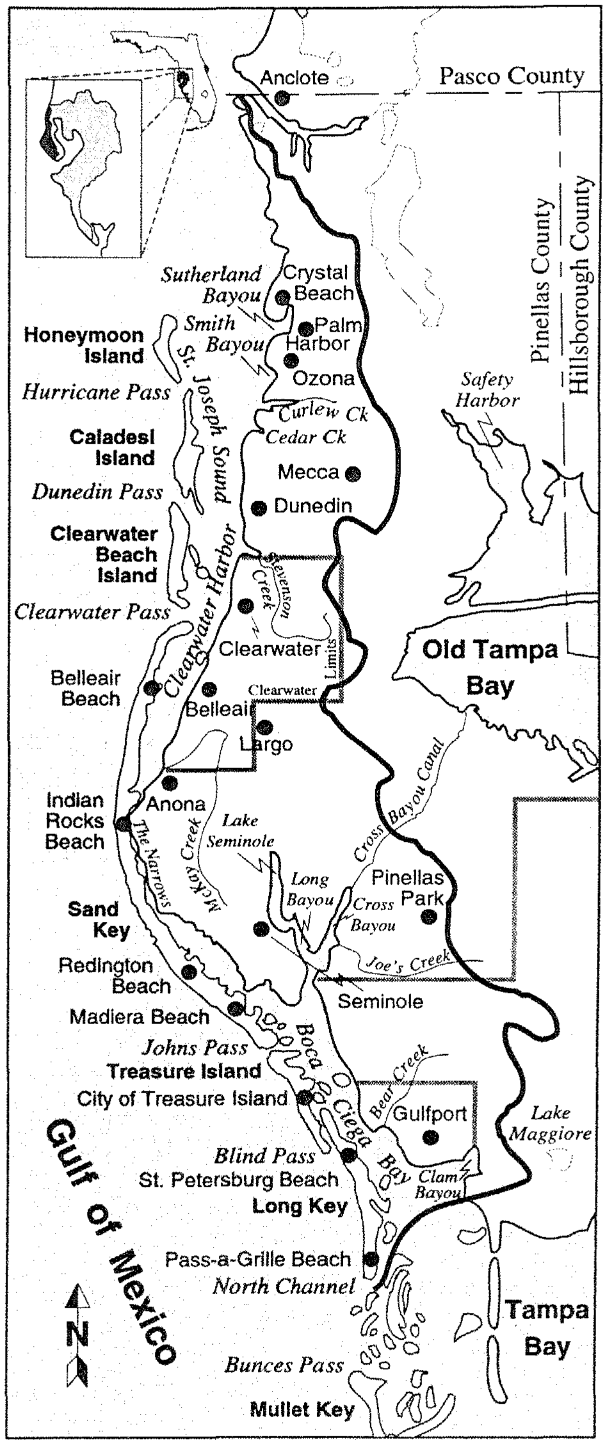


Figure 56. West Pinellas peninsula basin.

The major tributary to St. Joseph Sound is Curlew Creek, a small stream north of Dunedin that drains west into the Sound. Its channel slope ranges from about 11 m/km at the headwaters to less than 1 m/km near the mouth. The headwaters drain a hilly area northwest of Safety Harbor. Flow at the creek mouth is estimated at 0.5 m^3/s (Cherry et al. 1970).

Water quality in Curlew Creek is greatly influenced by six point-source dischargers and, in particular, Greenbriar Service Corporation, which discharges 38.1 mg/L BOD (ESE 1977). Water-quality data downstream of the point sources show high levels of total phosphorus (0.41 mg/L), NH_3 (0.23 mg/L), total Kjeldahl nitrogen (TKN) (1.55 mg/L), and total coliforms (TC) and fecal coliforms (FC) (TC 13,700/100 mL; FC 1,010/100 mL) (ESE 1977). Nitrate, total phosphorus and orthophosphate concentrations decrease toward the mouth of the creek. Dissolved oxygen concentrations are acceptable and exceed 6.6 mg/L.

The limited data reported for St. Joseph Sound show an increase of water color and chlorophyll *a* levels from north to south in the fall, which corresponds to a north-to-south increase in urbanization and point-source discharges (ESE 1977). The aquatic preserve between Caladesi Island and the mainland is directly offshore from two major point sources, the Dunedin sewage plant and a citrus processor that discharges high-BOD wastes.

South of St. Joseph Sound is Clearwater Harbor, which receives drainage from the northwest side of Pinellas Peninsula, extending from Dunedin southward to the Madeira Beach Bridge. The area contains barrier beaches, intracoastal waterways, and coastal lowlands and uplands. Clearwater Harbor separates Clearwater Beach Island and the northern section of Sand Key from the mainland. Farther south, the mainland is separated from the central section of Sand Key by the "Narrows," and from the southern section of Sand Key by Boca Ciega Bay. Both the Narrows and northern Boca Ciega Bay are designated aquatic preserves.

Drainage on the mainland is generally to the west through creeks, channelized ditches and streams, underground storm sewers, and overland flow. Land northeast of Dunedin drains south through an unnamed creek that empties into Stevenson Creek 1 km upstream of its mouth. Stevenson Creek flows from the central hilly part of Pinellas County (northeast of Largo) to the north and northwest, entering Clearwater Harbor just north of Clearwater. The lower reach of the creek is tidal. Flow at its mouth averages 0.5 m^3/s (Cherry et al. 1970). From Clearwater to McKay Point, south of Bellaire Causeway, stormwater runoff enters Clearwater Harbor by overland flow and through urban drainage systems and a small creek. McKay Creek, the other major tributary to Clearwater Harbor, drains a 3 km stretch southwest of Largo. Two reservoirs, Walsingham Reservoir and Taylor Lake, are located in the highly urbanized upper reaches of McKay Creek. Flow at the creek mouth is estimated at 0.15 m^3/s (Cherry et al. 1970).

The water of the streams and creeks entering Clearwater Harbor typically exhibits high concentrations of nutrients and coliforms, and depressed dissolved-oxygen levels. The poor water quality is caused by a combination of sewage treatment-plant effluent and storm water. Stevenson Creek, for example, receives effluent from the Marshall Sewage Plant in Clearwater. The result is high levels of suspended solids ($\leq$69 mg/L), ammonia (6.0 mg/L), nitrite (0.42 mg/L), nitrate (0.98 mg/L), TKN (9.0 mg/L), total phosphate (1.6 mg/L), and BOD (11.0 mg/L). Fecal coliform counts in a small stream receiving waste from the Bellaire Sewage Treatment Plant in Clearwater have been reported as high as 15,300/100 mL. Similar counts have been found in McKay Creek (ESE 1977b).

Urban storm water also contributes high concentrations and loads of pollutants to Clearwater Harbor. The storm water is generally high in BOD, suspended solids, nutrients, heavy metals, and bacteria. Discharge from the Turner Street storm drain in Clearwater showed high BOD (10.4 mg/L), high total coliform (3.8×10^5/100 mL) and fecal coliform (1.4×10^4/100 mL) counts, and lead (405 μg/L) and zinc (255 μg/L), all of which exceeded state water quality standards (Lopez and Giovannelli 1984). High concentrations of phosphorus (TP = 0.52 mg/L), nitrogen

(TN = 1.5 mg/L), and chemical oxygen demand (COD = 89 mg/L) were also reported. The long-term effect of point (sewage) and nonpoint (storm water) source loadings to Clearwater Harbor has been poor water quality.

Poor water quality continues into the Narrows, where the McKay Creek Sewage Treatment Plant discharges into the Narrows and Boca Ciega Bay aquatic preserves. High ammonia (0.55 mg/L), total phosphorus (0.26 mg/L), orthophosphate (0.13 mg/L), and TKN (1.79 mg/L) levels have been reported (ESE 1977). Surface drainage is by overland flow and urban storm-water drainage systems.

The southern half of the Pinellas Peninsula exhibits low surface relief, with a maximum elevation of only 8 m; consequently, no streams of any appreciable size develop, and drainage occurs through storm-water drainage systems, bayous, and small tidal creeks. Most prominent among these in the southwest peninsula are Long Bayou, Cross Bayou Canal, Bear Creek, and Clam Bayou. Lake Seminole branches off upstream of Long Bayou, as does Lake Maggiore off Clam Bayou. Cross Bayou Canal bisects the Pinellas Peninsula, connecting Boca Ciega Bay to Old Tampa Bay.

Boca Ciega Bay is possibly the most modified estuarine system on Florida's gulf coast, both physically and hydraulically. From 1950 to 1965 about 1,400 ha or 20% of the bay surface area was filled, and five major causeways cross the bay, connecting the barrier islands (Sand Key, Treasure Island, Long Key, and Cabbage Key) to the mainland (Taylor and Saloman 1969). The bay covers about 70 km^2 with a mean depth of less than 2 m over 80% of the area.

Water exchange between the bay and the Gulf of Mexico is quite good near the barrier-island passes and in the Narrows. Away from the passes in Boca Ciega Bay near Pinellas Bayway and south of Johns Pass, the water movement is drastically reduced (Geo-Marine, Inc. 1973a,b; Saloman 1974). The pattern of water movement in the bay also differs seasonally (Geo-Marine, Inc. 1973a,b). Cross Bayou Canal is affected tidally by both Old Tampa Bay and Boca Ciega Bay, creating a complex tidal pattern; however, net flow in the canal is toward Boca Ciega Bay (Hickey 1979).

Water quality in the bay tributaries reflects the urban character of its drainage area. For example, 77% of the Lake Seminole drainage area and 84% of the Lake Maggiore drainage area are urban (Myers and Edmiston 1983).

Lake Seminole was formed in 1950 by damming the upper reach of Long Bayou. Its chloride concentration decreased from 2,300 mg/L in 1950 to 25 mg/L in 1957. Since 1957, the concentrations have ranged from 30 to 180 mg/L. The lake shows minimal seasonal change and no evidence of tidal fluctuation. Outflow to Long Bayou averages 0.3 m^3/s (Cherry et al. 1970). Urban storm water and historic sewage plant effluent have caused the lake to become eutrophic, with high chlorophyll *a* (76 µg/L), total nitrogen (2.06 mg/L), and total phosphorus (0.75 mg/L) concentrations. Several fish kills have been reported (Myers and Edmiston 1983).

The other major lake in the southwest peninsula, Lake Maggiore, has outflows to Boca Ciega Bay (Clam Bayou) and Tampa Bay (Bayboro Bayou via Salt Creek). Based on water-quality data, Lake Maggiore is considered one of the ten worst lakes in Florida. It is characterized by poor light penetration (0.3 m secchi disk) and high concentrations of chlorophyll *a* (158 µg/L), total nitrogen (4.45 mg/L), and total phosphorus (0.28 mg/L).

Tributaries to Boca Ciega Bay (e.g., Bear Creek) have been modified to underground storm sewers or open ditches (Lopez and Michaelis 1979). The upper reaches of Joe's Creek, for example, are 67% storm sewer and 33% open ditch. Background water quality in these creeks is fair and does not reflect the poor water quality of storm water that flows to Boca Ciega Bay through these tributaries, or the contaminants remaining in the sediments (Lopez and Michaelis 1979; Lopez and Giovannelli 1984).

Bear Creek drains to southern Boca Ciega Bay on the west side of South Pasadina. Most of the Bear Creek basin is residential. Storm water from this creek has high total coliforms (6.8×10^5 counts/100 mL), fecal coliforms (6.6×10^5 counts/100 mL), lead

(128 µg/L), and zinc (83 µg/L). Pesticides such as chlordane, Silvex, 2,4-D, and 2,4,5-T have been detected in the storm water (Lopez and Michaelis 1979; Lopez and Giovannelli 1984). Sediment samples have shown high levels of volatile solids, total nitrogen, total phosphorus, and lead, as well as the presence of several pesticides such as chlordane, DDD, dieldrin, PCB, and hepta-chlor-epoxide (Lopez and Michaelis 1979).

Joe's Creek crosses through a mixed urban area north of St. Petersburg and drains into Cross Bayou Canal near Boca Ciega Bay. Both storm-water quality and sediment characteristics are similar to those found in Bear Creek (Lopez and Michaelis 1979; Lopez and Giovannelli 1984). The commercial and light industry influence on the watershed's storm water is evidenced in much higher concentrations of the heavy metals, lead (mean concentration = 349 µg/L) and zinc (mean concentration = 182 µg/L).

The effect of the tributary storm-water and point-source loadings on Boca Ciega Bay is dependent on distance from the tributary mouths and the circulation. Cross Bayou, Long Bayou, Joe's Creek, and Cross Bayou Canal are surface waters close to pollutant discharges and are restricted hydraulically from mixing with the bay. These areas, particularly the upper reaches, exhibit the worst water quality in the Boca Ciega Bay system, characterized by low oxygen levels, high nutrient concentrations and BOD, and high coliform counts (Geo-Marine, Inc. 1973a,b).

Water quality in Boca Ciega Bay is better away from Long Bayou and Cross Bayou and away from the point sources along the western shoreline (Taylor and Saloman 1969; Geo-Marine, Inc. 1973b; Saloman 1974). Salinity, temperature, and pH of the bay are similar to that reported for near-shore gulf waters and lower Tampa Bay. Storm water may cause temporary stratification or pockets of higher temperature and lower salinity waters (Geo-Marine, Inc. 1973b). This stratification causes differences in surface-to-bottom dissolved-oxygen levels and is more apparent towards Cross Bayou and in dredged channels (Taylor and Saloman 1969). Temperature fluctuates most (diurnally and seasonally) over shallow seagrass flats and may range from 4.8°C (January) to 36.9°C (July).

Seasonal changes in water quality include decreased dissolved oxygen and dissolved nutrient levels, increased BOD, and increased color in late summer and early fall (Geo-Marine, Inc. 1973b). The decrease in dissolved nutrients suggests a concurrent assimilation of nutrients by phytoplankton and macrophytes.

Water quality offshore is relatively stable and shows only minor changes with depth, to seaward, along shore, and by season (Saloman 1974). The passes act as nutrient sources for the adjacent seaward areas, as evidenced by higher nutrient concentrations in and adjacent to the passes during the ebb tide.

Seaward of the Pinellas County beaches are long, relatively deep borrow pits formed from dredging sand for use in beach restoration projects. Off Sunset Beach, one pit runs parallel to the beach for 390 m and is 130 m wide and 9 m deep (Saloman 1974). Its side slope is 30° to 45°. Unconsolidated soft sediments about 3 m deep have accumulated on the bottom. The restricted circulation in the pit and the soft, highly organic sediments have caused low dissolved-oxygen levels and a depauperate benthic community.

4.3.3 Old Tampa Bay and Southeastern Pinellas County Peninsula

This drainage area encompasses eastern Pinellas County and western Hillsborough County (Figure 57). Drainage for the eastern Pinellas County Peninsula and western Interbay Peninsula is characterized by open-ditch channels and storm sewers emptying into the tidal creeks and bayous of upper Tampa Bay and Old Tampa Bay. Most of the area north of Old Tampa Bay is drained by three creeks, Lake Tarpon Canal and Brooker Creek, Rocky Creek, and Sweetwater Creek. Portions of all three creeks have been channelized, with control structures to regulate flow and prevent saltwater intrusion (HCEPC 1984).

Two streams, Salt Creek and Booker Creek, drain the lower southeastern Pinellas County peninsula. Salt Creek receives the outflow from Lake Maggiore, and Booker Creek drains south-central St. Petersburg.

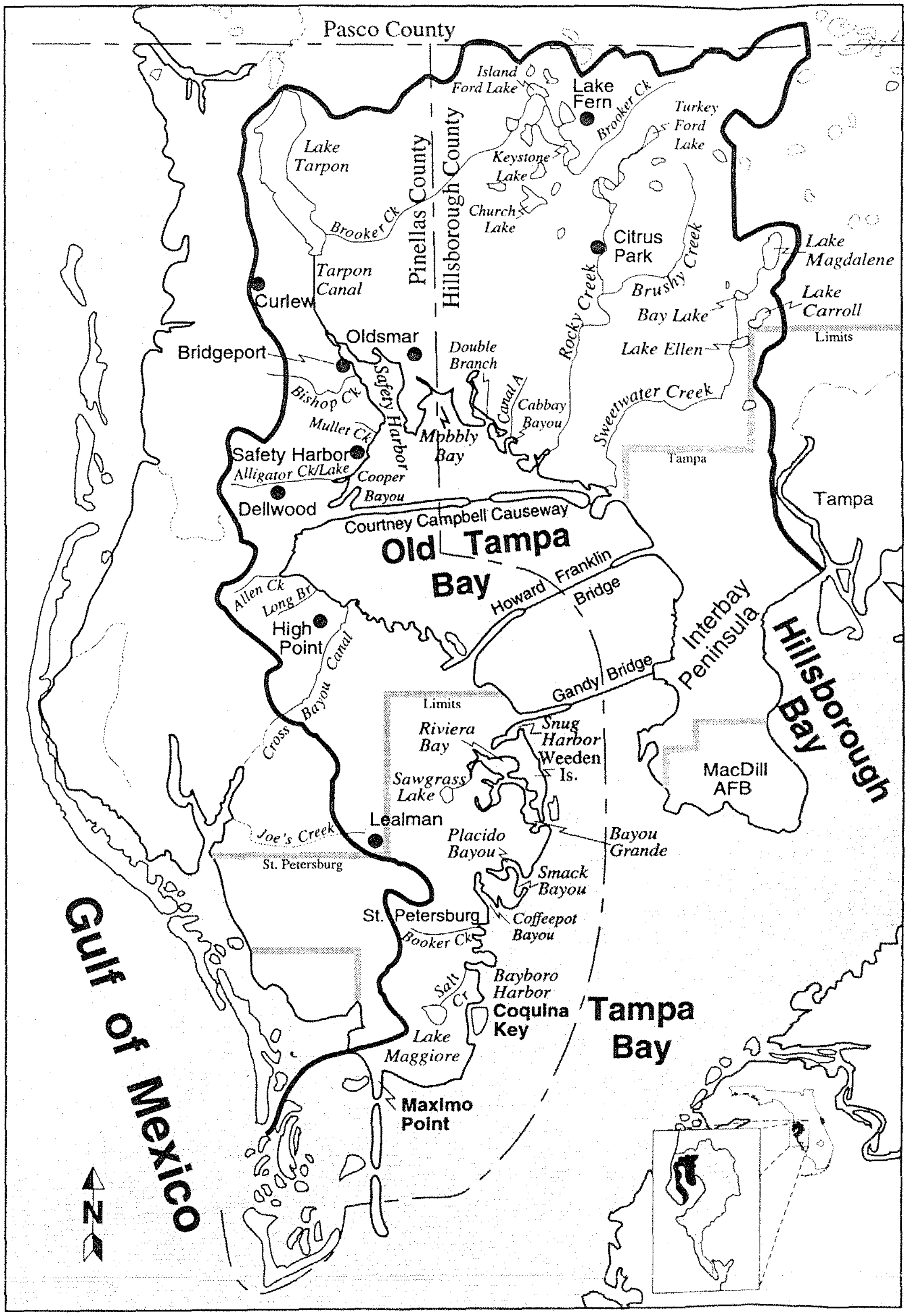


Figure 57. East Pinellas Peninsula and Old Tampa Bay basin.

Both creeks flow into Bayboro Bayou and then empty into lower Tampa Bay. Little water quantity or quality data are available for Salt Creek; however, Booker Creek was one of several sites chosen by the USGS for a study of urban watersheds in the Tampa Bay area (Lopez and Michaelis 1979; Lopez and Giovannelli 1984). Base flow in Booker Creek, 2.5 km upstream of the mouth, averages 0.03 m^3/s. Under base flow conditions, the creek is turbid (140 JTU) and high in nutrients (TP = 0.25 mg/L, TN = 2.0 mg/L). Compared to the bottom sediments of other urban watersheds in the Tampa-St. Petersburg area, those of Booker Creek contain relatively low levels of contaminants. One exception is PCB, which, at the time of the study, averaged 34 µg/kg of sediment (Lopez and Giovannelli 1984). Storm water in Booker Creek exhibits high levels of nutrients (nitrogen and phosphorus), BOD, coliforms (fecal and total coliforms), lead (190 µg/L), and zinc (Lopez and Michaelis 1979; Lopez and Giovannelli 1984).

Drainage in the southeastern drainage area is through ditch systems directed east toward Old Tampa Bay and upper Tampa Bay. There are also small inland lakes, particularly in northeast St. Petersburg and east Pinellas Park. Bays in this predominantly urban setting (60%) include Big Island Gap, Snug Harbor Bayou, Riviera Bay, Bayou Grande, and Smacks Bayou. Agriculture (unimproved pasture) and wetlands (mangrove) account for about 13% and 20%, respectively, of the land use in the area. Much of the mangrove wetland is located in the Weedon Island area (ESE 1977; Getter et al. 1983; Kunneke and Palik 1984; Dial and Deis 1986).

Point-source discharges to this area's waters are given in Table 15. The thermal plume from the Florida Power Corporation (FPC) Bartow station reportedly follows the shore and enters Masters Bayou during flood tide.

Water quality in many bayous and finger canals in the area is poorly documented. Tanglewood Estates canals, northeast of St. Petersburg and open to upper Tampa Bay, are one exception. The canals exhibit dissolved oxygen stratifications that are most pronounced in July and August (Lindall et al. 1973, 1975). Bottom DO levels in the summer often remain at or near zero, as illustrated in Figure 58. Temperature and salinity stratifications in the canals were minor, except after heavy rains in August, when surface and bottom salinities differed by as much as 14 ppt.

The Hillsborough County Environmental Protection Commission (HCEPC) conducts routine water-quality sampling in Tampa Bay and has placed a station at the mouth of Grande Bayou in the vicinity of the St. Petersburg Northeast Treatment Plant. Water quality in Grande Bayou is much worse than adjacent Tampa Bay. High BOD (5 mg/L), and high concentrations of ammonia (0.5 mg N/L) and total phosphorus (1.5 mg P/L) are reported near the bayou mouth, where flushing with the bay water is the greatest. Farther into the bayou, where flushing decreases,

Table 15. Point sources discharging to eastern Old Tampa Bay and Upper Tampa Bay (after ESE 1977b; Hartigan and Hanson-Walton 1984).

Receiving waters	Treatment facility	Effluent volume (mgd)
Old Tampa Bay	Florida Power Corp. Bartow Station	560.0[a]
	Feather Sound Development	0.6
Upper Tampa Bay	St. Petersburg Northeast[b]	6.8
	Al Whitted STP	15.27
Artificial lake	Monumental Properties	0.03

[a]Once-through cooling waters with maximum temperature elevation of 10°C.
[b]Near mouth of Bayou Grande.

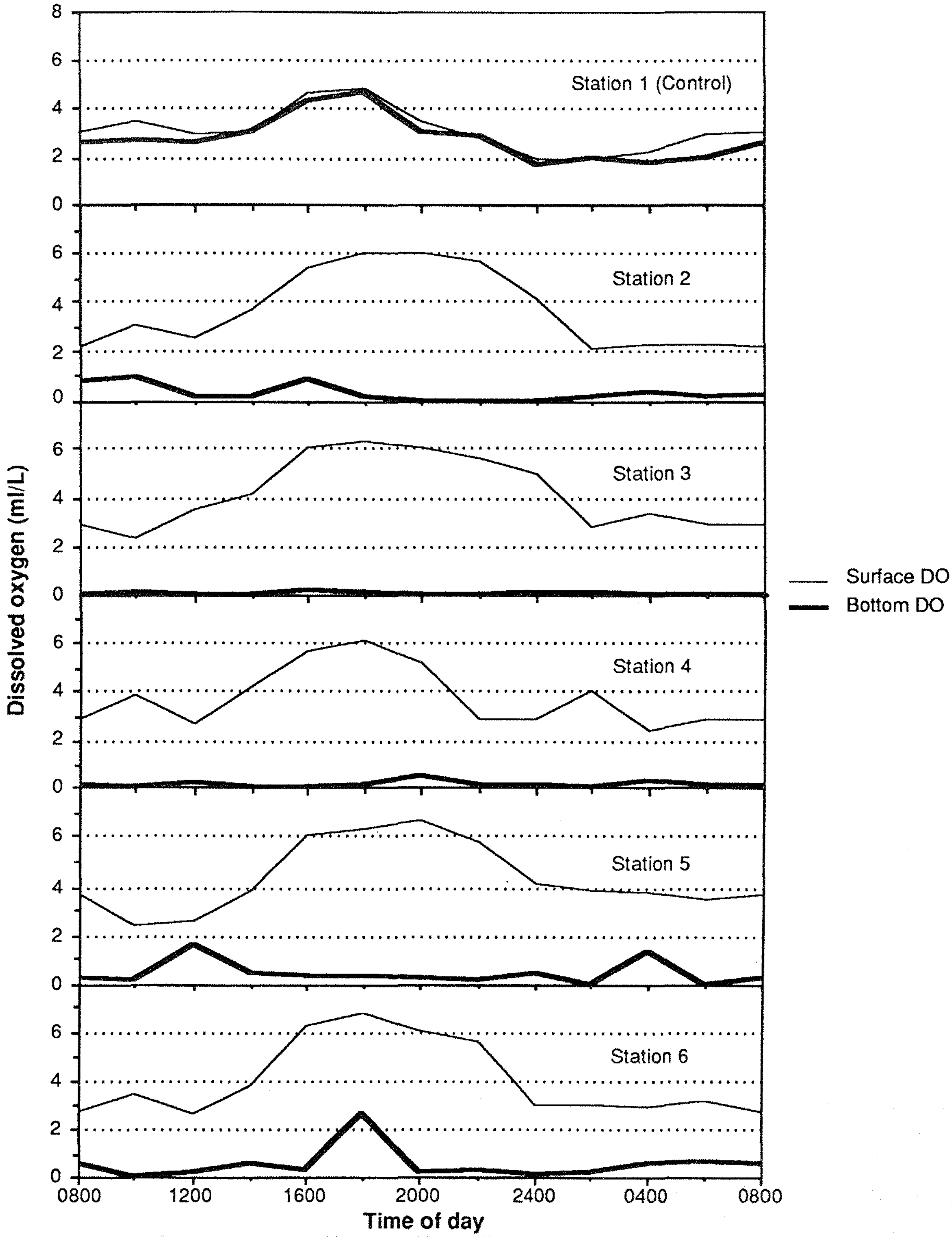


Figure 58. Dissolved oxygen values in Tanglewood Estates canals, northeast St. Petersburg (after Lindall et al. 1973).

the water quality is predicted to be worse. At the bayou mouth, dissolved oxygen has varied from 4 mg/L to 15 mg/L near the surface where high concentrations of chlorophyll *a* were reported (ESE 1977b).

West of these bayous and north of Joe's Creek and Booker Creek is Sawgrass Lake, which drains eastern Pinellas Park and northwest St. Petersburg. Although much of the lake's drainage area is urban (70%), the lake itself is surrounded primarily by a red maple swamp and to a lesser extent a mixed-oak ridge (Rochow 1979, 1982). Outflow from the lake is routed through canals to Riviera Bay and upper Tampa Bay. Nutrient loading to the lake was ranked fourth highest for lakes in Florida, but the in-lake concentrations varied considerably, possibly caused by the dense mats of water hyacinth (*Eichhornia crassipes*) that completely cover the lake's surface and assimilate nutrients into their biomass (Dooris 1979). Dissolved-oxygen concentrations below the hyacinth mat decrease sharply to near zero.

North of the Sawgrass Lake drainage area, Cross Bayou Canal bisects the Pinellas Peninsula, connecting Boca Ciega Bay on the Gulf of Mexico to Old Tampa Bay. The canal receives urban drainage from Pinellas Park. Complex flow patterns in the canal are caused by the out-of-phase tidal patterns in Boca Ciega Bay and Old Tampa Bay, and a higher high tide of 0.15 m in Old Tampa Bay (Geo-Marine, Inc. 1973b). Maximum currents are near Old Tampa Bay and approach 0.75 m/s.

Upstream from Old Tampa Bay 1.5 km, DO values often drop below 4 mg/L and high coliform counts are reported (Geo-Marine, Inc. 1973b). At the canal mouth, DO values are typically greater than 4.0 mg/L even in predaylight hours. Water quality problems in the canal are attributed to the presence of several municipal and industrial point-source dischargers (Appendix Table A-5).

Five coastal streams lie between Tarpon Canal and Cross Bayou Canal. These are Bishop, Mullet, Alligator, and Allen Creeks and Long Branch. The first three streams discharge to the bay north of Courtney Campbell Causeway, the remaining two between Courtney Campbell and Howard Franklin Causeways. Urban land uses dominate this drainage area, which includes the cities of Bridgeport, Dellwood, Safety Harbor, and portions of Largo and Clearwater. The area pasturelands are primarily located north of S.R. 60 in the Alligator, Mullet, and Bishop Creeks watersheds. The mix of urban, agricultural, and native upland and wetland areas is about 4:1:1 (ESE 1977b). At least 30% of the watershed is storm sewered, including most or all of Safety Harbor, Clearwater, Largo, Oldsmar, and Pinellas Park. Numerous municipal and industrial sewage treatment plants discharge to watershed waters as shown in Appendix Table A-5.

In-stream water quantity and quality data are limited to tidal and upstream portions of Allen Creek and Alligator Creek and Alligator Lake. Allen Creek originates northeast of Largo and flows east to Largo Inlet and Old Tampa Bay. Flow at the mouth is estimated at 0.4 m^3/s (Cherry et al. 1970). The upper creek is drained to the north by storm sewers and to the south by open ditches, and is relatively steep—4.43 m/km (Lopez and Michaelis 1979). Tidal and upstream portions of Allen Creek have shown wide fluctuations of dissolved oxygen; high levels of BOD (10 mg/L); high concentrations of nitrogen (TN = 2.4 mg/L), phosphorus (TP = 0.52 mg/L), lead, and zinc; and high fecal and coliform counts (ESE 1977b; Lopez and Michaelis 1979; Lopez and Giovannelli 1984). Excessive plant growth and stagnant or negligible flows prevent flushing of the stream and allow intermittent accumulation of nutrients and organic matter (ESE 1977b).

Alligator Creek heads in a hilly area east of Clearwater and flows east to Alligator Lake just south of the City of Safety Harbor. Alligator Lake was formed by damming off a saltwater inlet. Flow 1.5 km upstream of Alligator Lake averages 0.6 m^3/s and ranges from 0.007 m^3/s to 18 m^3/s (Cherry et al. 1970; USGS 1982). Alligator Creek has historically had high numbers of coliforms, high concentrations of phosphate, high BOD, and low dissolved-oxygen levels (ESE 1977b). These conditions have been repeated downstream in Alligator Lake where chlorophyll *a* concentrations average 38 µg/L.

The westernmost of the three major drainage areas entering Old Tampa Bay from the north is Lake Tarpon-Brooker Creek. Before 1969, Lake Tarpon was hydraulically connected to the Anclote River and Spring Bayou through a sinkhole on the northwestern end, and salinities fluctuated widely, ranging from 0 to 5,000 mg/L (Hunn 1974). In 1969, an earthen dike was built to separate the sinkhole from the lake. The result was a rapid drop in salinity to about 250 mg/L and a decrease of nitrogen and phosphorus levels (Bartos et al. 1977). After removal of the water's access to the sinkhole, Brooker Creek became the dominant factor influencing the lake's limnology.

Brooker Creek runs 24 km and drains about 108 km^2 of land area. The creek forms in northwest Hillsborough County, east of the town of Lake Fern, flows south-southwest to Keystone Lake, north to Island Ford Lake, and then southwest through swamps and marshes to Lake Tarpon (Menke et al. 1961; Bartos et al. 1978). From the headwaters to Lake Tarpon, the creek drops about 12 m. Numerous lakes, often surrounded by citrus groves, are located in the headwaters. Keystone Lake (157 ha), Church Lake (28 ha), and Echo Lake (10 ha) are the three largest lakes (Menke et al. 1961; Reichenbaugh 1977). Keystone Lake receives overland runoff from cypress swamps, pastures, citrus groves, and lakefront residential areas. Dredged shorelines for residences create nearshore pits as deep as the maximum center-lake depths of 5.5–7.0 m. The volume of runoff is low because of internal drainage through numerous sinkholes (Reichenbaugh 1977). Outflow is highest in August and September with a minor peak in March. Turbidity and nutrient concentrations increase in proportion to the flow from the lake, but the water is of fairly good quality in and just downstream of the lake.

Flow in Brooker Creek near Tarpon Springs and 3 km upstream of its mouth averages 0.6 m^3/s and ranges from 45 m^3/s to no flow. Decreased flow in Brooker Creek since 1960 is attributed to groundwater withdrawals from several wellfields in and north of the Brooker Creek watershed (Bartos et al. 1978).

Lake Tarpon has an area of 1,036 ha with an average depth of 2.7 m and a maximum depth of 4.5 m, except for dredged holes that are 9.0 m deep. The 155 km^2 drainage area is about 11% urban, and the remainder is split between agriculture and wetlands. Water quality is generally very good. Dissolved oxygen ranges from 4.6 to 9.1 mg/L, and neither DO nor temperature vertical profiles show stratification (Bartos et al. 1977, 1978). Nutrients, chlorophyll *a*, coliforms, turbidity, and BOD levels correspond to a clean, oligo-mesotrophic lake. Changes in chloride, iron, color, transparency, and nutrients are proportional to Brooker Creek flow (Bartos et al. 1977). Lake-stage height peaks in fall and winter and is lowest in spring and early summer.

Lake Tarpon Canal, completed in 1971, is a flood-control canal that runs south from the south end of Lake Tarpon for about 3 km and then southeast to Safety Harbor and upper Old Tampa Bay (Bartos et al. 1978). Midway down the canal is a saltwater-barrier/flood-control structure. Canal flow averages 1.0 m^3/s and ranges from 64 m^3/s to no flow (USGS 1982). The canal exhibits high DO levels (7.0 to 8.0 mg/L), neutral pH (7.0), generally low nutrient concentrations, and high conductivities (ESE 1977b; Dooris and Dooris 1985).

Double Branch Creek is a relatively small, tidally influenced drainage area sandwiched between the Lake Tarpon-Brooker Creek and Rocky Creek watersheds. The creek drains 7.3 km^2 and has an estimated discharge of 1 m^3/s (Simon 1974). The tidal influence is seen in high salinities (12 ppt) measured at the Hillsborough Avenue bridge (HCEPC 1983, 1984). High levels of nutrients, organics (TOC), and coliforms peak in the wet season and are caused by urban storm water (including runoff from the Florida Downs Racetrack) and pastureland runoff (HCEPC 1983, 1984; Dooris and Dooris 1985). Low fecal-coliform to fecal-streptococcus ratios (FC/FS) suggest a strong influence of animal waste (HCEPC 1984). The high levels of nutrients, particularly NH_3, (2.2–3.1 mg/L), TOC (21.9 mg/L), and color (153 platinum-cobalt units), keep the average DO at less than 5.0 mg/L (HCEPC 1983, 1984; Dooris and Dooris 1985). Urban effects on this drainage area are still much lower than observed in Rocky Creek, Channel A, and Sweetwater Creek. Color, much higher in Double Branch Creek than the other creeks to the east, and low to moderate phosphate concentrations indicate the still-strong influence of wetland areas on the water quality of this stream (HCEPC 1983, 1984).

Rocky Creek begins at Turkey Ford Lake in north-central Hillsborough County and flows southwest through several small lakes, then south to upper Old Tampa Bay. The run and drainage area are about 18 km and 115 km^2, respectively (TI 1978c). The flow rate 9.5 km upstream of Rocky Creek's mouth averages 1.0 m^3/s and ranges from 80 m^3/s to zero (USGS 1982). Land use is mainly agriculture (pasture) in the upper drainage area, with a sparse population near lakes. The lower drainage area is urban north of Hillsborough Avenue, but retains much of its natural salt marsh-mangrove wetland southward to the bay (Cherry et al. 1970; Getter et al. 1983; Kunneke and Palik 1984). Brushy Creek is the major tributary to Rocky Creek, draining about 28 km^2 of the eastern drainage area starting near Starvation Lake (Menke et al. 1961). Other lakes in the upper watershed are Hobbs, Cooper, Thomas, and Round. All the lake levels in this area have been lowered in the past 20 years because of pumpage from several wellfields to the north, (i.e., Cosme). A flood-relief channel in the lower drainage area, Channel A, was constructed in 1966 and carries flood water southwest into Cabbay Bayou and Old Tampa Bay. Salinity barriers were built in 1977–78 in Channel A and Rocky Creek (Dooris and Dooris 1985).

In Brushy Creek and the upper reaches of Rocky Creek, water quality is generally good with occasional high concentrations of ammonia (NH_3) and total phosphorus (ESE 1977b). Total and fecal coliform bacteria may also reach levels well above State standards and the FC/FS indicates that the origin of these bacteria is probably pasture runoff. Dissolved oxygen in the upper creek is relatively low. Nutrient concentrations decrease downstream within the creek's freshwater portion.

Except for Turkey Ford Lake, lakes in the upper drainage area (e.g., Hobbs, Round, Starvation) exhibit good water quality with relatively low nutrient concentrations. Nitrogen concentrations in Turkey Ford Lake are twice that of the surrounding lakes (TN = 1.6 mg/L). Water in the lower reach of Rocky Creek at Hillsborough Avenue exhibits low DO levels (less than 4.0 mg/L), moderate to high nitrogen concentrations, and high bacterial counts (HCEPC 1983, 1984; Dooris and Dooris 1985). Relatively low salinity and color (compared to Double Branch Creek) reflect decreased influence by wetlands and tidal waters caused by increased urbanization and construction of the saltwater barrier. Fecal-coliform to fecal-streptococcus ratios averaging 0.76 and 1.20 in 1982 and 1983 suggest contamination from sewage effluent and urban storm water (HCEPC 1984).

In Channel A, turbidity, five-day BOD (BOD_5), total phosphorus, pH, and dissolved oxygen tend to be higher than in the lower reaches of Rocky Creek, while total nitrogen and bacteria levels are lower. Water-quality differences between these two waterways suggest a more prolific phytoplankton community in Channel A. Channel A contains twice the chlorophyll *a* concentration, very low nitrate levels (0.05 mg/L), and total nitrogen levels equal to those found in Rocky Creek (HCEPC 1983, 1984; Dooris and Dooris 1985). In 1983, Channel A exhibited DO concentrations that approached zero, caused by domestic waste (discharge from a 0.9-mgd wastewater treatment facility), urban stormwater runoff, channelization (deepening and elimination of shoreline wetlands), and flood-control structures creating a stagnant lake-like condition rather than a flowing stream (ESE 1977b; HCEPC 1984). The absence of wetlands has also been caused by urbanization, which is apparent from very low color levels—the lowest reported from Hillsborough County tributaries in 1982 and 1983 (HCEPC 1984).

Sweetwater Creek forms in western Hillsborough County near Lake Magdalene, flows west to Bay Lake, south to Lake Ellen, and then south-southwest to upper Old Tampa Bay near the eastern end of Courtney Campbell Parkway. The creek drops from about 15 m above m.s.l., an average of 2 m/km in the middle reaches to 0.2 m/km near the creek mouth. In the upper reach, the land is relatively flat, poorly drained, and contains many shallow lakes that are interconnected by canals and culverts (Cherry et al.

1970). The largest of these lakes are Lake Magdalene (93 ha) and Lake Carroll (75 ha). In high-flood conditions, Sweetwater Creek receives some overflow from Cypress Creek through a low, swampy area separating the Hillsborough River and Sweetwater Creek watersheds. Sweetwater Creek is 17 km long and drains about 65 km^2. Flow is affected by an overflow structure in the upper reaches (from the Hillsborough River) and in the lower reaches (through Channel G to Rocky Creek) by control structure G-1 (USGS 1982). The drainage area is primarily urban (85%), with single family residences accounting for 61% of the land use (ESE 1977b). The drainage system receives heated or sewage effluent from 11 municipal or industrial facilities.

Lakes in the upper reaches of the creek are in fair condition with low concentrations of total phosphorus (0.02–0.003 mg/L) and moderate levels of total nitrogen (0.57–0.79 mg/L) and chlorophyll *a* (4.9–13.8 µg/L).

Upper Sweetwater Creek data indicate rather poor water quality; DO averages less than 3.0 mg/L and BOD_5 averages 6.0 mg/L. Downstream DO concentrations improve slightly to 3.7 mg/L, in spite of the added effluent from several point sources. In the tidal portion of the creek, DO, BOD_5, and nutrient concentrations indicate degraded conditions (ESE 1977b; HCEPC 1983, 1984; Dooris and Dooris 1985). Throughout the creek, coliform counts are the highest reported for Hillsborough County, and in 1981, 8% of the samples showed an FC/FS ratio in excess of 4.0, suggesting human-waste contamination (HCEPC 1983). The FC/FS ratio decreased in 1982 and 1983, but still remained between 0.7 and 4.0, indicating a continued influence of sewage (HCEPC 1984).

From south of Sweetwater Creek to the southern point of the Interbay Peninsula is the urban complex of the City of Tampa. Drainage on the western side of the peninsula is routed through underground storm sewers and ditches to Old Tampa Bay. One drainage system in this area, Gandy Boulevard Drainage Ditch, was part of a USGS study of urban watersheds in the Tampa/St. Petersburg region (Lopez and Michaelis 1979; Lopez and Giovannelli 1984). The Gandy Boulevard watershed is composed of 45% residential, 26% commercial, and 29% open space. Base flow in the ditch showed relatively high BOD and nutrient levels, as did the ditch sediments. Nutrient concentrations generally decreased during storms, but NH_3 increased from 0.19 mg/L to 0.40 mg/L. High total coliform (3.0×10^5/100 mL) and fecal coliform (1.5×10^5/100 mL) counts and lead (154 µg/L), and zinc (103 µg/L) concentrations were reported in storm water sampled.

4.3.4 Hillsborough River Basin

The Hillsborough River begins east-northeast of Zephyrhills in southeastern Pasco and northwestern Polk Counties (Figure 59). Its headwaters originate in the southwestern portion of the Green Swamp, where it also receives overflow from the Withlacoochee River. The river flows southwest 87 km to upper Hillsborough Bay and drains more than 1,800 km^2. River-basin elevation ranges from 43 m east of Plant City to sea level at the river mouth.

Perennially flowing tributaries to the Hillsborough River are Big Ditch, Blackwater Creek, and Flint Creek (Figure 59). Intermittent streams are Indian Creek, New River, Two Hole Branch, Basset Branch, Hollomans Branch, Clay Gully, Trout Creek, and Cypress Creek. Flood waters are diverted from the Hillsborough River at the confluence of Trout Creek and upstream of the Tampa Reservoir Dam through the Tampa Bypass Canal to McKay Bay. Sixteen kilometers upstream of the mouth of the Hillsborough River is the Tampa Reservoir dam, which creates a narrow reservoir about 20 km long. This reservoir provides water for the city of Tampa.

A majority of the land use in the river basin (54%) is agricultural. The remainder is evenly distributed between range (14%), wetland (13%), and urban (15%) areas (Fernandez et al. 1984). The northern and central portions of the drainage area are rural, and the southern part is mainly urban and industrial. Major incorporated urban centers include Tampa, Temple Terrace, Plant City, and Zephryhills. Forested areas above Trout Creek are lush and thick and river banks are heavily wooded. Nearshore habitats are shaped by fallen trees, wetland floodplain, low

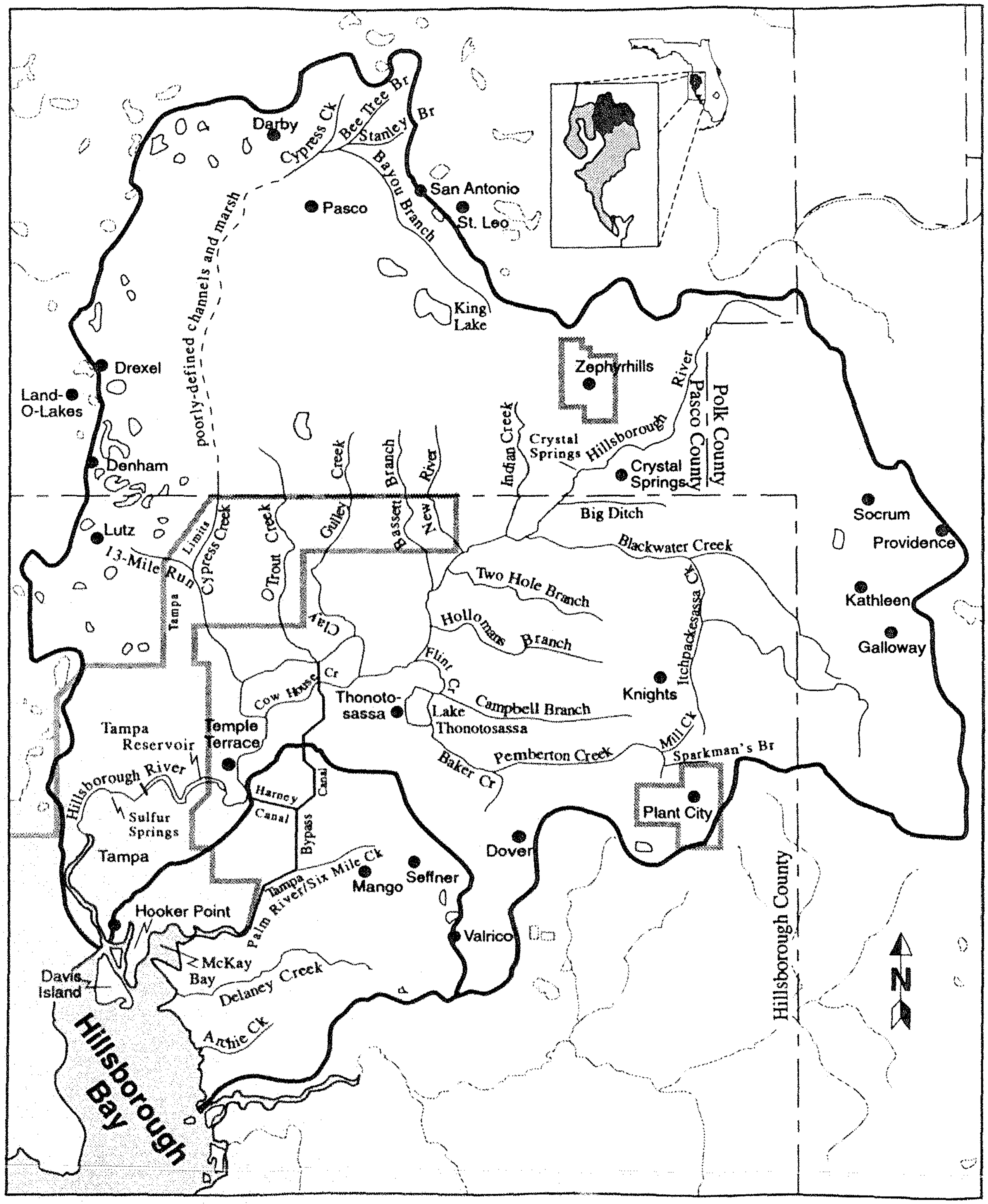


Figure 59. Hillsborough River and Tampa Bypass Canal drainage basins.

bluffs, and shoals intertwined with a variety of submerged and floating aquatic plants. Downstream of Trout Creek, the river shoreline is urbanized. Vegetation is ornamental mixed with native oaks. The aquatic flora remains, but is much less diverse. Park and wildlife management areas, all in the upper watershed, are the Hillsborough River State Park, the Hillsborough Wildlife Management Area, and the Green Swamp Wildlife Management Area.

Flow at various locations down the Hillsborough River are presented in Table 16. Discharge hydrographs for two gaging stations on the upper Hillsborough River are illustrated in Figure 60. Peak flows are in late winter/early spring and late summer/early fall (USGS 1983; Fernandez et al. 1984). Low flows generally occur from late October to early December and again from April to mid-July. The river is primarily supported by springs (Crystal Springs and Sulfur Springs) during low flow.

a. Upper Hillsborough River drainage area. The upper river drainage area extends from the headwaters in the Green Swamp to just below the confluence with Flint Creek (Figure 59). The area is further divided into Zephyrhills, Blackwater Creek, New River, and Lake Thonotosassa watersheds.

Uppermost is Zephyrhills, which consists of the Hillsborough River headwaters and the tributaries of Fox Branch, Big Ditch, Crystal Springs, and an unnamed tributary west of State Road 156 on the outskirts of Zephyrhills. Canals drain the area in and adjacent to Zephyrhills Army Base and empty

Table 16. Point-source dischargers in the western Old Tampa Bay drainage area (after ESE 1977b; Hartigan and Hanson-Walton 1984).

Receiving water	Treatment facility	Effluent volume (mgd)
Mullet Creek	Safety Harbor Municipal	0.33
Alligator Creek	Aerosonics[a]	0.005
	Boulevard	0.018
NW Old Tampa Bay	South Gate	0.011
	Tropic Hill	0.015
	Clearwater East[b]	4.31
	Clearwater Northeast	3.20
Allen Creek	Belcher Rd. Elementary	0.009
Long Branch	Midway Services Corp.	0.150
Cross Bayou Canal	<u>Industrials</u>	
	Culligan Pinellas Water Conditions	0.01
	Modern Plating Corp.	0.06
	U.S. Plating	?
	U.S. ERDA	?
	<u>Municipals</u>	
	Largo	7.5
	Pinellas Park[c]	1.6
	Juvenile Court	0.015
	Holiday Harbor	0.01
	Yankee Travel	0.009

[a]Surface water discharges to be discontinued (after 1984).
[b]Discharges south of Courtney Campbell Causeway.
[c]Discharges to Boca Ciega Bay via Canal South.

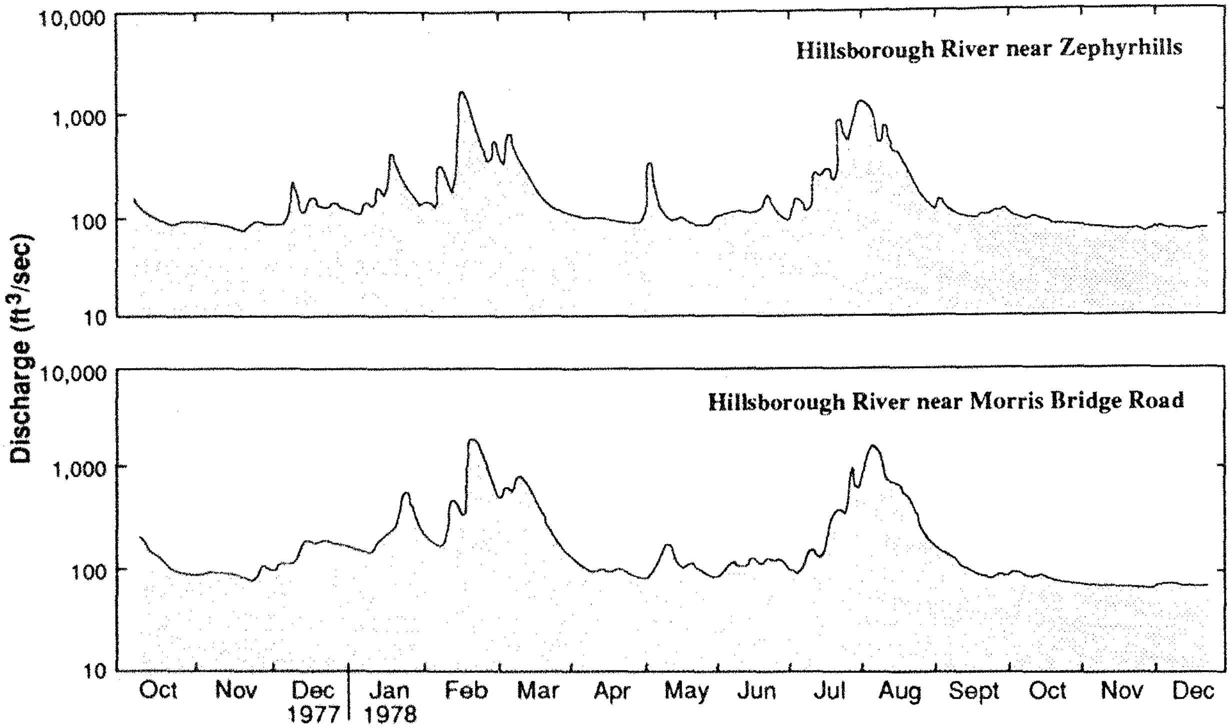


Figure 60. Discharge hydrographs for two gauging stations on the Hillsborough River (after Fernandez et al. 1984).

through a hardwood swamp forest to the Hillsborough River. The urban area of Zephyrhills drains to a marsh strand that takes water south to a ditch and then to the Hillsborough River.

The major urban area is centered around Zephyrhills. Elsewhere land use is mainly agricultural, specifically improved pasture (59%), unimproved pasture (35%), and citrus (6%) (ESE 1977). Citrus groves are primarily found near Zephyrhills. Wetland forests flourish along the Hillsborough River and around and in numerous ponds and depressions, particularly in pasture lands south of the river (ESE 1977b).

C.F. Industries, which enters upper Big Ditch, is Zephyrhills watershed's only point-source discharger (Priede-Sedgwick, Inc. 1980). This chemical-processing plant also produces gypsum waste that is stored in a settling pond formed by an earthen dam, and from which waste effluent has been discharged in emergency situations (ESE 1977b).

Little water-quality information exists for this headwater area. Flow ranges from negligible to 50 m^3/s. Water quality above Zephyrhills and Crystal Springs, at State Road 98, typify wetland waters. Dissolved oxygen concentrations are low (34% of observations were below 5.0 mg/L), nutrients are relatively low, the water is acid and colored, and total coliform counts are high (ESE 1977b; Hand and Jackman 1984).

In the dry season, the river flow comes largely from Crystal Springs, which has an average discharge of 1.7 m^3/s (Fernandez et al. 1984). Water from the spring is low in dissolved oxygen (2–4 mg/L) because of the low oxygen content of ground water that feeds the spring (USGS 1983). The spring-water temperature ranges from 23°C to 24°C, conductivity is moderately high, and nutrient concentrations are low (ESE 1977b; USGS 1983). Dissolved oxygen levels and nutrient concentrations increase rapidly down the 0.8 km spring run; DO ranges from 4 to 6 mg/L where it enters the Hillsborough River (USGS 1983; Hand and Jackman 1984). Coliform counts in the spring run and below the run in the river are relatively low.

On the opposite side of the river and further downstream from Crystal Springs is Big Ditch, a channelized canal system that receives agricultural and industrial runoff. Nutrient levels in Big Ditch are very high in response to an upstream point source (C.F. Industries). High concentrations of nitrate (19.4 mg/L) and orthophosphate (7.74 mg/L) are found near the plant and decrease downstream, but remain high at the creek mouth (Hand and Jackman 1984). Total coliform counts and DO levels follow a similar pattern.

Blackwater Creek, the first major tributary to the Hillsborough River, is 25 km long and drains 310 km^2; 10 km upstream of its mouth, it is joined by Itchepackasassa Creek, a channelized stream that drains the southern half of the Blackwater Creek watershed.

Except for an urban area centered around Plant City in the southeastern portion of the watershed, the dominant land use is improved pasture. The normally flood-prone area is kept drained by an extensive network of feeder ditches and canals (ESE 1977b). Plant City is storm sewered and indirectly discharges to Itchepackasassa Creek. One small domestic point-source (Meadowbrook Mobile Park) discharges to upper Blackwater Creek (Priede-Sedgwick, Inc. 1980). Three industrial dischargers in the watershed include a chemical-processing plant in upper Blackwater Creek and two citrus-processing plants in upper Itchepackasassa Creek. Other significant pollutant sources are several cattle feedlots near both streams (ESE 1977b). Flow in the Itchepackasassa Creek, 9 km upstream of its confluence with Blackwater Creek, ranges from 0.003 m^3/s to 4.56 m^3/s (USGS 1983). Water quality in this area and the upper reaches of Blackwater Creek are characterized by low DO, high coliform counts, and high nutrient concentrations (Hand and Jackman 1984). Downstream the average DO level increases in response to luxuriant aquatic weed growth. Instantaneous DO concentrations exhibit large diurnal fluctuations that often fails to meet acceptable saturation levels (80%–120%), indicating eutrophic conditions. In the Itchepackasassa Creek at A-F Cattle Ranch, zinc, copper, and mercury concentrations have occasionally exceeded water-quality standards. Nutrients and coliforms remain high throughout the creek run (ESE 1977b; Hand and Jackman 1984). Highest nutrient levels were found in June and July (the beginning of the wet season) and probably are caused by nonpoint-source runoff from improved pastures and cattle feedlots (ESE 1977).

Flow in Blackwater Creek near Knights, and about 8 km upstream of the mouth, averages 2.3 m^3/s and has ranged from 155 m^3/s to zero (USGS 1983). Levels of nitrogen, specifically nitrate (0.2–1.4 mg/L) and organic nitrogen (0.67–1.9 mg/L), and phosphate (orthophosphate = 0.64–2.1 mg/L) are relatively high. Dissolved oxygen levels average 6.1 mg/L, with 20% of the measurements below 5.0 mg/L and 80% of the samples failed to meet saturation criteria of 80%–120% (Hand and Jackman 1984; USGS 1983). Sampling in 1975 and 1976 revealed FC/FS ratios indicative of pastureland or feedlot runoff (ESE 1977b). Fecal and total coliform counts exceed water quality standards in 28% and 85% of the observations, respectively (Hand and Jackman 1984). Coliform levels and phosphorus concentrations increase in the Hillsborough River adjacent to and downstream of the confluence of Blackwater Creek. Dissolved oxygen, pH, and nitrate show little change (Hand and Jackman 1984; HCEPC 1984).

New River drains the northwestern side of the upper Hillsborough River watershed, entering the Hillsborough River downstream of Blackwater Creek (Figure 59). Land use in the New River watershed is primarily improved pasture, rangeland, and hardwood forest wetlands. The upper reaches of the river are channelized, in marked contrast to the lower river's hardwood swamps (ESE 1977b).

Water quality in New River reflects the extensive agricultural drainage network and presence of cattle. Dissolved oxygen fluctuates greatly, failing to meet acceptable saturation levels (80%–120%) 84% of the time (Hand and Jackman 1984). Aquatic weeds flourish in the waterways where concentrations of coliforms, suspended solids, and ammonia are high (ESE 1977b; Hand and Jackman 1984).

Land use and water quality of Two Hole Branch, a small tributary downstream of New River (Figure 59), are similar to New River. Forested wetlands dominate the lower floodplain reaches of the tributary; the upper watershed is characterized by improved and unimproved pasturelands. The creek contributes high levels of nutrients, BOD, and bacteria to the Hillsborough River. Coliform levels and ratios suggest contamination by livestock by pastureland runoff (ESE 1977b; Hand and Jackman 1984).

Water quality in the Hillsborough River downstream of Two Hole Branch is generally good except for high concentrations of nitrate and phosphorus, particularly in the dissolved, oxidized forms, e.g., orthophosphate at 0.49–3.1 mg/L and nitrate at 0.60–1.4 mg/L (Hand and Jackman 1984; USGS 1983). Values for conductivity, bicarbonate, calcium, sulfate, color, and organic carbon reflect the strong influence Crystal Springs imposes on the river. Occasional high levels of nitrite (2.0 mg/L), BOD (5.0 mg/L), and ammonia (12.0 mg/L) are possibly caused by processing plants and feedlot effluent in the Blackwater Creek and Big Ditch watersheds (ESE 1977b). Dissolved oxygen (DO) levels are generally low at midday (4 to 6 mg/L), but occasionally reach supersaturation (10 to 12 mg/L) (ESE 1977b; USGS 1983). In addition to large DO fluctuations, the moderate to high concentrations of chlorophyll *a* (30 µg/L) and nutrients, and the relatively sluggish flow of the river, suggest high instream plant productivity (ESE 1977b; Hand and Jackman 1984). Heavy metals that occasionally exceed water-quality standards are iron (max. 510 mg/L), cadmium (max. 12 µg/L), lead (max. 200 µg/L), zinc (60 µg/L), and mercury (max. 5.2 µg/L). Cadmium, associated with phosphate fertilizer production, is contained in runoff from agricultural land fertilized with the phosphate. Lead is generally associated with auto emissions, while mercury may be associated with mercurial fungicides. Zinc may result from weathering of natural minerals, metal alloys, galvanized metals, and electrical equipment.

Hollomans Branch is a small tributary to the Hillsborough River that drains the area south of the Two Hole Branch watershed (Figure 59). The flow from this tributary is often negligible even in the wet season. Land use in the watershed is mainly pastureland and wetlands. The effect of the pastureland on water quality is seen in the very high coliform counts (Hand and Jackman 1984). Fecal streptococci counts as high as 59,000/100 mL have been reported (ESE 1977b). Nitrate and total phosphorus concentrations are moderately high (Hand and Jackman 1984).

The largest of the upper Hillsborough River tributary watersheds is the Lake Thonotosassa watershed (150 km^2). Drainage in the watershed is characterized by channelized streams fed by lateral canals and feeder ditches. Flint Creek, tributary to the Hillsborough River, receives the outflow of Campbell Branch and originates at the outflow of Lake Thonotosassa (Figure 59). Lake Thonotosassa receives inflow from Baker Creek to the south and Pemberton Creek to the east. Mill Creek and Sparkman Branch are tributaries to Pemberton Creek and drain much of the Plant City urban area. A dredged borrow channel runs along the eastern shore of Lake Thonotosassa (Reichenbaugh and Hunn 1972).

Agricultural (improved pasture and citrus) and urban areas cover about 90% of the watershed. Urban areas are primarily confined to Plant City and the shoreline of Lake Thonotosassa. In addition to the pasture and citrus, other forms of agriculture are cropland—located near Baker, Pemberton, and Campbell Creeks—and dairy feedlots—located throughout the watershed (ESE 1977b). Plant City is storm-water sewered and at least three 1.5-m culverts discharge indirectly to Mill Creek and Sparkman Branch.

Prior to 1970 untreated wastes from vegetable and citrus processing plants and primary-treated waste from Plant City were discharged to Mill Creek. Now, food-processing and municipal wastes undergo advanced waste treatment at the Plant City Municipal Wastewater Plant. The plant currently discharges through a series of channels stocked with water hyacinth to achieve final nutrient removal before discharging to Mill Creek and finally to Pemberton Creek (Priede-Sedgwick, Inc. 1980). Florida Sip, Inc., a citrus processor, discharges cooling water and evaporator blowdown in addition to processing-waste effluent. Two other industrial point-source dischargers are Edgar Plastic Kaolin Company, a mining and processing operation that discharges to Sparkman Branch; and Treasure Isle, Inc. (Ocean Products), a seafood processor that discharges to a tributary of Baker Creek in its upper reaches (ESE 1977b; Priede-Sedgwick, Inc. 1980).

Water quality in the Lake Thonotosassa watershed is generally poor, as evidenced by high average concentrations of nutrients, chlorophyll *a* , and turbidity; high levels of bacteria; high pH; and large fluctuations of dissolved oxygen (HCEPC 1982, 1984; FDER 1983; Hand and Jackman 1984; USGS 1983). These problems are caused by historic contributions of untreated municipal and industrial waste; agricultural and urban runoff; and runoff from dairies and poultry, meat, and citrus processing plants (Hand and Jackman 1984; HCEPC 1984).

Mill Creek and Sparkmans Branch, which form the headwaters of Pemberton Creek, drain the eastern portion of the Lake Thonotosassa watershed and the western half of Plant City, the major urban areas in the upper Hillsborough River watershed. Mill Creek, which receives storm-sewer effluent from the northwest side of Plant City, exhibits poor water quality. Dissolved oxygen ranges from low to supersaturated, and bacteria, nutrients, and turbidity are typically high in the creek (Hand and Jackman 1984). These problems are caused by urban stormwater, Plant City Sewage Treatment Plant effluent, and discharge from Schuylkill Metals, a battery-breaking operation that salvages lead and uses ammonia to neutralize the batteries sulfuric acid. Leachate from the battery-salvage operation's holding pond contained high concentrations of ammonia (NH_4^+) (476 mg/L as N), and because of the relatively high pH of the discharge, much of this was in the much more toxic form of un-ionized ammonia (NH_3) (27.6 mg/L as NH_3). Samples of the leachates proved to be toxic in bioassay tests (FDER 1983). Although water samples downstream of the plant showed permissible concentrations of heavy metals associated with this industry, a permanent station farther downstream (Lake Thonotosassa outfall at Flint Creek) has measured lead concentrations as high as 1,050 µg/L (Hand and Jackman 1984).

From the confluence of Mill Creek and Sparkman's Branch, Pemberton Creek flows northwest and then southwest to join Baker Creek just upstream of Lake Thonotosassa. Like Mill Creek, Pemberton Creek has poor quality water, characterized by low levels of DO and high bacterial counts, nutrient concentrations, and turbidity, and low pH (FDER 1983; Hand and Jackman 1984; HCEPC 1984). Dissolved oxygen often exceeds the 120% saturation level, indicating a high level of plant productivity (macrophytes and phytoplankton). Dissolved oxygen concentrations in Pemberton Creek near its mouth averaged less than 5.0 mg/L in 1982 (HCEPC 1984). Nitrogen is mainly in the nitrate (1983–1.74 mg/L) and organic forms (1983–1.00 mg/L), and orthophosphate dominates the phosphorous forms (HCEPC 1982, 1984; Hand and Jackman 1984; USGS 1983). Total phosphate (as P) averaged 1.28 mg/L in 1983 (HCEPC 1984).

Baker Creek drains the southern portion of the watershed, an area dominated by citrus, cropland, pasture, dairies, and several food-processing plants (e.g., Treasure Isle). Dissolved oxygen is often (42%) below 5.0 mg/L and commonly fails to meet acceptable saturation levels (80%–120%). Mercury has occasionally exceeded water quality standards, averaging 0.18 µg/L (Hand and Jackman 1984).

Lake Thonotosassa is the largest lake (335 ha) in the Hillsborough River watershed, receiving drainage from a 155-km^2 watershed. A semiconfining clay lens restricts seepage from the lake to the Floridan Aquifer. Water-level fluctuations of about 0.5 m are caused mainly by surface-water inflow from Baker/Pemberton Creek and, to a minor extent, by in-lake rainfall and evaporation (Reichenbaugh and Hunn 1972). The lake has a mean depth of 3 m and a detention time of 0.21 years (Reichenbaugh and Hunn 1972). Urban and agricultural land uses compose 19% and 70%, respectively, of the watershed. Aquatic macrophytes cover only a minor (1.2%) portion of the lake, and phytoplankton, often blue-green algae, dominate the aquatic flora (Cowell et al.

1975; HCEPC 1982, 1984; Hand and Jackman 1984; Myers and Edmiston 1983).

Lake Thonotosassa and its tributaries make up one of the major water-quality problem areas in the Hillsborough River watershed (FDER 1983). The lake is highly eutrophic and has repeated blue-green algal blooms and fish kills (HCEPC 1982, 1984). Annual averages of chlorophyll *a* consistently exceed 50 µg/L and more than 50% of the DO measurements exceed 120% saturation (FDER 1983; HCEPC 1984). In 1983, chlorophyll *a* averaged 68.5 µg/L in the center of the lake (HCEPC 1984). The high level of algal productivity, particularly by blue-green algae, shifts the pH balance to the basic end of the scale, as evidenced by 50% of the pH values in the lake exceeding 8.5. Nutrients, BOD, bacteria, and turbidity are also very high (Hand and Jackman 1984). Trend analysis for the period from 1970 to 1980 show increased pH, DO, and chlorophyll *a* , and a slight decrease in total phosphorus. By 1980, TKN average concentrations at the lake's outfall at Flint Creek had increased from 0.3 mg/L to 2.0 mg/L. Coliform levels, particularly near the lake inflow (Baker/Pemberton Creek) often exceed State water quality standards (Hand and Jackman 1984; HCEPC 1984). The outfall also exhibits occasional high levels of lead, copper, and zinc. As waters pass from Baker/Pemberton Creek to Flint Creek, coliforms, color, phosphorus, and inorganic nitrogen forms (NO_3 and NH_3) decrease; while BOD, chlorophyll *a*, turbidity, pH, DO, and organic nitrogen increase (HCEPC 1982, 1984). The lake acts like a settling pond where phytoplankton productivity assimilate inorganic nutrient sources into biomass. Some of the phosphorus is evidently lost to the sediments. Fourteen years of citrus pulp sedimentation in the lake has also created a muck bottom that serves as an oxygen sink and nutrient reservoir (Cowell et al. 1975).

In Flint Creek, near Lake Thonotosassa and 4.5 km upstream of its confluence with the Hillsborough River, the flow averages 1.03 m^3/s and ranges from zero to 17 m^3/s (USGS 1983). Further downstream at SR 582, average DO has decreased, although 67% of the measurements fail to meet saturation limits (80%–120%); pH decreases (7.5), and the nutrients remain at the levels measured near the lake's outfall (Hand and Jackman 1984).

b. Lower Hillsborough River drainage area. The lower Hillsborough River watershed extends north from the Interbay Peninsula and the Alafia River watershed to just west of St. Leo to the north, and from the Land-O-Lakes region on the west to the Baker Creek watershed on the east (Figure 59). Major tributaries are Cypress Creek and its tributaries (Thirteen Mile Run, Bee Tree Branch, Stanley Branch, and Bayou Branch), Trout Creek, Clay Gulley Creek, and Cow House Creek. All but Cow House Creek enter the Hillsborough River from the north. Cow House Creek is actually an old cut-through or meander channel of the Hillsborough River that exits near Morris Bridge and enters upstream of the Tampa Reservoir. During periods of high river flow, the overflow is diverted to the Tampa Bypass Canal from near Trout Creek and across Cow House Creek, and from the upper Tampa Reservoir via Harney Canal. The Tampa Bypass Canal enters the Palm River-Six Mile Creek system and empties into McKay Bay. Other coastal creeks in the southeast watershed are Delaney Creek and Archie Creek (Figure 59).

