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

Volume II

Tide Control and Tidal Characteristics

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

St. Johns River Water Management District
Palatka, Florida

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FINAL REPORT

ST. JOHNS RIVER, FLORIDA

TIDE CONTROL AND TIDAL CHARACTERISTICS

SEPTEMBER 1993

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I. INTRODUCTION

This report has been compiled by the Ocean and Lake Levels Division (OLLD), National Ocean Service (NOS), National Oceanic and Atmospheric Administration (NOAA) and is considered the assessment required as Deliverables 2 and 3 in the Cooperative Agreement between NOAA/NOS and the U.S. Army Corps of Engineers, Jacksonville District for tidal data analysis and review of the St. Johns River.

The purpose of this report is to provide specialized analyses of the data collected from tide stations operated on the river during the Federal/State cooperative effort in the late 1970's, for stations occupied more recently for NOS hydrographic surveys, and for a long term historical data set from the Long Branch, USE-DDP station in Jacksonville. This report is a much expanded version of the Review and Assessment Phase Report provided as Deliverable 1 in August 1992.

This report should be considered in tandem with the "Draft Final Report, St. Johns River Basin Water Quality Management Study - Phase I Vertical and Horizontal Measurements" being prepared by the Bureau of Survey and Mapping, Florida Department of Natural Resources (FLDNR). The FLDNR report provides the latest information on each station on the St. Johns River with regard to bench mark descriptions, bench mark conditions, geodetic datum connections, and backup material such as photographs and sketches.

II. HISTORICAL TIDE STATIONS

Table 1 is an updated listing of the historical NOS tide stations located on the St. Johns River. The table summarizes other information, such as: station location; availability of historical data, digital data and harmonic constants; geodetic datum connection; and availability of published tidal datums relative to local bench marks.

Some of the historical locations originally listed in the appendix of the Agreement are not listed in Table 1 because they have very little to contribute to information on tidal characteristics. Their observed time series are only a few days in length, the time series are from observations prior to 1960, and the bench marks have not been recently recovered. The tidal portion of the river has fairly good spatial coverage of locations providing at least some type of information on water levels. The observations are also fairly recent, as the time series observed were part of the cooperative program between NOS and FLDNR. Almost all of the stations observed during the cooperative program have published or issued tidal datums on local bench marks relative to the 1960-78 National Tidal Datum Epoch. Issued tidal datums are distinguished from published datums because they have qualifiers or caveats with them.

The station at Mayport is part of the NOS National Water Level Observation Network (NWLON) and has continuous observations since April 1928. As part of this project, NOS has digitized the entire data set back to 1928. The next longest continuous series was observed at the Long Branch, USE-DDP station in Jacksonville from May 1953 through April 1968. These data have also been digitized for this project. The only other 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.

