Special Publication SJ94-SP12

# St. Johns River, Florida
# Water Quality Feasibility Study
# Phase I Interim Report

## Volume I

## Executive Summary

U.S. Army Corps of Engineers
Jacksonville District
South Atlantic Division

St. Johns River Water Management District
Palatka, Florida

Revisions to Special Publication SJ94-SP12

*St. Johns River, Florida*
*Water quality feasibility study*
*Phase I interim report*
*Volume 1, Executive Summary*

Page 103, replace reference citation for Bergman, Martinus J. with the following:

Bergman, Martinus J. 1992. Volume 2 of the Lower St. Johns River Basin reconnaissance, surface water hydrology. Technical Publication SJ92-1. Palatka, Fla.: St. Johns River Water Management District.

# Table of Contents

**ST. JOHNS RIVER, FLORIDA**
**FEASIBILITY STUDY**

**INTERIM PHASE I**

**(CWIS 12336)**

## SYLLABUS

The purpose of this phase of the study is to assess and quantify water quality related conditions and to develop evaluation tools for assessing water quality problems of the lower St. Johns River. The study is a water quality management investigation which is outside traditional Corps of Engineers General Investigation missions. This study was conducted at the request of the St. Johns River Water Management District under the authority provided by the Supplemental Appropriations Act of 1987 (P.L. 100-71) which directed the Corps to initiate the feasibility phase of the St. Johns River Study, Florida. The U.S. Army Corps of Engineers has the primary responsibility for conducting the study and preparing this report.

The primary study area is the lower 101 mile reach of the St. Johns River from the confluence of the Oklawaha River to the Atlantic Ocean. This includes the urban area of Jacksonville, Florida.

This report presents the results of investigations on the St. Johns River recommended in the Interim Water Quality Management Plan Findings (Reconnaissance Report, January 1986). The Reconnaissance Report reported areas which needed more investigation. This interim phase 1 report focused on ambient water quality conditions within the lower St. Johns River basin to include tidal currents and circulation; vertical and horizontal measurements and tidal analyses; sediment management; groundwater interaction from the Floridan aquifer to the St. Johns River; and data and database management within the Corps of Engineers.

The Corps of Engineers had technical capability to hire qualified expertise to perform investigations on these specific areas. The results of these investigations were the focus of this report. There was no economic or environmental analysis and as such, it is unlikely that additional studies would result in a recommendation of a Corps project.

TABLE OF CONTENTS

TABLE OF CONTENTS



LIST OF FIGURES

# INTRODUCTION

This report presents the results of investigations on the St. Johns River recommended in the Interim Water Quality Management Plan Findings (Reconnaissance Report, January 1986). The Reconnaissance Report reported areas which needed more investigation. This report will focus on ambient water quality conditions within the lower St. Johns River basin to include tidal currents and circulation; vertical and horizontal survey controls and tidal analyses; sediment characteristics and management; groundwater interaction from the Floridan aquifer to the St. Johns River; and data and database management within the Corps of Engineers. The study provides a numerical model approach to answer management and user needs suitable to meet objectives of Florida's Surface Water Improvement and Management (SWIM) program. The study is a water quality management investigation which is outside traditional Corps of Engineers General Investigation missions.

## STUDY AUTHORITY

Specific language in the Energy and Water Development Appropriations Act of 1984 directed the Corps to develop the reconnaissance report. The Supplemental Appropriations Act of 1987 (P.L. 100-71) directed the Corps to initiate the feasibility phase of the St. John River Study, Florida.

> *...Using funds previously appropriated in the Energy and Water Development Appropriations Act, 1987, Public Law 99-500 and Public Law 99-591, the Secretary of the Army is directed to undertake the following studies: ...St. Johns River Study, Florida.*

Specific guidance from Headquarters, U.S. Army Corps of Engineers, interpreted from P.L. 100-71, instructed the Corps to initiate the feasibility phase of the St. Johns River Study.

## STUDY PURPOSE AND SCOPE

The primary purpose of this study was the assessment and the quantification of water quality related conditions and the development of evaluation tools for assessing problems of the lower St. Johns River. This study consisted of the assembly, review, and evaluation of existing data and information essential for developing:

* a basic understanding of the natural system operating within the St. Johns River Basin;

* basic information necessary for structuring water quality management evaluation tools;

* simple field-level evaluation tools for field inspection, problem assessment, or area screening purposes;

* other evaluation tools essential for understanding the need for new agency policies, interagency agreements, and state legislative actions; and

* a system for managing data and information on the hydrodynamics and sediments within the LSJRB.

The feasibility study assembled, reviewed and evaluated existing data and information needed to assist water managers' water quality management practices within the St. Johns River system. This study enhanced the goals of Florida's Surface Water Improvement and Management (SWIM) Plan for the lower St. John's River to improve the quality of the river and restore selected locations.

The goals of the lower St. Johns River SWIM plan are:

* restore and protect the basin's surface water quality Class III or better (Chapter 373.453, F. S.).

* restore and protect natural systems associated with the basin's surface waters;

* increase public awareness of water resource problems in the basin to generate public support for restoration and protection efforts; and,

* enhance interagency coordination and management of water resources throughout the basin.

The scope of local interests regarding single purpose water quality management planning is outside of the traditional Federal authorities provided by Congress to the Corps of Engineers. However, the Corps had technical capabilities for undertaking regional water quality evaluations needed for improved water resources management functions normally conducted within the framework of a multi-purpose feasibility study.

## STUDY PROCESS

Since this study was not a traditional feasibility study, the process was different. There was no economic benefit analysis and no recommendation for project construction.

The reconnaissance study identified areas of concern and data development. This feasibility study investigated these areas. Results of these investigations along with recommendations for further study were evaluated. Recommendations for further study were assessed.

There was no environmental assessment, Findings of No Significant Impact (FONSI), or environmental coordination. This main report is an interim feasibility report.

## THE REPORT

The study is structured as a main report and supporting documentation. Since this is not a normal feasibility study, a synopsis of the investigations performed during the study are included in the main report. The actual work and documentation from each area of concentration are included in the supporting documentation.

# PRIOR AND ONGOING STUDIES

## PRIOR FEDERAL STUDIES AND REPORTS

The St. Johns River Basin has been included in many River and Harbor Acts dating from the latter part of the 19th Century. These Acts are presented in Table 1. The existing federally authorized flood damage prevention project works and Federal navigation projects considered for review in this investigation are presented in Table 2.

Investigations for Mill Cove were covered under two Section 107 Reports. In 1970, a recreational small boat channel was considered through Mill cove but was found to be not feasible. A study in 1974 indicated favorable findings for a similar channel but there was no local sponsor for the project. These reports ended with no recommendation for further action. A feasibility report was written on Jacksonville Harbor-Mill Cove dated September 1980. The investigation was conducted to determine whether the existing Jacksonville Harbor Project resulted in degradation of Mill Cove and the need for improvements for circulation, flow, and navigation. The project was authorized by WRDA 1986 and completed in 1988.

Another Section 107 Report was written for Stokes Landing. the purpose of the study was to investigate the feasibility of providing a Federal navigation channel from the St. Johns River to Stokes Landing near Palatka. This study was discontinued in 1982 due to lack of interest by the local sponsor.

### TABLE 1

### RIVER AND HARBOR ACTS

| ACTS | WORK AUTHORIZED | DOCUMENT |
|---|---|---|
| 14 June 1880 | Contemplated a channel over Volusia Bar with a 15-foot depth at Mean Low Water. Jetties at entrance. (maintenance only) | Annual report for 1879, Page 767 |
| 14 July 1880 | Improving Volusia Bar. Called for two jetties on the bar and a 6-foot deep channel | |
| 5 July 1884 | Improvement between Lakes George and Monroe | |
| 13 July 1892 | Secure 15-foot depth through the reach from Dames Point to Mile Point | |
| 3 June 1896 | Channel 300 feet wide and 24 feet deep from Jacksonville to the ocean with extending jetties | House Document No 346, 53rd Congress, 3rd Session |
| 3 March 1899 | 200-foot wide, 13-foot-deep channel from Jacksonville to Palatka | House Document No. 523, 55th Congress, 2nd Session |
| 13 June 1902 | Maintenance of improvement at Volusia Bar and maintain a 5-foot-deep channel between Palatka and Sanford | |

## TABLE 1 (CONTINUED)

## RIVER AND HARBOR ACTS

| ACTS | WORK AUTHORIZED | DOCUMENT |
|---|---|---|
| 2 March 1907 | A depth of 24 feet at Mean Low Water between the 24-foot curve and the pierhead line at Jacksonville | House Document No. 663, 59th Congress, 1st session |
| 25 June 1910 | A channel 100 feet wide and 8-feet deep from Palatka to Sanford with a side channel to Enterprise and thence 5-feet deep to Lake Harney | House Document No. 1111, 61st Congress, 2nd Session |
| 25 June 1910 | Main channel, 30-feet deep at Mean Low Water and in general 300-feet wide, and the anchorage basin opposite Mayport | House Document No. 611, 61st Congress, 2nd Session |
| 4 March 1913 | Provided for a channel 100 feet wide and 8 feet deep from the St. Johns to Cresent City | House Document No. 1320, 62nd Congress, 3rd Session |
| 2 March 1919 | Improvement to Deep Creek | House Document No. 699, 63rd Congress, 2nd Session |
| 5 June 1920 | Present Project effected by the consolidation of former projects | Specified in Act |
| 3 July 1930 | Cutoffs at Butcher Bend, Snake Creek and Starks and Easing Bends at other Points | House Document No. 691, 69th Congress, 2nd Session |
| 3 July 1930 | Widening the bend at Dames Point | House Document No. 483, 70th Congress, 2nd Session |
| 30 August 1935 | Widening Drummond Creek, Trout Creek, and Six Mile Creek, cuts to 400 feet and a channel 30 feet deep and 400 feet wide along the terminals at Jacksonville | Senate Committee 74th Congress, 1st Session |
| 2 March 1945 | A channel 10 feet deep and 100 feet wide from Palatka to Sanford with a side channel to Enterprise, and with side cutoffs and easing of bends | House Document No. 603, 76th Congress, 1st Session |
| 2 March 1945 | Maintenance of existing channel widths, widening Terminal Channel to 590 feet; the 28-foot area between Laura Street and St. Elmo West Acosta Bridge; channel along south side of Commodore Point; and Basin at Naval Reserve Armory | House Document No. 322, 77th Congress, 1st Session |
| 2 March 1945 | Main channel 34 feet deep via Terminal Channel | Senate Document No. 230, 78th Congress, 2nd Session |
| 2 March 1945 | Combining two previous Acts (3/2/45 and 7/3/30) into a single project for the St. Johns River, Jacksonville to Lake Harney, and for a cutoff 5 feet deep and 75 feet wide between Lake Monroe and the vicinity of Osteen Bridge (Woodruff Creek Cutoff) | House Document No. 445, 78th Congress, 2nd Session |
| 2 March 1945 | Dame Point-Fulton Cutoff 34 by 500 feet | Senate Document No. 179, 79th Congress, 2nd Session |
| 24 July 1646 | A channel 12 feet deep and 100 feet wide from Palatka to Sanford and in the branch to Enterprise | Senate Document No. 208, 79th Congress |
| 27 October 1965 | Maintain existing entrance channel depths of 40 and 42 feet; deepen main ship channel to 38-foot depth to mile 20; and widen channel near Mile 5 and Mile 7 | House Document No. 214. 89th Congress |
| 17 November 1986 | Enlarge Mill Cove Control Structure to a 1300 x 12 foot opening; enlarge channel between Mill Cove & St. Johns River near Reddie Point to a 650 x 12 foot opening; and install flow diversion features on east & west ends of Mill Cove | Public Law 99-662 |

# TABLE 2
# ST. JOHNS RIVER
# SURVEY REPORTS AND PRELIMINARY EXAMINATION

| DATE | REPORT | RECOMMENDATIONS | RECOMMENDATIONS (1) OF THE CHIEF OF ENGINEERS | DOCUMENTS |
|---|---|---|---|---|
| 24 May 1853 | Survey Report and Fort George Inlet | | | |
| 29 January 1869 | Survey Report Mouth | | | Annual Report Of Chief of Engineer 1869, page 266 |
| 25 March 1872 | Survey Report Jacksonville to the Ocean | | | Annual Report of Chief of Engineers 1872, page 672 |
| 16 July 1878<br>16 July 1978 | Survey Report between Lakes Monroe and George<br>Survey Report, Volusia Bar | F | | Annual Report of Chief of Engineers 1879, page 795 |
| 30 June 1879 | Survey Report Mouth | F | | Annual Report of Chief of Engineers 1879, page 767, with maps |
| 23 May 1882 | Survey Report to Charlotte Harbor or Peace Creek via Topokalija Lake, Waterway | | | Senate Ex No. 1 47th Congress, 1st Session, Annual Report of Chief of Engineers 1882, page 1204 |
| 9 January 1883<br>5 October 1883 | Preliminary Examination Survey Report at entrance to and exit from Lake Monroe and between Lakes George and Monroe | F | | Senate Ex. No. 6, 48th Congress 1st Session, Annual Report of Chief of Engineers 1884, page 1138 |
| 3 November 1884 | Preliminary Examination to Jupiter inlet and Lake Worth, Waterway, via Mosquito Lagoon, and Indian River | F | | Annual Report of Chief of Engineers 1885, page 1291 |
| 26 January 1891 | Preliminary Examination Upper , from Lake Monroe southward | U | U | House Ex. No. 240, 51st Congress, 2nd Session, Annual Report of Chief of Engineers 1891, page 1666 |
| 26 January 1891 | Preliminary Examination To Sanford and near Orange Mills | U | U | House Ex. No. 240, 51st Congress, 2nd Session, Annual Report of Chief of Engineers 1891, page 1666 |
| 18 February 1895 | Survey Report Jacksonville to the ocean | F | | House Ex. No. 346, 53rd Congress, 3rd Session, Annual Report 1895, page 1586 |
| 23 February 1895 | Preliminary Examination at Orange Mills Flat near Palatka | U | | House Ex. N. 347, 53rd Congress, 3rd Session, Annual Report 1895, page 1560 |
| 30 May 1898 | Survey Report at Orange Mills Flat near Palatka | F | | House No. 523, 55th Congress, 2nd Session, Annual Report 1898, page 1343 |
| 4 December 1905 | Survey Report St. Johns River | F | F | House No. 663, 59th Congress, 1st Session |
| 3 June 1907 | Preliminary Examination to Sanford, Sanford to Lake Harney | F | | House No. 1111, 60th Congress, 2nd Session |

# TABLE 2 (CONTINUED)

## ST. JOHNS RIVER
## SURVEY REPORTS AND PRELIMINARY EXAMINATIONS

| | | | | |
|---|---|---|---|---|
| 1 October 1908 | Survey Report to Sanford, Sanford to Lake Harney | | | House No. 1111, 60th Congress, 2nd Session |
| 30 April 1909<br>22 November 1909 | Preliminary Examination<br>Survey Report Jacksonville to the ocean | F<br>F | F | House No. 611, 61st Congress, 2nd Session, with maps |
| 5 May 1911 | Preliminary Examination Channel through Dexter and Woodruff Lakes | U | U | House No. 252, 63rd Congress, 1st Session |
| 29 May 1911 | Preliminary Examination, Jacksonville to Palatka | U | U | House No. 281, 62nd Congress, 2nd Session |
| 12 July 1911<br>7 November 1911 | Preliminary Examination<br>Survey Report to Cumberland Sound | U<br>F | F | House No. 898, 62nd Congress, 2nd Session |
| 15 July 1911 | Preliminary Examination St. Johns River, Florida | F | U | House No. 493, 62nd Congress, 2nd Session |
| 18 December 1912 | Preliminary Examination, Lake Harney to Lake Washington | U | U | House No. 1397, 62rd Congress, 3st Session |
| 5 June 1913 | Preliminary Examination Canal to Lake Beresford | U | U | House No. 208, 63rd Congress, 1st Session |
| 26 October 1916 | Preliminary Examination to Key West, Florida (Florida East Coast Canal) | U | U | House No. 1147, 65th Congress, 2nd Session |
| 29 April 1922<br>4 March 1926 | Preliminary Examination<br>Survey Report Jacksonville to Sanford | F<br>F | | House No. 483, 70th Congress, 2nd Session |
| 15 March 1924<br>30 October 1926 | Preliminary Examination<br>Survey Report Jacksonville to Sanford | F<br>U | F | House 691, 69st Congress, 2nd Session |
| 9 November 1926<br>29 August 1939 | Preliminary Examination<br>Survey Report | U<br>F | F | House No. 603, 76th Congress, 3rd Session |
| 20 April 1928 | Preliminary Examination to Indian River, Florida, channel from Sanford to near Titusville | U | U | Not Published |
| 28 November 1933 | Preliminary Examination To Indian River, Florida, channel from Sanford to near Titusville | F | U | Not Published |
| 1 November 1930<br>15 May 1931 | Preliminary Examination<br>Survey Report Erosion at Dames Point and New Berlin | F<br>U | U | Not Published |
| 2 February 1931 | Preliminary Examination Lake Harney to lake Washington | U | U | Not Published |

# TABLE 2 (CONTINUED)

## ST. JOHNS RIVER
## SURVEY REPORTS AND PRELIMINARY EXAMINATIONS

| | | | | |
|---|---|---|---|---|
| 3 June 1935 | Survey Report Jacksonville to the ocean | | | |
| 15 July 1935 | Survey Report to Indian River, Florida channel from Sanford to near Titusville | U | U | Not Published |
| 26 March 1936 | Preliminary Examination to Deleon Springs, Waterway | U | U | Not Published |
| 22 October 1936 | Preliminary Examination St. Johns River, Florida | U | U | Not Published |
| 6 December 1938 | Preliminary Examination Sanford to Tampa, Florida, Waterway | F | U | Not Published |
| 7 September 1939 | Survey Report To Lake Beresford, Florida | U | U | Not Published |
| 19 November 1940 | Survey Report Jacksonville to the ocean | F | F | House No. 322, 77th Congress, 1st Session |
| 11 December 1943 | Survey Report Jacksonville to Lake Harney | | F | House No. 445, 78th Congress, 2nd Session |
| 23 May 1944 | Survey Report Jacksonville to ocean 35-foot channel | | F | Senate No. 230, 78th Congress, 2nd Session |
| 9 August 1945 | Survey Report Jacksonville to the ocean | | F | Senate No. 179, 79th Congress, 2nd Session |
| 10 April 1946 | Survey Report | | F | Senate No. 208, 79th Congress, 2nd Session |
| 26 December 1950 | Preliminary Examination Jacksonville to the ocean | | U | Not Published |
| 23 January 1953 | Preliminary Examination, St. Johns River, Florida | | U | Not Published |
| | | RICE CREEK | | |
| 8 July 1947<br>14 January 1952 | Preliminary Examination, Survey Report, Putnam County, Florida | F | F | House No. 446, 82nd Congress, 2nd Session |
| 29 October 1951 | Preliminary Examination Rice Creek, Florida | U | | Not Published |
| | | OKLAWAHA RIVER | | |
| 7 February 1889 | Survey Report | F | F | Annual Report of Chief of Engineers 1889, page 1360 |
| 5 September 1905<br>16 April 1906 | Preliminary Examination<br>Survey Report | F<br>F | F | House No. 782, 59th Congress, 1st Session |
| 29 December 1911<br>21 January 1913 | Preliminary Examination | F<br>F | F | House No. 514, 63rd Congress, 2nd Session, (with Maps) |
| 27 February 1917 | Survey Reports | F | F | House Committee No 1., 65th Congress, 1st Session |

## TABLE 2 (CONTINUED)

## ST. JOHNS RIVER
## SURVEY REPORTS AND PRELIMINARY EXAMINATIONS

| | | | | |
|---|---|---|---|---|
| 23 January 1953 | Preliminary Examination | | U | Not Published |
| | | WEKIVA RIVER | | |
| 3 November 1884 | Preliminary Examination | U | | House Ex, No. 71, 48th Congress, 2nd Session, Annual Report of Chief of Engineers 1885, page 1281 |
| 6 June 1907 | Preliminary Examination | U | U | House No. 532, 60th Congress, 1st Session |
| 20 May 1911 | Preliminary Examination | U | U | House No. 271, 63rd Congress, 1st Session |
| 29 May 1927 | Preliminary Examination | U | U | Not Published |

(1) F = FAVORABLE; U = UNFAVORABLE

A Water Resources Study of Metropolitan Jacksonville, Florida, was completed in August 1980, with the final report prepared in 11 volumes:

1. Summary Report
2. Background Information Appendix
3. Annex I - Base Condition Analysis
4. Annex II - Supporting Appendixes
5. Plan Formulation Appendix
6. Annex I - Area Wide Wastewater Management
7. Supplement A - Water Quality Modeling
8. Annex II - Water Supply Management
9. Annex III - Flood Plain Management
10. Annex IV - Small Boat Navigation Assessment
11. Public Involvement and Comments Appendix

## FLOOD PLAIN MANAGEMENT STUDIES

Flood Plain Management Studies conducted for localities in the St. Johns River Basin have included the following brochures:

a. Jacksonville, Florida - March 1969

b. Vicinity of Southeast Volusia County, Florida - June 1972

c. Vicinity of Little Wekiva River - September 1970

d. Lake Monroe Near Sanford, Florida - July 1971

e. Vicinity of Northeast Volusia County, Florida - July 1971

f. Lake Beresford and the St. Johns River, Volusia and Lake Counties, Florida - September 1974

Flood Plain Information Reports and Special Hazard Information Reports for localities in the St. Johns River Basin are as follows:

FLOOD PLAIN INFORMATION REPORTS

a. Duval County, Lower St. Johns River - March 1969*

b. Orange County, Little Wekiva River - April 1970

c. Seminole County, Little Wekiva River - September 1970

d. Seminole County, Lake Monroe - July 1971

e. Northeast Volusia County - July 1971*

f. Southeast Volusia County - July 1972*

g. Volusia and Lake Counties, St. Johns River and Lake Beresford - September 1974

h. Northwest Putnam and Southwest Clay Counties - September 1975

SPECIAL FLOOD HAZARD INFORMATION REPORTS

a. Econlockhatchee River - June 1970*

b. Hogans Creek, Jacksonville - July 1971

c. City of Hastings - February 1972

d. Howell Creek Basin - March 1974

e. St. Johns River, Brevard County - March 1976

*Not Available

## CORPS OF ENGINEERS STUDIES

The predecessor to this feasibility report was The St. Johns River Basin, Florida Interim Water Quality Management Plan (Reconnaissance Report) which was prepared in response to Public Law 98-50. In January 1986, the Corps produced the reconnaissance report with the following findings.

1. Technical information is lacking on water quality improvement and environmental enhancement needs.

2. The need exists to apply existing physical science knowledge and technological capabilities to the determination of ambient water quality conditions within the river system.

3. The establishment of a technical basis for understanding ambient water quality conditions at any given locality within the St. Johns River would require five general types of evaluations consisting of: (1) hydrodynamics; (2) soils, geology, and groundwater; (3) sediments, benthos, and sessile communities; (4) surface water inflows or effluents from tributary watersheds and areas immediately adjacent to the river; and (5) water column data.

Currently, the Wetland Restoration, Section 1135, Oklawaha River Project is underway. The project will utilize Section 1135(b) of the Water Resources Development Act of 1986 to provide additional structural features (inlet flow structure, outlet flow structures, and canal segments) to re-establish flow through approximately four miles of historic oxbow channel. Work will include construction of an inlet flow control structure from the C-231 to the project site; replacement of an existing discharge structure with a discharge structure that will handle the desired flow; the construction of C-231 channel improvements to prevent erosion caused by increased design flow; and the restoration of the Oklawaha River to its natural state (vegetation and silt removal).