At Morris Bridge, downstream of Flint Creek's confluence with the Hillsborough River, the river exhibits a decreased influence of upstream livestock, industrial (food and fertilizer processing), and municipal sewage contamination (ESE 1977b). Nitrate and bacterial counts are still relatively high, but are less than upstream values. The FC/FS ratio suggests contamination from pasture (livestock) runoff, and increased concentrations of organic nitrogen and orthophosphorus probably reflect the inflow from the Lake Thonotosassa watershed (Hand and Jackman 1984; Fernandez et al. 1984). Other aspects of the water quality indicate that the river is assimilating the upstream load. Dissolved oxygen levels show fewer violations, turbidity is low, and the pH approaches neutral (ESE 1977b; Hand and Jackman 1984; Fernandez et al. 1984).

From Flint Creek to Fowler Avenue, the Hillsborough River is V-shaped and meandering. Its depth ranges from 0.3 to 5.0 m and at low flow it is 10 to

35 m wide (Fernandez et al. 1984). This portion of the watershed is rural, dominated by pine flatwoods, citrus groves, improved pasture, and wetlands. Tributaries that drain to the north side of this reach are Clay Gully Creek, Trout Creek, and Cypress Creek. South of the river is Cow House Creek. Much of the western Hillsborough Wildlife Management Area is drained by Clay Gully, Trout, and Cow House Creeks.

Trout Creek and Clay Gully Creek drain the north side of the river between Cypress Creek and Flint Creek. Both drainage areas are unimproved pasture and rangeland in the upper reaches and hardwood swamp forests near the Hillsborough River. There are no major point sources and only scattered residences here.

Flow in Trout Creek has averaged 0.46 m^3/s and ranged from a dry stream bed to 44 m^3/s (USGS 1982). Swamp drainage, stagnation, channel depth, and plant color cause low dissolved-oxygen concentrations. BOD is usually less than 2 mg/L, and nutrients are reported at low to moderate levels (ESE 1977b; FDER 1983; Hand and Jackman 1984). Bacteria counts occasionally violate water-quality standards and the FC/FS ratios point to livestock as the source (ESE 1977b).

Cow House Creek, formed from an old meander of the Hillsborough River, drains the south side of the Hillsborough River and enters the river just upstream of the Tampa Reservoir. Construction of the Tampa Bypass Canal has split the creek's watershed (Figure 59), diverting some of the upper-reach flow away from the Hillsborough River system. Land use is evenly distributed among residential, improved pasture, citrus, and wetlands, and no major point sources or stormwater outfalls are present along the tributary (Priede-Sedgwick, Inc. 1980). Flow is typically less than 2.7 m^3/s but has reached 40 m^3/s. Average dissolved oxygen concentrations range from 3.7 mg/L at the headwaters to 5.0 mg/L near Temple Terrace, often failing to meet acceptable saturation limits (80% to 120%). Inorganic nitrogen and phosphorus levels are high, averaging 1.04 and 0.220 mg/L, respectively (FDER 1983; Hand and Jackman 1984).

Cypress Creek extends north almost to the Hernando County line and drains an area of more than 415 km^2. The tributaries, Bee Tree Branch, Bayou Branch, and Stanley Branch, join the creek west of St. Leo before it turns south and runs alternately through well-defined channels and wide swamplands, collectively known as the Big Cypress Swamp area of Pasco County. There are numerous lakes to the north and west, particularly in the residential Land-O-Lakes and Lutz areas, and many of these drain into the creek through canals, marshes, and cypress sloughs (Henderson 1983). Thirteen Mile Run originates in such an area south of Lutz and flows southeast to Cypress Creek. Cypress Creek joins the Hillsborough River near SR 582A. Although the potentiometric surface of the Floridan aquifer forms a trough in the Cypress Creek watershed, it is above the land surface in the Big Cypress Swamp, so upward seepage may occur where the aquifer's confining layer is absent or broken (e.g., sinks) (Ryder 1978; Wolansky et al. 1978; Henderson 1983).

Citrus and improved pasture are the most common land uses in the northern reach of the watershed. Three small private domestic wastewater plants discharge to waters in the northern portion of the Cypress Creek watershed. These are Lake Padgett Mobile Home Park, Quail Hollow Golf and County Club, and Stuckey's. All discharge through Big Cypress Swamp to Cypress Creek (ESE 1977b; Priede-Sedgwick, Inc. 1980). Flow in Cypress Creek at SR 581 averages 2.5 m^3/s, ranging from 50 m^3/s to zero (USGS 1982).

The riverine swamps along Cypress Creek provide the dominant influence on the stream's water quality. Dissolved oxygen values are low, ranging from 4.5 mg/L at Worthing Gardens in the upper reach to less than 2.0 mg/L at SR 581 (HCEPC 1982, 1984; Hand and Jackman 1984). Color, a measure of humic and fulvic acids from decomposed leaf litter, is very high, averaging 147.4 and 114.8 platinum-cobalt units in 1982 and 1983, respectively (HCEPC 1984). High total organic carbon (TOC) levels (20–30 mg/L) result from decomposed organic material. Low nutrient (particularly phosphorus), BOD, turbidity, and chlorophyll *a* levels, and fecal coliform counts suggest minimal influence of point and nonpoint sources on the creek's water quality (HCEPC 1982, 1984; Hand and Jackman 1984).

Lakes in the vicinity of Lutz and Land-O-Lakes have, in the past, exhibited good water quality with relatively low nutrients (TN = 0.75–1.42 mg/L; TP = 0.01–0.04 mg/L), moderate dissolved-oxygen values, and low chlorophyll *a* concentrations (Henderson 1983). In some lakes (e.g., Lake Padgett, Saxon Lake), there are nuisance levels of torpedo-grass (*Panicum repens*) and hydrilla (*Hydrilla verticillata*) (Seaburn and Robertson, Inc., and Biological Research Associates 1977). Pasture and citrus areas around these lakes are being converted to residential development, and lake bottoms have been dredged in many areas to fill low-lying shorelines. A trend of increasing organic nitrogen and specific conductance has been observed for the last decade (1970 to 1980), and major wellfields that sandwich the lake area are apparently causing a 0.3–0.6 m reduction in lake levels (Henderson 1983).

From Fowler Avenue to Hillsborough Bay, the lower Hillsborough River watershed encompasses most of Tampa, Temple Terrace, the eastern Interbay Peninsula, and Davis Island. Major water bodies include Hillsborough Reservoir, the lower Hillsborough River and its tributary Sulphur Springs, western McKay Bay, and Hillsborough Bay. Major channels associated with port facilities and the Tampa Bypass Canal transect Hillsborough and McKay Bays and are bordered by dredge-spoil islands.

Urban land use dominates the lower Hillsborough River watershed. Two municipal and fifteen industrial dischargers are located mainly around the two bays (Figure 59). The effluent characteristics are presented in Table 17 (Priede-Sedgwick, Inc. 1980; Hartigan and Hanson-Walton 1984). The Hookers Point sewage treatment plant (STP), located on the peninsula between Hillsborough and McKay Bays, is the largest municipal waste treatment facility on the Florida gulf coast. In 1983, about 53 mgd were discharged to Hillsborough Bay (Hartigan and Hanson-Walton 1984). The volume of effluent routinely exceeds 60 mgd. Industrial dischargers include nine industries involved in the receipt, storage, and distribution of refined oil, and six industries that discharge thermal effluent.

The hydrology of the lower Hillsborough River watershed and associated water quality form two distinct environments separated by the Tampa Reservoir Dam. Upstream, from the dam to Fowler Avenue, the

Table 17. Description and water-quantity data for four continuous-record gauging stations in the Hillsborough River (after Foose 1983, USGS 1983, Fernandez et al. 1984).

Distance above river mouth (km)	Location	Drainage area	Average flow [Max–Min Flow]	Data available[a]
64	Near Zephyrhills	570 km^2	7.28 m^3/s [357 m^3/s–1.25 m^3/s]	QW,PKT, PY,BCT, SED,FLO,WL
47	At Morris Bridge Rd. near Thonotosassa[b]	975 km^2	6.80 m^3/s [116 m^3/s–1.02 m^3/s]	QW,FLO, WL
32	At Fowler Avenue near Tampa [b]	1,630 km^2	5.9 m to 9.9 m [c]	QW,WL
16	Near Tampa [d]	1,700 km^2	16.8 m^3/s [413 m^3/s–zero]	

[a]Data: QW, water quality; PKT, phytoplankton; PY, periphyton; BCT, bacteriology; SED, sediment; FLO, flow; and WL, water level.
[b]Affected by backwater.
[c]Gauge height only available data.
[d]An appreciable amount of water is diverted from watershed into Tampa Bypass Canal in May, August, and September.

river is a freshwater reservoir. Downstream, the river is tidal. Flow data and types of water quality data taken at selected stations are presented in Table 17.

The Hillsborough River has provided freshwater for the City of Tampa since 1926. In 1945, a dam was built 16 km upstream of the river mouth to create the Tampa Reservoir (Metcalf and Eddy, Inc. 1980). In 1964, to meet further water demands, structures were completed to allow intermittent pumping of Sulfur Springs waters upstream to the reservoir during periods of low flow (Fernandez et al. 1984). Use of Sulphur Springs to supplement the reservoir water has declined since 1980 because of a new water supply provided by the Morris Bridge Water Treatment Plant (City of Tampa 1981). Storm water from about 50 km^2 of urban (75%) and open-space (25%) land flows directly to the reservoir (Metcalf and Eddy, Inc. 1980; Priede-Sedgwick, Inc. 1980). This storm water makes up only 5% of the reservoir's annual inflow, compared to 95% contributed by the upper Hillsborough River (Priede-Sedgwick, Inc. 1980). Water outflow is through control structures at the dam, and during high-flow conditions, is partially diverted to the Tampa Bypass Canal and eventually to McKay Bay.

The reservoir is long (16 km) and relatively narrow, surrounded by the cities of Temple Terrace and the northern portion of Tampa. At low stage, the lower downstream half of the reservoir consists of one main channel and one or two shallow channels. Average depth and width in this lower reach are 6 m and 150 m, respectively (Metcalf and Eddy, Inc. 1980; Fernandez et al. 1984). Upstream, the reservoir narrows to about 60 m, with an average depth of 3 m. Bottom sediments range from sand to soft silt and clay with organic detritus (Fernandez et al. 1984). Hydraulic residence times vary from one month during low flow (2 m^3/s) to one or two days in high flow conditions (57 m^3/s). Flow, velocity, and residence times for the reservoir are presented in Figure 61.

Just upstream of the reservoir, the Hillsborough River exhibits good water quality; a reflection of the river's assimilation of upstream wastes and the influence of the Cypress Creek drainage system. Riverine swamps in the Cypress Creek basin and along the Hillsborough River above the Tampa Reservoir cause high TOC and color and low DO, averaging between 2.0 mg/L and 3.0 mg/L in 1982 and 1983 (HCEPC

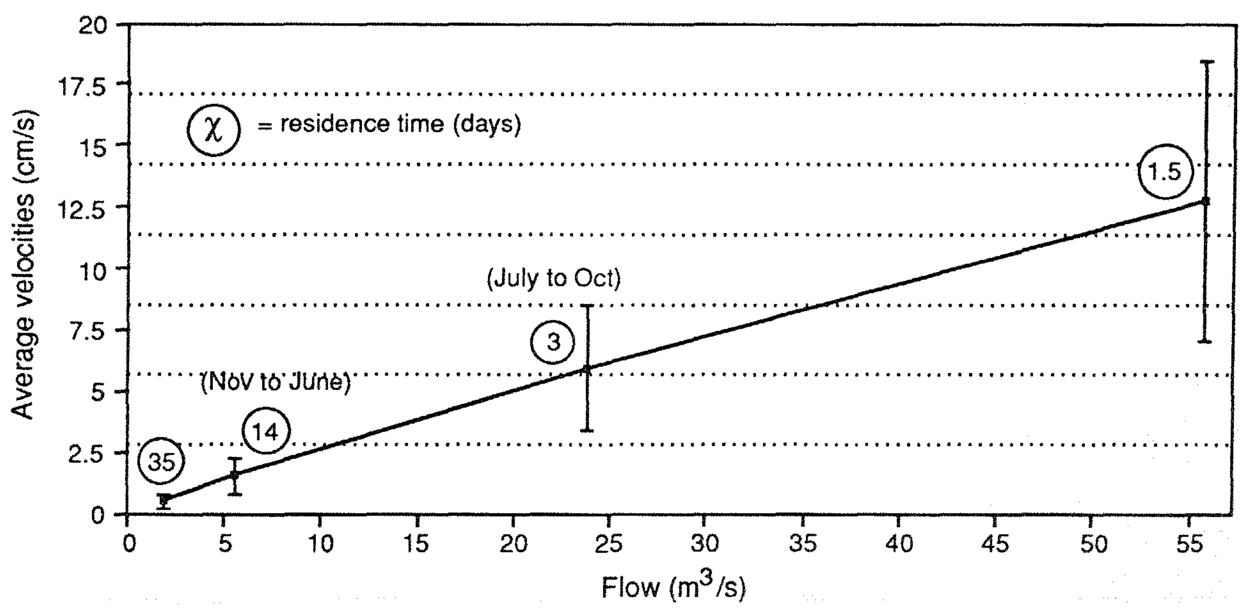


Figure 61. Flow, current velocity, and residence times for the Tampa Reservoir (after Metcalf and Eddy, Inc. 1980).

1984). Nutrients, BOD, turbidity, and chlorophyll *a* concentrations, and coliform counts are some of the lowest reported in the Hillsborough River watershed (HCEPC 1982, 1984).

Major water-quality problems in the reservoir are low dissolved-oxygen levels and high nutrient and heavy-metal concentrations. Dissolved oxygen levels at middepth typically range from 4 to 5 mg/L, but decrease to 1.0 mg/L in September and during high flow conditions, and in spring during low flow (Metcalf and Eddy, Inc. 1980; Fernandez et al. 1984). Levels are lower nearer the bottom and lowest in the downstream reaches of the reservoir near the dam. Changes in DO are apparently controlled by plant productivity. This is supported by low and stable BOD concentrations, greatly fluctuating surface water DO, and the presence of blue-green algal blooms and dense growths of water hyacinth. Algal blooms are most frequent from April to July when flows are low, residence times long, and water temperatures high (Metcalf and Eddy, Inc. 1980).

Phosphorus ranges from 0.25 to 0.7 mg/L and is highest in August and September (Metcalf and Eddy, Inc. 1980; HCEPC 1982; Hand and Jackman 1984; Fernandez et al. 1984). Only 5% of the annual phosphorus load to the reservoir is contributed by direct stormwater runoff. Most is derived from upstream sources (Priede-Sedgwick, Inc. 1980). Inorganic nitrogen forms (NO_3 and NH_3) are lowest in high-flow conditions and highest following rainfall in the dry season (May). Concentrations range from 0.3 to 2.0 mg/L and are lowest downstream toward the dam (Metcalf and Eddy, Inc. 1980; HCEPC 1982; Hand and Jackman 1984).

Of the heavy metals reported, only mercury exceeded State standards with average concentrations ranging from 0.23 and 0.55 µg/L in the wet and dry seasons, respectively (Metcalf and Eddy, Inc. 1980; Hand and Jackman 1984). Lead averaged 20 µg/L and was highest following dry-season rainfalls (Metcalf and Eddy, Inc. 1980).

The last reach of the Hillsborough River, a 16-km stretch between the Tampa Reservoir Dam and Hillsborough Bay, is tidal and brackish (Figure 62). It receives inflow from dam releases, Sulphur Springs, urban stormwater, and tidal flow from Hillsborough Bay. The immediate drainage area is about 100 km^2, urban in land use, and generally storm sewered.

Flow in the lower Hillsborough River ranges from 2 to 65 m^3/s, averages 17.4 m^3/s, and is derived mainly from dam releases (85%) (Metcalf and Eddy, Inc. 1980; Priede-Sedgwick, Inc. 1980). Hydraulic residence times range about 0.8, 6.9, and 16.7 days for high-, intermediate-, and low-flow conditions, respectively (Metcalf and Eddy, Inc. 1980).

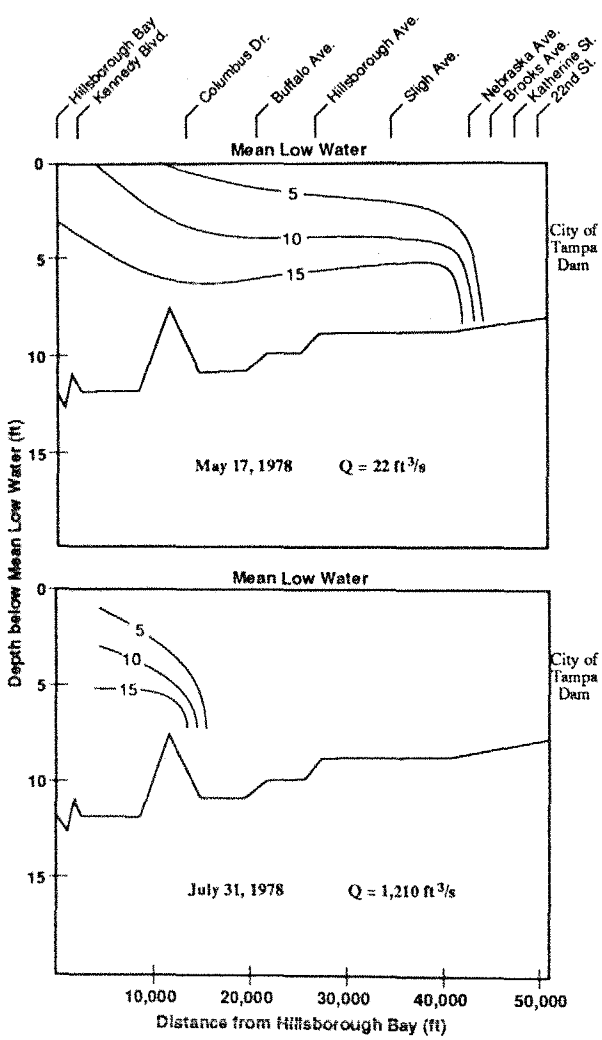


Figure 62. Salinity (ppt) in the lower Hillsborough River (after Metcalf and Eddy, Inc. 1980).

Water quality in the lower river is controlled primarily by the inflow from the dam and to a lesser extent by storm-water discharge. The most obvious example of the influence of flow is its effect on salinity (Figure 62). A saline wedge may penetrate up the Hillsborough River to the confluence of Sulphur Springs under low-flow conditions (<3 m^3/s) and be flushed downstream as far as Columbus Drive when the flow exceeds 25 m^3/s. Near Columbus Drive, about 3.6 km upstream of the bay, a natural sill-like barrier rises about 1 m and prevents flushing of saline waters bayward of this point at any time. Changes in salinity caused by flow are typically a seasonal phenomenon. The saline wedge penetrates farthest in April or May, at the end of the dry season. Tides cause a more moderate and short-lived movement of the saline wedge in the river (Metcalf and Eddy, Inc. 1980, 1983). Average salinities from 1980 to 1983 range from 0.2% below dam to 12.3% at Columbus Drive (HCEPC 1982, 1984).

Major water-quality problems in the Hillsborough River downstream of the dam are low DO levels, high coliform counts, and high nutrient concentrations (Metcalf and Eddy, Inc. 1980, 1983; HCEPC 1982, 1984). Low DO concentrations are strongly tied to the location of the saline wedge throughout the year and in 1981 were the lowest values (average and instantaneous) reported in Hillsborough County (Table 18)(HCEPC 1982; Metcalf and Eddy, Inc. 1983). Levels in the saline waters fall below 4.0 mg/L and are lowest (<2.0 mg/L) in May and June when flow is minimal and saltwater extends to Sulphur Springs. Surface DO rarely dropped below 4.0 mg/L and often exceeded saturation, particularly in May and June, as illustrated in Figure 63. BOD is usually less than 2.0 mg/L, and thus has only a minor influence on DO changes.

Algal productivity, sediment oxygen demand, flow, and the tides cause most of the changes seen in DO concentrations (EPA 1982; Metcalf and Eddy, Inc. 1983). Short-term fluctuations are caused by tides and result in decreased DO levels in the flood tide and increased levels in ebb flow. Freshwater flow suppresses both tidal and diurnal (algal-caused) cycles and generally increases the river's DO concentrations. Moderate flow (5.5 to 11 m^3/s) greatly increased levels at Columbus Drive, but not near the bay (Metcalf and Eddy, Inc. 1983). Levels decreased near the dam in high flow with the release of oxygen-poor bottom reservoir waters through the lower control gates. A summary of dissolved oxygen statistics for several stations downstream of the dam are illustrated in Figure 63 and presented in Appendix Table A-6.

Increases of fecal and total coliform counts closely follow rainfall activity in the watershed, and commonly exceed State water quality standards. After a rain, the fecal coliform count rose to more than 1.0×10^5 per 100 mL near Hillsborough Bay, and generally decreased to acceptable levels towards the dam (Figure 64) (Metcalf and Eddy, Inc. 1980, 1983; HCEPC 1982, 1984). Near the dam, river waters

Table 18. Summary statistics for dissolved oxygen levels in the lower Hillsborough River (after Metcalf and Eddy, Inc. 1983).

Station	Range of DO concentrations (mg/L)	Average (50%) DO concentrations (mg/L)	% of time DO concentrations are <4.0 mg/L
Platt Street	0.0–10.0	3.6	59
Columbus Drive	0.0–10.0	4.3	41
Sligh Avenue	0.0–10.0	4.8	31
22nd Street	0.0–6.0	5.2	24

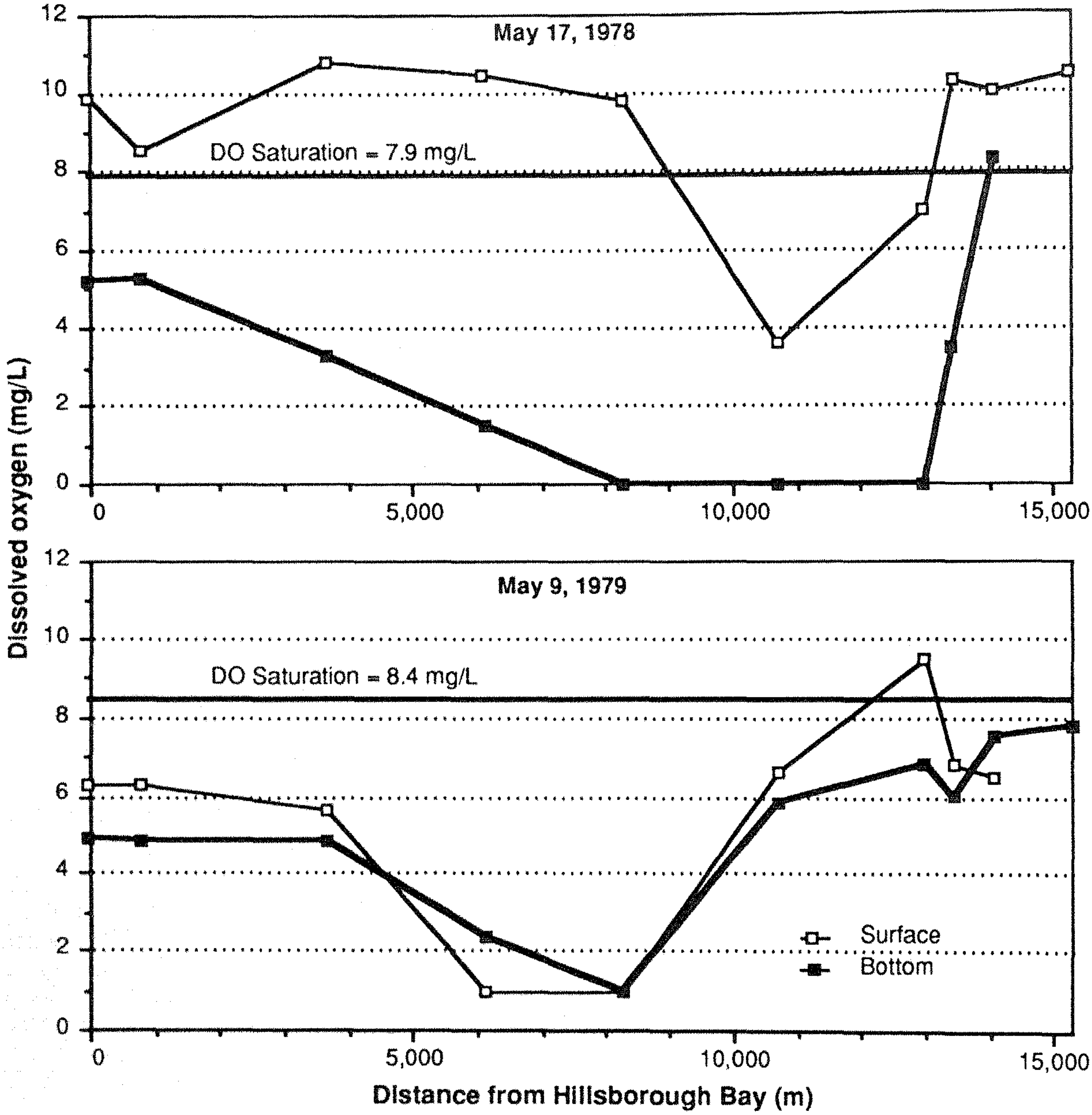


Figure 63. Dissolved oxygen in lower Hillsborough River (after Metcalf and Eddy, Inc. 1980).

reflect low-coliform reservoir releases rather than stormwater discharge. The highest levels observed in the upper surface water are more directly influenced by urban storm water (Metcalf and Eddy, Inc. 1983). Occasionally, the sewage collection system in the watershed has overflowed and coliform bacteria from raw sewage have been carried by the storm water to the river. This occurred in 1979, 1980, and 1982 and caused significant increases of coliforms in the lower Hillsborough River, particularly near the mouth (HCEPC 1982, 1984).

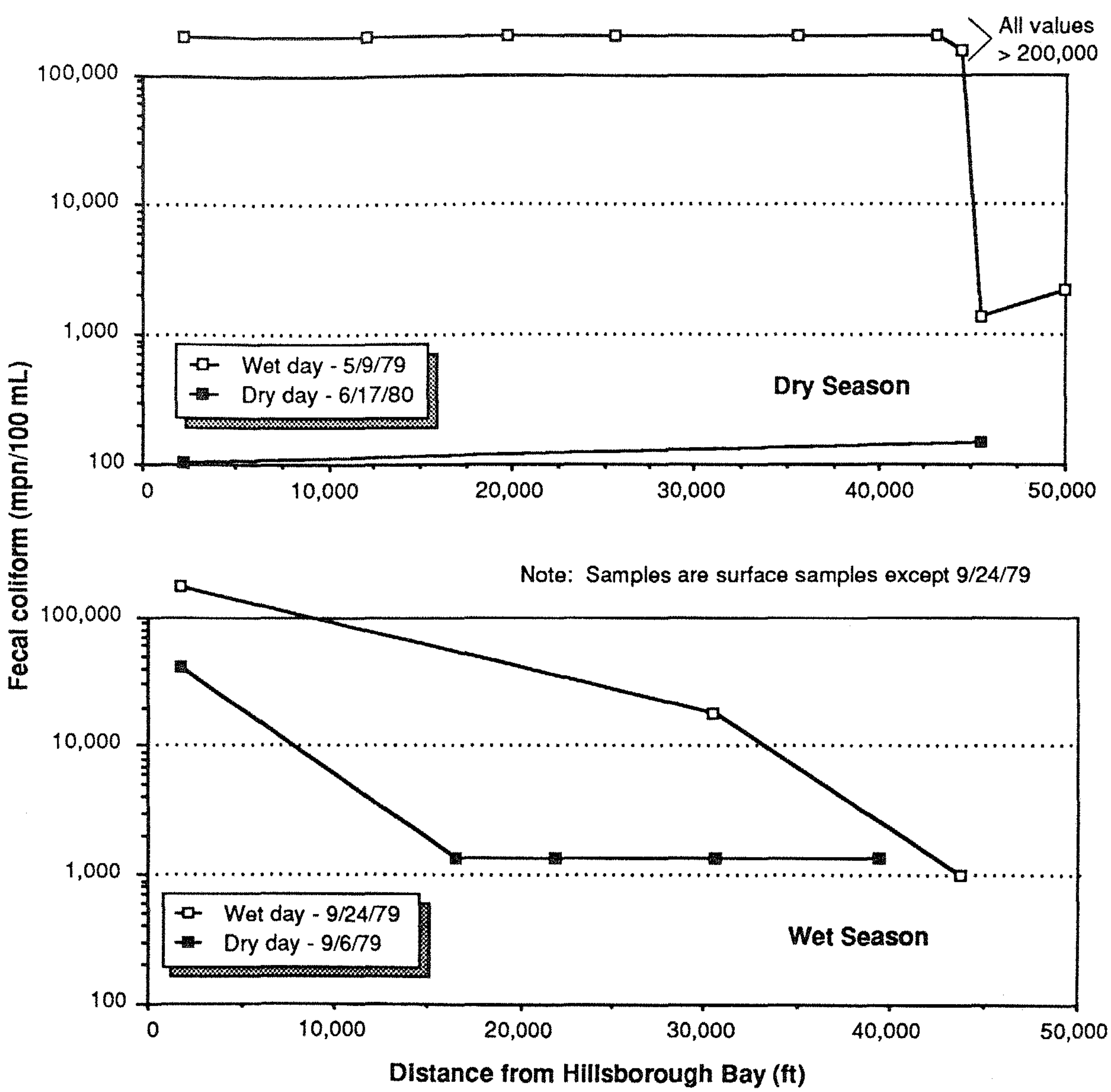


Figure 64. Fecal coliform in the lower Hillsborough River (after Metcalf and Eddy, Inc. 1980).

Storm water and upstream inflows have varying effects on inorganic nutrients. Generally nutrients are higher in the lower reach, apparently imported from Hillsborough Bay (Metcalf and Eddy, Inc. 1980, 1983). Under high-flow conditions, orthophosphate ranged from 0.3 to 0.5 mg/L and was well mixed in the water column, except in the last 3-km reach near the bay. There, in saline waters, bottom concentrations were higher and ranged from 1.0–1.5 mg/L (Metcalf and Eddy, Inc. 1980). In low-flow periods, orthophosphate concentrations in the surface waters (0.2–0.4 mg/L) were consistently less than those reported from near the bottom (0.5 to 1.5 mg/L). This stratification may extend as far as 13 km upstream of the bay. Storm-water discharge in the dry season reduced the orthophosphate concentration and eliminated the stratification in much of the river downstream of the dam (Figure 65).

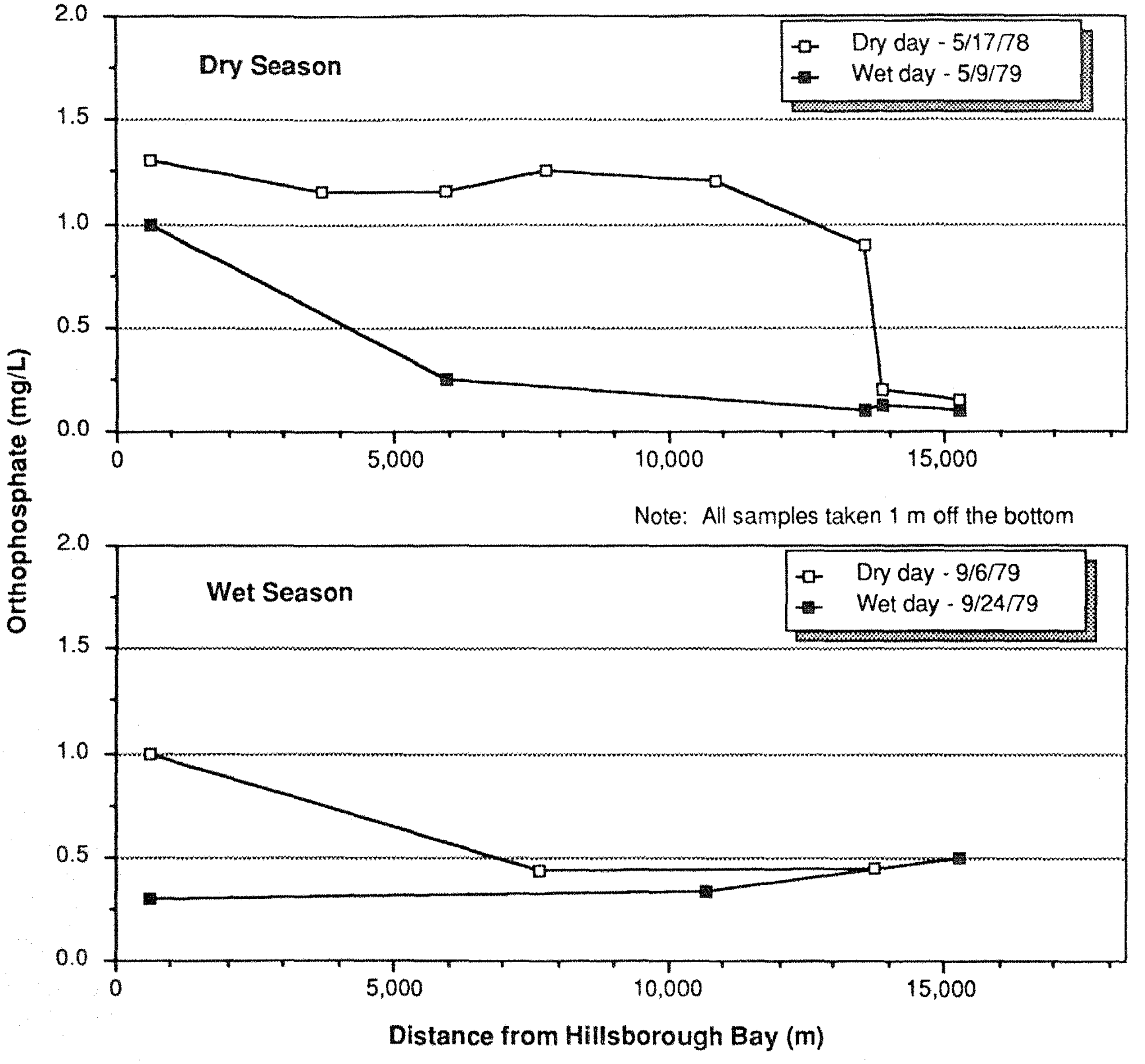


Figure 65. Orthophosphate in the lower Hillsborough River (after Metcalf and Eddy, Inc. 1980).

Ammonia and nitrate concentrations respond much like orthophosphate in the wet season. They are vertically well mixed except near the bay, where the saline wedge contains higher concentrations, especially ammonia (Metcalf and Eddy, Inc. 1980). Combined values in the river range from 0.0 to 0.7 mg/L. In the dry season ammonia concentrations from the reservoir have been generally less than 0.05 mg/L, increasing to a maximum (0.2–0.3 mg/L) midway between the dam and the bay near the bottom of the river. Nitrate during low flow shows no apparent trend between the dam and the bay, and ranges from zero to 0.4 mg/L.

Most of the total phosphorus is found in the orthophosphate form. Nitrate and ammonia are relatively minor forms of nitrogen in the lower reach of the Hillsborough River, where a majority of the nitrogen was bound in organic forms that ranged from 0.38 to 5.60 mg/L (Metcalf and Eddy, Inc. 1983).

In the 1981 study, copper was the only heavy metal to exceed State standards in the river downstream of the dam. Concentrations ranged from 3 to 57 µg/L and apparently were carried into the river by direct storm-water discharge. Other metals, including lead, iron, and mercury, exceeded standards in storm-water runoff but not in the river. The metals were tied to solids suspended in the storm water and rapidly fell out of the water column and into the organic sediments that thicken toward the river mouth (Metcalf and Eddy, Inc. 1983).

Urban storm water draining to the lower Hillsborough River is characterized by high levels of nutrients and coliforms, moderate BOD and TOC values, and occasionally high heavy-metal concentrations (Lopez and Michaelis 1979; Lopez and Giovannelli 1984). The contribution (quality and quantity) from any discharge depends on its land use, conveyance system (e.g., curb and gutter, swale and ditch), slope, percentage of impervious surface, percentage of directly contributing impervious surface, and existing storm-water treatment facilities (e.g., retention ponds). Storm-water quality measured from three drainage basins that discharge to the lower Hillsborough River showed very similar characteristics for all parameters except lead and zinc (Table 19). Concentrations for these two metals were highest from the Artic Street drainage basin, where 61% of the surface area is impervious, consisting mainly of roads and two large shopping centers. Apparently the high lead and zinc come from automobiles associated with the two shopping-mall parking lots and a high-traffic-density six-lane road (Lopez and Giovannelli 1984). Another striking difference between the Artic Street drainage basin and the other two more residential drainage areas (Kirby and St. Louis streets) was the relationship between base flow and storm-water concentrations. Nutrient, BOD, and COD values in

Table 19. Stormwater and baseline flow water quality data from three drainage basins to the lower Hillsborough River (after Lopez and Giovannelli 1984).

Parameter (average)	Drainage basin[a] Artic Street	Kirby Street	St. Louis Street
Slope (ft/mi)	12.3	8.1	10.2
Flow (m^3/s)	2.010(-)b	0.425(0.005)	1.897(0.006)
Turbidity (NTU)	73(72)	18(2.3)	35(10)
BOD_5 (mg/L)	6.2(26)	4.5(2.1)	6.1(3.0)
COD (mg/L)	57(163)	64(38)	55(44)
TOC (mg/L)	13(-)	20(12)	10(25)
TP (mg/L)	0.28(0.80)	0.25(0.12)	0.45(0.14)
OP (mg/L)	0.28(0.22)	0.12(0.08)	0.14(0.08)
TN (mg/L)	1.7(1.6)	2.2(2.1)	3.0(2.5)
Org N (mg/L)	0.94(1.9)	1.4(1.1)	1.8(1.0)
NH_3 (mg/L)	0.48(0.06)	0.25(0.32)	0.55(1.0)
NO_3 (mg/L)	0.24(0.36)	0.48(0.28)	0.31(0.14)
TC (counts/100 ml)	2.1×10^5(-)	1.6×10^5(6.8×10^4)	5.5×10^5(3.5×10^4)
FC (counts/100 ml)	8.0×10^4(-)	9.8×10^4(1.4×10^4)	2.1×10^5(8.0×10^3)
Aluminum (µg/L)	1(2)	- (1)	2(1)
Copper (µg/L)	16(14)	- (-)	16(12)
Lead (µg/L)	734(320)	50(12)	213(54)
Zinc (µg/L)	172(150)	- (20)	133(50)

[a] Artic and St. Louis streets' conveyance systems are enclosed and streets are curb and gutter. Kirby Street has swales and ditches draining to an open ditched channel.

[b] Numbers in parentheses are reported from base-flow conditions.

the Artic Street base flow were much greater than the other two drainage sites and in several cases much greater than its own storm-water concentrations (Table 19). These high base-flow levels suggest that effluent from an unknown point source was entering the storm-water conveyance system.

The significance of storm-water discharge directly to the river below the dam varies according to season and parameter. Coliforms and heavy metals have the greatest impact on the instream water quality, particularly following rainfall in either the dry or the wet season. Phosphorus in this runoff is least important and was only 6% to 10% of the total load to the river. Most of it (90%–94%) was derived from upstream sources discussed previously (e.g., chemical processing plants, natural sources). Suspended solids, BOD, and total nitrogen in storm water are significant contributors to the pollutant budget of the lower Hillsborough River, especially in the dry season, when they account for 37%–40% of the seasonal load (Priede-Sedgwick, Inc. 1980; Metcalf and Eddy, Inc. 1983).

c. Tampa Bypass Canal. Before 1970, the Palm River and Six Mile Creek drained about 105 km^2 south and southeast of the Hillsborough River watershed. The headwaters were located east of the Tampa Reservoir; flow originated from Eureka Springs and seepage springs in a flat, wet prairie called Harney Flats (Menke et al. 1961; Motz 1975). These springs provided the base flow for Six Mile Creek, which flowed southward about 11 km to join the Palm River and then flowed 3 km to McKay Bay.

Since 1970, channelization has extended Six Mile Creek west and north to intersect the Hillsborough River at two points: the confluence of Trout Creek and near the midpoint of the Tampa Reservoir. The modified Six Mile Creek has been renamed the Tampa Bypass Canal (TBC), and is now made up of two canals with five water control structures illustrated in Figure 59. Flow at the control structures is regulated by manipulation of vertical lift gates and slide gates (USGS 1983). Structures S-162 and S-159 are primarily used to minimize the TBC's impact on the regional hydrology, particularly in the Harney Flats area. The TBC is made up of two canals; the Harney Canal (C-136) that runs from the Tampa Reservoir to join the second and longer canal, C-135, which connects the Hillsborough River at Trout Creek to the Palm River. Agriculture (e.g., improved pasture), a sanitary landfill, and urban (e.g., commercial, industrial, transportation/utility) land uses dominate the watershed (USACE 1974; ESE 1977; Priede-Sedgwick, Inc. 1980). Domestic municipal and industrial point sources that discharge to the TBC are listed in Appendix Table A-6.

Flow in the TBC since 1970 has ranged from a maximum of 110 m^3/s to zero and in 1982 averaged 14 m^3/s (USGS 1983). Water between the structures tends to pond, particularly in the dry season, and instead of a naturally flowing stream, the TBC has become a series of pools or narrow lakes that serve as catchment basins for industrial and domestic waste and storm-water runoff (HCEPC 1982, 1984).

Major water-quality problems in the TBC and Palm River are low dissolved-oxygen levels (annual averages ranging from 1.8 to 3.2 mg/L at SR 60 between 1980 and 1983), high coliform counts, nutrient, and chlorophyll *a* concentrations and BOD (HCEPC 1982, 1984; Hand and Jackman 1984; USGS 1983). Fecal coliform to fecal streptococcus ratios occasionally exceed 4.0, suggesting contamination to the canal from human waste (HCEPC 1982; 1984). General water-quality conditions tend to worsen toward McKay Bay, where the urbanization is greater and more point sources are present.

South of the Tampa Bypass Canal system, Delaney Creek drains pastureland sandwiched between the city of Brandon to the east and an urban area reaching from the bay to U.S. 301 (Figure 59). Point sources discharging to Delaney Creek are Redwing Carriers, Inc. (trucking—oil-waste tank), Nitram Chemicals, Inc. (fertilizer plant—ammonia/nitrate pond), Trademark Nitrogen, Progress Village (domestic STP), IMC (terminal), and Chloride Inc. (sewage unit) (ESE 1977; Priede-Sedgwick, Inc. 1980; Hartigan and Hanson-Walton 1984).

Delaney Creek downstream of U.S. 41 is usually brackish, while upstream of U.S. 301 the stream is fresh. Dissolved oxygen concentrations in both the upper and lower reaches remain very low even during late afternoon hours, generally below 4 mg/L despite an average depth of 0.5 m or less (HCEPC 1984). BOD often exceeds 4 mg/L upstream of U.S. 301 and is higher at U.S. 41 (3 to 9 mg/L). High mean values of total coliforms (20,466/100 mL), fecal coliforms (18,360/100 mL), and fecal streptococcus (131,000/100 mL) are reported for both upper and lower reaches of the creek (HCEPC 1982). Low FC/FS ratios suggest that livestock-contaminated runoff enters the creek.

All nutrient species are high and in several cases are the highest reported in Hillsborough County (HCEPC 1982, 1984). Total phosphorus upstream at U.S. 301 averaged from 0.50 to 0.77 mg/L from 1980 to 1983. Downstream at U.S. 41 the average concentration increased to 6.33 mg/L in 1980 and 1981, but has since decreased (1982–83) to values slightly greater than reported at U.S. 301. Nitrogen in every form is extremely high. Large increases of nitrogen concentrations between stations upstream and downstream of the discharge point result from industrial waste generated by Nitram, Inc., a nitrogen fertilizer processing plant (HCEPC 1982, 1984). In 1983, for example, nitrate averaged 0.56 mg/L upstream and 35.22 mg/L downstream of the Nitram point source (HCEPC 1984).

Average chlorophyll *a* levels of 15.4 µg/L (at 36th Ave and 54th St in 1981) and 22.8 µg/L (at U.S. 41 in 1982) indicate occasionally large numbers of algae and a probable occurrence of algal blooms. Analysis for the metals copper, mercury, chromium, and zinc for upper and lower Delaney Creek shows no problems.

4.3.5 Alafia River Watershed

The Alafia River watershed is located in Hillsborough and Polk Counties, south of the Hillsborough River watershed (Figure 66). The river drains more than 105 km^2, originating in west-central Polk County and flowing 39 km westward to empty in southeast Hillsborough Bay. Major tributaries are the North Prong, South Prong, Little Alafia River, and Turkey Creek.

Unlike most Florida streams, and even though changes in elevation are not great, the tributary streams making up the Alafia River are rather narrow, swift-flowing streams with deep-cut banks and comparatively few large swamps. Only Alafia Creek, tributary to South Prong, is an exception, draining a large wetland slough, Hooker's Prairie. The lower Alafia River drops sharply near Bell Shoals Road, and then downstream to U.S. 301, meanders in a narrow, deeply incised channel 14 to 140 m wide and 1.2 to 4.0 m deep. From U.S. 301 to U.S. 41, it widens 105 to 460 m with little change in depth (Giovannelli 1981). The river is tidal upstream to Bell Shoals Road. Lithia Springs, a large artesian spring near Little Fishhawk Creek, contributes a major part of the river's dry-season flow. There are no natural lakes in the watershed, but several lakes have been produced by phosphate mining activities (e.g., borrow pits, slime ponds, reservoirs for recycling process waters), mostly in the upper watershed. The Edward Medard Reservoir at Pleasant Grove is one such lake, formed by a concrete dam with earthen embankments that cut across the Little Alafia River and encompass strip-mine pits and tailing ponds (USGS 1983).

Land use in the Alafia River watershed is primarily agriculture (improved pasture, citrus, fish ponds), rangeland (unimproved pasture), wetlands, and barren land (FDER 1982). Barren land, making up 12% of the watershed, is a byproduct of phosphate mining and processing, and dominates the landscape drained by the North and South Prongs.

Point sources in the Alafia River watershed are mainly concentrated in the eastern half, particularly in the North Prong drainage area (Figure 66). Most dischargers are related to mining, processing, and enrichment of phosphate ore (Appendix Table A-7). The only domestic point sources are a municipal point source, the city of Mulberry, that discharges 0.37 mgd to the North Prong of the Alafia River, and a small private point source, Gardinier, Inc., discharging 0.002 mgd to the Alafia River near its mouth. Characteristics of numerous industrial point sources in the watershed are presented in Appendix Table A-7 and Figure 66.

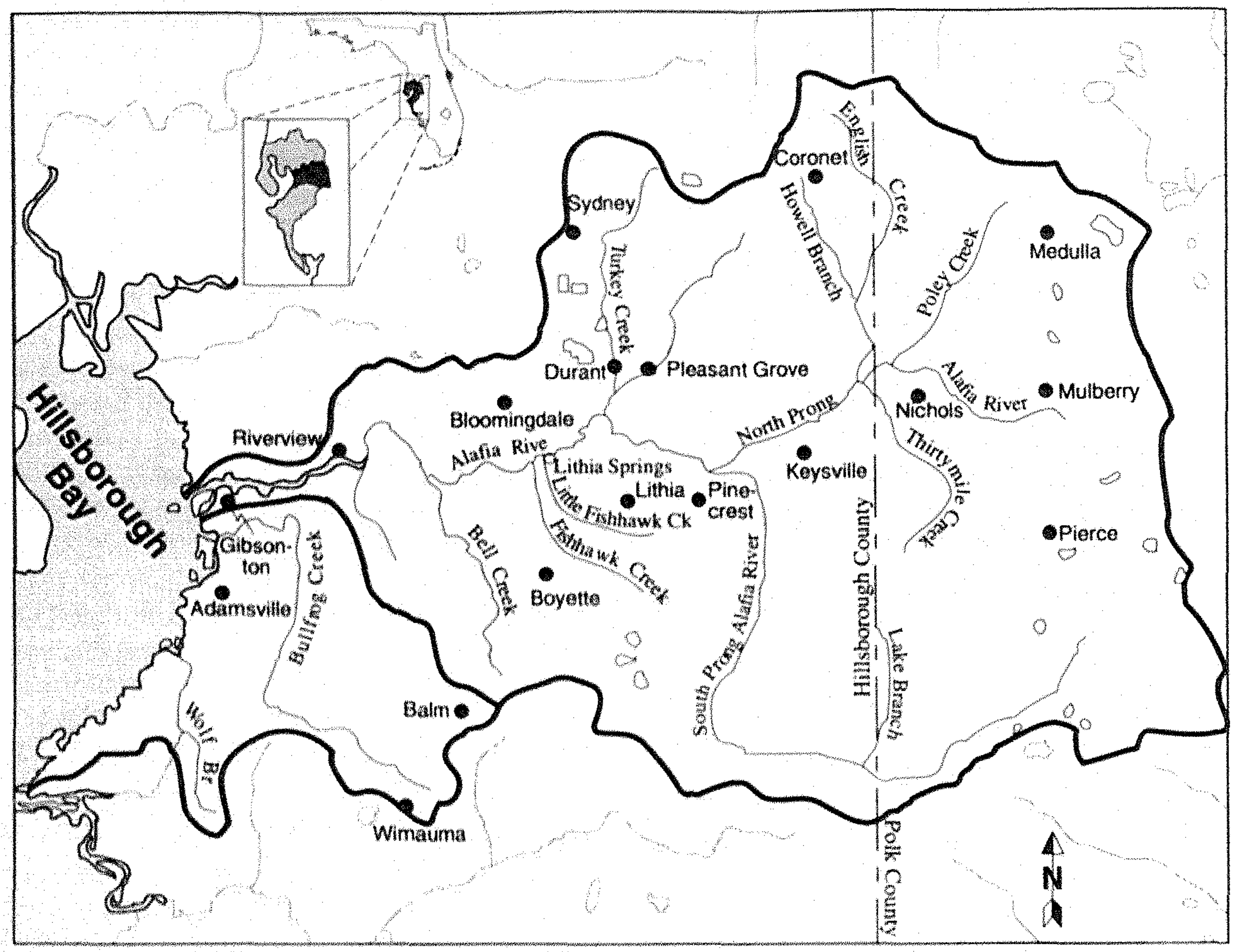


Figure 66. Alafia River drainage basin and Alafia River to Little Manatee River coastal area basin.

Flow in the Alafia River averages 10 m^3/s near Lithia and ranged from a maximum of 1,300 m^3/s in 1933 to 0.2 m^3/s in 1945 (USGS 1983). Upstream, the North Prong drains about 350 km^2; averages 4.7 m^3/s, ranging from 0.102 to 271 m^3/s. The South Prong drains a smaller area 277 km^2 and averages lower flow, 3.0 m^3/s. Lithia Springs discharges an average of 1.4 m^3/s to the Alafia River at a point just downstream of the North and South Prong's confluence.

South Prong is the less polluted of the two prongs that form the headwaters of the Alafia River, but still exhibits high levels of nutrients and coliforms (FDER 1982; HCEPC 1984). Over 80% of the South Prong drainage is agricultural, dominated by improved pasture (644 ha), citrus (3,154 ha), and rangeland (2,126 ha). Forested wetlands line the river and its tributary channels and give way to mixed deciduous and xeric pinelands at higher elevations.

These wetlands, particularly Hooker's Prairie, act as nutrient filters. Phosphorus levels, for example, drop about 1.0 mg/L between stations upstream and downstream of Hooker's Prairie (HCEPC 1982, 1984; Jackman 1983; USGS 1983). High upstream phosphorus levels are caused by phosphate mining concentrated in the upper reaches of South Prong. The influence of the wetland is also exhibited in an increase in water color and coliform counts and a decrease in conductivity and pH (HCEPC 1982, 1984; USGS 1983). Dissolved oxygen in the South Prong generally ranges from 5.0 to 9.5 mg/L, but occasionally drops below 4.0 mg/L in the summer. Instream primary productivity is very low, as evidenced by the low chlorophyll *a* and BOD concentrations (HCEPC 1982, 1984). Fluoride and phosphorus concentrations have greatly decreased in the last decade, fluoride from an average of 15.0 mg/L in 1965 to 1.5 mg/L in 1983 (HCEPC 1984), and phosphorus from 5.0 mg/L in 1975 to 1.7 mg/L in 1982 and 1983 (Jackman and Hand 1983; HCEPC 1984). The change was caused by pollutant abatement practices implemented by phosphate mining and processing companies in the late 1960's and mid-1970's. Problems of an episodic nature are still caused by accidental discharges (e.g., breaks in slime-pond dike walls), as evidenced by a large pulse in the ammonia and nitrate levels in February 1980 (Jackman and Hand 1983).

Much poorer water quality in the North Prong is caused by an increase in phosphate mining activity and a greater number of phosphate and chemical processing dischargers (Priede-Sedgwick, Inc. 1980; FDER 1982). The mining activity is greatest in the upper reach where the city of Mulberry sewage treatment plant and industrial point sources cause some of the worst water-quality conditions reported from the Tampa Bay area (HCEPC 1982, 1984). High concentrations of fluoride, total phosphorus (13 mg/L), ammonia (85–120 mg/L), BOD (46–53 mg/L), conductivity (up to 4,500 µmhos) and low pH are reported from this area (Jackman 1983). Farmland, a chemical manufacturer above Mulberry, discharged effluent containing about 130 mg/L of ammonia into the North Prong. Its effect was evident several kilometers below the discharge, as illustrated in Figure 67. Water quality improves in the lower reaches of the North Prong, but remains much poorer than that observed in the South Prong. Conductivity is 2 to 3 times as great (700–900 µmhos). Dissolved oxygen remains below 5.0 mg/L 50% of the time. Fluoride has decreased substantially since 1965, but still averages 3.5 mg/L, twice the level reported from the South Prong, as do phosphorus (TP = 6.0 mg/L) and nitrogen (TN = 5.0 mg/L) concentrations (HCEPC 1982, 1984; FDER 1982; Jackman 1983; USGS 1983). The absence of wetlands is apparent in the low color (20–40 NTU) and lower coliform counts (FDER 1982; HCEPC 1982; USGS 1983).

West of the North Prong drainage area is the Turkey Creek/Little Alafia River system, where a combination of urban land, agriculture, and mining have caused poor water quality second only to the North Prong. The urban lands are scattered residential areas and urban sprawl from Plant City, generally confined to the upper reaches of Turkey Creek. Agriculture is varied, ranging from improved pasture (built on reclaimed mined lands), specialty crops (strawberries and vegetables), fish ponds, and dairy farm operations (ESE 1977b; HCEPC 1982). Mined areas are located in the lower reaches and most are inactive or reclaimed. The Edward Medard Reservoir is made from a stripped mine site and a tailings pond.

Turkey Creek exhibits high BOD (6.0 mg/L), low dissolved oxygen, and high nutrients and coliform levels (ESE 1977b; HCEPC 1982, 1984; Jackman 1983). The elimination of an industrial point source (Lykes Brothers Meat Packing Plant) has reduced TKN concentrations from 12.77 mg/L in 1977 to 2.27 mg/L in 1981, but other sources, principally dairy farm operations, have kept the TKN levels relatively high and also are a principal source of high fecal (averaged 20,608/100 mL in 1983) and total (averaged 31,042/100 mL in 1983) coliform levels (HCEPC 1982, 1984).

The lower Alafia River watershed, from Turkey Creek to Hillsborough Bay, is dominated by agricultural and urban land uses. South of the river, four tributaries (Bell, Fishhawk, Little Fishhawk, and Rice Creeks) drain a predominantly agricultural area. Improved pasture, rangeland, and specialty farms (fish, citrus, vegetables, and foliage) are the primary land uses. Less significant are some floodplain forests, particularly along Fishhawk Creek, and the abandoned phosphate-mined areas (ESE 1977b). The area north of the Alafia River is much more urban, particularly around the developed areas of Brandon, Valrico, and Dover. Buckhorn Creek is the only major tributary to the north side of the River (ESE 1977b).

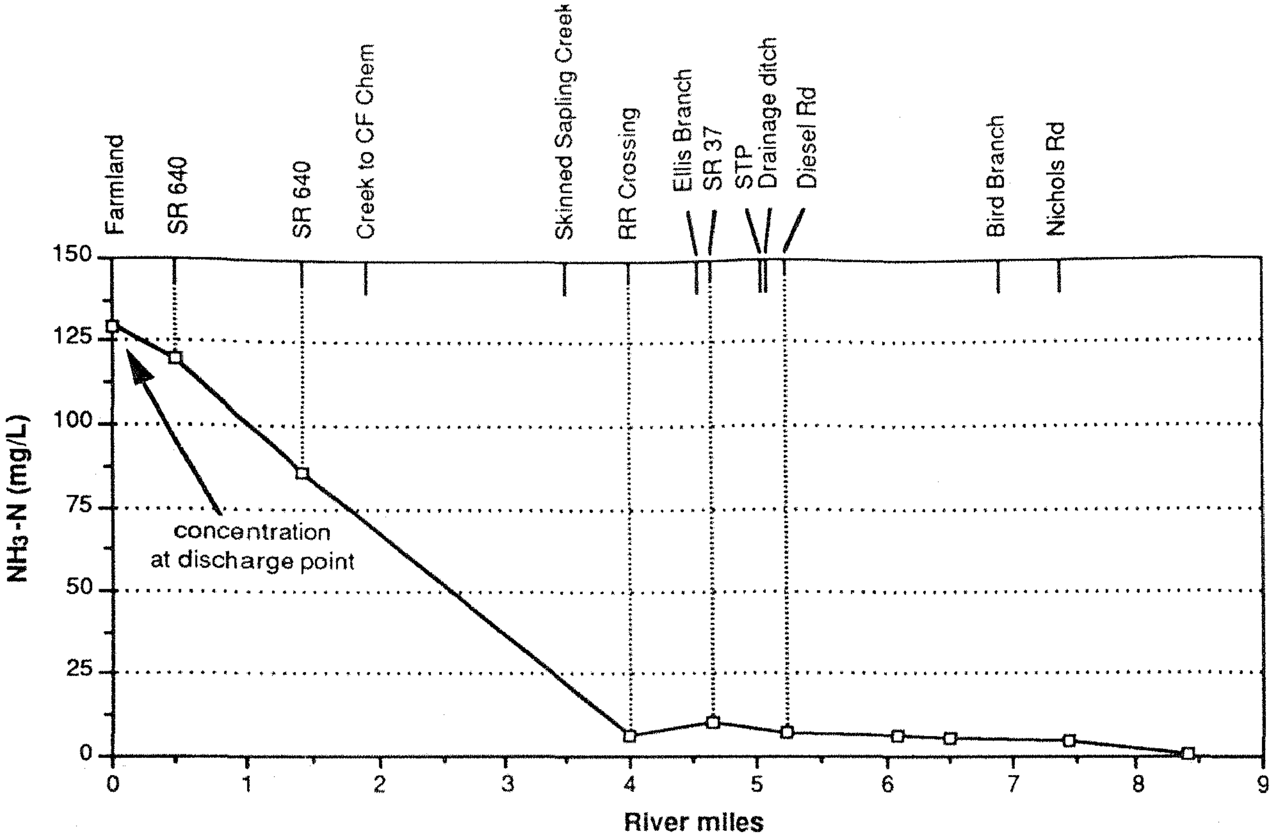


Figure 67. Ammonia concentrations in the North Prong Alafia River, February 2, 1982 (after FDER 1982).

Water quality in the lower Alafia River tributaries is poorly documented. Bell Creek exhibits high coliform levels (FC, 1100/100 mL) and high nitrogen concentration (NO_3, 3.0 mg/L), particularly in the wet season (ESE 1977b; Jackman 1983).

One additional and important inflow to the lower Alafia River is Lithia Springs. The spring discharge averages 1.4 m^3/s, ranging from 0.2 to 2.4 m^3/s (USGS 1983). Flow peaks in the wet season, when it contributes less than 10% of the total flow in the lower Alafia River. In the dry season, the spring contributes as much as 27% of the river water budget (ESE 1977b). The spring water is relatively low in phosphorus (0.05–0.1 mg/L); moderate in fluoride (0.3–0.6 mg/L); and low in TOC, BOD, and the nitrogen species, except for nitrate, which has been reported as high as 2.4 mg/L (ESE 1977b; USGS 1983). Dissolved-oxygen concentrations vary widely (2.8 to 7.9 mg/L) due to the influence of ground water and are often reported at less than 50% saturation.

The main stem of the Alafia River flows west to Hillsborough Bay from the confluence of the North and South Prongs—a distance of 35 km. Water-quality conditions in this reach are better than those reported in North Prong and Turkey Creek, but are still degraded and show the influence of phosphate mining and agricultural land use in the upper watershed (HCEPC 1984). Phosphorus is high, decreasing from 4.8 mg/L in the upper reach to 1.2 mg/L at U.S. 41 near the bay (FDER 1982; HCEPC 1982, 1984; USGS 1983). The effect of the high phosphorus concentration is exerted well into Hillsborough Bay, where concentrations historically have responded to nutrient changes in the river (Figure 68).

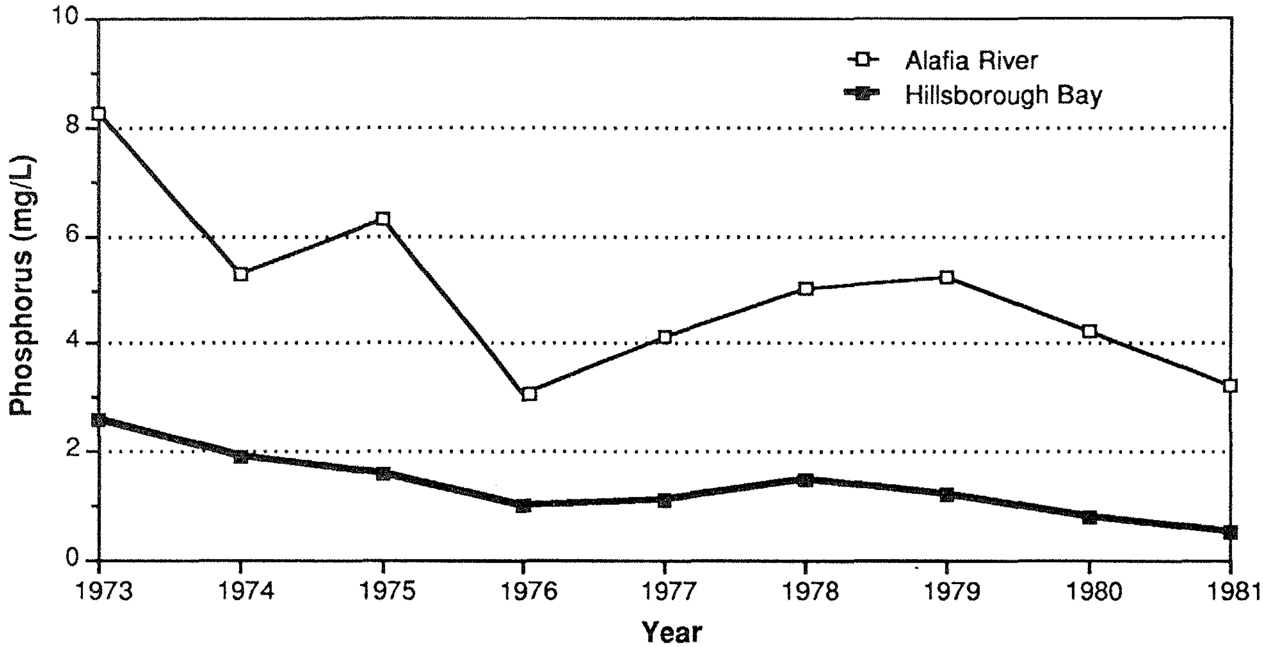


Figure 68. Dissolved phosphorus trends in Hillsborough Bay and the Alafia River (after FDER 1982).

Total nitrogen, nitrate, and coliform levels follow much the same pattern of phosphorus. Values are high in the upper and middle reaches and decrease towards the bay (HCEPC 1982, 1984; USGS 1983). A reversal in this pattern is found in levels of ammonia and organic nitrogen, which increase near the bay. One probable cause for this increase is an industrial point-source discharge (Gardinier, Inc.) near U.S. 41 (FDER 1982; HCEPC 1982, 1984).

Water color, conductivity, temperature, and dissolved-oxygen concentrations exhibit seasonal trends, while nitrogen and phosphorus do not (FDER 1982; Jackman and Hand 1983). Conductivity is inversely related to flow (Figure 69). High water inundates floodplain wetlands, where organic color is leached and carried into the river. As a result color is inversely related to conductivity and correlated to flow. Changes in conductivity also indicate changes in water use by the major mining and agricultural water users. Water users draw more heavily on artesian waters high in dissolved solids in the dry season and rely more on rainfall/surface waters in the wet season.

Although certain chemical and biological parameters show improvement near Hillsborough Bay (e.g., total phosphorus, coliforms, total nitrogen), water quality is still degraded, as evident in the large number of algal blooms and fish kills reported from the area (FDER 1982). These problems are caused by tidal influence, the saltwater-to-freshwater interface, the industrial point source near U.S. 41, and the inflow of relatively poor-quality river water (Giovannelli 1981; FDER 1982; HCEPC 1982, 1984).

The river is tidal as far as 17 km upstream of the bay (Figure 70); from there to U.S. 301 it drops rapidly, meandering generally westward in a narrow, deeply incised channel, 14–135 m wide and 1.2–4 m deep (Giovannelli 1981). From U.S. 301 to U.S. 41 the channel widens to as much as 450 m with little change in depth, and the flow becomes much more sluggish. In the reach, from the bay to Bell Shoals Road, an oscillating saline wedge causes degraded conditions similar to those described for the lower Hillsborough River below the dam. Under conditions of high flow and high tide , salinities may range from less than 1 ppt on the surface to more than 20 ppt near the bottom. Figure 71 shows conductivity profiles

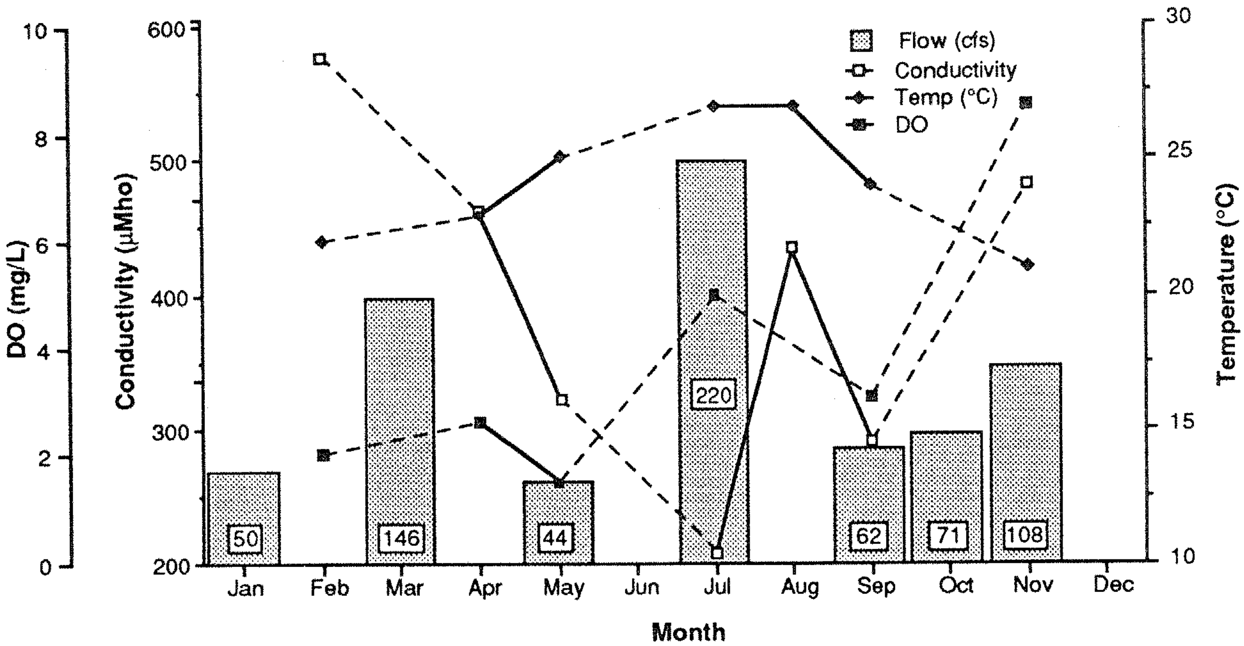


Figure 69. Seasonal water-quality conditions in the lower Alafia River (data from USGS 1982, 1983).

depicting these salinity conditions. Dissolved-oxygen levels near the mouth are vertically stratified because of the saline wedge and the high algal productivity at the surface (24.1 µg/L, chlorophyll *a*), often dropping below 4.0 mg/L at middle and bottom depths (HCEPC 1984).