TABLE 1. NOS HISTORICAL WATER LEVEL STATIONS, ST. JOHNS RIVER

STATION NUMBER	STATION NAME	LAT.	LONG.	START DATE	END DATE	A	B	C	D
872-0186	Ft. George Island	30 26.4	81 26.3	02 12 54	04 07 54	no	no	no	no
				04 01 78	09 30 78	yes	no	yes	yes
872-0189	Cedar Heights	30 26.2	81 38.5	08 09 77	01 31 78	yes	yes	yes	yes
872-0194	Little Talbot Island	30 25.8	81 24.3	04 28 74	11 27 74	yes	yes	yes	yes
				01 16 75	02 08 75	yes			
872-0196	Sisters Creek	30 25.0	81 41.8	09 01 77	03 23 78	yes	no	yes	yes
872-0198	Clapboard Creek	30 24.4	81 30.6	08 12 77	01 31 78	yes	yes	yes	yes
872-0203	Blount Island Bridge	30 24.8	81 32.7	08 15 77	01 23 78	yes	yes	yes	yes
872-0213	Trout River, Sherwood Forest	30 25.2	81 43.7	03 23 78	12 31 78	yes	no	yes	yes
872-0215	Jacksonville, Navy Fuel Depot	30 24.0	81 37.6	01 01 59	03 31 59	no	no	no	no
				08 26 77	03 28 78	yes	yes	yes	yes
872-0216	Ribault River, Lake Forest	30 23.9	81 41.9	03 22 78	08 25 78	yes	no	yes	yes
872-0217	Moncrief Creek Entrance	30 23.5	81 39.7	08 26 77	01 31 78	yes	no	yes	yes
872-0219	Dame Point	30 23.5	81 33.9	08 12 77	02 23 78	yes	yes	yes	yes
872-0220	Mayport	30 23.5	81 25.9	04 26 28	05 30 93	yes	yes	yes	yes
872-0221	Fulton	30 23.4	81 30.4	09 01 77	03 06 78	yes	no	yes	yes
872-0225	Phoenix Park	30 23.0	81 38.2	06 01 23	07 31 24	no	no	no	no
				08 17 77	02 23 78	yes	no	yes	yes
872-0232	Pablo Creek Entrance	30 22.6	81 26.9	08 30 77	01 31 78	yes	yes	yes	yes
872-0242	Long Branch, USE-DDP	30 21.6	81 37.2	07 21 28	06 30 33	no	no	yes	-
				01 01 35	07 31 35	-	-	-	-
				01 12 39	02 01 39	-	-	-	-
				05 01 53	04 30 68	yes	yes	yes	yes
				08 22 77	01 31 78	yes	no	no	no
872-0244	Mill Cove	30 22.2	81 33.5	08 22 77	03 31 78	yes	yes	no	yes
872-0268	Jacksonville, Acosta Bridge	30 19.5	81 39.9	12 01 58	03 31 59	no	no	no	no
				07 05 78	03 14 79	yes	no	yes	yes
872-0274	Little Pottsburg Creek	30 18.6	81 36.6	06 14 78	01 17 79	yes	no	yes	yes
872-0296	Ortega River Entrance	30 16.7	81 42.3	08 02 78	02 13 79	yes	no	yes	yes
872-0333	Piney Point	30 13.7	81 39.8	02 01 59	03 31 59	no	no	no	no
				03 10 78	02 21 79	yes	no	yes	yes
872-0374	Orange Park	30 10.1	81 41.7	06 09 78	11 20 78	yes	no	yes	yes
872-0406	Doctors Lake, Peoria Point	30 07.2	81 45.5	05 18 78	11 29 78	yes	no	yes	yes
872-0409	Julington Creek	30 08.1	81 37.8	04 12 78	11 28 78	yes	no	yes	yes
872-0434	Black Creek	30 04.8	81 45.7	07 27 78	11 06 78	yes	no	yes	yes
872-0496	Green Cove Springs	29 59.4	81 39.8	03 11 35	05 14 35	no	no	no	no
				03 09 78	04 19 79	yes	yes	yes	yes
872-0596	East Tocoi	29 51.5	81 33.2	05 15 35	06 11 35	no	no	no	no
				08 14 78	02 14 79	yes	no	yes	yes
872-0653	Palmetto Bluff	29 45.8	81 33.7	08 10 78	04 30 79	yes	no	yes	yes
872-0767	Buffalo Bluff	29 35.7	81 40.9	10 05 78	04 24 79	yes	no	yes	yes
872-0774	Palatka	29 38.6	81 37.9	06 01 35	07 31 35	no	no	no	no
				12 16 73	12 31 73	yes	-	-	-
				08 02 74	03 31 76	yes	-	-	-
				08 02 78	04 30 79	yes	yes	yes	yes
872-0782	Sutherlands Still, Dunns Creek	29 34.4	81 36.2	11 01 78	04 18 79	yes	no	yes	yes
872-0832	Welaka	29 28.6	81 40.5	01 25 37	02 28 37	no	no	no	no
				08 14 78	05 08 79	yes	-	-	-
				12 05 79	02 01 80	yes	no	yes	yes

NOTES: A - DIGITAL DATA AVAILABLE
B - GEODETIC NETWORK CONNECTION
C - HARMONIC CONSTANTS AVAILABLE
D - PUBLISHED OR ISSUED TIDAL DATUMS AVAILABLE

TABLE 1. CONTINUED

STATION NUMBER	STATION NAME	LAT.	LONG.	START DATE	END DATE	A	B	C	D
872-0855	Crescent City, Crescent Lake	29 25.8	81 30.4	11 02 79	11 30 79	yes	no	no	no
872-0877	Georgetown	29 23.1	81 38.2	12 30 73	05 23 74	yes	-	-	-
				09 08 74	12 31 74	yes	-	-	-
				03 01 75	06 30 75	yes	-	yes	-
				03 01 76	03 31 76	yes	no	no	no
872-1002	Juniper Club, Lake George	29 14.8	81 38.3	03 07 37	04 08 37	no	-	-	-
				02 14 80	03 05 80	yes	no	no	no
872-1061	Astor & Volusia	29 10.0	81 31.4	01 05 38	03 01 38	no	no	no	no
				03 05 80	03 10 80	yes	no	no	no
872-1175	Deland Landing	29 00.5	81 22.9	11 20 37	03 31 38	no	no	no	no
				03 10 80	03 28 80	yes	no	no	no
872-1324	Sanford, Lake Monroe	28 48.9	81 16.1	02 25 39	03 29 39	no	no	no	no
				04 01 80	04 15 80	yes	no	no	no