A Section 22, Planning Assistance to States study is underway for the Econlockhatchee River Basin. The Econlockhatchee River is a tributary of the St. Johns River and is located northeast of Orlando, Florida. The purpose of the study is to provide the St. Johns River Water Management District with the 10, 25 and 100-year storm flood stages and flooded areas using HEC-1 and HEC-2 computer modeling.

Another Section 22, Planning Assistance to States study is underway for the Wekiva River Basin, a tributary of the St. Johns River, north of Orlando, Florida. This study will provide the St. Johns River Water Management District with an economic analysis for the 10, 25, 50, and 100-year storm flood stages. The economic analysis will consist of a land use distribution study, flood control study, and technical analysis.

## OTHER FEDERAL STUDIES

The Federal Emergency management Agency (FEMA) has produced Flood Hazard Boundary, Floodway and Flood Insurance Rate Maps for communities participating in the National Flood Insurance Program. Communities with detailed Flood Insurance Rate Maps include 100-year and 500-year base flood elevations and area delineations; 10-year flood elevations can be interpreted from information provided. In this program, each participating municipality or county is considered a community. Table 3 contains a listing of communities within the St. Johns River Basin participating in this FEMA program as of 31 January 1991.

The U.S. Department of Agriculture completed a comprehensive study of the river basin in 1969. This study points out the need for a comprehensive plan for agricultural, industrial, and urban land and water resource users in the basin. Land uses were projected into the future so that water-use projections could also be made. Currently, agriculture faces problems of relocation and expansion to satisfy production needs in an environment of growing competition for resource use.

## LOCAL STUDIES

Numerous topical studies have been conducted over the years in the St. Johns River Basin. The St. Johns River Water Management District, since its creation by the Water Resources Act of 1972, has undertaken, and continues to conduct studies on the basin's water quality and water supply conditions and problems. A water use survey is published annually by the SJRWMD. The District also publishes an annual report for each water year which lists their technical reports, memorandums, and circulars for the period. In 1977, a Water Resource management Plan (Phase I) was adopted by the SJRWMD.

The State of Florida Game and Fresh Water Fish Commission conducted a study of the fishery resources in the St. Johns River. This study covered the period 1976-1981 and was known as the Dingell-Johnson Project. The purpose of the study was to collect and correlate biological and limnological information as it related to the sport fishery resource and its management. In the upper river, water quantity was found to have a critical effect on fish populations - dewatering of the headwaters marsh has destroyed much of the natural forage base. Water quality had a greater effect on the biota of the lower river than water quantity.

# TABLE 3

## PARTICIPATING COMMUNITIES
## NATIONAL FLOOD INSURANCE PROGRAM

| Community Number | Community Name | Date of Entry | Date of Current Effective May |
|---|---|---|---|
| 120001 | Alachua county - Unincorporated Areas | 28 Sep 1984 | 4 Nov 1988 |
| 120290 | Altamonte Springs, City of Seminole County | 18 Mar 1980 | 18 Mar 1980 |
| 120180 | Apopka, City of - Orange County | 29 Sep 1978 | 23 Oct 1981 |
| 120075 | Atlantic Beach City of Duval County | 15 Mar 1977 | 17 Apr 1989 |
| 120181B | Belle Isle, City of - Orange County | 15 Sep 1978 | 15 Sep 1978 |
| 125092 | Brevard county - Unincorporated Areas | 22 Sep 1972 | 3 Apr 1989 |
| 120086 | Bunnell, Town of - Flagler County | 3 Jan 1986 | 3 Jan 1986 |
| 120291 | Casselberry, City of - Seminole County | 2 July 1980 | 2 July 1980 |
| 120064 | Clay County-Unincorporated Areas | 2 Jul 1981 | 1 Aug 1983 |
| 120020 | Cocoa, City of - Brevard County | 28 Sep 1979 | 3 Apr 1989 |
| 120408 | Crescent City, City of Putnam County | 18 Dec 1979 | 18 Dec 1979 |
| 120307 | Deland, City of - Volusia County | 22 Dec 1980 | NSFHA* |
| 120182 | Eatonville, Town of Orange county | 1 Dec 1978 | 1 Dec 1978 |
| 120085A | Flagler County - Unincorporated Areas | 5 Feb 1986 | 5 Feb 1986 |
| 120065 | Green Cove Springs, City of Clay County | 1 Mar 1979 | 26 Mar 1982 |
| 120266 | Haines City, City of - Polk County | 16 Sep 1981 | 16 Sep 1981 |
| 120282 | Hastings, Town of - St. Johns county | 2 Jul 1981 | 16 Jul 1987 |
| 120077 | Jacksonville - City of Duval | 1 Dec 1977 | 15 Aug 1989 |
| 120078 | Jacksonville Beach, city of -Duval County | 15 Mar 1977 | 17 Apr 1989 |
| 120416 | Lake Mary, City of - Seminole County | 18 Mar 1980 | 18 Mar 1980 |
| 120292 | Longwood, City of Seminole County | 18 Mar 1980 | 18 Mar 1980 |
| 120184 | Maitland, City of - Orange County | 5 Sep 1979 | 5 Sep 1979 |
| 120185 | Ocoee, City of - Orange County | 1 Nov 1978 | 1 Nov 1978 |
| 120179 | Orange County - Unincorporated | 1 Dec 1981 | 5 Dec 1989 |
| 120066 | Orange Park, Town of - Clay County | 18 Mar 1980 | 18 Mar 1980 |
| 120186 | Orlando, City of - Orange County | 5 Sept 1980 | 26 Mar 1982 |
| 120189 | Osceola County - Unincorporated Areas | 3 Feb 1982 | 16 Mar 1989 |
| 20293 | Oviedo, City of - Seminole County | 28 Sep 1979 | 28 Sep 1979 |

# TABLE 3 (CONTINUED)

## PARTICIPATING COMMUNITIES
## NATIONAL FLOOD INSURANCE PROGRAM

| Community Number | Community Name | Date of Entry | Date of Current Effective Map |
|---|---|---|---|
| 120273 | Palatka, City of - Putnum County | 4 Jun 1980 | 4 Jun 1980 |
| 120418 | Pomona Park, Town of - Putnam County | 4 Dec 1979 | 4 Dec 1979 |
| 120027 | Rockledge, City of - Brevard County | 15 Nov 1979 | 3 Apr 1989 |
| 125152A | Titusville, City of - Brevard County | 16 June 1972 | 3 Apr 1989 |
| 120188 | Winter Park, City of - Orange County | 15 Nov 1979 | 4 Feb 1983 |
| 120295 | Winter Springs, City of Seminole County | 16 Sep 1981 | 15 Jan 1982 |

*NSFHA - No Special Flood Hazard Area (Non-Flood Prone Community)

## STUDY PARTICIPANTS

The U.S. Army Corps of Engineers, Jacksonville District was the lead agency in the preparation of this report. Valuable information and assistance was provided by the St. Johns River Water Management District, the study sponsor, and contractors for this study including U.S. Army Waterways Experiment Station, Hydraulics and Environmental Laboratories; National Oceanic and Atmospheric Administration, National Ocean Service, Ocean and Lake Levels Division, Office of Oceans and Earth Sciences; U.S. Geological Survey, Orlando Sub-District; Florida Department of Environmental Protection, Bureau of Surveying and Mapping; and Dunn and Associates, Boca Raton, Florida.

# ST. JOHNS RIVER BASIN CONDITIONS AND STUDY AREA

## LOCATION

The St. Johns River, an elongated estuary with low gradient and an extensive floodplain, is located in the northeastern part of Florida. The river borders or crosses through ten counties: Brevard, Orange, Seminole, Volusia, Lake, Marion, Putnam, Clay, St. Johns and Duval (See Figure 1). From its headwaters inland of Ft. Pierce to Jacksonville, the St. Johns River flows generally south to north, for a distance of about 285 miles. At Jacksonville, in Duval County, the river turns eastward and flows for another 15 miles until it discharges into the ocean at Mayport. The upper part of the St. Johns River drainage basin encompasses a number of major and minor lakes including Lake Hellen Blazes, Sawgrass Lake, Lake Washington, Lake Winter, Lake Poinsett, Lake Harney, Lake Monroe, Lake George and Crescent Lake.

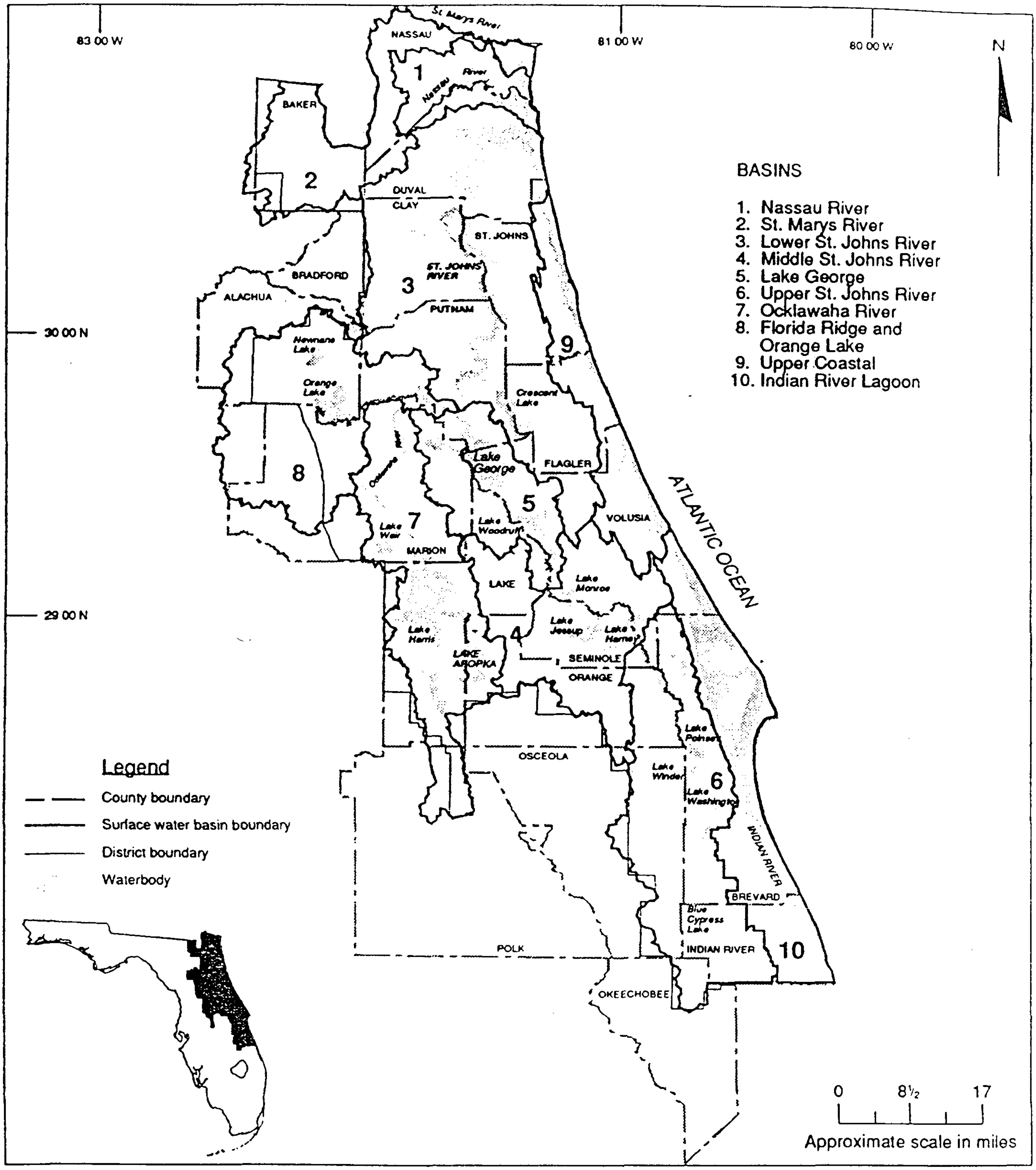
The portion of the river referred to in this study as the Lower St. Johns River is the 101 mile reach from the confluence of the Oklawaha River to the inlet at Mayport. In addition to the Oklawaha River, thirteen other major tributary streams drain into the Lower St. Johns River (See Figure 2). Numerous lakes are contained within the lower river drainage basin which covers portions of Volusia, Putnam, Flagler, St. Johns, Clay, and Duval Counties. Two of the largest lakes, Crescent Lake and Doctors lake, have direct connections to the river.

## POPULATION

According to the 1990 U.S. Census, over 2 million people live in the St. Johns River basin. Approximately 640,000 people live within the basin in the Jacksonville metropolitan area. Based on current projections, more than 3 million people will reside in the entire basin by the year 2000. The Jacksonville metropolitan area is expected to grow to a population of about 880,000 by the year 2010.

## ECONOMY

In 1989, the industries located in the Lower St. Johns River Basin employed 362,000 persons. Of that number 106,000 persons or over 29 percent were involved in service industries. Another 83,000 persons or 23 percent were employed in retail trade. Finance, insurance, and real estate employed a reported 41,000 persons or 11 percent of the total. The manufacturing sector with 39,000 workers also accounted for about 11 percent of the total employment. The total number of agricultural employees in the Lower St. Johns River Basin, in 1989, was reported to be 3,400 or about 1 percent the total. The total of wages and salaries reported in 1989 for the Lower St Johns River Basin was approximately $12 billion. Over 85 percent of the total wages and salaries was generated in Duval County.




Source: St. Johns River Water Management District

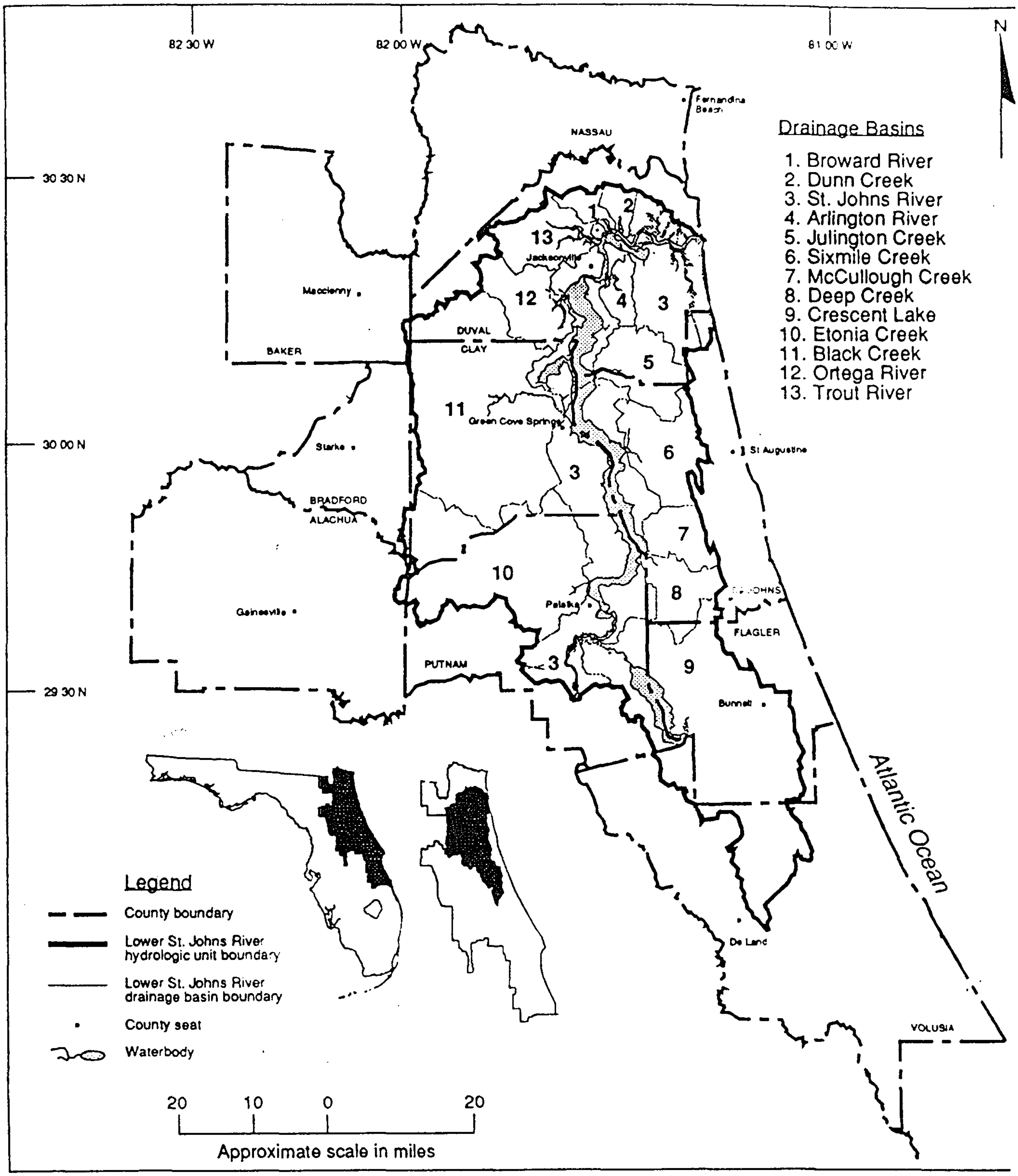
**ST. JOHNS RIVER, FLORIDA**

## ST. JOHNS RIVER BASIN

SCALE AS SHOWN

**DEPARTMENT OF THE ARMY**
**JACKSONVILLE DISTRICT, CORPS OF ENGINEERS**
**JACKSONVILLE, FLORIDA**

Figure 1




Source: St. Johns River Water Management District

**ST. JOHNS RIVER, FLORIDA**

**STUDY AREA**

SCALE AS SHOWN

**DEPARTMENT OF THE ARMY**
**JACKSONVILLE DISTRICT, CORPS OF ENGINEERS**
**JACKSONVILLE, FLORIDA**

Figure

The city of Jacksonville is the principal market place of northeast Florida and south Georgia for financial institutions, insurance, and real estate, medical manufacturing, and the transportation industry. Industrial activities in the area include electric power generation, pulp and paper production, food processing, chemical factories, and maritime works. Jacksonville is home to a deep water port which handled over $33.7 billion in trade in 1991. Major imports include automobiles and trucks, lumber, steel, coffee, and bulk commodities. Major exports include linerboard, paper products, clay, scrap metals, phosphate, peanuts, wood pulp, citrus, and general consumer goods. Jacksonville has two naval air stations and one naval station which in 1991 employed over 40,000 people.

Agricultural sales in the Lower St. Johns River Basin amounted to over $128.5 million in 1987 according to the Census of Agriculture. The major crops included potatoes, ferns, nursery and greenhouse products, poultry, dairy, and cattle and calves. Many of the crops depend on use of irrigation from the St. Johns River, its tributaries, or ground water sources. The direct economic impact of the commercial fishing industry in the lower basin in 1987 was estimated to be $7 million.

In 1989, the recreation, tourism and convention industries the attracted about 2.7 million visitors who spent about $339 in the lower basin. This amount includes estimated direct economic impacts of $81 million for the recreational fishing industry and $111 for the convention industry.

## CLIMATE

The St. Johns River Basin has a humid subtropical climate. In summer, daily average maximum and minimum temperatures are about 90 degrees F and 72 degrees F, respectively. Prolonged summer temperatures exceeding 98 degrees F are rare. In the southern part of the basin, temperatures above 90 degrees F can occur in any month of the year. During the winter, cold waves associated with frontal activity can cause temperatures to fall below freezing throughout the basin. However, cold waves with hard freezes are usually of short duration. Freezing temperatures normally occur at night and during the early morning hours with winter midday temperatures usually rising well above the freezing point even under the dominance of a cold air mass. Freezing temperatures may begin as early as November in the northern part of the St. Johns River basin but only occur occasionally each winter season in the extreme southern headwater areas of the basin.

Most of the basin's annual precipitation occurs during the months of June through September. Short duration, high intensity rainfall, usually associated with thunderstorms, accounts for the majority of summer precipitation. Based on rainfall data provided by the St. Johns Water Management District, the basin's mean annual precipitation ranged from 48.99 to 59.14 inches for the period 1947-1976. For the same period of record, the basin's annual maximum precipitation was 84.95 inches and the annual minimum precipitation was 27.44 inches. In the southern part of the basin, short intense rainfall events exceeding 1 inch are common. On rare occasions, snow may fall in the northern part of the basin.

Winds in the basin generally blow from the northwest and northeast during fall and winter and from the southwest and southeast in the spring and summer. Since the prevailing winds are aligned approximately with the longitudinal axis of the river, winds have a strong effect on the hydrodynamics of this wide, shallow riverine system. Average wind speeds range from 6 to 10 mph.

Short duration winter storms, with fast moving fronts and low rainfall can occur during the fall through spring seasons. These storms are occasionally associated with major freezes. During the fall and winter months, storms called northeasters, with persistent winds speeds of 20 to 30 mph, produce higher than normal water levels in the lower and middle basins. In the summer and fall months, major intense episodic events such as tropical storms (wind speeds between 38 and 73 mph) and hurricanes (winds speeds in excess of 74 mph) can bring damaging winds, heavy rainfall, and high storm tides.

## GEOMORPHOLOGY AND GEOLOGY

The surface of the St. Johns River drainage basin consists of low, nearly level plains to gently rolling hills; numerous intermittent ponds, swamps, and marshes; many lakes, and a few perennial streams. The lower basin is composed of three major landscape divisions: the Sea Island District located in the north and northwestern portions of the basin, the Eastern Flatwoods District which covers the eastern most part of the basin, and the Central Lake District located on the south and southwest flanks of the basin. The basin owes its origins to the emergence of the three distinct marine terraces which rose above the level of sea during the Pleistocene age. The Pensacola Terrace extends inland about 20 miles and includes the eastern part of the Eastern Flatwoods District and the northeastern portion of the Sea Island District. On the east, the Pensacola Terrace merges with shore features of recent origin. The elevation of the Pensacola Terrace rises from sea level near the coast to about 40 feet above sea level along the western margin. On the western edge of the Lower St. Johns River Basin, the higher Tsala Apopka (between the 40 to 70 foot contours) and Newberry Terraces (between the 70 to 100 foot contours) contain the river basin's portion of the Central Lake District and the remainder of the basin's Eastern Flatwoods and Sea Island Districts. Erosion and deposition have produced ridges and depressions on the surfaces of the emergent terraces. Various subclassification schemes have been used to describe these minor landforms. The St. Johns River valley and associated elongated lakes appear to be remnants of coastal lagoons formed before the pleistocene sea retired.

The study area is underlain by a thick sequence of sedimentary rocks that overlie a basement complex of metamorphic strata. Major stratigraphic units include sedimentary rocks ranging in age from late Paleocene to Holocene. Stratigraphic units in ascending order are: Cedar Keys Formation of late Paleocene age, the Oldsmar Formation of early Eocene age, the Avon Park Formation of middle Eocene Age, the Ocala Limestone of late Eocene age, the Hawthorne Formation of Miocene age, and the undifferentiated surficial deposits of late Miocene to Holocene age.

## SURFACE WATERS

The St. Johns River drainage basin encompasses an approximately 9,200 square-mile drainage area. The basin covers all or parts of 15 counties that comprise most of the east-central and northeastern parts of the state. The upper headwaters of the St. Johns River are located in northwestern St. Lucie County and northeastern Okeechobee County about 300 miles upstream from its mouth. At about mile point 275 the first discernable channel of the St. Johns River becomes apparent. The average water surface gradient of the St. Johns River is approximately 0.1 foot per mile. Tidal influences may extend upriver for a distance of over 200 miles, although normally they are negligable near Welatka (98 miles upstream). The drainage area of this tidally influenced segment is about 7,200 square miles. The lower 101 miles of the river, downstream of the Oklawaha River (near Palatka) is considered for management purposes to be the Lower St. Johns River. This lower 101 mile segment of the river has a contributing drainage area of about 2,600 square miles.