In the last few years, concentrations of phosphorus and fluoride have decreased greatly in the entire river system; nitrogen has increased; and dissolved oxygen has decreased (FDER 1982). Phosphorus and fluoride have decreased because of pollutant-abatement techniques instituted by the phosphate mining industry and a reduction of phosphate slime-pond spills in recent years. Changes in nitrogen and DO are caused by an increased number of chemical processors in the watershed, the expansion of intensive agricultural land uses (e.g., speciality crops, fish ponds, dairy farms, improved pasture), and the reduction of native rangeland, woodland, and wetlands (Jackman 1983; Jackman and Hand 1983).

Included with the discussion of the Alafia River watershed is Bullfrog Creek, a small drainage area (102 $km^{2)}$ south of the Alafia River watershed that discharges into Hillsborough Bay about 1.5 km south of the Alafia River. Land use in this small basin is primarily agriculture (75%), with some single-family homes. Improved pasture, citrus, and tropical fish farms are the major agricultural users. Two privately-owned sewage-treatment plants discharge about 0.01 mgd of domestic waste into the creek (Priede-Sedgwick, Inc. 1980).

Bullfrog Creek originates just north of Wimauma and flows northwest, north, and finally west to Hillsborough Bay. In the upper reaches the creek flows in a fairly well-defined channel over a steep gradient that flattens out near the mouth (Giovannelli 1981). The channel ranges from 9 to 60 m wide and 0.2 to 2 m deep, narrowing upstream of U.S. 41. Flow near Wimauma, 13.5 km upstream of the bay, averages 1.0 m^3/s and ranges from 67 m^3/s to zero (USGS 1983). Stream flow responds quickly to rainfall, causing a wide range of conductivities (300 to 42,000 µmhos/cm) at U.S. 41 near the bay and minimizing vertical stratification of dissolved oxygen and salinity (Giovannelli 1981).

Nutrient levels are moderate; occasional problems with instream sludge buildup, apparently from

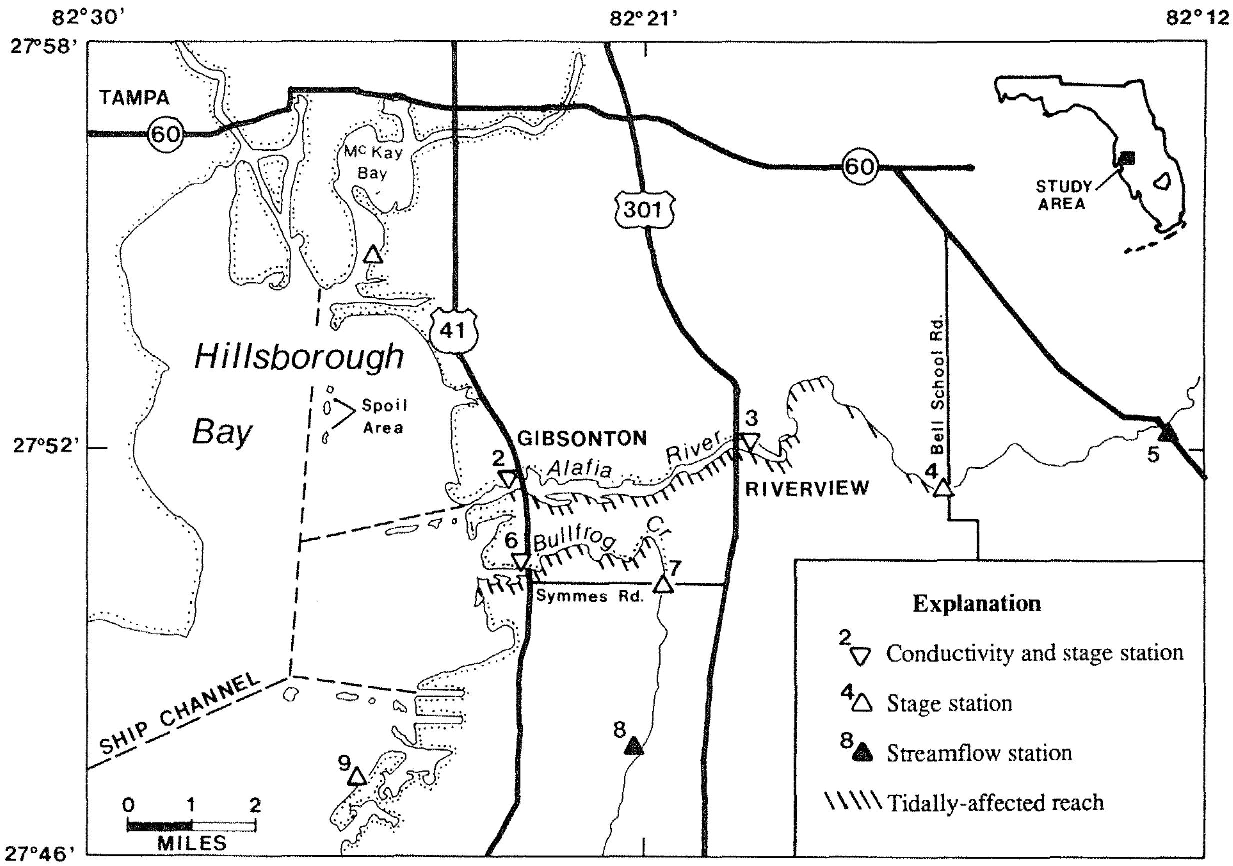


Figure 70. Conductivity, stage, and streamflow stations on Lower Alafia River and Bullfrog Creek (after Giovannelli 1981).

fishpond drainage, have caused increases in BOD and high levels of coliforms (ESE 1977b; HCEPC 1982, 1984). Even so, average BOD is low (1.4 mg/L), and annual DO averages from 1980 to 1983 ranged from 5.7 to 7.0 mg/L (HCEPC 1982, 1984; USGS 1983).

4.3.6 Manatee and Little Manatee River Basins

The area encompasses the coastal tributaries southwest of Bullfrog Creek, the Manatee River, the Little Manatee River, and the Terra Ceia and Cockroch Bays coastal drainage area (Figure 72). Monthly average flow in these rivers is presented in Figure 54. Peak flows are in July, August, and September; low flows are in November and April. A secondary flow peak occurs from January to March.

a. Little Manatee River. The Little Manatee River drainage area extends from eastern Tampa Bay to the southeastern corner of Hillsborough County (Figure 72). The river drains about 566 km^2 and flows westerly a distance of almost 65 km (Brown 1982b; FDER 1982). At the headwaters, near Fort Lonesome, the channel is 30 m wide and flows down a relatively steep gradient of 1.3 m/km that eventually flattens out in the middle and lower reaches (ESE 1977b). Tides affect river stage and discharge 24 km upstream (Brown 1982b; USGS 1983). South Fork is

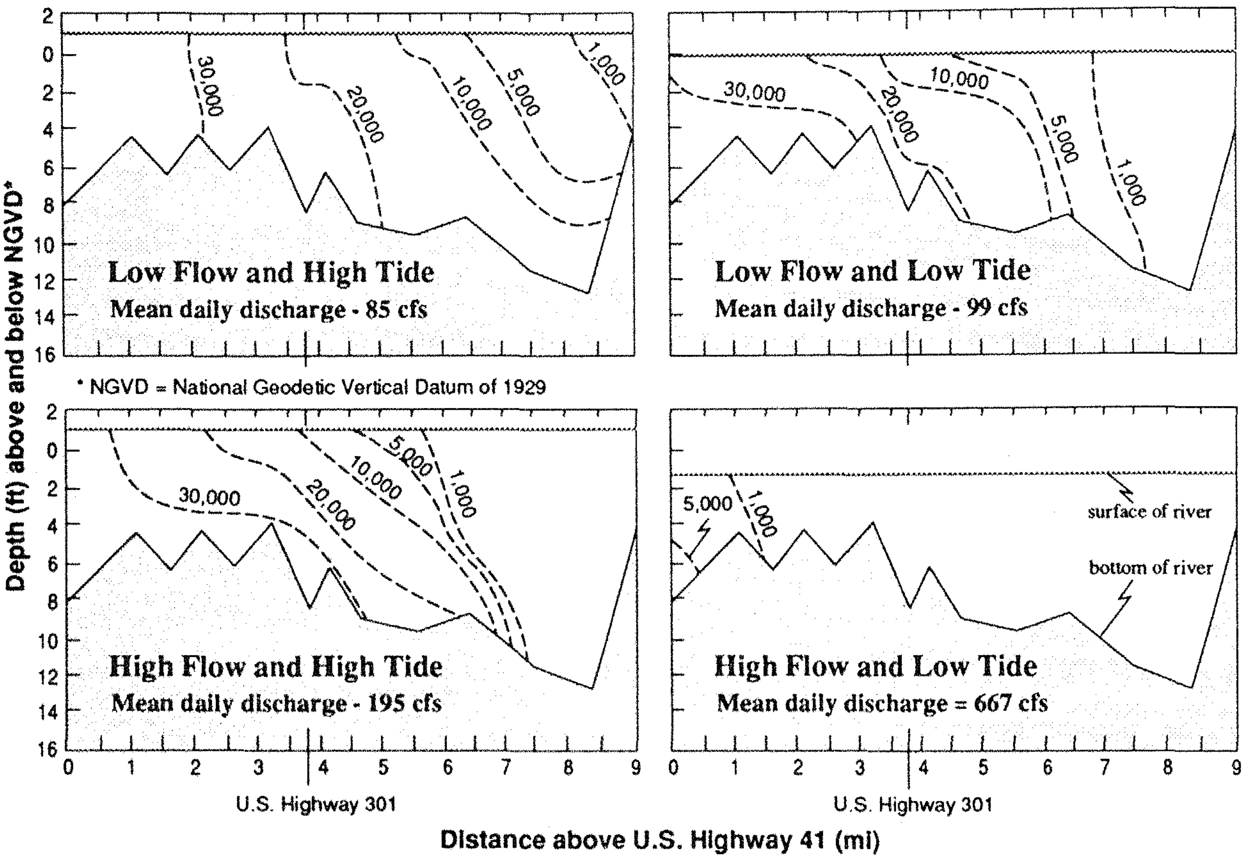


Figure 71. Conductivity profiles (μmhos/cm) in the lower Alafia River (after Giovannelli 1981).

the Little Manatee's largest tributary, 22.5 km long and draining 107 km^2, almost entirely in northeast Manatee County. Numerous small solution ponds are located south of the middle and lower reaches and in the easternmost portion of the watershed. A few large lakes (e.g., Lake Carlton, Lake Wimauma) are near Wimauma, and a 1,620-ha cooling reservoir is located south of the river where it dips into Manatee County (Seaburn and Robertson, Inc. 1980). Urban areas are limited to the middle and lower reaches (i.e., Wimauma, Sun City, Sun City Center, Ruskin), and more than 80% of the watershed is agricultural, partitioned mainly between improved pasture, citrus, and rangeland (ESE 1977b; FDER 1982). Much of the citrus is in the bedded form, grown on spodic soils that require extensive drainage and irrigation networks. Wide flood-plain forests are located along most tributaries except in the river's headwaters, where steep banks reduce the wetland zone and xeric pineland forests border the streams.

In the upper reach of Little Manatee River above its confluence with South Fork is the highest concentration of agriculture in the watershed (85%), consisting mostly of citrus, improved pasture, and rangeland. There are no urban centers and no industrial or domestic point sources, although a phosphate mine and beneficiation plant is expected to begin operation in the extreme upper basin. Tributaries (e.g., Pierce and Carlton Branches, Alderman Creek) flow down relatively steep gradients often exceeding 2.3 m/km (ESE 1977b; Brown 1982b). Flow in Alderman Creek near Fort Lonesome averages 0.16 m^3/s. Color is high, ranging from 100 to 230 NTU, and all nutrient forms except ammonia are moderately high (USGS 1983). High color content is common in the upper-

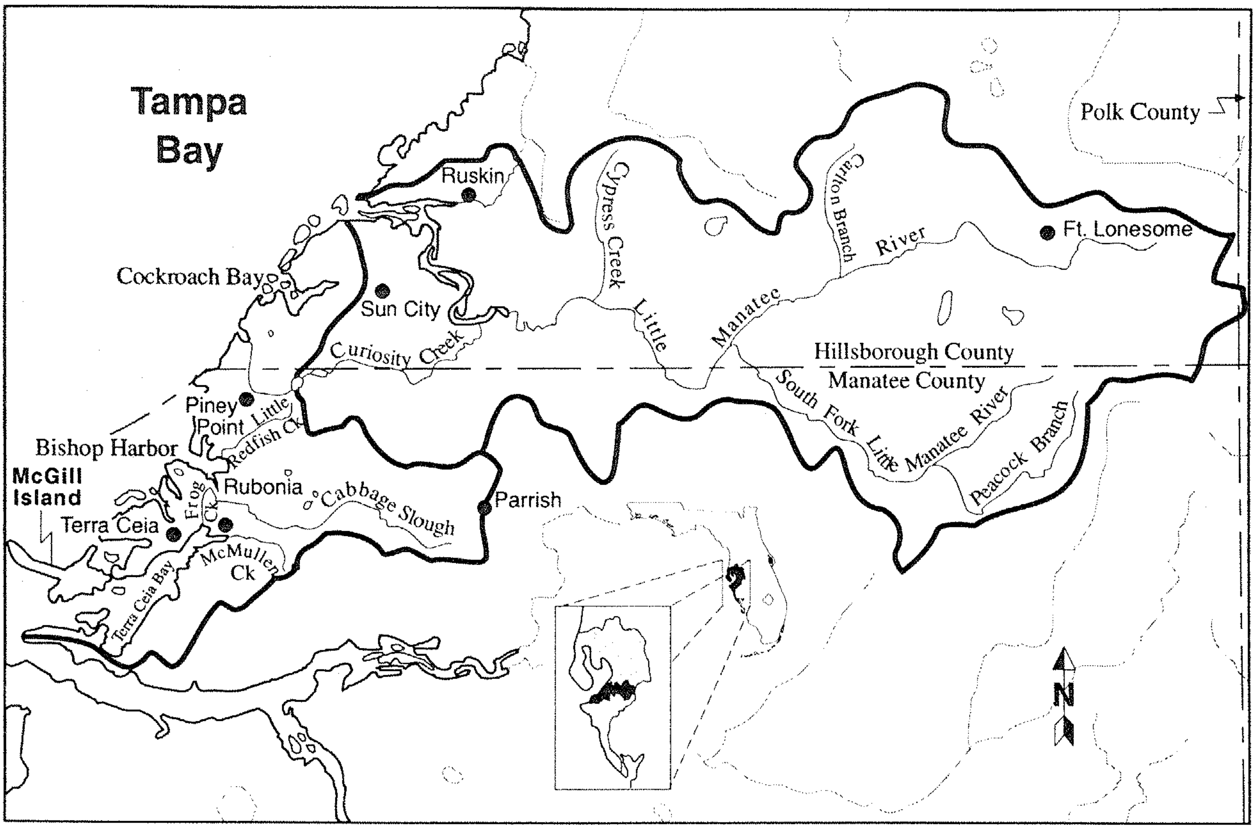


Figure 72. Little Manatee River basin and Terra Ceia and Cockroach Bays coastal area drainage basins.

reach waters and reflects the sizable forest swamps bordering the river channel. The high nutrient levels are probably caused by agricultural, highway, and wetland runoff (ESE 1977b; FDER 1982). Downstream, at SR 674 near Fort Lonesome, the flow in the Little Manatee River averages 0.83 m^3/s. Color remains high, showing the continued influence of the floodplain wetlands (HCEPC 1984). Dissolved oxygen averages range between 5.0 and 7.0 mg/L, chlorophyll *a* is low, and total organic carbon (20 mg/L in 1982) is relatively high. All these factors suggest a strong influence by wetland runoff. High nutrients and moderate coliform levels point to agricultural runoff (FDER 1982; HCEPC 1982, 1984; USGS 1983). Between SR 674 and SR 579 (just above the river's confluence with South Fork), the floodplain decreases in width. The reduction of floodplain wetlands may explain the decrease in color and total organic carbon, as well as the increase in nitrate nitrogen, DO, and pH reported at SR 579 (HCEPC 1982, 1984).

South Fork drains the southern half of the upper watershed, mostly lands in northeastern Manatee County. Land use consists primarily of rangeland (6,178 ha), cropland (462 ha), citrus (445 ha), and specialty farms (45 ha). Forested swamps composed 1,599 ha (ESE 1977b). There are no significant urban areas, mining activities, or point sources. The streambed's average slope is 4 m/km. Low dissolved oxygen (4.8 mg/L) and high color are caused by natural decomposition in the floodplain wetlands. The influence of wetlands is also evident in high total organic-carbon and low dissolved-nitrogen concentrations (FDER 1982; HCEPC 1982, 1984). Moderate to high levels of organic nitrogen and orthophosphate (0.37 to 0.70 mg/L) are attributed to agricultural runoff (ESE 1977b).

In the middle and lower reaches of the Little Manatee River, the drainage area consists of single-family residential communities and service-type commercial areas. Headwaters of Dug Creek and Cypress Creek receive storm-water runoff from urban Wimauma and Sun City Center, respectively, and numerous canals around the mouth of the Little Manatee River pass storm water to small bay areas.

Flow near Wimauma averages 4.8 m^3/s, and ranges from 396 m^3/s to 0.022 m^3/s. Stage and discharge of the river at this location, 24 km upstream, is affected by the tides (Brown 1982b; USGS 1983). Since 1974, water has been diverted 5.3 km upstream to the Florida Power and Light Manatee Power Plant cooling reservoir, a 1,619 ha artificial lake, at an average rate of 9.8 mgd (Brown 1982b; USGS 1983).

Major water-quality problems are high coliform counts and moderate to high nutrients (FDER 1982; HCEPC 1982, 1984; USGS 1983). Low FC/FS ratios indicate non-human contamination, possibly from feedlots, dairies, or speciality farms (e.g., fish ponds). Dissolved-oxygen levels average 7.0 mg/L and are supersaturated in late spring (ESE 1977b; HCEPC 1982, 1984).

Because of its relatively undisturbed setting, the Little Manatee River displays what might be considered natural background water quality for the general area east of Tampa Bay. Background fluctuations in physical and chemical conditions provide a comparative tool for assessing the water quality in other nearby watersheds where phosphate mining and agricultural activities affect stream conditions. The seasonal relationship between flow, conductivity, and temperature and dissolved oxygen are illustrated in Figure 73. It is clear that flow and conductivity are inversely related. During low-flow periods, mineralized ground water contributes relatively more to the river than during higher flow periods when surface runoff dilutes this base flow.

Temperature and DO fluctuate inversely, peak oxygen concentrations in winter being concurrent with minimum temperatures (Figure 73). The oxygen curve also correlates quite well with flow. When flows are low and conductivity is high, oxygen is also high, suggesting that organic loading and temperature

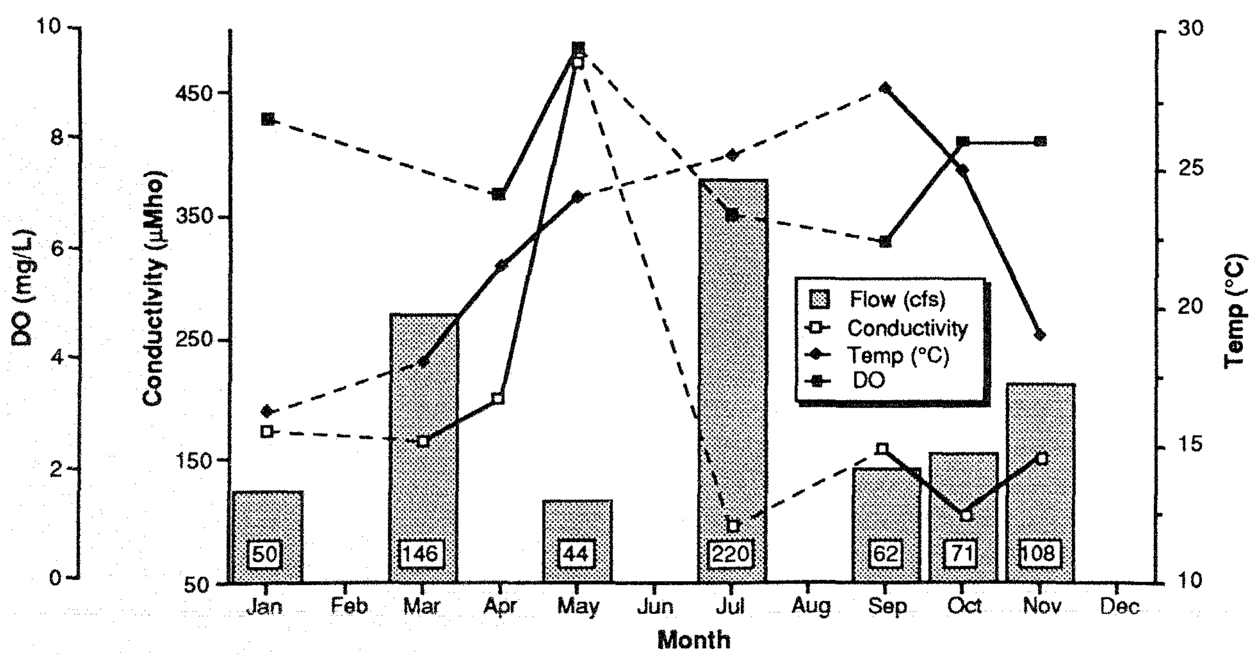


Figure 73. Seasonal water quality conditions in the Little Manatee River (after FDER 1982).

are probably more important than flow in controlling changes in DO. Total nitrogen and total phosphorus are less predictable in terms of overall seasonality.

Farther downstream at U.S. 41, the river and floodplain widen. Salt marsh dominates the floodplain and salinities average 9.0 to 12.3 ppt (HCEPC 1982, 1984). Water quality is changed substantially from that reported upstream at U.S. 301 (HCEPC 1982, 1984). Coliforms and nitrate levels are lower. Organic nitrogen, at a moderate level, is the major nitrogen species present. Dissolved oxygen averages drop from 7.0 mg/L at U.S. 301 to 4.7 mg/L at U.S. 41. The saline wedge, sluggish river flow, and, to a lesser extent, urban storm-water runoff from Ruskin probably contribute to these depressed DO concentrations (HCEPC 1982). Phosphorus concentrations remain relatively high (0.40 to 0.60 mg/L).

Between the major river systems that empty into eastern Tampa Bay are smaller coastal drainage areas characterized by tidal tributaries, bays, bayous, and harbors fed by overland runoff through coastal wetlands, and in increasing amounts, by urban storm-water runoff.

From Bullfrog Creek to the north to Little Manatee River is an area drained by numerous coastal streams, including Sims Branch, Newman Branch, and Wolf Branch. All are less than 4.8 km in length, and all are freshwater at their headwaters (ESE 1977b; Priede-Sedgwick, Inc. 1980). The majority of the land use is agricultural, dominated by cropland (1,769 ha), improved pasture (308 ha), and specialty farms (e.g., fish ponds) (150 ha) (ESE 1977b). There are three small private domestic sewage treatment plants. All three are located near Sims Branch and discharge to unnamed canals entering Hillsborough Bay (Priede-Sedgwick, Inc. 1980). The industrial dischargers are Ruskin Tomato Growers, Inc.; Ruskin Vegetable Corp.; and the Tampa Electric Company (TECO) Big Bend Station. TECO holds Federal permits for seven discharge points, but only four are continuous and three are intermittent and storm-water related. All TECO effluent is discharged directly to Hillsborough Bay; the most significant portion is over 1,000 mgd of thermal effluent entering the bay just north of Apollo Beach (TECO 1975; Priede-Sedgwick, Inc. 1980). Water-quality data in the area are restricted to the vicinity of the TECO thermal discharge (TECO 1975; ESE 1977b). Dissolved oxygen concentrations have often been below 5.0 mg/L and stratified, with DO values approaching 1.0 mg/L near the bottom. These patterns are amplified in the canals, particularly the inland canals west of Apollo Beach. Turbidity is also highest in these inland canals, indicating poor flushing and a resuspension of fines caused by storm-water runoff.

The coastal area between the Little Manatee River and the Manatee River encompasses a number of bays, bayous, and tidal tributaries that are rapidly becoming urbanized. Most prominent of the surface water bodies are Cockroach and Terra Ceia bays. Major tributaries are Cockroach Creek, feeding Cockroach Bay, and Frog Creek, feeding Terra Ceia Bay. Land use inland is predominantly agricultural, composed of cropland, and to a lesser extent, improved pasture, citrus, and speciality farms such as fish hatcheries (ESE 1977b). From the Little Manatee River mouth to Piney Point, the coastal waters and wetlands have been designated as a State Aquatic Preserve, with restrictions placed on discharges and types of development in the area, so that mangroves and other wetland plants are protected. The bay is very shallow and exhibits moderate to high chlorophyll *a* concentrations, averaging 16.7 to 33.2 μg/L from 1980 to 1983 (HCEPC 1982, 1984). Nutrients and coliforms are moderately high and dissolved oxygen averages between 5.0 and 6.0 mg/L (HCEPC 1982, 1984).

Just to the south of the aquatic preserve are the Borden Phosphate Plant at Piney Point and a major Tampa Bay port facility, Port Manatee. Next to the phosphate plant is a tailings pond whose discharge contains excessively high phosphate concentrations (ESE 1977b). Bishop Harbor, south of Piney Point, has also exhibited high phosphate concentrations (orthophosphate = 1.0–2.0 mg/L). From Bishop Harbor to the mouth of the Manatee River is the Terra Ceia Bay drainage area. Saltwater wetlands are well developed in the estuary, particularly on Terra Ceia Island. Inland, 50% of the land is in agricultural use (cropland, citrus, and improved pasture), followed by rangeland, wetland, and urban development (e.g., western portion of the city of Palmetto). Frog Creek is the major tributary to Terra Ceia Bay; three of the six point sources in the area (a mobile home park and two fish hatcheries) discharge to the creek. The other point sources discharge directly to Terra Ceia Bay. Palmetto Sewage Treatment Plant, the largest of the six, causes the only coliform violations in the south portion of the bay (ESE 1977b). This point source is also apparently responsible for high orthophosphate concentrations in the southern bay. Nitrates generally are less than 0.1 mg/L and dissolved oxygen usually exceeds 4.0 mg/L and mirrors the fairly good quality of the bay waters away from the sewage outfall (ESE 1977b).

b. Manatee River watershed. The headwaters of the Manatee River form in the northeastern corner of Manatee County and flow 85 km west to south Tampa Bay, draining about 922 km^2 (FDER 1982). Major tributaries are the Braden River, Gamble Creek, and Gilley Creek (Figure 74). Thirty-eight kilometers upstream from the bay, the river is impounded, forming Lake Manatee. The 810-ha lake was completed in 1967 and serves as the potable water supply for more than 200,000 people in Manatee County (Heyl 1982).

Agriculture (38%, improved pasture, citrus cropland) and rangeland (41%) are the watershed's dominant land uses. Wetlands are prevalent in river and tributary floodplains, scattered karst features (cypress domes, sloughs, ponds), and a large portion of the Braden River drainage area (FDER 1982). The urban centers of Bradenton and Palmetto sandwich the lower reach of the Manatee River, particularly west of the Braden River.

The upper reach of the Manatee River (upstream of the Manatee Reservoir Dam) consists of Lake Manatee, Gilley Creek, the North and East Forks of the Manatee River, and several small tributaries (e.g., Webb Branch, Fisher Branch, Corbit Branch). The drainage area above the dam is about 307 km^2 and the stream channel slopes an average of 11 m/km (Brown 1982b). The East and North Forks of the Manatee River drain the headwaters. Downstream of their confluence, the river flows southwesterly and then northwesterly to the confluence of Gilley Creek, located near the upstream end of Lake Manatee. Land uses are predominantly agriculture (cropland, citrus), native rangeland, and wetlands. Phosphate mining is planned for the easternmost area of the watershed (Heyl 1982).

Flow downstream of the confluence of the North and East Forks averages 2.2 m^3/s, ranging from 135 m^3/s to zero (USGS 1983). Water quality in the river is influenced by the floodplain wetlands, as evidenced by the water's high color content, low pH, and high organic nitrogen and TOC concentrations (USGS 1983). High phosphorus concentrations and occasionally high total coliform counts and ammonia levels suggest natural and agricultural runoff as the contributing source (ESE 1977b; FDER 1982). Downriver, Gilley Creek exhibits high nutrient concentrations, low dissolved oxygen and pH, and occasional high coliform counts (ESE 1977b). The quality of the lake water is generally good, although nutrients are sometimes high (TN = 0.94 mg/L; TP = 0.18 mg/L), and dissolved-oxygen levels, particularly near the lake bottom, are often less than 4.0 mg/L (ESE 1977b; FDER 1982). These depressed DO levels are apparently caused by decomposition of organics carried into the lake by agricultural and wetland runoff and the longer hydraulic residence times imposed by the reservoir. Algal productivity is low (chlorophyll $a = 7.28$ µg/L) and does not seem to be a significant factor controlling DO levels.

Downstream of the Lake Manatee Dam, the river is saline and tidal, as is the Braden River (Brown 1982b; FDER 1982). Gamble Creek and the Braden River are the major tributaries that drain the north and south sides, respectively, of the lower Manatee River (Figure 74).

Gamble Creek is located just downstream of the Lake Manatee Dam and receives runoff from an extensive drainage network north and northwest of Lake Manatee. Tides normally affect the creek stage and discharge near the mouth, but may extend upstream to the Frye Canal under hurricane conditions (ESE 1977b). Land use is predominantly (72%) range and improved pasture, with a smaller amount of acreage in citrus and cropland. Unforested and

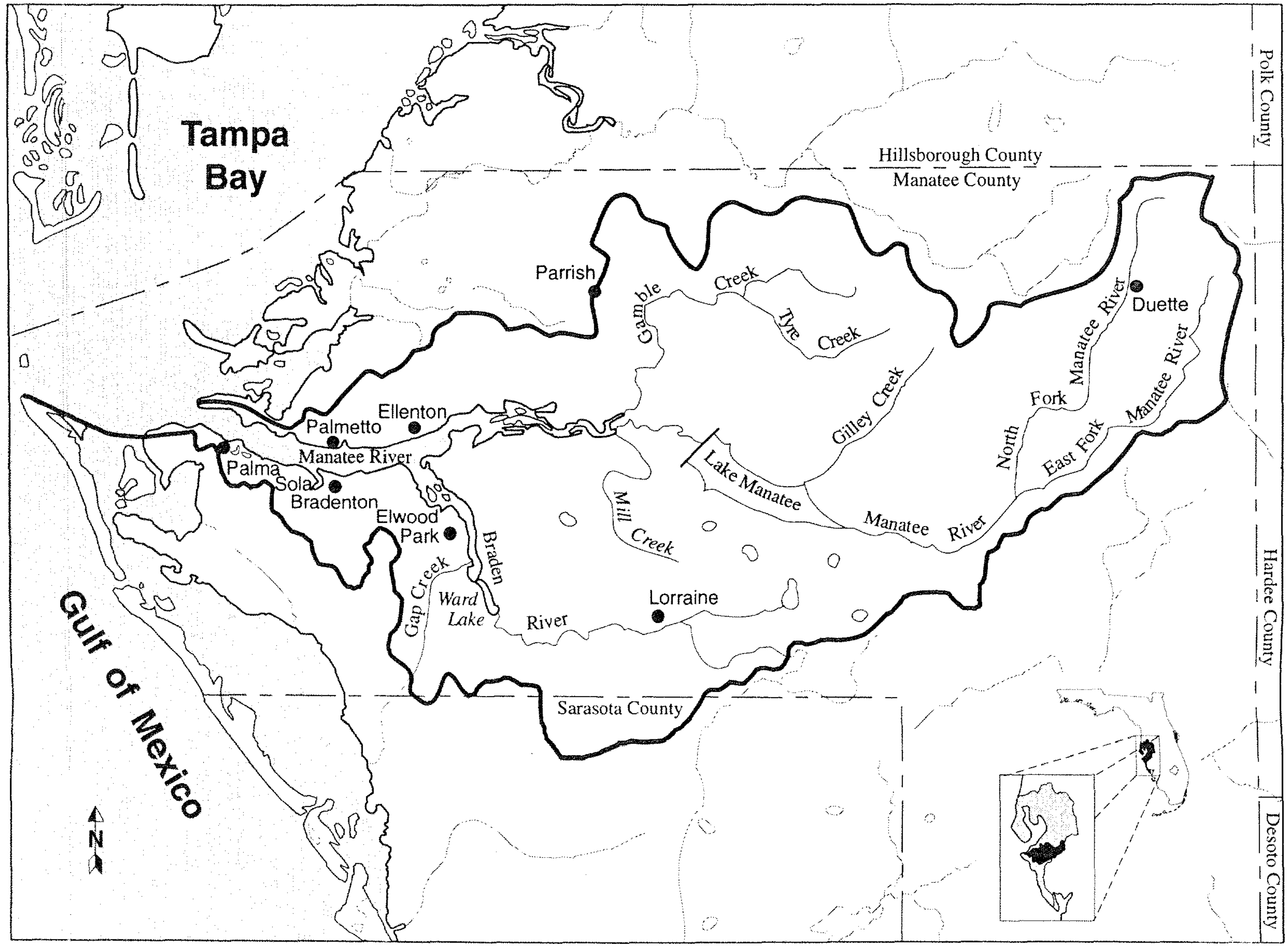


Figure 74. Manatee River drainage basin.

forested wetlands exist in the floodplains and are scattered through the pine flatwoods. The small town of Parrish (population 1,000) is the only urban area in the Gamble Creek drainage area (ESE 1977b). Major water quality problems are high total coliform counts (1.0 x 10^5/100 mL) that often follow heavy rains and high concentrations of total phosphorus (0.94 mg/L), TKN (2.46 mg/L), and suspended solids, all thought to be caused by pastureland runoff (ESE 1977b; Heyl 1982). Conductivity, especially from the mouth of the creek upstream a kilometer or two, ranges from 78 to 3,748 µmhos/cm, showing the oscillating upstream freshwater and downstream saline water influences. The saltwater influence rapidly decreases only a kilometer or two further upstream (Heyl 1982). Dissolved oxygen concentrations are often less than 4.0 mg/L near the mouth, but rarely drop below 4.0 upstream, and while DO profiles at the mouth decrease with depth, the opposite is true 1.5 to 3 km upstream. Higher DO levels near the stream bottom at upstream locations suggest a highly productive benthic floral community of macrophytes and benthic algae. While most of the time macrophyte and benthic algae dominate the stream flora, as evidenced in low chlorophyll *a* levels (0.71 µg/L), there are occasional pulses of high nutrients and increases in chlorophyll *a* , up to algal bloom concentrations (100.2 µg/L), particularly in late summer and early fall (Heyl 1982).

About 10 km downstream of Gamble Creek, the Braden River enters the Manatee River from the south (Figure 74). The Braden River is the largest tributary (37 km) to the Manatee River, draining 220 km^2 of south-central Manatee County (Brown 1982b). Like the Manatee River, the Braden River has been impounded about 0.8 km south of State Road 70 to form Ward Lake, a 24-ha drinking-water reservoir. Tributaries to the Braden River are Wolf Slough, Cooper Creek, Rattlesnake Slough, Williams Creek, and Gap Creek. Over 80% of the drainage area is in agriculture, mainly native range, followed by improved pasture and cropland. Extensive drainage related to improved pasture and cropland are confined primarily to the east side of the river (ESE 1977b). Substantial wetlands occur in the floodplains and lowlands, particularly in the Cooper Creek drainage area. The eastern portion of Bradenton occupies the northwestern edge of the Braden River watershed, particularly the Sugarhouse Creek area.

Ward Lake generally exhibits good water quality with moderate levels of nutrients (TP = 0.08–0.21 mg/L; TN = 0.59–1.0 mg/L) and low coliform counts (ESE 1977b; USGS 1983). Dissolved-oxygen concentrations are often less than 4.0 mg/L, particularly near the bottom, probably because of the decomposition of organic matter imported from upstream. Considering its size and its importance in the Tampa Bay watershed, relatively little data have been gathered on the Braden River, particularly upstream of the dam.

Downstream of the dam, the Braden River takes on the characteristic of the estuary, and salinities typically range from 14 to 26 ppt in the dry season and 2 to 19 ppt in the wet season. Decreases in salinity are strongly correlated with decreases in DO concentrations and increased coliform levels (Heyl 1982). Dissolved oxygen often drops below 4.0 mg/L in the summer during periods of increased freshwater flow. Nutrients, particularly nitrogen, exhibit erratic seasonal patterns. Most of the nitrogen, which ranges from 0.1 to 4.4 mg/L, is tied up in organic form. Phosphorus, mostly in the orthophosphate form, ranges from 0.14 to 0.34 mg/L (Heyl 1982).

The main stem of the lower Manatee River from Lake Manatee Dam to Tampa Bay is tidal. From the dam downstream to the confluence with Mill Creek, the river has a relatively narrow, meandering course (Figure 74). Bayward of Mill Creek the river widens, broken up by emergent salt marsh and mangrove islands. The islands end about 16 km from the bay where the river broadens to almost 1.6 km. Urban land borders the river in the last 16-km stretch; the city of Bradenton lies to the south and Palmetto to the north. Upstream of Ellenton, land use is primarily agricultural (improved pasture, cropland, citrus) and native range (ESE 1977b). Several municipal point-source dischargers empty into this lower reach or to small tributaries (e.g., Wares Creek). The largest, by far, is the Bradenton Sewage Treatment Plant (ESE 1977b; FDER 1982).

As is the case with the Hillsborough River below the dam and the lower Alafia River, the quality of water in the lower Manatee River is generally related to the river flow and the location of the saltwater-freshwater mixing zone (Heyl 1982). The saline wedge is located upstream about 18 km in the wet season and 27 to 29 km in the dry season (Figure 75). The coefficient of variation in Figure 75 is highest where the widest range of salinities is reported, which is the saltwater-freshwater interface. Dissolved oxygen in the area of the salt-freshwater interface is often the lowest in the lower river, ranging between 2.0 and 4.0 mg/L, particularly in the summer.

Nutrient levels are high and generally decrease from the dam to the river mouth. Plankton productivity as measured by both chlorophyll *a* and light- and dark-bottle phytoplankton growth is quite variable, temporally and spatially (Table 20). High nutrients near the dam are attributed to agricultural runoff (Heyl 1982). Urban storm-water runoff and waste-treatment plants are suspected of causing the water-quality problems at the mouths of the Braden River and Wares Creek and in nearshore areas adjacent to intense urban development.

4.3.7 Manasota Coastal Area

The Manasota coastal area encompasses a series of lagoons and associated drainage areas paralleling the coast from Lemon Bay on the south through Sarasota Bay on the north (Figures 76 and 77). From south to north these lagoons are Lemon Bay, Dona and Roberts Bays, Blackburn Bay, Little Sarasota Bay, an additional Roberts Bay, and Sarasota Bay.

Systematic studies on the hydrology and water-quality dynamics of Manasota coastal lagoons and tributaries are relatively few. Quantity and distribution of runoff has been cursorily documented, usually in relation to questions of water supply (Joyner and Sutcliffe 1976; Hydroscience 1980). Until recently, extensive data on the quality of drainage waters existed only for a few creeks such as Cow Pen Slough (Lincer et al. 1975) and Phillipi Creek (ESE 1978). Limited water-quality data are available for some stations in and around Sarasota and Little Sarasota bays (FDER 1982). There is some information on circulation patterns and tidal exchange for Sarasota Bay (Chive et al. 1970; Ross 1973) and Dona and Roberts Bays (Lincer et al. 1975).

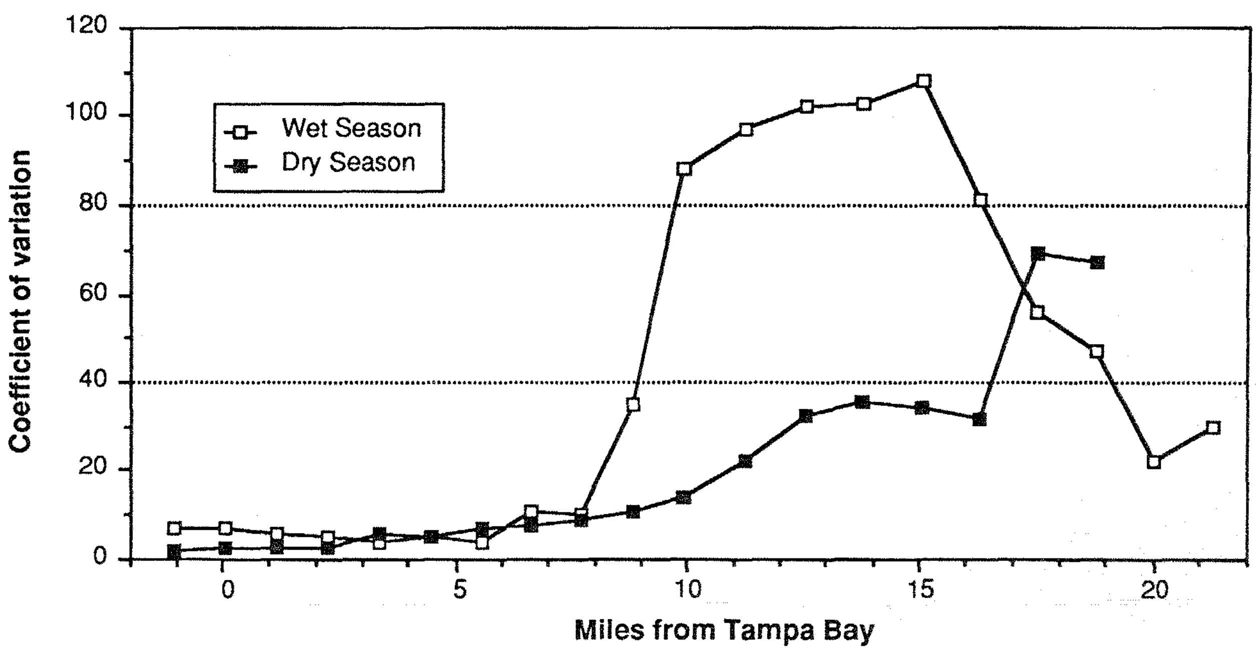


Figure 75. Wet- and dry-season salinity variation in the Lower Manatee River (after Heyl 1982).

Table 20. Primary productivity and chlorophyll a *concentrations in the lower Manatee River (after Heyl 1982).*

Station	Net photosynthesis (mg DO/L)	Gross photosynthesis (mg DO/L)	Respiration (mg DO/L)	Net productivity (g C/m^3/day)	Chlorophyll *a* (μg/L)
		July 7, 1982			
11	0.93	1.00	0.07	2.575	15.29
11 Dup	0.79	1.15	0.36	2.187	a
14	1.41	1.43	0.02	3.904	19.25
15	0.63	0.66	0.03	1.744	19.25
17	0.82	0.80	-0.02	2.270	13.26
17 (B)	-0.01	a	a	-0.270	11.87
21	0.30	0.09	0.09	0.830	3.93
		September 16, 1982			
11	13.03	20.22	7.19	21.60	288.95
11 Dup	12.88	17.55	4.67	21.79	217.58
14	2.89	3.35	0.46	5.29	36.59
15	1.75	2.18	0.43	3.40	19.16
17	1.48	1.63	0.15	3.19	18.23
17 (B)	-0.20	0.13	0.33	-0.45	16.36
21	1.08	0.94	-0.14	2.76	21.14

[a] Data not available

The major source of water quality data for streams and bays in Sarasota County is the Sarasota County Environmental Services Laboratory monitoring network. Since the late 1970's, this county program has produced annual and monthly reports (Laura McAdam, Sarasota Services Laboratory, personal communication 1987). By 1984, the network consisted of 41 bay stations and 39 stream stations. With the addition of a microcomputer in 1987, the data analysis includes an examination of trends, seasonal variations, and spatial differences.

Lemon Bay extends from near the southern tip of the study area approximately 24 km north by northwest to the town of South Venice. On the south, the bay is connected to Placida Harbor by the Intracoastal Waterway. The bay flushes to the Gulf of Mexico through Stump Pass, located about 5 km from the southern end of the bay across from Grove City. Three small creeks (from south to north), Buck Creek, Oyster Creek, and Ainger Creek, drain the sandy soils upland of this stretch of the bay. Englewood and rural agricultural lands to the north and northeast drain into Godfrey Creek (also known as Deer Creek), which in turn empties into Lemon Bay.

Northwest of Englewood, Lemon Bay gradually narrows behind Manasota Key with only two minor sources of freshwater drainage, Forked Creek at the town of Buckan and Alligator Creek at South Venice. The bay terminates in a small, shallow embayment known as Red Lake just north of South Venice.

Freshwater discharge to Lemon Bay is relatively minor, causing only localized and transient dilution of seawater, primarily near creek mouths (SCESL 1985). Circulation within the bay is probably controlled by the tides, but this is not well documented. A tidal node believed to exist in the vicinity of "The Narrows" at the south of the bay may effectively restrict significant exchange with Placida Harbor (Morrill et al. 1977).

Tides in Lemon Bay are semidiurnal to mixed and have a mean diurnal range of 0.6 m. Maximum flood-tide velocity at Stump Pass is 1.1 kn; maximum ebb-tide velocity is 0.6 kn (Morrill et al. 1977). Seawater

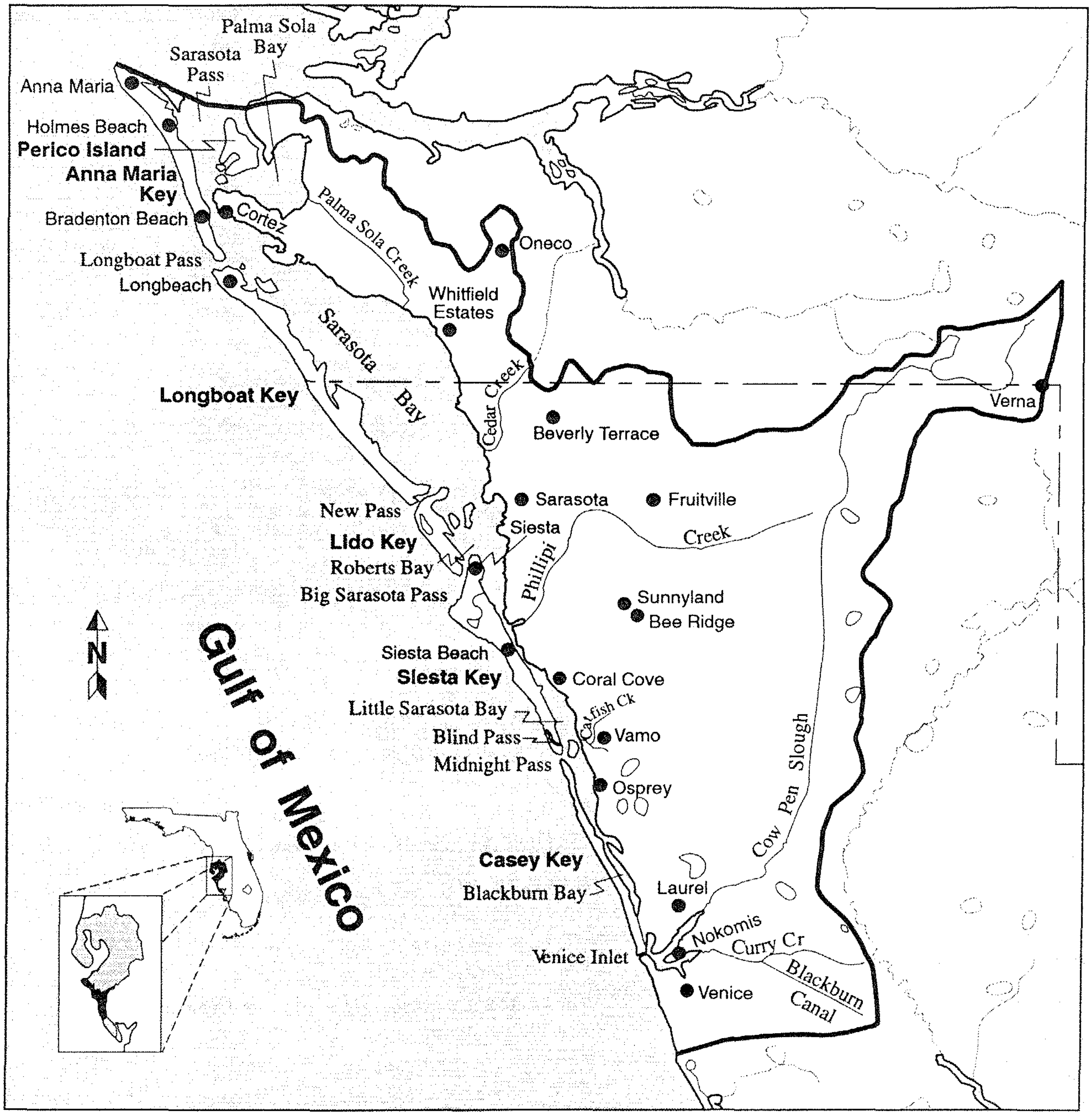


Figure 76. Upper Manasota coastal area drainage basin.

temperature at Stump Pass varies between 14.0°C (January) and 32.7°C (August).

In all seasons, water quality in Lemon Bay exhibits less variation than its tributaries. Nutrient concentrations decrease from the tributaries bayward and are highest during ebb tide. Total phosphorus concentrations, for example, ranged from 0.12 to 1.41 mg/L in the tributaries, and between 0.01 and 0.24 mg/L in Lemon Bay (Morrill et al. 1977; SCESL 1985). Organic nitrogen is the predominant nitrogen

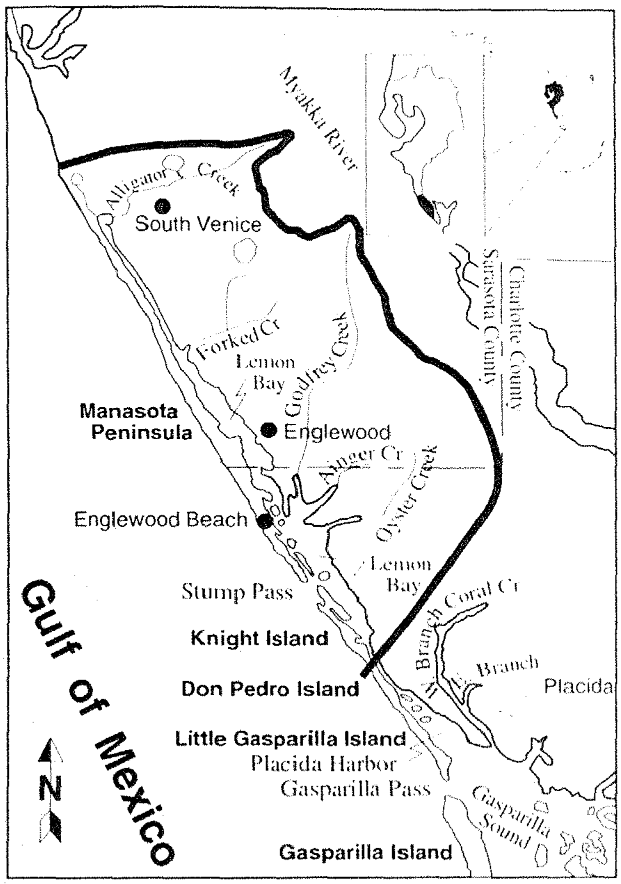


Figure 77. Lower Manasota coastal area drainage basin.

species. Dissolved-oxygen concentrations in the dry season (March) ranged from 6.9 to 9.8 mg/L in the bay, and 4.0 to 6.6 mg/L in the tributaries. Wet-season (August) concentrations were much lower, particularly in the early morning hours during ebb tide, when DO in the bay and the tributaries was less than 3.3 mg/L.

Coliform levels have been acceptable in the bay, but high in several tributaries (e.g., Godfrey Creek [Deer Creek], Ainger Creek, Oyster Creek, Buck Creek, Alligator Creek). With the exception of Buck Creek, where onsite wastewater systems have apparently caused some coliform contamination, and Alligator Creek, where sewage treatment plants discharge, elevated coliform levels are probably caused by agriculture runoff. In the wet season, the bay and its tributaries show a decreased level of coliforms (Morrill et al. 1977; SCESL 1985).

Branching off the channel connecting Red Lake and Lemon Bay is the Intracoastal Waterway, which runs through the coastal town of Venice to Roberts Bay. Hatchett Creek empties into the waterway near its confluence with Roberts Bay. Dona and Roberts Bay converge in a rough V shape at the town of Nokomis on the north side of Roberts Bay. Curry Creek and the Blackburn Canal drain into upper Roberts Bay. Bordering Nokomis to the north is Dona Bay, which receives drainage from Cow Pen Slough (Salt Creek), Fox Creek, and Cow Pen Slough Canal. Toward the Gulf of Mexico, Dona and Roberts Bays are joined from the north by Lyons Bay. Tidal exchange with the gulf takes place through the Venice Inlet, which separates the mainland from Casey Key on the north.

Proceeding north behind Casey Key, the Intracoastal Waterway connects lower Lyons Bay with Blackburn Bay. A small tributary, South Creek, drains into Blackburn Bay about 5 km north of the town of Laurel. At this point the bay is constricted by a spit of land from Casey Key and other islands that leads to a partially separate bay to the north, Dryman Bay. Throughout this stretch of coastline the associated uplands are literally riddled with shallow depressions loosely referred to as lakes.

Water quality in the bays and streams from Roberts Bay to Dryman Bay reflects the relatively rural setting of the region. Pine flatwood forests used as native rangeland or drained for improved pasture dominate the uplands. Streams draining these areas are colored, slightly acidic, occasionally high in fecal coliforms (from livestock runoff), and low in dissolved oxygen. Hatchett Creek, entering the Intracoastal Waterway just south of Roberts Bay, had the lowest mean DO and the highest coliform counts (particularly at Railroad Bridge) of any monitored water body in this coastal stretch in 1984 (SCESL 1985).

Agricultural runoff in Cow Pen Slough causes a phosphorus peak in the wet season (Lincer et al. 1975.). Nitrate nitrogen follows a similar seasonal pattern, ranging from less than 0.1 mg/L in February to 1.6 mg/L in September. Dissolved-oxygen concentrations exhibit a wide range (2.1–10.0 mg/L in 1984) in upper and lower reaches (SCESL 1985). Color, produced by humic and fulvic acids (the breakdown products of natural litter decomposition), is high in all of these coastal streams (from Redman Lake to Dryman Bay) and highest in South Creek, which drains Oscar Sherer State Park. In 1984, color was reported as high as 220 cobalt-platinum units, and is an indication of the natural background levels for this coastal region. Dissolved oxygen concentrations remain low throughout the year. Nutrients, predominantly in the organic forms, are moderate to high in concentration (Lincer et al. 1975, SCESL 1985).

The Dona and Roberts Bay estuaries, downstream of Cow Pen Slough and Curry Creek, respectively (Figure 78), are restricted embayments with a complex circulation pattern illustrated in Figures 79 and 80. In addition to the two freshwater sources, water may enter or leave the bays through the Intracoastal Waterway on the north and south, and the Venice inlet to the west. A number of islands and canals further complicate water movements.

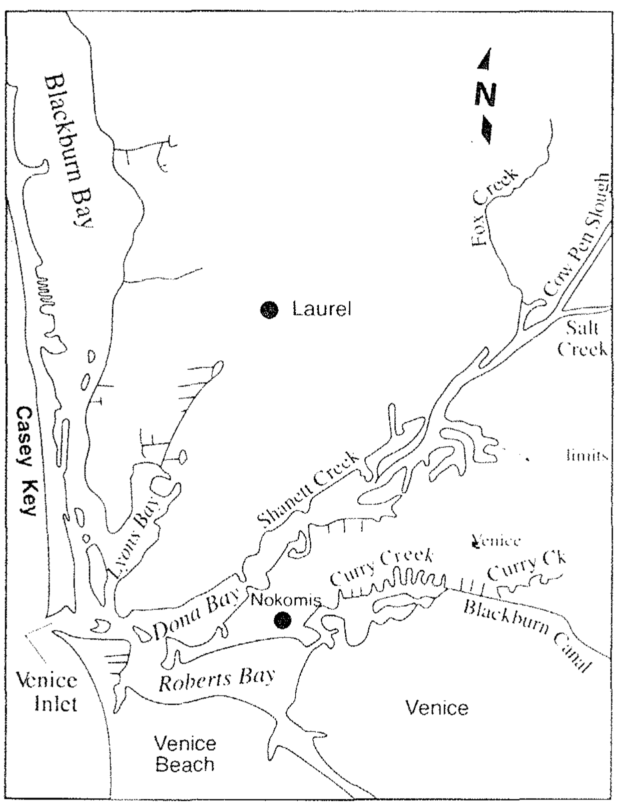


Figure 78. Blackburn, Lyons, Dona, and Roberts Bays and their tributaries.

Because of the relatively small, channelized drainage areas, salinities in Dona and Roberts Bays respond quickly to local rains. In wet weather, flood-tide currents in Dona Bay may be completely obliterated by runoff. The ratio between salinities in Dona, Roberts, and Lyons Bays (to the north) is about 1:3:8 in the wet season. During low flow, tides dominate the circulation and the salinities in the three bays are more uniform.

North of Lyons Bay, salinities in Blackburn Bay and Dryman Bay are relatively high and stable with the diminished input of freshwater from inland waterways. Only near South Creek is the bay water quality affected by freshwater runoff. Coliform levels at South Creek, while not violating State standards, are the highest reported from the bays in this region. During the year, conductivity fluctuates between 13,000 and 53,000 µmhos/cm. Highest bay color and lowest pH values are reported here (SCESL 1985). Dissolved-oxygen concentrations, coliform counts, and nutrient levels in these bays indicate fairly good water quality and no violations of State standards (SCESL 1985).

Little Sarasota Bay lies north of Dryman Bay. The small town of Osprey lies along the southern end of the bay on the mainland side. Drainage into Little Sarasota Bay arises from Catfish and North Creeks, which enter at the town of Vamo. Just across from their mouths are the Bird Keys, shallow supratidal islands that protect Blind Pass, a long embayment into Siesta Key that runs parallel to the Coast. Midnight Pass just south of the Bird Keys separates Siesta Key from Casey Key and serves as the main connection between Little Sarasota Bay and the Gulf of Mexico. Less than 1 km north of Blind Pass on Siesta Key lies Heron Lagoon, a narrow, enclosed body of water approximately 2 km long (Figure 76). Several small bayous (e.g., Elligraw Bayou) and creeks (e.g., Matheny Creek, Clowers Creek) dot the mainland

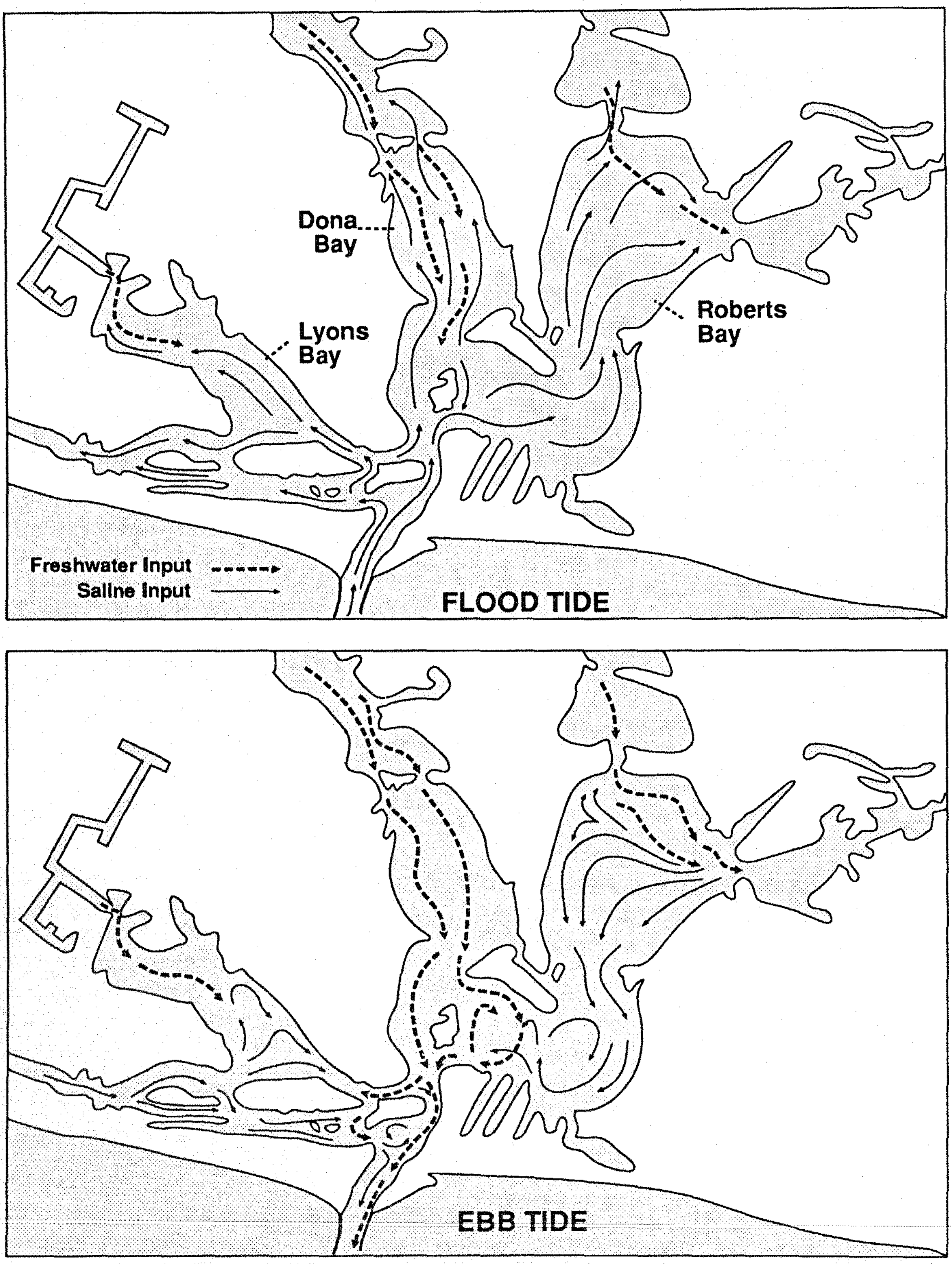


Figure 79. Dry season hydrography in Dona, Roberts, and Lyons Bays (after Lincer et al. 1975).

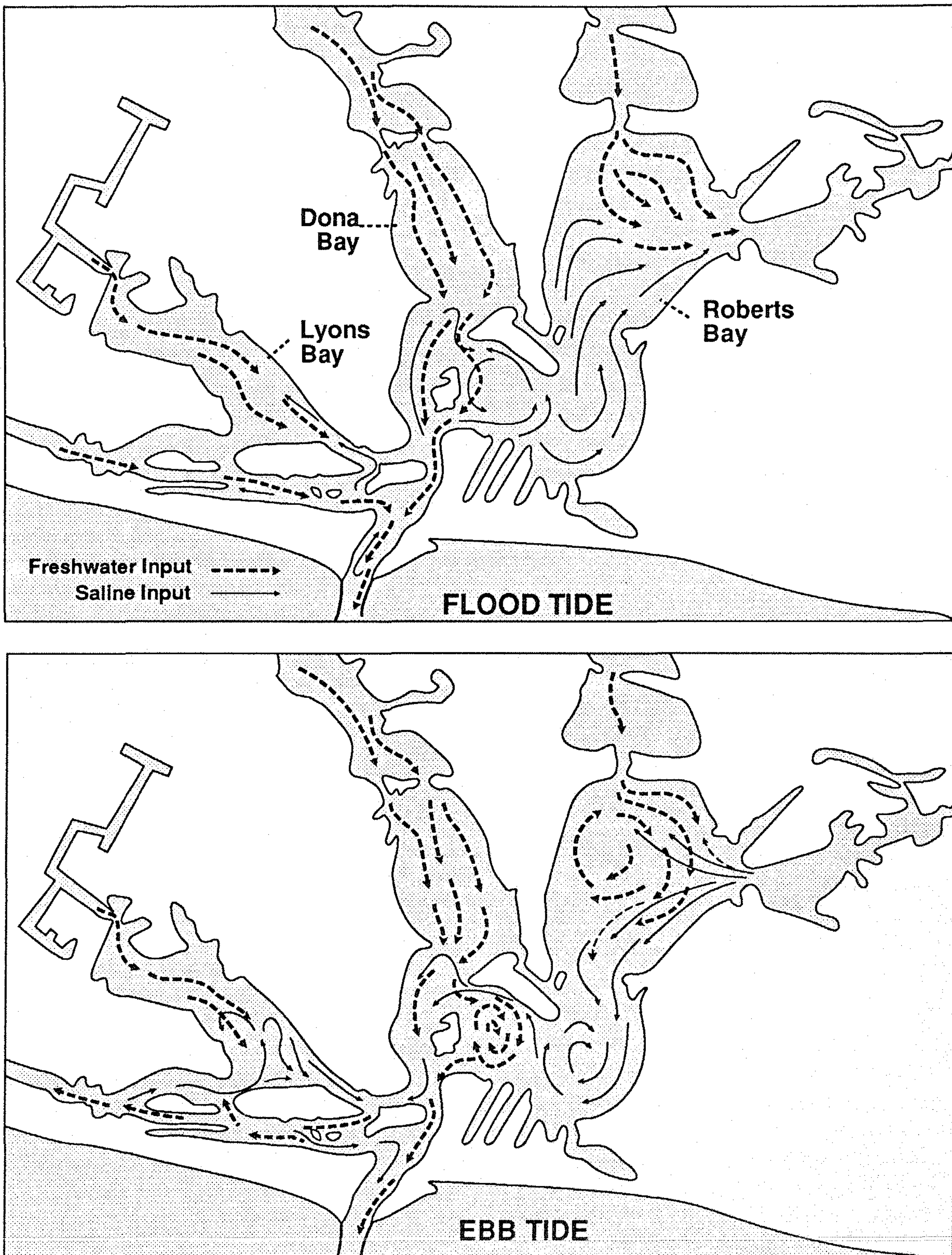


Figure 80. Wet season hydrography in Dona, Roberts, and Lyons Bays (after Lincer et al. 1975).

shoreline of Little Sarasota Bay north of Catfish Creek.

As Little Sarasota Bay gradually narrows at the northern end, the suburban sprawl of Sarasota dominates both the mainland and the barrier beaches. Phillippi Creek drains both agricultural uplands and urban Sarasota and joins Little Sarasota Bay north of its narrowest point. The shallow embayment between this point and Siesta Drive, connecting Siesta Key with the mainland, is known as Roberts Bay. Along the bay side of Siesta Key are numerous bayous and bays, and the Grand Canal connects Roberts Bay to an extensive maize of finger canals in the interior of the island.

The cusp-shaped northwest shore of Siesta Key is formed by Big Sarasota Pass, which connects the highly modified lower end of Sarasota Bay with the Gulf of Mexico. Immediately inside and along the axis of the pass is the extensively developed and channelized Bird Key. North of Big Sarasota Pass lies Lido Key, to which St. Armands is connected by three roadways. New Pass, located about 4 km north of Big Sarasota Pass, separates Lido Key from Longboard Key to the north and serves as a second major connection between Lower Sarasota Bay and the Gulf of Mexico.

Upland drainage to Sarasota Bay is often indistinct. Two of the more prominent creeks are the Pearce Canal, connecting the Braden River with Sarasota Bay through Whitaker Bayou, and Bowlees Creek, beginning south of Bradenton and discharging north of Sarasota. Palma Sola Creek, a poorly defined drainageway, connects Palma Sola Bay to northeastern Sarasota Bay.

On the gulf side of the bay is Longboat Key, a barrier island, approximately 16 km long and between 0.5 and 2 km wide. Longboat Pass separates Longboat Key from Anna Maria Key to the north and connects upper Sarasota Bay to the Gulf of Mexico. The bay side of Longboat Key is extensively channelized and seawalled for boating access. Numerous small islands of very low relief are also found on the lee side of the island. Anna Maria Key is north of Longboat Pass, separated from the mainland by Sarasota Pass along the southern half and Anna Maria Sound along the northern half. West of Sarasota Pass is Palma Sola Bay.

Long-term surface runoff data in the Manasota watershed is available from only one USGS station, Phillippi Creek. Flows in the creek are highest and most variable from August through October. Secondary peaks in the seasonal flow cycle are in February, April, and July. Similar patterns in flow were noted by Miller and Morris (1981) for the Peace and Myakka River watersheds.

Phillippi Creek is a low-sloping channel that drops only about 12 m over its 19-km length. Consequently the majority of its length (10 km) is affected by tidal fluctuations originating in Roberts Bay (ESE 1978). The gauging station lies above the reach of saline waters, as evidenced by monthly average conductivity values that range from 602 μmhos/cm in August to 979 μmhos/cm in December.

Two other parameters, color and total phosphorus, also have a seasonal pattern apparently tied to the flow cycle (Figure 81). Phosphorus appears to peak in June or July at the end of the dry season and beginning of the wet season (maximum total phosphorus during 1984 was 2.15 mg/L at the 17th St. Bridge), and decreases gradually with increasing flow (ESE 1978; SCESL 1985). Concentrations are lowest in the low-rainfall/runoff months, January–March.

Color appears to be bimodal with peaks in both winter (January, February, March) and summer (July, August, September). It is possible that seasonal peaks in color result from something of a region-wide "first flush" effect. As rainfall (or flow) increases, accumulated coloring agents are leached from the extensive wetlands and sandy soils of the basin. In winter, runoff is small and color may leach out over an extended time before soils become effectively cleansed (around April). In low-flow months (April, May, and June), color may again accumulate in the soil until the onset of the summer wet-season rains flood a greater wetland area. Though color is high throughout the Phillippi Creek watershed, values are highest in the rural eastern portion and lowest in more densely urbanized areas (SCESL 1985).

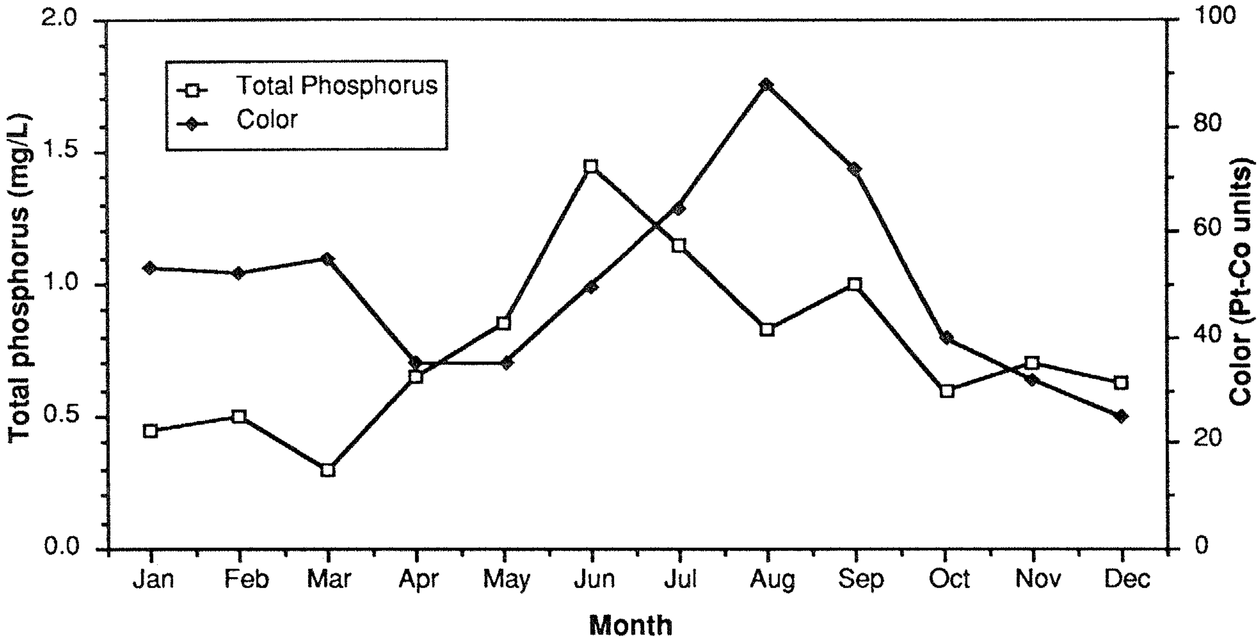


Figure 81. Average monthly concentrations of total phosphorus and color in Phillippi Creek (after FDER 1982).

Levels of dissolved oxygen in Phillippi Creek strongly suggest persistent organic contamination from several sewage treatment plants (Atlantic Utilities, Southeast Plaza Utilities, Florida Cities Water Co. South Gate, and Kensington Park Utilities sewage treatment plants). Monthly averages range from a low of 2.57 mg/L in April to a high of only 5.3 mg/L in October; minimum values approach zero (FDER 1982; Hand and Jackman 1984; SCESL 1985). In all but two months, the average DO is less than 4.0 mg/L. High concentrations of total and inorganic nitrogen (12.5 mg/L TN as N, 1984) confirm that the creek is significantly polluted. Fecal coliform bacteria also frequently exceed State water quality standards (Hand and Jackman 1984, SCESL 1985).

Water quality of streams entering Little Sarasota, Roberts, and Sarasota Bays generally decreases from south to north and from rural to urban settings (SCESL 1985). Urban tributaries (e.g., Phillippi Creek, Clowers Creek, Whitaker Bayou) not only receive greater pollutant loads from stormwater runoff, but also sewage treatment-plant effluent. The effect is increased coliform counts, high nutrient concentrations, and low dissolved oxygen (Hand and Jackman 1984; SCESL 1985, 1987). In January 1987, ammonia concentrations in Whitaker Bayou ranged between 0.04 mg/L in the upper reach and 4.68 mg/L at the mouth. Phosphorus, mainly in the ortho form, followed a similar pattern, peaking at 1.55 mg/L at the mouth (SCESL 1987).

The bays (Little Sarasota, Roberts, and Sarasota) show improving water-quality conditions away from the tributaries and from hydraulically restricted shoreline areas (e.g., Payne Terminal, Grand Canal, Buttonwood Harbor). The same water-quality problems observed in streams such as Phillippi Creek, Whitaker Bayou, and Matheny Creek—e.g., high bacteria counts, high nutrient concentrations, and low dissolved-oxygen levels—are manifested in the adjacent bay waters. Away from these influences toward the open channel, nutrients, coliforms, and color decrease, dissolved oxygen increases, and salinity increases and remains fairly stable (SCESL 1985, 1987). This improvement continues close to and inside the coastal passes—e.g., New Pass, Big Sarasota Pass—where nutrient-poor and oxygen-rich gulf waters reside (SCESL 1985).

4.3.8 Tampa Bay

Hydrology and water quality in Tampa Bay have been extensively studied over the past 10 to 15 years. Quantitative descriptions of hydraulics include not one but two major modeling efforts, one being a modification of the Reid and Bodine (1968) model of storm surge (Ross and Anderson 1972a,b; Ross 1973; Ross et al. 1976a,b, 1977a,b) and the other, a modification of the Leendertse (1967) model (Goodwin 1977, 1980). Other quantitative descriptions of circulation-related phenomena include stream-flow simulations (Turner 1979), salt-balance regression equations (Giovannelli 1981), and watershed runoff models (Copeland 1973). Currently data collection and modeling efforts are focused around the impact of urban runoff from Tampa to the Hillsborough River and Bay and the effects of continued dredging throughout Tampa Bay.

Water-quality data for Tampa Bay have been collected by the State of Florida (FSBH 1965; Eldred 1966; FDER 1980, 1982), the Federal Government (Finucane and Dragovich 1966; FWPCA 1969; Saloman and Taylor 1972; Reichenbaugh et al. 1973; Goodwin et al. 1974; Goetz and Goodwin 1980), and locally by the HCEPC (HCEPC 1982, 1984), as well as by numerous independent researchers. A summary of basic physical and chemical characteristics of Tampa Bay waters for 1982 and 1983 is presented in Appendix Table A-8.

Predominantly semidiurnal tides (two high and two low tides daily) in the Tampa Bay estuary exhibit tidal heights that range between 0.60 and 0.85 m (HCEPC 1984). Maximum current velocities generally occur near the mouth of the bay and may range from 1.8 m/s on ebb tides to less than 1.1 m/s on flood tides. In upper Hillsborough and Old Tampa bays, current velocities decrease to as little as 10% of those at the bay mouth.

Circulation in the bay is characterized by a series of gyres, most of which rotate counterclockwise (Figure 82) (Ross 1973). Clockwise gyres, operating singly, are noted in upper Old Tampa Bay above the Courtney Campbell Causeway and at the mouth of the Manatee River in the lee of the Sunshine State Parkway.

Clockwise gyres appear along with these counterclockwise movements in upper Hillsborough Bay and along the western shore of Old Tampa Bay between the Courtney Campbell Causeway and the Howard Franklin Bridge. The latter gyres appear to work off one another somewhat like hydraulic gears. Bottom topography (spoil islands, dredged channels, shoreline location and shape) and the location and magnitude of freshwater inputs also determine net circulation patterns.

The circulation pattern is important because it controls how and where particles (i.e., water masses) are distributed within the bay system and how long they reside in one location. A diagram showing how uniformly distributed particles in the Tampa Bay Estuary look after 30 days of mixing is presented in Figure 83. Prevailing currents appear to sweep certain areas of the bay clean while particles definitely accumulate in other segments (Ross 1973).

Over the past 100 years, dredging and subsequent spoil disposal have significantly altered the bottom topography in Tampa Bay. By comparing the existing condition with an approximation of the undisturbed bay morphology, Goodwin (1981) concluded that existing hydrologic modifications have increased the net tidal transport of water in Hillsborough Bay. Most of this increased transport takes place within the dredged ship channels. As more water moves in and out per unit of time and per unit of bottom surface area, the net energy to which the bay bottom is exposed also increases. This implies that more particulate matter may remain suspended or be resuspended than would be under the undisturbed condition. Such an increase could conceivably add nutrients and toxic compounds to the water column that might otherwise have been rendered unavailable by sedimentation. The chronic destabilization and agitation of the sediment-water interface probably also influences the suitability of the bay bottom for rooted macrophytes, burrowing infauna, and epibenthic fauna (Simon and Dyer 1972).

One of the most comprehensive surveys of water-quality conditions in Tampa Bay has been conducted by the HCEPC (HCEPC 1984). Since 1972 this agency has collected water-quality data on more than

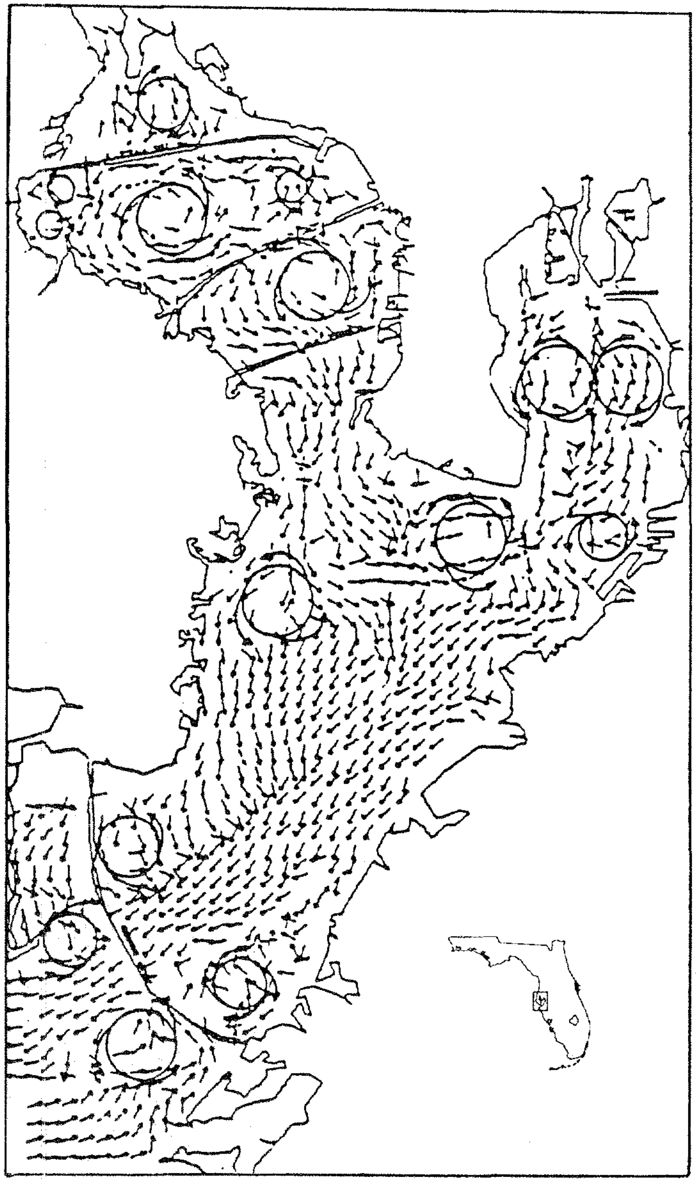


Figure 82. Circulation pattern in Tampa Bay (Ross 1973).

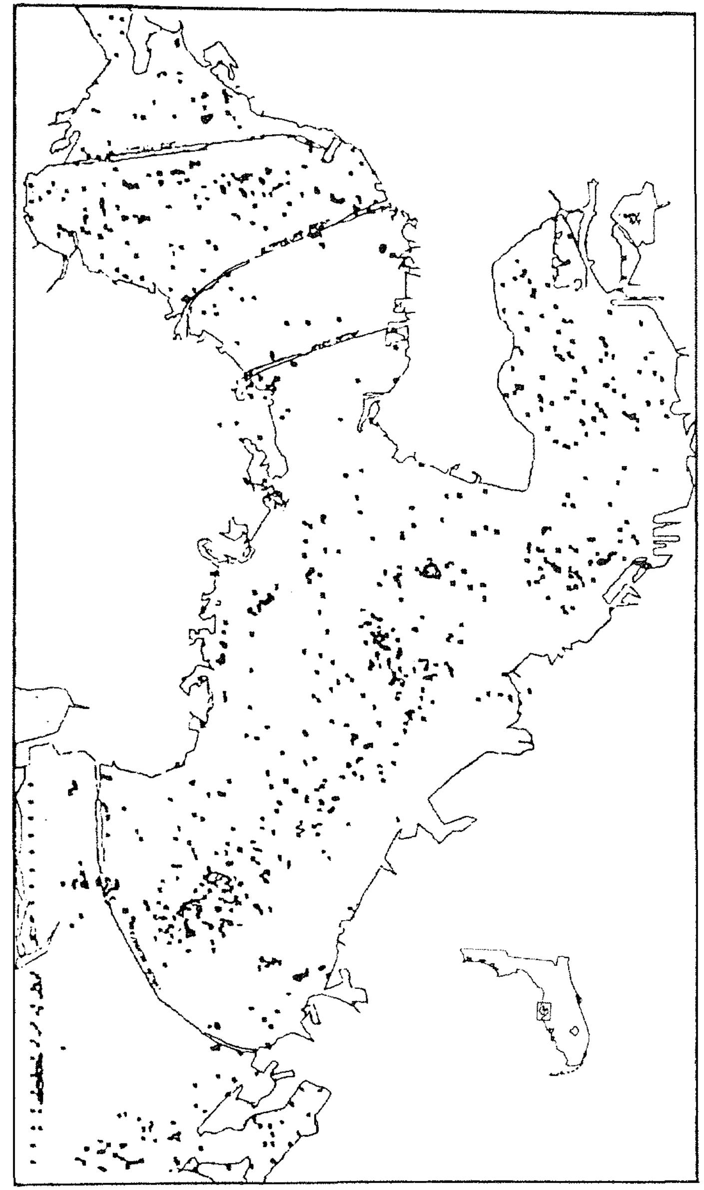


Figure 83. Location of evenly distributed particles after 30 days of mixing in Tampa Bay (Ross 1973).

50 parameters from over 50 sampling stations in Tampa Bay and published its findings in biannual reports (HCEPC 1982, 1984)(Appendix Table A-8). Although there are some other long-term analysis and collection efforts, the HCEPC's biannual reports are the most accessible, comprehensive, and current. Much of the following summary of Tampa Bay water quality conditions is based on these reports.

A general water-quality index developed by HCEPC shows McKay Bay, Hillsborough Bay, Old Tampa Bay northeast of the Courtney Campbell Causeway, and Old Tampa Bay in the Largo Inlet area, to exhibit the worst water quality in 1982 and 1983 in Tampa Bay (Figures 84 and 85). Water quality is shown to improve south in the bay toward Egmont Key.

High nutrient levels (Figure 86) and BOD (Figure 87) have caused depressed DO levels (Figure 88), increased turbidity (Figure 89), accelerated algal growth (chlorophyll *a*) (Figure 90), and reduced effective light penetration (Figure 90) to existing benthic flora. Although BOD and nutrient concentrations have decreased over the last 10 years, the residual wastes present in the sediment have continued to cause algal and DO problems.

Bacteria as represented by total fecal coliforms have been in high concentrations in Hillsborough Bay since the agency (HCEPC) started its sampling program. Since 1980 the problem has been lessened due to the completion of the Hookers Point advanced wastewater treatment (AWT) plant and the reduction in overflows from the Tampa sewage collection system into the Hillsborough River. Occasional overflows have occurred more recently (e.g., 1982) and caused total coliforms in 1982 to exceed 10,000 counts/100 mL at the mouth of the Hillsborough River. Old Tampa Bay northeast of Courtney Campbell Causeway also shows high coliform counts that are caused by several Hillsborough County sewage treatment plants (recently taken off-line) and urban stormwater runoff, which has increased with population growth in northwest Hillsborough County and northeast Pinellas County. The bacterial contamination is further aggravated by poor tidal flushing north of the Courtney Campbell Causeway, resulting from its construction (HCEPC 1984).

The sources of nutrient problems in the bay are urban stormwater runoff, sewage treatment-plant discharges, phosphate mining and processing discharges (Alafia River), other industrial waste discharges (e.g., Nitram, Inc. via Delaney Creek), and residual waste found in the bay sediments. Contributions from point sources (industrial and domestic waste facilities) have decreased since the middle to late seventies because of improved treatment practices, and as evident in Figure 86 for total phosphate. Although waste from point sources has decreased in recent years, increased urban stormwater runoff and the residual wastes in Tampa Bay have caused other water pollutant indicators to rise slightly or remain constant over the last 10 years. In certain cases (e.g., DO (Figure 88), chlorophyll *a* (Figure 90)), where Hillsborough Bay has shown improvement, Old Tampa Bay and middle Tampa water-quality conditions have worsened. DO and chlorophyll *a* are controlled to some extent by rainfall, as are color (Figure 90) and turbidity (Figure 89). High rainfall and runoff years correspond to higher chlorophyll *a* concentrations and lower bottom DO levels (Figure 88). As expected, seasonal water-quality conditions worsen in late summer and early fall as the wet season peaks.

Turbidity and light penetration are controlled not only by wastes introduced into the bay, but also by activities within the bay. Algal blooms caused by nutrient inflow and suspended solids carried by urban runoff and point-source discharges are examples of outside influences that cause turbidity to increase and light penetration to decrease. Dredging activities (e.g., Tampa Harbor Deepening Project), resuspension of shallow water sediments by winds, and beach renourishment projects are examples of activities in the bay that have caused past increases in turbidity (HCEPC 1984).

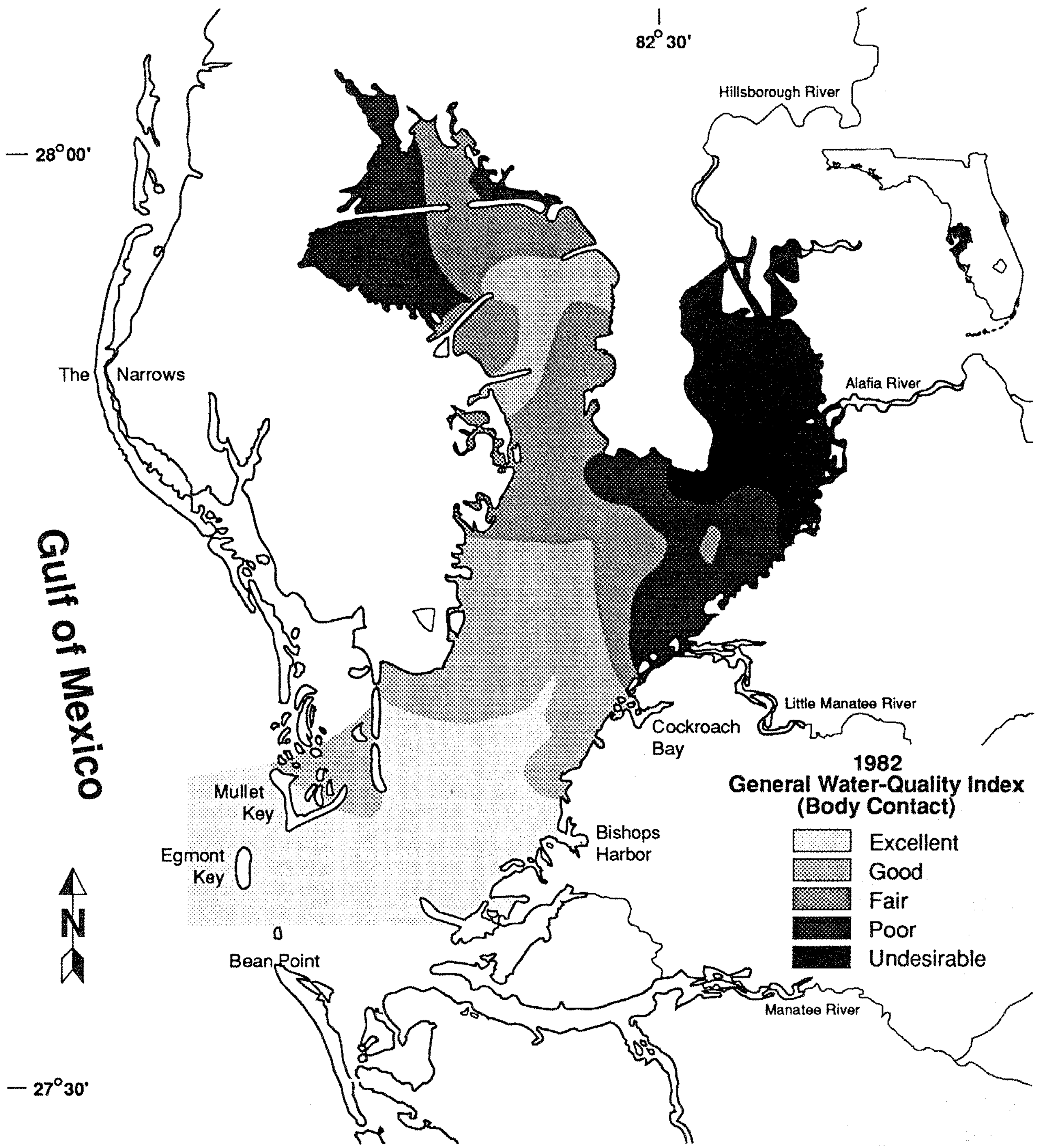


Figure 84. General water quality index of Tampa Bay for 1982 (data from HCEPC 1984).

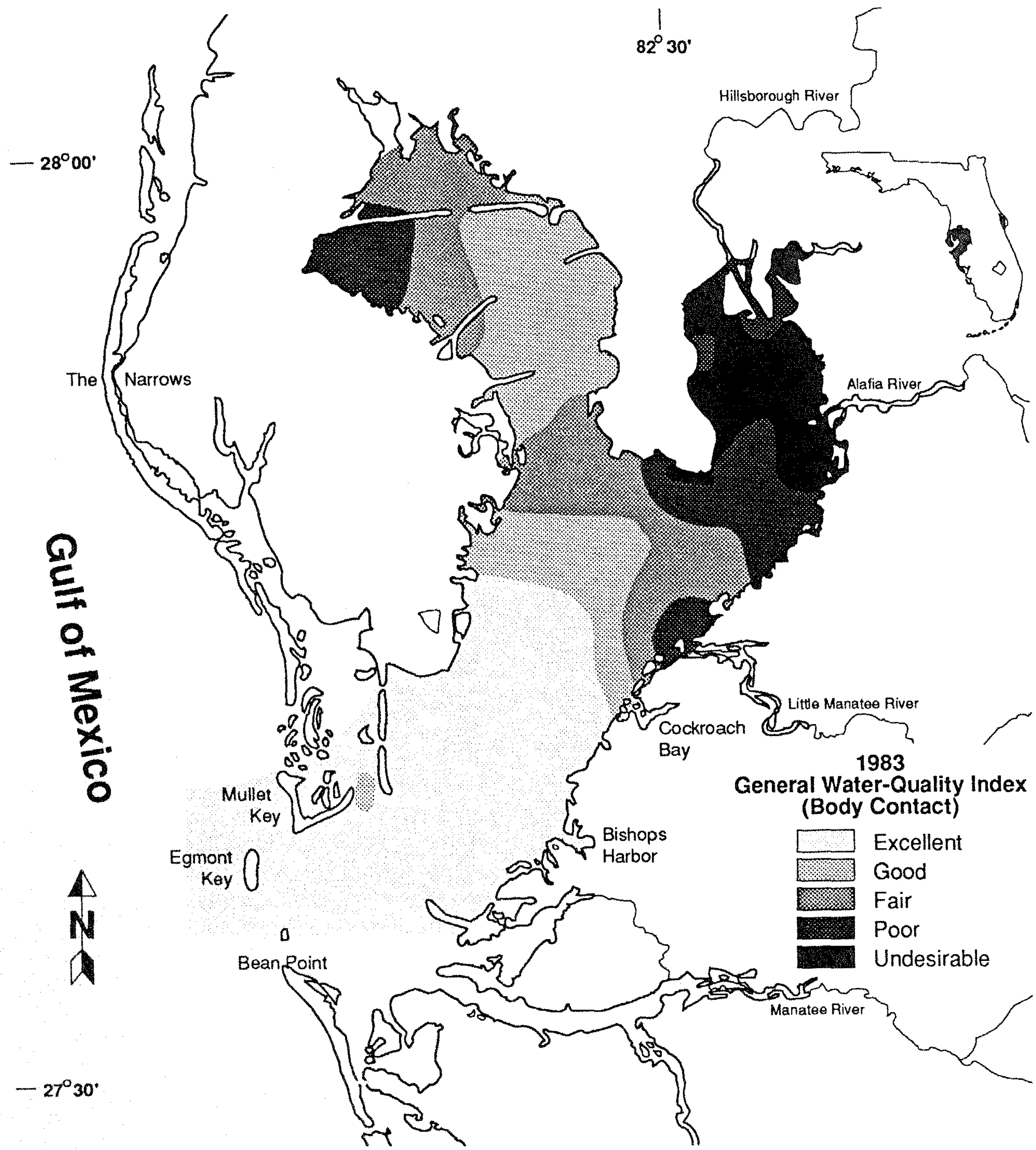


Figure 85. General water quality index of Tampa Bay for 1983 (data from HCEPC 1984).

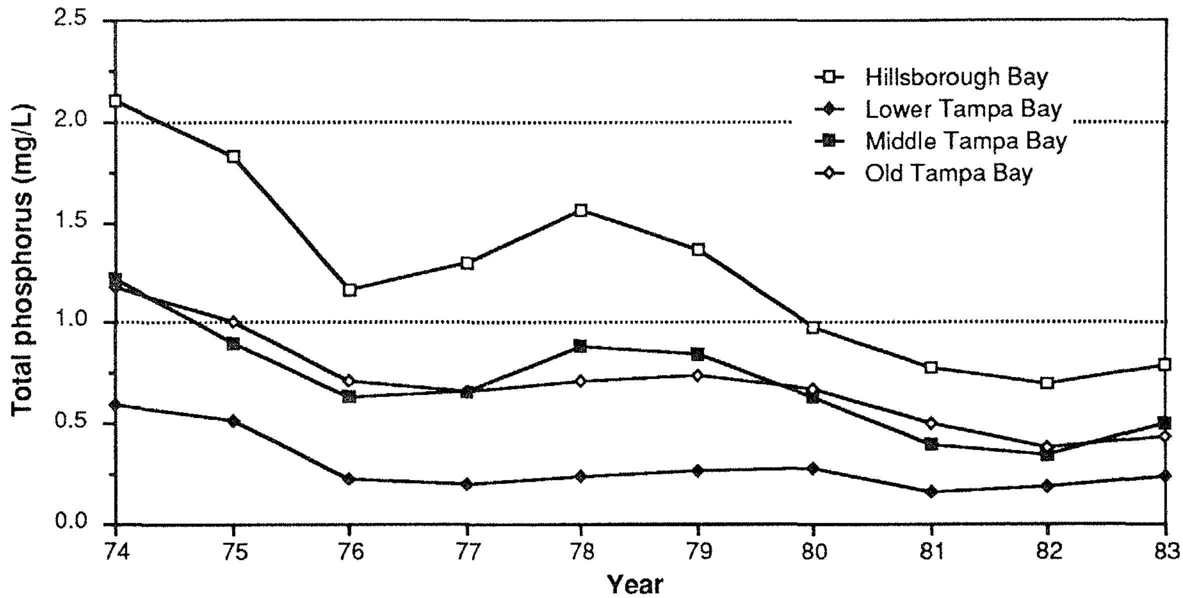


Figure 86. Total phosphate concentrations in the Tampa Bay estuary, 1974–83 (after HCEPC 1984).

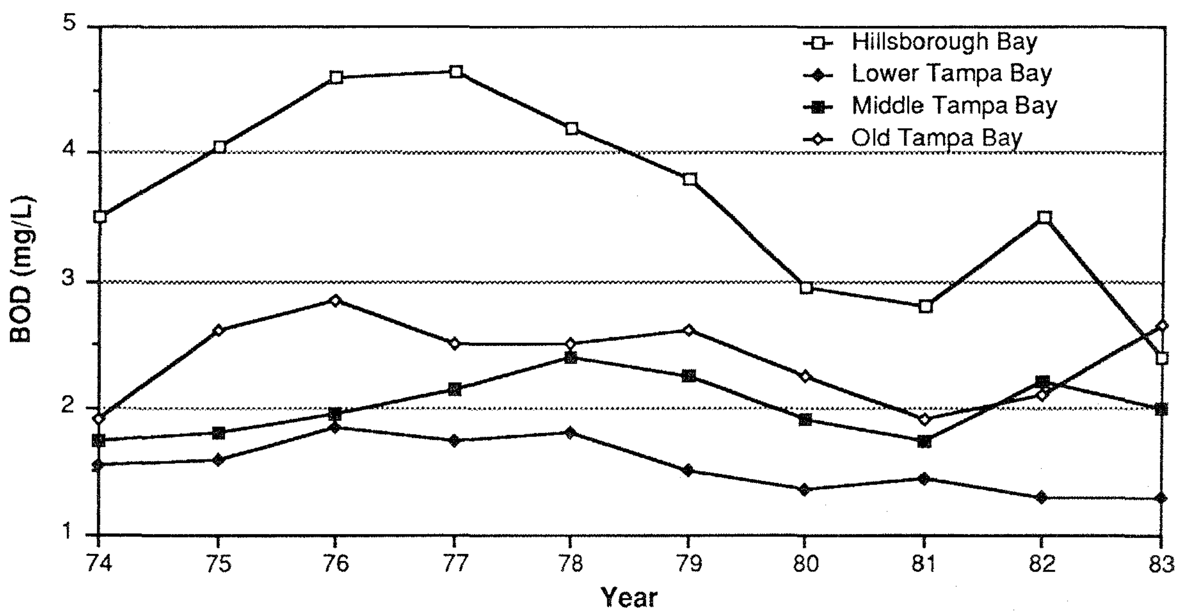


Figure 87. Biochemical oxygen demand (BOD) in the Tampa Bay estuary, 1974–83 (after HCEPC 1984).

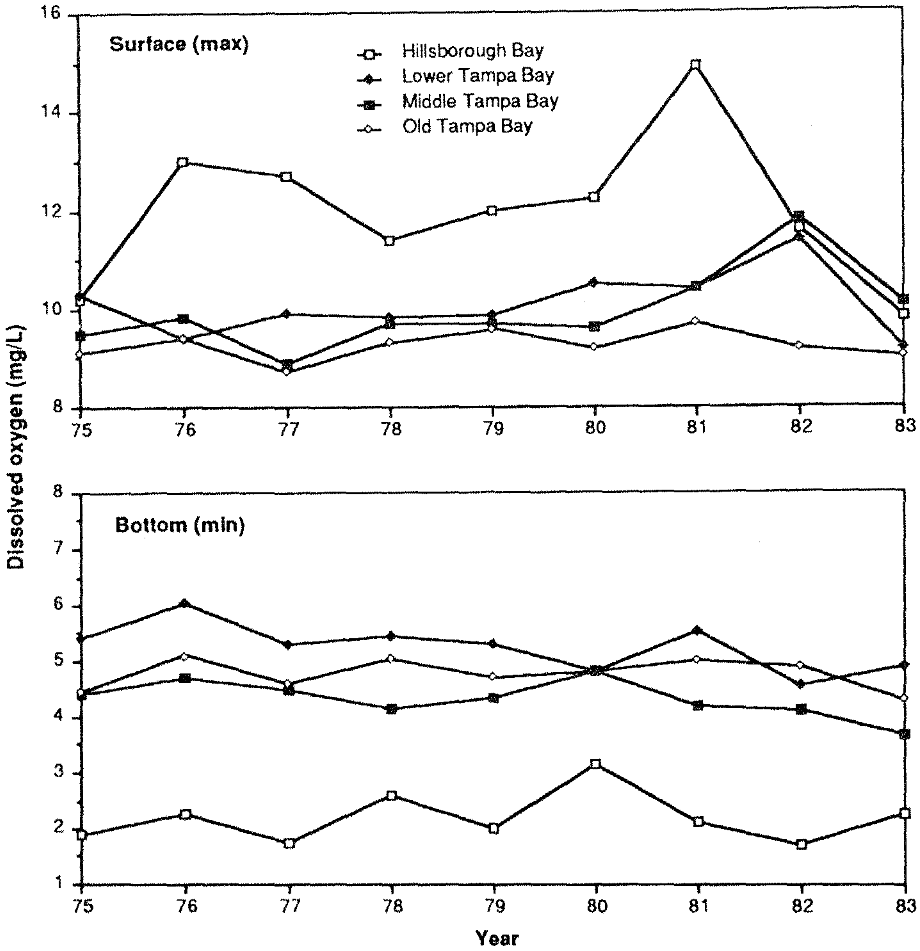


Figure 88. Maximum surface and minimum bottom DO concentrations in Tampa Bay, 1974–83 (after HCEPC 1984).

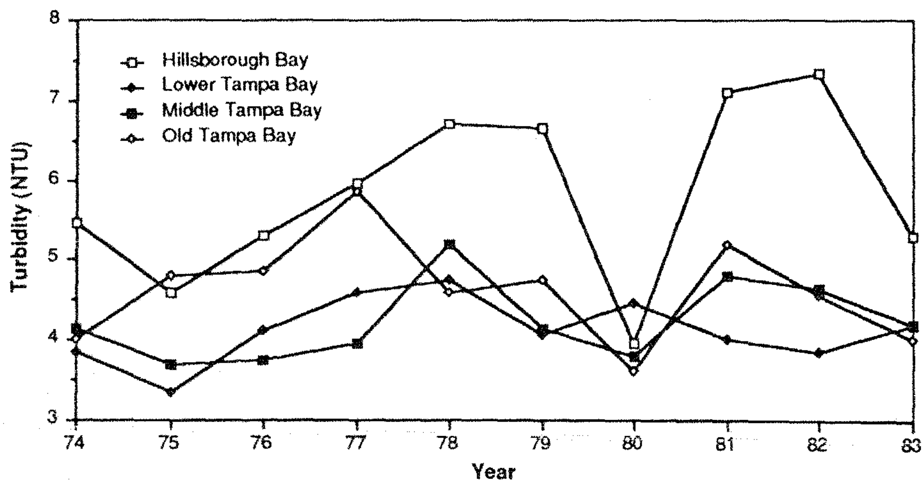


Figure 89. Turbidity in the Tampa Bay estuary, 1974–83 (after HCEPC 1984).

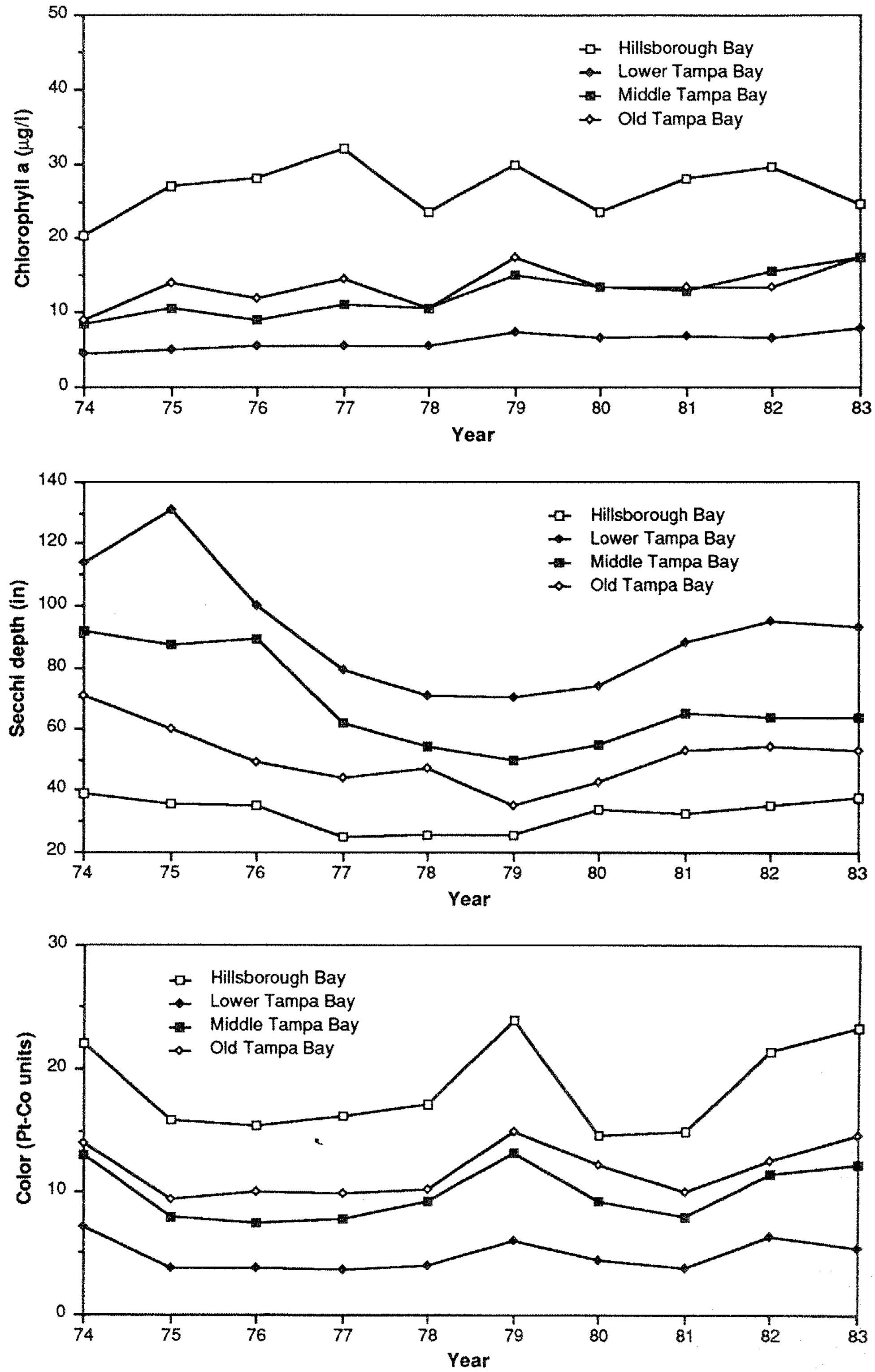


Figure 90. Chlorophyll *a* concentrations, light penetration, and color in the Tampa Bay estuary, 1974–83 (after HCEPC 1984).

Chapter 5. Vegetation Communities (Habitats)

N. Scott Schomer, Richard D. Drew, and Paul Johnson

5.1 Introduction

Odum (1971) described a biotic community as any assemblage of populations living in a prescribed area or physical habitat: "it is an organized unit to the extent that it has characteristics additional to its individual and population components and functions as a unit through coupled metabolic transformations."

Abundance and species composition in a biotic community are controlled by physical and chemical factors (e.g., climate, soil or sediment type, wave action, salinity) and biological factors (e.g., interspecific and intraspecific competition, predation, reproductive strategies, biologically mediated habitat modifications, and recycling of organic matter). Superimposed on these natural forces is the pressure of industrial, residential, and agricultural development. Taken together they mold the structural and functional aspects of habitats uniquely characteristic of the Tampa Bay watershed.

In this and the next chapter, communities in the Tampa watershed are described based on associated flora and fauna (Chapter 6), using physical habitat characteristics of the region. Figure 91 shows the distribution of vegetation and land use in the Tampa Bay watersheds.

5.2 Terrestrial Habitats

Terrestrial habitats are divided into three major categories: pinelands, prairies, and hammocks. In this framework are many variations, depending upon local environmental background conditions and historical influences. The unifying environmental characteristic that sets these communities apart is their virtual lack of a hydroperiod. With the exception of the hydric hammock, standing water is seldom, if ever, present in these communities.

In his landmark mapping of the natural vegetation of Florida, Davis (1967) identifies four upland communities in the study area: pine flatwoods, sand pine scrub forest, long leaf pine/xerophytic oak forests, and grasslands (or dry prairies). A potential fifth community, the coastal strand, is discussed as a component of beach, dune, and coastal strand communities, rather than as an upland community of the interior watershed. In a later study, Layne et al. (1977) identify nine distinct vegetation communities that may be placed into four larger categories as follows:

1. Pine-oak woodlands
    a. Sand pine scrub
    b. Scrubby flatwoods
    c. Sandhills (longleaf pine-turkey oaks)
2. Pine flatwoods or typical flatwoods
3. Prairies
4. Hammocks
    a. Live oak hammocks
    b. Cabbage palm hammocks
    c. Mesic hammocks
    d. Hydric hammocks

The following description and discussion of vegetative community types in the study area is taken largely from Layne et al. (1977) and based on the above classification. Other site-specific information has been included as appropriate.

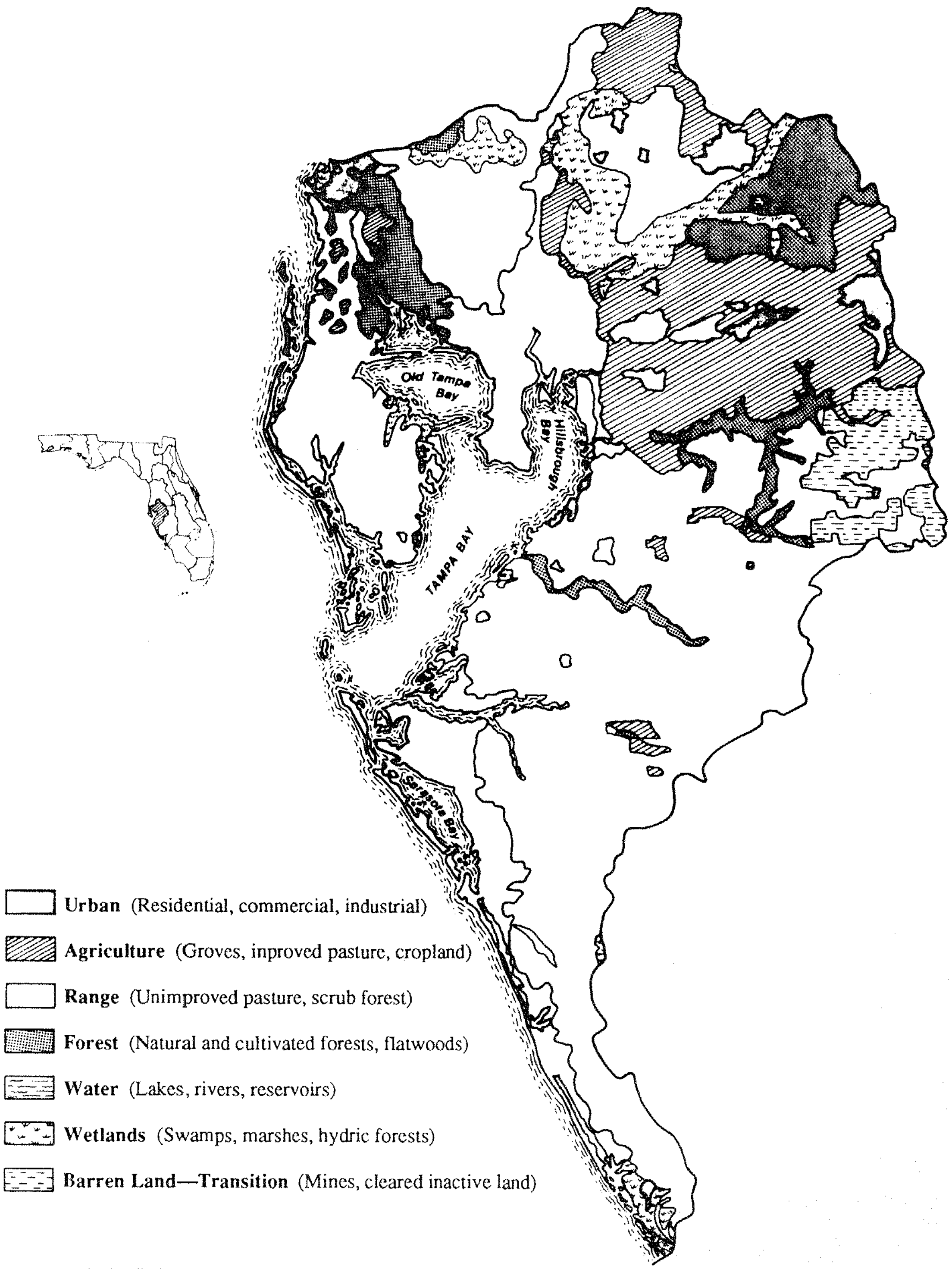


Figure 91. Vegetation and land use in the Tampa Bay drainage basin (after Hafer and Palmer 1978).

5.2.1 Pine-Oak Woodlands

a. Sand pine scrub. This association occurs on ridges and other elevated sites, usually relict dunes or sandbars formed by earlier stands of sea level. The soils are deep, acidic, excessively drained sands, usually of the St. Lucie or Lakewood series.

This habitat is characterized by an overstory of sand pine *(Pinus clausa)* and a well-developed shrub layer consisting largely of evergreen species. Herbaceous ground cover is sparse, although patches of true mosses and lichens, especially reindeer moss *(Cladonia)*, are frequent. Three xeric oak species, sand live oak *(Quercus virginiana* var. *geminata)*, myrtle oak (*Q. myrtifolia*), and Chapman oak (*Q. chapmanii)*, are particularly diagnostic of the shrub layer. It is interesting to note that these are the species of oak found on present-day dunes as well (Kurz 1942). Other typical shrub species include staggerbush *(Lyonia ferruginea)*, silk bay *(Persea humilis)*, rosemary *(Ceratiola ericoides)*, saw palmetto *(Serenoa repens)*, and scrub palmetto *(Sabal etonia)*.

Sand pine scrub, also referred to as sand scrub or rosemary scrub, is the most distinctive vegetative association in the state. It is found only in Florida and along the coast of southeastern Alabama. The most extensive areas of sand pine scrub in Florida are found in the Ocala National Forest in north-central Florida (the "Big Scrub") and at the southern end of the Lake Wales Ridge in Highlands County. The southernmost examples of this habitat in the State are along the coasts. Sand pine scrub is a minor habitat in the Tampa Bay watershed, although it is found in all counties. It is most frequent on the ridges in the upper watershed and occurs more sporadically elsewhere.

Sand pine scrub is a fire-maintained association. The height and density of the pines and shrub layer of a particular stand reflect its fire history. Where fires are relatively frequent, the sand pines are usually widely scattered and the shrubs form low, dense clumps separated by bare patches of white sand. In this stage, the scrub community is one of the most xeric environments found in Florida. Scrubs that have gone without burning for many years may have a dense stand of pines with a completely closed canopy, taller shrubs and small trees in the understory, and a well-developed litter layer. Such mature scrubs are more mesic than the open phases. In the absence of fire, succession is toward a xeric, oak-dominated hardwood woodland and, ultimately, to a mesic hammock association (Laessle 1942).

The sand pine scrub association is one of the most endangered of Florida habitats. Never extensive, it is continually being degraded or destroyed. Its well-drained soils make it desirable for real estate and agricultural development, and considerable acreage has been converted to residential use, citrus groves, and improved pastures. Where patches of scrub are surrounded by grazing lands, they are often severely cropped and trampled by cattle.

The association is the primary habitat of an unusually large number of endemic and rare Florida species including the Florida scrub lizard, blue-tailed mole skink, sand skink, short-tailed snake, Florida scrub jay, and Florida mouse (Woolfenden 1983). These species are more typical of the very dry early successional stages of scrub than of the more humid mature stands with closed canopy. Thus, where scrubs are fully protected from fire, they may succeed to a stage less suitable for typical scrub wildlife.

b. Scrubby flatwoods. Found on slight rises with well-drained, fairly deep sandy soils, the scrubby flatwoods are similar to sand pine scrub in their xeric character and dominance by shrubby evergreens. The difference is the dominance of the slash pine (*Pinus elliottii*) or longleaf pine (*P. palustris*) rather than sand pine, and the somewhat more frequent presence of herbaceous plants than in true scrub. The well-developed shrub layer has essentially the same species composition as the sand pine scrub, and like sand pine scrub, scrubby flatwoods have a patchy distribution and are often found as small areas surrounded by vegetation types of lower, not so well-drained soils. The height and density of the pines and shrubs are largely dependent on the frequency and severity of fires. Endemic sand pine scrub also characterizes scrubby flatwoods.

An association comprising predominantly xeric oaks (sand live oak, myrtle oak, running oak (*Q. pumila*), and/or Chapman oak) and lacking pine is regularly encountered in the Springs Coast and has been termed "Oak Scrub." Its physiognomic, vegetative, and environmental characteristics generally resemble those of sand pine scrub and scrubby flatwoods except for the absence of pines. *Smilax* (greenbrier) vines may be well developed here, lending a much lower and denser aspect to the vegetative cover than found in other dry sandy areas.

c. **Sandhills.** Sandhill vegetation occurs on level to gently rolling uplands with well-drained, deep, acidic sandy soils that usually contain some loam in their lower layers. Although relatively dry and sterile, these soils are not as excessively drained as those of the sand pine scrub association.

This association is characterized by the presence of longleaf pine and turkey oak (*Quercus laevis*). Bluejack oak (*Q. incana*) and live oak (*Q. virginiana*) may also be found. In lower areas with somewhat richer and moister soils, bluejack oak may replace turkey oak as the dominant species. The sandhill association has low tree-species diversity compared to other forest types in Florida (Monk and McGinnis 1966). Shrubs are also scarce. The ground cover is well developed, however, being characterized by many more herbaceous species than is sand pine scrub. Typical components of this layer include wire-grass (*Aristida stricta*), gopher apple (*Chrysobalanus oblongifolius*), milk pea (*Galactia fasciculata*), hoary pea (*Tephrosia chrysophylla*), silkgrass (*Heterotheca graminifolia*), yellow buttons (*Balduina angustifolia*), and blue bonnet (*Lupinus cumulicola*). The ground cover is seldom complete and bare, sandy patches are often present.

In the original undisturbed sandhill association, pines were apparently dominant and occurred as a fairly open stand with scattered turkey oaks in the understory. As the result of intensive logging, pines are now relatively scarce and widely spaced, and turkey oak is the dominant overstory species in most present-day sandhill habitats. Slash pine often displaces the longleaf pine, and in some cases pines are completely absent. The turkey oaks may then occur as open or dense stands.

As in the case of sand pine scrub and scrubby flatwoods, the sandhill association is relatively xeromorphic, as the result of its well-drained soils and open vegetative structure that allows free air circulation and exposure of the ground to sunlight. Fire is also an important factor in the ecology of this association. In the absence of fire, hardwoods become denser and pine reproduction ceases, leading to a mesophytic hardwood community through a live oak hammock succession stage (Laessle 1942).

Sandhill vegetation is confined to the panhandle and the peninsula north of Lake Okeechobee. It was the predominant vegetative association of much of the better drained portions of the Central Highlands underlain by the Citronelle Formation, but has been drastically reduced throughout the State by development and cultivation, and natural examples are becoming increasingly difficult to find. Many thousands of hectares of former sandhill vegetation have been converted to citrus groves, improved pastures, and pine plantations. Other areas have been overprotected from fire and are succeeding to hardwoods.

Within the study area, the sandhill association was formerly most extensive on the sandy ridges of Polk County and in central Hillsborough County east of Tampa. Other adjacent areas include those along the Peace River to Hardee and DeSoto Counties, with smaller and more widely scattered stands elsewhere, particularly south of the Tampa Bay area. As in other parts of the state, many areas of this habitat in the Tampa Bay watershed have been destroyed, and a large portion of what remains has been adversely modified by human activity.

Highly characteristic vertebrates of the sandhills are the gopher tortoise, gopher frog, and southeastern pocket gopher. Also typical of this habitat type are the fence lizard, pine snake, Florida mouse, and Shermans fox squirrel (where mature pines are present).

5.2.2 Pine Flatwoods (Typical Flatwoods)

This pine-dominated association is found in generally flat, poorly drained areas. The soils contain an organic hardpan, located at varying depths below the surface, that impedes water percolation. Flatwoods cover extensive areas and often contain smaller areas of other habitat types such as ponds, marshes, bayheads, or cypress heads. Two major types of pine flatwoods recognized in the study area are the "slash pine (*Pinus elliottii*) flatwoods" and the "longleaf pine (*P. palustris*) flatwoods." The former occur in wetter, poorly drained areas, and the latter in drier sites.

Composition of the pine flatwood understory and ground vegetation is variable. Some examples have both well-developed shrub and ground cover, and others are essentially two-layered communities consisting of the pine overstory and a dense, low ground cover with only occasional shrubs or small trees. All intermediate conditions are found. Major components of the shrub layer are gallberry (*Ilex glabra*), fetterbush (*Lyonia lucida*), saw palmetto (*Serenoa repens*), waxmyrtle (*Myrica cerifera*), and scattered hardwood sprouts and saplings in the overstory (e.g., live oak, water oak—*Quercus nigra*, and laurel oak—*Q. laurifolia*). Diagnostic ground cover species of this association include wire-grasses (*Aristida* spp.), running oak (*Q. pumila*), bunch-grasses (*Andropogon* spp.), elephant's foot (*Elephantopus tomentosus*), black root (*Pterocaulon undulatum*), and various other grasses, forbs, and low shrubs. Much of the rich herbaceous flora exhibits active growth only in the rainy season. A number of the characteristic low shrubs of the drier longleaf pine flatwoods are xeromorphic types.

Pine flatwoods depend upon fire for their maintenance, with slash pine being less tolerant of fire than longleaf. In the absence of fire, succession may proceed in several directions, depending upon the type of pine and site conditions (Monk 1968). The longleaf phase tends to develop into a xerophytic hardwood association, often dominated by live oak, while drier areas of the slash pine phase succeed to mesic hardwoods, and the wetter and more acidic stands to the bayhead association. The longleaf pine that dominated the area's pine forest in the past has been displaced to a large degree by the slash pine. Several factors favor this shift, including harvesting pressure, selective planting of slash over longleaf pine, fire control, and urban growth in the higher and dryer flatwoods areas that are more favored by the longleaf pine.

Pine flatwoods are the most widespread terrestrial vegetative association in Florida and are estimated to have covered half the state before 1900 (FDNR 1975). They are most characteristic of the coastal flatlands physiographic region and are the dominant vegetative association in the Tampa Bay watershed. However, considerable acreage of this association is used as native rangeland or has been converted to improved pasture through intensive drainage. Thus, in many cases the pines remain, but the original native shrubs and ground-cover species have been drastically reduced or eliminated. A significant proportion of the area shown as cropland and pasture and rangeland in Figure 91 is, or was, pine flatwoods. The most common shrubs in these converted or modified pasture lands are saltbush (*Baccharis halimifolia*) and saw palmetto, with waxmyrtle occurring frequently (Cowell et al. 1974). Other common shrubs include dahoon holly (*Ilex cassine*), milk buckthorn (*Bumelia reclinata*), chickasaw plum (*Prunus angustifolia*) and others (Cowell et al. 1974). Wetter sites may have elderberry (*Sambucus simpsonii*) and rattlebox (*Sesbania punicea*). The herbaceous component includes several pipeworts (*Eriocaulon* spp. and *Lachnocaulon* spp.), marsh pink (*Sabatia* spp.), meadow beauty (*Rhexia* spp.), kuntze (*Seymeria pectinata*), bluehearts (*Buchnera floridana*), redroot (*Lachnanthes caroliniana*), tickweed (*Coreopsis leavenworthii*), and a number of sedges and grasses, particularly in the sloughs and at the edges of other wet sites. Epiphytes are sparse, as are vines, although some of the greenbriers (*Smilax* spp.) are sometimes found.

Vertebrates typically associated with pine flatwoods include the box turtle, pine woods snake, brown-headed nuthatch, red-cockaded woodpecker, Bachman's sparrow, and Sherman's fox squirrel. Other common species in this habitat are the pine woods tree frog, oak toad, eastern diamondback rattlesnake, great horned owl, pine warbler, least shrew, cotton rat, and gray fox.

5.2.3 Prairies

Native prairies are level, treeless areas on relatively dry or periodically wet soils. The dry prairie association occurs on sandy soils that are rarely flooded, both as fairly small openings within other vegetation types such as pine flatwoods or hammocks, or as large areas. The dry prairie is essentially a mixed short grass and forb association with scattered saw palmetto and low shrubs. The general aspect and vegetative composition of this association is similar to that of pine flatwoods without the pines. Wiregrasses and broomsedges (*Andropogon* spp.) are abundant, and carpet-grasses (*Axonopus furcatus, A. compressus,* and *Paspalum setaceum*) are also characteristic. Saw palmetto is the most common shrub species, and in some areas, termed "palmetto prairies," it accounts for a major share of the total plant coverage. Other shrubs found in dry prairies include sand live oak (often occurring as thickets), staggerbush, and the blueberry (*Vaccinium myrsinites*).

The most extensive areas of native prairies in the watershed occur in Sarasota and southeastern Manatee counties. Vast areas of these native grasslands have been converted to improved pastures, and this trend is continuing. The best representation of a dry prairie remaining in the region is believed to be in southeastern DeSoto County outside the Tampa Bay watershed.

Dry prairies are the primary natural habitat of several distinctive wildlife species, including the crested (or Audubon's) caracara, the Florida burrowing owl, and Florida sandhill crane. Other prairie species include the box turtle, black racer, turkey vulture, black vulture, common nighthawk, eastern meadowlark, least shrew, hispid cotton rat, eastern harvest mouse, and eastern spotted skunk.

In addition to the more characteristic prairies, areas of brushland consisting of scattered shrubs, usually waxmyrtle, may be found intermixed with areas of weeds or low herbaceous cover. These usually develop in open prairie or pasture land that has not been burned for some time. The dry brushland areas in the watershed vary in size from 0.4 to 0.8 ha. Extensive tracts are present in Charlotte County, east of Charlotte Harbor. The black racer, eastern diamondback rattlesnake, red-tailed hawk, loggerhead shrike, hispid cotton rat, and eastern cottontail commonly occur in these dry brushlands.

5.2.4 Hammocks

Laessle (1942) excludes forest areas that are periodically flooded (swamps) from this category, whereas others (e.g., Carr 1940) have included some associations of this type in the hammock category. Deciduous Forest Land of the USGS system, Other Hardwood Forest of the Florida system, and Davis's (1967) Hardwood Forest correspond to this category. Four types of hammock associations are considered in the following discussion, classified by the dominant tree species and moisture level. These are the live oak hammock, cabbage palm hammock, mesic hammock, and hydric hammock.

a. Live oak hammocks. Live oak hammocks are relatively xeric associations found on well-drained, sandy soils. Live oak is the dominant tree species and bluejack oak, laurel oak, and cabbage palm (*Sabal palmetto*) may occur as subdominants. Cabbage palm may be a codominant or even greatly exceed the oaks in abundance, in which case the association would be classified as Cabbage Palm Hammock, described below. Live oak hammocks are generally rather open. Shrubs are often abundant, but herbaceous ground cover tends to be sparse. Chapman oak, beautybush (*Callicarpa americana*), and southern sumac (*Rhus copallinum*) are typical shrub species of this habitat type. A well-developed litter layer of dry leaves is usually present.

Live oak hammocks in the Tampa Bay area are often found on slightly elevated, better drained soils in pine flatwoods or pasturelands. This habitat type was referred to as xeric hammock by Laessle (1942).

Typical vertebrate species in this association include the squirrel tree frog, southern toad, green anole, black racer, screech owl, blue jay, eastern mole, cotton mouse, and southern flying squirrel.

b. Cabbage palm hammocks. In this hammock type, which occurs on moist, highly organic soils, the cabbage palm dominates in monospecific stands or mixed with other trees, commonly live oak. Understory plants such as shrubs and vines are abundant and wild citrus trees are frequently encountered. Cabbage palm hammocks vary greatly in size, ranging from small, isolated patches of a few trees to extensive tracts covering several hundred hectares. Within the Tampa Bay watershed, cabbage palm hammocks are particularly characteristic of the prairie regions. Representative vertebrates of this association include the squirrel tree frog, rat snake, Carolina wren, fish crow, cotton mouse, and raccoon.

c. Mesic hammocks. These are hammock associations intermediate in moisture conditions between the driest (live oak hammock) and the wettest (hydric hammock) type. The soil is rich in organic matter, with considerable water-holding capacity. Typical tree species of this association in the watershed include laurel oak, pignut hickory (*Carya glabra*), water oak, redbay (*Persea borbonia*), and occasionally sweetgum (*Liquidambar styraciflua*) in wetter areas. Characteristic shrubs of this association include saw palmetto, beautybush, and sparkleberry (*Vaccinium arboreum*). Such vines as greenbrier (*Smilax* spp.), Virginia creeper (*Parthenocissus quinquefolia*), and muscadine grape (*Vitis rotundifolia*) are common. This is considered to be the climax vegetation in north-central Florida (Laessle 1942).

Common vertebrates of mesic hammocks include the southern toad, green anole, pileated woodpecker, great crested flycatcher, red-eyed vireo, gray squirrel, and cotton mouse.

d. Hydric hammocks. Laessle (1942) excludes forest areas (swamps) that are periodically flooded from this category, whereas others (e.g., Carr 1940) have included some associations of this type in the hammock category. Deciduous Forest Land of the USGS system, Other Hardwood Forest of the Florida system, and Davis' (1967) Hardwood Forest correspond to this category.

Hydric hammocks occur on wet, poorly drained soils. Typical trees include swamp bay (*Persea palustris)*, water oak, sweetgum, laurel oak, and Florida elm (*Ulmus americana* var. *floridana)*. Vines are often common; waxmyrtle and saw palmetto are frequently present. Herbaceous plants, though relatively sparse, include various fern species and lizard's tail (*Saururus cernuus)*. This hammock type often occurs along rivers and stream courses in the watershed. Excellent examples may be seen on the Pithlachascottee and Anclote rivers in Pasco County; on the Hillsborough, Alafia, and Little Manatee Rivers in Hillsborough County; and on the Manatee River in Manatee County. Typical vertebrates of this association include the green tree frog, southern leopard frog, red bellied woodpecker, and cotton mouse.

5.3 Freshwater Wetland Habitats

Freshwater wetlands in the Tampa Bay watershed are divided here into three categories based on a combination of the degree of inundation and the type of vegetation dominating the site. The three categories are cypress, hardwood and mixed swamp forest; wet prairies, marshes and sloughs; and lakes, ponds, and rivers.

These various wetland habitats are not totally independent of one another. The major inland freshwater swamps and marshes (especially cypress sloughs) are interconnected by a complex system of streams and creeks that gradually coalesce to form the riverine systems eventually leading to the estuary. Many lakes and ponds in the study area are bordered by or, in times of extreme drought, may phase into wetland swamps and prairie habitat associations.

5.3.1 Swamp Forests

These communities are tree-dominated wetlands found along rivers and edges of lakes and in basins that are seasonally or periodically flooded. As noted previously, hydric hammocks are sometimes included in this category. Bay forests also are often classified as swamps, but because of their rather distinctive characteristics, they are here considered as a separate forested wetland type. At least four major types of forested swamps can be recognized in the study area: hardwood swamps; cypress swamps; mixed cypress-hardwood swamps; and bay forests.

In the study area, bottomland hardwood swamps have been only cursorily studied. The major emphasis has been on documenting species composition at various locations for permit application purposes

(Conservation Consultants, Inc. 1975; TI 1978c; Ardaman and Associates et al. 1979) or assessments for water and wildlife management areas (Cowell et al. 1974; Rochow 1976; Rochow and Bartos 1978). The dynamics of ecological structures and functioning of floodplain hardwood swamps of the southeast have been summarized by Wharton et al. (1982). Cypress dome and strand ecology has been summarized by Odum et al. (1976), Wharton et al. (1977), and Brown (1981), based primarily on information from outside the area.

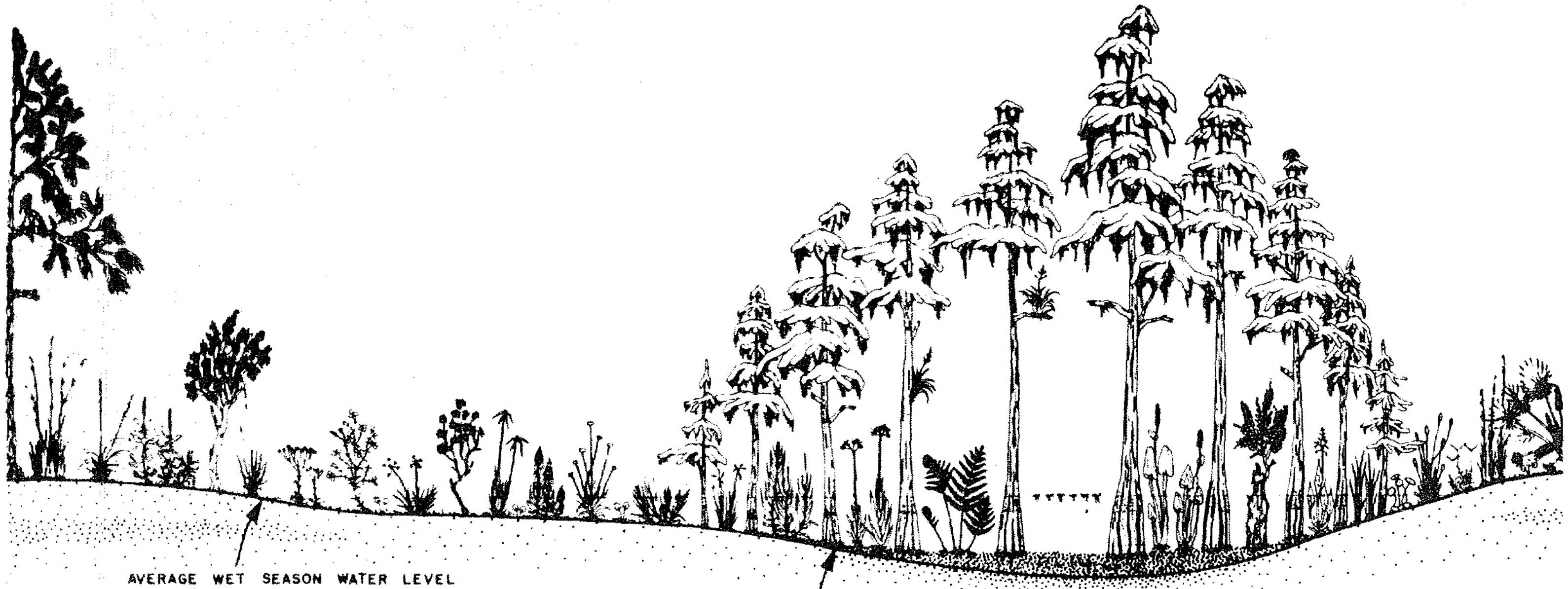
a. Hardwood swamps. This association is made up of a mixture of broad-leaved deciduous species, commonly including red maple (*Acer rubrum*), water oak (*Quercus nigra*), blackgum (*Nyssa biflora*), water hickory (*Carya aquatica*), and popash (*Fraxinus caroliniana*). Baldcypress (*Taxodium distichum*) is a minor element. Typical understory species of hardwood swamps include buttonbush (*Cephalanthus occidentalis*), waxmyrtle (*Myrica cerifera*), and Virginia willow (*Itea virginica*). Herbaceous vegetation tends to be sparse, often allowing large areas of mud to be exposed during dry periods. Lizard's tail, smartweed (*Polygonum punctatus*), pennywort (*Hydrocotyle umbellata*), and various grasses and sedges are among the typical ground cover species.