The entire St. Johns River valley receives ground water discharge as water table seepage or as upwelling from the Floridan aquifer under artesian pressure. The potentiometric head of the Floridan aquifer is at or above 20 feet NGVD 29 (National Geodetic Vertical Datum) throughout much of the lower river basin and land elevations below that level are subject to influence from artesian flows.

It was assumed that during normal dry seasons and during extended droughts a significant volume of water being discharged through the St. Johns River is emergent Floridan aquifer waters. Even during extended dry periods, many tributary streams flowing into the St. Johns River from the central Florida uplands are perennial with dry season flow supplied by ground water as base flow. However, during this study the total ground-water rate of flow (diffuse upward leakage and spring flow) to the Lower St. Johns River from the Upper Florida aquifer was estimated to be 86 cubic feet per second based on the September 1990 ground water heads and 133 cubic feet per second based on the September 1991 ground water heads.

The lower 40 miles of the river flow through Duval County or Jacksonville, Florida. Downtown Jacksonville is located about 23 miles above the mouth of the river. Downstream of Jacksonville, the river is subject to strong reversing tides with high volumes of water being mixed during each tide reversal cycle. The strongest currents occur at ebb tide and can exceed 3 knots. The natural water depth of the river at downtown Jacksonville approaches 90 feet. A dredged channel depth in excess of 40 feet is maintained along the lower 20 miles of river.

Upstream of downtown Jacksonville and extending to Palatka, a distance of roughly 57 miles, the river takes on a broad lake-like character. In Duval County, upstream of Jacksonville, the width of the river varies up to three miles. Progressing upstream, the river gradually narrows to less than a 0.5 mile width at Palatka. Throughout this approximately 57 mile reach, a central channel depth in excess of the Federal Project depth of 13 feet is generally maintained by natural physical conditions. Water depths typically diminish gradually towards each shoreline to extended vegetated shallow waters with numerous mud flats and sandy shoals near shores. Current flow throughout this segment of the river is influenced by slow moving discharge waters, reversed current flows with incoming tides progressing up the river, and wind conditions. Tidal currents are typically less than 1 knot.

Discharge volumes and river currents are influenced by runoff during the normal rainy season and ground water discharges during dry seasons and droughts. The normally sluggish tributary discharge currents are significantly modified by increased discharge volumes resulting from major regional storms.

Throughout the Lower St. Johns River Basin, the progression of flood tides upstream gradually reduces the downstream flow, causes lateral eddy currents as the incoming tide progressively prevails, and finally results in reversed currents. Reversals of currents due to flood tides have been measured into Lake George, well upstream of the Lower St. Johns River Basin.

Wind conditions significantly affect current flows and the transport of sediments within the river throughout much of the Lower St. Johns River Basin. Winds affect currents on the St. Johns River in several fundamental manners. Prevailing winds from the east (northeasters) result in higher tide conditions at the mouth of the river. Winds prevailing for extended periods set up wind-driven currents. Strong winds set up water oscillations that disturb and resuspend bottom sediments. Wind strength, wind duration, and length of fetch over which the wind blows determines the depth to which the wind generated oscillations can reach.

For example, northeasterly storms may prevail for two or three days resulting in discharge water retention within the St. Johns River, major redirection of current flow, and significant resuspension and transport of sediments. During these occurrences, differentially raised water surface elevations can occur within the river.

As a second type of influence, consistent winds of moderate intensities or short-duration strong winds typical of thunderstorms cause wave actions and flow of water with the wind. The wind-driven water results in raised water elevations on the onshore wind side of the river and reduced water elevations on the offshore wind side of the river.

Strong winds also generate water oscillations in the river that can resuspend bottom sediments from the river bed at depths of 10 or more feet. Substantial resuspension and transport of fine sediments within the extensive lake-like part of the Lower St Johns River occurs as a result of wind action.

## GROUND WATER HYDROLOGY

The St. Johns River exhibits typical characteristics of an estuary, where saline water from the ocean mixes freely with fresh water from inland drainage. The water becomes well mixed near the Duval-Clay County line. Under drought conditions, sea water intrusion extends upstream until it reaches Palatka. Further upstream from Palatka, salinity increases due to chlorides introduced from ground water seepage and salt water springs.

Three hydrogeologic units are present in the study area: the surficial aquifer system, the intermediate confining unit, and the Floridan aquifer system. The surficial aquifer system overlies the intermediate confining unit and consists of deposits containing sand, clay, shell, and some limestone and dolomite. The intermediate confining unit underlies the entire area and retards the vertical movement of water between the surficial aquifer system and the Floridan aquifer. The intermediate confining unit consists of beds of relatively low permeability sediments that vary in thickness and areal extent and may be breached by sinkholes, fractures, and other openings. The Floridan aquifer system is composed primarily of limestone and dolomite. The rate of leakage through the intermediate confining unit is controlled by the leakage coefficient of the intermediate confining unit and the head difference between the Upper Floridan aquifer and the surficial aquifer system.

The Cedar Keys, Oldsmar and Avon Park Formations and the Ocala Limestone are part of the Floridan aquifer system. The Upper Floridan aquifer is contained primarily in the Ocala Limestone. The Hawthorn Formation is the principal confining unit that covers the Floridan aquifer in much of the basin. The surficial aquifer consists primarily of the undifferentiated surficial deposits.

## SEDIMENTS

River sediments consist primarily of inorganic substances of marine origin mixed with fine particulate matter resulting from decomposing inorganic material. Intensive human interference in the form of urbanization, industrialization, agricultural practices and recreational activities have resulted in elevated concentrations of pollutants at a number of locations throughout the riverine system. Approximately 360 domestic and 49 industrial permitted point sources release more than 2 billion gallons per day into the surface waters of the Lower St. Johns River Basin. In addition approximately 70 point sources discharge directly into the groundwater. Due to the ability of aquatic sediments to function as sources and sinks for suspended and dissolved pollutants, concerns have been raised about sediment quality and its impact on environmental conditions in the lower river basin. Field studies have documented the existence of enriched levels of nutrients, trace metals (cadmium, chromium, copper, mercury, nickel, lead and zinc), polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), aliphatic hydrocarbons, chlorinated pesticides and coprostanol in the sediments and aquatic biota of the main river and its tributaries. These pollutants are indicative of agricultural and industrial runoff, residues of fuel combustion, boat traffic and leachate from septic tanks. Past sediment quality studies are few, of short duration and are suitable only for remedial plans covering point sources. A continuous and systematic sediment quality monitoring program is needed in order to develop comprehensive sediment quality management plans for the Lower St. Johns River. Presently, no quantitative data exists pertaining to the movement of the suspended and bottom sediments in the river and its tributaries other than navigation channel records. Additional information is needed to establish a reliable mass balance of the transported sediments. Knowledge of the sediment mass balance is essential for assessment of the pathways of transported sediments and the sediment-bound contaminants.

# FORMULATION

The 1986 Reconnaissance Report recommended areas which needed more study. The St. Johns River Basin, Florida Interim Water Quality Management Plan also stated that the water column conditions at any locality in the river at any moment in time represent a biogeochemical composite of impacts of the other physical system conditions requiring evaluation. Hydrodynamic evaluations should include weather and climatic analyses to determine the seasonal and storm-related variations in the triburary area and watershed discharges that result in normal fluctuations of river water flow. Almost the entire course of the St. Johns River occurs within a valley system where groundwater seepage emerges and flows as surface water.

Development of improved information on solids and geology, as these determine the quality of groundwater that becomes seepage surface water flows, is critical for the determination of ambient water quality conditions. While water column conditions vary continually, evaluation of sediments, benthos, and sessile communities provide more stable information suitable for establishing general or long-term ambient water quality conditions. Finally, as surface water from seepage and rainfall moves through areas adjacent to the river, these flows can greatly impact localized river water quality conditions. Tributary area sheet-flow-like distributed discharges to the river are very different from the point-type flows from tributary watersheds with well-defined streams. A long-range program to develop technical knowledge of seasonal variations in flows and companion water qualities from these inflow sources remain to be developed for the river system.

A Feasibility Cost Sharing Agreement was signed 12 March 1990 which negotiated a path for study between the St. Johns River Water Management District and the Corps. Areas identified which needed more study are:

1. Tidal Currents and Circulation - Review and Evaluation of Hydrodynamic Modeling and Review of Water Quality Monitoring and Recommendations for Water Quality Modeling of the lower St. Johns River;

2. Vertical and Horizontal Measurements and Tidal Analysis - Vertical and Horizontal Control Surveys and Water Level Measurement Stations and Tide Control and Tidal Characteristics;

3. Ground Water Contributions - Natural Discharge and Chemical Constituent Loading from the Upper Floridan Aquifer;

4. Sediment Management and Nutrients and Selected Toxic Materials in Estuarine Sediments - Sediment Management and Sediment Quality; and

5. Unpublished Corps Data and Database Development.

As the study evolved and was negotiated with the SJRWMD, the tidal currents and circulation effort centered on the need to determine estuarine hydrodynamics and water quality in the Lower St. Johns River Estuary (LSJRE). There also existed a need to determine the state-of-the-art of models and if these models could be used to assess the issues in the LSJRE. The U.S. Army Corps of Engineers, Waterways Experiment Station, Hydraulics Laboratory and the Environmental Laboratory were hired to accomplish this goal. A synopsis of their effort is contained in the following section of this report.

The Florida Department of Environmental Protection, Bureau of Survey and Mapping was hired to prepare a plan for reviewing the existance of vertical and horizontal controls (benchmarks) and the extent of tide in the tributaries of the Lower St. Johns River. A synopsis of this effort is contained in the following section of this report.

The National Oceanic and Atmospheric Administration's National Ocean Service was hired to provide a comprehensive review of the tidal characteristics of the St. Johns River based on non-harmonic and harmonic analyses using the latest tidal data. A synopsis of this effort is located in the following section of this report.

The U.S. Geological Survey was hired to estimate the quantity and quality of Upper Floridan aquifer ground water that discharges naturally into the main stem of the lower St. Johns River. A synopsis of this effort is contained in the following section of this report.

Dunn and Associates of Boca Raton, Florida were hired to compile the work on sediment management and nutrients and selected toxic materials in the estuarine sediments. A synopsis of this effort is located in the following section of this report.

A synopsis of the historical data and database management of the Jacksonville District is also located in the following section of this report.

A workshop on the Lower St. Johns River was held on 14-16 September 1993 to share results from this phase of the study with interested citizens and scientists and to discuss issue relating to the SWIM plan for the St. Johns River.

# STUDY RESULTS

## REVIEW AND EVALUATION OF HYDRODYNAMIC MODELING[1]

### PURPOSE

The purpose of this review and evaluation effort was to provide information and recommend criteria for selecting a hydrodynamic model to achieve St. Johns River Water Management District goals of quantifying the hydrodynamic sediment transport and water quality processes of the Lower St. Johns River Estuary.

### INTRODUCTION

In order to measure the transport of particulates and dissolved materials, it is necessary to understand the hydrodynamic processes that govern the Lower St. Johns River Estuary (LSJRE). Existing numerical hydrodynamic models for accomplishing this task range from complex three-dimensional models to simple one-dimensional models. The selection of an appropriate estuarine hydrodynamic model depends upon the output desired, the amount of descriptive information for the estuary, the extent of field data collection, and the available resources including computer hardware and software and work force. Reliability of velocity and water surface elevation data generated by the hydrodynamic model is important since these data are used in the transport model to advect and disperse material during simulation. In support of the objective of selecting an appropriate numerical modeling approach for the Lower St. Johns River Estuary, this report contains the following information: (1) a review of state-of-the-art hydrodynamic/salinity modeling of estuaries, (2) comparisons of major modeling technologies, (3) an outline of data requirements for application of a hydrodynamic model to the Lower St. Johns River Estuary, (4) a recommendation for an approach for developing a system of models and monitoring programs for the Lower St. Johns River Estuary, and (5) a discussion of computer hardware and software issues that will affect the productivity of the modeling system.

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[1] This is a synopsis of the findings from the U.S. Army Corps of Engineers, Waterways Experiment Station (WES), Hydraulics Laboratory.

## HYDRODYNAMIC MODELS

### Three-Dimensional Models

Modeling techniques for estuarine systems are based on equations which describe unsteady three-dimensional flow.

The equations used in existing three-dimensional numerical estuarine hydrodynamic models are derived from the Reynolds form of the Navier-Stokes equations for conservation of momentum, the equation of mass continuity, the advection-diffusion equation for salinity and/or temperature transport, and the equation of state relating water density to salinity and/or temperature.

Although three-dimensional hydrographic models are relatively complex, more difficult to apply and require greater resources, they incorporate fewer limiting assumptions than the simpler two-dimensional or one-dimensional models.

### Two-Dimensional, Vertically Averaged Models

A two-dimensional, vertically averaged approximation of estuarine hydrodynamics is frequently applied when vertical velocities are negligible and vertical density gradients are negligible. Vertical averaging requires parameterization of bottom stress. This technique introduces a major simplification to the equations. The bottom stress is one of the tractive forces acting on the fluid body, and is normally parameterized using a Chezy or Manning's friction formulation. Vertically-averaged equations can also be used to speed up the computations of three-dimensional models. The technique, called mode splitting, involves solving the two-dimensional vertically-averaged equations for free surface elevation and depth-averaged horizontal velocity in the longitudinal (x) and lateral (y) directions. The computed values are then used to solve for velocity and salinity in the vertical.

In open water situations, in the absence of complex boundaries, the vertically averaged equation for mass continuity is sometimes replaced with a wave-continuity equation. However, the wave-continuity equation is not well suited for rivers, particularly where there is a mixing of tidal and riverine flows. In cases where freshwater inflow is small compared to sea water contributions a constant density, vertically averaged approximation can be applied. This approximation eliminates the need to solve for the transport of salt and temperature. When vertical stratification dominates a system, as may be the case in narrow, non-branching estuaries, and lateral flow is sufficiently uniform, two-dimensional laterally averaged equations can be used to simplify hydrodynamic models.

### One-Dimensional Equations

One-dimensional equations for unsteady open channel flow can be used for hydrodynamic modeling in estuaries that are narrow, non-stratified and non-branching. Estuaries that are narrow, non-stratified and branching may be modeled by a one-dimensional channel network. The equations for these models are obtained by integrating the three-dimensional equations in the lateral (y) and vertical (z) directions.

### Multi-Dimensional Approximations

Certain models are capable of applying combinations of one-dimensional, two-dimensional vertically or laterally averaged and three-dimensional approximations in the same computational mesh. A multi-dimensional approach is advantageous when the estuary encompasses a large, diverse area. Multi-dimensional approaches provide a means for reducing computational costs.

### Spectral Methods

Periodic tidal forcing dominates estuarine circulation and may be approximated by harmonic solutions of equations of estaurine hydrodynamics. A frequency domain solution propagates the water surface elevation and the velocities in time by means of harmonic series. Spectral models are particularly useful for predicting regional tide levels, but are not recommended for examining alternative channel geometries, infrequent storm events or extreme events.

## NUMERICAL SOLUTION TECHNIQUES

### Computational Grids

The equations of estuarine hydrodynamics are solved by finite difference methods which use structural grids, or by finite element or finite volume methods which may use structural grids, but normally employ unstructured grids to allow for greater flexibility in mapping. Structured grids have ordered X, Y, Z coordinate points called nodes, that can be referenced by an index. In unstructured grids the nodes have an irregular spacial arrangement which cannot be indexed, but is advantageous for describing complex geometries and for adding local grid detail. Unstructured grids require a special bookkeeping system to keep track of node numbers and connections. In addition to positional information, other attributes can be assigned to nodes including bed roughness, tributary inflow, and wind forcing.

Structured grids that have indices which coincide with the coordinate directions are called cartesian grids. Structured grids which follow another defined set of index directions are called curvilinear grids. The term "boundary fitted" is used to describe structured grids that are curved to fit domain boundaries. Cartesian grids are not boundary fitted. Instead, nodes that lie outside the boundary are omitted, leaving a jagged edge. Unstructured grids are organized into elements or volumes by connecting the nodes. One-dimensional grids have connecting lines. In two-dimensional solutions the nodes are usually connected by triangles and quadrilaterals. The connecting elements of three-dimensional solutions may include tetrahedra, pyramids, wedges, and bricks.

The spacing of computational nodes, or grid resolution depends on the size and shape of the solution domain. Increased grid resolution (reduced node spacing) is required to define flow around channel bends, peninsulas and islands. Grid resolution is also dependent upon spatial distribution of sediment types, channel roughness and water quality sources. A gradual transition in local grid resolution introduces less error in model results than abrupt changes. A gradual change in grid size and corresponding nodal spacing is easier to achieve with an unstructured grid, because nodes are not tied to an index. When adding local refinement to a structural grid, the entire grid must be reworked. Some structural grid models do not permit local grid refinement. Instead the nodel spacing over the entire grid is reduced to capture local effects.

## Time Stepping

Numerical solutions of estuarine hydrodynamic equations require descretization in time as well as space. For time stepping current estuarine hydrodynamic models may use explicit finite difference formulation, an implicit finite difference formulation, or a semi-implicit finite difference solution. Explicit and semi-implicit formulations include stability criteria that limit the permissible length of time step in the simulation. The time steps for explicit formulations of the estuarine hydrodynamic equations vary from 15 seconds to 2 minutes for explicit formulations and 30 seconds to 15 minutes for semi-implicit formulations. Although, the time step for an implicit formulation is not limited by stability constraints, it must be short enough to resolve important features of the tidal signal at estuary boundaries. A 15 minute time step may be necessary to resolve shoreline movement over tidal flats.

## Hydrodynamic and Transport Model Interface

The velocity , salinity, temperature and water surface elevation data generated by the hydrodynamic model are used to drive the transport of sediment and water quality in subsequent modeling efforts. Sediment and water quality affect circulation, therefore, transport processes and hydrodynamic processes cannot be regarded as separate systems. The models are done separately, because the time scale of interest for transport processes is generally much longer than the time scale for tidal variation. In practice, a numerical interface is used to interchange information between the hydrodynamic and transport models. These kinds of model interfaces can be inconvenient and may introduce additional numerical errors. Attempts to fully interface the models may result in an oversimplified or inadequate transport model.

## HYDRODYNAMIC MODEL EVALUATION

Six individual estuarine hydrodynamic models were evaluated in connection with the study.

a. ECOM (Estuarine and Coastal Circulation Model). Authors: Alan F. Blumberg and George F. Meller. Organization: Dynalysis of Princeton, Princeton, New Jersey.

b. RMA-10 (3-D hydrodynamics and conservative constituent transport). Author: Ian Piking. Organization: University of California, Davis , California.

c. ADCIRC-3DL (Advanced three-dimensional circulation model, local). Authors: R. A. Luettich, Jr, and J. J. Westerlink. Organization: University of North Carolina at Chapel Hill, Institute of Marine Sciences (Luettich) and University of Notre Dame, Department of Civil Engineering (Westerlink).

d. TRIM-3D (Tidal, Residual, Intertidal, Mudflat Model). Authors: Ralph T. Cheng and Vincenzo Casulli. Organization: U. S. Geological Survey, Menlo Park, California (Cheng), and Istituo per Applicazioni del Calcolo, Rome (Casulli).

e. CH3D (Curvilinear-Grid hydrodynamic 3-D). Author: Y. Peter Sheng. Organization: University of Florida, Gainesville, Florida.

f. RBFVM-2D Authors: Di Hua Zhao, Guillermo Q. Tabios, and Hsieh Wen Shen. Organization: University of California, Berkley, California.

Since three-dimensional models will be the state-of-the-art within a few years, they were the only ones selected for evaluation, except for the RBFVM-2D model which has demonstrated potential for three-dimensional development. All models evaluated have corresponding two-dimensional, vertically averaged capabilities and some have laterally averaged and one-dimensional capabilities as well.

## SELECTION CRITERIA

The following specific feature criteria were applied to each of the six models evaluated to determine which ones had the potential to produce reliable velocity and water surface elevations and other related data needed to determine ambient water quality conditions in the Lower St. Johns River Estuary.

a. Minimum Dimensionality: A two-dimensional, vertically averaged estuarine hydrodynamics model was selected as the minimum required to achieve satisfactory tidal simulations. One-dimensional models require a verification process which frequently results in unrealistic values. Two dimensional vertically averaged models require far less tuning to achieve satisfactory tidal simulations. A vertically-averaged model will capture momentum losses due to expansions and contractions of the river channel and provide a good representation of lateral momentum transport occurring at the junctions of the main stem with tributaries, but omits vertical variability.

b. Potential Dimensionality: A three-dimensional, baroclinic hydrodynamic model is required in order to describe vertical velocity gradients and secondary circulation which are caused by vertical stratification due to salinity or temperature gradients. Secondary currents can also result from flow around channel bends and from wind stress.

c. Geometry: The scale of the flow phenomena along the St. Johns River varies because of the dramatic changes in width and depth. Under these conditions either a stretched, curvilinear boundary fitted finite difference grid or an unstructured finite element grid (or finite volume grid) are appropriated choices.

d. Wetting and Drying Option: The model must have the capability to simulate intermittent flooding of tidal and fresh water marshes along the main stem and tributaries of the St. Johns River.

e. Horizontal Turbulent Fluctuation Terms: Due to the complex geometry of the estuary and boundary shear conditions the model must include horizontal turbulent fluctuation terms. Wave equations that ignore horizontal eddy viscosity are not appropriate for this system.

f. Turbulence Closure Model: An advanced turbulence closure model is recommended in order to capture the stratified behavior of the estuary.

g. Model Maintenance: The modeling system should be designed to take advantage of new theoretical developments, and new computer technology. Arrangements should be made for model maintenance and upgrading.

## RECOMMENDED MODELS

From the list of six estaurine hydrodynamic models evaluated, the following three models were considered to be appropriate for the Lower St. Johns River Estuary System:

a. RMA-10 and associated models, Ian P. King

b. CH3D, Y. P. Sheng

c. ECOM, Alan F. Blumberg and George L. Mellor

Each of the three models possess the computational capabilities specified in the foregoing discussion of Selection Criteria. RMA-10 and CH3D are public domain models. ECOM is a proprietary model and is available by contract with the authors. The Waterways Experimental Station employs both the ECOM and CH3D models.

## FIELD MEASUREMENTS FOR MODEL SUPPORT

In support of the hydrodynamic modeling effort a variety of field measurements most be obtained at various locations within the estuary. Depending on the type of measurements, sampling may be required at 2 minute, 5 minute, 30 minute, hourly or daily intervals. To establish boundary and initial conditions measurements of tidal elevations, velocity or discharge, salinity, temperature, and wind speed and direction will be needed. The measurements necessary for model verification are tidal elevation, velocity, salinity and temperature.

## MODEL DEVELOPMENT TIME FRAMES

The estimated time frame for developing a hydrodynamic model of the Lower St. Johns River Estuary is 4 years. The sediment transport and water quality models would each require about 5 years to complete development. Each of the programs for hydrodynamic, sediment and water quality monitoring could be developed in time frames of approximately 5 years.

## COMPUTER HARDWARE REQUIREMENTS

### Two-Dimensional Models

Two dimensional, vertically averaged models for estaurine hydrodynamics are currently being run on personal computers and mid-size work stations. The cost of the cpu and memory in this class of machines has decreased steadily over the past several years and this trend is expected to continue. The advantages of the workstation environment include fast turn around times for batch jobs, graphical user interface, moderate initial cost, personal control of job scheduling, and multi-tasking.