Hardwood swamps generally occur along rivers and streams and in overflow areas of lakes. Along the banks of the Hillsborough River, especially in the upper reaches in the northern part of Hillsborough County, water oak, cypress, and cabbage palmetto are very abundant. In the south of the county along the banks of the Little Manatee River, southern red cedar, red maple, bay, sweetgum, and cypress flourish. Ecologically, the hardwood swamp is an important floodplain component that effectively moderates river flow in times of flooding and promotes favorable water-quality characteristics. In all seasons of the year these areas stand out as some of the verdant portions of the landscape and support an abundance of fish and wildlife (Chapter 6).

b. Cypress swamps. These forested wetlands are dominated by baldcypress or pond cypress (*Taxodium distichum* var. *nutans*). The former is typical of cypress swamps along rivers, sloughs, lagoons, and lakes, while the latter is characteristic of the symmetrical, dome-shaped cypress swamps known as "cypress heads" or "cypress domes" located in depressions in pine flatwoods or wet prairies. Figure 92 shows a typical cypress dome with associated plants leading through a wet prairie to a pine flatwoods habitat. The shape appears to be a function of localized site factors, such as a small basin overlying a hardpan compounded by the effects of fire. At the periphery of these communities, unfavorable soil conditions tend to limit the growth rate of trees, making them generally smaller than those toward the center (Harper 1927). This effect is augmented by periodic fires and recurring droughts and floods, which tend to remove the more stressed peripheral trees. The net result is to create a younger age class of trees in a suboptimal growth medium at the edges of the community (Kurz and Wagner 1953; Duever et al. 1975).

Previously subject to harvesting, land clearing, and fire pressures, very few large cypress trees (> 60 cm diameter at breast height) remain in the Tampa area. There are some young, pure stands that date from the last period of clearcutting activities (Cowell et al. 1974). In purer stands, a dense, single-layer canopy is supported with straight, unbranched trunks that rise from bare ground or from permanent waters. Associated hardwood trees common to most sites in the Hillsborough drainage basin include popash and red maple. Sweetgum (*Liquidambar styraciflua*), blackgum, water hickory, and blue beech (*Carpinus caroliniana*) frequently occur as well. Understory trees and shrubs such as willow (*Salix* sp.), buttonbush, stiffcornel dogwood (*Cornus foemina*), and Florida privet (*Forestiera ligustrina*), appear in canopy breaks and along the swamp forest periphery. Epiphytic Spanish moss (*Tillandsia* sp.) is common in the tree canopy where some light penetrates. Herbaceous species associated with this habitat include royal fern (*Osmunda regalis*), smartweed (*Polygonum* sp.), pennywort (*Hydrocotyle* spp.); various sedges and grasses, pickerelweed (*Pontederia cordata* var. *lanceolata*), arrowhead (*Sagittaria* spp.), and occasionally, sawgrass (*Cladium jamaicense*).

c. Mixed cypress-hardwood swamps. As the name suggests, this association contains a mixture of



A. *Pinus palustris* (longleaf pine)
B. *Schizachyrium stoloniferum* (creeping bluestem)
C. *Aristida stricta* (wire grass)
D. *Pterocaulon pycnostachyum* (blackroot,)
E. *Myrica cerifera* (wax myrtle, bayberry)
F. *Aristida affinis* (longleaf three-awn)
G. *Bigelowia nudata* (yellowhead)
H. *Rhexia mariana* (pale meadow beauty)
I. *Cyperus* spp. (sedge)
J. *Hypericum fasiculatum* (St. John's wort)
K. *Dichromena colorata* (whitetop sedge)
L. *Amphicarpum muhlenbergianum* (blue maidencane)
M. *Eriocaulon decangulare* (common pipewort)
N. *Panicum repens* (torpedograss)
O. *Crinum americanum* (strap lily, swamp lily)
P. *Panicum hemitomon* (maidencane)
Q. *Lachnanthes caroliniana* (redroot)
R. *Woodwardia virginica* (chain fern)
S. *Taxodium ascendens* (pond cypress)
T. *Lemna* spp. (duckweed)
U *Pontederia cordata* (pickerelweed)
V *Lyonia lucida* (fetterbush)
W. *Sagittaria lancifolia* (duck-potato, arrowhead)
X. *Cladium mariscoides* (narrowleaf sawgrass)
Y. *Hydrocotyle umbellata* (water pennywort)
Z *Xyris* spp. (yellow-eyed grass)
AA *Axonopus affinis* (carpet grass)
BB. *Andropogon capillipes* (chalky bluestem)
CC. *Serenoa repens* (saw palmetto)

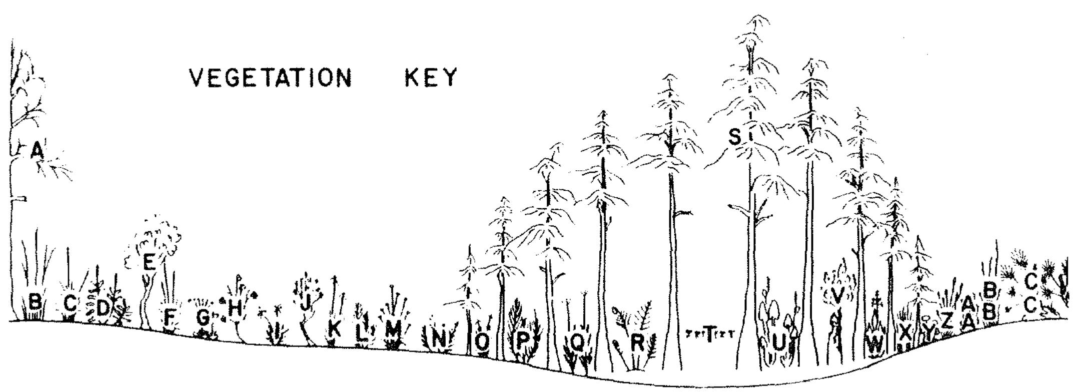


Figure 92. Typical cypress dome with associated plants (Coordinating Council on the Restoration of the Kissimmee River Valley and Taylor Creek-Nubbin Slough Basin1978).

cypress, various hardwoods, and occasionally southern red cedar (*Juniperus silicicola*). The canopy is moderately high (to 20 m), closed to open, with dense shrub and herbaceous layers in canopy breaks and along the periphery. The common tree species are water oak and laurel oak (*Quercus laurifolia*), sweetgum, ironwood (*Bumelia lycioides*), water hickory, Florida elm (*Ulmus americana* var. *floridana*), red maple, black gum, and popash. In more open sites, particularly those near rivers or long-lasting ponds, water locust (*Gleditsia aquatica*), cabbage palm (*Sabal palmetto*), southern red cedar, or southern magnolia (*Magnolia grandiflora*) may become prominent.

The understory shrubs and herbaceous plants are very diverse, although their occurrence is patchy through the swamp forest (Cowell et al. 1974). Common and fairly generally distributed shrubs are Florida-privets (*Forestiera* spp.), waxmyrtle, blackhaw (*Viburnum obovatum*), buttonbush, stiffcornel dogwood, strawberry-bush (*Euonymus americana*), gallberry (*Ilex glabra*), hawthorn (*Crataegus* spp.), and chickasaw plum (*Prunus angustifolia*). Strap lily (*Crinum americanum*) and several ferns (*Osmunda* spp., *Thelypteris* spp., and *Woodwardia* spp.) are locally frequent. Resurrection fern (*Polypodium polypodioides*) is widespread on branches and trunks with no apparent restriction as to the trees on which it grows. A related species, *Polypodium plumula*, is less common but spectacular where it occurs (i.e., portions of the Hillsborough River system), drooping from trees over the river. All five of the local species of air plants (*Tillandsia*) are epiphytic in this community, as are the orchids *Encyclia tampensis* and *Epidendrum conopseum*. Another tiny epiphytic orchid, *Harrisella porrecta*, is found close to the water on large *Juniperus*.

The various types of freshwater swamps described above provide a haven for a variety of animals which often hunt or forage in the surrounding open waters, flatwoods, and open pasturelands. Common vertebrates of various types of swamps include the green tree frog, squirrel tree frog, ground skink, American alligator, barred owl, limpkin, wood duck, red-shouldered hawk, river otter, gray squirrel, raccoon, and opossum.

d. Bay forests. This association occurs on wet, acidic, highly organic soils that are often seasonally flooded. Although bay forests are often classified as swamps, water-level fluctuations are not as dramatic as those in more typical swamps.

Bay forests are dominated by three broad-leaved evergreen species, loblolly-bay (*Gordonia lasianthus*), redbay (*Persea borbonia*), and sweet bay (*Magnolia virginiana*). These trees are generally similar in appearance and growth form. Occasional slash pines remain on higher sites as relics from an earlier successional stage. The trees of the bay forest usually form a dense stand with complete canopy, so that the interior is very humid and deeply shaded. Shrubby undergrowth, usually best developed in a zone at the edge of the bay forest, consists primarily of waxmyrtle, gallberry, and fetterbush. Herbaceous vegetation tends to be sparse in the interior because of the shady conditions.

Bay forests usually occur as "bayheads" in depressions in pine flatwoods or at the margins of the flatwoods ponds. They develop from marshes, low pine flatwoods, and swamps, particularly cypress heads, through stages involving accumulation of organic matter (Davis 1943). According to Laessle (1942) and Monk (1968), under improved drainage conditions bay forests succeed toward hydric hammock associations.

Bay forest, mainly in the form of bayheads, is found throughout the Tampa Bay watershed, although it is seldom very extensive. It is the primary habitat of the southeastern shrew, one of the rarest vertebrates in the area. The yellow-billed cuckoo, Carolina wren, blue-gray gnatcatcher, short-tailed shrew, and cotton mouse are other common inhabitants of bay forests.

5.3.2 Wet Prairies and Marshes

a. Wet prairies. These open, mixed grass-forb associations occur in areas subject to periodic flooding. The distinction between wet prairies and marshes is somewhat arbitrary, but wet prairies are usually dominated by shorter grasses as opposed to the taller grasses, sedges, rushes, and broad-leaved aquatic species of typical marshes and tend to be drier for a greater part of the time (Davis 1943). The general appearance of the prairie is that of an overgrown field. The two types often grade into each other without a distinct line of demarcation, and one may encompass the other.

Soils in wet prairies are commonly mineral and organic alluvial, level, and poorly drained, with coarse-textured surfaces underlain by clay or sand (Brown and Starnes 1983). A thick organic layer is often present, giving the soils a high water-holding capacity. These soils retard runoff, providing valuable water storage and often improving the quality of the water leaving the site. Fire and artificial water-level fluctuations (common in flood control areas) are the major factors affecting these areas. Variations in the natural sequence of either event change the prairies' diversity and productivity (Brown and Starnes 1983). Exclusion of fire or permanent water-level reduction lead the plant succession to a wooded community of pine flatwoods or hardwoods.

Characteristic species of wet prairies include maidencane (*Panicum hemitomon*), cordgrass (*Spartina bakeri*), beak-rushes (*Rhynchospora* spp.), St. John's wort (*Hypericum* spp.), and yellow-eyed-grass (*Xyris ambigua*). Wet prairies are found frequently throughout the region, but are probably most extensive in the general grasslands areas of the Osceola and DeSoto Plains (Layne et al. 1977). Figure 93 shows the many plant species of this association found along a typical water-level gradient from wet prairie to submerged slough.

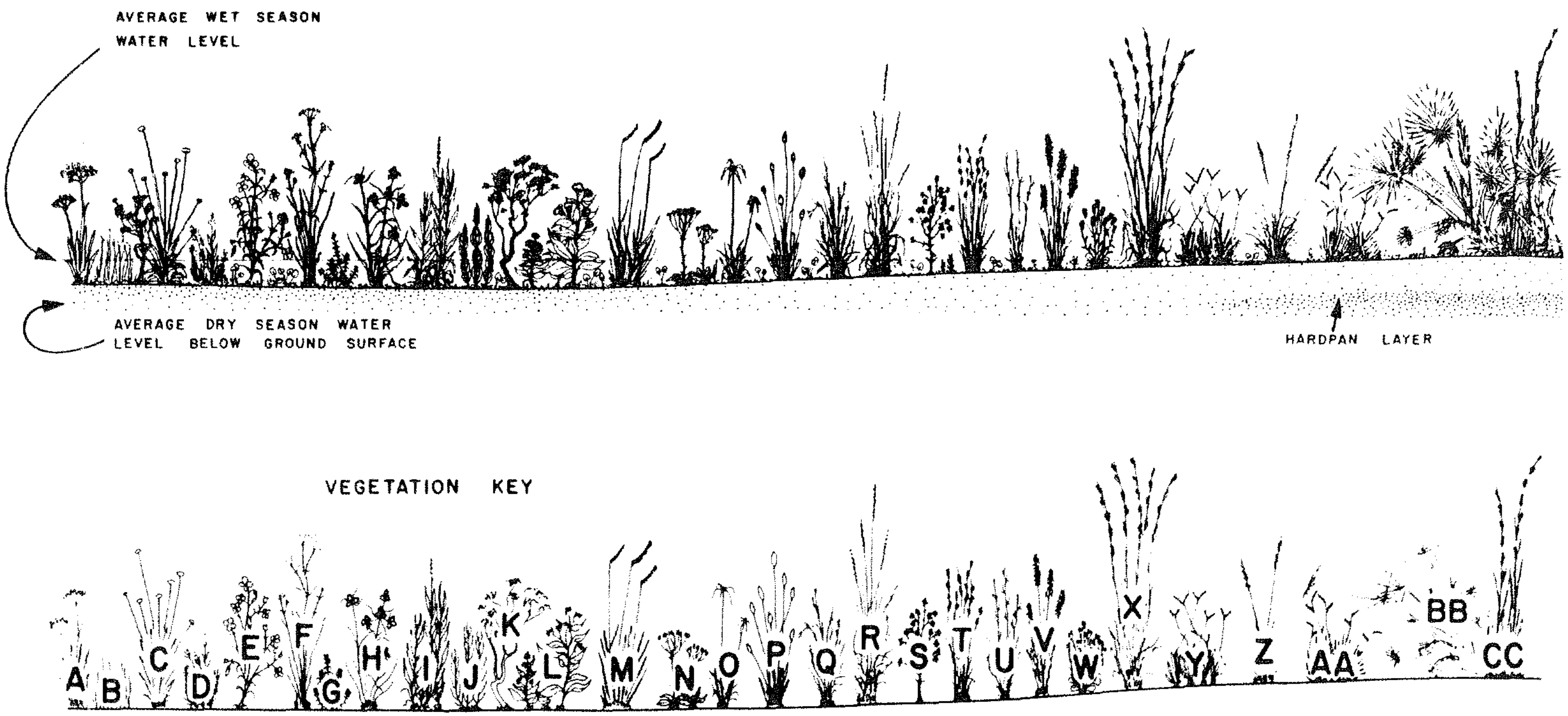
A number of species of wading birds forage in wet prairies when water is present. The ribbon snake, pygmy rattlesnake, hispid cotton rat, and marsh rabbit are prominent. When water levels permit, the round-tailed muskrat also inhabits this association.

b. Marshes. Marsh associations consist of grasses, sedges, rushes, and various other herbaceous species growing in areas continually or periodically flooded. As noted above, the distinction between marshes and wet prairies is a rather subtle one; thus the two associations are often considered as a single unit. Freshwater marshes are located along or in rivers, streams, canals, ditches, standing water bodies, or depressions removed from permanent water sources. They grow on many types of soils ranging from fine sands to the highly organic mucks and peats. A wide variety of plant species is associated with marsh habitats, the species composition of a particular type of marsh depending upon a variety of influences, including soil type, hydroperiod, water depth, and successional stage. Vegetation within a particular marsh is also often zoned in response to water depth and other factors. Figure 94 shows some of the marsh plant species associated with this habitat type. Characteristic marsh species include maidencane species, pickerelweed (*Pontederia cordata*), cattail (*Typha* spp.), bulrush (*Scirpus* spp.), smartweed (*Polygonum* spp.), arrowhead (*Sagittaria lacifolia*), fire flag (*Thalia geniculata*), sawgrass species, rushes (*Juncus* spp.), and redroot (*Lachnanthes caroliniana*). Floating or submerged aquatic species may reside in deeper and more permanently flooded parts of the marsh. Although herbaceous plants dominate in marshes, woody species such as willow, buttonbush, and blackgum are often present.

The transition zone between marshes and swamps is typically brushy. Marsh succession in the watershed proceeds toward bay forest or swamp via a swamp thicket stage. Examples of some of the types of marshes in the Tampa Bay watershed, based on the most prevalent species, include cattail marsh, bulrush marsh, flag marsh (dominated by pickerelweed), sawgrass marsh, cordgrass or switchgrass marsh, maidencane marsh, and spikerush or needlegrass (*Eleocharis* spp.) marsh. There is a broad range of intergradation between these and other marsh types, and several types may be found in different parts of the same marsh, forming a mosaic of vegetation types.

Marshes provide a habitat for several vertebrates, including the greater siren, southern cricket frog, pig frog, American alligator, banded water snake, red-winged blackbird, common snipe, sora rail, marsh rice rat, and round-tailed muskrat. Marshes also provide critical nesting areas for the Florida sandhill crane.

Morris and Miller (1977) describe two particularly extensive areas of marsh, wet-prairie, and thicket



A. Lachnanthes caroliniana (redroot)
B. Eleocharis spp. (needle grass, spikerush)
C. Eriocaulon decangulare (common pipewort)
D. Panicum spp. (panic grass)
E. Rhexia cubensis (Florida meadow beauty)
F. Oxypolis filiformis (water dropwort)
G. Diodia virginiana (diodia)
H. Fuirena squarrosa (umbrella-grass)
I. Panicum hemitomon (maidencane)
J. Amphicarpum muhlenbergianum (blue maidencane)
K. Hypericum fasciculatum (St. John's wort)
L. Pluchea foetida (stinking fleabane)
M. Ctenium floridanum (Florida toothache grass)
N. Bigelowia nudata (yellowhead)
O. Dichromena colorata (white-top-sedge)
P. Xyris elliottii (yellow-eyed-grass)
Q. Panicum tenerum (bluejoint panic grass)
R. Aristida affinis (long-leaf three-awn)
S. Sabatia spp. (marsh pink)
T. Andropogon longiberbis (hairy bluestem)
U. Manisuris tuberculosa (Florida joint-tail
V. Aristida spiciformis (bottle-brush three-awn)
W. Polygala ramosa (yellow candyweed)
X. Andropogon capillipes (chalky bluestem)
Y. Axonopus spp. (carpet grass)
Z. Aristida stricta (pineland three-awn)
AA. Paspalum spp. (paspalum)
BB. Serenoa repens (saw palmetto)
CC. Schizachyrium stoloniferum (creeping bluestem)

Figure 93. Typical wet prairie with associated plants (Coordinating Council on the Restoration of the Kissimmee River Valley and Taylor Creek-Nubbin Slough Basin1978).

A. *Cladium jamaicense* (sawgrass)
B. *Typha* spp. (cattail)
C. *Thalia geniculata* (arrowroot, fire flag)
D. *Sagittaria lancifolia* (arrowhead)
E. *Pontederia cordata* (pickerelweed)
F. *Panicum hemitomon* (maidencane)
G. *Scirpus validus* (great bulrush)
H. *Cyperus* spp. (sedge)
I. *Hypericum fasciculatum* (St. John's wort)
J. *Eleocharis* spp. (needle grass, spikerush)
K. *Dichromena colorata* (white-top-sedge)
L. *Eriocaulon decangulare* (pipewort)
M. *Panicum* spp. (Panic grass)
N. *Xyris elliottii* (yellow-eyed-grass)
O. *Centella asiatica* (coinwort)
P. *Andropogon* spp. (bluestem)
Q. *Paspalum* spp. (paspalum)
R. *Serenoa repens* (saw palmetto)
S. *Aristida stricta* (pineland three-awn)
T. *Pinus* spp. (pine)

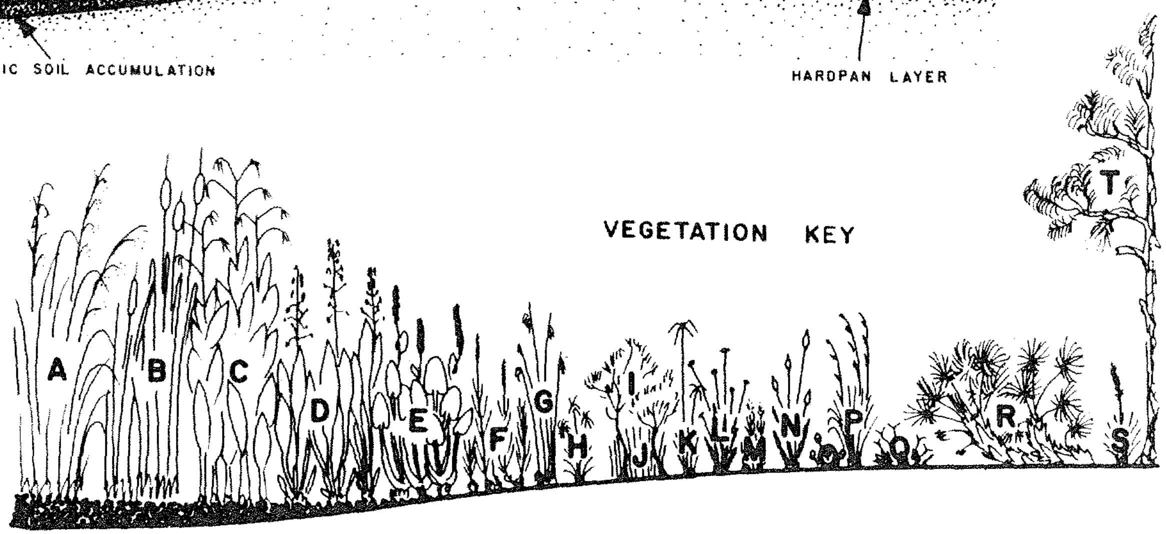


Figure 94. Typical freshwater marsh with associated plants (Coordinating Council on the Restoration of the Kissimmee River Valley and Taylor Creek-Nubbin Slough Basin1978).

vegetation along the southeast border of the watershed, primarily in the Myakka River Basin—the Tatum Sawgrass and the Flatford Swamp. In the latter area, which is surrounded by pine flatwoods and dry prairies, eight habitats were identified. Together, these eight habitats encompass nearly the full range of wetland successional stages found in south central Florida. At the edge of the swamp, as conditions gradually become wetter, pine flatwoods and dry prairies are replaced by oak hammocks, predominantly laurel oak (*Quercus laurifolia).* Farther into the swamp, wet-prairie vegetation characterized by iris (*Iris hexagona* var. *savannarum),* marsh fleabane (*Pluchea purpurascens),* sawgrass (*Cladium jamaicense),* water purslane (*Ludwigia repens),* and tickseed (*Coreopsis gladiata)* is found. A thin line of red maple (*Acer rubrum)* and waxmyrtle (*Myrica cerifera)* is often located at the transition from pinelands to wet prairie. Popash (*Fraxinus caroliniana)* dominates over the wet prairie/marsh in many areas, forming a canopy 8–15 m high. Relatively open freshwater ponds vegetated by pickerelweed (*Pontederia cordata* var. *lanceolata),* smartweed (*Polygonum densiflorum),* and water purslane may also be found surrounded by stands of popash. Often a dense thicket of buttonbush (*Cephalanthus occidentalis)* occupies the side of the pond. Deeper within the swamp, closer to the river bed, other hardwoods such as swamp bay (*Persea palustris),* loblolly bay (*Gordonia lasianthus),* black tupelo (*Nyssa sylvatica*), sweetgum (*Liquidambar styraciflua),* red maple, Florida elm (*Ulmus americana* var. *floridana),* dahoon holly (*Ilex cassine),* and buckthorn (*Bumelia reclinata* var. *reclinata)* may be found.

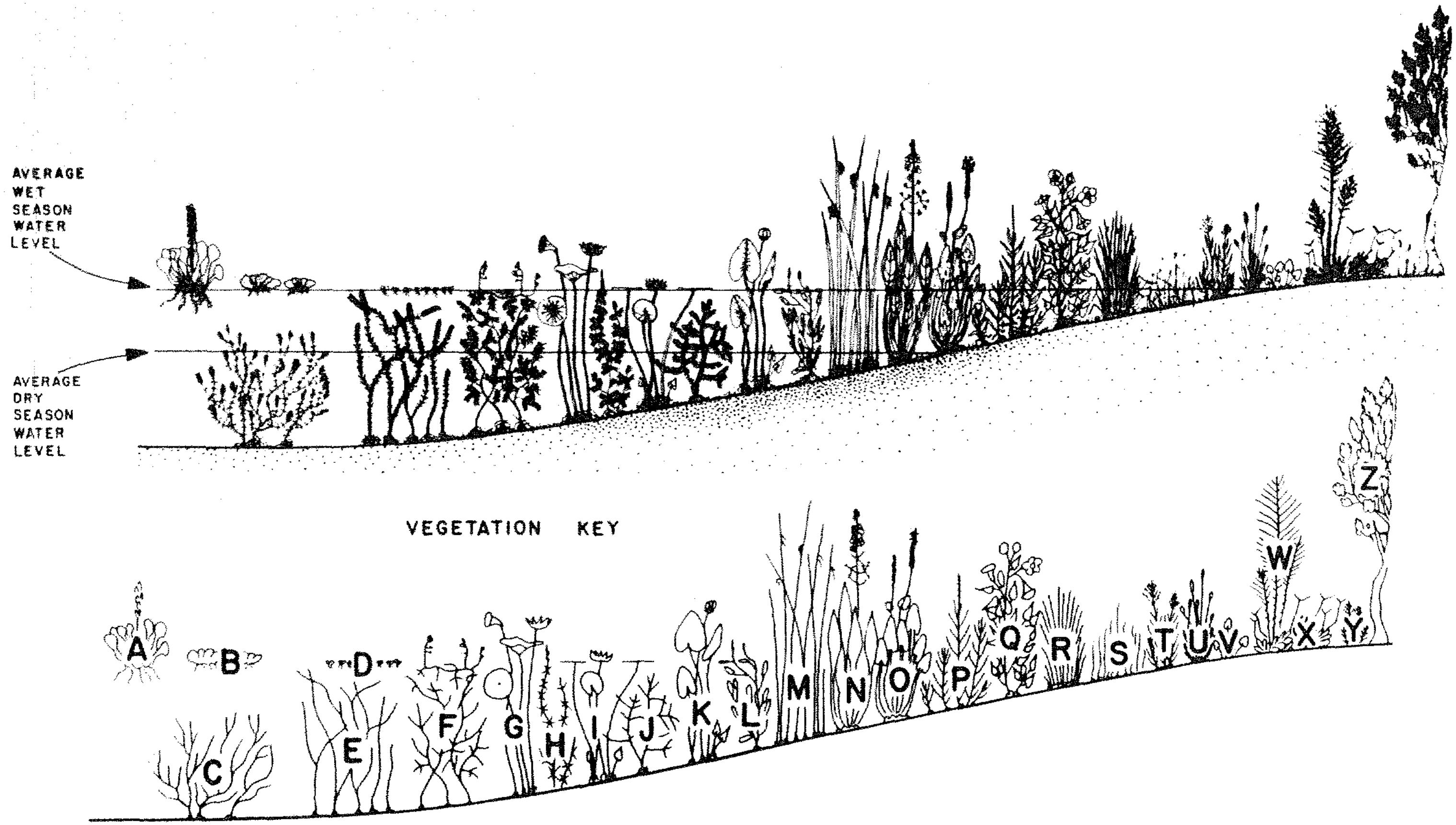
5.3.3 Lakes, Ponds, and Rivers

Permanently inundated freshwater habitats can be divided into two basic categories: flowing (lotic) waters (i.e., rivers, streams, canals, etc.) and static (lentic) waters (i.e., lakes, ponds, artificial impoundments, etc.). Detailed classifications of Florida freshwater ecosystems have been presented by various authors, including Byers (1930), Rogers (1933), Carr (1940), Hobbs (1942), Berner (1950), Herring (1951), and Beck (1965). Of these, Berner's classification is the most detailed. In all the above cases, except Beck (1965), the classification was prepared in connection with the study of a particular taxonomic group of organisms. Beck's (1965) classification was limited to flowing waters and was based on a combination of physical, chemical, and biological criteria. Although a number of ecological surveys conducted within the study area have involved sampling of aquatic habitats, for the most part the general terms lake, pond, river, stream, ditch, etc. have been used to describe these environments. Barnett (1972) described five habitats, based on fish species composition, in the Hillsborough drainage basin. These included a hyacinth (*Eichhornia crassipes)* community, a swift-current community, a narrow-streamlet community, a cypress-swamp community, and an egeria (*Egeria densa)* community.

Algae and aquatic vascular plants are the primary producers in these aquatic systems, converting solar energy and inorganic elements (i.e., carbon, nitrogen, etc.) into organic compounds, which can be utilized by other organisms as food. Additionally, during the day these plants oxygenate the water, thus improving an essential requirement for animal life.

Generally speaking, aquatic vascular plants are restricted to the nearshore or littoral zone in larger (deeper) bodies of water. A typical littoral-zone community is composed of zones of rooted aquatic plants arranged as water depth increases. Starting from the shoreline, the first zone is that of emergent plants that provide a connection between terrestrial and aquatic areas. Examples of plants in this zone are cattail (*Typha),* softrush (*Juncus),* bulrush (*Scirpus),* and spikerush (*Eleocharis).* The next zone consists of floating rooted plants such as lotus (*Nelumbo),* spatterdock (*Nuphar),* and water lilies (*Nymphaea).* Interspersed among these two zones are various forms of free-floating aquatics such as duckweed (*Lemna perpusilla),* water fern (*Salvinia rotundifolia),* water lettuce (*Pistia),* and water-hyacinth. The last zone is that of submerged vegetation. Plants of this area include naiads (*Najas* spp.*),* coontail (*Ceratophyllum),* water-milfoil (*Myriophyllum heterophyllum),* and eelgrass (*Vallisneria* spp.*).*

Figure 95 shows the distribution of aquatic plants across a typical freshwater habitat. Separation of the



A. Eichhornia crassipes (water-hyacinth)
B. Pistia stratiotes (water lettuce)
C. Najas spp. (bushy pondweed)
D. Lemna spp. (duckweed)
E. Hydrilla verticillata (hydrilla)
F. Utricularia spp. (bladderwort)
G. Nelumbo lutea (American lotus)
H. Myriophyllum spp. (water-milfoil)
I. Nymphaea odorata (fragrant water-lily)
J. Ceratophyllum demersum (coontail)
K. Nuphar luteum (spatterdock)
L. Potamogeton spp. (pondweed)
M. Scirpus validus (great bulrush)
N. Sagittaria lancifolia (arrowhead)
O. Pontederia cordata (pickerelweed)
P. Panicum hemitomon (maidencane)
Q. Hibiscus spp. (hibiscus)
R. Juncus effusus (soft rush)
S. Eleocharis spp. (spikerush)
T. Panicum virgatum (switchgrass)
U. Xyris elliottii (yellow-eyed grass)
V. Centella asiatica (coinwort)
W. Eupatorium capillifolium (dog fennel)
X. Axonopus spp. (carpet grass)
Y. Panicum spp. (low panicum)
Z. Myrica cerifera (wax myrtle, bayberry)

Figure 95. Typical freshwater aquatic plant habitat (Coordinating Council on the Restoration of the Kissimmee River Valley and Taylor Creek-Nubbin Slough Basin1978).

aquatic zones is not always obvious and plants characteristic of two different zones may intergrade to provide a more varied habitat than either zone alone. Seasonal variations in temperature, rainfall, light and nutrient availability all affect aquatic plant growth and influence the time and location at which different species reach their peak abundance. A listing of vascular aquatic plants commonly found in lentic (standing) and lotic (flowing) water systems within the Tampa Bay watershed is provided in Tables 21 and 22, respectively.

Increased nutrient loads and the introduction of exotic aquatic macrophytes such as *Hydrilla* have contributed to the development of excessive growths of aquatic macrophytes in many water courses and area lakes. These growths may seriously interfere with domestic, agricultural, industrial, and recreational activities. Monocultures of *Hydrilla* cover up to 64% of the surface area of some Tampa Bay watershed lakes (Schardt and Nall 1982). This species and other exotics (e.g., water-hyacinths, torpedograss) restrict water flow, hinder navigation and the operation of water-control structures, and reduce floral and faunal diversity.

a. Lakes. Lakes are most abundant in the northern part of the watershed, particularly in the Land-O-Lakes region of northeast Hillsborough County and in north-central Pasco County. These lakes are frequently bordered by large areas of marsh and wet prairie vegetation. In some of the lakes, a narrow fringe of mixed swamp forest lies between open water and herbaceous marsh and prairie (McPherson 1979). Because the soils in the area are typically well drained, many of the lake margins, as well as the uplands between lakes, have been converted into citrus groves. Where phosphate deposits have been mined, lake-fringing marshes have been diked and reduced in size. Finally, since lakes represent prime real estate for residential use, many lake borders have been developed. The ecological condition of any one lake in this area depends heavily upon its surrounding land-use configuration, its land-use history, and the intensity of land use and hydrologic modifications. Other important factors that affect vegetative cover in a given lake are water levels, intraspecific competition, weed control, and nutrients.

One of the better studied lakes in the area with respect to vegetative communities is Lake Tarpon, a relatively large lake (1,036 ha) located in northern Pinellas County. Typical of many Florida lakes, it is relatively shallow, with a mean depth of 2.7 m and a maximum natural depth of 4.6 m. In order to enhance the multiple water-resource potential of the lake (i.e., recreation, natural-resource maintenance, and water supply) a water-level fluctuation schedule was adopted by the SWFWMD in 1972, along with a monitoring program to assess the effects of the schedule on lake limnology. A major portion of the environmental monitoring effort was vegetation sampling of the aquatic and littoral plant communities of the lake (Bartos et al. 1977, 1978). Discussion of various other aspects of the lake's limnology can also be found in Taylor (1953), Chapman (1974, 1975), Courser et al. (1974), Dooris (1975), Bartos (1976a,b) and Bartos et al. (1977).

Cattails (*Typha* sp.), eelgrass (*Vallisneria neotropicalis*), and water-hyacinth were the three dominant aquatic plants in the lake. Other common species included southern naiad (*Najas quadalupensis*), water fern, coontail (*Ceratophyllum demersum*), water-milfoil, torpedograss (*Panicum repens*), water pennywort (*Hydrocotyle umbellata*), smartweed (*Polygonum hydropiperoides*), swamp lily (*Crinum americanum*), sawgrass (*Cladium jamaicense*), water hyssop (*Bacopa monnieri*), waterfern (*Ceratopteris pteridoides*), spikerush (*Eleocharis* spp.), and duckweed. Although changes in vegetative cover and diversity were noted following the 1-in-5-year drawdown, species composition and abundance appeared to recover rapidly (Bartos et al. 1978).

A total of 93 algal genera were found in Lake Tarpon. The Chlorophyta (green algae) and Chrysophyta (yellow algae-diatoms) dominated with 45 and 31 genera respectively. Other groups represented were the Cyanophyta (9 genera), the Euglenophyta (4 genera), the Pyrrophyta (3 genera), and the Cryptophyta with a single genus. Diversity of algal genera fluctuated seasonally (Figure 96) with either the Chrysophyta (primarily Bacillariophyceae) or the Chlorophyta dominating. The types of algae found in Lake Tarpon are considered indicative of oligotrophic or mesotrophic lake conditions (Hutchinson 1967).

Table 21. Typical lentic aquatic vascular plants in the Tampa Bay watershed (adapted from TI 1978b).

Species	Species
Water-hyacinth (*Eichhornia crassipes*)	Water-pennywort (*Hydrocotyle* spp.)
Hydrilla (*Hydrilla verticillata*)	Bladderwort (*Utricularia* spp.)
Floating heart (*Nymphoides aquatica*)	Hedge hyssop (*Gratiola* spp.)
Watergrass (*Hydrochloa caroliniensis*)	Water hyssop (*Bacopa* spp.)
St. John's wort (*Hypericum myrtifolium*)	Elodea (*Elodea* spp.)
Panic grass (*Panicum* spp.)	Aquatic moss (*Fissideus* spp.)
Cattail (*Typha* spp.)	Water-lettuce (*Pistia stratiotes*)
Arrowhead (*Sagittaria* spp.)	Parrot-feather (*Myriophyllum brasiliense*)
Spikerush (*Eleocharis* spp.)	Eurasian watermilfoil (*M. spicatum*)
Duckweed (*Lemna* spp.)	Arrow arum (*Peltandra* spp.)
Pickerelweed (*Pontederia cordata* var. *lanceolata*)	American frog's-bit (*Limnobium spongia*)
Rushes (*Juncus* spp.)	Mosquito fern (*Azolla caroliniana*)
Smartweed (*Polygonum* spp.)	Water fern (*Salvinia rotundifolia*)
Water lily (*Nymphaea* spp.)	Swamp fern (*Blechnum serrulatum*)
Spatter-dock (*Nuphar luteum*)	Cordgrass (*Spartina bakeri*)
Primrose (*Ludwigia* spp.)	

Table 22. Typical lotic aquatic vascular plants in the Tampa Bay watershed (adapted from TI 1978b).

Species	Relative[a] abundance	Species	Relative[a] abundance
Water-hyacinth (*Eichhornia crassipes*)	C	Arrowhead (*Sagittaria* spp.)	O
Rushes (*Juncus* spp.)	C	Water-lettuce (*Pistia stratiotes*)	O
Panic grass (*Panicum* spp.)	C	Alligator weed (*Alternanthera philoxeroides*)	C
Smartweed (*Polygonum* spp.)	C	Widgeon-grass (*Ruppia maritima*)	C
Pickerelweed		Watergrass (*Hydrochloa caroliniensis*)	U
(*Pontederia cordata* var. *lanceolata*)	O	Shoal grass (*Halodule* spp.)	C
Yellow water-lily (*Nymphaea mexicana*)	O	Bulrush (*Scirpus* spp.)	C
Water pennywort (*Hydrocotyle umbellata*)	C	Dock (*Rumex* spp.)	C
Duckweed (*Lemna* spp.)	C	American frog's-bit (*Limnobium spongia*)	O
Water primrose (*Ludwigia palustris/repens*)	A	Cape weed (*Lippia nodiflora*)	O
Primrose willow		Thalia (*Thalia geniculata*)	U
(*Ludwigia octovalvis/peruviana*)	A	Water hyssop (*Bacopa monnieri*)	O
Eel-grass (*Vallisneria americana*)	C	Wild orchid (*Habenaria* sp.)	O
Bushy pondweed (*Najas* spp.)	C	Floating heart (*Nymphoides* sp.)	O
Water fern (*Salvinia rotundifolia*)	O	Baby tears (*Micranthemum umbrosum*)	O
Aquatic moss (*Leptofictyum* spp.)	P	Bog moss (*Mayaca* sp.)	U
Pondweed (*Potamogeton* spp.)	C		

[a] A - Abundant; U - Uncommon; C - Common;
P - Present, but with no indication of abundance; O - Occasional occurrences

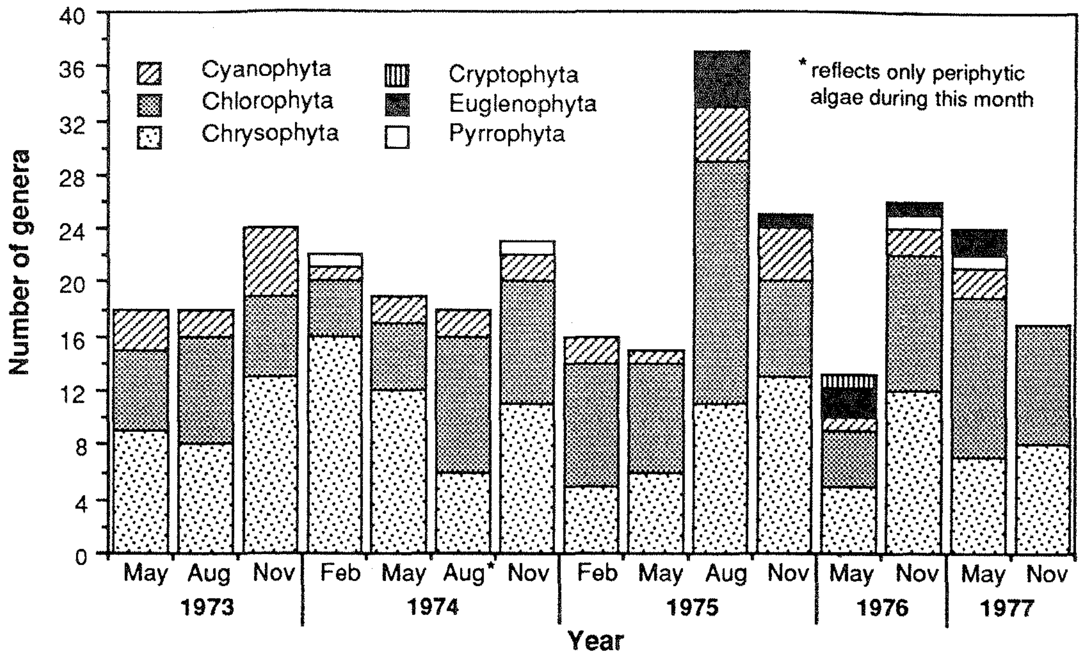


Figure 96. Seasonal variation of periphytic algal genera in Lake Tarpon, 1973–1977 (after Bartos et al. 1978).

This trophic state was also confirmed based on Shannon and Brezonik's (1972) system of quantitative parameters used to classify many Florida lakes.

b. Ponds. Numerous types of ponds occur throughout the study area. Some may be relatively permanent; some may experience pronounced seasonal variations in water levels, but usually contain some water; others may be flooded only during unusually wet years. True aquatic vegetation, shown in Table 21, is generally not present in this last type. Periodic drawdowns or water level fluctuations are helpful in eliminating nuisance aquatic plant species and allowing mucky, anaerobic sediments (the result of eutrophication) to consolidate and oxidize. Following drawdowns, flooded habitat conditions greatly improve for native vegetation and fish populations tend to increase.

Ponds with dense aquatic growth, especially maidencane (*Panicum hemitomon)*, may be inhabited by the round-tailed muskrat. Marsh rice rats and marsh rabbits are also common around ponds with dense herbaceous aquatic vegetation. The lesser siren is typical of ponds in pine flatwoods areas. The hooded merganser and many wading and shore birds also have a predilection for pond habitats. Depending upon the permanence, depth, and other features of a pond, fish may be absent to abundant. The mosquitofish, golden topminnow, least killifish, lake chubsucker, and warmouth are common species in native ponds.

Another pond habitat common in the Tampa Bay area is that artificially created for raising tropical fish. In a survey (Drda and Knox 1981), 73% of the 279 aquaculture facilities identified across the state were located in the Tampa Bay watershed. Primarily concentrated in Hillsborough County along the lower drainage basins of the Alafia and Little Manatee rivers (Figure 97), these fish farms provide limited habitat to native vegetation and wildlife due to their structure and conflicting use of raising exotic fish species. Algae and weed control practices and control of fish predators (wading birds, small mammals and reptiles) are often necessary to maintain fishpond production. Swordtails, guppies, and platies are the most common ornamental fish produced in the area.

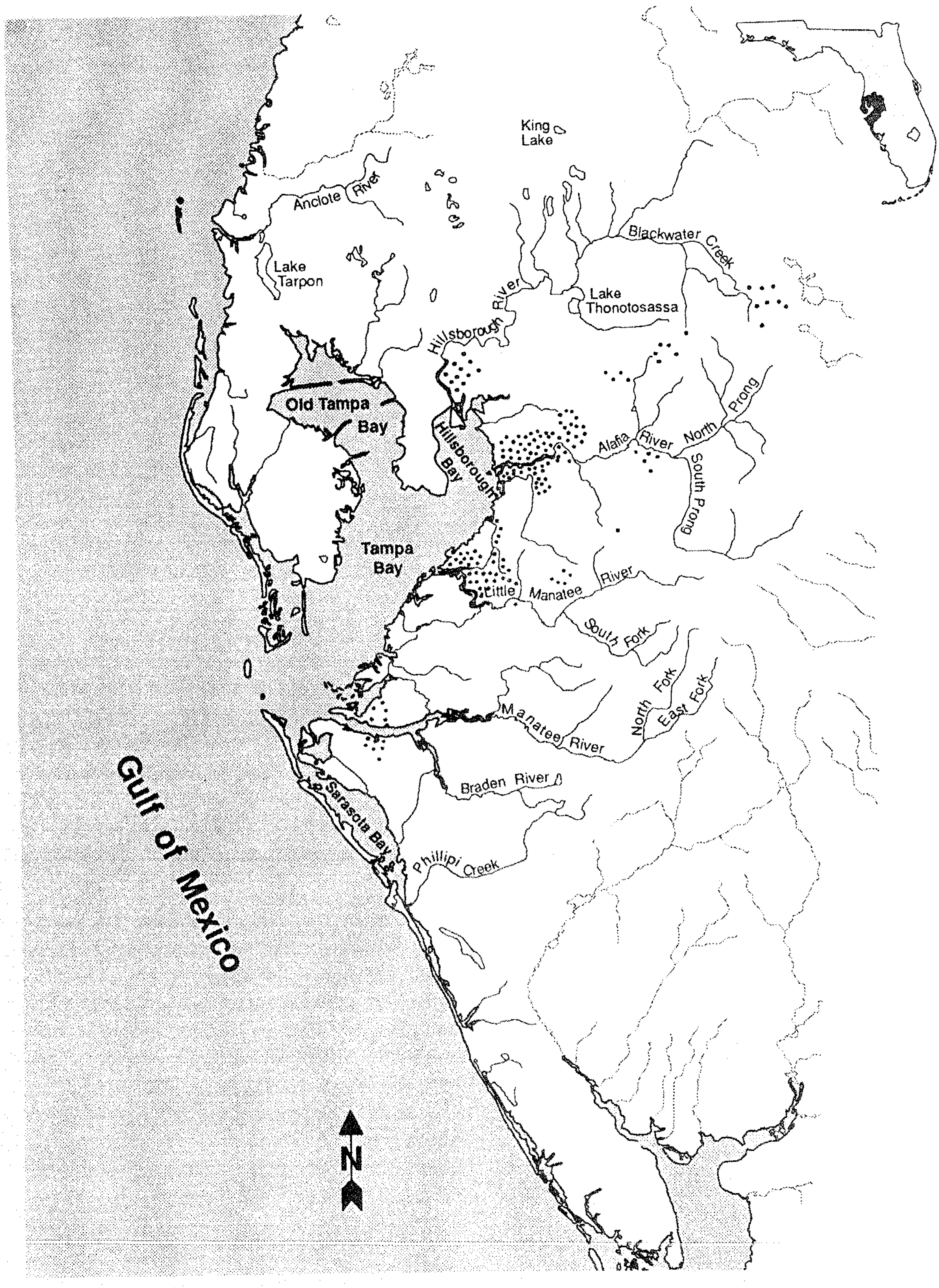


Figure 97. Distribution of fish farms in the Tampa Bay watershed (after Drda and Knox 1981).

c. Rivers and streams. Compared with many regions of Florida, west-central Florida is notable for its number of rivers and streams. These water bodies vary considerably in size, substrate, water quality, flow, and other factors, all of which influence distribution and composition of aquatic vegetation. The larger rivers have continuous flows, whereas smaller streams may be intermittent. Common types of aquatic plants in rivers and streams include pondweeds (*Potamogeton)*, naiads, eelgrass (*Vallisneria americana)*, and water-hyacinth. Table 22 presents a more complete list of the vascular plant species and their relative abundance in lotic environments of the Tampa Bay watershed.

Two river systems in which aquatic habitats have been surveyed are the Alafia and Little Manatee rivers in Hillsborough County. As part of a hydrobiological assessment of these rivers by Dames and Moore (1975), aquatic macrophytes and algae were sampled at selected sites along the course of these two rivers during three seasons (fall, winter, and spring).

Twenty-one species of aquatic macrophytes were collected from the Alafia River, and 16 species from the Little Manatee River (Dames and Moore 1975). Distribution of the various species along the two river courses is presented in Appendix Table A-9. According to their report, densities appeared greater in the Alafia River, although a greater number of water-hyacinths were observed on the Little Manatee. Little seasonal change in species composition or abundance was noted.

In the lower portions of the rivers affected by marine and brackish waters, aquatic macrophytes were essentially absent, and the shoreline was dominated by mangrove swamps near the river mouths and rush and cattail marshes upriver. Water-hyacinth mats were common and most concentrated in the backwaters.

Farther upstream, shallow riffle areas were often heavily covered by aquatic vegetation. Bushy pondweed (*Najas flexilis)* was most abundant here, followed by waterweed (*Elodea canadensis)* and water-milfoil. Shoreline areas were often covered with a dense mat of smartweed (*Polygonum sp.*) and spikerush (*Eleocharis acicularis)*. In waters less than 0.3 m deep, the bryophyte fissideus (*Fissideus* sp.) was abundant. Duckweed often formed dense windrows or mats in the quiet backwaters of the upper river.

Five divisions of phytoplankton were collected during the seasonal sampling periods (Table 23). Diatoms were the dominant forms at all stations in both rivers. Pyrrophyta (dinoflagellates) were also abundant, with highest numbers reported in the marine and brackish waters at the mouths of the rivers. Green algae (Chlorophyta) and euglenoids (Euglenophyta) were more prevalent upriver and seasonally as salinities decreased.

Table 23. Phytoplankton genera collected in the Alafia and Little Manatee Rivers (adapted from Dames and Moore 1975).

Chrysophyta	Chrysophyta (cont.)	Chlorophyta	Cyanophyta
Nitzschia	*Pinnularia*	*Scenedesmus*	*Oscillatoria*
Cymbella	*Surirella*	*Ankistrodesmus*	*Merismopedia*
Navicula	*Bacillaria*	*Oocystis*	*Chroococcus*
Amphora	*Frustulia*	*Tetastrum*	
Eunotia	*Diploneis*	*Mougeotia*	**Euglenophyta**
Synedra	Centric diatoms	*Closterium*	*Euglena*
Gyrosigma		*Closteriopsis*	*Phacus*
Gomphonema	**Pyrrophyta**	*Actinastrum*	*Trachelomanos*
Cocconeis	*Peridinium*	*Crucigenia*	
Chaetoceros	*Gymnodinium*	*Trubaria*	
Skeletonema		Unknown green	

Phytoplankton genera generally decreased in both river systems from fall to spring. The Alafia supported higher numbers of genera and organisms during all seasons than the Little Manatee, reportedly in response to higher levels of critical nutrients (i.e., ammonia, nitrate, phosphate, organic nitrogen, and iron) in the Alafia. The levels in the Little Manatee River were considered limiting.

Canals and ditches abound in the Tampa Bay watershed area and often have high wildlife value as foraging areas for wading birds and other animals. When overgrown with aquatic plants, they provide a rich habitat for a variety of organisms. Mosquitofish and various cyprinodontid fish are typical species of these environments. The lesser siren and striped swamp snake may be especially abundant in hyacinth-covered ditches. Further information on canals and drainageways is presented in Section 5.5.4.

A few springs, characterized by artesian flow, relatively high calcium content, and uniform water temperature, occur in the Tampa Bay watershed. Shoreline modifications for recreational facilities are common and the vegetation present is very similar to that found in the river system into which they flow. Lithia Springs, off the Alafia River in Hillsborough County, is an important example. Among the vertebrate species found in this spring run are the redeye chub and Suwannee cooter, both very rare in the Tampa Bay watershed (Layne et al. 1977).

5.4 Estuarine, Saltwater Wetland, and Coastal Habitats

The pervasive influence of salt in the form of saline soil water, dilute brackish surface waters, tidal fluctuations, and salt spray marks the beginnings of what we consider the estuarine, saltwater wetland, and coastal habitat zone. Plant communities that occupy this zone are uniquely adapted to the oscillating salinity, tidal, and meteorological conditions that characterize their physiochemical environment.

The ecotone that sets these habitats apart from more upland or marine communities may be sharp and spatially fixed, as in the case of the beach/dune transition found along the coastal barrier islands, or very gradual, as in the case of the major tributaries leading into Tampa Bay. Because of river influence, for example, the latter transition from freshwater cypress swamp to marine mangrove swamp occurs over a 32- to 48-km stretch, while on the barrier islands the transition from seagrass flats to coastal strand and upland hammock may occur over a distance of only a few hundred meters (Morrill and Harvey 1980).

The following discussion of estuarine and coastal habitats progresses from the fringing and more upland communities to the open estuarine waters, and finally to the beach-dune and other barrier island communities. Many of the more upland habitats are also found far downstream. Salt marshes, salt flats, and mangroves, for example, are frequently found in narrow bands along the low-energy back sides of barrier islands, as well as the fringing and more upland communities.

5.4.1 Salt Prairies and Marshes

A vegetation zone dominated by salt-tolerant herbs and succulents is frequently found at the transition between upstream freshwater prairies, floodplain hardwoods, and mangroves or intertidal flats. This zone, referred to as the "Saltern" by Estevez (1981), usually contains several species, though it may appear at particular sites to be a vast monoculture. The occasional inundation with brackish waters followed by exposure to the air, evaporation, and upward movement of saline ground water promotes a wide range of salinities and defines the vegetative zonal patterns observed. Salinities here may range from 1 ppt to as high as 115 ppt (Estevez 1981). These rapidly changing physiochemical conditions caused by tides, evaporation, and freshwater runoff result in a unique and patchy assortment of vegetation. Large stretches of bare sand are often evident, interspersed with succulents such as keygrass (*Monanthocloe littoralis*) and saltgrass (*Distichlis spicata*). Normally freshwater forms such as spikerush (*Eleocharis* spp.) may also be found. Other plant species that may appear further down gradient include beach carpet

(*Philoxerus vermicularis*), buttonweed (*Diodia rigida*), glasswort (*Salicornia virginica*), and saltwort (*Batis maritima*). Buttonwood (*Conocarpus erectus*) and silver buttonwood (*C. erectus* var. *sericea*) may occupy higher elevations. On the seaward end of this gradient, extensive growths of saltmarsh species such as smooth cordgrass (*Spartina alterniflora*), marsh hay (*S. patens*), and black rush (*Juncus roemerianus*) may be found.

Tidal creeks and inlets create an environment in which fresh and saline waters oscillate quite freely and frequently. Where tidal inundation is occasional (generally on local topographic highs), black rush may grow in a vast monoculture (USACE 1978). Associated species in these areas include leather fern (*Acrostichum aureum*), buttonwood, big cordgrass (*Spartina cynosuroides*), and coastal dropseed (*Sporobolus virginicus*), along with saltwort and saltgrass. The deep saltwater marsh, dominated by nearly pure stands of smooth cordgrass, is generally associated with higher salinities, more wave action, and more regular tidal fluctuation than *Juncus* marsh sites.

Both marsh types, however, also compete with mangrove forest vegetation. Often the two communities, salt marsh/prairie and mangroves (particularly white mangrove, *Laguncularia racemosa*) are found in close association.

There is some evidence suggesting that salt-prairie vegetation (i.e., *Batis* and *Salicornia*) is nutrient limited (Wilcox 1979). Furthermore, experimental addition of nutrients tends to shift the species assemblage toward dominance by *Batis*.

Salt prairies and marshes provide habitat for a variety of fish and wildlife. In general, the moderate-to high-salinity marshes support more aquatic invertebrates (snails, mussels, polychaetes) than do the low-salinity marshes (Carter et al. 1973). Gastropods are particularly abundant in the *Batis-Salicornia* prairies (Wilcox 1979). Other important invertebrate groups include amphipods, benthic foraminiferans, insects and their larvae, arachnids, and oligochaete worms. Marshes also attract numerous wading birds (herons and egrets), other more transient birds (red-winged blackbird, marsh hawk), mammals (rabbits, raccoons), and some reptiles (alligators, salt marsh snakes).

5.4.2 Mangrove Forests

The presence of scattered buttonwood trees (*Conocarpus erectus*), generally located on the downstream side of salt marshes, signifies the beginning of the estuarine wetland zone dominated by mangrove forest vegetation. In addition to buttonwood, three species of mangroves: red mangrove (*Rhizophora mangle*); white mangrove (*Laguncularia racemosa*); and black mangrove (*Avicennia germinans*); form the dominant tree species of this zone. Other salt-tolerant plants frequently associated with mangroves include typical salt-prairie species such as saltwort (*Batis maritima*) and glasswort (*Salicornia virginica*) (Carlson 1972; GDC 1975; Herwitz 1977).

In addition, there is a distinctive and important assemblage of root and mud algae associated with the intertidal prop roots of red mangroves. Figure 98 summarizes the flora and fauna commonly found attached to the prop roots (Carter et al. 1973; Odum et al. 1982). Further discussion of the algal community association with mangroves is presented in Section 5.4.3.

Theories on why mangrove species associations are distributed as they are follow two complimentary trains of thought, one strictly phytosociological, based on the theory of successional relationships between associations (Davis 1940), and the other based on consideration of the environmental factors favoring species dominance and physiognomy of forest growth (Lugo and Snedaker 1974; Wharton et al. 1977).

The Davis approach (Figure 99) presents an empirical summary of the major habitats of the estuarine zone with emphasis on the mangrove zonation relative to tide levels. With the exception of Davis' interpretation that mangroves actively build land and that successional processes per se are involved in the empirical trends of Figure 99, the diagram is a fair representation of vegetation associations in the mangrove zone. At present, the consensus

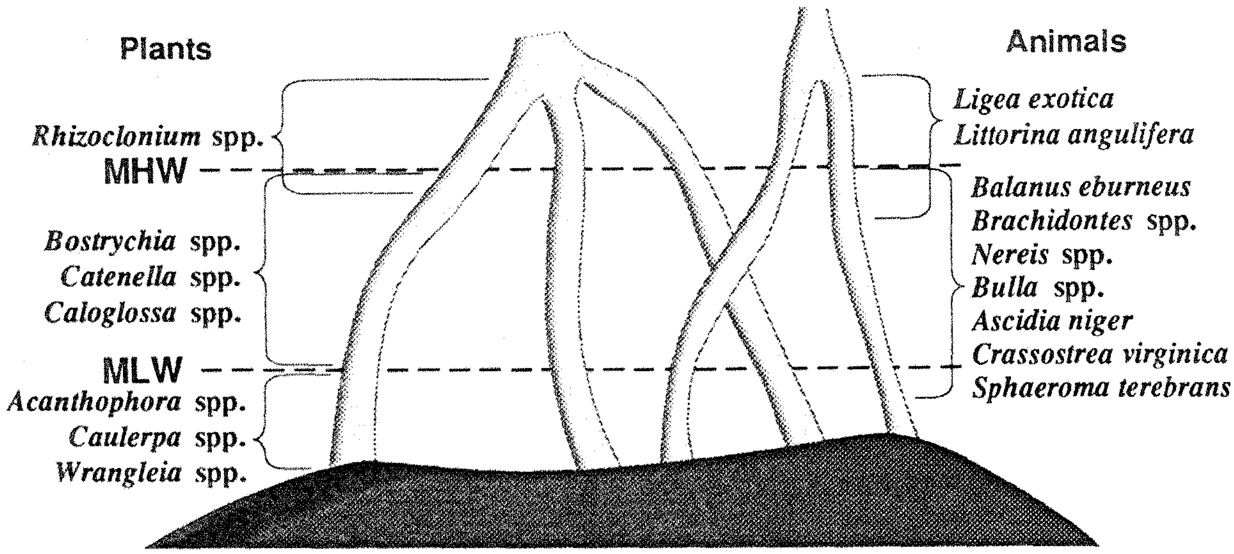


Figure 98. Vertical distribution of selected algae and invertebrates on red mangrove prop roots (after Odum et al. 1982).

is that mangroves, particularly red mangroves, through their ability to trap sediments, act as land stabilizers rather than land builders (Odum et al. 1982). Other physical forces such as sea-level fluctuation, long-term drainage patterns, and hurricanes exert the primary controlling influence on exactly where the land ends and the ocean begins. Localized environmental factors such as soil salinity, tidal flushing, and so forth determine zonation patterns among mangrove species.

If one incorporates such environmental factors as topography and hydrology into Davis' figure, the mangrove forest types of Figure 100 emerge. The following description of mangrove forest types is taken mainly from Lugo and Snedaker (1974) and Wharton et al. (1977).

The fringe forest lines protected shorelines and is especially well developed at elevations above mean high tide. Low tidal velocities allow the well-developed mangrove root systems to act as efficient sediment traps. Due to their exposure along shorelines, these forests may be affected by winds, causing breakage and accumulation of debris among the prop roots.

Riverine forests occur along river and creek drainages, usually separated from them by a shallow berm, though flushed by daily tides. They are often fronted by fringe mangrove forests. Riverine forests consist of straight-trunked, relatively tall red mangrove trees, with varying mixtures of black mangrove and white mangrove.

The overwash forests are characteristic of the smaller islands and fingerlike projections of land within bays and estuaries. These forests are generally overwashed by daily tides; thus little litter accumulates. The forest consists of fairly small, uniform trees with little or no understory foliage, giving the forest a rather symmetrical appearance when viewed from within.

Basin forests occur inland along drainage depressions that channel runoff toward the coast. In coastal locations, red mangroves are dominant, but as one moves inland dominance is shared with black and white mangroves.

The dwarf or scrub forest is found at the extremes of physiochemical conditions or biogeographic range. Due to restricted flushing and salinity stress (e.g., along southeast coast), or excessive flushing and stress due to inhospitable substrate (e.g., in the Florida Keys), or reduced flushing combined with temperature stress (e.g., along Florida west coast), trees in this

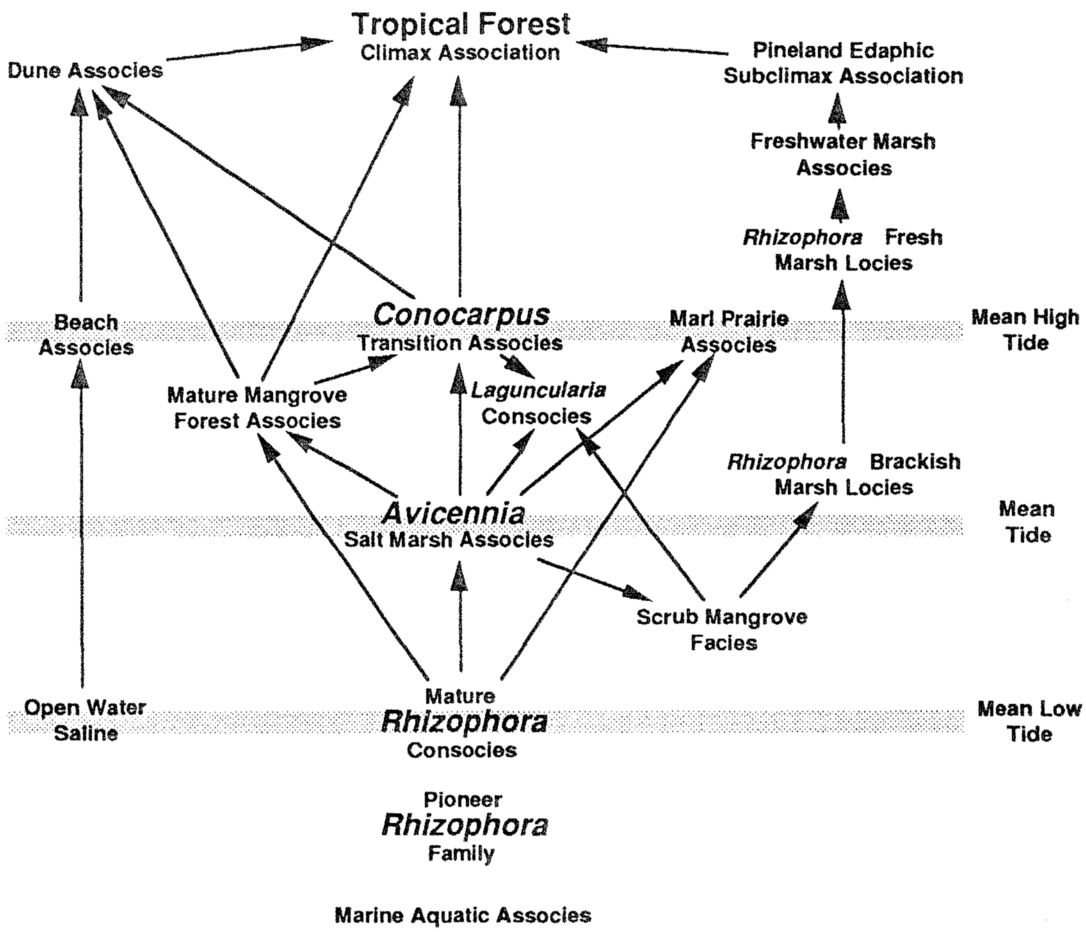


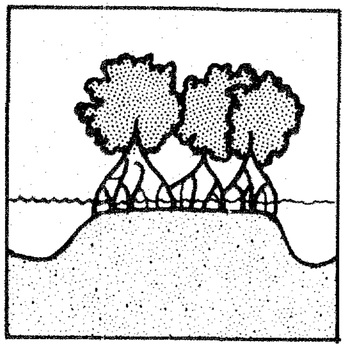
Figure 99. Successional relations of mangrove communities and some associated plant communities in relation to approximate tide levels (after Davis 1940).

forest type are characteristically stunted, though they may be quite old (40 years). Lugo and Snedaker (1974) also mention that some dwarf forests may be nutrient limited.

Zonation of species within the mangrove forest appears to be controlled by the interplay of physical and chemical factors such as soil salinity, tidal flushing, and tidal sorting of seedlings (propagules) as well as biological factors such as interspecific competition (Odum et al. 1982). The success of all three species within the intertidal or supratidal zone is possible only because of their specialized physiologies, which allow these basically freshwater species to thrive preferentially in a salt-rich, oxygen-poor environment (Snedaker and Brown 1982).

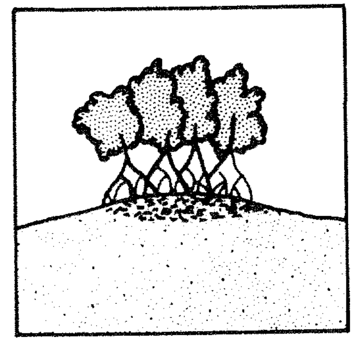
It appears that the salt secreters (black and white mangroves) tolerate higher soil salinities than the salt excluders (red mangroves) (Odum et al. 1982). Substrate also seems to play a role in salinity tolerance. A moderate clay content apparently increases the tolerance of black and white mangroves to hypersaline conditions, while pure sand tends to reduce their tolerance (Odum et al. 1982).

The sediments in which mangroves grow are frequently shifting and anaerobic. Consequently, the root systems of mangroves must have adaptive mechanisms for dealing with these chronic conditions. Such mechanisms fall into two broad categories: structural adaptations of the root system to deal with the problem of stability and functional



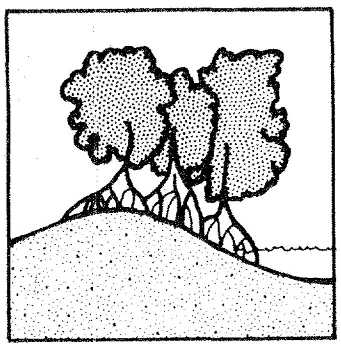
Overwash Mangrove Islands

1. Overwashed by daily tides.
2. High rate of organic exports.
3. Dominated by red mangroves but all species may be present.
4. South Florida, south coast of Puerto Rico.
5. Sensitive to ocean pollution.



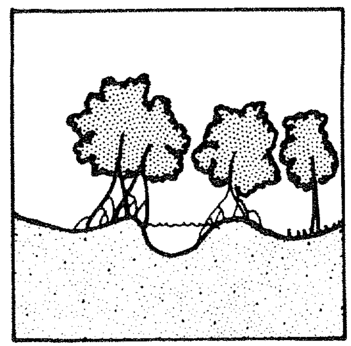
Hammock Mangrove Wetlands

1. On land rises in south Florida.
2. Low export of organic matter.
3. All mangrove species.
4. South Florida everglades.
5. Sensitive to fire and drainage.



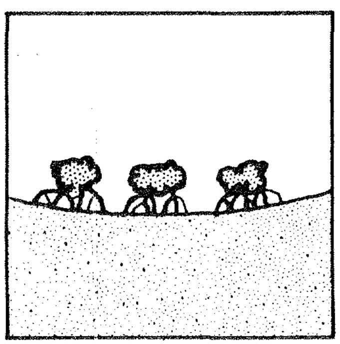
Fringe Mangrove Wetlands

1. Line waterways.
2. High rate of organic exports.
3. Dominated by red mangrove.
4. Throughout south Florida, Puerto Rico, and Florida's east and west coast.
5. Sensitive to ocean pollution.



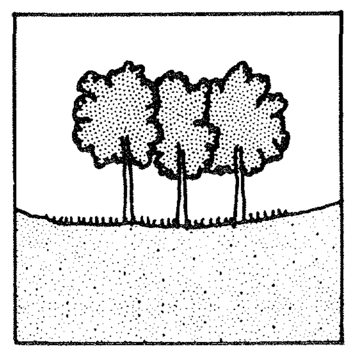
Riverine Mangrove Wetlands

1. Along flowing waters.
2. High export of organic matter.
3. All mangrove species, reds predominate.
4. South Florida, north coast of Puerto Rico.
5. Sensitive to alterations of water flow.



ScrubMangrove Wetlands

1. On extreme environments.
2. Low organic exports.
3. Usually red or black mangroves.
4. Southeast Florida, south coast of Puerto Rico, high latitudes on west coast of Florida..
5. Sensitive to further stress.