### Three-Dimensional Models

Three-dimensional models are computationally very expensive and time consuming. Current run times for fully non-linear 3-D estaurine models running on mini-computers are typically about one-half of real time, depending on the size of the grid and the solution technique. Super-computers such as the CRAY Y-MP are used for long term 3-D simulations. However, workstation cpu power is gaining rapidly on the super-computer market. Low-end multi-processor machines are also being developed which can take advantage of vectorized codes. With these advancements, a locally owned, powerful workstation with periodic upgrades is likely to be the most cost efficient solution for estuarine modeling. At the current rate of workstation development a biannual evaluation and upgrade is recommended. In addition to the cpu, the following equipment and software are required:

a. Digitizer
b. Graphics monitor
c. Plotting software
d. High quality printer for graphics
e. Mass data storage device

## GRAPHICAL USER INTERFACE

Estuarine models require a great deal of spatial and time varying data. The models generate three-dimensional time series of the hydrodynamics, sediment transport, and water quality parameters. A graphical user interface is necessary to organize information, to analyze results and to gain a physical understanding of the processes described by these data. The geophysical interface should be designed to manage model I/0, visualize three-dimensional data, and facilitate model development and applications. Several graphical user interfaces have been developed specifically for handling data sets arising from geophysical flow models. A graphical interface may be purchased from a third party vendor or as a part of the model license. As with other components of the modeling software, a contract for software maintenance and updates is recommended.

## COSTS

Table 4 contains estimated costs for a small scale model development plan that can be applied to the Lower St. Johns River Estuary. Development costs would increase if specific management questions arise that require more elaborate and sophisticated plans. Costs for implementing the hydrodynamic water quality and sediment monitoring programs are not included in the estimates. It is assumed that field programs will be conducted by local agencies, and therefore must be budgeted according to local labor and equipment resources. The costs cited reflect the efforts

## TABLE 4

## COSTS FOR COMPREHENSIVE ESTUARINE FLOW MODEL EXCLUDING FIELD PROGRAMS FUNDING ($) BY YEAR

| System Component | 1 | 2 | 3 | 4 | 5 | TOTAL |
|---|---|---|---|---|---|---|
| Hydrodyn. Modeling System | 100,000 | 100,000 | 50,000 | 10,000 | 0 | 260,000 |
| Sediment Trans Sys. | 10,000 | 100,000 | 100,000 | 50,000 | 10,000 | 270,000 |
| Water Qual. Modeling System | 10,000 | 50,000 | 100,000 | 100,000 | 50,000 | 310,000 |
| Comp. Eqp. Purchase and Maint. | 50,000 | 10,000 | 10,000 | 30,000 | 10,000 | 110,000 |
| Graph. User Interface | 20,000 | 20,000 | 10,000 | 10,000 | 10,000 | 70,000 |
| Oversee Hydrodyn. Monitor Prog. | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 | 100,000 |
| Oversee Sediment Monitor Prog. | 20,000 | 50,000 | 50,000 | 20,000 | 20,000 | 160,000 |
| Oversee Water Qual. Monitor Prog. | 20,000 | 50,000 | 50,000 | 20,000 | 20,000 | 160,000 |
| TOTALS | 250,000 | 400,000 | 390,000 | 260,000 | 140,000 | 1,440,000 |

## WATER QUALITY MONITORING AND RECOMMENDATIONS FOR WATER QUALITY MODELING[2]

### PURPOSE

The purpose of this study was to review present water quality monitoring on the Lower St. Johns River (LSJR) and recommend possibilities for upgrading the monitoring program to support a water quality model of the Lower St. Johns River as well as a recommendation of a water quality model to be applied to the river.

[2] This is a synopsis of the findings from the U.S. Army Corps of Engineers, Waterways Experiment Station Environmental Laboratory.

## WATER QUALITY MONITORING

Existing water quality monitoring is spatially extensive with over 100 routinely sampled stations on the LSJR including the major tributaries and point source loads. Sampling frequency is typically monthly for most of the parameters sampled. Parameters presently sampled are given in Table 5.

## RECOMMENDATIONS

Recommendations for additional parameters for water column sampling include total nitrogen, phosphorus and silica, and dissolved and particulated organic nitrogen and phosphorus. In addition, particulate inorganic phosphorus should be included. Additional parameters include dissolved and particulate carbon and biogenic silica. Sediment sampling should include particulate organic carbon, nitrogen, and phosphorus as well as particulate inorganic phosphorus. Additional processes/fluxes should include primary production, respiration, sediment oxygen demand, and sediment fluxes for ammonium, nitrate, phosphorus, silica, and COD. Sampling frequency should be monthly at a minimum and, for tributary inflows, should be designed to account for most of the loading during storm events. Regression equations relating loadings to flows should then be developed.

## TABLE 5

## SAMPLED WATER QUALITY PARAMETERS

| PARAMETER | FREQUENCY |
|---|---|
| Ammonium-N | monthly |
| Nitrate + Nitrite-N | monthly |
| Total Kjeldahl N | monthly |
| Total phosphorus | monthly |
| Orthophosphate | monthly |
| Dissolved oxygen | monthly |
| Dissolved silica | monthly |
| Total suspended solids | monthly |
| Total dissolved solids | monthly |
| Sulfate | monthly |
| Chloride | monthly |
| Chlorophyll A,B,C, and pheophyton | monthly |
| Total organic carbon | monthly |
| Alkalinity | monthly |
| Turbidity | monthly |
| Color | monthly |

A water quality model of the LSJR should include the following characteristics: 1) conservation of mass, 2) the ability to link to a 1-, 2-, or 3-D model, 3) higher order transport which minimizes numerical diffusion, 4) complete suite of water quality variables which include algal/nutrient dynamics, 5) a sediment submodel capable of modeling carbon diagenesis and nutrient fluxes to/from the sediments in both salt- and freshwater, and 6) the ability to conduct multi-year long simulations economically. The only water quality model which currently meets these requirements is CE-QUAL-ICM - the 2-D laterally-averaged Corps model developed for the Chesapeake Bay.

## VERTICAL AND HORIZONTAL MEASUREMENTS AND EXTENT OF TIDE[3]

### PURPOSE

The purpose of this study was to compile and evaluate existing information, and prepare procedures and a plan for establishing a network of positional and tidal survey control locations that, by extension, can be used to more precisely define the tidal characteristics for an estuarine hydrodynamic model of the Lower St. Johns River Estuary.

### INTRODUCTION

A network of control points must be present along the Lower St. Johns River Estuary to provide a reference system for extending higher order horizontal and vertical positioning information, and tidal control and range data to the coordinate points in the computational grid used in the estuarine hydrodynamic modeling system. This study involved the compilation of an inventory of existing first and second-order positional points and tidal reference points. The study effort also included a description and evaluation of techniques used to establish existing positional points and tidal levels, and an evaluation of the accuracy of inventoried points. A concept design and associated cost estimate was developed for a complete control network that would satisfy the requirements of a hydrodynamic model for the Lower St. Johns River Estuary. The concept design involved filling in the gaps in the existing control network consisting of predicted percentages of established positional and tidal points that have not been subsequently damaged or destroyed and can be recovered in the field.

### CONTROL POINT AND TIDAL STATION ATLAS

The principal study product is an atlas containing an inventory of horizontal and vertical control points and tide stations along the St. Johns River from its confluence with the Atlantic Ocean (river mile 0.0) to Lake George (river mile 110.0). Information on positional control and tidal data have been segmented by reach. Each reach is 10 miles long. The reaches have been divided into 2.5 mile diameter sub-areas called "nodes", which serve as conveniently sized areas of reference for assessments and recommendations concerning control points. The manual has 11 chapters containing control listings, descriptions, and cost estimates for extending the present system of reference points within the control survey corridor.

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[3] This is a synopsis of the findings from the Florida Department of Environmental Protection, Bureau of Surveying and Mapping.

The control survey network corridor extends two miles away from each shoreline. A two mile limit was chosen, because beyond that distance control points could not readily be used for extension of control for project purposes. The reference line for stationing along the St. Johns River is the centerline of the existing channel. The stationing consists of a consecutive numbering system based on statute miles.

## NATIONAL GEODETIC CONTROL NETWORK AND DATUMS

In surveying and mapping large areas, it is necessary to establish control frameworks. These networks provide reference systems for all surveying and mapping operations. Horizontal and vertical control networks consisting of stable, identifiable points tied together by extremely accurate observations have been created by the Federal government. From these observations datum values are computed and published. A datum is a reference system in which a set of numerical quantities serves as a common basis. The network of reference stations is maintained by the National Geodetic Survey and the Office of Charting and Geodetic Service. These organizations are components of the U.S. Department of Commerce, National Ocean Service.

Control points are classified according to different levels of accuracy. The level of accuracy is referred to as the "order" of the point. The order indicates control point accuracy with respect to all other points in a control network.

### Horizontal and Vertical Control Network Datum

The North American Datum of 1983, which was readjusted in 1990 (NAD 83/90) is the preferred horizontal reference system now in use in the United States.

### Vertical Control Network Datums

The National Geodetic Vertical Datum of 1929 (NGVD 29) is the vertical datum previously adopted as the standard reference for elevation surveys in the United States. NGVD 29 was based on mean sea level measurements taken over a period of years at 26 tidal stations along the Atlantic, Gulf of Mexico, and Pacific Coasts. It was derived from a general adjustment of first-order leveling nets of both the United States and Canada.

The North American Vertical Datum of 1988 (NAVD 88), which was adjusted in 1991, is the currently preferred vertical datum for elevation surveys in the United States.

In practice, the Florida Department of Environmental Protection currently uses NAD 83/90 as a horizontal reference system and NAVD 88 as a vertical reference system, while maintaining reference data for elevations tied to NGVD 29.

## RESEARCH AND RECONNAISSANCE

The Florida Department of Environmental Protection interviewed more than 30 people and 14 agencies, consultants, and universities in its search for water level and control survey measurements. The interview process yielded information on the Global Positioning System surveys in connection with a mapping project for the Jacksonville Electric Authority and the St. Johns River Water Management District. The interview effort also led to selection of the river mileage system used in this report for the Lower St. Johns River, which is based on a method developed by the U.S. Geological Survey.

Only first and second-order horizontal and vertical control points were considered to be sufficiently accurate to meet the requirements of the hydrodynamic modeling effort. Horizontal and vertical survey networks in the study area containing points meeting these higher order criteria have been established by the following organizations or their predecessors:

a. National Ocean Service

b. Florida Department of Environmental Protection (in cooperation with the National Ocean Service)

c. Geonex, Inc. (Horizontal surveys, using Global Positioning System methods)

Reconnaissance surveys other than for tidal stations and tidal control markers have not been performed prior to the date of the recommendations in this study. A weighted analysis has therefore been used to predict the probability of horizontal and vertical control point recovery. Reconnaissance of all horizontal and vertical control points in control survey network corridor is recommended before extension of the network is attempted.

## HORIZONTAL CONTROL POINTS

Horizontal control points set within the control survey network corridor number 644. Of these 390 are listed as being third-order and not recommended for network expansion. Of the remaining 254 first and second-order points, approximately 58 percent have been set or recovered since 1973. The prospect of finding 200 of these points is considered good. Global Positioning System control surveys would appear to be a cost effective method of extending horizontal control in those areas where reconnaissance shows deficiencies exist.

## VERTICAL CONTROL POINTS

A total of 329 vertical control points have been established in the control survey network corridor by the National Ocean Service and the Florida Department of Environmental Protection or their predecessor agencies. Of these, 71 monuments were tidal bench marks. Approximately 45 percent of all known vertical control points were set between 1933 and 1972. It is expected that, including tidal bench marks, approximately 250 to 275 vertical control monuments will be found in satisfactory condition.

## TIDAL REFERENCE POINTS

In the United States, mean water levels at the middle and extremes of the tidal range are calculated for a specific 19-year period referred to as the National Tidal Datum Epoch. The present Epoch adopted by the National Ocean Service as the official segment is 1960 through 1978. Mean water levels in tidal waters are obtained by averaging the long-term series of six-minute interval tidal water level measurements over the 19-year Epoch. The calculated mean value of local water level measurements will not usually coincide with NGVD 29 or NAVD 88 since sea level is constantly changing. Mean Sea Level Datum, an arithmetic mean of hourly heights observed over the National Tidal Datum Epoch, is generally no longer used as a datum for surveying and mapping purposes.

As part of this study, a field reconnaissance was conducted to recover 53 tide stations that were established in the past in the Lower St. Johns River Basin in connection with efforts to establish the mean high water line for boundary location purposes. Following ten years of operation the National Ocean Service computed tidal datums at the gage locations. During the intervening period the Florida Department of Natural Resources (now called the Florida Department of Environmental Protection) tied permanent bench marks at each tide station to the vertical control survey network. The field reconnaissance in connection with this study resulted in the recovery of 49 of the 53 National Ocean Service tidal stations.

A table included in the study report contains a listing of the recovered tidal stations in the Lower St. Johns River Basin and the number of tidal bench marks recovered at each station. The report also contains a separate listing of the 112 tidal bench marks located in the project area, together with NGVD 88 heights. In a few instances, NGVD 29 heights are also shown for these marks. Of the 258 previously established tidal bench marks in the Lower St. Johns River Basin, 189 were recovered, although, 82 of these require new descriptions. Another 12 tidal bench marks were found to be new or had been reset.

## EXTENSION OF EXISTING CONTROL NETWORKS

Additional work will be necessary to recover, upgrade, and extend control in the control survey network corridor. The efforts required can be separated into three tasks.

The initial task should be reconnaissance and recovery of Global Positioning System first and second-order control monuments established by Geonex, Inc. in 1990. The Geonex system contains about 150 control points. The estimated cost of the recommended reconnaissance effort in connection with the Geonex system is $10,000. The reconnaissance can be accomplished in approximately three months by a two-person field crew.

The next priority task should be reconnaissance of the entire survey network corridor to determine the need for additional horizontal and vertical control. A reconnaissance of the entire network for this purpose can be accomplished in about three months by a two-person survey crew at a cost of approximately $19,100.

The third recommended task is a longer term effort to extend vertical control level runs along each side of the river and four river crossing vertical tie lines. Also included in this task is establishment of Global Positioning System control points and azimuth marks at existing National Ocean Service tide stations and all survey networks found to have deficient horizontal control monuments. The estimated cost of this network-wide survey extension is $241,000.

## EXTENT OF TIDE ANALYSIS

Extent of tide information would be useful for delineating boundary conditions in the Lower St. Johns River Water Quality Model. The tidal signal along the main stem is known to extend past Welaka (river mile 98.4), however, it dissipates before reaching Georgetown (river mile 107.7). It is also known that the tidal signal dissipates in Dunns Creek between the St. Johns River and Crescent Lake. The Florida Department of Environmental Protection has found that methodologies to determine extent of tide are still elusive. Computer modeling using data assimilation to derive extent of tide is at best an uncertain procedure. The data collection effort for this type of model for tributaries in the Lower St. Johns River would require:

a. Simultaneous water level observations in adjacent tidal and non-tidal reaches.

b. Bathymetric surveys including river profiles and cross sections at various intervals.

c. Current and velocity studies.

The estimated cost for the extent of tide research effort is $50,000 to $100,000 which includes the cost of differential leveling and computer modeling using data simulation. The St. Johns River Water Management District has given extent of tide research a low priority with respect to the overall goals of the Water Quality Management Study.

## TIDE CONTROL AND TIDAL CHARACTERISTICS[4]

### PURPOSE

The purpose of this study was to collect and analyze existing tidal data and determine the additional tidal measurements that will be needed in the preparation of a hydrodynamic water quality model of the Lower St. Johns River Estuary. The study includes a review and update of historical information, a review of tidal characteristics, and the assessment of long-term data sets.

Data used in the analyses were collected from tide stations operating in the St. Johns River during the Federal/State cooperative effort in the late 1940's, for stations occupied more recently for Natural Ocean Service hydrographic surveys, and for a long term historical data set from the Long Branch, USE-DDP station in Jacksonville.

### INTRODUCTION

This report consists of a comprehensive review of the tidal characteristics of the St. Johns river based on non-harmonic and harmonic analyses using the latest tidal data. The effort included the digitization and recovery of hourly height time series from several stations including the long term series at Mayport and Long Branch. Tidal datum elevation relationships to Natural Geodetic Vertical Datum (NGVD 29) along the main stem of the St. Johns River are shown. Based on the hourly height time series, harmonic analyses were completed on all available data sets, and the results are integrated into a discussion of tidal characteristics. A brief summary of expected uncertainty in predicted tides was completed from comparisons of observed and predicted data. Using the harmonic analyses results, predicted tides can now be produced for individual stations that are more accurate than those produced from corrections found in the Natural Ocean Service tide tables.

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[4] This is a synopsis of the findings from the National Oceanic and Atmospheric Administration, National Ocean Service, Ocean and Lake Levels Division, Office of Ocean and Earth Sciences.

Long term sea level variations and trends have been investigated using the existing data sets at Long Branch and Mayport. Correlation analyses with mean river flow have been completed to put the variations due to the effects of river flow into perspective with the variations due to the effects on sea level transmitted from the continental shelf. Long term trends and variations in the yearly mean sea level and yearly mean range at Mayport are presented. Based on the analyses, it is recommended that recommendations are for the establishment of additional stations to provide tidal information for the Lower St. Johns Estuary hydrodynamic model.

## HISTORICAL TIDE STATIONS

This study included an inventory of historical National Ocean Service tide stations on the St. Johns River. Information provided in the report for each station includes location; availability of historical data, digital data and harmonic constants; geodetic datum connection; and availability of published tidal datums relative to local bench marks. The tidal portion of the river has fairly good spacial coverage of locations providing at least some type of information on water levels. The observations are also fairly recent. Most of the stations were observed after 1970 and have published or issued tidal datums on local bench marks relative to the 1960-78 National Tidal Datum Epoch. The station at Mayport is part of the National Ocean Service, National Water Level Observation Network and has continuous observations since April 1928. As part of this study, the Natural Ocean Service digitized the entire data set back to 1928. The next longest series was observed at the Long Branch, USE-DDP station in Jacksonville from May 1953 through April 1969. These data were also digitized for this study. The only series of one year in length was observed at Green Cove Springs. Except at four of the non-tidal upriver stations, all recent time series were from three to nine months in length.

## ASSESSMENT OF INFORMATION ON TIDAL CHARACTERISTICS

### Non-Harmonic Analyses

For each of the inventoried stations, information is provided in the report which permits comparisons of variations in the time of high and low waters, in the range of tide, and in the geodetic datum relationship proceeding upstream from the ocean entrance. The values listed are considered non-harmonic parameters, because they are determined from the tabulation of the tide from the record and not through a harmonic analysis.

In terms of understanding the tidal characteristics of the river, the ocean entrance from the jetties up river to Mayport is one of the most complex areas. Summary information from the open coast station show a decrease of mean range of tide by 0.3 feet from just north of the entrance at Little Talbot Island to south of the entrance at Jacksonville Beach. The mean range of tide decreases from 5.5 feet at Little Talbot Island to 4.5 feet at Mayport within a 2 mile distance. The jetties and the river topography effectively damp the tidal signal as it progresses into the entrance. The times of high water show a 0.4 hour delay while the times of low water show virtually no delay over the same distance. The progression of the time of tide and the changes in the range of tide vary smoothly progressing up river from Mayport to the last station with tidal information at Welaka. It takes the high waters approximately 8 hours and the low waters approximately 9 hours to progress the 100 miles from the entrance. At river mile 10 a crossover point occurs where the low water time differences become greater than the high water time differences proceeding upstream. These relative changes are manifested in a change in the shape of the tide curve. If the time difference in low water and high water were the same, the tide curves at each station would generally be symmetrical in shape. The range of tide steadily decreases proceeding upriver until Julington Creek (from 5.5 feet down to 0.71 foot) where the range then increases slightly proceeding to Palatka (from 0.71 foot to 1.09 feet) at river mile 79.

The range becomes negligible at some point between Welaka (mile 98) and Georgetown (mile 108). Dunns Creek, the connection from the St. Johns River to Crescent Lake, is tidal at least to Sutherlands Still with the range of tide becoming negligible at some point before Crescent Lake. The transition from tidal to non-tidal waters occurs in a geographic zone with the exact transfer point moving up and down river depending on the strength of the tide signal.

It is useful to perform harmonic analyses on the hourly height time series for several reasons. The first is that the decomposition of the time series into its fundamental response to the tide-producing forces provides further information on the tidal characteristics of the river. Harmonic analyses of long period records of several months provides information on the contribution of tidal and non-tidal components to the total variability of the water level. Lastly, harmonic analyses provide the ability to more precisely predict the tidal variations at a particular location than the use of time and range correctors found in the NOS Tide Tables.

Harmonic analyses was performed for 23 stations explicitly as a deliverable for this project. NOS uses two distinct harmonic analysis programs depending on series length. For hourly height time series less than 6-months in length, a 29-day harmonic analysis program based on fourier analysis techniques is used in which the amplitudes and phases of 10 constituents are derived using amplitude and phase relationships from equilibrium theory. For hourly height time series of 6-months to one-year, a least-squares harmonic analysis program is used in which amplitudes and phases for 37 separate constituents are solved. The harmonic analysis of tidal station data on the St. Johns river supplied amplitude and phase information for the 8 dominant harmonic constituents found in the river. Relationships and ratios for these constituents were developed that can be used to describe the tidal characteristics of the river system.

The M2 constituent is the major semidiurnal lunar constituent in the direct tide producing force of the moon. S2 is the major semidiurnal solar constituent due to the sun. M2 and S2 interact in and out of phase on a monthly basis to cause the Spring tide/Neap tide cycle. N2 is the lunar constituent that accounts for the fact that the moon's orbit is an ellipse which results in the monthly perigee/apogee cycle in the tide. Lunar diurnal constituents K1 and O1 interact in and out of phase on a monthly basis to cause maximum diurnal tides (tropic tides) during the maximum northern and southern declinations of the moon in its monthly orbit. Solar diurnal constituents K1 and P1 interact in and out of phase on a yearly basis to cause greater diurnal tides during times of maximum solar declination each year. K1 is a lunar-solar constituent and has a lunar and a solar component at the same frequency. The constituents M4 and M6 are higher harmonics and are classified as shallow water constituents. They are not produced directly by the tide producing forces, but by the friction, inertia, river flow, and resonance of the river at a particular location.

The amplitude of the M2 constituent is much larger than the amplitude of the other constituents, as it is typically for most of the east coast of Florida. The shape of the M2 amplitude curve is closely correlated with the curve for the mean range of tide and shows the same general features. Amplitudes of all 8 constituents generally gradually decrease proceeding up river without any noticeable anomalies. The phases of semidiurnal and diurnal constituents show a general linear trend of increasing phase with a noticeable change in slope after river mile 36. The shapes of the phase curves for the semidiurnal constituents are closely correlated with the curves showing time differences in high water and low water from the river entrance. The ratios of the shallow water constituent amplitudes of M4 and M6 steadily increase up river. The increase is dramatic after river mile 80. From that point on these constituents have a significant effect on the shape of the tide curve. The ratio of the constituent amplitudes, (K1+O1)/(M2+S2), is a traditional method of defining the type of tide. A ratio of less than 0.25 indicates a semidiurnal tide, a ratio from 0.25 to 1.5 indicates a mixed tide, and a ratio of greater than 1.5 is a diurnal tide. The ratios hold close to 0.25 until mile 30, where the jump in the ratio indicates that the diurnal tide has a slightly increased effect. The M2-K1-O1 phase relationship helps to describe the shape of the expected tide curve. A consistent relationship along the river would indicate similar shapes in the tide curve at each location. A slight shift in the relationship occurs near mile 26 indicating a small change in the shape of the fundamental tide curve. Additionally, there are important constituents that must be addressed that are not considered in the above discussion. The long period annual (Sa) and semi-annual (Ssa) constituents are available only at Mayport and Long Branch which have long time series of data. These long period constituents are obtained through a separate analysis of the monthly mean sea level values over several years. The amplitudes are significant when compared to other semidiurnal and diurnal constituents. The amplitudes and phases of the Sa and Ssa constituents are as follows:

| | Mayport | | Long Branch | |
|---|---|---|---|---|
| Constituent | Amplitude | Phase | Amplitude | Phase |
| Sa | 0.38 | 190 | 0.38 | 192 |
| Ssa | 0.25 | 55 | 0.24 | 47 |

Although theoretically derived from the yearly and semi-yearly variations in the tide producing forces, in practice, they represent the annual and semiannual variation in mean sea level to seasonal meteorological forcing in large scale wind and barometric pressure patterns. In tidal rivers, such as the St. Johns River, a part of the amplitude of these long period constituents is also due to variations of seasonal changes in the river flow. The fact that the amplitudes and phases of these constituents are similar at Mayport and Long Branch suggests that the seasonal sea level variations should be similar at the stations. This is confirmed in the non-harmonic analysis of data sets for the two tidal stations, as described in the section of this report entitled, Analysis of Long-Term Sea Level Variations, Seasonal Patterns and Variability.

Predicted and Observed Comparisons

Differences in predicted and observed tides can be due to a number of reasons. Estimates of the uncertainty in the prediction of tidal elevations in the St. Johns River can be obtained through the statistical comparison of predicted and observed tides. The levels of uncertainty are not only due to the natural variability of the system that is not due to the tide, but also due to constraints imposed by the limited source of information from which to perform a tidal prediction. A comparative analysis of the tidal characteristics of the river is also limited due to the lack of simultaneous observations between all locations.

In a comparison of predicted and observed tides at Mayport for the 12-months of calendar year 1991, the comparison of hourly heights shows that the mean difference between the observed and predicted hourly heights was 0.29 foot with a one-standard deviation of 0.49 foot about the mean. The 0.29 foot bias results from the yearly mean sea level for 1991 being 4.31 feet on station datum, while the NOS predicted tides use the 19 year, 1960-78 Epoch mean sea level value of 4.02 feet. Tides predicted by NOS for Mayport include values for the long term Ssa and Sa constituents based on analysis of several years of monthly mean sea levels. Values for the other constituents are based on a one-year least-squares analysis. A reduction of variance analysis for 1991 data shows that the predicted tides account for 93 percent of the total variance in the hourly height record. The residual 7 percent variance left is due to meteorological and oceanographic induced variations that are not accounted for in the standard astronomical tide prediction.

In a similar comparison at Long Branch, Jacksonville, a comparison of hourly heights for calendar year 1966 shows a mean difference of -0.04 foot with a standard deviation of 0.44 foot about the mean. The yearly mean sea level in 1966 happened to be close to the 19-year long term mean sea level value used in the reduction. The predicted tides also included values for Ssa and Sa based on analysis of several years of monthly mean sea level values and values for the other constituents based on a one-year least-squares harmonic analysis. The reduction of variance analysis for calendar year 1967 shows that the predicted tides accounted for only 81 percent of the total variance in the hourly heights. Thus the unaccounted residual variance is twice that found at Mayport for 1991 data.

For the station at Green Cove Springs, values for Ssa and Sa constituents are not available, however a least squares analysis on 8-months of hourly heights is available to obtain values for the other tidal constituents. The comparison of hourly heights from April 1, 1978 through November 30, 1978 shows that the mean difference between observed and predicted hourly heights was 0.28 foot with a one-standard deviation of 0.50 foot about the mean. Again, the 0.28 foot bias is due to the fact that the 8-month mean sea level was 0.28 foot higher than the estimated 19-year Epoch value used in the prediction. The predictions are limited by lack of knowledge of Ssa and Sa values due to the limited length of the data. The reduction of variance analysis shows that only 23 percent of the total variance in the 8-months of hourly heights is due to the tide.

Similarly, at Welaka, a least-squares analysis was performed on 8-months of data to obtain constituent values for prediction. Values for Ssa and Sa could not be obtained due to the short series length. The comparison of hourly heights from September 1978 through April 1979 shows that the mean difference between observed and predicted hourly heights was 0.06 foot with a one-standard deviation of 0.57 foot about the mean. Because Ssa and Sa could not be used to formulate a prediction, the reduction of variance analysis shows that only 4 percent of the total variance in the 8-months of hourly heights was due to the tide.

The uncertainties in predicting hourly heights at these four stations along the river, as expressed by the standard deviations, are approximately the same, with a slight increase proceeding upriver. However, an uncertainty of .57 foot at Welaka has much more impact because the mean range of tide is only 0.35 foot. Similarly, at Green cove springs, the uncertainty is 0.50 foot with a 0.74 foot mean range. Long Branch has an uncertainty of 0.44 foot with a mean range of 2.08 feet and Mayport has an uncertainty of 0.49 foot with a mean range of 4.51 feet.

A seasonal comparison of times and heights of the observed and predicted tides was made for the station at Mayport. The statistics were derived for the four fundamental phases of higher high water, lower high water, higher low water, and lower low water that typically occur each tidal day. The times of tide for both high and low water were predicted very well, with no overall biases and with standard deviations of 0.2 hours. For 1991, the greatest mean differences in elevation occurred in the April through June time period, however, the largest standard deviations occurred in the October through December time period. The uncertainties in the higher low and lower low water elevations were higher as evidenced by the larger standard deviations for each period.

Using harmonic constants from the stations listed, the National Ocean Service can provide predicted tides as required to users. The predictions based on the harmonic constants produce a much more precise and realistic description of the tide than the use of the average time and range correctors.

## TIDAL DATUM RELATIONSHIPS

An investigation of tidal datum elevations along the St. Johns River shows that they have significant slopes relative to the National Geodetic Vertical Datum of 1929 (NGVD 29). Tidal datum elevation relationships to NGVD 29 cannot be extrapolated over significant distances in the river. The relationships are generally dependent on the tidal range and the elevation of mean sea level (and mean tide level) above the geodetic datum. Table 6 lists the difference between NGVD 29 and the commonly used tidal datums of Mean High Water (MHW), Mean Sea Level (MSL), and Mean Low Low Water (MLLW). The asterisked (*) values indicate that the NGVD 29 bench mark elevations are preliminary and have not been fully processed or adjusted. Those relationships will be updated, along with the new North American Vertical Datum of 1988 (NAVD 88), when the National Geodetic Survey finishes the processing and adjustment procedures and the National Ocean Service re-establishes the elevation relationships to the tidal bench marks and local station datums. This effect will be coordinated with the Florida Department of Environmental Protection so they will have the latest elevation relationships as they become available.

# TABLE 6

## ST. JOHNS RIVER, FL: RELATIONSHIPS OF TIDAL DATUMS TO NGVD

| STA. NO. | RIVER MILE | MSL-NGVD | MHW-NGVD | MTL-NGVD | MLLW-NGVD |
|---|---|---|---|---|---|
| 194 | 0.3 | 0.48 | 3.28 | 0.53 | -2.41 |
| 220 | 2.2 | 0.36 | 2.56 | 0.31 | -2.10 |
| 232 | 3.5 | 0.41 | 2.36 | 0.41 | -1.64 |
| 221 | 7.3 | 0.46 | 2.26 | 0.43 | -1.51* |
| 198 | 8.1 | 0.47 | 2.29 | 0.47 | -1.47 |
| 203 | 10.0 | 0.55 | 2.18 | 0.43 | -1.44 |
| 219 | 11.0 | 0.48 | 2.04 | 0.45 | -1.25 |
| 215 | 15.1 | 0.56 | 1.87 | 0.56 | 0.84 |
| 225 | 16.1 | 0.56 | 1.83 | 0.56 | -0.80* |
| 242 | 18.2 | 0.72 | 1.77 | 0.73 | -0.39 |
| 274 | 21.0 | 0.76 | 1.80 | 0.77 | -0.35* |
| 268 | 23.2 | 0.77 | 1.51 | 0.75 | -0.09* |
| 296 | 26.1 | 0.81 | 1.40 | 0.85 | 0.22* |
| 333 | 30.2 | 0.76 | 1.23 | 0.79 | 0.28* |
| 374 | 35.2 | 0.68 | 1.05 | 0.68 | 0.23* |
| 409 | 38.2 | 0.80 | 1.16 | 0.81 | 0.38* |
| 496 | 47.1 | 0.70 | 1.06 | 0.69 | 0.25 |
| 596 | 59.8 | 0.69 | 1.13 | 0.68 | 0.16* |
| 653 | 66.5 | 0.65 | 1.19 | 0.67 | 0.08* |
| 774 | 78.6 | 0.62 | 1.19 | 0.65 | 0.17 |
| 767 | 89.2 | 0.86 | 1.37 | 0.90 | 0.38* |
| 832 | 98.4 | 0.90 | 1.09 | 0.92 | 0.70* |

ALL ELEVATIONS IN FEET
*NOTE: NGVD ELEVATIONS ARE PRELIMINARY

## ANALYSIS OF LONG-TERM SEA LEVEL VARIATIONS

The availability of simultaneous observations at Mayport and Long Branch from 1954 through 1967 allows for a long-term comparative study of mean sea level and mean range of tide. For comparison purposes the data from the USGS station at Deland is used as the representation of variations in the river flow.

Generalized seasonal patterns were obtained by averaging the monthly mean values over each calendar year for the 14-year period, 1954-1967. Mayport and Long Branch have very similar seasonal patterns.

Although Long Branch has a much smaller mean range (2.08 feet) than Mayport (4.51 feet), they both show a slight maximum in July and a slight minimum in September and October with the rest of the months approximately the same value. The monthly mean sea level values are relative to station datum at each location and also show extremely similar patterns, with a primary maximum in October and a secondary maximum in May and June. The lowest monthly mean sea levels occur in February. These seasonal variations are taken into account in the prediction of tides by using values for the Ssa and Sa constituents. The monthly mean river flows recorded at Deland also show a maximum in October, however the secondary maximum occurs in March and April, with a distinct minimum occurring in May and June.

The average seasonal variations must also be put in context by looking at the year-to-year variabilities that went into the seasonal averages. Although the monthly mean sea levels and monthly mean ranges show significant year-to-year variability, the monthly mean river flow clearly has the largest year-to-year variation. The fall season of 1960 appears to be an anomalous year during the 14-year period, with an extremely high river flow and very high monthly mean sea levels at both Long Branch and Mayport.

A correlation analysis was run on the monthly time series. For the 14-year period 1954-1967, the correlation coefficients between the various combinations of parameters, Mean Sea Level (MSL), Monthly Mean (MN) and Monthly River Flow (MRF) are as follows:

| VARIABLE | CORRELATION COEFFICIENT |
|---|---|
| Mayport MSL and Long Branch MSL | 0.97 |
| Mayport MN and Long Branch MN | 0.69 |
| Mayport MSL and Deland MRF | 0.35 |
| Long Branch MSL and Deland MRF | 0.50 |
| Mayport MN and Deland MRF | 0.30 |
| Long Branch MN and Deland MRF | 0.05 |

Variations in monthly MSL and MN are significantly correlated between Mayport and Long Branch. Monthly MSL variations at Long Branch show higher correlation with variation with MRF than at Mayport, however, neither of the correlations is very high. Variations in monthly MN at both Mayport and Long Branch are not well correlated with MRF, and appear to be slightly negatively correlated. This is not totally unexpected, as extremely high river flows tend to minimize tidal effects in tidal rivers.

The fairly low correlation coefficients between MSL and MRF are also not unexpected, as the mean sea level variations in tidal rivers are due to a combination of effects beyond the local river flow, most noticeable the variations in sea level that are transmitted from the continental shelf up into the river. These seasonal variations are due largely to the response of the continental shelf waters to large-scale seasonal weather patterns and associated tendencies in wind speed and direction, barometric pressure, and changes in ocean circulation patterns. This large scale effect is confirmed by the extremely close patterns in the average seasonal mean sea level variations over the eastern coast. For instance, the average monthly MSL pattern for Mayport and Long Branch are extremely similar to the seasonal monthly MSL patterns found from Charleston, South Carolina south to Miami, Florida.

Long-term variations in mean sea level and mean range of tide for the St. Johns River area can be estimated by using the historical series at Mayport. Continuous monthly and yearly mean values are available back to May 1928.

An analysis of the yearly mean sea level (MSL) values for the entire series, referenced to the same station datum reveals the dominant features are the consistent upward trend and the relative high degree of year-to-year variability in the values. The relative apparent secular trend in this series as determined from the slope of the least-squares line of regression fit through the data is 0.007 foot/year. The standard error of this trend is +/-0.0009 foot/year, with a variability or standard deviation from the line of regression of +/- 0.115 foot.

The trend in MSL is a relative trend because the long term variation due to vertical land movement cannot be distinguished from the long term variation due to global sea level and climate change. The number should be interpreted as relative to the land. Sea level at Mayport is estimated to be rising at a rate of +0.007 foot/year. As a caution, comparing sea level trends with other locations should be done using simultaneous time periods of data if possible. The estimate of a trend in the data can be significantly dependent on the length of series used and on the start and end dates used. This is due to the high degree of variability in yearly mean sea level records over time. For the common time period 1950 through 1986, the relative sea level trends are +0.007 ft./yr. at Fernandina Beach, +0.006 ft.yr. at Mayport, +0.007 ft./yr. at Miami, and +0.008 ft./yr. at Key West.

The yearly mean range of tide values for the entire series shows a very distinct periodicity in the long term variation in mean range. This periodicity, of approximately 19-years, is the fundamental reason why accepted values of tidal datums are computed from 19-year time series called National Tidal Datum Epochs. The 19-year periodicity is due to the "regression of the Moon's nodes" where a lunar node is the point where the plane of the Moon's orbit intersects the ecliptic. It takes approximately 18.6 years for the regression of the moon's nodes to complete a 360 degree circuit of longitude. The effect is a corresponding change in the inclination of the Moon's orbit with respect to the plane of the Earth's equator along with subsequent variations in the tide producing forces.

The St. Johns River can be divided into four discrete sections using tidal characteristics as a criteria. These sections are 1) from the river entrance up river to Mayport (river mile 2.2), 2) from Mayport up river to Jacksonville, Acosta Bridge (river mile 23.2), 3) from Jacksonville up river to Palatka (river mile 78.6) and 4) from Palatka up river to Georgetown (river mile 107.7).

Adequate tidal datum information is lacking in the first section. The range of tide, time of tide, geodetic datum relationships, etc., all change rapidly over a relatively short distance. Tidal datum elevations can only be linearly interpolated from the ocean upstream to Mayport, however the changes in tidal characteristics are most likely not linear. Adequate control requires the simultaneous occupation of at least two new locations in this section to adequately determine tidal datums and their spacial changes.

The analyses show fairly steady and smoothly varying changes in tidal characteristics in the second section and the existing knowledge of the tide and locations of tidal control appear adequate. There are no new locations in particular at which additional tidal datums and vertical control are required.

There are some fundamental changes in the tidal characteristics in section 3 from section 2. There are shifts in the slopes and relationships of the times and high and low water curves; the mean range of tide decreases to a minimum and then increases up to Palatka; there are changes in the M2 constituent amplitudes and the harmonic constant ratios, and there is a crossover of the MLLW:NGVD relationship from negative to positive. The river topography is partially responsible. The river channel is fairly constrained up to Jacksonville, Acosta Bridge, and then widens until the next narrowing just up river from Palatka. The narrowing of the basin at Palatka acts as a partial reflection point for the tide, resulting in a slight increase in the range of tide and the other shifts shown in the figures.

Section 4 is the head of tide transition zone where the tidal signal becomes weak and variable, There is a fundamental change in the shape of the tide curve. The tide curves at Green Cove Springs and Palatka are similar, except for a range difference and a slight time shift. The curve at Welaka not only shows the reduced range but is much more complex with a flattish low water almost containing a secondary extra tide. This complexity is quantified by the harmonic constant ratios of the shallow water constituents which increase dramatically in the vicinity of Welaka.

A head of tide study, in Section 4 would require additional short term stations to monitor the seasonal change in the transition zones.

The analysis shows that except in the river entrance and for a head of tide study, there are no particular locations where a new tide station is required. However, there is a strong requirement for the existing tidal datums to be upgraded with additional measurements at existing historical locations. Especially in sections 3 and 4 defined above, the existing tidal datums are based on time series that are both too short and did not have sufficient control stations for comparison to be considered precise enough for many applications. The year-to-year variability of the river system needs to be accounted for in the datum computation. This requires a network of primary (19-year stations), secondary (1 to 5-year stations) and tertiary (1 to 3-month) stations.

The existing primary station at Mayport provides sufficient long term control for the river system. However, direct comparison of data from tertiary stations in sections 3 and 4 of the river with Mayport for datum computation is not adequate because of the differences in tidal characteristics and the fact that seasonal sea level variations are different between Mayport and these upriver sections. Thus a network of secondary stations is required to account for the local seasonal sea level effects on tidal datums along the river. Such a network would include a secondary station in each of the sections described, preferably operating simultaneously. Recommended locations are Long Branch, Green Cove Springs, Palatka, and Welaka. After datums are upgraded based on at least one year of observation at these locations through comparison with Mayport, tidal datums at all other historical locations could then be upgraded as required through comparison with the appropriate secondary station. All tertiary stations would not have to be reoccupied simultaneously. Eventually, because the existing tidal datums are based on information that is 15-20 years old, datum updates will require new observations. Stations should not be reoccupied randomly, but within the hierarchical system described above.

## NATURAL DISCHARGE AND CHEMICAL CONSTITUENT LOADING FROM THE UPPER FLORIDAN AQUIFER[5]

### PURPOSE

The purpose of the ground water study was to provide estimates for the quantity and quality of Upper Floridan aquifer discharge to the Lower St. Johns River. These ground-water discharge data can be used by regulatory agencies concerned with evaluating point and nonpoint discharge to the river.

### INTRODUCTION

It is believed that in some areas of the Lower St. Johns River, ground-water discharge from the Upper Floridan aquifer may be more mineralized than the river water. Therefore, it is possible that some constituent loads contributed by ground-

[5] This is a synopsis of the findings from the Orlando District, U.S. Geological Survey. This report is in USGS internal review until December 1993.

water discharge from the aquifer are greater than those contributed by manmade sources. Chloride and sulfate, for example, usually are present in both effluent and in ground-water entering the river from the aquifer. This report includes information that will aid in the assessment of constituent loads that are contributed exclusively through ground-water discharge from the aquifer. This report provides a general description of the three hydrogeologic units underlying the Lower St. Johns River. Information on Upper Floridan aquifer water levels and water quality is provided. This report also describes the confining bed leakage coefficient values as determined from Regional Aquifer - System Analysis ground-water flow models. In conclusion, the report contains estimates of natural discharge and the constituent loading for selected chemical constituents from the Upper Floridan aquifer into the surficial aquifer system.

## GEOLOGIC FRAMEWORK

The study area is underlain by a thick sequence of sedimentary rocks that overlie a basement complex of metamorphic strata. Stratigraphic units and corresponding hydrogeologic units in northeastern Florida include sedimentary rocks ranging in age from late Paleocene to Holocene. Stratigraphic units of interest, in ascending order are: Cedar Keys Formation of late Paleocene age, the Oldsmar Formation of early Eocene age, the Avon Park Formation of middle Eocene age, the Ocala Limestone of late Eocene age, the Hawthorn Formation of Miocene age, and the undifferentiated deposits of late Miocene to Holocene age.

Subsurface structures (such as collapse features and related fractures, joints, and faults) may all play a substantial role in the quantity and quality of ground water discharging from the Upper Floridan aquifer discharge to the Lower St. Johns River. Previous investigators have inferred the presence of several faults within the study area. Circular depressions are present on the surface of the Ocala Limestone. Some of the depressions were formed by sinkhole collapse caused by the gradual dissolution of underlying carbonate materials. Other depressions may be erosional features formed before the Hawthorne Formation was deposited. Recent investigations have revealed the presence of numerous collapse features along the St. Johns River in Duval County that originated in rocks that constitute the Floridan aquifer system.

## HYDROGEOLOGY

Three hydrogeologic units are present in the study area: the surficial aquifer system, the intermediate confining unit, and the Floridan aquifer system.

## Surficial Aquifer

The uppermost water-bearing unit is the surficial aquifer system. It is primarily composed of Holocene to upper Miocene deposits of sand, clay, shell, and some limestone and dolomite. The thickness of the surficial aquifer system is highly variable, ranging from about 20 to 120 feet throughout the study area. The depth of the water table of the surficial aquifer system ranges between 1 and 15 feet below the land surface, depending upon topography. However, the depth is generally less than 5 feet. The water table varies seasonally within a range of about 5 feet. The maximum depth to water occurs during the spring and early summer months. Water levels generally recover during the wet summer months and reach their annual high in September or October.

The surficial aquifer system yields small to moderate amounts of water to wells and is an important source of water supply in those areas where the Floridan aquifer system water is too highly mineralized for use. In the areas where the Floridan aquifer system is less mineralized, the surficial aquifer system is used only to supply small amounts of water for domestic and irrigation use.

## Intermediate Confining Unit

The intermediate confining unit, which consists primarily of the Hawthorn Formation of Miocene Age, contains beds of lower permeability sediments that confine the water in the Floridan aquifer system under artesian pressure.

However, in the extreme southern part of the area where the Hawthorn Formation is thin or absent, other deposits of Miocene age or younger may act as a confining unit. The intermediate confining unit consists of interbedded clay, silt, sand, limestone, and dolomite. The thickness of the intermediate confining unit varies considerably, from more than 500 feet in the central part of Duval County to less then 50 feet in much of southern Flagler and northern Volusia Counties. The intermediate confining unit also may be locally breached by sinkholes where it is relatively thin, or by other openings that serve to connect the Floridan aquifer system directly with the river.

## Floridan Aquifer

The Floridan aquifer system is a vertically continuous sequence of Tertiary-age carbonate rocks of generally high permeability that are hydraulically connected to each other in varying degrees. The aquifer system consists of rock units which vary in age from Paleocene to Eocene. The Floridan aquifer system ranges in thickness from 1,500 to 2,000 feet and underlies all of the study area. It is the principal source of municipal, industrial and agricultural water supply for most of northeastern Florida. The top of the aquifer ranges from less than 50 feet in the extreme southern part of the study area to more than 550 feet below sea level in parts of central Duval County.

In the northern part of the study area, the Floridan aquifer system has three major water-bearing zones (the Upper Floridan aquifer, the upper part of the Lower Floridan aquifer, and the Fernandina permeable zone) separated by less permeable semiconfining units.

The Floridan aquifer system in northeastern Florida is divided into the Upper Floridan aquifer and the Lower Floridan aquifer which are separated by a zone of lower permeability. Two major water-bearing zones exist within the Lower Floridan: the upper part of the Lower Floridan aquifer and the Fernandina permeable zone. These zones are separated by another less permeable semiconfining unit. The Fernandina permeable zone is thought to be absent in the southern part of the study area. In this study, however, only hydrogeologic and chemical data obtained from the Upper Floridan aquifer is of interest.

The principal recharge area of the Upper Florida aquifer is the region located in the western part of the study area. In this area, water enters the Floridan aquifer system by several means: by downward leakage where the water table is above the potentiometric surface of the Upper Floridan aquifer; through sinkholes and other features having enhanced permeability; and by lateral inflow from adjacent areas. Areas of discharge primarily are present along the coast and throughout the St. Johns River Valley. Discharge from the Florida aquifer system is by diffuse upward leakage in areas where the potentiometric surface of the Florida aquifer system is above the water table, by pumping and flowing wells, by springs, and by lateral outflow.

## POTENTIOMETRIC SURFACE

The potentiometric surface for September 1990 and 1991 were selected for the estimate of discharge from the Upper Floridan aquifer to the Lower St. Johns river. Ground-water levels in much of northeastern Florida were at or near record lows in September 1990 due to below normal rainfall. Water levels in September 1991 were about 2 to 6 feet higher than in September 1990 because of near-record rainfall in northeastern Florida. The altitude of the potentiometric surface of the Upper Floridan aquifer ranged from about 75 feet above sea level in the western parts of Clay and Putnam Counties to less than 10 feet above sea level in the southern part of Flagler County in September 1990 and from about 80 to less than 15 feet above sea level in September 1991.