Basin Mangrove Wetlands

1. In depressions or areas of slow water movement.
2. High seasonal export of organic matter.
3. Black mangroves predominate.
4. Inland locations in south Florida and Puerto Rico.
5. Sensitive to alteration of sheet flow, sea-water input, and prolonged high water.

Figure 100. Mangrove forest types represented in the Tampa Bay watershed (after Wharton et al. 1977).

adaptations that funnel oxygen from the atmosphere to the root systems (Odum et al. 1982).

Structural stability in the red mangrove is achieved by way of their conspicuous prop roots. These roots, in effect, distribute what would be the basal mass of a tree growing in a stable environment into a series of small above-ground roots spread over a wider area. This horizontal spread apparently provides greater stability than a centralized trunk. Black mangroves achieve their stability through a system of shallow underground "cable" roots that radiate from the central trunk. Root systems in all Florida mangroves are shallow, with no appreciable tap roots. Judging from the relative persistence of red mangroves where wave and current energies are high, the prop roots appear to be the more effective stabilizing device.

Oxygen-funneling mechanisms of mangrove root systems occur in two forms, each associated with a particular adaptation in root-system structure. The prop roots of red mangroves contain many small pores called lenticels, which at low tide allow oxygen to diffuse from the atmosphere into the plant and down to the underground roots through passages known as aerenchyma (Scholander et al. 1955). The black mangrove usually exhibits small roots called pneumatophores, growing up from the cable roots and into the atmosphere. At low tide air diffuses from the atmosphere into the pneumatophores and down the aerenchyma. White mangroves usually have neither prop roots nor pneumatophores but use lenticels in the lower trunk (Odum et al. 1982).

In addition to the salinity preferences and physical root-structure adaptations that tend to promote the classic mangrove zonation scheme, other factors such as reproductive strategies and tidal sorting of the propagules of the three species also influence species and forest type distribution along characteristic lines. The essential differences in reproductive strategy appear to be in three categories: flowering and fruiting, obligate dispersal time for floating propagules, and site conditions required for seedling establishment and growth. Table 24 summarizes these differences. The short dispersal times and obligate stranding required for black and white mangroves propagules implies that they will probably not do well in and along constantly inundated tidal creeks or basins. Red mangrove propagules, on the other hand, remain viable for quite some time in seawater and can establish themselves in shallow intertidal waters.

Primary productivity, litterfall, and nutrient cycling of mangroves in south Florida has been investigated by Carter et al. (1973) and Snedaker and Lugo (1973) and summarized by Wharton et al. (1977) and

Table 24. Reproductive strategy differences between three species of mangrove found in the Tampa Bay watershed.

Species	Flowering	Fruiting	Obligate dispersal time (days)	Time required for root establishment (days)	Viable period (days)
White mangrove (*Laguncularia racemosa*)	May to Aug.[a]	July to Sept.[a]	8 (5-day stranding required)	5[c]	35[c]
Black mangrove (*Avicennia germinans*)	May to July[a]	Aug. to Nov.[a]	14 (5-day stranding required)	7[c]	110[c]
Red mangrove (*Rhizophora mangle*)	All year[b] (Predominate May through June)	July to Oct.[b]	40 (establishes in shallow waters)	15[c]	365[d]

References: [a]Loope 1980; [b]Savage 1972; [c]Rabinowitz 1978; [d]Davis 1940.

Odum et al. (1982). The latter authors list the following 19 factors that they believe influence mangrove productivity:

1. Species composition of the stand.
2. Age of the stand.
3. Presence or absence of competing species.
4. Degree of herbivory.
5. Presence or absence of disease and parasites.
6. Depth of substrate.
7. Substrate type.
8. Nutrient content of substrate.
9. Nutrient content of overlying water.
10. Salinity of soil and overlying water.
11. Transport efficiency of oxygen to root system.
12. Amount of tidal flushing.
13. Relative wave energy.
14. Presence or absence of nesting birds.
15. Periodicity of severe stress (hurricanes, fire, etc.).
16. Time since last severe stress.
17. Characteristics of groundwater.
18. Inputs of toxic compounds or nutrients from human activities
19. Human influences such as diking, ditching, and alternating patterns of runoff.

A number of trends have been noted on mangrove forest productivity in the Tampa Bay watershed. Although transpiration is generally regarded as being low because of the high negative pressure maintained in the xylem (Odum et al. 1982), wood production rates are fairly high as compared to estimates of other types of forest. Lugo et al. (1975) believe that, in terms of net primary production, red mangroves rank highest, black mangroves intermediate, and white mangroves least when the trees are growing in their optimum conditions. For pioneering red mangroves, there appears to be an inverse relationship between gross primary productivity (gpp) and salinity. For black and white mangroves, there appears to be an optimum point on the salinity curve, above and below which gpp declines. The cumulative effect of these trends is a bell-shaped productivity curve that shows maximum net productivity somewhere between purely freshwater and marine conditions (Carter et al. 1973; Hicks and Burns 1975; Odum et al. 1982).

With regard to nutrients, trace elements, and heavy metals, mangrove forests tend to act as net accumulators. These materials are removed from overlying waters by the concerted action of prop roots and associated algae, sedimentation, and filtration by associated biota. The metals copper, chromium, iron, lead, manganese, and zinc are consistently more concentrated in the sediments of mangrove forests than in the surface waters. Differences of several orders of magnitude are typical. More importantly, mangrove tissues consistently exhibit heavy metal concentrations six to seven orders of magnitude greater than the sediments. It is currently unknown whether uptake occurs by sediment or water transfer, or both.

An information search by Snedaker and Brown (1982) found a great deal of information on the structural aspects of mangrove biogeochemistry (i.e., chemical concentrations in various components of tissues, soils, and so forth), but very little information on the dynamic aspects such as transfer functions and uptake rates among major components of the mangrove system. One of the most important and conspicuous aspects of mangrove forests is their energy contribution to adjacent estuaries (Heald 1971; Odum 1971). Considering the degree of dependence of the estuarine food chain on detrital energies, it is important to know something about litter production export and degradation. Using the six mangrove-forest type categories of Lugo and Snedaker (1974), Snedaker and Brown (1982) present a list of mangrove ecosystem dynamics based on leaf-litter production rates (Figure 101). This index has proven to be a reliable indicator of overall mangrove productivity.

As the mangrove debris awaits its fate of either sedimentation or washout into the open waters by tidal or freshwater flushing, it is subjected to a variable intensity of degradation forces (Heald 1971). In general, leaves degrade faster in predominantly fresh water than they do on dry land, and even faster in brackish or sea water. The latter increase in rate is apparently due to increased grazing by small marine crustaceans, particularly amphipods.

This pattern of detrital degradation also coincides with the quality of the mangrove forest structure. The

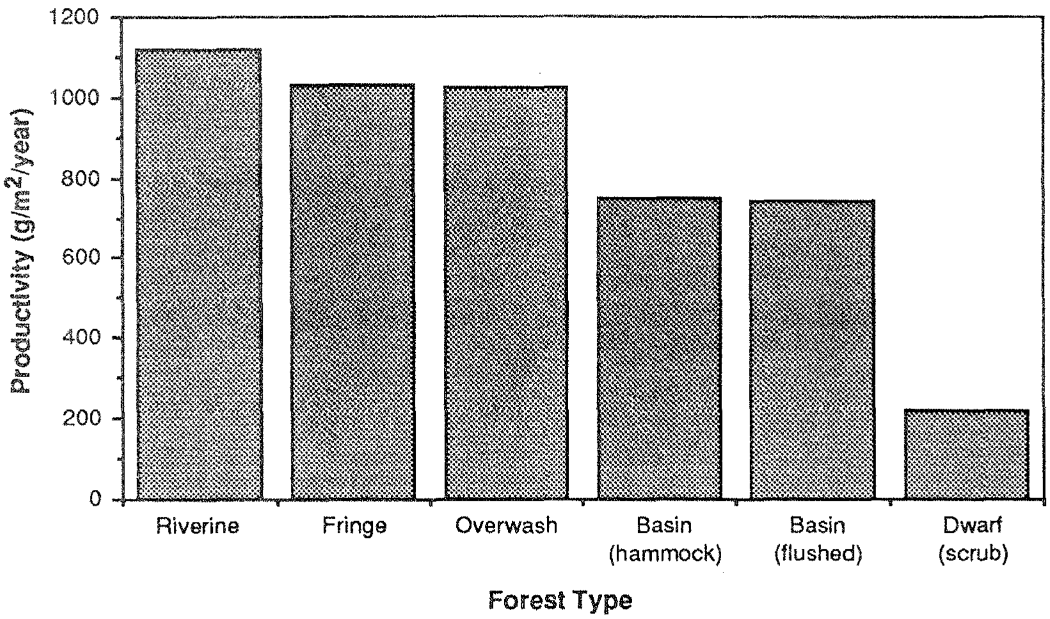


Figure 101. Leaf-litter production rates in mangrove forest categories (after Snedaker and Brown 1982).

best developed forests form where soil salinities are well moderated by freshwater and/or tidal flushing. Marginal environments for forest development are in association with uniformly high or low annual salinities, excessive siltation, arid climates, in sedimentary carbonate environments, or where tidal amplitude is small (Snedaker and Brown 1982).

Initially, the grazing of freshly fallen red mangrove leaves is delayed by the heavy cuticular wax. Black mangrove leaves have much less wax (Twilley et al. 1985). As the wax disintegrates, bacterial and fungal populations increase and grazing by microcrustaceans begins. Needlerush and sawgrass debris are seldom grazed upon after abscission and thus degrade more slowly.

Heald (1971) documents a microfloral succession on red mangrove leaves leading to the increased availability and usefulness of the detritus to microconsumers. The principle physical and biochemical features of this successional process (i.e., a relative enrichment of the leaf with animal protein at the expense of plant protein as particle size decreases) are summarized in Figure 102.

Mathis (1973) reports a bacterially induced 3- to 200-fold enrichment of the heavy metals Fe, Mn, Cu, and Cd in various decomposition stages of red mangrove leaves, compared with living leaves. This

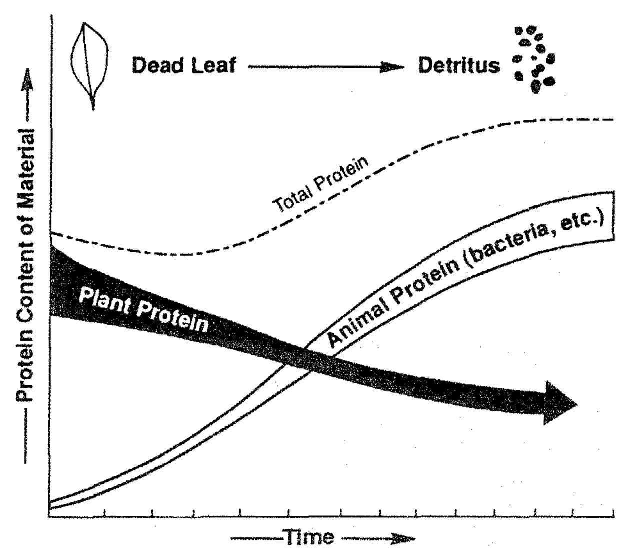


Figure 102. Diagrammatic representation of the principle of protein enrichment of red mangrove debris during degradation (Heald 1971).

could be an important pathway of heavy metal enrichment in the fish and wildlife of nearby estuaries via microfloral and faunal predation.

5.4.3 Oscillating-Salinity Open Waters

The open waters of the estuarine zone encompass two closely related but nonetheless distinct habitats: the benthos, which may be divided into vegetated communities (e.g., seagrasses and algal beds) and nonvegetated open-bottom benthic communities composed of varying mixtures of sand, mud and oystershell (living oyster reefs are, for our purposes, considered a variant of the open-bottom benthic community); and the midwater planktonic environment, usually dominated vegetationally by phytoplankton.

These basic habitats are present along a series of spatially varying environmental gradients. Tidal rivers and creeks, bayside inlets, bayous, open bay waters, high-velocity channels, and slow-moving lagoons together present a range of geographic settings exhibiting gradations in salinity regime, current velocities, wind-driven wave action, depth, and substrate composition. The physiological tolerances of the organisms limit the range of physical conditions within which they can survive. The interactions of the organisms with each other within these limits determine planktonic and benthic community structure and function. These habitats have been severely altered by the activities of port development (e.g., canalization, channel dredging, spoil disposal), and urbanization (e.g., upland development, sewage or industrial discharges). As discussed below and in Lewis and Estevez (1988) and others, these activities have affected and changed the composition and function of these communities.

a. Seagrass beds. Seagrass beds are widely recognized as one of the most productive benthic habitats encountered in estuarine and nearshore waters of the gulf coast. As primary producers they have high growth and production rates, thus providing a food source for many organisms, both directly to grazing animals and indirectly in the form of detritus. As a habitat, the seagrasses provide a surface of attachment and refuge for large numbers of epiphytic and benthic organisms, which in turn provide food and cover for many estuarine fish and invertebrates, especially during critical juvenile life stages. The rhizome-root mat tends to trap and bind fine sediment particles, preventing erosion, while the higher organic-matter content within seagrass beds encourages an active sulfur cycle in the sediments and provides a sink and source for nutrients within the bay system.

Observation and research on the seagrasses in the Tampa Bay watershed have been ongoing for at least 20 years. A recent annotated bibliography of seagrass research conducted within the bay (Continental Shelf Associates 1983a) lists over 25 published articles and reports. More recently, a review by Lewis et al. (1985), summarizes the types of seagrass meadows to be found within the bay, their habitat values, physiological ecology, reproductive biology, and ongoing research and revegetation efforts. This latter work has been heavily relied upon in developing the following discussion on the ecological aspects of seagrasses in the watershed. Important earlier works on seagrasses for the area include Phillips (1960, 1962), Taylor and Saloman (1969), McNulty et al. (1972), Taylor (1973), and Lewis and Phillips (1981).

Of the seven species of seagrass occurring in Florida (Eiseman 1980), five are found in the Tampa Bay area. These include widgeon-grass (*Ruppia maritima*), manatee-grass (*Syringodium filiforme*), shoalgrass (*Halodule wrightii*), turtle-grass (*Thalassia testudinum*), and *Halophila engelmannii* (Lewis et al. 1985). The dominant species are turtle-grass and shoalgrass. Widgeon-grass dominates the northern portions of the bay, while shoalgrass and turtle-grass dominate the southern portions. Manatee-grass is commonly found in association with the latter two species, but in lower abundance. *Halophila engelmannii* has been reported only rarely from Boca Ciega Bay (Taylor and Saloman 1969), behind Egmont Key (Taylor 1973) and, more recently, around Cockroach Bay in middle Tampa Bay (Lewis and Phillips 1980; Durako and Moffler 1982). A recent mapping of the distribution of the four dominant species within the bay (Continental Shelf Associates 1983b) is presented in Figure 103.

Species distribution and abundance within seagrass beds are primarily related to water

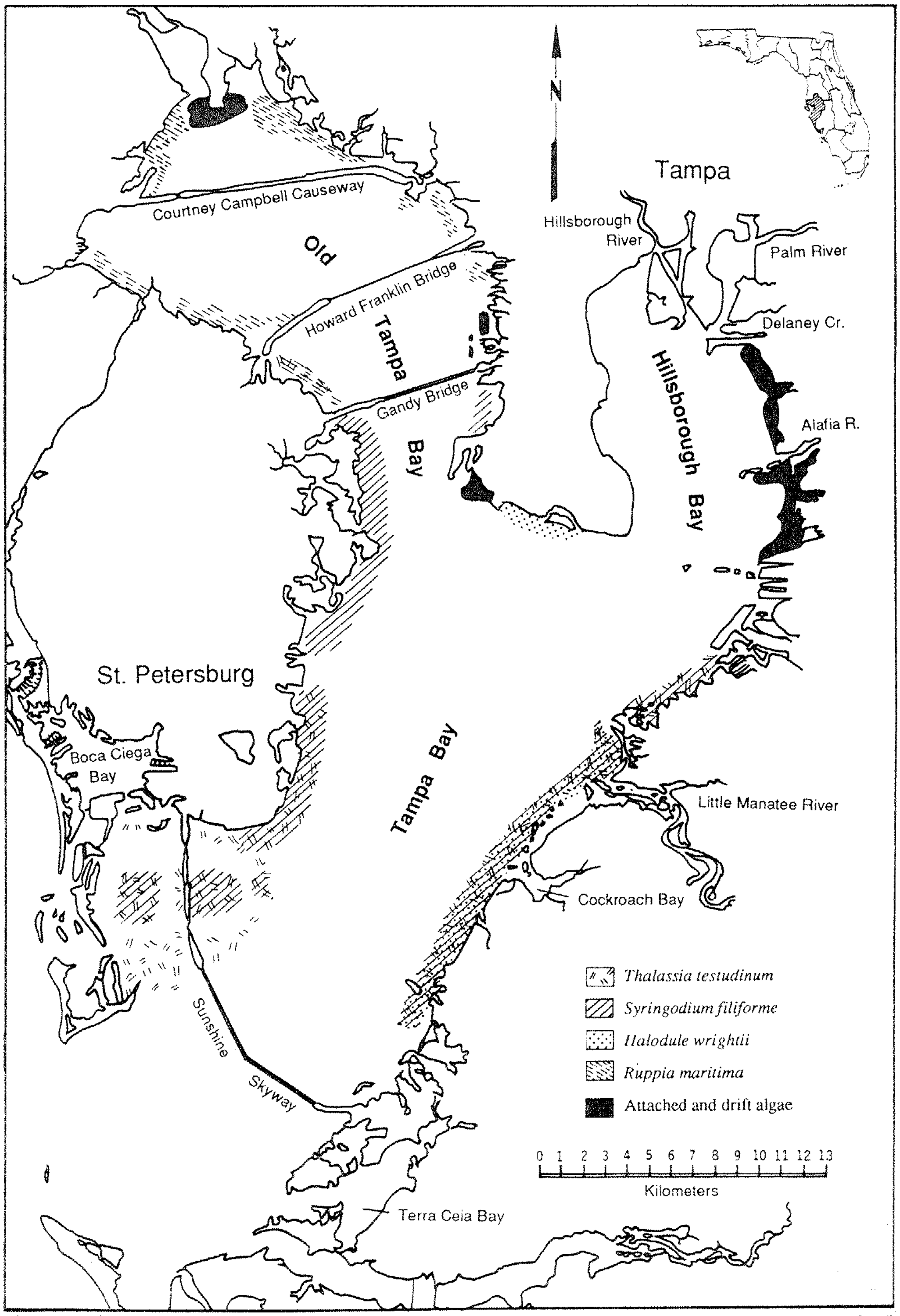


Figure 103. Distribution of major seagrass species in Tampa, Florida during July 1983 survey (Continental Shelf Assoc., Inc. 1983b).

transparency, salinity, temperature, substrate, bottom topography, and depth. High turbidity and the consequent low light penetration is reportedly responsible for the relatively shallow depth (<2 m) at which seagrasses grow in the Tampa Bay watershed; wave action and desiccation tend to limit the shoreward growth of the seagrass beds.

Figure 104 presents a generalized schematic of species zonation among seagrasses in Tampa Bay relative to depth and salinity. Widgeon-grass is listed but is commonly found in the lower salinity (5 ppt) waters of Tampa Bay. Though Thorne (1954) and Humm (1973) considered this species as a primarily freshwater one capable of invading brackish waters, it can also be found in salinities in excess of 35 ppt. Its tolerance of lower salinity waters may be responsible for its dominance north of the Courtney Campbell Causeway in Old Tampa Bay and previously in Hillsborough Bay (Phillips 1962; Lewis et al. 1985). Tidal zonation of widgeon-grass in Tampa Bay may actually be a secondary effect of this species' preference for brackish water areas, which often are found at the surface of the water mass.

Shoalgrass, another euryhaline species, can reportedly tolerate higher water temperatures and longer air exposures than other seagrasses in the bay (Humm 1956). It is not surprising, then, that this species is the most abundant seagrass between the neap high and low tide lines (Phillips 1960, 1962). In low-salinity areas, shoalgrass is commonly mixed with widgeon-grass intertidally, but is most abundant between the neap low and spring low tide lines in higher salinities. Subtidally, this species has also been reported to dominate higher salinity areas of upper Old Tampa Bay where turbid waters restrict the occurrence of manatee-grass and turtle-grass (Lewis et al. 1985). It appears, then, that zonation of shoalgrass is not entirely restricted by physical factors; rather it may be outcompeted by these two more stenohaline species in less turbid areas of the lower bay (Lewis et al. 1985).

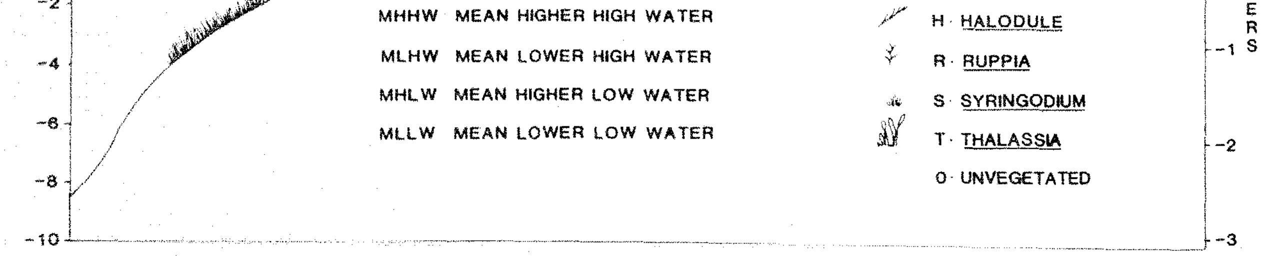


Figure 104. Generalized schematic of species zonation among seagrasses in Tampa Bay relative to depth and salinity (Lewis et al. 1985).

Both manatee-grass and turtle-grass exhibit a preference for higher salinity waters (20-40 ppt). Manatee-grass becomes dominant at the spring low-tide line, and frequently grows interspersed with turtle-grass in deeper water (Humm 1956; Phillips 1960, 1962). Although turtle-grass is considered the dominant subtidal species in the Gulf of Mexico (Humm 1956; Earle 1972), salinities within the bay are probably suboptimum (< 25 ppt) for this species, resulting in relatively sparse populations compared to areas such as Boca Ciega Bay (Hutton et al. 1956; Pomeroy 1960; Taylor and Saloman 1968) and seagrass beds surrounding Mullet Key (Lewis et al. 1985). Here, where turtle-grass is the dominant seagrass, salinity typically exceeds 30 ppt.

Halophila engelmannii also reportedly requires relatively high salinities (Taylor 1973), which may partially account for its low abundance in the bay. When found, this species occurs subtidally in association with turtle-grass and manatee-grass (Lewis et al. 1985).

Seagrasses are generally limited to soft marl, mud, or sand substrates in the Gulf of Mexico. Certain characteristics of the substrate (i.e., grain size and composition, percent organics, and depth of the redox potential) are important factors in determining which species will be present. In turn, seagrasses locally influence and modify their sedimentary surroundings by trapping detritus and stabilizing finer sediment particles. This tends to increase the percentage of organic matter and decrease sediment sorting and mean particle size within the grass bed compared to adjacent unvegetated areas. Increased sedimentation and stabilization within the seagrass bed results in a characteristic bed form raised above the original sediment level. Water depth consequently decreases from fringe to midbed regions (Zieman 1972; Durako and Moffler 1982), a distinct advantage for certain species limited by light penetration in turbid estuarine waters.

Dense turtle-grass beds in Tampa Bay are typically found in muddy sand substrates with a high silt/clay content (Phillips 1960) and varying amounts of calcium carbonate (Patriquin 1972). The former may be important in establishing a reduced environment in the near-surface layer of the sediments, required for anaerobic uptake of nitrogen and sulfur by the roots, while the calcium carbonate is important in determining phosphate and sulfate availability to the plant for normal growth and development (Lewis et al. 1985). Shoalgrass may occur on the same substrate types as turtle-grass, as well as on extremely coarse to muddy sand bottoms (Phillips 1960; Grady 1981). It does not, however, require a reduced sedimentary environment and is, in fact, more prevalent on oxidized substrates.

Manatee-grass occurs on a variety of substrate types, both oxidized and reduced. According to Lewis et al. (1985), "the ability [of this species] to grow in both types of substrates reflects the intermediate successional nature of manatee-grass, which is thought to follow shoalgrass and precede turtle-grass in the serial development of a seagrass bed." Widgeon-grass is reportedly found on predominantly muddy sand and silt substrates that contain a finer textured sand than that associated with the other three species (Phillips 1960; Lewis et al. 1985). *Halophila* has been reported to grow on soft, muddy sand in Tampa Bay (Phillips 1960) and limestone bottoms and even the prop roots of mangroves in south Florida (Earle 1972).

Productivity of seagrass systems is regarded as extremely high for marine communities. Pomeroy (1960) reported turtle-grass and manatee-grass were as important as phytoplankton and benthic microflora in terms of primary production in Boca Ciega Bay, fixing 500 gC/m^2 in leaf material per year. Belowground biomass, when measured, is usually much higher than aboveground leaf material (Table 25) for most species. Higher biomass values generally reported for *Thalassia* compared to the other species are a result of the larger size of all three major plant parts (e.g., leaves, shoots, and roots). Lower biomass values for *Thalassia* in Tampa Bay relative to Tarpon Springs and Boca Ciega Bay (Table 26) partially reflect suboptimal conditions for this species in the bay (Lewis et al. 1985).

Several authors have measured leaf length to monitor *Thalassia* growth in Tampa Bay (Phillips 1960; Taylor et al. 1973; Durako and Moffler 1982).

Table 25. A comparison of nutritive values for various plant parts of turtlegrass in the Tampa Bay area (adapted from Lewis et al. 1985).

Dry weight (% fresh wt)	Ash (%dwt)	Protein (%dwt)	Carbohydrate (%dwt)	Lipid (%dwt)	Reference
Leaves					
-	24.8	13.0	35.6	0.5	Burkholder et al. 1959
8-19	46-50	9-12	38.0	0.7	Bauersfeld et al. 1969
15-20	30-40	3-12	3-12	-	Dawes et al. 1979
15-22	33-43	5-15	5-10	-	Dawes and Lawrence 1979
15-20	29-44	8-22	6-9	0.9-4	Dawes and Lawrence 1980
Short Shoots					
12-12.9	47-56	3-10	8-12	-	Dawes and Lawrence 1979
9-12	24-42	2-5	9-16	-	Durako and Moffler 1982
Rhizomes					
6	50	9.6	-	-	Bauersfeld et al. 1969
14-21	21-37	5-12	21-51	-	Dawes and Lawrence 1979
14-18	24-36	7-16	12-36	0.2-1.6	Dawes and Lawrence 1980
15-17	19-27	1-3	19-32	-	Durako and Moffler 1982
Roots					
11-15	26-36	2-5	9-16	-	Durako and Moffler 1982

Table 26. Biomass values for seagrasses in the Tampa Bay area (adapted from Lewis et al. 1985).

Location	Biomass (g dwt/m^2)		Reference
	Aboveground	Belowground	
	Turtle-grass (*Thalassia testudinum*)		
Boca Ciega Bay	32.4	48.6	Pomeroy 1960
Bird Key (BCB)	32.5	-	Phillips 1960
Cat's Point (BCB)	98	-	Phillips 1960
Boca Alga Bay (BCB)	636	-	Bauersfeld 1969
Tarpon Springs	601–819	-	Dawes et al. 1979
Tampa Bay	0.41–52.7	-	Heffernan and Gibson 1982
Tampa Bay	25–180	600–900	Lewis and Phillips 1980
	Manatee-grass (*Syringodium filiforme*)		
Tampa Bay	5–11	-	Heffernan and Gibson 1982
Tampa Bay	50–170	160–400	Lewis and Phillips 1980
	Shoalgrass (*Halodule wrightii*)		
Tampa Bay	4-27	-	Heffernan and Gibson 1982
Tampa Bay	38-50	60-140	Lewis and Phillips 1980
	Widgeon-grass (*Ruppia maritima*)		

These measurements reveal a bimodal seasonal growth pattern (Figure 105) with peaks in the early summer and fall and declines in the winter and mid-summer months. Diebacks in the winter are related to low water temperatures, while those in the summer are related to a combination of high water temperatures, decreasing salinity, and flowering (Lewis et al. 1985). Optimal temperatures for all five seagrass species in Tampa Bay range between 20 and 30 °C (Phillips 1960; Woodburn 1961).

Five types of seagrass beds or meadows identified for Tampa Bay by Lewis et al. (1985) are listed below:

1. Mid-bay shoal perennial.
2. Healthy fringe perennial.
3. Stressed fringe perennial.
4. Ephemeral.
5. Colonizing perennial.

Each type is illustrated in Figure 106 and briefly described below according to Lewis et al. (1985).

(1) Mid-bay shoal perennial. These meadows are generally composed of *Halodule, Thalassia* and *Syringodium*. *Ruppia* is rarely seen, perhaps due to the generally high current regime and/or higher salinities than meadows closer to shore. These meadows are located on natural shoals existing in the middle portion of the bay. They are present year round (perennial) although variations in cover by the different species varies with seasons.

(2) Healthy fringe perennial. These meadows are the most common meadow type in the bay and extend from approximately the mean low water mark out into water depths of approximately -2 m m.s.l. All five species of seagrasses found in the bay occur in this meadow type. Zonation begins with *Ruppia* in the shallowest water close to shore and grades with increasing depth through nearly pure patches of *Halodule*, followed by *Thalassia* and then *Syringodium*. Unlike the generalized meadow cross section from McNulty et al. (1972), healthy fringe meadows in Tampa Bay normally have an unvegetated offshore sand bar separating the main portion of the meadow from open bay waters and creating a "basin" behind the bar. This basin was described by Phillips (1960) as a "central declivity." Similar sand bars have been observed offshore of seagrass meadows in Charlotte Harbor and are plainly visible in aerial and satellite

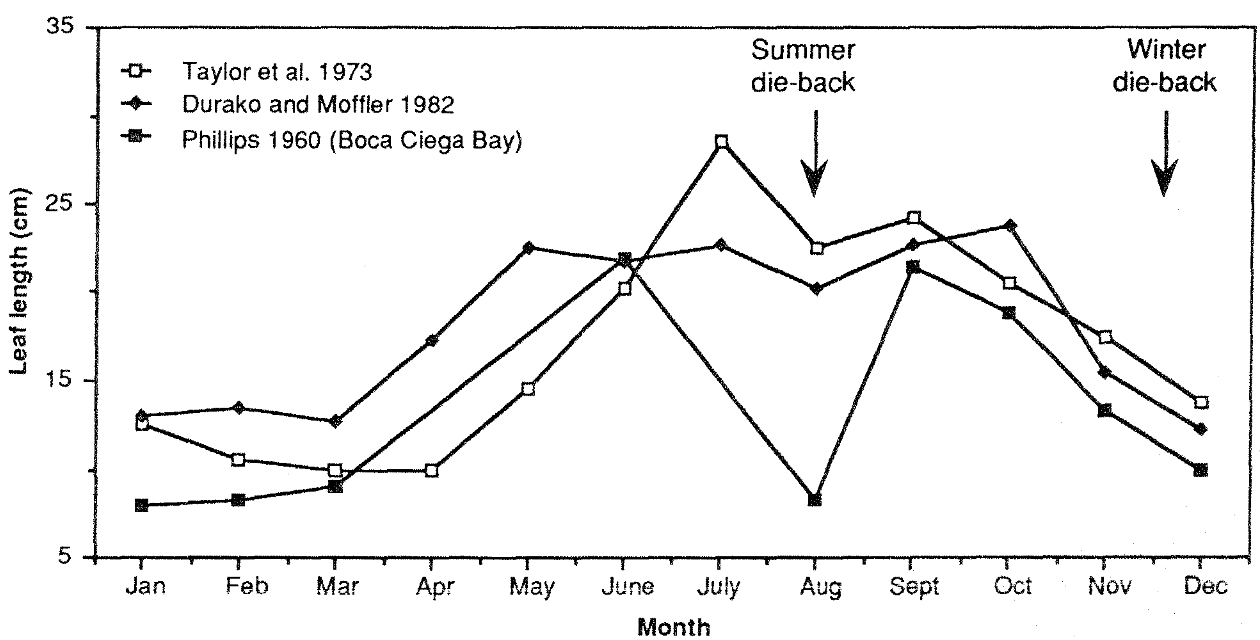


Figure 105. Seasonal growth pattern for *Thalassia* in Tampa Bay (adapted from Lewis et al. 1985).

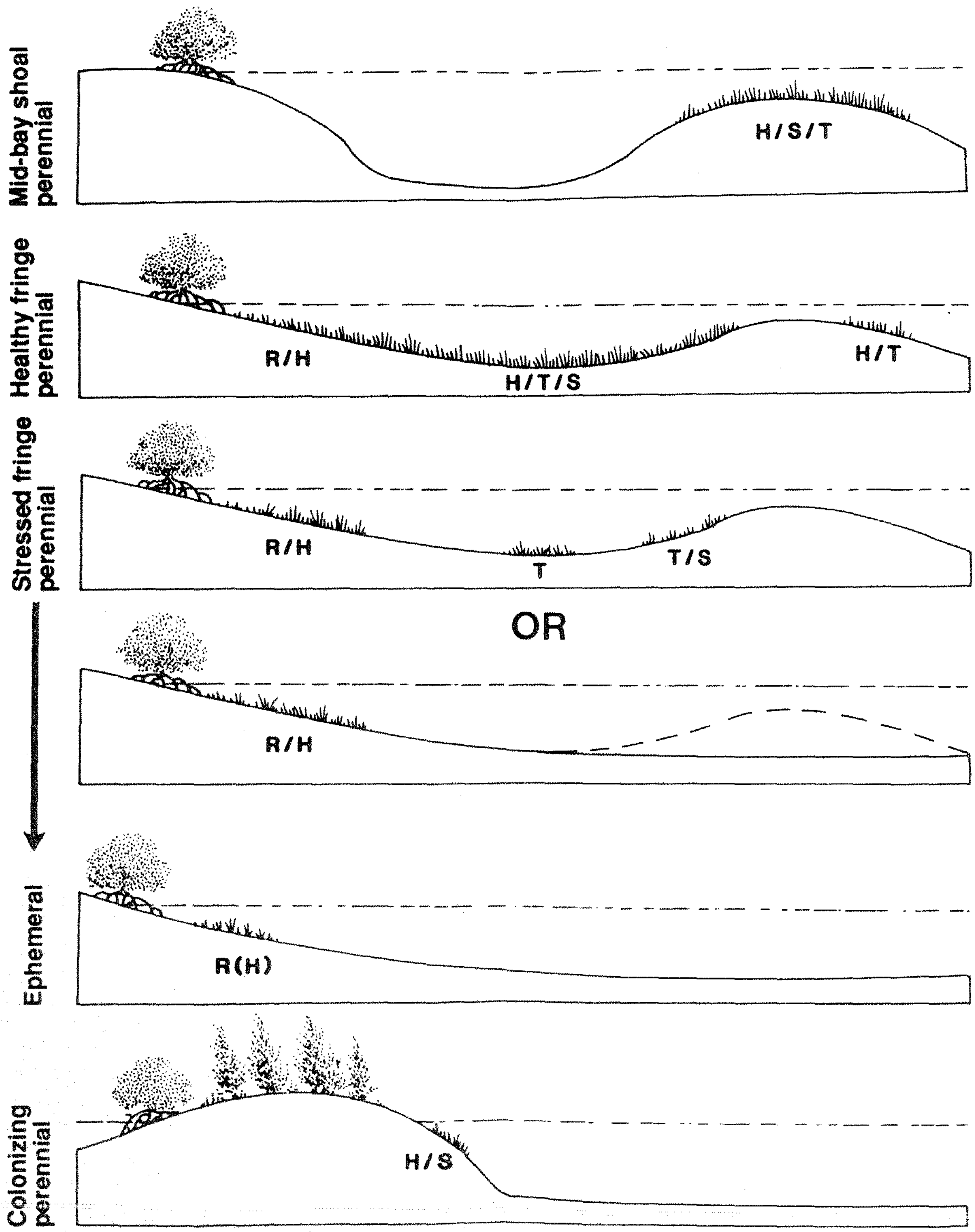


Figure 106. Five types of seagrass beds identified within Tampa Bay (H = *Halodule*, R = *Ruppia*, S = *Syringodium*, T = *Thalassia*) (Lewis et al. 1985).

photography of that area (Allen Huff, Florida Department of Natural Resources; personal communication).

(3) **Stressed fringe perennial.** These meadows are similar to healthy fringe perennial meadows except that total cover is reduced within the basin behind the offshore bar and destabilization of the offshore sand bar apparently leads to its inshore migration and eventual disappearance (Figure 106). These types of meadows generally occur in areas closer to Hillsborough Bay.

(4) **Ephemeral.** These meadows are composed almost entirely of *Ruppia* with occasional sprigs of *Halodule*. They are not present year round and their locations often vary from year to year. Phillips (1962) noted the unusual appearance of *Ruppia* patches in Hillsborough Bay along Bayshore Boulevard and at the mouth of Delaney Creek in the winter of 1961. No other seagrass species were seen in these areas. Mangrove Systems, Inc. (1978) also noted the cyclic appearance and disappearance of a monospecific *Ruppia* meadow near the Big Bend power plant in Hillsborough Bay during 1976–78. These meadows probably represent the final stage of seagrass meadow degradation in Tampa Bay and would be followed by the complete absence of meadows as presently seen in most of Hillsborough Bay.

(5) **Colonizing perennial.** This meadow type is commonly found in a narrow band in the euphotic zone of fill areas such as Courtney Campbell Causeway, Howard Franklin Bridge Causeways, and the Picnic Island fill. It is believed to represent a meadow type dominated by species that can produce abundant propagules that disperse and colonize appropriate shallow substrates. Only *Ruppia* shows large-scale sexual reproduction and seed production in Tampa Bay. The other four species show rare to nonexistent seed production and therefore can only disperse using asexually produced rhizomes through fragmentation as a means of colonization. Due to the exposed nature of the man-made fills and their generally coarser sediments, *Ruppia* is not as common as in the inshore portions of the fringe meadows. Both *Halodule* and *Syringodium* produce large amounts of detached rhizomes, particularly during storms, and it is theorized that these float into unvegetated areas, attach through new root formation, and establish new meadows. *Thalassia* produces relatively fewer detached rhizomes and, due to its more buoyant rhizome, is less likely to sink into an area appropriate for meadow establishment. Even if it does happen to sink, its slower root and rhizome growth rates would make it less likely to establish a new meadow by asexual means. For these reasons, *Halodule* and *Syringodium* are the dominant species in this meadow type.

Lewis et al. (1985) hypothesized that types 2 through 4 are stages in the eventual disappearance of a seagrass meadow due to human-induced stress, as illustrated by the arrows in Figure 106, though this has not been tested experimentally.

Based on the most recent estimates, there are now 5,546 to 5,750 ha of seagrass meadows in Tampa Bay (FDER 1983; Lewis et al. 1985). Using aerial imagery comparisons (Figures 107 and 108), significant losses of grass beds can be seen. The most striking change took place between 1940 and 1963 when about 50% of the grass beds were lost (Table 27). During this period, Hillsborough Bay alone lost 94% of its grass beds, Old Tampa Bay lost 45%, and Tampa Bay proper lost 35%. These losses have been attributed primarily to major shoreline modifications. Many area grass beds were completely filled in for land development, while those remaining suffered from siltation (e.g., reduced light penetration and muddy bottoms not conducive to growth and reproduction). Since 1963 (Figure 108), grass beds have continued to decline in the upper bays to a point where Hillsborough Bay has now lost all grass beds and Old Tampa Bay has lost nearly 60%. In the lower bay, grass beds appear to have regained some acreage, increasing about 14% in areal coverage.

Using a broader historical perspective, Lewis et al. (1985) estimate that seagrass beds covered 30,970 ha before human influence upon the bay (c. 1876). Based on their 1981 estimate of 5,750 ha, an estimated 81% reduction of seagrass beds has occurred bay-wide.

A somewhat similar mapping effort comparing grass-bed distributions within the Sarasota County

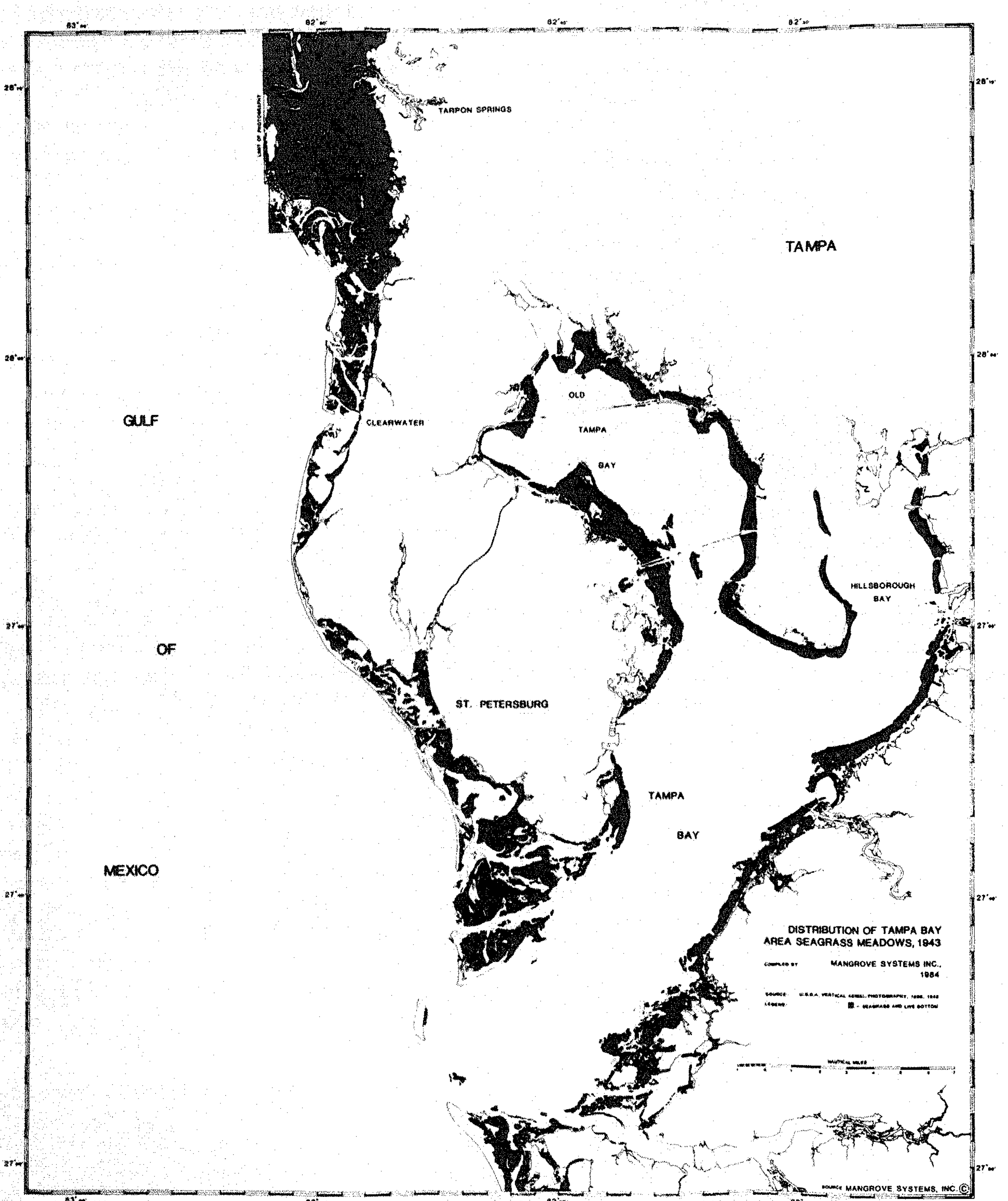


Figure 107. Seagrass distribution in 1943 (Lewis et al. 1985).

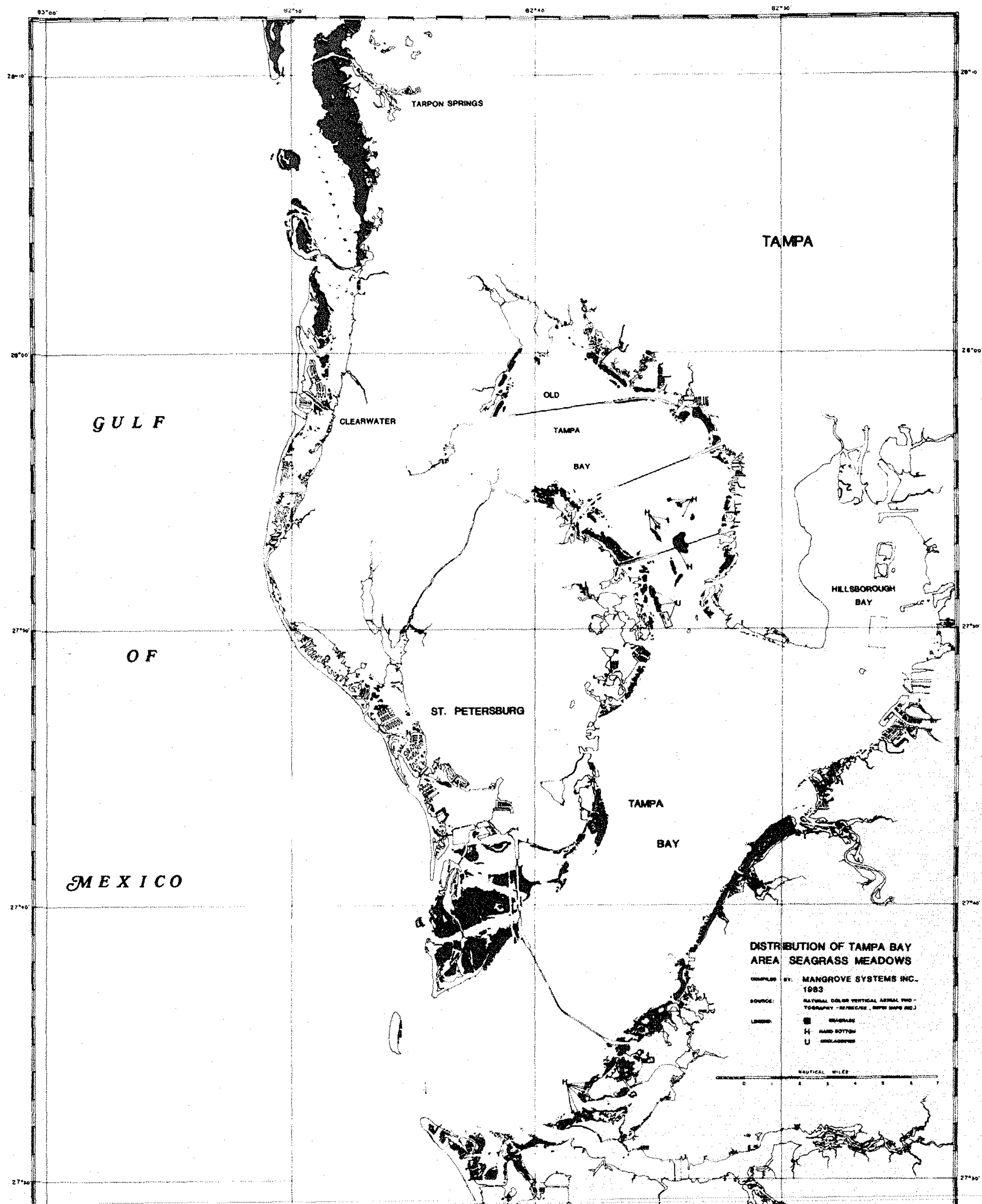


Figure 108. Seagrass distribution in 1983 (Lewis et al. 1985).

Table 27. Changes in seagrass distribution in the Tampa Bay system from ca. 1940 to 1983, based on aerial mapping (adapted from Lewis et al. 1985).

Location	c.1940	c.1963	Year 1973[a]	1979[a]	1983[b]
Hillsborough Bay					
Area (acres)	5,258	334	252	242	-0-
% of total bay system	18.7	2.4	1.7	1.7	-0-
% of 1940 acreage	100	6.4	4.8	4.6	-0-
% of 1963 acreage	—	100	75.4	72.5	-0-
Old Tampa Bay					
Area (acres)	11,653	6,405	6,467	6,185	5,409
% of total bay system	41.4	45.7	42.6	44.3	39.3
% of 1940 acreage	100	55.0	55.5	53.1	46.4
% of 1963 acreage	—	100	101.0	96.6	84.4
Tampa Bay Proper					
Area (acres)	11,260	7,292	8,451	7,534	8,340
% of total bay system	39.9	51.9	55.7	54.0	60.7
% of 1940 acreage	100	64.8	75.1	66.9	74.1
% of 1963 acreage	—	100	115.9	103.3	114.4
Total Bay System					
Area (acres)	28,171	14,030	15,170	13,961	13,749
% of 1940 acreage	100	49.8	53.8	49.6	48.8
% of 1963 acreage	—	100	108.1	99.5	98.0

[a] Mapping of seagrass distributions based on aerial photographs taken in January 1973 and 1979.
[b] Mapping of seagrass distributions based on aerial photographs taken in July 1983.

bay systems between 1948 and 1974 was conducted by Evans and Brungardt (1978). They reported an approximate 20% loss of seagrass coverage in the county (Table 28). Losses were attributed mainly to dredge-and-fill activities and the decline in water quality. The increase of 9% coverage in Little Sarasota Bay may be attributed to changes in current patterns as a result of construction of the Intracoastal Waterway, which increased both salinity and general water quality in the area.

Beyond the previous explanation for past loss of seagrass beds through direct burial and/or excavation, Lewis et al. (1985) suggest a subtler cause for continued declines (or absence of recovery) of area grass beds. They suggest that progressive eutrophication in the bay due to high nutrient loading from previously poor sewage treatment and continued urban runoff have increased microalgae and macroalgae populations to the point of reducing the amount of light reaching seagrass meadows.

Although there is no experimental data to document competition between phytoplankton and seagrasses in Tampa Bay, such competition has been theorized for other estuaries where nutrient enrichment has been followed by increases in microalgae (phytoplankton) and macroalgae and decreases in seagrass meadows (Cambridge 1975; Davis and Brinson 1980). This competitive turnover of primary producers has far-reaching implications for the overall environmental quality of the bay and should be investigated further.

b. Macroalgae. Macroalgae, defined here as macroscopic multicellular photosynthetic algae and usually found attached to a substrate, are another important vegetative community type within the open estuarine and nearshore waters of the Tampa Bay watershed. Separable from the phytoplankton, which are characteristically unicellular, free-floating, and microscopic, macroalgae are found in a wide variety

Table 28. Changes in seagrass distribution in Sarasota County bay systems between 1948 and 1974 (adapted from Evans and Brungardt 1978).

Location	Area (hectares) 1948	1974	Change Area	%
South Sarasota and Robert's Bay	784[a]	591	-193	-25
Little Sarasota Bay	156	170	+14	+9
Dryman, Blackburn, Dona and Robert Bays	108	77	-31	-29
Lemon Bay	259	204	-55	-21
TOTAL	1,307	1,042	-265	-20

[a] Complete aerial photographs were not available; this figure is an estimate based on 1974 data and historical information.

of habitats and serve a function similar to that described for seagrasses in providing food and cover for many small benthic and epibenthic invertebrates. Additionally, some species of marine algae are so prolific in the bay as to become a nuisance and a possible link in the eutrophication of the bay system (LaPointe et al. 1976; Bird et al. 1981; Dawes 1981, 1985).

Previous studies on the macroalgae in the area include those of Phillips (1960) for Tampa Bay, Boca Ciega Bay, and Tarpon Springs; Dawes (1967) within Tampa Bay; and Ballantine and Humm (1975) and Hamm and Humm (1976) for the Anclote estuary. Additional information on macroalgae communities offshore of Tampa Bay may be found in Phillips and Springer (1960), Dawes (1974), Mathieson and Dawes (1975), and Cheney and Dyer (1974). A recent review by Dawes (1985) provides the best description of habitats, physiological ecology, and environmental and economic features of the macroalgae of the Tampa Bay estuarine system. This latter work has been the foundation for the following discussion and should be referred to for further information on macroalgae within the bay system.

Two hundred twenty-one taxa, including 23 blue-green, 68 green, 1 xanthophyte, 30 brown, and 99 red macroalgae are reported for the Tampa Bay area (Dawes 1985). Sixty-nine of these are primarily tropical in distribution, leading Dawes (1985) to suggest that the macroalgal flora of Tampa Bay and vicinity has strong tropical affinities. Similar conclusions were drawn by Phillips and Springer (1960) for offshore areas.

The wide diversity of habitats available in the bay system is reflected in the diversity of algal communities that occur there. Extensive intertidal and shallow subtidal areas support emergent mangrove and salt-marsh plants and submergent seagrasses upon which are many epiphytic species of algae. Oyster shells, seawalls, limestone rubble, docks, and piling also provide readily available substrates for algal community growth. Other species are adapted to growing in the sediments within seagrass beds and on intertidal sand and mudflats. The macroalgal flora is more diverse and tends toward more tropical forms in the southern part of the bay, than in the northern regions that experience greater salinity and temperature fluctuations and reduced light penetration through higher turbidity.

Macroalgal communities in the estuary are best characterized by their relationships to tidal fluctuations and substrates. As described for grass beds, zonation is a common feature among algal assemblages. The upper limits are in part indicative of their physiological tolerances and reflect the effects of exposure to physical factors, so that species are distributed along a number of environmental gradients. Some of the more apparent physical factors affecting zonation include light, temperature, and exposure to desiccation, while chemical factors include oxygen level, salinity, nutrient levels, and pH.

The typical growth pattern of algal communities present in mangrove, salt marsh, and jetty habitats in Tampa Bay is that the upper intertidal zone is dominated by blue-green algae, the intermediate region by green algae, and lower intertidal region by red algae.

As with seagrasses, subtidal algae are limited in depth to about 3 m by the high turbidity of most bay waters. *Penicillus lamourouxii* and *Caulerpa* spp. flourish in the sand areas within grass beds, especially in the lower bay (Dawes 1985). Epiphytic species growing on the seagrasses include *Champia, Lomentaria, Polysiphonia, Acrochaetium, Fosliella, Hypnea, Spyridia, Cladosiphon, Ectocarpus*, and *Cladophora*. According to Dawes (1985), some or all of these may be present at one time, but the brown epiphytes are typically found in the late winter months.

Subtidal species common on limestone rubble, oyster shells, and man-made objects include *Hypnea, Cladophoropsis, Gracilaria, Chaetomorpha, Spyridia, Pterocladia, Padina, Sargassum*, and *Caulerpa*. Many of these are typically found at the south end of the Skyway bridge and Bishops Harbor (Dawes 1985).

Physiological studies of marine algae in Tampa Bay include Dawes et al. (1978); Hoffman and Dawes (1980); Bird et al. (1980, 1981); and Davis and Dawes (1981). All demonstrate typical estuarine adaptations to wide fluctuations in salinities and low light levels. In these studies, Tampa Bay macroalgae show highest photosynthetic rates in summer when temperatures reach 24–30°C. Dawes (1985) states, "such responses suggest a physiological basis for the tropical affinity of the Tampa Bay flora when compared to temperate and tropical floras," from other regions.

Macroalgal biomass and the energy available to consumers is essentially unknown for Tampa Bay or the gulf coast of Florida (Dawes 1985), although biomass can be quite high. Dawes et al. (1979), for example, report that the biomass of psammophytic and drift algae in a seagrass bed adjacent to Tampa Bay was equal to that of the seagrasses. Jones (1968) found that annual production of epiphytic algae was 20% of the estimated average net production of *Thalassia* in a turtle-grass bed in Biscayne Bay (Miami, Florida). The contribution of macroalgae productivity in seagrass beds specifically and to the estuarine system in general is poorly known and requires further study.

b. Open-bottom communities. Unvegetated bottoms, since they lack the superstructure of seagrasses and macroalgae, depend upon microscopic algae and imported detritus as the basis of their food chain. Where light penetration and nutrient levels permit, benthic diatoms and other microscopic algae may fix the energy into chemical bonds, thereby increasing their biomass and storing energy for later use. Where insufficient light precludes photosynthesis, heterotrophic production by bacteria or fungi may be the only method by which biomass may increase.

Although phytoplankton have been well studied in the bay, both taxonomically and as primary producers, benthic microalgal assemblages are not well known, even through they represent a significant primary production component of an estimated 100–200 gC/m^2/yr (Steidinger and Gardiner 1985). The importance of benthic microalgae in the food web of open-bottom communities may be high and deserves further study.

Benthic microalgae can serve as food sources for a variety of heterotrophs, act as sediment stabilizers, and often become entrained in the water column during turbulent events. On an areal basis, Steidinger and Gardiner (1985) suggest "primary production of benthic microalgae could equal planktonic production values yearly, yet trophically, benthic microalgae may represent a more direct food source to herbivores such as ciliates, small crustaceans, and filter or other suspension feeders than phytoplankton or detritus from the water column." The importance of this system in the energetics of the open-bottom community needs further study.

Without the seagrass or macroalgae structure, the majority of biological activity in open bottoms is confined to the sediment/water interface or within the sediments. Benthic infauna inhabiting open bottoms are generally detritivores obtaining their nutrition by ingesting microflora and the bacteria on decaying plant material and fecal pellets. Information on estuarine benthic fauna is summarized in Chapter 7.

c. Planktonic communities. Within Tampa Bay's water column, phytoplankton—free-floating, usually single-celled microscopic algae—are the primary producers. Compared with seagrasses, mangroves, and saltmarshes, productivity values per unit of surface area for phytoplankton are very small (Table 29). However, the area of potential production (the entire bay system through the photic zone—the depth limit of light penetration) is sufficiently large that their contribution to the estuarine system is great.

Phytoplankton, unlike the vascular plants, do not need to undergo the various steps required in the detrital food web before consumption, and so are a readily available food source for many estuarine inhabitants. Zooplankton and many larval fish feed heavily on phytoplankton, and in turn provide a food base for other estuarine animals in the watershed.

Phytoplankton in brackish and marine habitats are mainly represented by four microalgal groups: phytomicroflagellates (seven or more classes), diatoms, dinoflagellates and blue-green algae. Most range in size from less than 5 µm (ultraplankton) to 200 µm (microplankton) with some larger species (i.e., *Noctiluca)* reaching 1–2 mm in diameter. Nannoplankton, in the middle size range of 5–20 µm and often less than 15 µm, reportedly dominate the waters in Tampa Bay numerically (Steidinger and Gardiner 1985). However, due to their small size and taxonomic difficulties, few quantitative studies (Gardiner 1982) have been performed on this group in the bay.

Numerous studies on the phytoplankton in Tampa Bay and surrounding coastal waters are summarized in a review by Steidinger and Gardiner (1985). The major body of phytoplankton research in Tampa Bay has been provided by personnel at the National Marine Fisheries Service (Finucane and Dragovich 1959; Dragovich et al. 1961, 1963, 1965; Dragovich and Kelly 1964a, 1966; Rounsefell and Nelson 1966; McNulty et al. 1970) and the Florida Department of Natural Resources (Eldred et al. 1964; Saunders et al. 1967; Steidinger et al. 1967; Steidinger and Williams 1970; Steidinger and Ingle 1972; El-Sayed et al. 1972; Steidinger 1973, 1975a,b; Steidinger and Haddad 1981). The majority of these two agencies' contribution was in response to data needs for assessing the nature of Florida west-coast red tides. Additional studies and monitoring programs involving phytoplankton standing stock, associated physio-chemical variables, and/or primary productivity have been conducted or are under way by the Hillsborough County Environmental Protection Commission, the city of Tampa, Tampa Electric Company, and the

Table 29. Net primary production (NPP) of major estuarine habitat components (adapted from Harris et al. 1983).

Habitat	Average ($gC/m^2/day$)	Range ($gC/m^2/day$)	Source
Mangroves (all species)	5.3	1.0–12.6	Odum et al. 1982
Seagrasses (*Syringodium, Halodule,* and *Thalassia)*	1.0–4.0	0.5–16.0	Zieman 1982
Salt marsh	4.2	0.8 - 8.2	Durako et al. 1983
Mud flat	0.5	—	Pomeroy 1960
Water column (phytoplankton)	0.9	—	Thayer and Ustach 1981

Florida Department of Environmental Regulation. The University of South Florida, through various theses and contract work, has added greatly to the body of knowledge on phytoplankton in the Tampa Bay system.

A total of 272 taxa of microalgae identified to species or varieties have been recorded from the Tampa Bay system (Steidinger and Gardiner 1985). Diatoms are the most diverse group with 167 species in 65 genera, followed by dinoflagellates with 78 species in 28 genera, microflagellates with 25 species in 18 genera, and blue-green algae with only four species. A complete listing of these species with reference to their records of occurrence may be found in Steidinger and Gardiner (1985).

In addition to other environmental factors for seagrasses and macroalgae, circulation patterns often limit the occurrence, diversity, and abundance of phytoplankton. Where there is less water exchange, there may be higher standing stocks of phytoplankton due to increased accumulation and growth and reduction in mixing and export to other areas. This is particularly true in upper reaches of estuaries such as Tampa Bay, where flushing and mixing rates are low and addition of nutrients is high. Under these conditions massive algal blooms often result, which may lead to anoxic conditions in the water column that result in fish kills and mass mortality in benthic infaunal communities (Taylor 1970; Simon 1974).

McNulty et al. (1970) associated spring phytoplankton blooms with temperature and nutrients and summer peaks with salinity and nutrients. Rounsefell and Nelson (1966) found no correlation with high occurrence of *Ptychodiscus breve* (formerly *Gymnodinium breve)* and nutrients but did with temperature, salinity, and onshore winds. Although theoretically, some nutrients could be growth limiting, particularly during seasonal blooms, phytoplankton have varied nutritional strategies and adaptations in relation to availability and uptake (Steidinger and Gardiner 1985). Bioassay work (Smayda 1974) suggests that microconstituents produced as external secretions or ectocrines, acting as either growth inhibitors or stimulators, regulate succession of certain phytoplankton populations, rather than inorganic macronutrients such as nitrate, nitrite, ammonia, and orthophosphates. Steidinger and Gardiner (1985) state, "It is conceivable that light, temperature, and salinity influence the breaking of dormancy in benthic resting stages [of certain phytoplankton] and that ectocrines and circulation patterns influence dominance and abundance of planktonic stages—at least for dinoflagellates." An example is *Gonyaulax monilata*, a toxic dinoflagellate that yearly appears in blooms from July through September in Tampa Bay, but is usually absent from the water column in other months. *Gonyaulax monilata* is primarily an estuarine species and has known seedbeds that inoculate the water column in Old Tampa Bay (Steidinger and Gardiner 1985).

Most bloom species are autochthonous like *G. monilata* and originate in the bay system either from benthic or planktonic populations. Two exceptions are *Ptychodiscus breve* and *Oscillatoria erythreae,* which periodically enter the bay from oceanic or coastal sources. Of special interest is the toxic dinoflagellate *P. breve*, which is mainly responsible for Florida's red tides. This species originates from offshore benthic seed beds in a discrete zone some 15–65 km offshore (Steidinger 1973, 1975a,b), not inshore near passes as formerly thought. Offshore initiation of a bloom event is thought to be associated with intrusions of oceanic water on the broad Continental Shelf (Haddad and Carder 1979; Steidinger and Haddad 1981; Haddad 1982). The bloom is then transported into coastal and bay waters by currents and winds. Once in the estuary, the degree of penetration and duration of the bloom in the bay is dependent on the salinity regime. As described by Steidinger and Gardiner (1985); "Between 1946 and 1982, various portions of the Tampa Bay system were exposed to this invader [*P. breve*] at least 12 times, usually in the lower reaches. In two outbreaks, 1963 and 1971, *P. breve* penetrated the upper reaches and in one instance, this species dominated for over three months. The only reason *P. breve* was able to establish itself in the upper portion of the system was because of higher than normal salinity regimes (up to 31 ppt) due to drought conditions at the time of the outbreak. In 1963, with the lowering of salinities due to rainfall, the species quickly disappeared, but in

1971 there was no or minimal rainfall during its bloom duration. The species does not survive in waters less than 25 ppt."

When in high concentrations, *P. breve* produces a neurotoxin sufficient to cause death in many marine and estuarine animals (>250,000 cells/liter is considered lethal to fishes). Eldred et al. (1964) reported on the 1963 Tampa Bay red tide and were the first to associate a cause-effect relationship between *P. breve* populations and the periodic toxicity of shellfish to humans. This was later confirmed by McFarren et. al. (1965), using mouse bioassays. Although mortalities of inshore reef fish have been documented (Steidinger and Ingle 1972), repopulation is fairly rapid and no great impact to commercial fisheries have occurred. The greatest economic concern from Florida red tides is the reduction in tourism and resident recreational use of the affected areas.

An indirect measure of the quantity of phytoplankton in a body of water is through chlorophyll analysis, an analytical measurement of the color pigments found in most plants. Although admittedly not a true measure of phytoplankton biomass, since chloroplasts may vary in number, size, and pigment content per cell, chlorophyll determinations are useful in comparing phytoplankton abundance between areas and over time.

Chlorophyll has been measured throughout the bay system for some time. Perhaps the most comprehensive sampling has been done by the HCEPC, who have been monitoring the bay system since 1972. Although chlorophylls *a*, *b*, *c*, and totals have been measured, chlorophyll *a* was the pigment most precisely and accurately determined (HCEPC 1982).

A definite north-to-south trend in chlorophyll *a* levels is found in the bay, increasing as one proceeds up the estuary. This is evident in Figure 109, which shows average chlorophyll *a* values for 1981. High levels (20 µg/L or more) are typically reported throughout McKay and Hillsborough Bay, tapering to 15 and 20 µg/L in the upper east half of middle Tampa Bay. Most of Old Tampa Bay and the western portion of the middle bay average 10–15 µg/L, except for one area northeast of the Courtney Campbell Causeway (average 20 µg/L) and the Largo Inlet area, where values range between 15 and 20 µg/L. Chlorophyll *a* levels quickly decline through the lower bay to the mouth, where levels average less than 5 µg/L.

Temporal trends in chlorophyll *a* levels in the four areas of the bay delineated above are shown in Figures 110 and 111. As noted above, Hillsborough Bay consistently has the highest concentrations, due mainly to seasonal algal blooms throughout the year. Bloom species detected in various locations throughout the bay system during 1981 are presented in Appendix Table A-10. Old Tampa Bay and middle Tampa Bay do not experience algal blooms of the severity or longevity of Hillsborough Bay and therefore have lower chlorophyll *a* levels. It is interesting to note that a slight increase in chlorophyll *a* values has occurred for all areas of the bay over the time period of record. According to a review of these data by Steidinger and Gardiner (1985), values shown may actually be an underestimate of true phytoplankton productivity, particularly during diatom peaks or blue-green algal blooms, because of procedural inadequacies in extraction of chlorophyll from all cells.

The small, chain-forming diatom *Skeletonema costatum* is the most abundant planktonic species commonly reported in the bay (Dragovich and Kelly 1964a, 1966; Saunders et al. 1967; Steidinger et al. 1967; Turner 1972; Hughes and Parks 1977; Steidinger and Gardiner 1985). This species often numerically dominates the water column from January to April/May, and then again in the fall. *Skeletonema costatum* is followed in abundance by larger diatoms such a *Bellerochea* and *Rhizosolenia.* Certain species in these two genera can dominate in late spring and summer, as can *Chaetoceros.* Dinoflagellates (e.g., *Gymnodinium nelsonii, Ceratium hircus, Prorocentrum micans, Gonyaulax* spp., and others), either in mixed or in monospecific blooms, may dominate the upper and middle reaches of the bay in summer, fall, and even late spring, depending on environmental conditions. These bloom species, along with the blue-green algae *Schizothrix*, often lead to oxygen depletion in the shallow waters of the upper bay system, causing fish and invertebrate mortality.