A large depression in the potentiometric surface south of Jacksonville is believed to be caused, in part, by withdrawals from industrial and public-supply wells, and possibly by diffuse upward leakage or undetected spring discharge into the St. Johns River. A depression in the potentiometric surface of the Upper Florida aquifer in the Green Cove Springs area is likely caused by a combination of factors including withdrawals for public, agricultural, and domestic use and possibly from diffuse upward leakage or spring flow. Spring discharge and diffuse upward leakage are the likely cause of a depression in the potentiometric surface near the confluence of the St. Johns and the Oklawaha Rivers, near Welaka. The intermediate confining bed in this area is thin, making conditions favorable for spring formation. Additionally, it is possible that channel dredging or excavation in the St. Johns River has, in places, breached or partially beached the semiconfining unit overlying the Upper Floridan aquifer, and has allowed the Upper Floridan aquifer to discharge into the river.

## SURFACE WATER QUALITY

Generally, water quality ranges from good in the sparsely populated area of the Lower St. Johns River to poor in the urban area of Jacksonville. Water-quality problems include low dissolved oxygen concentrations, and elevated nutrient concentrations and bacterial populations which result from point and nonpoint sources such as industrial discharges, agricultural runoff, municipal water treatment plants, septic tanks, and dairy farms.

Water quality in the Lower St. Johns River varies significantly with changing flow conditions. The flow, hence the water quality, of the river is affected by ocean tides, rainfall, surface-water runoff, evapotranspiration, and wind. The extent to which these factors can affect the flow is primarily controlled by channel geometry and the available storage capacity of the river. Of these factors, ocean tides probably have the greatest effect on the quality of water in the river. Saltwater from the ocean advances up the St. Johns River during each incoming tide and recedes during each outgoing tide. A zone of transition is formed where the ocean water mixes with freshwater in the river. The length of the transition zone varies with each tidal cycle and with the amount of freshwater entering the river upstream. Freshwater sources include precipitation that falls directly into the river, runoff from adjacent lands, and ground-water discharge from the surficial and Florida aquifer systems. During periods of large freshwater inflow to the river, downstream flow can increase, reducing the length of the transition zone and shifting the zone toward the ocean. Reduced freshwater inflow can cause the transition zone to move a considerable distance upstream during periods of drought or reduced rainfall.

The chemical quality of water in the river also can change significantly over a short period of time as a result of the constant movement of the transition zone. At the Main Street Bridge in Jacksonville, for example, chloride concentrations increased more than fourfold in a few hours and more than tenfold in several days.

Upstream from, and probably in some areas of the Lower St. Johns River, an undetermined amount of mineralized ground water from the Upper Floridan aquifer is discharged through springs and by upward leakage through the intermediate confining unit. Ground-water discharge of mineralized water is a potential source of highly concentrated solute species such as chloride and sulfate. In some areas along the Lower St. Johns River, however, water from the Upper Floridan aquifer could be more mineralized than the river water. Under certain conditions, such as during a drought when lowflow conditions exist, ground water flows into the St. Johns River from surface-water sources during these periods and the mineralized ground water discharging into the river can significantly affect water quality. However, in the areas where saltwater intrusion from the ocean affects the quality of water in the Lower St. Johns River, water that enters the river from the Upper Florida aquifer probably is of better quality than the river water itself.

## QUALITY OF WATER FROM WELLS THAT TAP THE UPPER FLORIDA AQUIFER

Available data for ground-water quality in the study area were used to evaluate the potential effect of natural ground-water discharge from the Upper Floridan aquifer into the Lower St. Johns River. Maps indicating the distribution of selected constituents in the study area are included with the U.S. Geological Survey report that was prepared in connection with this study.

### Dissolved Solids

The concentration of dissolved solids in water is a common indicator of mineralization. The areal distribution of dissolved solids in water collected from the Upper Floridan aquifer in parts of Duval, Clay, St. Johns, Putnam, Flagler, and Volusia Counties ranged from about 100 to 5,000 mg/L and generally increase toward the east and the south. Lowest dissolved-solids concentrations are in much of Clay and western Putnam Counties, where concentrations of less than 150 mg/L are common. Highest dissolved-solid concentrations are in the Hastings area of southwestern St. Johns County. Relatively high dissolved-solids concentrations also are present in southwestern Flagler County, and in several areas adjacent to the St. Johns River near Welaka, east of Palatka, and north of Riverdale. Based on data for areas adjacent to the river, dissolved-solids concentrations in water from the Upper Floridan aquifer that underlies the Lower St. Johns river is estimated to range from 120 mg/L to possibly more than 2,000 mg/L.

## Chloride

Chloride is a major constituent of dissolved solids in parts of St. Johns, Putnam, and Flagler Counties. The primary mechanisms by which chloride increases in ground water include the dissolution of minerals in rocks of the aquifer, relict or connate water mixing with freshwater, and by the intrusion of seawater. Chloride concentrations in the study area range from 4 to 3,700 mg/L and generally increase toward the south. The lowest chloride concentrations are present in Clay, southwestern Duval, and western Putnam Counties where concentrations of less than 10 mg/L are common. Highest chloride concentrations were measured in southwestern Flagler County. Relatively high chloride concentrations (concentrations exceeding 500 mg/L) also are present in southern St. Johns and northern Flagler Counties and in several areas adjacent to the St. Johns River near Palatka and Welaka. The area north of Riverdale also may be an area where chloride concentrations in ground water exceed 500 mg/L. Chloride concentrations in water from the Upper Floridan aquifer that underlies the Lower St. Johns River are estimated to range from 4 to 1,800 mg/L.

## Sulfate

The distribution of dissolved sulfate in water from the Upper Floridan aquifer in the study areas range from about 1 to 1,300 mg/L and generally increases toward the east and south. Lowest concentrations typically occur in Clay and Putnam Counties, where concentrations of dissolved sulfate are less than 10 mg/L. Highest sulfate concentrations are present north of Riverdale. Sulfate concentrations greater than 500 mg/L also are present in southern St. Johns County and in a small area east of Green Cove Springs. Sulfate concentrations in water from the Upper Floridan aquifer that underlies the Lower St. Johns River are estimated to range from 10 to 900 mg/L.

High sulfate concentrations in southern St. Johns and parts of northeastern Putnam and northern Flagler Counties are often associated with high chloride concentrations. This may indicate that the high concentrations of sulfate are, in part, related to the presence of ancient seawater that has not been flushed from the aquifer by freshwater. However, in some areas of northwestern and west-central St. Johns County, the high concentrations of sulfate are not associated with high concentrations of chloride. High sulfate concentrations probably are the result of the dissolution of sulfate-bearing minerals.

# QUALITY OF WATER FROM SPRINGS

Nine gaged springs that discharge water into the St. Johns River are located in or near the study area. Only five springs are known to discharge water into the St.

Johns River between the Oklawaha River and Mayport. The remaining four springs, Beecher, Croaker Hole, Mud, and Forest Springs, are located a few miles to the south of the study area.

The quality of water discharging from these springs is variable. Limited water-quality data indicate that dissolved-solids concentrations range from about 133 to 3,564 mg/L and sulfate concentrations from 10 to 260 mg/L (Table 7). Sulfate concentrations in most of the springs, however, generally are less than 100 mg/L. Chloride concentrations range from 5.8 to 1,600 mg/L. Chloride concentrations in water from Green Cove and Wadesboro Springs in the northern part of the study area are out less than 10 mg/L. Chloride concentrations in water from springs near the confluence of the Oklawaha and St. Johns Rivers are higher and more variable. The average chloride concentration in water discharging from Satsuma Spring is 1,600 mg/L but at Beecher Springs, several miles to the south, chloride concentrations average only 78 mg/L. A water sample collected at the mouth of Croaker Hole Spring, located in Little Lake George (St. Johns River), had a chloride concentration of 720 mg/L; however, inside the spring, several vents observed discharging water had chloride concentrations ranging from 740 to 880 mg/L. Chloride concentrations as high as 1,600 mg/L also have been determined in water discharging from Salt Springs, about 8 miles south of the study area.

TABLE 7
AVERAGE DISCHARGE, LOADS, AND SELECTED CHEMICAL CONSTITUENTS OF SPRINGS FROM THE UPPER FLORIDAN AQUIFER IN AND NEAR THE STUDY AREA

| SPRING | AVERAGE DISCHARGE ($FT^3/S$) | DISSOLVED SOLIDS (MG/L) | DISSOLVED SOLIDS LOADS (TON/YR) | CHLORIDE (MG/L) | CHLORIDE LOAD (TON/YR) | SULFATE (MG/L) | SULFATE LOAD (TON/YR) |
|---|---|---|---|---|---|---|---|
| Beecher[1] | 10 | 252 | 2,483 | 78 | 769 | 13 | 128 |
| Croaker Hole[1] | 84 | [2]1,834 | 151,822 | 720 | 59,603 | 160 | 13,245 |
| Green Cove | 3.5 | 181 | 624 | 5.8 | 20 | 54 | 186 |
| Forest[1] | .30 | [2]1,518 | 449 | 600 | 177 | 87 | 26 |
| Mud[1] | 2.3 | 688 | 1,559 | 290 | 657 | 43 | 98 |
| Nashua | .27 | – | – | – | – | – | – |
| Satsuma | 1.8 | [2]3,564 | 6,322 | 1,600 | 2,838 | 260 | 460 |
| Wadesboro[3] | 1.2 | 133 | 157 | 8.5 | 10 | 10 | 12 |
| Welaka | 2.2 | 849 | 1,841 | 370 | 802 | 57 | 124 |

Note: $ft^3/s$, cubic feet per second; mg/L, milligrams per liter; ton/yr, tons per year; –, no data.
[1] Spring located outside of study area.
[2] Dissolved-solids concentrations estimated from specific conductance.
[3] May not be an Upper Floridan aquifer spring.

## GROUND-WATER DISCHARGE FROM THE UPPER FLORIDAN AQUIFER

Ground-water discharge from the Upper Floridan aquifer to the St. Johns River occurs as diffuse upward leakage or spring flow. Water from the Upper Floridan aquifer moves upward through the intermediate confining unit to the surficial aquifer system in the discharge areas of the Lower St. Johns River drainage basin. The water then moves laterally through the surficial aquifer system or into streams and creeks where it eventually discharges into the St. Johns River.

The rate of leakage through the intermediate confining unit is controlled by the leakage coefficient of the intermediate confining unit and the head difference between the Upper Floridan aquifer and the surficial aquifer system.

Leakage coefficients were obtained from Regional Aquifer-System Analysis (RASA) ground water flow models.

Leakage coefficients of the intermediate confining unit are highly variable and range from less than $1x10^{-8}$ (ft/d)/ft to more than $1x10^{-4}$ (ft/d)/ft. The lowest leakage coefficients generally are in the areas where diffuse recharge and discharge rates are low; those areas where the confining units are relatively thick or have low permeability. The highest leakage coefficients generally are in areas where diffuse recharge and discharge rates are highest; those areas where the confining units are relatively thin or permeable.

Total diffuse ground-water discharge to the Lower St. Johns River was calculated by determining leakage coefficients and average heads for the surficial aquifer system and Upper Floridan aquifer at 174 points within the St. Johns River study area. Average heads in the Upper Floridan aquifer at each point were determined by interpolating directly from the September 1990 potentiometric surface, which represented a time when water levels in much of northeastern Florida were at or near record lows. Water-level elevations in the surficial aquifer system were estimated from USGS 1:100,000 scale topographic maps.

Discharge rates for springs in and near the study area were determined by standard stream flow measurements (Table 7).

The effects of known springs on the potentiometric surface of the Upper Floridan aquifer are implicitly accounted for by the diffuse upward leakage rates determined during model calibration. Ground-water discharge from Satsuma and Welaka Springs was added to the diffuse upward leakage rate to get total ground-water discharge from the Upper Floridan aquifer to the surficial aquifer system.

Total ground-water discharge to the Lower St. Johns River, determined by adding the calculated flow from the 174 point locations with an upward hydraulic gradient in the study area and spring flow at Welaka and Satsuma Springs, was estimated at 86 $ft^3/s$ based on September 1990 Upper Floridan heads. Estimated leakage rates for each point within the Lower St. Johns River drainage basin ranged from about 0 to 9 in/yr.

Total ground-water discharge to the Lower St. Johns River also was computed for September 1991. Variables used to compute ground-water discharge for September 1990 were again used for the September 1991 estimate, except for potentiometric-surface elevation, which increased over the drainage basin by an average of 4 feet from the September 1990 levels. Potentiometric-surface elevations rose between 2 and 6 feet as a result of near-record rainfall in much of the study area. The calculated discharge rate from the Upper Floridan aquifer to the river was about 133 $ft^3/s$, an increase of about 55 percent from the September 1990 calculated discharge. The increase in ground-water discharge was due to a greater upward hydraulic gradient in discharge areas, as well as to a reversal in the hydraulic gradient from recharge to discharge in areas where the two heads were nearly equal.

Potentiometric-surface elevations in the Upper Floridan aquifer in most of the study area were near or at historical lows during September 1990. Accordingly, ground-water discharge to the Lower St. Johns River (assuming that the surficial aquifer system heads have remained relatively constant since predevelopment times) also may have been at a historical low. The average potentiometric surface of the Upper Floridan aquifer was higher during predevelopment times than at present. Estimated declines from predevelopment heads to heads measured in September 1990 range from less than 10 to more than 30 feet in the areas of higher pumpage (near Jacksonville). Although changes in the potentiometric surface do not occur equally over the entire area, ground-water discharge to the river during predevelopment times was considerably higher than during September 1990. Conversely, a continued average decline of another 4 feet from the September 1990 levels could decrease the amount of ground-water discharge to the Lower St. Johns River to about 51 $ft^3/s$, a decline of about 41 percent.

## CHEMICAL - CONSTITUENT LOADS

The contribution of constituent loads into the Lower St. Johns River from the Upper Floridan aquifer were determined by adding the calculated loads at each of the 174 point locations with an upward hydraulic gradient within the Lower St. Johns River drainage basin.

Because load is a function of ground-water discharge and constituent concentration, changes in either variable can affect the calculation of load. An average constituent concentration in water from the Upper Floridan aquifer for each point was determined by interpolating concentrations in water from selected wells. However, some uncertainty concerning the accuracy of constituent concentrations exist due to long-term and seasonal changes in the chemical quality of water within the aquifer. In much of the area, water analyzed from the Upper Floridan aquifer was collected during the 1980's; however, in some areas, the most recent water samples were collected during the 1970's. Increases in constituent concentration might have occurred over time in selected wells. Seasonal changes in water levels due to pumpage also can affect the constituent concentration in water from the Upper Floridan aquifer. Chloride concentrations in many wells increased during the spring, generally a period of greater irrigation-water use and lower potentiometric surface.

Total estimated constituent loads also can vary depending on the chemical and physical changes in the Upper Floridan Aquifer water as it moves through the intermediate confining unit and surficial aquifer system. The degree of mineralization and the chemical-constituent loading of water are largely determined by the initial chemical composition of water entering the overlying hydrogeologic units, the composition and solubility of rocks with which it comes in contact, and the length of time the water remains in contact with these rocks. Therefore, estimated constituent loads could vary depending on the geochemical reactions that occur. For the purpose of this report, the assumption was made that little chemical change occurs as the water moves through the intermediate confining unit and the surficial aquifer.

Dissolved-solids loads discharging into the Lower St. Johns River were estimated at 46,000 ton/yr based on September 1990 heads. Estimates of chloride and sulfate loads based on September 1990 heads were 18,000 and 9,500 ton/yr, respectively. The average 4-foot increase in the elevation of the potentiometric surface of the Florida aquifer over the entire Lower St. Johns River drainage basin during September 1991 increased dissolved-solids loads discharging into the Lower St. Johns River to about 81,000 ton/yr, a 76 percent increase from September 1990. Chloride loads increased to 39,000 ton/yr, a 117 percent increase; and sulfate loads increased to about 15,000 ton/yr, a 58 percent increase.

## SEDIMENT MANAGEMENT AND SEDIMENT QUALITY[6]

### PURPOSE

The purpose of this study was to provide information on the quality and quantity of sediments, and water-sediment dynamics in the Lower St. Johns River Basin. These sediment data are to be used in water quality/water transport models of the Lower St. Johns River Estuary and in the development of comprehensive water quality management plans.

### INTRODUCTION

This study provides an understanding of sediment properties and dynamics as they related to water quality analyses and management plans for the Lower St. Johns River Estuary. Problems and data needs are identified and guidelines are provided for future detailed studies and procedures.

The study summarizes the state-of-the-art on: sediment dynamics and modeling; contaminant decomposition, precipitation or partitioning in aquatic ecosystems; environmental impact assessment methods; and techniques for establishment of quantitative environmental indices. Pollution effects on benthic and sessile communities are also assessed.

In addition, information is provided on point and non-point pollution sources within the Lower St. Johns River Basin. Emphasis was placed on sediment management as related to urban expansion, industrial activities and agricultural practices.

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[6] This is a synopsis of the findings from Dunn and Associates of Boca Raton, Florida.

## SEDIMENT DYNAMICS

The extend of contamination of aquatic ecosystems can often be determined by analyzing sediments for metals and organic pollutants. Contrary to the once popular belief that sediments are acting only as pollutant traps, resuspended contaminated sediments can substantially contribute to the degradation of an ecosystem. Indeed, mobile sediments in an estuarine system may reduce navigability by shoaling, undermine the integrity of the foundation of marine structures by scouring, or increase turbidity levels and contaminant concentrations of the ambient water during resuspension events. Suspended or dissolved pollutants in aquatic environments can pose a very serious problem to cohesive sediment bottoms. Due to their small particle size (high specific surface) cohesive sediment particles have an affinity for dissolved or suspended pollutants. Understanding water-sediment interaction is very important for environmental quality assessment of aquatic ecosystems.

### Physicochemical Characteristics

Individual sediments are primarily characterized by specific gravity, particle size, and particle shape. For alluvial sediments the specific gravity ranges between 2.56 to 2.76. An average value of 2.65 is commonly used when field data are lacking. Particle diameters in the Lower St. Johns River Basin are small. For small particles it is difficult to quantify and utilize information based on particle sizes. Therefore, bulk properties such as density and mean fall velocity are commonly used to describe particle distribution. Particle frequency distribution is usually expressed in terms of particle diameter versus percentage of weight, plotted on a histogram or frequency distribution curve. The main characteristics of a frequency distribution curve are its spread, skewness, and kurtosis. Spread is the most important factor, relative to sediment transport dynamics, because it represents the uniformity of the sample.

Based on particle size, two major sediment groups are recognized: granular and cohesive. Granular materials are subject only to mechanical forces. Cohesive sediments in addition to mechanical forces are subject to electrochemical forces. Fine material comprised of fine silt, clay minerals and decomposed organic matter which collects on the bottom of estuaries may tend to aggregate and flocculate due to electrochemical forces.

In general, sediment dynamics is a time-dependent, multi-phase, nonlinear phenomenon subject to physical, chemical and biological effects. Sediments continuously undergo cycles of erosion, transport, deposition and resuspension. Of course, the sediment particles that participate in these cycles exchange continuously (i.e., particles continuously move in and out of the cycles). Based on their transportation mode, riverine sediments are classified as bed load or suspended load. In bed load, the sediment particles are transported while in suspension. There is no clear distinction between bed load and suspended sediments other than the time period that particles move continuously in suspension.

Based on their place of origin, sediments are classified as bed load or wash load materials. Bed load material is the part of the sediment that has the same composition as that of the soils in the riverine bed. On the other hand, wash load is the part that has compositions different from those in the riverine bed. Bed load is composed mostly of granular material while suspended loads are usually cohesive inorganic and organic sediments. The technical approach of studying granular or cohesive sediments differs substantially. The main physical parameters that govern the mechanics of granular sediment transport depend on water and sediment physical characteristics as well as on riverine geometry. The parameters pertaining to the water phase are as follows: water density and dynamic viscosity, the parameters pertaining to the sediment phase are: sediment density and particle diameter; and the riverine related characteristics are: width, depth and bottom slope. In addition to these parameters, particle incipient motion can be established by means of dimensional analysis. Once incipient motion is known a variety of methods can be used to estimate rates of bed load transport.

Bed forms occur in sandy soils and depend strongly on the flow regime. Since flow conditions within the St. Johns River are within the subcritical range, the bed forms are anticipated to be either ripples or dunes. However, this may not be the case for upstream regions in some tributaries immediately after storm events. Bed forms are not found in beds comprised of cohesive materials. An understanding of riverine bed formation is essential for a correct estimation of flow resistance which affects rates of bed load transport.

The behavior of cohesive sediments is more complicated than that of the granular material. Due to their small particle size, cohesive sediments resuspend more easily, remain in suspension for long time periods, and bind each other forming aggregates and flocculates. The sedimentation cycles of cohesive sediments involve erosion, advective transport, diffusion-dispersion, aggregation-flocculation, deposition, consolidation, and resuspension. While in suspension, cohesive sediments do not have a uniform vertical concentration profile. Suspended cohesive sediments in aquatic systems are normally found in a stratified state comprised of seven different layers. Counting from the top, these layers include: the mixed layer mobile suspension, the stratified mobile suspension, the fluccoline shear layer, the mobile hyperpycnal layer (fluid mud), the stationary mud, the deforming cohesive bed, and the stationary cohesive bed. Sediment dynamics in each of these layers is essentially different.

## Sediment Transport Modeling

For quantification of riverine dynamics, a number of two- and three-dimensional mathematical models have been developed. These models are based on different assumptions, have different input requirements, and their applicability and performance varies for each case. All of these models require information about the hydrodynamic field. The hydrodynamics of the system can be provided either from field measurements and/or historical records, or by numerical solutions of the hydrodynamic equations, i.e., mass continuity and momentum balance equations. All of the sediment transport models are based on a generalized mass balance equation.

## Cost Estimate

A preliminary cost estimate for development of a comprehensive sediment mass balance assessment in the Lower St. Johns River Basin is shown in Table 8. The cost for the study is divided into four main categories: field data collection, laboratory analyses, data interpretation and mathematical modeling. The cost estimates are based on a projected number of sixteen sampling stations (twelve in the tributaries and four in the main river). The monetary figures are rough estimates which can

**TABLE 8**
**COST ESTIMATES FOR DEVELOPMENT OF SEDIMENT BUDGET FOR THE LSJRB**

| ACTIVITY | | APPROXIMATE UNIT COST | NUMBER OF UNITS | TOTAL COST PER ACTIVITY |
|---|---|---|---|---|
| Field Data Collection | Per station: | $ 500 | 16 | $ 8,000 |
| Laboratory Analysis | Per sample: | $ 150 | 48 | $ 7,200 |
| Data Interpretation | Per station: | $ 500 | 16 | $ 8,000 |
| Mathematical Modeling | Hydrodynamics | $50,000 | 1 | $ 50,000* |
| | Sediments | $50,000 | 1 | $ 50,000* |
| Total | | | | $123,200 |

Note: (*) One-time cost item.

vary between different engineering/scientific companies and laboratories. More specifically, for the given budget the following services will be provided: the field data collection efforts will include waterways bathymetry, flow measurements and sediment sampling at pre-designated cross-sections. The laboratory analysis will be focused on the physicochemical properties of the aquatic sediments (both bottom samples and suspended material). Analysis of the sediment-bound contaminants is not included in this budget. The interpretation of the collected field data will provide a preliminary assessment of the sediment mass balance at each station, while the mathematical models will simulate the water/sediment dynamics throughout the entire LSJRB.

Preliminary Analysis

Based on the information and data from the previous sections, a preliminary analysis of the prevailing sedimentary conditions of the Lower St. Johns River Basin can be made. The bottom slope of the main riverine channel is very small. Thus, it is very unlikely to have any bed load discharge under normal flow conditions. Assuming an average bottom slope of 0.1 feet per mile, an average depth of $h = 3m$ and a specific gravity of sediments of 2.65, the critical particle diameter for erosion can be estimated using dimensional analysis. By trial and error, the critical particle diameter, $D_c$ (i.e., all particles with $D < D_c$ will erode), can be defined by using the well known Shields curve for particle incipient motion. This particle diameter under the aforementioned physical conditions was found to be approximately 0.6 mm. This conclusion does not apply to bank erosion and is not valid for cohesive beds. Bank erosion may occur due to various causes such as wave action from boat wakes, animal burrowing on the banks, human related activities, etc.

Erosion rates within the tributaries may differ from the rates in the main channel, since the gradient of the tributaries is higher. For example a rough estimate of the slope of the Etonia Creek gives approximately $S_o$ nearly equal to $1.5 \times 10^{-3}$, which is two orders of magnitude higher than the slope of the main channel.

A qualitative assessment of the riverine response can be established by using the relationship: $QS_o$ varies as $Q_s D_{50}$ where Q is the water discharge and $Q_s$ is the transport sediment discharge. Writing the same relation as follows: $Q_s$ varies as $QS_o/D_{50}$ it can be easily concluded that an increase in water discharge or bed slope will result in an increase of transported material, while an increase of the particle diameter will have the opposite effect.

For mud beds, typical values of critical shear stress for erosion range from 0.2 to 5.0 $N/m^2$. Assuming a velocity of 0.14 m/s (0.44 fps), and a bottom resistance $C_z$ = of 45 $m^{1/2}/s$, the bottom shear stress is estimated as nearly equal to 0.1 $N/M^2$ (less than the critical).

Measurable erosion is anticipated to occur after intensive precipitation events and during natural habitat disturbances, urbanization, highway construction, deforestation, etc. However, the effects of the latter will cease after the disturbance is stopped. Also, wind generated currents effect the rates of erosion.

Another situation that may effect sediment transport rates is the ephemeral streams subjected to cycles of wetting and drying. These streams can produce relatively high volumes of transported material during the first hours of a rainfall event.

Sedimentation conditions near the ocean inlet should be treated differently than in the rest of the river. Near the inlet, sediment composition is primarily sandy since strong currents wash out all of the fine material.

Recommendations

A comprehensive understanding of the dynamic processes and sedimentation budget of the Lower St. Johns River Basin requires detailed information of the prevailing hydrologic and hydrodynamic forces. Assuming that the hydrologic and hydrodynamic information is available, sedimentary field data and laboratory analysis should be conducted. The action plan should include the following items:

a. Identification of the most problematic areas based on reported shoaling, scouring, bank failures, etc.

b. Monitoring of bed changes in the problematic areas by bathymetric mapping, diver observations, sonar surveying, etc.

c. Placement of bottom sediment traps within the main river and in the major tributaries to identify any bed load discharge.

d. Establishment of a systematic suspended sediment data collection program. This will include weekly or monthly sampling of the water column for temperature, salinity, pH, and total suspended material. The stations should be located upstream from the mouth of each of the twelve main tributaries. The same data should also be collected at four locations distributed evenly along the length of main river. For identification of diurnal sedimentation patterns, some of the data should be collected on a continuous time basis.

e. Establishment of a special data collection program targeted to episodic events, as well as to areas with new development activities.

f. Analyses of the sediment samples and identification of the physical properties of the sediments and their vertical profiles.

g. Estimation of transported sediment volume from each tributary based on water discharge and suspended sediment data.

h. Development of a sediment budget model based on a simple mass balance relation, i.e., inflow - outflow = accumulation.

i. Development of an advection-dispersion type of mathematical model for simulation of sediment dynamics. Calibration and verification of the model would be based on the collected data.

## ENVIRONMENTAL IMPACT ASSESSMENT

The environmental impact assessment (EIA) is one of the most important tools that is available to assist managers to manage contaminated sediments. This assessment compares the "benefits" and "costs" of leaving a contaminated area untreated versus taking remedial action at the same site. The "cost-benefit" analysis should incorporate both ecological and human factors. The ecological factors should include: geography-geomorphology, hydrology/hydraulic/sediments, physicochemistry, and biology. The human factors include: sociology and culture, economy, and human health.

The general steps required for an EIA are:

a. Identification of the location, size, special features, and degree of contamination of the polluted site.

b. Identification of pollution sources.

c. Qualitative description of the ecological components which are expected to be affected by the contaminated site, whether it is left untreated or remediated.

d. Establishment of baseline data and information.

e. Quantitative analysis and simulation of the anticipated pre-remediation and post-remediation environmental conditions (including the no-action option).

f. Analysis of the projected, possible changes in the prevailing ecological conditions.

g. Assessment of the trade-offs between beneficial and detrimental effects (e.g., health, cost, aesthetics, etc).

h. Statement of monitoring methodology and criteria for assessing attainment of environmental objectives.

i. Development of alternative plans.

Several network diagrams and checklists are available that can be used to facilitate the environmental assessment process.

## SEDIMENT REMEDIATION

### Preliminary Assessment

Solutes in water are very rarely in a perfectly dissolved state. As a result, portions of the solutes attach to solid surfaces. Organic, hydrophobic-persistent chemicals, metals, nutrients, and radionucleides have a particularly strong affinity for solid surfaces. Fine grain sediments tend to absorb pollutants on their surfaces. These sediments deposit in quiescent sections along rivers, waterways, lakes and estuaries, or they are ultimately transported and settle in the oceans. Thus, depending on the dynamics of the ecosystem, pollutants in aquatic environments may be temporarily or permanently stored within bottom sediments. Natural forces (e.g., tides, wind waves, etc.) and human-induced activities (e.g., boating, dredging, etc.) may disturb the surficial sediment deposits and cause entrainment and release of the accumulated pollutants. Therefore, even if the source of polluting elements and chemical compounds has been eliminated, recovery of the ecosystem in affected areas may occur very slowly or not at all unless the contaminated sediments are removed. If untreated, contaminated sediments can cause environmental problems.

Both prevention of sediment-related pollution and remediation of contaminated sediments require an initial evaluation and a preliminary study plan. Such a preliminary plan involves three phases: reconnaissance, investigation pertaining to physicochemical and biological processes, and bioavailability assessment.

Once the extent and toxicity of the sediment contaminants has been established, the appropriate remedial action should be selected. Development of an appropriate remedial plan depends on the collection of the following information:

a. Site of contamination.

b. Source of contamination.

c. Type of magnitude of contamination.

d. Ecological, recreational and/or commercial value of the contaminated area.

e. Cost of the remedial action.

f. Estimated success of the proposed clean-up.

g. Anticipated benefits.

h. Existence, activity, and possible control of adjacent pollution sources.

Treatment

There are two basic remedial options for treatment of sediment-related pollution. The first option is to remove the sediment from the contaminated site, and the second option is to contain and/or treat the sediment in place. Sediment removal involves dredging and subsequent disposal of the spoil. Depending on the extent of the dredge/disposal operation, the dredging cost ranges from $2 to $4 per cubic yard. Besides its high operational cost, dredging may have an adverse near-field environmental impact. There are three options for disposal of dredged materials: ocean dumping, disposal in U.S. water, and inland disposal.

In-situ treatment of contaminated sediments may be accomplished by mechanical encapsulation, chemical treatment, diminution of contaminant concentration, or biological treatment.

A comprehensive management plan for sediments in an aquatic ecosystem involves a series of investigations, decisions, actions, and evaluations. Presently, there are no state regulations pertaining to management of contaminated sediments. In general, however, the components of such a comprehensive plan are:

a. Problem identification.

b. Initial evaluation of the level of contamination.

c. Source evaluation.

d. Assessment of the extent and importance of the problem.

e. Feasibility of remediation.

f. Determination of disposal or in-situ treatment alternatives.

g. Identification of potential problems associated with remediation procedures.

h. Establishment of testing protocol.

i. Assessment of potential solutions.

j. Design of implementation strategies.

k. Selection of remedial options.

l. Consideration of design.

m. Determination of available control measures.

n. Monitoring of water/sediment system including physicochemical parameters and toxicity tests both in-situ and in the laboratory.

## SEDIMENT QUALITY

### Sediment Quality Determination

#### Quality Risk Indices

Traditionally environmental indicators were limited to water quality. Recently, however, numerical indicators for aquatic sediment have been under development.

The U.S. Environmental Protection Agency (EPA) has developed a range of contamination levels due to different elements and compounds. For estuarine sediments EPA has suggested two quantitative indicators: acute sediment toxicity and number of different chemical contaminants in sediments. For assessment of metal enrichment attributed to anthropogenic activities, the Florida Department of Environmental Protection uses the metal-aluminum ratio technique which compares the metal-aluminum ratios in carbonate rocks of uncontaminated ecosystems with those from areas suspected of being polluted. Aquatic pollution can be effectively assessed by means of biotic indices which refer generally to species diversity, similarity and stability.

Many of the pollutants found in aquatic ecosystems are toxic and can cause acute chronic health problems to humans through the food chain. Lipid soluble pollutants (i.e., pesticides, PCBs, dioxins, etc.) in the water-sediment system can be magnified, passing through the aquatic food chain into edible fish. Aquatic animals can also be seriously affected by pollution sediments.

## Recommendations

The Lower St. Johns River Basin is a very diverse system with a variety of ecological and land-use characteristics. A broad attack on the problem of sediment contamination would be a very complex and possibly financially prohibitive task. Before pursuing any remedial action, the following steps are recommended:

a. Select any highly contaminated area based on consideration of the surficial sediment composition. Since pollutants have an affinity for fine sediments, aquatic bottoms comprised of silt, clay, and organic matter generally have higher levels of contaminant concentration than those comprised of sandy soils. Therefore, in order to estimate contamination effects, a site with high percentages of silt-clay fractions should be selected.

b. Identify all of the current and historical point and non-point pollution sources (domestic, industrial, agricultural) by using GIS, permit information, etc.

c. Once the sources have been identified, quantify their relative importance and determine whether each is presently active or inactive. This will include the types of chemicals used and/or produced, values of discharges and/or emissions, the degree and type of effluent treatment, etc.

d. Survey the site(s) and determine the degree of contamination.

e. Decide whether remediation is desirable/necessary based on level of contamination.

f. Determine the objectives of the remedial action and consider the probability of successful control of sources.

g. If the present (active) pollution sources cannot be controlled, any remedial action will ultimately fail; therefore, the only appropriate action in this case is to monitor and document contamination trends.

h. Suggest approaches for control of the active pollution sources; i.e., compliance/enforcement of EPA/DEP regulations, permitting, increased level of effluent treatment, etc.

i. If the pollution sources can be controlled, a remedial action plan can be developed.

j. Along with any remedial action, a monitoring plan should be established for the selected site that will include physical, chemical, and biological sampling and testing. Emphasis should be placed on bio-availability and bio-accumulation tests. The monitoring plan should include sampling of both sediments and ambient water for analysis of nutrients (P and N); toxic metals (As, Cd, Cr, Cu, Hg, Pb, Se, Zn); chlorinated phenols; PAHs; PCBs; chlorinated pesticides; and coprostanol.

k. Short-term and long-term, temporal and spatial variations of contaminant concentrations should be documented and analyzed for identification of any pattern or trend of contamination changes.

l. Set criteria for evaluating the success of the ecological improvement plan.

Existing Environmental Conditions

Pollution Sources

The riverine system of the Lower St. Johns River and its tributaries is a very complex system whose pollution levels are extremely hard to describe. The St. Johns River is a "black water" estuary; i.e., the water has a dark brownish color due to high loads of tannin from decomposing forest leaves and suspended solid particulates. Because of the resulting reduction in light penetration, aquatic plants grow only in the shallows, and under natural conditions the system is a net consumer of oxygen.

The Lower St. Johns River Basin (LSJRB) system is the receiver of a variety of pollutants from point and non-point pollution sources. A number of these sources are discharging into the tributaries, where weak circulation patterns prevent efficient flushing of the pollutants. There are approximately 360 domestic and 49 industrial permitted sources discharging approximately 2,009 million gallons per day (MGD) into the surface waters of the LSJRB. The majority of these sources are located in the Jacksonville metropolitan area and discharge either directly into the main river or in some of its tributaries.

Of these effluents, 95.23% is released into the St. Johns River basin while the remaining 4.77% is discharged into the other sub-basins as follows: Etonia/Rice Creek - 2.49%, Black Creek - 0.64%, Trout River - 0.50%, Intracoastal Waterway - 0.44%, Ortega River - 0.27%, Arlington River - 0.19%, Broward River - 0.16%, Dunns Creek - 0.04%, Crescent Lake - 0.03%, Julington Creek -0.02%, and Sixmile Creek 0.003%. Besides the open water effluent discharging, there are approximately 73 point sources discharging into the groundwater. These sources release 1.395 MGD (million gallons per day); i.e., 0.07% of the total amount of point source discharges. It is believed, however, that the point sources account for only 10% of the pollution, with 90%

attributed to non-point sources. The non-point pollution is related mainly to urban growth.

In spite of the removal of raw sewage outfalls and untreated paper mill discharges by 1978, the water quality in metropolitan Jacksonville is still poor. Violations of dissolved oxygen and coliform standards were often observed during the 1980's. The FDER's 1990 305(b) report reiterated the fact that the main stem of the river near downtown Jacksonville is of poor water quality. In the same report, water quality was listed as "poor" in the Ribault River, Moncrief Creek, Wills Branch, Ortega River, Cedar River, Strawberry Creek, Doctors Lake, and the Rice Creek/Etonia Creek system. The rest of the riverine system was found to be in either fair or good condition. An earlier report by FDER (1975) suggested that the majority of tributaries in Duval County suffer from low dissolved oxygen, odor, high coliform count, and high nutrient concentrations.

Industrial activities in Duval County (e.g., Cedar River) have resulted in high accumulations of heavy metals and organic priority pollutants, particularly in sediments. Disposal and storage of hazardous industrial and military wastes increased the potential of surface water contamination and have had a significant impact on various sections of the LSJRB. Under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, eight sites in the Lower St. Johns River Basin have been targeted for clean-up by the EPA's Superfund Program. Seven of these sites are in Duval County, and one is in Volusia County. In addition to the Superfund sites, as of September 30, 1989, nine military installations in Duval and Putnam Counties, with a total of 106 contaminated sites, have been identified for remediation by the Defense Cleanup Programs.

Dredging Activities

The St. Johns River estuary is associated with four main waterway systems. These are: the main river waterway from Sanford to Jacksonville, the unfinished Cross Florida Barge Canal, the Jacksonville Harbor which extends from downtown Jacksonville to the Atlantic Ocean, and the Atlantic Intracoastal Waterway. The main river waterway has channel improvements between river mile 169.5 above Lake Monroe, and river mile 24.9 at downtown Jacksonville. Currently the channel is 34 ft deep and 200 ft wide from the ocean to Jacksonville, 13 ft deep and 200 ft wide between Jacksonville and Palatka, 12 ft deep and 100 ft wide between Palatka and Sanford, and 5 ft deep and 100 ft wide between Sanford and Osteen bridge upstream of Lake Monroe. The main river waterway is connected to the Jacksonville Harbor waterway at the Florida East Coast (FEC) Railroad Bridge at river mile 24.9. The Jacksonville Harbor waterway is 30 ft deep and 300-600 ft wide between FEC Railroad Bridge and Commodore Point. Then the waterway increases to 34 ft deep and 590 ft wide via Terminal Channel to river mile 20. Downstream from that point the waterway continues at 38 ft deep and 400-1,200 ft wide to the Atlantic Ocean.

The U.S. Army Corps of Engineers oversees an active dredging program in the estuarine portion of the St. Johns River system. Dredging operations are mainly conducted between Mayport and downtown Jacksonville. The dredged material is either used for beach nourishment, or disposed of at nearby dredged material disposal sites (i.e., Buck Island, Quarantine Island, Blount Island) or in the ocean. Dredging operations follow an approximate 18-month cycle.

In order to evaluate the impact of dredging on the river's ecosystem a monitoring program should be established. Past data on the environmental conditions of the system must be compiled and used as baseline information. Since the major pollutants resulting from these marine activities include fuel byproducts, solvents and paints, it is relatively easy to identify the contamination problems and sites suspected of potential contamination. In order to evaluate seasonal effects, monitoring should be conducted on a seasonal basis (i.e., twice per year). However, if this is cost-prohibitive, monitoring can be limited to an annual basis. However, depending on the data evaluation new stations may be added (if new contamination problems arise) or monitoring of old stations may be reduced or deleted if the pollution source ceases to exist and the conditions of the area under surveillance are back to normal.

In the Lower St. Johns River Basin emphasis should be based on the metropolitan Jacksonville area where most of the ship/boat industry related activities are concentrated. Past data collection studies already documented the presence of trace metals and organic compounds (PAHs, PCBs and coprostanol) in this general area.

## Previous Studies

To assess the environmental conditions of the Lower St. Johns River Basin, a number of water and sediment quality data have been collected in the past. The data involves analyses of water-sediment physicochemical characteristics and estimations of nutrients, heavy metals, and organic pollutants.

Although data describing specific levels of sediment chemical contamination are very limited, it is apparent that anthropogenic pollutants have accumulated in the surficial sediments in the LSJRB. The most comprehensive studies on sediment quality in the Lower St. Johns River Basin are the following six:

a. Dames and Moore Maintenance Dredging Study, 1983.

b. Mote Marine Laboratory Study, 1988.

c. Jacksonville Port Authority Study, 1988.

d. Coastal Zone Management, FDER, Study, 1988.

e. University of Florida Study, 1991.

f. Bio-Environmental Services Division Laboratory and SJRWMD (1989-91).

Within a two year period, the Mote Marine Laboratory and the FDER studies analyzed data from over 120 sites throughout the lower basin. The data included physical characteristics, nutrients, heavy metals, and organic priority pollutants. Whenever possible, the data were compared with existing standard limits for determination of the pollution level. Metal concentrations were compared using aluminum as a reference element.

Study Findings

Although the existing sediment quality data for the LSJRB is limited, it provides a preliminary basis for planning future sediment management. Starting with the Dames and Moore Study in 1983, the sediment quality database extends to 1991 with the majority of the data collected during 1988. In spite of the fact that a nine-year period for data is relatively short to fully assess the dynamics of sediment contamination or to establish a detailed trend analysis, general conclusions can be made.

The majority of available data are for sediment samples taken from the SJR in the Jacksonville metropolitan area. This region has experienced anthropogenic impacts resulting from intensive urbanization and industrialization. Data were also collected in several tributaries, where low flow conditions (relative to the river) promote sedimentation and subsequent accumulation of toxic substances in the bottom sediments. Based on the six independent sediment quality studies, it is clear that the most contaminated section of the LSJRB extends from Jacksonville upstream to Julington Creek. One of the areas with the highest metal enrichment is downtown Jacksonville. Comparing the data collected by the various studies with the sediment quality criteria given by EPA it is evident that many sites are moderately to heavily polluted by trace metals. Enrichment by Cr, Cd, Hg, Ni, and Zn were found at Commodore Point, Talleyrand, and the mouth of the Trout River. The study by the Coastal Zone Management Section, indicated enrichment from only mercury. A year later, the BES Division found elevated levels of Cd, Cr, Pb, and Zn in the mouth of the Trout River. In the Blount Island area, Dames and Moore found enrichment in Cd, Cr, and Hg; the Jacksonville Port Authority noted enrichment in Cr and Zn, while the Coastal Zone Management Section study showed increased Hg levels. In spite of the slight differences in the type or number of toxic metals, the three studies of tributaries consistently found high metal enrichment in all stations except the Broward River. The Coastal Zone Management Section found no metal contamination, at that location. These differences indicate that contaminant level at the same site can vary. However, all of the studies conducted between 1982-1991 found that the sediments have been contaminated by toxic metals. This indicates that either pollution sources are still active and contributing heavy metals to the system, or that deposited sediments are rarely subject to resuspension events, or both of the above.

With respect to organic pollutants, all of the studies support the fact that the area from the Trout River to Julington Creek is extensively contaminated by PAHs and chlorinated pesticides. Contamination by PCBs is present, but to a lesser extent than by other organic compounds. Negligible levels of Cl-pesticides and PCBs were found by Dames and Moore (1983) and Coastal Zone Management, FDEP in this part of the system. However, both studies were concentrated in the main channel instead of the tributaries or other protected site.

In order to assess the environmental state of the system, the individual and cumulative contamination factors were applied for the most recent data (1991) of the Bio-Environmental Services Division Laboratory. The cumulative contamination factor which is based on the heavy metal and PCB concentrations is indicative of the environmental conditions. From these data it is evident that out of fifteen sampling stations, five were highly contaminated, one had a considerable degree of contamination, three were moderately polluted and six had a low degree of contamination. Data for the rest of the sampled stations showed negligible contamination. Exceedence of the EPA sediment quality criteria, high individual and cumulative contamination factors, elevated metal:aluminum ratios, were indicative of moderate to high anthropogenic contamination at various sites of the LSJRB. Although the exact environmental impact cannot be assessed based on the existing data, it is reasonable to believe that violation of these environmental criteria, regardless of their objectivity, may have serious negative effects on the ecosystem.

## Future Sediment Quality Data Collection

### Sampling Needs

To determine the status and health of an aquatic ecosystem, it is important to collect and analyze both long-term water quality and sediment quality data. Water quality data is useful because it provides information about short-term conditions. Indeed, water circulation and mixing caused by tides and winds can rapidly change water quality conditions; thus, only short-term effects can be detected. Interpreting short-term water quality data is difficult because water quality changes quickly as a result of numerous factors, e.g., rain storms, tides, seasons. On the other hand, sediment quality is indicative of long-term, cumulative impacts and conditions. Indeed, analysis of undisturbed bottom sediment layers can provide a detailed short-term (surficial samples) or long-term (core samples) history of pollution. By estimating particle deposition rates and analyzing sediment quality characteristics layer-by-layer, a chronological relationship between anthropogenic events and sediment contamination can be developed.

Examination of the top few centimeters of sediments provides information about the recent history of contamination. This type of data is particularly useful for active (movable) bottoms, since it can establish spatial sediment-contaminant distribution. All of the studies reviewed in the LSJRB were focused on the top layer and not on sediment core profiles. Sediment quality data can be combined with data pertaining to documented or suspected point and non-point pollution sources so that a cause/effect relationship can be developed. This method relates changes in chemical components (e.g., toxic metals, organic pollutants) to changes in effluent discharges or use of adjacent watersheds. In case a pollution source ceases to exist, periodic or continuous monitoring of sediment quality will document the rate of sediment clean-up by natural processes. Based on such information, decisions can be made with respect to management actions that should be taken to remediate contamination, permit point sources, or control non-point sources.

A database containing all sediment data should be developed to facilitate the analysis. This database should include the exact location of the sampling station, the date the sample was taken, the prevailing environmental conditions during the sampling event, qualitative and quantitative contaminant analyses, and, if possible, identification of the source. Based on the spatial distribution of the sampling stations evaluation of the impact of point and non-point pollution sources should be assessed. Comparing data on pollution sources to historical sediment quality records will permit a determination of environmental trends. Cross-correlations of the sediment quality data with other pertinent data (e.g., anthropogenic activities, weather pattern, episodic events, etc.) should be used to develop cause/effect relations. Establishment of site-specific relations for each contaminant or group of contaminants (e.g., nutrients, trace metals and organic compounds) can lead to the development of management decisions pertaining to control of pollution sources or to remediation of sediment quality. The database should be user-friendly, have a quality control/quality assurance system for data input, and provide quantitative sediment quality indices for easy comparison and evaluation of the data.

Sampling Locations

Based on the number of contaminated sites in each sub-basin, a preliminary prioritization for protection or remediation of LSJRB can be made (Table 9). The

Cedar River sub-basin, the Trout River sub-basin, and sites near the Jacksonville downtown area of the SJR sub-basin are the most seriously contaminated areas and may require remediation.