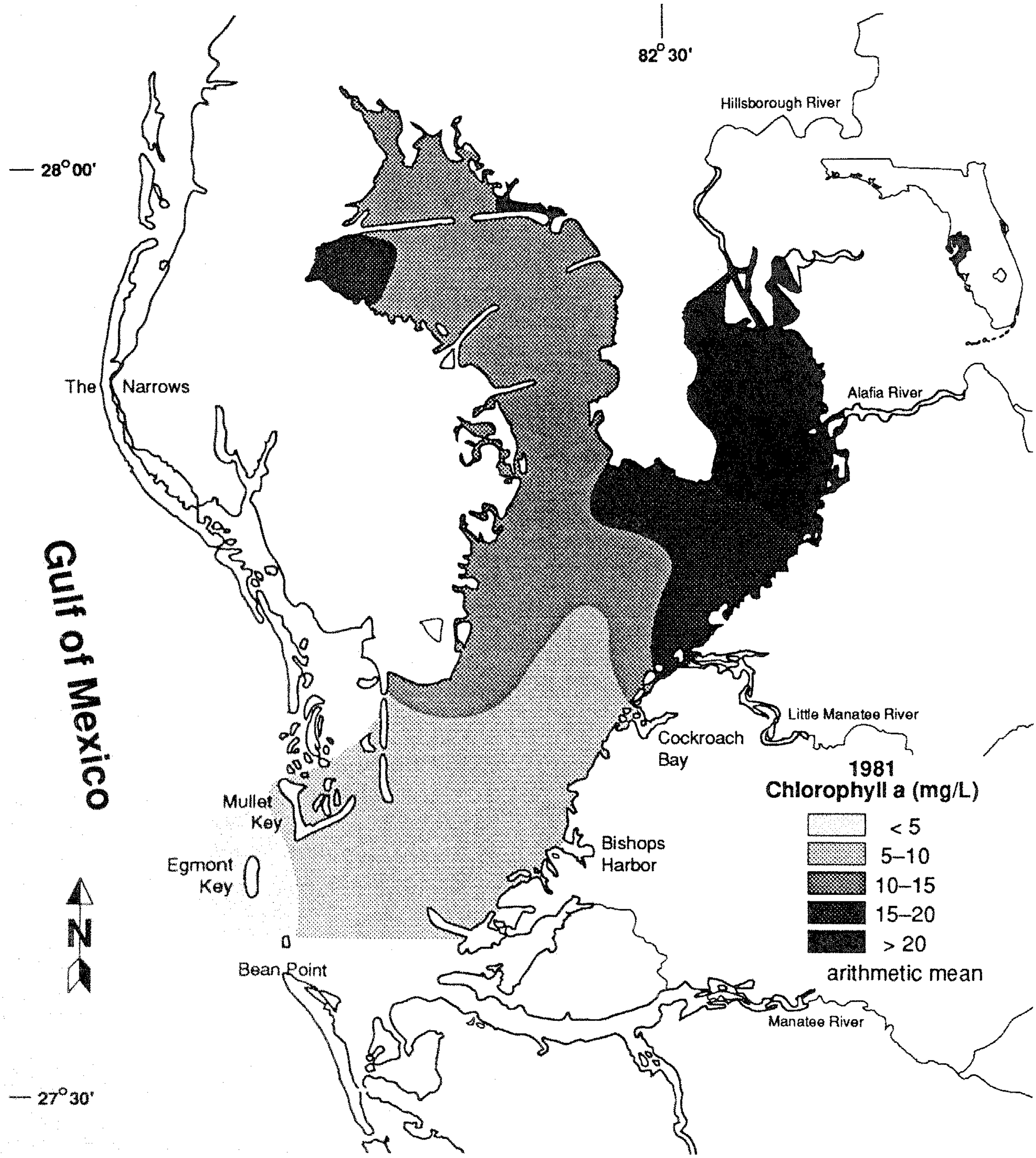


Figure 109. Average levels of chlorophyll a in the Tampa Bay system 1981 (after HCEPC 1982).

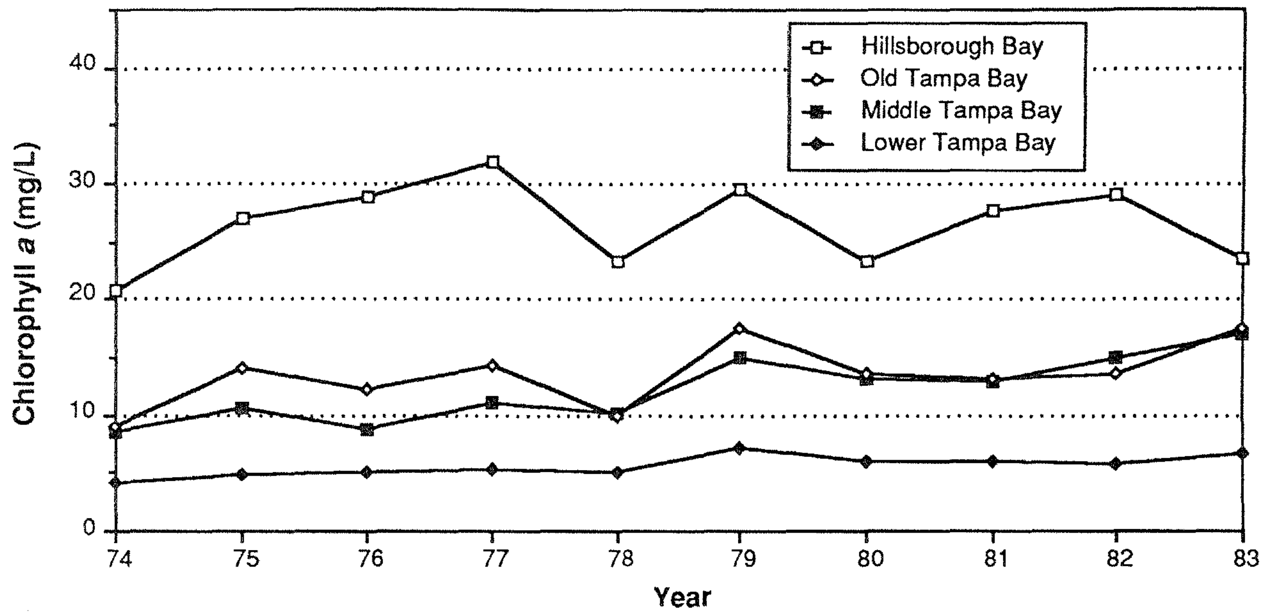


Figure 110. Yearly trends in chlorophyll *a* concentrations in four areas of Tampa Bay (after HCEPC 1983).

Even though there are year-to-year fluctuations in species occurrence and dominance, a broad temporal pattern appears to emerge in the phytoplankton community, from small diatoms to larger diatoms to dinoflagellates to blue-green algae. According to Steidinger and Gardiner (1985), this successional sequence implies that major seasonal events such as freshwater inputs, temperature, photoperiod, organic conditioning agents, and life-history strategies (i.e., benthic resting stages), are more important than nutrient regimes, at least in estuaries.

5.4.4 Beach, Dune and Coastal Strand

The ecological communities that develop along the beachfront occupy a very sharp transition zone that ranges from open marine conditions on the seaward end to well-drained sandy terrestrial conditions on the other, frequently within distances of only a few meters. These transition communities are regularly exposed to physical and chemical extremes such as high winds, salt spray, storm surges, ceaselessly pounding waves, and intense heat and drought.

Figure 112 presents a generalized profile of the typical transition from beach to coastal strand community. This profile represents a composite from several authors (Ingle 1962; Collard and D'Asaro 1973; Riedl and McMahan 1974; Herwitz 1977; Morrill and Harvey 1980).

The upland end of this transition may be dominated by any number of plant communities, depending on specific local conditions and historical influences. Herwitz (1977) identifies no less than 12 different habitats on Cayo Costa Island. Those dominated by terrestrial vegetation include beach, coastal strand, savannah, cabbage palm forest, tropical hammock, Australian pine forest, and pine flatwoods. Morrill and Harvey (1980) report the same communities from North Captiva Island, as well as a unique hardwood swamp association. Freshwater marshes and ponds are also reported by Herwitz (1977), as are saltwater wetlands such as brackish and hypersaline pools, salt barrens, salt flats, salt marshes, and mangroves.

On the less wave-influenced spoil islands in the lee of barrier chains, fewer communities are evident and coastal strand, Australian pines, mangroves, and salt barrens predominate (Carlson 1972). As beach

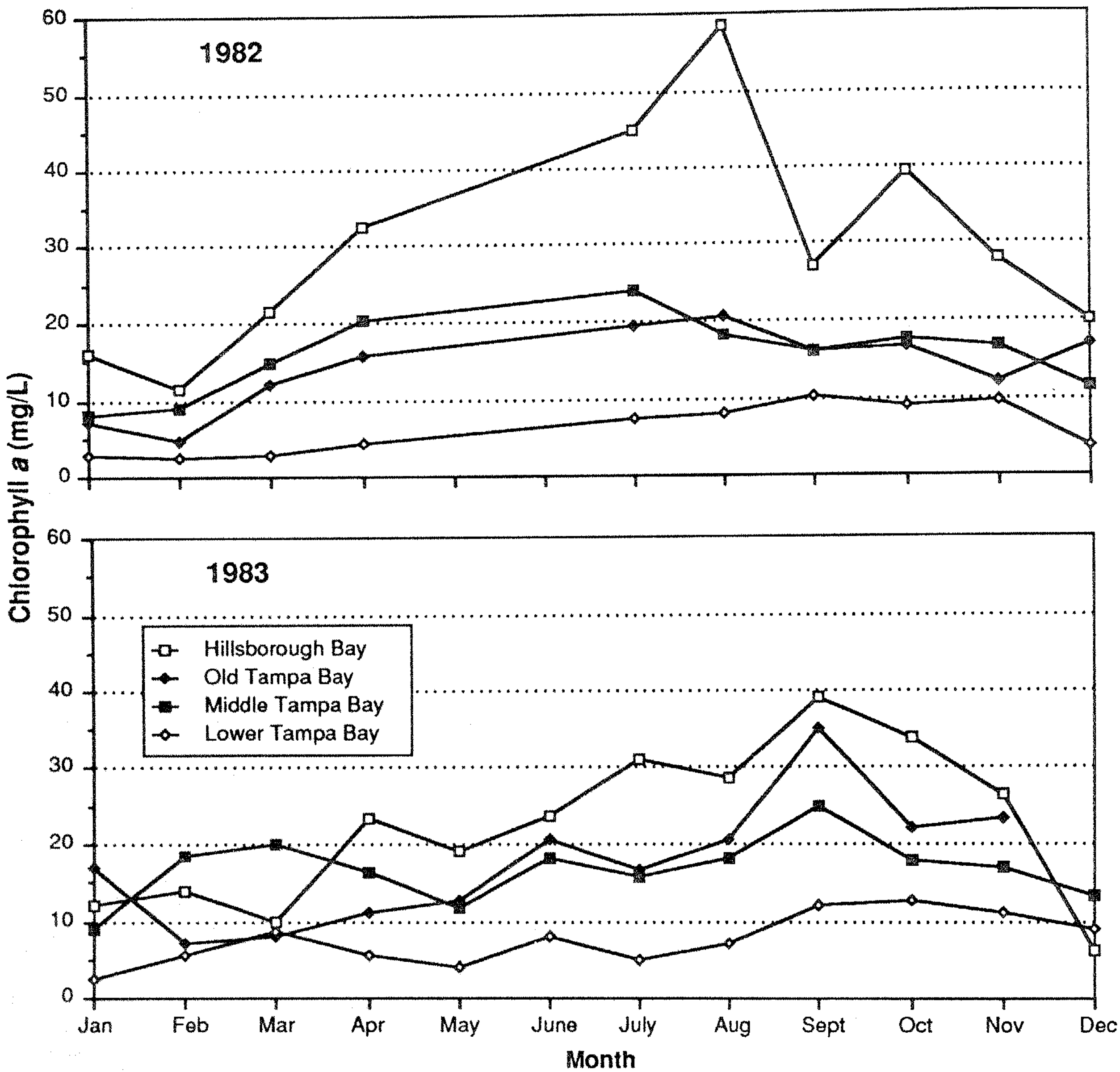


Figure 111. Monthly trends in chlorophyll *a* concentrations in four areas of Tampa Bay during 1982-83 (data from HCEPC 1982).

barrier islands are developed, at least two additional types of land cover are created—residential and commercial sites. Disturbances for construction and maintenance of these land uses, as well as roadways, further complicate vegetation patterns and habitat development (Morris et al. 1978). Invasion of disturbed hammocks by Brazilian pepper-tree (*Schinus terebinthifolius*) is an example.

The beach zone is in a constant state of change. Consequently, species diversity is always low. An additional source of energy in this community is provided by the influx of sea wrack, a variable-sized mass of detritus washed up onto the beach by storm waves and seasonally high tides (Rabkin and Rabkin 1978). Seagrasses, algae, and assorted animal debris are major contributors to sea wrack.

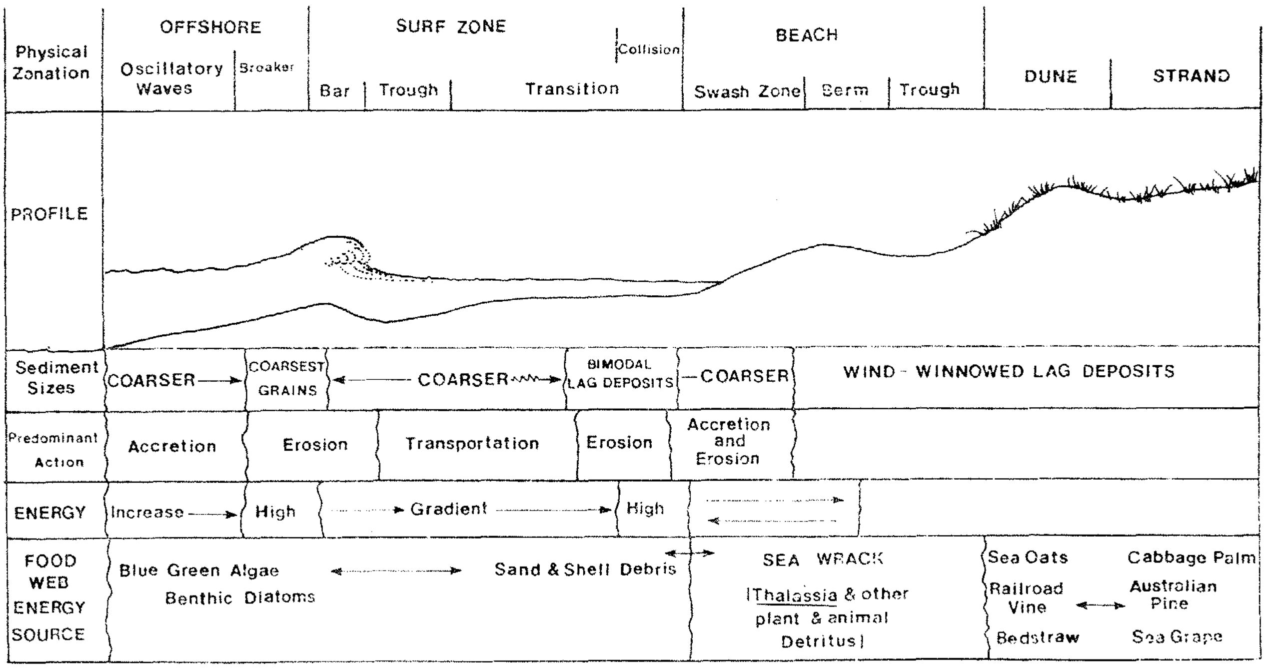


Figure 112. High energy beach community showing major zones relating to sand motion (adapted from Riedl and McMahan 1974).

Just inland from the beach, where physical conditions are relatively more stable, pioneering plant species have morphological adaptations suited to the environment. Thickened cuticle and succulent foliage are evident in many species such as sea rocket (*Cakile edentula*), sea purslane (*Sesuvium portulacastrum*), inkberry (*Scaevola plumieri*), sand atriplex (*Atriplex arenaria*), sea blite (*Suaeda linearis*), marsh elder (*Iva imbricata*), and spurge (*Chamaesyce mesembryanthemifolia*). Those having subterranean and surface runners include railroad vine (*Ipomoea pes-caprae*), coastal dropseed (*Sporobolus virginicus*), and milkweed vine (*Cynanchum angustifolium*). One of the most noteworthy capacities of beach plants is their ability to maintain their position above accumulating sand particles. The most adept at this are sea oats (*Uniola paniculata*) and marsh elder.

Stands of sea oats and marsh elder moderate the effects of wind and salt spray and permit less tolerant species to survive. Croton (*Croton punctatus*) and Hercules club (*Zanthoxylum clava-herculis*) are among the members of this coastal strand association. Other members that suggest less stressed inland communities include greenbriers (*Smilax auriculata*), muhly-grass (*Muhlenbergia capillaris*), Larry gramagrass (*Bouteloua hirsuta*), ernodea (*Ernodea littoralis*), joewood (*Jocquivia keyensis*), and necklace pod (*Sophora tomentosa*). Pioneer weed species also play a big role in the coastal strand. Representatives include beggar tick (*Bidens pilosa*), dayflower (*Commelina erecta*), spurge (*Chamaesyce blodgetti*, *C. cumulicola*), fingergrass (*Chloris petrea*), digitaria (*Digitaria villosa*), and sandspurs (*Cenchrus incertus*, *C. gracillimus*). Many beach species such as inkberry, prickly pear cactus (*Opuntia humifusa*), Spanish bayonet (*Yucca aloifolia*), and evening primrose (*Oenothera laciniata*) also thrive in the strand environment.

Inland of the rolling strand-vegetated dunes, the environment is more moderate, and savannah-like habitats may develop. This inland gradient of protection arises not only from foredune ridges covered by coastal strand vegetation, but also, in places, by stands of Australian pine (*Casuarina* *equisetifolia).* Younger stages of the savannah development are characterized by grasses such as *Bouteloua hirsuta* and considerable areas of open sand. Within the savannas, islands of cabbage palms *(Sabal palmetto)* may be found, generally on the higher elevations. Frequent associates of this community assemblage include cocoplum *(Chrysobalanus icaco)*, seagrape *(Coccoloba uvifera)*, varnish leaf *(Dodonaea viscosa)*, and emodea. The understories of such islands may serve as habitat for other vines (*Toxicodendron*), grasses *(Muhlenbergia)*, and epiphytes *(Tillandsia, Phlebodium*, and *Encyclia)*.

As the savannas become sufficiently protected from salt spray, other trees and herbaceous plants, such as lantana *(Lantana ovatifolia)*, myrsine *(Myrsine floridana)*, waxmyrtle *(Myrica cerifera)*, and live oak *(Quercus virginiana)* begin to invade the cabbage palm islands. In the grassy swales, *Bouteloua hirsuta* shares dominance with muhly-grass, prickly pear, gopher apple *(Licania michauxii)*, and varnish leaf.

Extensive and well-developed stands of cabbage palm forest may develop. These forests generally have closed canopies shared by cabbage palm and live oak. A humus layer is usually present on the forest floor as well. The resulting temperature moderation and moisture-holding capacity provide a suitable environment for ferns such as golden polypody *(Phlebodium aureum)*, swamp fern *(Blechnum serrulatum)*, marsh fern *(Thelypteris palustris)*, *T. humilis*, chain fern *(Woodwardia virginica)*, shoestring fern *(Vittaria lineata)*, resurrection fern *(Polypodium polypodioides)* and bracken fern *(Pteridium aquilinum)*. Table 30 outlines the major vegetational changes observed between savannas and cabbage palm forests.

Because periodic fire is a factor in cabbage palm forest development, species composition varies with the specific site history and characteristics. Herwitz (1977) identified at least four subassociations within the cabbage palm forest zone:

1. Monotypic cabbage palm stands
2. Live oak and saw palmetto saplings more abundant than cabbage palm, giving the habitat a scrub-like appearance.
3. Sparsely scattered herbs such as pinweed (*Lechea* sp.), pink purslane *(Portulaca pilosa)*, and heliotrope *(Heliotropium angiospermum)*.
4. Site invaded with slash pine *(Pinus elliottii)*, and with grasses such as *Setaria corrugata* and *Muhlenbergia capillaris*.

The cabbage palm forest is regarded as an arrested subclimax in such narrow barrier island systems. If island width were greater, further forest development might proceed toward an oak climax association (Kurz and Wagner 1957; Herwitz 1977).

Occasional stands of slash pine may spread and reach canopy dominance in areas of human disturbance. Other species in these atypical flatwoods associations include saw palmetto *(Serenoa repens)*, procession flower *(Palygala incarnata)*, ground cherry *(Physalis viscosa)*, prickly pear cactus, galingale *(Cyperus planifolius)*, and *Rhynchosia reniformis*. The woody species myrsine, lantana

Table 30. Major vegetational changes from savannah to cabbage palm forests on a coastal barrier island (adapted from Herwitz 1977).

Increased abundance	Decreased abundance	New elements
Bayberry *(Myrica cerifera)*	Cocoplum *(Chrysobalanus icaco)*	Marlberry *(Ardisia escallonioides)*
Myrsine *(Myrsine floridana)*	Seagrape *(Coccoloba uvifera)*	Beauty-berry *(Callicarpa americana)*
Wild coffee *(Psychotria nervosa)*	Varnish leaf *(Dodonaea viscosa)*	White stopper *(Eugenia axillaris)*
Live oak *(Quercus virginiana)*	Ernodea *(Ernodea littoralis)*	Florida privet *(Forestiera segregata)*
Cabbage palm *(Sabal palmetto)*	Joewood *(Jocquivia keyensis)*	Lead tree *(Leucaena leucocephala)*
Saw palmetto *(Serenoa repens)*	Necklace pod *(Sophora tomentosa)*	Redbay *(Persea borbonia)*
Poison ivy *(Toxicodendron radicans)*		Rouge plant *(Rivina humilis)*
Tallow-wood *(Ximenia americana)*		Muscadine grape *(Vitis rotundifolia)*

(*Lantana camara*), randia (*Randia aculeata*), snowberry (*Chiococca alba*), and coral beam (*Erythrina herbacea*), found in cabbage palm forests, are usually absent from pine flatwoods.

On some elevated and well-drained locations such as Indian mounds or storm-accumulated shell deposits, tropical hammocks may develop. Table 31 lists typical species of the tropical hammock association.

Another upland vegetation association in coastal settings is the introduced Australian pine (*Casuarina equisetifolia*) (see section 5.5). In its most developed state, this association is a monotypic stand, the only other species being the saprophytic fungus *Pogonomyces lyduoides* which lives on dead trunks and branches. More commonly, Australian pines grow on gulfside foredunes, where they invade the sea oat, elder, and inkberry zone. Some species diversity tends to be maintained around ponds, probably from the increase of available habitats. Occasionally, Australian pines may also invade bayside locations where soil salinities are low and drainage adequate. Some interior swales of barrier islands are seasonally saturated, producing wetlands dominated primarily by graminoid (grass) species. Three wetland subassociations are identified by Herwitz (1977), based on dominant species. Species dominance appears to be related to the proximity of the water table (Table 32). In addition to grass-dominated freshwater wetlands, hardwood swamps may occur (Morrill and Harvey 1980). On the perimeter of such sites, characteristic savannah vegetation is found. Toward the center are widely spaced cabbage palms and a few old buttonwoods (*Conocarpus erectus*). Strangler fig (*Ficus aurea*) and waxmyrtle may also occur. Still lower, near the water's edge, species dominance changes from cabbage palm to pond apple (*Annona glabra*), with a few large buttonwoods.

According to Herwitz (1977), the vegetation zonation of west-coast barrier islands develops in response to two forms of salt influence. From the gulf side, salt spray and waves control vegetative succession, whereas on the bay side, high tide inundation and underground seepage are responsible. These two patterns of influence are summarized in Figure 113.

From the bayside direction, the transition proceeds from regularly inundated mangrove pools through salt barrens and flats to freshwater marshes. Characteristic species are similar to those in more interior locations of the watershed. Salt flats are dominated by saltwort (*Batis maritima*) and sea daisy (*Borrichia frutescens*). Where species such as saltgrass (*Distichlis spicata*) and coastal dropseed dominate, the flat is referred to as a salt meadow. Salt barrens, because of the hypersaline soil water, are generally devoid of vegetation. As this soil water slowly leaches from the surface and is diluted by rainwater, salt flats and meadows may form. As the water continues to freshen on such locations, characteristic freshwater marsh species begin to dominate. Two subassociations of marshes are noted by Herwitz (1977), one dominated by sawgrass (*Cladium jamaicense*), and one dominated by cattail (*Typha domingensis*). These two types of marsh are distinguished from the interior wetlands on the basis of their soils. The wetlands occur in sandy depressions that are low enough to tap into the shallow water table part of the year. The marshes occur in sandy muck and become high ground as halophytic vegetation accumulates and slowly decomposes into peaty soils.

Superimposed onto the natural successional processes of barrier islands are the impacts of human development. A variety of examples may be found in the region, ranging from relatively undisturbed (e.g., Cayo Costa) to rather intensively developed (e.g., Sanibel Island). Major categories of disturbed habitats include spoil from dredge operations, bulkheaded or riprap shorelines, jeep trails, and the immediate vicinities of structures (roads, buildings). In addition to the introduction of nonnative flora, considerable impact may also be caused by faunal introductions such as the feral hog (*Sus scrofa*) (Herwitz 1977). Their movements and mode of feeding result in a constant disturbance to native flora and fauna. Their food preferences are believed to be responsible for the paucity of small vertebrates such as snakes, lizards, turtles, and small rodents (Herwitz 1977).

Table 31. Characteristic species of the tropical hammock association on a coastal barrier island (adapted from Herwitz 1977).

Trees	**Shrubs**
Gumbo-limbo (*Bursera simaruba*)	Marlberry (*Ardisia escallonioides*)
Jamaica capertree (*Capparis cynophallophora*)	Snowberry (*Chiococca alba*)
Papaya (*Carica papaya*)	Guinea-hen weed (*Petiveria alliacea*)
Seagrape (*Coccoloba uvifera*)	Wild coffee (*Psychotria nervosa*)
White stopper (*Eugenia axillaris*)	Rouge plant (*Rivina humilis*)
Boxleaf stopper (*Eugenia foetida*)	Wild lime (*Zanthoxylum fagara*)
Strangler fig (*Ficus aurea*)	
Wild-mastic (*Mastichodendron foetidissimum*)	**Vines**
Cabbage palm (*Sabal palmetto*)	Moon flower (*Ipomoea indica* var. *acuminata*)
	Poison ivy (*Toxicodendron radicans*)
Herbs	Summer grape (*Vitis aestivalis*)
Leafless cynanchum (*Cynanchum scoparium*)	
Sweet broom (*Scoparia dulcis*)	

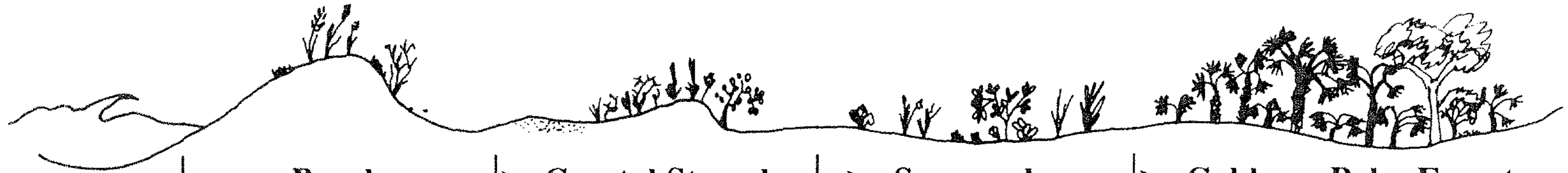
5.5 Disturbed Communities

As the land is developed to serve human cultural needs, the natural balance and relative abundance of vegetation communities are inevitably rearranged. These changes may be effected directly, as in the wholesale replacement of one community (e.g., a pineland forest) with one more suited to the human economy (e.g., a citrus grove) or by the removal of the natural community, as in mineral-resource development. They may also happen indirectly, as with the inadvertent introduction of exotic species, or through regional drainage and flood- or erosion-control operations. Of the direct changes, strip mining is a wholesale replacement of the existing communities; however, the imposed land use is relatively short lived (few years) and is followed by natural succession or human-assisted reclamation.

Such disturbances bring about fundamental changes in the relative distribution and abundance of habitats available to fish and wildlife and in the relationships between such habitats, by a restructuring of the community that favors some species and disfavors others. When a community is disturbed, the exact impact of the restructuring on fish and wildlife is often indirect and difficult to predict. If the soil profile is changed or soil cover is removed, for example,

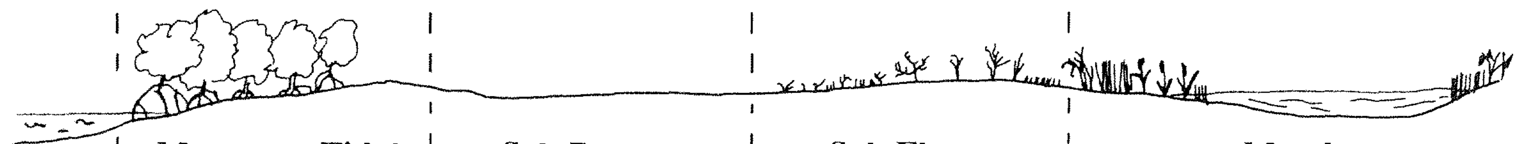
Table 32. Species composition of the wetland subassociations on a coastal barrier island (adapted from Herwitz 1977).

Elevation	Dominant Species	Characteristically associated species
Driest	Leather fern (*Acrostichum danaeifolium*)	*Blechnum serrulatum, Hydrocotyle umbellata, Pluchea rosea, Samolus ebracteatus.*
	Beard grass (*Andropogon glomeratus*)	*Dichromena colorata, Flaveria linearis, Muhlenbergia capillaris, Panicum virgatum, Scleria triglomerata, Setaria geniculata, Toxicodendron radicans.*
Wettest	Saw grass (*Cladium jamaicense*)	*Acrostichum danaeifolium, Apium leptophyllum, Bacopa monnieri, Polygonum hydropiperoides, Sagittaria lancifolia, Spartina bakeri.*



Gulfside Succession

Beach →	Coastal Strand →	Savannah →	Cabbage Palm Forest
Little-to-no vegetation	Coast sandspur *(Cenchrus incertus)*	Hairy grama *(Bouteloua hirsuta)*	Cabbage palm *(Sabal palmetto)*
Sea oats *(Uniola paniculata)*	Muhly grass *(Muhlenbergia capillaris)*	Broom-sedge *(Andropogon virginicus)*	Live oak *(Quercus virginiana)*
Beach elder *(Iva imbricata)*	Spanish bayonet *(Yucca aloifolia)*	Seagrape *(Coccoloba uvifera)*	Saw palmetto *(Serenoa repens)*
Railroad vine *(Ipomoea pes-caprae)*	Beach-berry *(Scaevola plumieri)*	Gopher apple *(Licania michauxii)*	Greenbriar *(Smilax auriculata)*
Sea rocket *(Cakile lanceolata)*	Coco plum *(Chrysobalanus icaco)*	Joewood *(Jocquivia keyensis)*	Wax myrtle *(Myrica cerifera)*
	Croton *(Croton punctatus)*	Varnish leaf *(Dodonaea viscosa)*	
	Seaside evening primrose *(Oenothera humifusa)*	Cactus *(Opuntia humifus)*	



Bayside Succession

Mangrove Tidal Pools →	Salt Barrens →	Salt Flats →	Marsh
Red mangrove *(Rhizophora mangle)*	**Little or no vegetation**	Saltwort *(Batis maritima)*	Southern cattail *(Typha domingensis)*
White mangrove *(Laguncularia recemosa)*		Sea daisy *(Borrichia frutescens)*	Cordgrass *(Spartina bakeri)*
Black mangrove *(Avicennia germinans)*		Saltgrass *(Distichlis spicata)*	Water hyssop *(Bacopa monnieri)*
Buttonwood *(Conocarpus erectus)*		Dropseed *(Sporobolus virginicas)*	Hedge hyssop *(Gratiola virginiana)*
		Glasswort *(Salicornia virginica)*	Cowpea *(Vigna luteola)*
		Christmas berry *(Lycium carolinianum)*	Sawgrass *(Cladium jamaicense)*
		Sea oxeye *(Borrichia frutescens)*	

Figure 113. Two patterns of spatial succession of vegetation community types on west coast barrier islands.

changes are also induced in the soil arthropod community. In turn, those organisms trophically linked to soil arthropods may be affected. The new soil structure may be less able to protect burrowing amphibians from desiccation during drought. Important water- and nutrient-holding capacity may also be lost, causing physiological stress for the remaining vegetation. Any loss of or stress to vegetation may result in the loss of fauna dependent on the food and shelter the habitat provides.

For discussion purposes, disturbed communities in the watershed are combined into six main categories:

1. Exotic invaders.
2. Agricultural communities.
3. Urban/industrial communities.
4. Canal and other artificial-structure communities.
5. Phosphate strip-mined communities.
6. Spoil island communities.

These six categories cannot be clearly delineated from one another; e.g., agricultural crops could be a special case of invasion by an exotic species, and canal and other artificial communities are often integral parts of the other disturbed-community categories.

The success of disturbed communities can frequently be linked to changes in environmental conditions brought on by associated development activities. Virtually all disturbances create sites or ecological niches that have not previously existed in south Florida. Thus, as agriculture, urban-industrial development, strip-mining, and channelization result in new physical-chemical background conditions, they may provide new directions in ecological interactions, succession, and fish and wildlife production. In principle, at least, human activities function as analogs of natural arresting and diversionary influences on community succession. However, they often alter communities so that many species cannot adapt. The disturbances resulting from human activities differ from natural influences in a number of important ways including the following:

1. Historical persistence—most human influences have occurred only in the past 100 years.
2. Frequency—unlike hurricanes, floods, or fire which are acute but only periodic events, human influence is often continuous and chronic.
3. Spatial coverage—the spread of development activities usually follows a radiating pattern from preexisting disturbances with little regard for existing vegetation or soil conditions. In contrast, natural successional influences are more strongly modified by existing conditions (e.g., ground cover, soil types, elevations).
4. Selective direction—by chronic control of environmental conditions, human influences favor success of new species associations with unknown fish and wildlife value.
5. Energy cost—environmental changes induced by human activity almost always involve long-term operation and maintenance costs as well as startup costs. These costs must be balanced by society against the benefits derived from the altered communities.
6. Form—local anthropogenic ecological changes are frequently motivated by events, needs, and processes far removed from the disturbance, (e.g., fertilizer needs in the Soviet Union result in disturbances of Polk County pine flatwoods).

5.5.1 Exotic Plant Communities

Although both agricultural crops and ornamental plants may be considered "exotic" species, this section of the report deals only with those exotics that survive and spread in the wild. The cultivation of crops and ornamentals presents a unique set of disturbances that are dealt with in Section 5.5.2.

Exotics that survive and spread in the wild are quite common in south-central Florida and account for about 16% of the species (Long 1974). Duever et al. (1979) list over 250 exotic plant species found in the Big Cypress National Preserve. These authors cite two reasons why south Florida is particularly vulnerable to invasion by exotics:

1. The area is geologically young, somewhat island-like, and squarely located at the interface of temperate and tropical climates.
2. The area is subject to intensive and rapid alterations by human activities.

The geological youth of the area implies that the flora has had relatively little time to reach a condition of true homeostasis or ecological balance. The processes of evolutionary adaptation to this unique environment have simply not had much time to operate. In addition, the south-central Florida peninsula is geographically isolated from areas of similar climatic conditions. This slows the influx of preadapted colonizers from subtropical America. Together, these conditions tend to create a flora that is "undersaturated" with species. Many of the species that comprise the climax hardwood hammocks of south Florida are typically second-growth colonizers elsewhere in tropical America, a fact which Duever et al. (1979) claim attests to the immaturity of the flora.

Additionally, the low incidence of invasion by preadapted colonizers leads to a situation in which both temperate and tropical species may be poor competitors when more specialized exotics invade. Florida represents the physiological limits of both temperate and tropical species. Many of the temperate species lose their leaves in winter, which may not be the best season for dormancy, and new foliage production must then occur during the stressful spring drought period. Tropical species begin to encounter frost stress as they try to move up the State. Consequently, Duever et al. (1979) hypothesize that native south Florida species do not use the environment optimally, allowing certain invaders to take advantage of unused niches.

There is little doubt that invasions by exotic species in peninsular Florida has been greatly aided by humans. Drainage, development, agriculture, logging, and so forth leave bare ground open to new colonizers and create new site conditions with altered hydroperiods, fire frequencies, and soil types. Human importation of ornamentals from all over the world provides a vast new seed pool for colonizing such sites. The introduction of tropical fruits and vegetables into south Florida for agricultural purposes has also resulted in the escape of certain species into the wild.

Of the total number of exotics in south Florida, only a few pose a significant threat to native communities. In the Big Cypress National Preserve, Duever et al. (1979) identify five species that warrant attention: cajeput (*Melaleuca quinquenervia*), Australian pine (*Casuarina* spp.), Brazilian pepper-tree (*Schinus terebinthifolius*), water-hyacinth (*Eichhornia crassipes*), and hydrilla (*Hydrilla verticillata*). These five are also among the major species of concern in the Tampa Bay watershed.

a. Cajeput (*Melaleuca quinquenervia*). Cajeput (or punk tree) is one of several species of *Melaleuca* grown and used in south Florida as an ornamental. Of those species growing in Florida, only *M. quinquenervia* has become naturalized and spread into the wild.

Cajeput originates in Australia where the monsoonal climatic conditions closely resemble the alternating wet and dry seasons of south Florida. Its preferred substrate in Australia is acid, sandy soil, which is frequently high in sulfides. The trees grow in thick monocultures behind brackish coastal swamps, and along riverbanks up to 16 km inland. In terms of its natural distribution in Australia, cajeput is quite reminiscent of buttonwood (*Conocarpus erectus*) in the American tropics.

In south and central Florida, cajeput is largely restricted to disturbed sites such as roadsides, drained areas (farms, developments), or sites with soils altered by mining, farming, etc. (Capehart et al. 1977; Zellars-Williams, Inc. 1980). Although there is much public concern over the apparent spread of cajeput, Duever et al. (1979) contend that this is somewhat distorted by the fact that most people see only the roadsides and disturbed areas where cajeput is highly successful. They point out that in one area of Lee County where cajeput appears to be quite predominant, it really only comprises about 0.4% of the land cover. Elsewhere in south-central Florida, the natural vegetation seems to be holding its own. At the same time there is the problem of having observed the spread of cajeput for only a short period. It may well be that the spread of the species is greatly slowed by the natural vegetation, but not stopped. For instance, in Lee County where the species was first introduced around 1910, the trees have begun to move slowly away from the roadsides into more natural settings.

The unique adaptations of cajeput to stress, its physiological preferences, and its reproductive biology have led many authors to hypothesize that it is filling (or capable of filling) a vacant niche in the south Florida flora. In addition, this vacant niche is being widened and made even more abundant by the building of roads, the dredging of canals, increased farming, and urban development.

With regard to reproductive strategy, cajeput is not suited for long-distance seed dispersal. The plant flowers in late fall and early winter when relatively few other plants are available for insects such as bees to feed upon (and thus pollinate). The seeds (anywhere from 17,000 to 34,000 per gram) are streamlined, unwinged, and may be stored in scrotinous capsules on the tree for a number of years without any loss of viability (Meskimen 1962; Myers 1975). One tree 10 m tall may conceivably store over 20 million seeds, all of which may be released by the right stimulus. Woodall (1978, 1982) and Duever et al. (1979) conclude that the cajeput seed is adapted to a medium-distance dispersal, that is, to an area immediately adjacent to the source tree. Wind dispersion plays a minor role in seed distribution, although strong wind has been observed to carry seeds for more than a kilometer (Schroeder and Browder 1979). Woodall (1982) describes two distinct reproductive strategies for *Melaleuca* seed release; one of low intensity and long or continuous duration, and the second of high intensity and short duration. The first insures a continuous supply of fresh seeds on the ground "which allows the species to exploit all reproductive opportunities—no matter how short in duration." These seeds rain down below the tree, sprout into seedlings and eventually become trees themselves, rapidly cutting off ambient light, consuming nutrients and water, and creating the characteristic monoculture. The second form of release is keyed to catastrophic events (e.g., fires) that release the accumulation of several years' seed production, and help to maintain the community reproduction in periods of seed-tree mortality or reduced vegetative reproduction.

As the cajeput monoculture grows, the trees not only store massive amounts of seeds, but also thin themselves (due to increasing canopy coverage). Thus all the leaves are at the top and the understory is little more than bare trunks. When a disturbance such as fire hits the cajeput site, it is quickly transferred to the crown, thus sparing the spongy bark and triggering the release of seed capsules. On the surrounding burn sites the seeds find nearly perfect germination conditions. Overtopping vegetation has been removed to eliminate problems of shading. Nutrients have been released into the soil by fire oxidation of organic matter. Litter has been removed, allowing the seeds direct contact with the soil, thereby reducing both desiccation and the possibility of future fire damage to seedlings. Rapid upward transfer of the fire allows the original trees to sprout just below the lowest point of total fire damage.

The cajeput tree responds to other disturbances such as frost and mechanical stress (e.g., logging) in a similar manner, although the surrounding site conditions are not as good for germination as they are with fire. Massive amounts of seeds may be dropped as a result of frost or logging, but fewer seedlings survive.

Apparently the most critical factor preventing cajeput germination is desiccation of the seeds (Myers 1975). With adequate moisture, seeds will germinate within 3 days. Low temperatures and anaerobic conditions slow germination (Duever et al. 1979). Open, water-logged soils, often found during the wet season after a burn, are ideal for this species to get started. There is evidence that cajeput may even germinate underwater if sufficient dissolved oxygen is available. This has been observed in the field in water a few centimeters in depth. Recently dropped cajeput seeds resist wetting and, buoyed by the water's surface tension, may float for days. These seeds may remain viable for as long as 5 months (Myers 1975, 1976). This characteristic provides another means of seed dispersal, which under certain circumstances may greatly extend the previously observed dispersal range (Woodall 1982).

In addition to its extremely efficient fire adaptations, cajeput also possesses specialized mechanisms for dealing with periodic inundation and resultant anaerobic soils. The most notable of these adaptations is the plant's ability to produce adventitious roots from virtually any vegetative surface in contact with the water. A fibrous sheath of these water roots may be seen surrounding the base of the trunk up to the high-water mark. Large tufts of clumps of these roots may form from underground roots some distance from the main tree, analogous to the knees of cypress trees (Duever et al. 1979).

One of the more compelling arguments in favor of the vacant niche theory comes from the findings of Duever et al. (1978) that there is a "vacant" hydroperiod, averaging between 155 and 224 days, where no distinct plant community dominates in southwest Florida. In addition, there are no tree-dominated plant communities prevalent between 113 and 245 days. Thus the possibility does exist that cajeput may be moving into an underutilized ecotone between those of cypress and pine.

Some authors believe that the native cabbage palm (*Sabal palmetto)* may closely parallel cajeput in terms of site requirements (Woodall 1978), particularly since this is one of the few species that can reproduce within cajeput stands. Cabbage palm and cajeput are very similar in their adaptations to the extremes of fire, flooding, and drought found in south Florida (Myers 1975). However, differences do exist between them, most notably with respect to the opportunistic benefits of the seed storage and release ability of cajeput stands.

b. Australian pine (*Casuarina* spp.). Three species of Australian pine are known from south Florida (Long and Lakela 1971) and all are reported in the Tampa Bay watershed (Herwitz 1977; Fla. Bureau of Geol. 1980). The species of most concern, particularly in coastal areas, is *C. equisetifolia* (Herwitz 1977). The other two species, *C. cunninghamia* and *C. glauca,* are much less of a problem, apparently due to lack of reproductive success.

Australian pine (which is actually an evergreen angiosperm, not a true pine) grows in dense monospecific stands on relatively high, dry soils. The trees may reach heights of 15–20 m. The leaves are tiny, scale-like, and whorled at each joint and borne on wiry, pale green, drooping branches. The copious leaf production around the base of the trees excludes all but a few understory plants (i.e., sea oats—*Uniola paniculata*) and beach-grass (*Panicum amarum),* and in many cases excludes all plants except for the saprophytic fungus *Pogonomyces lyduoides,* which lives on the dead trunks and branches. Reproduction is by way of small cones in *C. equisetifolia,* while *C. cunninghamia* reproduces vegetatively from root sprouts. *C. glauca* is limited in its reproduction by the isolation of male and female trees (Duever et al. 1979).

Australian pines were first introduced into south Florida as ornamentals and windbreaks along roads, canals, and baysides. In the Tampa Bay watershed their distribution extends from high, well-drained lake or pond banks in abandoned phosphate-mined areas in the Polk County area (Zellars-Williams, Inc. 1980) to the coastal barrier islands bordering Sarasota, Little Sarasota, Lemon, and Boca Ciega Bays (Carlton 1977, Herwitz 1977). Owing to their relative sensitivity to frequent fire and long hydroperiods, they tend to thrive only in those areas relatively protected from such stresses. High canal banks, berms, and coastal areas are examples of ideal Australian pine habitat. In coastal areas it competes with the coastal strand community for areas inland of beaches, newly deposited terraces, and spoil piles.

Australian pine typically forms rows parallel to the gulf-side beach ridge-swale complex. This "wall" of Australian pine, which forms along the beach line, effectively blocks onshore salt spray and permits less salt-tolerant plant communities characteristic of savannas to flourish nearer the beach (Herwitz 1977).

c. Brazilian pepper-tree (*Schinus terebinthifolius*). As its common name implies, *S. terebinthifolius* is a native of Brazil; it was introduced into Florida at numerous locations around the turn of the century. The plant is dioecious (separate sexes), and grows predominantly in thick monocultures to an average height of about 3 m. The females bear white flowers in late summer. The fruit, which becomes mature as red berries in November, has led some people to refer to Brazilian pepper-tree as Florida holly.

Although Brazilian pepper-tree generally abounds as a monoculture on disturbed sites such as abandoned farm fields, phosphate mines, spoil banks, and roadsides, it may be found as a component of many other communities as well. Pinelands, hammocks, savannas, prairies, dredge spoil islands, and even mangrove forests have been known to support scattered individuals, apparently at a self-sustaining level (Herwitz 1977; Zellars-Williams, Inc. 1980).

Brazilian pepper-tree exhibits all the characteristics of an early successional shrub species, namely intolerance of low light, abundant and readily dispersed seed stock, rapid growth, and adaptations to disturbances such as frost, fire, and hurricane stress. The pollen of *Schinus* is spread by insects, particularly bees, which utilize the flowers heavily during late summer when relatively few sources of nectar are available. Reproduction also occurs by root sprouting after defoliation by fire or frost, and by shoots and runners into nearby disturbed areas. The fruits of *Schinus* are widely consumed by a variety of wildlife such as wintering robins, opossums, and raccoons, which contribute to the dispersal of seeds. Little spread and dispersal is evident by either wind or gravity (Ewel et al. 1976).

d. Water-hyacinth (*Eichhornia crassipes*). Water-hyacinth has been described as a generalist species capable of invading a wide variety of aquatic conditions. It can withstand freezing temperatures, a characteristic which allows it to survive well north of the Tampa Bay area. It can also survive temperatures as high as 34°C and is tolerant of salinities as high as 3.4 ppt (Bock 1966, Morris 1974, TI 1978b). In full sunlight the growth rate of hyacinth can be fantastic, but at low light intensities it does very poorly. It may also be found on seasonally inundated wetlands, although the rhizomes must maintain a high water content to survive and grow (Penfound and Earle 1948).

Like Brazilian pepper-tree, *E. crassipes* originated in Brazil, although it has now spread throughout tropical and subtropical America. Most of its rapid growth occurs by way of vegetative sprouting and relatively less by seed production.

The distribution of water-hyacinth tends to be closely linked to the creation of disturbed sites, that is, in and around canals. It is generally found in open (but relatively shallow) canals, along open areas of rivers and tributaries, and along shores of lakes, ponds, and unreclaimed phosphate pits. The seasonal abundance and maximum-growth periods crest during the warmer summer months and decline toward winter, when the water-hyacinth often loses its competitive edge to a native species, water lettuce (*Pistia stratiotes*) (Lazor 1973; Duever et al. 1979). Thus numerous canals, lakes, ponds, and rivers in central and south Florida shift seasonally between infestations of floating water-hyacinth and water lettuce (Lazor 1973).

Opinions vary on the ecological and hydrologic impact of hyacinths in the Tampa Bay watershed. Hyacinths obviously interfere with the drainage function of canals. However, there is some evidence suggesting that evapotranspiration (ET) rates of hyacinth mats may reach three to four times the rate of open water evaporation alone. Thus, the increased ET may somewhat offset the clogged drainage flow in the overall hydrologic budget (Timmer and Weldon 1967; Murphy 1968; Kelleher 1976; Duever et al. 1979).

Hyacinth mats are frequently used by wading birds and many other vertebrates as a source of food and cover. Crowder (1974) claims that *E. crassipes* supports considerable populations of insects and other invertebrates that are important components of the aquatic food web. Others (e.g., Ware and Fish 1969) have found that the number of organisms and their benefit to the food web are generally inversely related. In slow, sluggish streams or pools with high levels of organic material, the hyacinth root zone often harbors the most productive invertebrate habitat in numbers and biomass (Ware and Fish 1969). However, the diversity is low and a majority of those species present represent undesirable foodstuffs for the larger invertebrates and vertebrates (Ware and Fish 1969).

e. Hydrilla (*Hydrilla verticillata*). Hydrilla, or Florida elodea, is a member of the Hydrocharitaceae family and originates from central Africa. Only female plants have been introduced into the United States; thus reproduction by seed propagation has never been observed in this country. Although introduction into Florida is fairly recent (1967), the species is now quite common in many canals, where it tends to be interspersed with other species.

The absence of seed production by hydrilla is more than compensated for by its four means of vegetative reproduction (Haller 1977):

1. Apical fragments with leaf whorl can develop into new plants.
2. Axillary buds (turions) may develop on floating plants, drop to the bottom, and sprout.
3. Sprouts may develop from nodes on stolons and rhizomes.
4. Tubers may develop on the ends of rhizomes embedded in the hydrosoil.

Unlike hyacinth, hydrilla cannot grow in areas that are not fully watered year round. An exception to this is the hydrilla tuber which, once embedded in the soil, can survive drought, ice cover, and chemical sprays. Also unlike hyacinths, hydrilla can grow quite well in both full and reduced (1%) sunlight. Although it differs from hyacinth in its water and sunlight requirements, hydrilla is similar in that its growth rates are often phenomenal.

Hydrilla was by far the most abundant species encountered in a recent aquatic plant survey of Florida (Schardt and Nall 1982). Alone, this species covered 17,000 ha of inland lakes, rivers, and canals. In those lakes surveyed for aquatic plants in 1980, hydrilla was found to have a net increase of approximately 2,025 ha (12%) in only 2 years.

Occurrences of hydrilla in the Tampa Bay watershed are moderate compared with the surrounding basins (e.g. Charlotte Harbor, Caloosahatchee and Kissimmee Rivers). Water bodies containing hydrilla within the Tampa Bay watershed are presented in Table 33. Although the percentage of coverage over all water bodies was low (6%), problem areas do exist in some area lakes and canal systems.

There are mixed opinions on the fish and wildlife value of hydrilla. Before 1960, Lake Trafford (located south of the Tampa Bay watershed) had no rooted vegetation and was noted as a poor bass-fishing spot. Ten years after being infested with hydrilla, the lake reportedly supported a sizable bass population (Duever et al. 1979) and is well known now for its fishing. In central Florida lakes, it receives a mixed review. Hydrilla is associated with stunted fish populations of excessive numbers of small forage fish and few large predators (Haller 1977). However, other wildlife, particularly waterfowl including the American coot (*Fulica americana*), ring-necked duck (*Aythya collaris*), blue-winged teal (*Anas discors*), and American widgeon (*Anas americana*), feed on hydrilla, in some cases extensively (Montalbano et al. 1978, 1979; Gasaway et al. 1979).

Whether the consumption of hydrilla is by preference or by availability is unclear; however, some observations suggest a preference for this aquatic weed (Montalbano et al. 1979). In Lake Wales a decline in numbers of some waterfowl species is attributed to reductions in hydrilla (Gasaway et al. 1979).

Since hydrilla acts to clog canals, it also tends to accelerate sediment buildup and ultimately its own demise. At times, hydrilla mats may become so dense that terrestrial vegetation colonizes them. Such undesirable interference with the drainage function of canals and the recreational function of lakes has prompted the use of chemical and physical controls. In addition to dredging and use of herbicides such as diquat and copper sulfate, much attention has also focused on potential biological control in the form of another exotic species, the grass carp or white amur (*Ctenopharyngodon idella*) (Kilgen and Smitherman 1971; Michewicz et al. 1972; Terrell and Fox 1975; Beach et al. 1976). This fish readily ingests hydrilla and other soft macrophytes (Gasaway and Drda 1977; Gasaway et al. 1979). However, as the full spectrum of its dietary preferences in south Florida is becoming better understood, its detrimental effect on fauna (invertebrates, fish, and waterfowl), either by habitat modification or competitive exclusion, indicates that its use should be restricted to closed, highly manageable situations where the fish can be easily removed (Ware and Gasaway 1976; Gasaway and Drda 1977, 1978; Gasaway et al. 1979).

5.5.2 Agricultural Communities

Agricultural operations almost always involve chronic alterations to the land that vary widely in both form and intensity. Over a few years an agricultural area may be planted, fertilized, sprayed, drained, irrigated, and harvested in response to variable seasonal crop and climatological conditions. The vegetation

Table 33. Water bodies containing Hydrilla *within the Tampa Bay watershed (adapted from Schardt and Nall 1982).*

County	Water body	Surface area (hectares)	*Hydrilla* area (hectares)	Percent[a] coverage
Hillsborough	Channel A	14	4.3	30
	Channel G	15	2.0	14
	Hillsborough River	324	54.7	17
	Little Manatee River	61	1.2	2
	Rocky Creek	10	0.4	4
	Tampa Bypass Canal	171	1.6	1
Manatee	Braden River	89	2.4	3
	Lake Manatee	628	2.4	0
	Manatee County Drainage	1,260	24.3	2
	Manatee River	12	0.4	3
Pasco	Anclote River	203	1.6	1
	Moon Lake	40	5.1	13
Pinellas	Alligator Lake	29	0.8	3
	Chantougua Lake	18	3.2	18
	City of Clearwater Drainage/ Allens Creek/Stevenson Creek	14	2.4	17
	City of Dunedin	41	2.6	7
	City of Dunedin Drainage Canals and Retention Ponds	49	2.8	6
	Pinellas Park WMD	154	24.3	16
	City of St. Petersburg	122	6.1	5
	City of St. Petersburg Flood Control Canals and Retention Ponds	178	8.1	5
	Sall's Lake	3	0.4	14
	Sawgrass Lake	16	2.0	13
	Seminole Bypass	30	4.1	13
	Lake Seminole	290	2.8	1
	Lake Tarpon	1,026	54.7	5
	Lake Tarpon Outfall Canal	16	6.1	38
	Taylor Park	19	12.2	64
	VFW Lake	3	0.4	14
	Walsingham Reservoir	32	24.3	75
Sarasota	Cow Pen Slough	69	40.5	59
Total		**4,934**	**298.3**	**6**

[a] Percent coverages of 1% or less are listed as 1%.

community that develops within and peripheral to such activity is thus highly influenced by factors outside the bounds of "natural" background conditions.

It appears that the monospecific nature of conventional crop-type agriculture is the characteristic that most separates it from the natural communities. Monocultures exhibit structural and functional attributes that may become quite suboptimal for prolonged production of a balanced mixture of fish and wildlife. A second factor that amplifies the negative effect of monocultures is the cumulative regional intensity of such operations.

In general, incidental species found in agricultural "ecosystems" are highly opportunistic and capable of colonizing continually disturbed habitats, but either do not compete well under conditions of habitat stability or are capable of exploiting a variety of disturbed habitats.

The primary agricultural pursuits in the Tampa Bay watershed are cattle production (rangeland), citrus crops (orchards), and vegetable crops (fields) (TI 1978c). In the Southwest Florida Water Management District (SWFWMD), which encompasses this watershed, rangelands alone cover 24% (6,005 km^2); cultivated crops cover an additional 28% (7,000 km^2) of the area. Refer to Figure 91 for the land use pattern in the Tampa Bay watershed.

Citrus fruits are grown in two distinct geographic areas: lowlands along the rivers where the soils are extensively ditched, bedded, and drained; and upland ridges where deep relict terrace sands are naturally very well drained and require irrigation. Grove production in the coastal counties is much less significant because of the low relief, dense urbanization of ridge areas, and most importantly, the higher chloride concentrations in the water supply (Floridan aquifer).

The effect of agricultural operations on vegetation communities, and consequently fish and wildlife, depends to some extent upon two factors: the specific crop and the management of individual farms, and the cumulative regional intensity of agricultural operations. The result of converting a pine-palmetto forest to improved pasture is obviously quite different from converting it to an an orange grove or a tomato field. Further, pasture may have different effects, depending on the number of cattle grazing and age of the pasture. Other groves and fields may have different effects based on irrigation and drainage requirements, pruning schedule, crop, fertilizer and pesticide application schedules, and other management decisions, all of which depend upon the discretion of individual landowners.

The second factor, cumulative regional agricultural intensity, suggests that widespread conversion of vast areas of natural habitat to a mixture of agricultural uses is itself a factor influencing fish and wildlife populations. This influence may operate by creating discontinuity between species populations in spatially remote habitats and by eliminating breeding sites, thereby reducing population numbers and gene flow below the levels necessary for maintaining birth rates. Other avenues by which agricultural development at the regional scale may influence vegetation patterns and associated fish and wildlife include channelization and streamside alterations, changes in regional drainage and runoff characteristics, and the introduction of pesticides into soils and water. The one characteristic these regional effects share is that they are cumulative. That is, the effect of each operation may be quite small, but when added together, their cumulative effects may become significant, especially when high-technology farming techniques (e.g., irrigation and drainage control and pesticide and fertilizer applications) become an integral part of their management.

The most severe effects of overgrazing on vegetation cover is evidenced where cattle congregate, such as around high-quality forage, near supplemental feeding stations, on dry uplands (in the wet season), and around water holes (during the dry season) (Duever et al. 1979; Barnett et al. 1980). In pinelands, grazing has an effect similar to that of fire in reducing the diversity of the plant community, limiting invasion of shrubs, and promoting the production of grasses (Hilmon and Lewis 1962; Hughes 1974; Barnett et al. 1980). In some hammocks virtually all of the understory vegetation is destroyed or consumed, and all small trees are killed by grazing cattle (Duever et al. 1979). In some marshes and dry and wet prairies subjected to grazing, between 70% and 80% of the live biomass may be consumed.

Intensive cultivation of annual vegetable crops exhibits at least three major effects on vegetation cover:

1. The cultivated crop becomes a seasonally dominant species.
2. Disturbances in and around farming sites make them particularly vulnerable to invasion by exotic species.
3. Cropland requires extensive drainage systems, which average approximately 120 km of ditches or canals for every hectare of cropland (Bedient 1975). Obviously, this practice drastically alters the natural hydrology and nutrient balance.

The artificial hydroperiod and repeated soil disturbance associated with conventional farm crops in south and central Florida provide ideal stimuli for the invasion of exotics such as cajeput and Brazilian pepper-tree. The required location of such farming sites near major roads, canals, and minor urban centers assures a ready corridor of disturbed sites down which the exotics may spread. Construction of ditches and canal banks essentially creates two new sites, one high and dry, the other permanently wet, where before there was a single seasonally oscillating site. Thus, instead of species characteristic of the single background condition (e.g., dry prairie), other species such as Brazilian pepper-tree (terrestrial) or hydrilla (aquatic) may become dominant, attended by characteristic changes in fish and wildlife communities.

The vegetation structure of citrus croplands presents still another unique variation on natural community structuring and species composition in the watershed. A typical orchard is planted in clean-cut rows to allow easy access by workers and machinery and to maximize resource utilization by each tree (i.e., sunlight, water nutrients in soil). Blocks of land of up to a section (260 ha) are managed so that all trees are of one age and size and to facilitate access. Understory vegetation varies depending on the physiography. In upland ridge areas with well-drained soils and a rolling landscape, understory vegetation is removed to minimize freeze damage and reduce competition for available water. In lowlands where a drainage network is required, grasses are maintained between rows to reduce erosion and accelerate near-surface evapotranspiration. In neither case is there any resemblance to a natural community.

5.5.3 Urban–Industrial Communities

Human influence on vegetation in urban areas is both complex and variable, depending on the intensity of localized selection pressures. Whereas one portion of a community may be completely obliterated by urban structures such as roadways and commercial and residential buildings, another portion may be altered only slightly. Often the changes brought on by such activities are gradual. They may first affect vegetation, then fish and wildlife. Many are functions of cumulative and subtle development pressures and attitudes.

Urban-industrial communities are generally zoned into numerous categories such as residential, commercial, and industrial, and further subdivided with descriptors such as light, medium, and heavy. For our purposes the urban-industrial category also includes the communities along roadsides, railroads, and transmission lines. These sites are included as disturbed communities of the urban-industrial type because they constitute one of the more pervasive alterations to the land in urban-industrial development. High-quality transportation and power transmission corridors are essential to maintaining urban-industrial activities. They facilitate rapid flow of materials, energy, and information between urban-industrial centers and between agricultural production sites and consumer markets. Consequently, a considerable amount of energy and money is expended to see that they function as designed. Part of this maintenance effort is aimed at strictly controlling the vegetation community.

Power transmission corridors are less like roads and urban environments than like early succession fields. The annual cutting of vegetation to keep the lines clear plays a role similar to that of fire by repeatedly selecting for early-succession, fast-growing shrubs and grasses. Cutting by power companies differs from fire, however, in both schedule (i.e., fixed, as opposed to random frequency) and selectivity. Since fire tolerance is not a factor where vegetation is held in check by mechanical mowing, fire-intolerant species may become an important part of the community.

The changes in vegetation community structure brought about by urban development can be viewed in terms of a shift in local selection pressure. In the natural setting without human influences, species survival is determined by their abilities to respond to the physical and chemical conditions present and by their interactions with other species, present and invading. In general terms, the rigid control of habitat and the active and passive vegetation and wildlife selection factors that prevail in urban centers tend to favor generalist species over those more dependent on a narrow range of background conditions.

In the Tampa Bay watershed those "community associations" that appear to have dominated the natural setting where major urban centers are now located are presented in Table 34. Information on species composition and other structural-functional attributes of these communities was presented earlier in this chapter.

When urban development begins to take over, the prevailing local selection pressure shifts away from one involving a multispecies balance to one favoring the desires and attributes of a single, highly technological species, *Homo sapiens.* Consequently, selection pressures unheard of in the natural setting, such as vegetation selection for aesthetic purposes regardless of site conditions, or removal of vegetation for flood control, or construction of structures having a purely urban function (e.g., buildings, roads, parking lots), become dominant in the urban setting. Through dredge-and-fill activity, canals and uplands appear in place of wetlands. These activities frequently bring about cumulative and subtle changes in the structure and function of communities, going well beyond the simple removal of vegetation from the involved sites. Table 35 presents a list of the general categories of structural and functional changes that occur in natural communities in response to the gross changes brought on by urbanization. Unfortunately, there is very little information beyond these qualitative observations on the long-term impacts of converting major fractions of natural communities into urban areas.

Table 34. Previous community associations of major or representative urban centers in the Tampa Bay watershed (after Davis 1967).

Urban center	Communities affected
Clearwater	Coastal strand, Beach and Dune, Longleaf Pine Forest
Tampa	Mangroves, Hardwood Swamp Forest, Longleaf Pine Forest, Pine Flatwoods
Plant City	Pine Flatwoods, Sand Pine Scrub Forest
Lakeland	Longleaf Pine Forest, Hardwood Forest
St. Petersburg	Pine Flatwoods, Dry Prairies
Bradenton	Pine Flatwood, Hardwood Swamp Forest
Sarasota	Pine Flatwoods, Prairies, Coastal Strand

To a degree, the columns in Table 35 represent a complex stimulus-response process with considerable overlap between many of the categories. For instance, it is obvious the gross changes in structure and function that accumulate with development occur in two interrelated stages: at the onset of construction, in which the associated secondary responses dominate; and over the lifetime of the structure, in which it is used and maintained by the daily activities of urban dwellers.

Although many of the functions of the two stages are similar, they often differ in form (i.e., how they are implemented) and intensity. For instance, whereas initial construction generally requires use of many people and heavy equipment and intense energy expenditure (acute impacts), the use of the structure involves the actions of a few individuals expending only minor amounts of energy (chronic impacts). The acute efforts, initial construction, must be followed by the chronic ones, maintenance, or the site will be reinvaded by native or exotic vegetation.

5.5.4 Canals and Other Artificial Structures

Major drainage and canal systems are fairly common in the Tampa Bay watershed. Figure 114 presents a schematic illustration of the impact of canals on both ground and surface water hydrology and terrestrial and aquatic habitat structure. Water quality and quantity impacts of channelization are discussed in Chapter 4. Most of the impacts on community structure have already been mentioned in the sections on riverine communities, exotic species, and agricultural and urban-industrial communities.

The most conspicuous environmental change resulting from channelization is the change in local topography and hydrology. Broad expanses of

Table 35. Structural and functional changes in natural communities in response to gross changes brought about by urbanization (construction and maintenance of urban-industrial component parts—roads, offices, houses, parking lots, etc.).

Gross structural change	Resulting functional change
Direct killing of overstory, understory, or other natural vegetation and wildlife.	Affects local microclimatic factors such as temperature, humidity, and incident light; may also influence runoff, erosion, subsequent species composition, and soil structure.
Altered local topography for construction or landscaping.	Affects runoff, recharge; erosion creates new microhabitats such as canals or high dry conditions, and even new soil types.
Removal of forest litter or soil duff layer.	Affects cation exchange capacity of soils, thus quality and quantity of runoff; affects soil nutrient and water holding capacity; constitutes a loss of productive microhabitat for soil building organisms and wildlife that is trophically dependent on them.

shallow wetland with undulating, low-sloping land surfaces are generally converted into a system having a more distinct boundary between land and water. This results in a narrower band of surface area having a fluctuating water level. In turn, wetland plant species are forced to compete for a narrower area, while upland and purely aquatic species are provided with relatively more area suitable to their needs. The steep-sided canal eliminates a littoral zone for rooted aquatic vegetation, but provides an ideal environment for the proliferation of floating plants, which can become a severe problem.

A frequent secondary change is the removal of overhanging trees, such as cypress or red maple, resulting in a new light regime for the exposed canal/upland system. Simultaneously, the lowering of the water table tends to dry out the upland soils, promoting more mesic communities such as pinelands or grassy scrubs. The chance of destructive fires will increase in the uplands, especially in the spring.

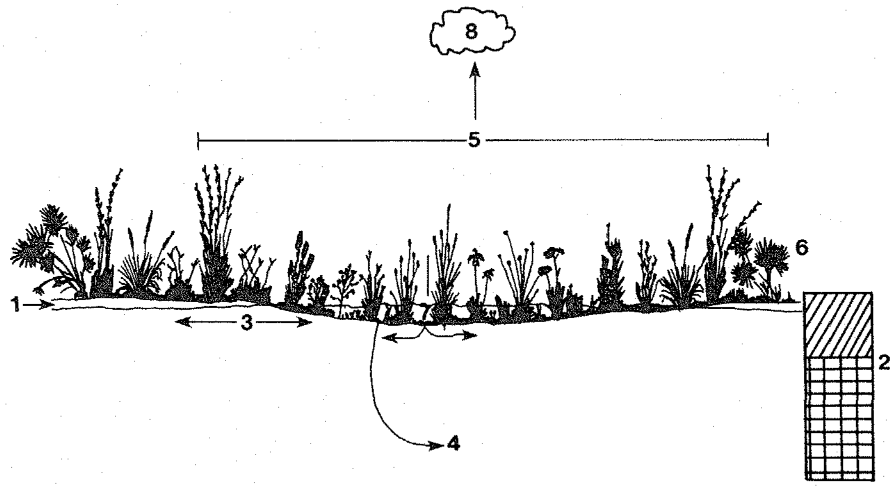
5.5.5 Phosphate-Mined Lands

Approximately 2,600 ha of wetlands, forests, rangeland, cropland, and pasture are mined each year for the phosphate contained in the Bone Valley Formation of west-central Florida. The majority of this activity occurs in the Alafia and Peace River Basins in Polk County, although there is developmental pressure to mine south in the headwaters of the Manatee, Little Manatee, and Myakka Rivers (Figure 115). Up to 74,000 ha are projected to be mined from 1977 to the year 2000, including 10,850 ha of wetlands and 8,650 ha of forests (EPA 1978).

To understand the effect of phosphate mining on natural habitats, one needs to be familiar with the area stratigraphy, the mining activity, and the reclamation processes.

Three stratigraphic units are involved in the mining process (Figure 116). The upper unit, or overburden, is an unconsolidated, leached sand, clay, and gravel layer that varies from 3 to 15 m thick. Under this the phosphate overbody, ranging in thickness from 1.5 to 18 m, is composed of quartz sands, clays, and about one-third phosphate in the form of fluorapatite (Fountain and Zellers 1972; EPA 1978). This zone contains phosphate particles ranging from silt to cobble size and is commonly referred to as the "matrix." Below it lie Miocene dolomitic limestones, dolomites, or a dark gray carbonaceous dolomitic clay, collectively termed "bedrock" by the phosphate industry.