## TABLE 9

## PRIORITIZATION OF REMEDIATION/PROTECTION OF LSJRB SUB-BASINS BASED ON SEDIMENT QUALITY DATA

| SUB-BASIN | TRIBUTARY OR LOCATION WITH SEDIMENT QUALITY PROBLEMS |
|---|---|
| Julington Creek | Julington Creek<br>Durbin Creek |
| Rice Creek | Rice Creek |
| Crescent Lake | - |
| Black Creek | - |
| Dunn Creek | - |
| McCullough Creek | - |

Note: The ranking is from highest priority to lowest priority

Based on the existing data, application of trends analysis is not feasible since sediment quality information is very sparse and most stations have only been sampled once, sample collection and analysis was not uniform for all of the studies, and detailed information on the prevailing hydrologic conditions is missing. Since so little data is available there may be other contaminated locations that have not been identified.

For a comprehensive understanding of sediment quality dynamics a continuous monitoring program must be established. The program should emphasize establishment of trends, parameter correlations, and cause/effects relationships rather than simply collection of sediment samples and estimation of their contaminant content. Sampling stations can be added or deleted from the monitoring program depending on documented or suspected environmental degradation or improvement, respectively.

Sampling locations for future studies should preferably be selected using the following three criteria: a) existence of available sediment quality data and information, b) high levels of pollutant concentrations in water or sediments, and c) areas with documented or suspected contaminant sources. Data should be collected twice per year (dry and wet seasons) every other year for each group of stations. For effective interpretation of the data, hydrologic conditions during the previous ten to fifteen days should be also collected. The hydrologic data will help to assess pollution inputs from watershed drainage. Based on the existing sediment quality data, the following sampling schedule is suggested:

Year 1: Station 1A - Confluence of Cedar/Ortega Rivers (1)
Station 2A - Mouth of Ortega River (2)
Station 3A - Upstream in Cedar River (2)
Station 4A - Mouth of Julington Creek (1)
Station 5A - Upstream in Durbin Creek (2)
Station 6A - Rice Creek (1)
Year 2: Station 1B - Mouth of Broward River (2)
Station 2B - Mouth of Trout River (1)
Station 3B - Confluence of Trout and Ribault River (2)
Station 4B - Main River off NAS (1)
Station 5B - Mouth of Arlington River (1)
Station 6B - Upstream in Pottsburg Creek (2)

Such a schedule capitalizes on existing information and will provide an effective picture of the sediment quality conditions in the LSJRB. Numbers in parentheses next to each sampling location indicate the first and the second choices if the number of stations must be reduced by half due to budgetary constraints.

For each site three samples should be collected from the surficial layer (top 5 cm) and analyzed for nutrients, heavy metals, and organic compounds according to EPA/FDEP approved methods. During the first sampling period a core sample should also be obtained (top 50 cm) in order to establish the history of sediment pollution.

A monitoring plan, like the one described above, will provide an assessment of the effects of remediation or permit changes and would help to develop effective management decisions for the Lower St. Johns River Basin.

## Sediment Sampling Procedures

Data collection procedures are very important for the ultimate success of an environmental project. It is believed that more errors are introduced by improper sampling techniques and handling of the samples than by the actual analysis of the samples in the laboratory. Among the typical data collection designs are random sampling, weighted random sampling, systematic sampling, and fixed location sampling.

In a random sampling design, sites are selected on a random basis and equal importance is assigned to each site. This design is very effective whenever the physicochemical or biological parameters under study are homogeneously distributed throughout the contaminated area. The method is commonly used for reconnaissance surveys in areas where little or no data are available, indicating that random sampling is the only available sampling choice.

Weighted random sampling is an improvement on the effectiveness of the previous method but requires some preliminary data pertaining to the physicochemical and biological conditions of the area under study. Based on this preliminary data, the area is divided into homogeneous sub-areas, and sampling sites are distributed according to the significance of each sub-area. In this way, only sites within the sub-areas are selected on a random basis.

In the systematic sampling design, sites are evenly distributed through the project area. This method is simple to implement but may produce biased information if the sediment distribution is non-homogeneous.

Fixed location sampling is restricted to fixed, preselected sites. Selection criteria for these sites include: accessibility, number and type of point-sources, etc. Thus, information is limited to only the sampled sites, and no statistical inference can be made for the areal distribution of the data.

After the sampling sites are selected, and data collection is initiated, the following steps of action are recommended:

a. Examine initial data to identify any spatial distribution of contaminants.

b. Examine the effectiveness of sampling devices over the range of expected natural conditions.

c. Collect replicate samples.

d. Perform quality control on collected data.

e. Perform statistical analysis on the data to assess the effectiveness of the selected sampling locations, number of sites, frequency of sampling, etc.

Sediment sampling is commonly divided into suspended sediment sampling, surficial sampling, and deep-bed sampling. Suspended sediment samples are indicative of the present conditions of the estuarine system. Surficial sampling is limited to the upper 1 to 3 cm of the sediment bed and is indicative of recent environmental conditions. Deep-bed sampling can be on the order of a few meters and is useful for the establishment of historical changes in pollutant concentrations.

Sampling of suspended matter is a more difficult task than sampling of bottom sediments. A typical suspended sediment trap consists of an anchor, a buoy, a support line, and cylinder acting as traps.

Surficial and deep-bed sediment sampling is accomplished by certain devices that can be separated generally into three categories: grab samplers, corers, and dredges. Grab samplers collect surficial sediments; corers collect both surficial and deep-sediment samples; and dredges collect large amounts of well-mixed, near-surface sediments. The advantage of corers over the other two devices is that corers obtain the least disturbed samples.

Once the sediment samples have been collected, a complete analysis should follow, including: physical analysis (i.e., manual and instrumental selection of water and sediment phases), chemical extractions and analyses of pertinent parameters, statistical manipulation of data, and mathematical modeling of the water/sediment dynamics and pollutant exchange.

Once a sediment quality database has been established, development of a set of sediment quality criteria (SQC) is feasible. These SQC must relate sediment-bound pollutant concentrations to adverse biological effects. There are several available approaches that can be utilized for the establishment of SQC.

The most effective of these approaches are the ones that utilize a wide range of physicochemical factors for different contaminants to assess bioavailability and bioaccumulation of benthic and water column communities.

For effective management, focused on environmental protection, remediation, or enhancement of an estuarine system, operational decisions should be made based upon a variety of information sources including but not limited to mathematical modeling, field and laboratory data, statistical analyses of the data, sediment quality criteria, etc. This information should incorporate physicochemistry of the water/sediment system and biological effects as related to the prevailing physicochemical conditions.

## Sediment Quality Modeling

While considerable scientific inquiry has centered on dissolved contaminants and their impacts on aquatic ecosystems, less is known about sediment-bound pollutants. However, polluted sediments can be a major source of aquatic contamination. Assessment of the potential for environmental impact caused by contaminated sediments requires simulation of dynamics and chemical behavior of sediment-bound pollutants specifically because sediment-bound pollutants behave differently from dissolved pollutants. Mathematical models can be used to describe sediment transport and distribution. Since the transport of particulate-bound pollutants is ultimately related to the transport of solid particles, both physical and chemical properties must be examined. Some of the physicochemical properties, e.g., diffusion coefficients, partitioning coefficients, etc., must be measured for each sediment type. How well the simulated system predicts actual conditions depends on the validity of the assumptions made and the similarity between the natural and the laboratory conditions under which the physicochemical coefficients were estimated. For example, experiments for estimation of the rates of erosion have shown that results can vary substantially by using either remolded or naturally deposited beds. The former bed erodes with a linear rate while the latter erodes with an exponential rate. Increased or decreased salinity in the water used for the experiments can also vary the erosional rates.

Modeling Physical Processes

The first step for any sediment contamination study is to quantify the sediment budget. Various methods and approaches are used to prepare a sediment budget. All of these methods are based on the simple concept of sediment mass balance, i.e., (sediment inflow) - (sediment outflow) = (change in sediment volume). Application of the mass balance principle requires definition of the quantities of sediment on the natural boundaries of the system under consideration. For large systems, since the areal distribution of the sediment mass is not uniform, the system is subdivided into a number of subareas where sediment distribution is assumed to be constant. Then, the mass conservation principle is applied for each individual subarea. The major physical processes required for quantification of sediment movement include advection by the moving water, dispersion and molecular diffusion, and erosion/deposition. These include the processes related to resuspension or internal loading, including the effects of surface wind waves.

Modeling Chemical Processes

For sediment-bound pollutants, the fate of a pollutant can be assessed by using a coupled approach, i.e., by coupling the sediment mass balance with the pollutant mass balance equations.

To model the chemical reactions which occur in an aquatic ecosystem, the following information is usually required:

a. Quantitative data related to the physicochemical parameters of the water-sediment system.

b. Thermodynamic and stoichiometric data referred to the equilibrium chemical state of the system.

c. Analytic expressions for the kinetics of the system; i.e., definition of the instantaneous rate of change given its present state.

Assessing the potential impact of pollution on an aquatic ecosystem depends on the measurement of pollutants such as heavy metals, oils, chlorinated hydrocarbons, pesticides, other organic priority pollutants, and radionuclides. Modeling of the chemical behavior of these toxic substances can be divided into three categories:

a. Physical processes, including: adsorption and volatization.

b. Chemical processes, including: oxidation, photolysis, hydrolysis, ionization, and complexation.

c. Biological processes, including: biodegradation, uptake, and excretion.

Statistical Modeling

Besides the deterministic methods for assessment of pollutant transport and exchange between water, sediments and biota, there are also some statistical approaches that are very useful for environmental impact assessment. These approaches provide data regarding the frequency of occurrence and duration of pollutant concentrations associated with certain hydrological events (e.g., surface runoff, high winds, etc.) or human actions (e.g., dredging, water treatment operations, etc). These data, which are mostly site-specific, are subsequently used to determine the potential and chronic impact of pollutants on aquatic biota and eventually on humans. Statistical approaches for modeling sediment quality include geostatistics, time series analysis and empirical models.

Geostatistics can be defined as a set of statistical procedures which help describe the correlation of spatially distributed random variables, and perform interpolation and real estimations for these variables. Most environmental data are usually collected in the form of time series. Time series analysis helps to characterize the homogeneous memory pattern (i.e., relationship between present and past observations). Empirical models are derived from a large amount of data and define normal pollutant concentrations based on a limited number of control parameters. These control parameters are usually chosen according to their relative importance regarding sediment-pollutant trace chemistry.

In spite of the usefulness and simplicity of the statistical models, they must be used with caution. Unless all of the conditions under which the correlations of these models were established are satisfied, the results may be misleading and inaccurate. For this reason, development of a good statistical model requires a wide breadth of data and a good documentation of its assumptions and applicability conditions.

## HISTORICAL DATA AND DATABASE MANAGEMENT WITHIN THE JACKSONVILLE DISTRICT CORPS OF ENGINEERS

Within the Jacksonville District U.S. Army Corps of Engineers, there are several forms of data and database management in use.

The first is the historical perspective.

The St. Johns River has been included in many River and Harbor Acts dating from the latter part of the 19th Century. These earlier reports are sparse by today's standards, but still give an indication of the condition of the river at that time. Later reports covering construction projects include more detailed data, including survey information and geotechnical data. Limited hydrographic survey data of the St. Johns River dates back to 1853.

Locating this information is difficult. The district office maintains a records holding area where old data is stored. A database of this information is maintained on a local area network (LAN). Problems exist because only major items are listed on the LAN. It is up to the user to survey the boxes and find pertinent data. Paper and microfiche maps and surveys pertaining to some of these project reports are also stored in the district office.

The second storage area is existing databases. The focus of this report is on the large databases currently in use by personnel in the Jacksonville District.

These databases are divided into several areas:

* Water Quality
* Water Management
* Regulatory
* Survey
* Administrative

There is one geographical information system (GIS) related database currently being used on the Planning Division's Coast of Florida Erosion and Storm Effects Study. Others are planned but currently not on line.

WATER QUALITY

Currently, the Jacksonville District uses three water quality storage systems. These are STORET, WATSTORE, and LATTIS.

The STORET system is maintained by Environmental Protection Agency. The water quality data is stored by parameter, but it has been reported that it is difficult to store data in this database since each location must be completely and properly defined before data for that location can be stored.

The WATSTORE is maintained by U.S.Geological Survey (USGS) and is available for usage, but not preferred by the Corps.

The Laboratory Analysis Test Tracking Information System (LATTIS) is the preferred system for the Corps. LATTIS is a pc LAN computer application which was purchased to replace the older Automated Upward Reporting and Analysis System (AURAS) which operated on the Harris mini-computer.

Coupled to the LATTIS is the LATTIS Results Analysis Module (LRAM). LRAM is designed to provide an easy-to-use method of transferring data on completed tests to district locations. The system also provides a flexible mechanism to select and report test results for an entire project or selected sampling stations and tests from one or more projects. LRAM is a Foxpro-based program operating on the Planning Division LAN. There are two sets of programs which are utilized under LRAM. The first set of programs resides on the South Atlantic Division (SAD) Laboratory LAN which creates year-to-date test results for districts and provides the district with these year-to-date analyses. The second program allows the district to analyze raw SAD data. District inputs include identification and location. Sample output includes date, time, depth, temperature, and 44 different parameters including DO, BOD, and metals.

Under the District's Construction-Operations Division, the Aquatic Plant Control Section maintains the "454" Computer Program. This program provides a 15-year database of all aquatic plant control activities in the state of Florida. The program is Foxpro-based and is maintained on the Construction-Operations LAN. Field offices can access the data, but only on a read-only basis. Information contained in this database is waterbody, herbicide use (gallons or pounds per day), acres controlled, and crews used and cost.

WATER MANAGEMENT

Water management information is utilized through WATSTORE which is managed by the USGS. This system provides modem connection or CD-ROM for water management purposes at gage sites throughout the district. Daily mean values of flow or stage are available as well as instantaneous data, published every 15 minutes.

REGULATORY

Our Regulatory Division maintains the Regulatory Analysis and Management System (RAMS). RAMS is an informix-based system developed by the Corps when the Harris mini-computers were phased out. The district has been using RAMS since 1989. The structure is divided into 87 areas with 100 tables and 3000 data fields.

The Jacksonville District utilizes 25 of these areas with a potential of 932 data fields. Permit data stored on this system includes information on the location, individual, work, alleged violation, compliance, enforcement, status, surveys, mitigation and acres impacted, filled or restored for wetlands, violations and mitigation wetland.

The Corps is currently rewriting the structure to RAMS2, which may be portable to Oracle. Beta testing is currently underway.

Permit files were started in 1899 under the law, but district files only go back to the 1920's. Historical records date from the late 1970's. Current automated records date from 1983.

SURVEY

The District Survey Branch maintains a monuments database with approximately 30,000 records. The data is stored in vertical and horizontal configuration (x, y, and z). The system is Foxpro-based and can be converted to ASCII. The data is free to the public, but the Government does not take responsibility for data errors.

Our Survey Branch also maintains digital hydrographic data since 1984 and digital topographic data since 1987. These surveys are referenced in state plane coordinates. An inhouse database showing the job number and description is maintained in the Survey Branch.

Paper copies of maps and field books of previous jobs are located in the Records Holding Area of information management. The bathymetric charts and field books are government property and can be loaned only.

## ADMINISTRATIVE

The Aquatic Plant Control Section also maintains the Natural Resources Management System (NRMS). This is a Dbase file used to log visitation, hours, dates and lockages at Corps recreation sites where a fee is collected.

The Topographically Integrated Geographic Encoding and Referencing System (TIGER) is a U.S. Bureau of Censes file which is in Dbase-format. This data is census data and contains line files which are a series of vector descriptions.

The Corps' Information Management office maintains the Local Area Network (LAN) for all offices. The LAN is used for many purposes, but the majority of the uses are for storage of software. The Project Management System is also stored on the Project Management LAN and contains project and financial data.

## GEOGRAPHIC INFORMATION SYSTEM

Currently, one operational ARC/INFO-based GIS exists in the district. This system is being developed by the Planning Division's Coast of Florida Erosion and Storm Effects Study. The purpose of this study is to evaluate coastal processes on a regional basis and develop a comprehensive body of knowledge and data on coastal processes.

GIS was selected because it was the best means for organizing various geotechnical, economic, coastal engineering and environmental data sets. Much time has been spent developing the hardware and software (technology), database design, digital database population, data base management (maintenance) and personnel including training. ARC/INFO software was selected for use since it met project needs and is a system already in use by several other state and county agencies. SPARC workstation and peripherals were purchased for running the software and storing the data bases.

Data themes and associated primary coverages for data used are shown in Table 10.

# TABLE 10
# DATA THEMES AND ASSOCIATED PRIMARY COVERAGES

| DATA THEMES | ASSOCIATED PRIMARY COVERAGES |
|---|---|
| Control | Geodetic |
| | Range |
| | Data reference zones |
| Aerial | Photo index |
| | Photography |
| | Imagery |
| Beach and navigation projects | |
| Survey | Beach profile |
| | Bathymetric Survey |
| | Contour |
| Infrastructure | Parcel |
| | Parcel Data |
| | Address Data |
| | Owner Data |
| | E-Street (street edges) |
| | C-Street (centerline) |
| | Building footprints |
| | Building measurement |
| | Parks |
| | Beach count |
| | Armor |
| Environmental | Protected Marine/Terrestrial Wildlife |
| | Common Marine/Terrestrial Wildlife |
| | Protected Coastal Vegetation |
| | Vegetation |
| | Hard ground |
| | Hard ground habitat quality |
| | Artificial reef |
| | Dune/wetland habitat |
| | Magnetic Survey |
| | Anomaly |
| Shore | Shoreline Base Map |
| | Long-term shoreline change rate |
| | Historic shorelines |
| | Generated shorelines |

TABLE 10 CONTINUED

| | |
|---|---|
| Geotechnical | Borrow site |
| | Sand Isopach map |
| | Core Boring |
| | Core Data |
| | Beach Grab Sample |
| | Grain Data |
| | Probe Borings |
| | Beach Compaction |
| | Seismic Track |
| Administrative | Administrative boundary |
| | Jurisdiction |
| | Census tract block |
| | Zip-code |

## GEOTECHNICAL

Core borings and logs are tied to projects. Paper copies of this information are stored in the files and date back to the 1940's. There is no database which currently contains core boring log records.

## CONCLUSION

The Corps has several large databases, but actually only a few might be applicable to the St. Johns River. Use of information from the Regulatory RAMS system, Water Quality LATTIS program, and Aquatic Plant Control "454 program" data could be useful for identification of known water quality conditions. Limited hydrographic and topographic digital survey data are now available. Benchmark data are also available.

The use of GIS for database development is increasing in the Jacksonville District. The Coast of Florida Study is underway and other potential users are finalizing their plans for systems.

# CONCLUSIONS

This phase of the St. Johns River, Florida Feasibility Study presents the findings of experts hired to assess and quantify water quality related conditions and the development of evaluation tools for assessing the problems of the lower St. Johns River. If there is interest in further study, the contractors recommended the following areas in which to assess.

The scope of local interests regarding single purpose water quality management planning is outside of the traditional Federal authorities provided by Congress to the Corps of Engineers. However, the Corps has technical capabilities for undertaking regional water quality evaluations needed for improved water resources management functions normally conducted within the framework of a multi-purpose feasibility study.

The next steps will be collection of the background data necessary to build a model for an evaluation tool and the model itself.

## BACKGROUND DATA

An inventory and preliminary analysis of existing networks of first and second-order positional points in the study corridor indicated that additional horizontal and vertical control will be needed in order to provide a complete reference system for extending control to any evaluation tool. Final plans could then be developed for extending the network.

An extent of tide study would be useful for delineating boundary conditions in the hydrodynamic models. The study includes simultaneous water level observations in adjacent tidal and non-tidal reaches, supporting bathymetric surveys, and current and velocity studies.

Also in support of the hydrodynamic effort a variety of field measurements must be obtained at various locations with the estuary. To establish boundary and initial conditions for model calibration and verification, measurements of tributary discharge, pollutant loading, water level, water velocity, river wide bathymetry, salinity, temperature, and wind velocity are needed.

Ground water data would be useful for delineating movement of groundwater into the St. Johns River. However, the low flow estimated by USGS of leakage from the Floridan aquifer, indicates that this effort is not needed at this time.

Water quality monitoring is needed to calibrate any water quality program. Minimum parameters needed are: ammonium-N, nitrate + nitrite-N, total Kjeldahl N, total phosphorus, orthophosphate, dissolved oxygen, dissolved silica, total suspended solids, total dissolved solids, sulfate, chloride, chlorophyll A,B,C, and pheophyton, total organic carbon, alkalinity, turbidity, and color.

## MODELING

Three estuarine hydrodynamic models were recommended as appropriate for the Lower St. Johns River Estuary System as follows:

a. RMA-10 and associated models. Author: Ian P. King

b. CH3D. Author: Y. P. Sheng

c. ECOM. Authors: Alan F. Blumberg and George L. Mellor

The three models selected are three-dimensional models with corresponding two-dimensional and vertically averaged capabilities. Each of the models has the capability for interface with sediment transport and water quality models. RMA-10 and CH3D are public domain models used for specific applications by the Department of the Army, Waterways Experimental Station. ECOM is a proprietary model, available by contract from the authors. The estimated time frame for developing a hydrodynamic model of the Lower St. Johns River Estuary is 4 years. The associated sediment transport and water quality models would each require about 5 years to complete development. The three models could be developed concurrently in a time frame of approximately 5 years.

## COSTS

Costs for these efforts are listed in Table 11.

**TABLE 11**
**ESTIMATED COSTS FOR FURTHER STUDY**

| ITEM | COST |
|---|---|
| Reconnaissance of existing controls | $14,000 |
| Extension of existing controls | $241,000 |
| Extent of Tide | $75,000 |
| Water quality monitoring | $100,000 |
| Data collection for model calibration and verification | *1 |
| River wide bathymetry | *2 |
| Hydrodynamic, water quality, and sediment modeling | $1,440,000 |

*1 Need identified by contractor, but cost not yet determined.

*2 Need identified in workshop, but cost not yet determined.

## REFERENCES


Bergman, Martinus J. 1992. Volume 2 of the Lower St. Johns River Basin Reconnaissance, Surface Water Quality. Lower St. Johns River Water Management District Technical Publication SJ 92-1. Palatka, FL.

Campbell, Dean et. al. 1993. SWIM Plan for Lower St. Johns River Basin. St. Johns River Water Management District. Palatka, FL.

Fenneman, Nevin M. 1938. Physiography of Eastern United States. McGraw-Hill, Inc. New York, NY.

Fernald, Edward A. ed. 1981. Atlas of Florida. Florida State University. Tallahassee, FL.

Roig, Lisa C. 1993. Review and Evaluation of Hydrodynamic Modeling for the Lower St. Johns River Estuary. Department of the Army, Waterways Experiment Station. Vicksburg, MS.

Scarlatos, P. D. 1992. St. Johns River Water Quality Management Study, Sediment Management. Dunn and Associates, Inc. Boca Raton, FL.

Spechler, R. M. 1993. Estimated Natural Discharges and Chemical-Constituent Loading from the Upper Floridan Aquifer to the Lower St. Johns River, Northeast Florida. Tallahassee, FL.

Thompson, Douglas A. 1993. A Plan for Lower St. Johns River, Florida, Vertical/Horizontal Control Surveys and Water Measurement Station. Florida Department of Environmental Protection. Tallahassee, FL.

U. S. Army Corps of Engineers, Jacksonville District. 1986. St. Johns River Basin, Florida, Interim Water Quality Management Plan Findings. Jacksonville, FL.

U. S. Department of Commerce, National Ocean Service. 1993. St. Johns River, Florida, Draft Final Report, Tide Control and Tidal Characteristics. Silver Spring, MD.

Watkins, Bill and CH2M HILL. 1992. Addendum to the Florida Governor's Nomination of the Lower St. Johns River Estuary to the National Estuary Program. St. Johns River Water Management District. Palatka, FL.