The phosphorite ore is strip-mined by first removing the overburden from cuts about 50–90 m wide and 200–900 m long. If an initial cut is being made, the overburden is placed on the adjacent ground to form a long hill. After the initial fill is either



Parameter or Process	Impact	Reference
1. Groundwater table fluctuations	Canals lower top of groundwater table; seasonal fluctuations dampened or shifted generally to lower lows and higher highs.	Klein et al. (1970); McCoy (1964); Carter et al. (1973).
2. Penetration into subsurface strata	Canals may penetrate into deeper strata (aquifer) below surficial sediments; aquifer drainage is facilitated, water quality affected.	Klein et al. (1970); McCoy (1964); Carter et al. (1973).
3. Groundwater flow gradient	By lowering water table, seasonal, recharge-discharge cycle disrupted; thus hydroperiods change, availability of soil moisture changes, saline waters intrude.	Klein et al. (1970); McCoy (1964); Carter et al. (1973).
4. Water storage and exchange	Stored groundwater may be discharged or tidal-exchange factor increased, thus changing extremes of drought and flood as well as background water quality.	Van de Kreeke (1979); Hicks (1979); Carter et al. (1973); SWFRPC (1980).
5. Shallow-water habitat and fish and wildlife	Area of wetland habitat decreases, replaced by upland and deep-water habitats; shallow-water dependent wildlife have less habitat, deep-water and upland-dependent species favored, aquatic weeds favored.	Duever et al. (1979); Brown (1974); Lehman (1976).
6. Terrestrial vegetation and wildlife	Shift from mesic to xeric conditions, promotes fire and early-succession communities, invasion by exotics. Wildlife also shift according to available habitat and other factors.	Brown (1974); Lehman (1976).
7. Water quality	Turbidity, color, dissolved oxygen, pH, conductivity, inorganic ions, metals, and other parameters may change with depth, groundwater drainage, sediment removal by canals.	Carter et al. (1973); Hicks (1979); SWFRPC (1980).
8. Evapotranspiration	Wetland habitat loss, excess discharge, lower soil moisture, lower water table, increased depth and storage in open canal reservoirs change the nature and magnitude of ET.	

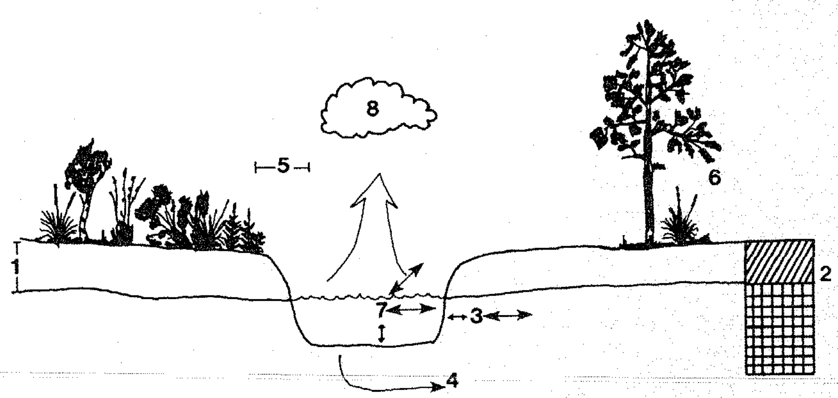


Figure 114. Schematic of effect of canal development on hydrology and habitat structure (Brown 1976).

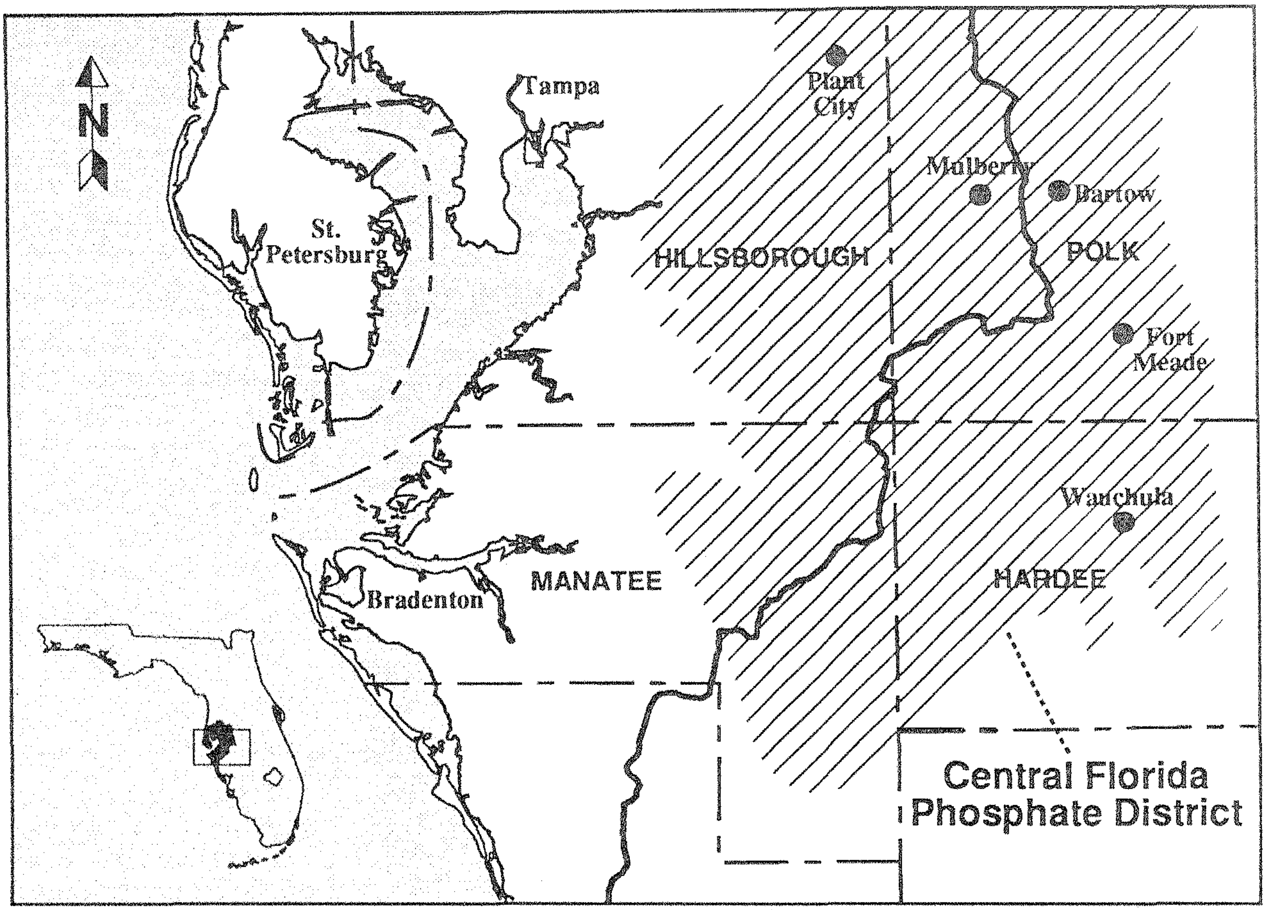


Figure 115. Location of central Florida phosphate district in relation to Tampa Bay watershed (Fountain and Zellars 1972).

spoiled onto the adjacent ground or into the previously mined adjacent cut, the matrix is removed from the cut and placed into a sluicing pit, where it is slurried by high-pressure (10,000–12,000 gpm at 200 psi)water guns and pumped to a benefaction plant. At the benefaction plant, phosphate is separated physically (using screening, washing, and sizing procedures) and chemically as illustrated in Figure 117. The ore is transported either to a fertilizer processing plant for further refinement, or to a port to be exported as unrefined ore. Approximately 70% of the matrix is returned to the site as waste material in the form of residual quartz sand or tailings, and residual clays or slime. The sands are typically pumped into the finger-shaped mine cuts as fill for reclamation or used for slime-pond dike material. Clay slimes, which have absorbed water and expanded considerably in volume, are pumped to diked retention areas with berms 15–18 m above ground level. These retention areas, or settling ponds, account for 50%–75% of the mined area and require 15–20 years of consolidation prior to final reclamation.

The slime consists of a mixture of clay (88%), silt (8%), and sand (4%). Montmorillonite dominates the clay, with lesser amounts of kaolinite, illite, and attapulgite. Although this clay mixture remains physically unstable for a long period, its chemical nature is quite conducive to rapid establishment and succession of aquatic and wetland vegetation.

Deltas generally form near the clay introduction inlet and exhibit the first signs of plant colonization,

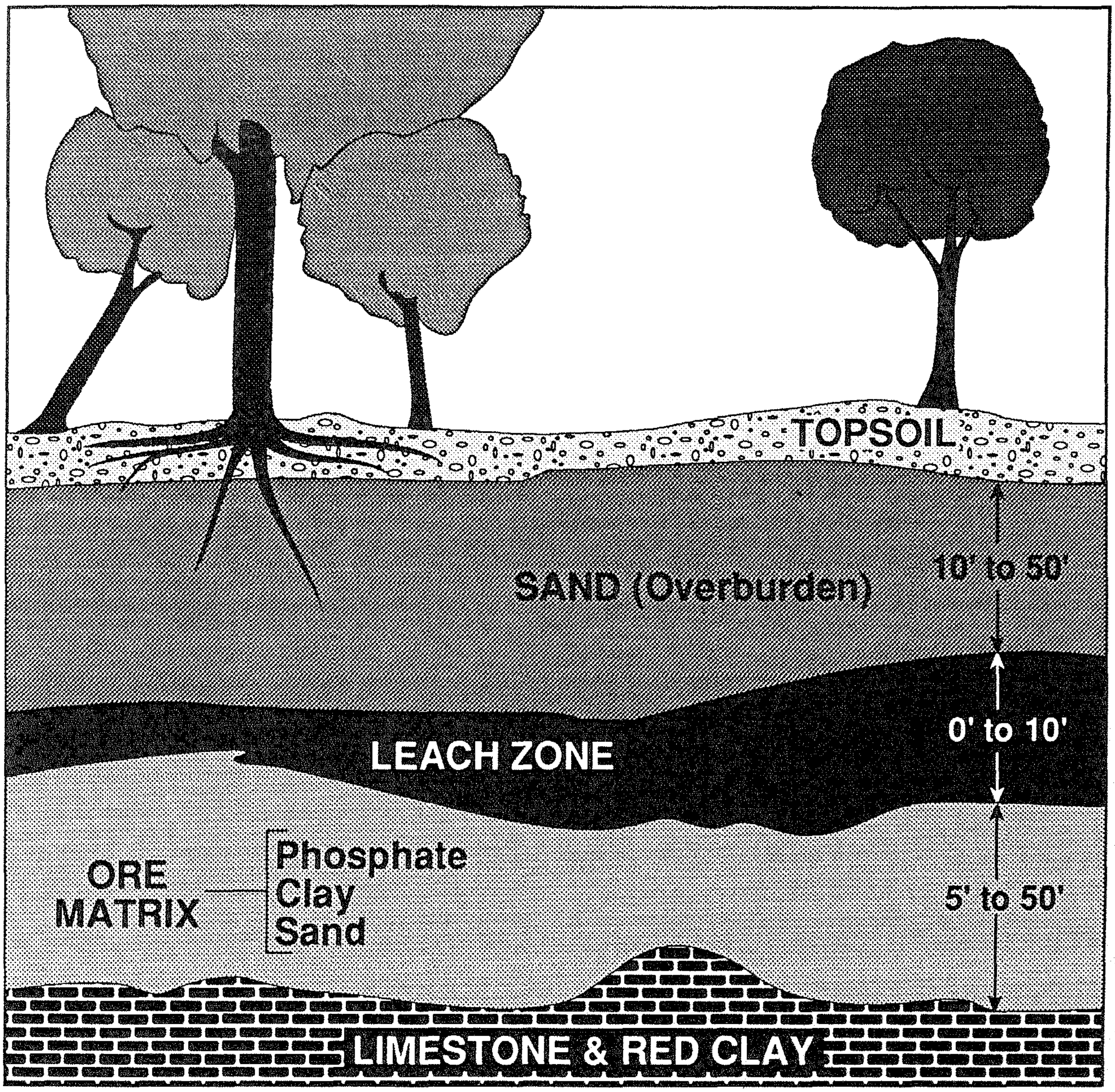


Figure 116. Stratigraphic units of concern in phosphate mining (Fountain and Zellars 1972).

which will eventually expand to cover the entire retention area. Broad, dense stands of cattail (*Typha* spp.) typically represent the initial emergent community type, and, as inundation decreases, succession proceeds from an emergent herbaceous community to a willow-dominated shrub forest. Prior to reclamation the community is vegetated by dense stands of willow, waxmyrtle, and salt bush with an understory of ferns and grasses. After clay consolidation, retention-area reclamation consists of capping the elevation basins with sand tailings or overburden, and planting pasture grasses. Mine-cut reclamation includes shaping and contouring the remnant spoil dike to create lake shorelines and uplands. The potential surface area of these finger lakes depends on the volume of waste sand and clay to be disposed of

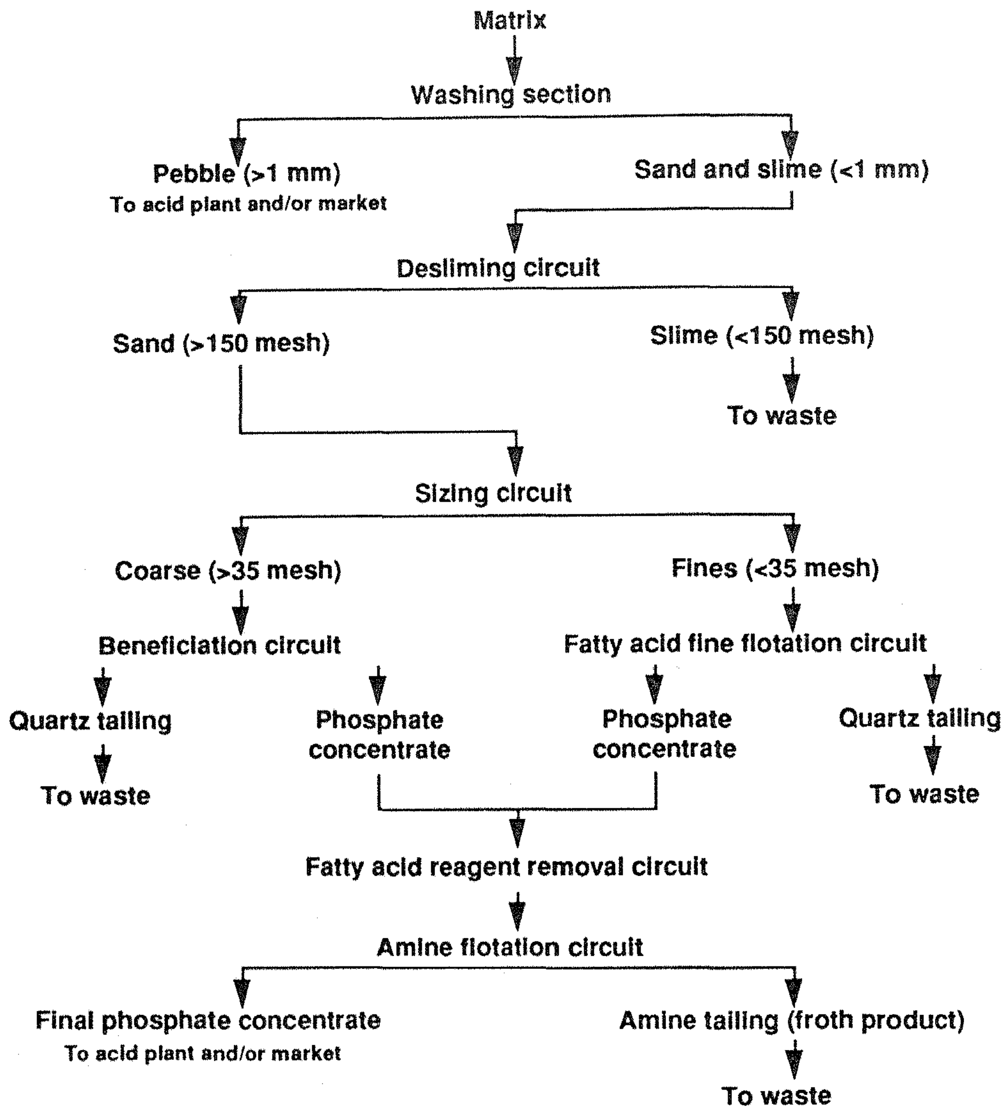


Figure 117. Generalized flowsheet of Florida phosphate-mining plants (after Lamont et al. 1975).

within the mined cuts. As previously mentioned, residual sands or tailings from the benefaction plant are also used to backfill the mined-out cuts and are subsequently covered by a layer of overburden to increase the sand's fertility and ability to retain moisture.

The reclamation technique used for a particular site determines the subsequent land and cover use. Table 36 lists the potential suitability for various land uses on the possible landfill or reclamation types. Sites that provide overburden as the substrate exhibit the most stable (structurally) and fertile qualities (chemically) of the landfill types. More detailed information on the general phosphate mining process is available from several sources, including the Phosphate Land Reclamation Study Commission (1978).

Before 1975, mining companies generally abandoned their mined lands and settling areas with little or no active reclamation. This "no action" practice served two purposes for the mining company; first, it

Table 36. Revegetation and land-use possibilities for various landfill types (after Zellars-Williams 1980).

	Potential Use[a]					
Landfill type	Pasture	Forestry	Citrus	Cropland	Residential/ industrial	Wetlands
Tailings sand fill	•	–	–	–	••	–
Tailings sand fill capped with overburden	••	•	•	•	••	–
Clay fill	••	–	–	•	–	••
Clay fill capped with sand	•	–	–	–	–	–
Sand-clay mix	••	••	–	•	–	••
No fill (lake areas)	••	••	•	•	••	•
Overburden fill	••	••	•	•	••	–

a – Landfill type not acceptable for revegetation/land-use alternative in majority of cases.
• Landfill type acceptable for revegetation/land-use alternative in some cases given proper site selection.
•• Landfill type acceptable for revegetation/land-use alternative in majority of cases.

minimized future site preparation for areas to be remined, and secondly, it allowed the lands to remain qualified for consumptive water use. The end result left mined areas and holding sites to recover naturally without prescribed manipulation of soil, topography, or pioneer biota (Schnoes and Humphrey 1980).

Since 1975, two actions, a 1975 reclamation/ severance tax law, and a 1978 revision to the law that provides a mechanism to use tax money to reclaim pre-1975 mined lands, have spurred reclamation activity and the examination of artificial habitat recovery methods (Gilbert 1977; Hawkins 1979; Shuey and Swanson 1979; Schnoes and Humphrey 1980; and Gilbert et al. 1981). Reclamation research since then has examined either historic reclamation (or the lack of it) and/or the more recent artificial manipulation of natural successional patterns.

The descriptions of the habitats found on pre-1975 phosphate-mined lands are drawn primarily from Schnoes and Humphrey (1980). The former provides an overall assessment of the mined area's floral and faunal assemblages as compared to the region's native assemblages, drawing from a survey of approximately 400 parcels (80 ha each) of disturbed lands. Schnoes and Humphrey (1980) concentrate on fewer sites (24) but examine in greater detail the successional patterns on clay settling areas, overburden spoil mounds ("Land and Lakes"), and reclaimed grazed and ungrazed pastures on overburden soil. Together these two studies provide a near-complete perspective of the area's disturbed lands.

Within the parcels examined by Zellars-Williams, Inc. (1980), terrestrial systems dominate both the number of parcels in which the system is present and the percentage of coverage per parcel. Aquatic systems were the least frequent, represented on little more than 50% of the parcels surveyed. Wetland systems were present on 94% of the parcels, but represent a low percentage of coverage per parcel.

The overall species diversity of vegetated communities is low for these areas. An average of 48 species per parcel were observed; parcels averaged 92 ha. A few hectares of pine-palmetto flatwoods or native freshwater marsh contain about 70 species, and a few hectares of native hardwood forest contain twice the number of tree species of the mined lands. A total number of 569 vascular plant species were observed, as compared to 1,353 species reported in the Tampa Bay region (Long 1974). The number observed (569) should be found on less than 1,400 ha of the phosphate-mined land that was examined (Zellars-Williams, Inc. 1980).

A very high number and percentage of exotic plants are present (127 species or 23%); most are weedy colonizers of disturbed habitats. Species frequency, particularly in wetland species, was generally low except for a very few species, that is, the system tended toward monocultures.

Table 37 lists the more common plant species observed on abandoned mine sites. Five tree species generally dominate the sampled quadrants; these are laurel oak (*Quercus laurifolia*), live oak (*Q. virginiana*), water oak (*Q. nigra*), slash pine (*Pinus elliottii*), and sweetgum (*Liquidambar styraciflua*). Other significant species included black cherry (*Prunus serotina*), waxmyrtle (*Myrica cerifera*), red maple (*Acer rubrum*), and cabbage palm (*Sabal palmetto*). Mean basal area measured is equal to or higher than other central Florida forests because basal area was estimated in quadrants placed where forest development was near-optimal for each parcel; and live oak, a species most common, grows in relatively open areas, which results in a development of short trunks with large girths and broad crowns. Native forest oaks are characteristically taller and more slender. It is interesting to note that none of Florida's endangered or rare species or species of special concern were observed in any of the parcels, which ranged from 25 to 70 years old.

Although Zellars-Williams, Inc., provides a comprehensive overview of the pre-1975 phosphate-mined land ecology, it touches only briefly on the great variability that exists in the region. The variability is keyed to the substrate type, which controls habitat formation and succession. The disruption of native soils, implicit with central Florida phosphate strip mining, is so complete that what remains may be discussed only in terms of clay slime, sand tailings, or overburden. The most prevalent of these, clay-slime settling ponds, are slow to be colonized by flora and have depauperate animal communities. Habitat formation on the far less common sand-tailing sites is at best incomplete because of the newness of the technique (Schnoes and Humphrey 1980). Little information exists on the nutrient supplements

Table 37. Occurrence of plant species in phosphate-mined areas of Florida (adapted from Zellars-Williams, Inc., 1980).

Common name[a]	Scientific name	Percent of parcels	Common name[a]	Scientific name	Percent of parcels
Dog-fennel	*Eupatorium capillifolium*	90.2	Duckmeat	*Spirodela polyrhiza*	53.2
Cattails	*Typha* spp.	88.9	Paragrass	*Brachiaria mutica*	51.9
Bermuda-grass	*Cynodon dactylon*	87.1	Black cherry	*Prunus serotina*	51.4
Camphorweed	*Heterotheca subaxillaris*	86.4	Hempvine	*Mikania scandens*	49.6
Willow	*Salix caroliniana*	83.8	Horseweed	*Conyza canadensis*	49.6
Broomsedge	*Andropogon* spp.	83.0	Slash pine	*Pinus elliottii*	49.6
Natal-grass	*Rhynchelytrum repens*	80.2	Goldenrod	*Solidago fistulosa*	47.8
Smutgrass	*Sporobolus indicus*	80.2	Shy-leaf	*Aeschynomene americana*	47.8
Waxmyrtle	*Myrica cerifera*	79.4	Cabbage palm	*Sabal palmetto*	47.8
Caesar-weed	*Urena lobata*	73.0	Goldenrod	*Solidago microcephala*	47.3
Bahiagrass	*Paspalum notatum*	70.4	Virginia creeper	*Parthenocissus quinquefolia*	47.0
Spanish needles	*Bidens pilosa*	67.4	Water oak	*Quercus nigra*	46.5
Muscadine grape	*Vitis rotundifolia*	64.0	Richardia	*Richardia brasiliensis*	46.0
Rattlebox	*Crotalaria spectabilis*	63.5	Shield fern	*Thelypteris kunthii*	45.0
Live oak	*Quercus virginiana*	60.7	Boston fern	*Nephrolepis* spp.	44.5
Duckweed	*Lemna* sp.	54.2	Pepper-vine	*Ampelopsis arborea*	43.7
Ragweed	*Ambrosia artemisiifolia*	53.8	Spanish moss	*Tillandsia usneoides*	40.9

[a] Species represented in at least 40% of all parcels surveyed (see text).

required for successful pasture growth or the grazing tolerance on sand-tailing pasture. Xeric communities, such as longleaf pine, sand pine, or rosemary (*Ceratiola*) deserts are most likely to survive on this substrate. An attempt at citrus planting between Barton and Winter Haven failed (Hawkins 1979).

The flora growing upon an overburden substrate exhibits rapid primary succession, which tends to xeric or mesic oak forest with rich animal communities. In those cases where overburden is used to cap sand-tailing filled pits or consolidated-clay settling ponds, succession has been artificially directed toward pasture, with planted grasses either grazed or mowed. Succession in these instances is arrested at a near monotypic grassland stage and provides for a poor animal habitat (Schnoes and Humphrey 1980). The overburden-capping procedure was the most widely used reclamation technique before 1975, in a time when active reclamation of any kind was uncommon.

Succession on consolidated-clay settling ponds follows a pattern of low diversity for herbaceous ground cover, shrubs, and trees. Initially, monocultures of cattail and rushes (*Juncus* spp.) dominate the shallows and shorelines. Herbaceous growth includes a few grasses such as salt-tail (*Imperata* spp.) and beard-grass (*Andropogon* spp.), shrubs dominated by saltbush (*Baccharis* spp.), and the willow (*Salix caroliniana*) as the principal tree or sapling found. As the site stabilizes, the willow maintains its position as the dominant tree and the density and diversity of shrubs increase. In the clay settling pond, the waxmyrtle establishes its dominance in a final successional stage, often to the exclusion of all other tree species. Schnoes and Humphrey (1980) concluded that clay settling ponds represent "excellent wetland habitats with much larger wildlife values, but once a crust formed and willows dominated the site much of the attractiveness to wildlife was lost."

The waxmyrtle's dominance may be related to several inherent factors. Dunnevitz and Ewel (1981) suggest an allelopathic effect whereby the trees physically or chemically inhibit colonization of other species in their vicinity. The waxmyrtle also hosts a symbiotic root bacterium that fixes atmospheric nitrogen (N_2). This supplemental source of nitrogen may provide the tree with a competitive edge in a soil typically very low in nitrogen. The trees also possess the ability to disperse seeds a great distance, so they can readily colonize the clay crust as well as grow in the underlying nutrient-poor colloidal clay sediments (Schnoes and Humphrey 1980).

As previously discussed, a system of finger lakes and elongated spoil islands dominate the terrain of the mined pits. The finger lakes are relatively deep with sharply dropping slopes that restrict the establishment of littoral-zone vegetation. An exception is where spoil-mound erosion deltas have formed. Aquatic vegetation here is generally attached, submerged, or floating macrophytes. Spoil mounds, which are entirely composed of surface overburden, exhibit vigorous and rapid old-field succession. During the first 5 years, grasses such as ragweed (*Ambrosia artemisiifolia*), dog fennel (*Eupatorium album*), and natalgrass (*Rynchelytrum repens*) are most prevalent, sharing some space with shrubs (i.e., saltbush). No trees are present. In the 5–15 years that follow mining, grasses reach maximum development; shrubs, vines, and saplings markedly increase; and the first pioneer trees appear. Dog fennel is replaced by several other grasses, including caesar weed (*Urena lobata*), cogongrass (*Imperata cylindrica*), and beard-grass. In addition to saltbush, shrub verbena (*Lantana camara*), grapevine (*Vitis rotundifolia*), blackberry (*Rubus* spp.), and several types of saplings form the understory. The pioneer trees include willow, waxmyrtle, *Baccharis*, and Brazilian pepper-tree. From 15 to 30 years after mining, grasses begin to disappear and be replaced by shade-tolerant ferns. Shrubs and trees remain similar to previous age classes. Cogongrass is replaced by panic-grass (*Panicum dichotomiflorum*) and the ferns *Polystichum acrostichoides* and *Thelypteris kunthii*. Blackberry decreases in the understory and is replaced by additional saplings of waxmyrtle and Brazilian pepper-tree. Waxmyrtle increases to maximum density in this period, often to the near exclusion of other trees. In the oldest age group observed (greater than 30 years old), herbaceous growth is minimal and restricted generally to ferns and panic-grass. Shrubs exhibit the greatest diversity, showing dramatic increases in shade-tolerant species such as vines. Pioneer tree species (e.g., waxmyrtle, willow) decline and are replaced by several other larger trees, which include camphor tree (*Cinnamomum camphora*), sweetgum, water oak, live oak, and American elm (*Ulmus americana*).

Where these pit and mound sites occur along topographic ridges and in the upland slopes around freshwater marshes, the spoil piles are well enough drained to prevent lake formation. The successional patterns for the overburden areas without lakes is similar to those with lakes except for an increase in dominance of live and water oaks, which may form a closed canopy. Epiphytic plants may occur in the canopy (i.e., orchids, bromeliads) and voluntary citrus may appear in the understory.

In summary, the unreclaimed overburden sites exhibit four successional stages. First is an old-field stage of grasses and forbs that reaches its maximum peak from 5 to 7 years after cessation of mining activity. This is followed by a pioneer shrub stage, characterized by *Lantana*, *Baccharis*, vines, and forbs, that dominates the landscape from 8 to 14 years. A waxmyrtle stage succeeds between 14 and 30 years, followed by the "climax" oak forest stage with water and live oak at sites 30 years or older.

Active control of natural habitat establishment has only recently been studied, primarily in the area of wetland creation (Shuey and Swanson 1979; Gilbert et al. 1981). Shuey and Swanson (1979) examined selective planting of marsh plants and mulching with organic matter from natural marshes, as well as natural recolonization. Mulching provided the most vigorous growth and the greatest diversity (twice that of natural recolonization) in the wetland sites, but still less than observed in native marshes, particularly the deep marsh. These results, however, were reported on only the first 10 months of data; more time may allow further diversification of the altered plots and eventual colonization of the deeper waters.

Gilbert et al. (1981) provide information on controlled colonization of aquatic, wetland, and upland habitats over a 17-month period. The planting method resembled the selective planting of marsh species used by Shuey and Swanson, with similar results. The open-water areas remained unvegetated and the emergent zone exhibited vegetative partitioning based on more subtle distinctions among inundation differences. In the wetter emergent area, sedges or a dense, narrow band of cattails formed. Dryer regions exhibited a variety of sedges, rushes, aquatic grasses, and shrubs. Approximately half of the 12,820 tree seedlings planted on a variety of community-type study plots survived. Bald cypress and red cedar exhibited the greatest combined growth and survival rates of the eight conifers and eight hardwood species tested. Transplanted trees typically showed high viability but low vigor.

Habitat modification increases the rate of colonization and the diversity of species on the reclaimed mine sites, but still falls short of the diversity observed on native wetlands. The successional rate and diversification of species is dependent upon several variables, including distance of site from seed source, adjacent natural plant community types, dispersal mechanism or aggressiveness of the species, and substrate.

Substrate is possibly the most important and least tested variable in habitat modification studies to date. The two previously discussed studies used overburden as a substrate, in some cases supplemented by marsh subsoils and in other cases by artificial fertilizers and exotic grasses. In one study (Shuey and Swanson 1979) the site had not been previously mined and the overburden was actually simulated by turning over the top 2 m of soil. The test site for the other study (Gilbert et al. 1981) was selected for use because of its proximity to a source of native plant materials and because its sloping topography facilitated the creation of an onsite drainage area and collection basin. Future mine reclamation will not always have the convenience of site selection nor the continued availability of overburden as a surface substrate.

The Phosphate Land Reclamation Study Commission (1978) has estimated that 39,200 to 78,800 ha will be reclaimed from lands mined from 1975 to 2000 in central Florida. Of the lands to be reclaimed, Table 38 shows the past and future pattern of reclamation techniques. Particularly dramatic is the shift in resultant surface substrate. In the 1970's over 70% of

Table 38. Types of reclamation recently completed or approved for implementation in the central Florida phosphate district (as of November 1979). The sequence of soil strata is shown from top to bottom. Mixed soil types are indicated by hyphens (adapted from Phosphate Land Reclamation Study Commission 1978).

Reclamation sequence (top/bottom)	**Relative area of reclamation types (percent and total hectares)**							
	1971-74[a]	1975[a]	1976[a]	1978[b]	1979[b,c]	1980-89[c]	1990-99[c]	2000-09[c]
Overburden (area includes some lake surface)	63.8	51.1	53.1	–	65.9	31.7	8.1	–
Overburden/sand tailings	1.4	4.0	8.2	28.7	–	16.7	–	–
Overburden/sand tailings/clay	–	–	–	–	1.8	16.9	–	–
Overburden/sand tailings-clay	–	–	–	–	27.5	9.8	–	–
Overburden/clay	–	–	–	–	4.9	1.2	4.7	–
Overburden-sand tailings	–	–	–	–	–	–	3.7	–
Overburden-sand tailings/natural ground	–	–	–	–	–	–	–	–
Overburden-sand tailings/clay	9.5	5.5	6.4	–	–	–	–	7.5
Subtotal	**74.7**	**60.6**	**67.7**	**28.7**	**100.1**	**76.3**	**16.5**	**7.5**
Clay	9.7	17.9	15.8	–	–	4.9	45.6	24.4
Clay/natural ground	–	–	–	–	–	2 .5	–	–
Clay/sand tailings	2.8	15.3	–	5.5	–	–	–	–
Subtotal	**12.5**	**33.2**	**15.8**	**5.5**	**0.0**	**7.4**	**45.6**	**24.4**
Sand tailings	12.9	6.3	12.6	–	–	0.4	–	–
Sand tailings/clay	–	–	–	65.8	–	11.8	–	–
Sand tailings/clay/natural ground	–	–	–	–	–	–	–	–
Sand tailings-clay	–	–	–	–	–	1.8	–	–
Sand tailings-clay/overburden	–	–	–	–	–	–	37.9	68.1
Sand tailings-clay/natural ground	–	–	–	–	–	1.5	–	–
Subtotal	**12.9**	**6.3**	**12.6**	**65.8**	**0.0**	**15.5**	**37.9**	**68.1**
Peat/sand tailings/clay	–	–	–	–	–	0.7	–	–
Total hectares	**1,565**	**1,037**	**1,742**	**229**	**982**	**4,408**	**3,704**	**2,080**

[a] Phosphate Land Reclamation Study Commission 1978.
[b] Based on release dates in records of the Bureau of Geology.
[c] Based on scheduled completion dates in records of the Bureau of Geology.

the reclamation was on deep overburden. In the 1980's, the majority of overburden surface substrate has been and will be in the form of a relatively shallow cup over sand tailings and/or clay. From 1990 to 2009, overburden will become a minor component of the reclaimed substrate for two reasons; overburden will be immediately used for clay settling-pond dikes; and overburden depth decreases to the south where the new mines will be located. In the interim period (present to 2000), the landscape will be dominated by active or recently inactive clay settling ponds with a legal life of as much as 30 years (20 years for filling and dewatering, and 10 years for reclamation). Therefore, the major habitat in the phosphate-mining region will be freshwater marshes that follow a successional pattern similar to the consolidated-clay settling ponds described by Schnoes and Humphrey (1980). Of those lands that are reclaimed, agriculture will consume a major share, averaging over 50% of the future reclaimed lands. Thus, while much of the cropland and pasture lost to mining will be reclaimed, very little of the wetland, forest, and native rangeland will be restored. When restored, however, these natural areas provide excellent habitat for wildlife. Settling-pond areas have been found to support significant numbers of migratory birds in the winter, especially waterfowl.

5.5.6 Spoil Islands

Spoil islands formed from the deposition of dredged material have become a significant land form on the west coast of Florida, particularly in and around the Tampa Bay area. Development of residential canals, marinas, turning basins, port facilities, and channel expansions throughout the Tampa Bay watershed are activities that create spoil material to be relocated. While dredging activities are greatly reduced under current environmental regulations, the area's population growth and a concurrent increase in marine commerce and pleasure-craft usage still produce demand for spoil-producing activities, in addition to creating a growing maintenance-dredging program. The best example is the Tampa Deepening Project, which, in the construction phase, has moved over 5 x 10^7 m^3 of spoil to two spoil sites that, combined, approach 1,400 ha of new land area. The 5-year maintenance dredging volume for Tampa Harbor alone could exceed 4.6 x 10^7 m^3 (Dames and Moore 1982). Since upland disposal sites for this material are becoming increasingly scarce along the commercially and residentially developed coastline, spoil island creation is often the only alternative.

The spoil islands constitute a new land form with unique habitat colonization and successional qualities. In many ways, the determining factors in development of these sites—site age, physiography, substrate, distance from seed-dispersal centers, and human use of the spoil island (Carlson 1972; Beaman 1973; Lewis and Lewis 1978)—parallel those that influence phosphate-mined site succession.

Spoil islands may be constructed with or without retention structures. In the latter case, the sediment slurry is dumped on shallow bottom sites near or adjacent to the dredged channels without berms or dikes to restrict its spread. The result is a low-sloped, low-profile island with sediment particles sorted laterally: large material (pebbles, rocks) at the center and fines radiating out several hundred meters from the shoreline (Carlson 1972). With retention dikes, the sediment sorts itself in a layered or vertical stack. If the dike areas are not filled or are filled unevenly, however, the slurry separates along the slope of the spoil, with fines collecting along the periphery behind the dike.

In either case, the resulting spoil island is unstable. Wind, waves, and currents continuously alter the shape of the island. Elongate islands formed parallel to the erosional forces (e.g., prevailing winds) erode on the upwind point and accrete on the downwind side to form a spit. Elongate islands situated perpendicular to the erosion forces will rapidly disappear from the ends to center (Lewis and Lewis 1978). Round islands, relatively unprotected, generally erode on the windward side and form two spits on the lee side. These accreting spits may eventually connect and form a land-locked pond or lagoon. Protected round islands develop uniform vegetation around the periphery with a gradation of habitats toward the center, and are the most stable of the spoil islands.

Besides the morphological changes, chemical changes after deposition of spoil material are marked and critical in determining the physical environment of a spoil area, and ultimately, the colonization and successional success of the vegetative communities. Particle-size redistribution affects interstitial water content of the soil and soil pH, and in turn, salinity regimes and organic content.

Plant-succession studies on dredged-material islands in Tampa Bay have been conducted by Dunstan and Lewis (1974), Coastal Zone Resources Corporation (1977), and Lewis and Lewis (1978). Similar work in Sarasota Bay and Charlotte Harbor has been done by Beaman (1973) and Carlson (1972), respectively.

Figure 118 illustrates generalized spoil-island habitat succession for the study area (Lewis and Lewis 1978). This is an idealized pattern based on a variety of islands in Tampa Harbor, Sarasota Bay, the Intracoastal Waterway, Charlotte Harbor, and other locations in south-central Florida. Any one island may drastically depart from this succession pattern; for example, plants will never colonize some islands because of unstable conditions (e.g., low, flat islands that experience high wave energy and are surrounded by bare sand beaches). Islands exposed to somewhat less severe stress (i.e., open Gulf of Mexico waters) may exhibit retarded or slowed successional patterns. The presence of certain physical features may prohibit colonization by a "typical" dominant plant. In Tampa and Sarasota Bays, for example, steep slopes on the islands prevent the establishment of the Australian pine, and a southern red cedar-cabbage palm climax community develops (Lewis and Lewis 1978). Table 39 presents the species most commonly found for each of the successional stages illustrated in Figure 118.

Spoil-island flora have been segregated into as many as 15 biotic associations or communities in the study area (Coastal Zone Research Corp. 1977). For purposes of presenting the typical spoil island habitats, four general communities described by Carlson (1972) and Beaman (1973) will be adopted. These are pioneer or beach strand, mangrove, Australian pine, and xeric uplands or barrens. Table 40 presents a summary of the substrate characteristics for these major habitat types, while Figure 119 provides a diagrammatic representation of their distribution on a typical spoil island.

Pioneer strand habitats typically appear along accreting spits, sheltered beaches on the leeward side of the islands, and margins of mangrove communities. The strand represents a steady-state, transient pioneer community on shorelines not taken over by competitive species of mangroves or Australian pine. The unstable nature of this environment, which is exposed to storm waves, changing shorelines, high salinity, and excessively drained soils, helps to maintain the pioneer quality of the community. Sea wrack (primarily *Thalassia)* often provides the only organic base for seed germination and water retention. Both Carlson (1972) and Beaman (1973) describe three vegetative zones in the strand habitat. In low, wet or marshy areas the dominant plants include saltwort (*Batis maritima)*, sea purslane (*Sesuvium portulacastrum)*, and glasswort (*Salicornia virginica)*. More elevated areas along the beach and intermediate ridges are dominated by sea rocket (*Cakile edentula)*, seaside heliotrope (*Heliotropium curassavicum)*, *Aster* spp., and seaside paspalum (*Paspalum vaginatum)*. Railroad vine (*Ipomoea pes-caprae)*, dropseed (*Sporobolus domingensis)*, Bermuda-grass (*Cynodon dactylon)*, and Australian pine seedlings (*Casuarina equisetifolia)* are commonly found on higher ridges. The primary colonization vector for seeds in the strand habitat is water. Recolonization of this primary community follows quickly after natural catastrophic events such as fire or hurricanes (Beaman 1973).

The mangrove zone on spoil islands resembles the natural island forest and swamp mangrove systems described previously, except for the reduced presence of the red mangrove (*Rhizophora mangle)*. Instead, the black (*Avicennia germinans)* and white (*Laguncularia racemosa)* mangroves dominate, sometimes exclusively. Possible causes of the absence of red mangroves are their more stringent soil requirements and the seed shape, which is less suited for germination on the unstable spoil island shores (Carlson 1972; Beaman 1973). Actually, the initial pioneer plant to this zone is often smooth cordgrass (*Spartina alterniflora)*, followed by black and white mangroves,

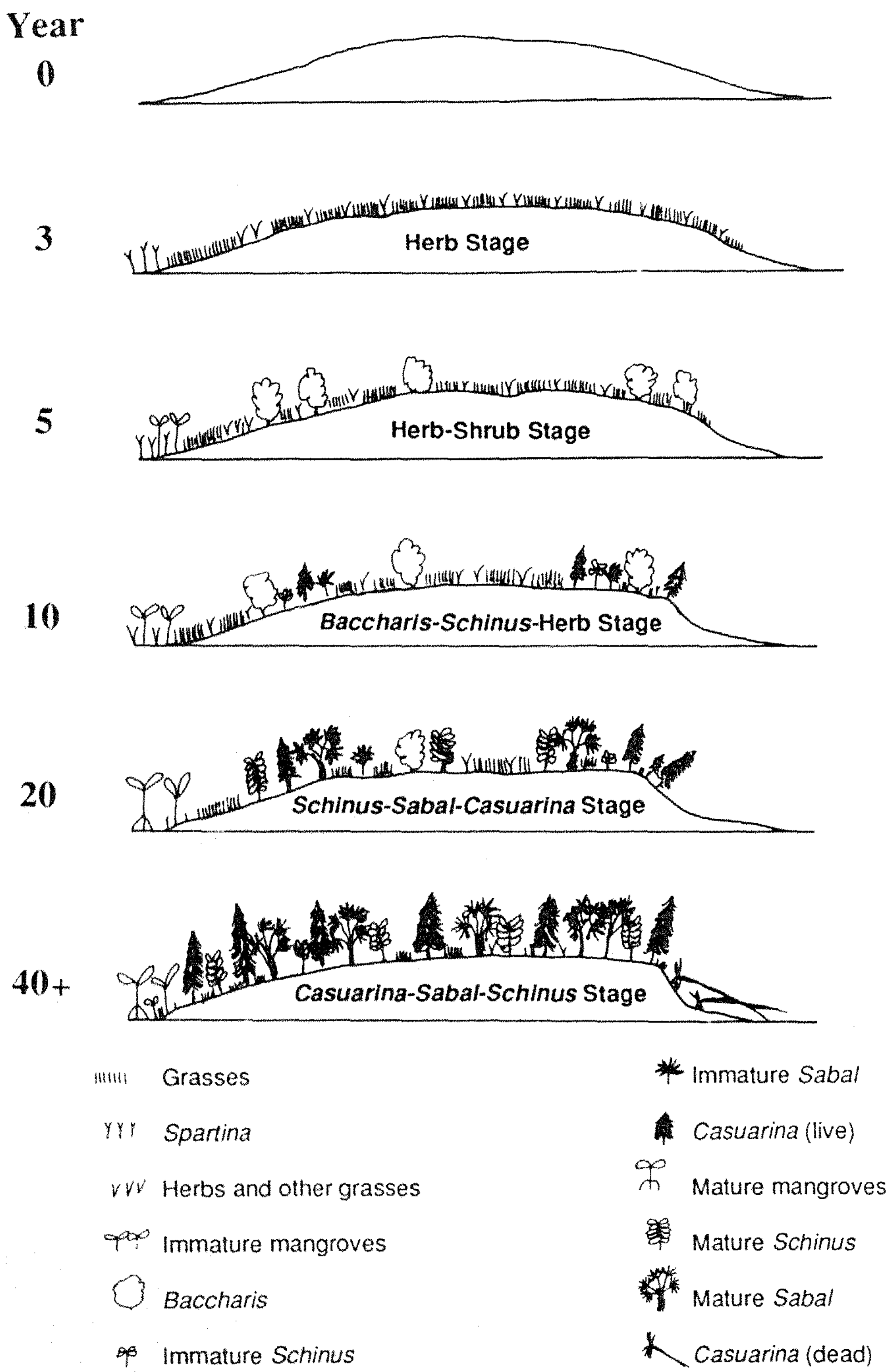


Figure 118. Generalized habitat succession on dredged material islands in Florida (after Lewis and Lewis 1978).

Table 39. Major plant species associated with the generalized plant succession pattern on dredged material islands in Florida (see Chapter 6) (adapted from Lewis and Lewis 1978).

Year	Scientific Name	Common Name
0	—	—
3	*Paspalum vaginatum*	Seaside paspalum
	Chloris glauca	Fingergrass
	Rhynchelytrum repens	Natal-grass
	Sporobolus potretii	Smutgrass
	Sporobolus domingensis	Dropseed
	Cenchrus spp.	Sandspur
	Spartina alterniflora	Smooth cordgrass
5	All of the above plus:	
	Oenothera humifusa	Seaside evening primrose
	Heterotheca subaxillaris	Camphor weed
	Baccharis halimifolia	Groundseltree
	Iva frutescens	Marsh elder
	Schinus terebinthifolius	Brazilian pepper-tree
	Laguncularia racemosa	White mangrove
10	*Baccharis halimifolia*	
	Schinus terebinthifolius	
	Paspalum vaginatum	
	Heterotheca subaxillaris	
	Oenothera humifusa	
	Sabal palmetto	Cabbage palm
	Casuarina equisetifolia	Australian pine
	Avicennia germinans	Black mangrove
	Laguncularia racemosa	
20	*Schinus terebinthifolius*	
	Sabal palmetto	
	Casuarina equisetifolia	
	Paspalum vaginatum	
	Avicennia germinans	
	Laguncularia racemosa	
	Rhizophora mangle	Red mangrove
	Conocarpus erecta	Buttonwood
40+	*Casuarina equisetifolia*	
	Sabal palmetto	
	Schinus terebinthifolius	
	Avicennia germinans	
	Laguncularia racemosa	
	Rhizophora mangle	

which eventually shade out the cordgrass except along the island fringes where it often grows in association with the red mangrove. Inshore, the black and white mangrove seedlings and young trees coexist with a wet-strand understory, typically consisting of saltwort, glasswort, and sea purslane. These ground-cover plants are gradually shaded out as the mangroves mature and the canopy closes. Seed vectors are aquatic, as expected from a community that lies strictly below the storm high-tide line (Carlson 1972).

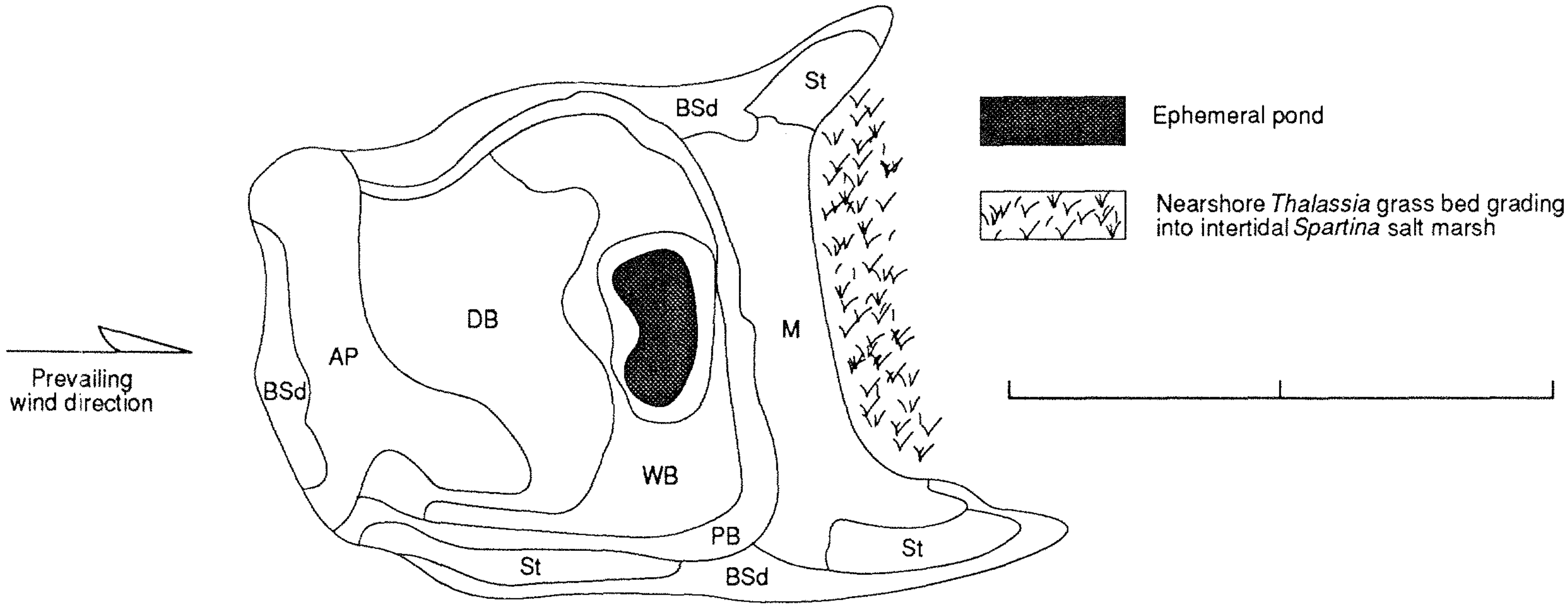
Australian pines form dense, occasionally monotypic stands along the shore and in nearshore areas (at or above the supratidal zone) on windward ridges, and occasionally in the centers of older islands. Waterborne seeds invade pioneer strand communities, which are eventually shaded out as the Australian pines mature. The shade-tolerant understory in a maturing Australian pine forest generally includes Brazilian pepper-tree (*Schinus terebinthifolius*), seagrape (*Coccoloba uvifera*), buttonwood (*Conocarpus erectus*), and seaside goldenrod (*Solidago sempervirens* var. *mexicana*). Other shrubs and trees around the fringe or between clumps of pines include saltbush (*Baccharis halimifolia*), cabbage palm (*Sabal palmetto*), and marsh elder (*Iva frutescens*). Where fire or winds remove a tree, numerous brush plants rapidly fill in the void. These include such plants as *Baccharis* seedlings, pokeweed (*Phytolacca americana*), fingergrass (*Chloris* spp.), dropseed, and capeweed (*Lippia nodiflora*) (Carlson 1972; Beaman 1973).

There are several reasons why the Australian pine flourishes on the spoil island. The copious production of leaf litter forms a thick organic mat that reduces both moisture loss (via percolation) and understory plant competition. The shallow, spreading root system remains close to the moisture-laden ground litter and far from the saline or hypersaline ground water. The leaf shape minimizes evapotranspiration. The nitrogen-fixing root nodules provide a supplemental source of nitrogen in a nitrogen-limiting environment. This community, like the mangrove system, exhibits very little seasonal change.

The shallow root system and the thick organic mat, while providing a competitive advantage, make the

Table 40. Summary of physiochemical soil parameters associated with vegetated community types on dredge spoil islands (adapted from Beaman 1973).

Community Soil parameters	Strand beach	Mangrove	Australian pine	Barrens (dry)	Barrens (wet)
Particle size	Beach ridge: coarse sand and shell Sheltered lagoon: fine sand		Coarse sand and shell	Coarse sand and shell	Coarse sand and shell
Soil moisture	Soils throughout are highly porous and have poor water holding capacity				
Factors affecting water retention	Layer of organic debris	Shade of older mangroves	Shade of needle litter	Increased vegetation cover	Increased vegetation cover
Sources of soil moisture	Tidal inundation, rain	Tidal inundation, rain	Rain, tidal inundation in some zones	Rain	Rain
Soil salinity	High	High	Medium high	Low	Low
Sources of soil salinity	Tidal inundation	Tidal inundation	Salt spray, storms	Salt spray, storms	Salt spray, storms
Organic content	Ranges from 0-12% with generally high values in the Australian pine and mature mangrove communities. All zones increase with age of the island and development of plant communities.				
Primary sources of organic content					
External:	*Thalassia* wrack	*Thalassia* wrack		Debris from large storms	Debris from large storms
Internal:	Plant death and decay	Plant death and decay (leaf fall)	Needle litter	Plant death and decay	Plant death and decay



St - Strand Community
Wet Saltwort (*Batis maritima)*
Sea purslane (*Sesuvium portulacastrum)*
Dry Sea rocket (*Cakile edentula*)
Seaside paspalum (*Paspalum vaginatum*)

M - Mangrove Community
Black mangrove (*Avicennia germinans*)
White mangrove (*Laguncularia racemosa*)

A - Australian Pine Community
Australian pine (*Casuarina equisetifolia*)
Brazilian pepper-tree (*Schinus terebinthifolius*)

DB - Dry Barrens Community
Sea oats (*Uniola paniculata*)
Capeweed (*Lippia nodiflora*)
Natalgrass (*Rhynchelytrum repens*)

WB - Wet Barrens Community
Broomsedge (*Andropogon virginicus*)
Bullrush (*Scirpus* spp.)
Cowpea (*Vigna luteola*)

PB - Periphery Barrens Community
Saltmarsh pluchea (*Pluchea purpurascens*)
Marsh elder (*Iva frutescens*)
Sea ox-eye (*Borrichia frutescens*)

BSd - Bare Sand (No vegetation)

Figure 119. Generalized vegetation map of a dredged disposal island in Tampa Bay (Lewis and Lewis 1978).

Australian pines more sensitive to the physical forces of hurricane and fire. Outer windward trees are easily uprooted during high winds and seas. Ground fires that appear to do little damage to the overstory pines often result in the death of the pine within a year of the occurrence (Beaman 1973).

The barren-zone habitat is typically located near or at the center of the spoil island, where extremely dry conditions prevail. The herbaceous shrub-dominated flora observed in this habitat varies in response to moisture resulting from slight differences in the physiography. Beaman (1973) described three subzones to account for the physiographic variation: dry, wet, and periphery barrens. The dry barrens exhibit the harshest conditions on the islands, characterized by very low moisture; excessively drained, coarse-grained substrates; large diurnal temperature fluctuations; and low organic debris content. Xeric conditions here often restrict growth to vines and grasses with running rootstocks, similar to coastal dune habitat (e.g., sea oats (*Uniola paniculata*), capeweed, and railroad vine) or sandy disturbed areas, (e.g., sandspur (*Cenchrus sp.*), fingergrass (*Chloris neglecta*), dog fennel (*Eupatorium capillifolium*), and natalgrass (*Rhynchelytrum repens*)). Even within the dry barrens subzone, the presence or absence of a particular species often reflects subtle changes in the soil environment. For example, the presence of capeweed frequently indicates a slight depression in which soil with better moisture retention ability has collected; sandspur colonizes the very dry areas. The dry barren subzone exhibits the greatest seasonal variation on the island, with productivity peaking in late spring and early summer (Beaman 1973; Lewis and Lewis 1978).

Wet barrens are found in depressions where the soil moisture is higher. Organic debris, plant size, density, and diversity are all greater here than observed in the dry barrens. Species commonly found in addition to those previously described include broomsedge (*Andropogon virginicus*), bulrush (*Scirpus* spp.), and cowpea (*Vigna luteola*).

Beaman's periphery barren zone is a transitory grass and herb community found between the central barrens and the other spoil island habitats. The area is less elevated, more shaded, and often more diverse. Plants commonly found include creeping cucumber (*Melothria pendula*), saltmarsh pluchea (*Pluchea purpurascens*), pink purslane (*Portulaca pilosa*), seaside paspalum, Bermuda-grass, buttonwood, marsh elder, and sea daisy (*Borrichia frutescens*) (Carlson 1972; Beaman 1973).

Seeds that colonize the barrens are transported by a variety of vectors, but predominantly by winds and birds. Reduced or absent growth in the barrens may be due to a barrier formed by Australian pines and/or mangroves that reduce or prevent wind and wave seed dispersion. In Tampa Bay where Australian pines are poorly established, the spoil island barrens are well colonized by herbaceous plants and shrubs, previously described.

Another form of spoil deposition in the Tampa Bay area is the creation of filled lands adjacent and contiguous to exiting shorelines. Boca Ciega Bay provides possibly the best example in the watershed, where during the 1950's approximately 1,400 ha of bay bottom were filled for housing and causeway construction. As in spoil islands, filled lands represent a new landform with unique habitat colonization and successional qualities. Fill lands differ from spoil dump areas, however, in that the surface is leveled, compacted, and reworked; the shorelines are usually protected from tidal action by seawalls; and the land area is closer to centers of seed dispersal.

In their study of the natural reclamation of filled land in Boca Ciega Bay, Passavant and Jefferson (1976) delineate the following eight vegetation communities:

1. Sandspur community.
2. Grass-sedge community.
3. Shrub community.
4. Palm community.
5. Pond community.
6. Salt-spray community.
7. Salt marsh-mangrove community.
8. Australian pine.

Many of the plant associations described here are reminiscent of the natural beach, dune, and coastal strand communities discussed in Section 5.4.4. Probable successional patterns on filled lands involving these plant communities are illustrated in Figure 120.

The sandspur community, which is characterized by the sandspurs (*Cenchrus echinatus* and *C. incertus*) and camphor plant (*Heterotheca subaxillaris*), is the colonizer of high, dry areas and locations where there is excessive soil disturbance by trampling and vehicles. This community first colonizes the new fill, stabilizes the sand and eventually gives way to the grass-sedge community. Together these two community types occupy the majority of undeveloped fill area in Boca Ciega Bay, especially on fills that have been repeatedly mowed. Typically, the soil has large shell fragments on the surface and little organic matter.

The grass-sedge community consists of distinct stands of broomsedge, gunigale (*Cyperus ligularis)*, and love-grass (*Eragrostis elliottii)*. Associated sedges and grasses include *Fimbristylis miliacea* and *Paspalum notatum*. Soils here are fine sands mixed with shell fragments, and relative to the other community types, are more alkaline and contain higher levels of sodium and lower levels of potash and phosphates. If left undisturbed, the grass-sedge community succeeds to the palm community to be discussed later. This pattern dominates in the majority of fill areas and is common in naturally disturbed areas as well.

A second pattern is seen adjacent to the seawalls. The salt-spray community grows in a narrow strip immediately behind the seawalls, where wave splash is frequent. As to be expected, many of the plants occupying this zone are salt tolerant and reminiscent of the beach/dune communities discussed in Section 5.4.4. The most prominent are railroad vine, seaside ground cherry (*Physalis viscosa)*, seaside primrose (*Oenothera humifusa)*, and saltgrass (*Distichlis spicata)*. Occasionally, sea oats colonize the moving sand. Soils are very fine sands with high pH values and low nutrient content. Woody plants, including palms, Brazilian pepper-tree, and mangroves may colonize this community if the original community is not mowed or disturbed.

The salt-spray community is then replaced by the shrub community, especially by stands of salt bush and Brazilian pepper-tree. The shrub community consists of stands of dog fennel, saltbush, golden rod (*Solidago sempervirens)*, and Brazilian pepper-tree (*Schinus terebinthifolius)*. Waxmyrtle, marsh elder, *Borrichia arborescens*, and *Melanthera aspera* also occur, but in smaller numbers. Soils are fine sands with a few large shell fragments on the surface. An organic layer is present and extends several centimeters into the soil. Litter, especially from Brazilian pepper-tree and salt bush, often covers the ground and aids in retaining moisture.

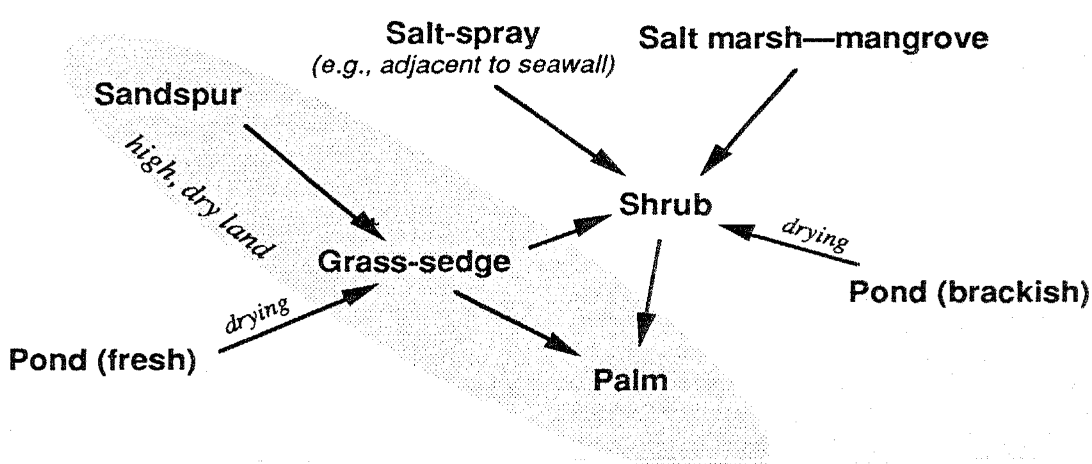


Figure 120. Plant community succession on filled land, Boca Ciega Bay (after Passavant and Jefferson 1976).

Freshwater or slightly brackish ponds and pools include natural water bodies, as well as dredged ponds and those formed by the unequal settling of fill material. The ponds are first invaded by aquatic plants such as *Ruppia maritima*, and are surrounded by cattail (*Typha latifolia*), capeweed, and several salt-marsh plants such as sea purslane, water hyssop (*Bacopa monnieri*), and seaside paspalum. A filamentous algae (*Oedigonium*) may cover the exposed substrate of these pools as the slightly brackish water recedes with the onset of the dry season. The edges of the more permanent ponds are surrounded by a lush growth of *Cyperus esculentus*, Brazilian pepper-tree, broom sedge, willow (*Salix marginata*), saltbush, and cattails (*Typha latifolia* and *T. angustifolia*). Soils are fine sands with a surface humus layer, but very low in nutrients compared to the other communities. If the pond dries up or is eventually filled in, the *Cyperus* stands are increasingly taken over by grasses.

If these communities are left undisturbed, they may finally develop into the palm community. This community is dominated by the cabbage palm, but the Washingtonia palm (*Washingtonia filifera*) and sago palm (*Cycas revoluta*) may also occur. The laurel oak (*Quercus laurifolia*) is often the codominant in this community (e.g., Mullet Key). Strands of torpedograss (*Panicum repens*) and seaside ground cherry may surround the palms. Typical plants of upland palm hammocks such as cat brier (*Smilax rotundifolia*), *Lantana sellowiana*, poison ivy (*Toxicodendron radicans*), Spanish bayonet (*Yucca aloifolia*), prickly pear cactus (*Opuntia humifusa*), blackberry (*Rubus* sp.), and laurel oak invade the undisturbed palm communities as they mature. Soils are fine sands and have a dark organic layer nearly a meter deep.

The Australian pine community is found wherever it has been planted or has invaded undiked fills. This species dominates the community to the exclusion of all other plants. Although it readily colonizes and initially stabilizes the shoreline, its roots are shallow and spreading and when the shoreline erodes away under the roots, the trees topple, dislodging large amounts of soil and accelerating local beach erosion.

As observed by Passavant and Jefferson (1976),

> ...the natural revegetation of filled land in Boca Ciega Bay includes succession patterns that involve stabilization of the soil, invasion of herbaceous and woody plants, canopy closure, and increasing species diversity. The initial rate of succession appears to be slow... [but] once a cover of grasses occurs, the complexity of the filled land communities accelerates.

These patterns are often disrupted, however, by disturbance to the vegetation by mowing, fire, and churning of the soil by vehicle, and succession is set back. In all cases, though (except when the vegetation is dominated by the exotics Australian pine or Brazilian pepper-tree) the successional patterns lead to a final climax palm community which naturally occurs on the east shore of Tampa Bay and on the interior of larger keys and barrier islands within the watershed, such as Mullet Key.

The salt marsh-mangrove community occurs on the shore of undiked fills. Smooth cordgrass grows nearest the water, followed by red and black mangrove. Just inland, saltgrass grows in a dense monoculture, replaced by the shrub or grass-sedge communities further upland. In low areas, black rush (*Juncus roemerianus*) grows in strands extending into the shrub community. Saltwort, glasswort, sea purslane, and other salt-tolerant succulents grow on the saturated soils, among the mangroves and salt-marsh grasses. Detritus gathers in these locations, and the soils are highly organic and reduced.

5.6 Endangered and Threatened Plant Communities.

Florida's flora consists of approximately 3,500 native and introduced plant species. Of these, over 400 have been designated by various governmental agencies as worthy of special concern (Wood 1989). Classification of a plant species status as rare, threatened, or endangered varies considerably, depending on the objectives of the group of individuals preparing the list, the geographical area in question, the amount of detailed field work conducted in the area, and the botanical and ecological expertise of the investigators.

Habitats in which these species may be expected are indicated in Appendix Table A-11. Three of these habitats—southern slash pine, open scrub cypress, and shell mounds—are absent or poorly represented in the Tampa Bay watershed. Species predominantly associated with the habitats, although recorded from the study area, are more typical of south Florida where these habitats are found.

Hammocks, with 51 species, harbor the greatest number of threatened and endangered plants appearing on this list, the majority being found exclusively in this habitat type. In this category are included all four hammock associations discussed in Section 5.2.4, along with the tropical hammock, more typical of the south Florida Everglades and Keys, but occurring as remnant associations as far north as Sarasota. The moist, nearly constant, and relatively stable environmental conditions of the hammock, with its diversity of microhabitats, provide ideal conditions for the many rare and endemic species of vines, ferns, and airplants associated with the hammock. Periodic fires, hurricanes, developmental pressures, and collectors are the main threats to many of these species.

The prairie grasslands category, including both wet and dry prairies, provides habitat for 41 species of rare plants. These grasslands are scattered throughout the watershed, transitionally situated between pine flatwoods and more typical wetland habitats such as freshwater marshes and swamps. It is not surprising, then, to find these rare plants in a variety of environmental settings. Club mosses (*Lycopodium* spp.), numerous orchids (*Calopogon, Spiranthes, Platanthera*), wild cocoa (*Eulophia)*, and a few evergreen shrubs (*Ilex)* are found in and around prairie grasslands.

Pine flatwoods (35 species) and southern slash pine forests (28 species), due to the similarity in habitat, have many species in common. Numerous grasses and orchids of rare or endangered status fall into this category. The sand pine scrub habitat, in contrast, has a unique flora with many endemic species. These include the curtis milkweed (*Asclepias curtissii)*, Florida bonamia (*Bonamia grandiflora)*, rosemary (*Ceratiola ericoides)*, pinweed (*Lechea cernua)*, scrub palmetto (*Sabal etonia)*, and associated shoestring fern (*Vittaria lineata)*. Alterations of this unique Florida habitat for agriculture, grazing, and residential development continue to threaten their existence.

Wetland habitats such as cypress swamps (26 species), swamp forests (26 species), and freshwater marshes (27 species) support many rare and endangered species. Development and drainage patterns in these ecologically fragile systems threaten to destroy and fragment these habitats so that small remnant pockets of cypress swamp and freshwater marsh are becoming increasingly common, rather than large strands. This isolation results in the increased likelihood of plant loss. Species of concern include the airplants (*Tillandsia fasciculata, T. setacea)*, twayblade (*Liparis elata)*, shadow witch (*Ponthieva racemosa racemosa)*, and the rare spoon-flower (*Peltandra sagittifolia)*.

The coastal strand (9 species) and the mangrove swamp/coastal marsh (5 species), although small in area, support a unique and fragile flora. Both the red mangrove (*Rhizophora mangle)* and black mangrove (*Avicennia germinans*) are considered species of special concern in Florida, due to the unique communities they support and their aid in shoreline stabilization. The leather fern (*Acrostichum danaeifolium)*, marsh mallow (*Kosteletzkya smilacifolia)*, and pond apple (*Annona glabra*) are all species considered threatened in the mangrove swamp/coastal marsh habitat. Along the coastal strand are many rare small plants and shrubs that are also of threatened status. These include the beach-creeper (*Ernodea littoralis)*, beach-sunflower (*Helianthus debilis vestitus*), yaupon (*Ilex vomitoria)*, pinweed (*Lechea divaricata*), prickly pear cactus (*Opuntia stricta)*, waterfall (*Physalis viscosa elliottii)*, scaevola (*Scaevola plumieri*), and Sanibel lovegrass (*Eragrostis tracyi)*. Sanibel lovegrass is found within the watershed only on Long Key and is now under review by the U.S. Fish and Wildlife Service for possible listing.

Other species of special interest because of their variety include the tropical curly-grass (*Schizaea germanii*), restricted to isolated populations in wet, rich soil under saw palmetto and gallberry bushes in Pinellas County; the Florida golden aster (*Chrysopsis floridana*), existing in two populations in Hillsborough County and previously in Pinellas County before its destruction by urbanization; and the prickly-apple (*Cereus gracilis*), found on shell mounds near mangrove swamps and wet thickets.