NOTES: A - DIGITAL DATA AVAILABLE
B - GEODETIC NETWORK CONNECTION
C - HARMONIC CONSTANTS AVAILABLE
D - PUBLISHED OR ISSUED TIDAL DATUMS AVAILABLE

III. ASSESSMENT OF INFORMATION ON TIDAL CHARACTERISTICS

A. Non-harmonic Analyses

Table 2 provides summary information of the tidal characteristics for each of the locations in Table 1 where valid information is available. The table can be used to compare the variations in the time of high and low waters, and in the mean range and diurnal range of tide. 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. The stations are listed in order as a function of distance from the ocean entrance. Side-rivers and creeks are separated by dotted lines in the table. Column A in the table, approximate distance from the ocean entrance, uses the river mile convention established by FLDNR in their Draft Final Report.

In terms of understanding the tidal characteristics of the river, the ocean entrance from the jetties upriver to Mayport is one of the most complex areas. Historical information from the open coast stations shows a decrease of mean range of tide by 0.3 foot 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 the ocean 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. Figures 1 and 2 show these changes in time of tide and range of tide for a selected set of stations representing the main channel or stem of the river. It takes the high waters approximately 8 hours and the low waters approximately 9 hours to progress the 100 miles from the entrance. Figure 1 shows a crossover point at approximately river mile 10, 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 differences in low water and high water were the same, the tide curves at each station would generally be symmetrical in shape. The changes shown in Figures 1 and 2 are typical of tidal rivers. As shown in Figure 2, the range of tide (MN) steadily decreases proceeding up river until Julington Creek (from 5.5 feet down to 0.71 foot) where the range then increases slightly continuing 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). Dunn's 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 or down river depending on the strength of the tide signal (e.g. spring or neap tides), and the interaction of the tide with the river flow and river level which also fluctuates monthly and seasonally.

TABLE 2. SUMMARY OF TIDAL CHARACTERISTICS

STATION NUMBER	STATION NAME	A	B	C	D	E	F
872-0194	Little Talbot Island	0.3	0.00	0.00	5.49	6.09	4 mos
872-0220	Mayport	2.2	0.39	0.06	4.51	4.92	19 yrs
872-0186	Ft. George Island	1.4	0.78	0.80	4.84	5.29	5 mos
872-0196	Sisters Creek	3.5	0.92	0.81	4.34	4.70	3 mos
872-0232	Pablo Creek Entrance	3.5	0.87	0.53	3.89	4.24	1 mos
872-0221	Fulton	7.3	0.80	0.64	3.66	3.97	4 mos
872-0198	Clapboard Creek	8.1	0.93	0.90	3.64	3.94	5 mos
872-0203	Blount Island Bridge	10.0	1.10	1.06	3.51	3.80	3 mos
872-0219	Dame Point	11.0	1.10	1.17	3.19	3.44	5 mos
872-0215	Jacksonville, Navy Fuel Depot	15.1	1.59	1.76	2.63	2.83	5 mos
872-0189	Cedar Heights, Broward River	14.6	1.54	1.73	3.03	3.24	3 mos
872-0217	Moncrief Creek, Trout River	15.9	1.60	1.98	2.56	2.76	3 mos
872-0213	Sherwood Forest, Trout River	15.9	2.09	2.19	2.65	2.88	4 mos
872-0216	Ribault River, Trout River	16.1	1.61	2.14	2.64	2.82	2 mos
872-0225	Phoenix Park	16.1	1.42	1.75	2.54	2.75	5 mos
872-0242	Long Branch (USE-DDP)	18.2	1.61	1.82	2.08	2.27	14 yrs
872-0274	Little Pottsburg Creek	21.0	1.90	2.12	2.05	2.23	6 mos
872-0268	Jacksonville, Acosta Bridge	23.2	2.14	2.19	1.51	1.68	6 mos
872-0296	Ortega River Entrance	26.1	2.54	2.75	1.11	1.26	6 mos
872-0333	Piney Point	30.2	3.03	3.56	0.88	1.00	2 mos
872-0374	Orange Park	35.2	3.79	4.71	0.74	0.87	4 mos
872-0406	Doctors Lake	39.9	3.98	4.94	0.78	0.91	5 mos
872-0409	Julington Creek	38.2	4.36	5.19	0.71	0.83	6 mos
872-0434	Black Creek	41.8	5.16	5.85	0.82	0.92	3 mos
872-0496	Green Cove Springs	47.1	5.45	6.15	0.74	0.86	12 mos
872-0596	East Tocoi	59.8	6.51	6.96	0.97	1.10	4 mos
872-0653	Palmetto Bluff	66.5	6.98	7.59	1.04	1.18	5 mos
872-0774	Palatka	78.6	7.57	8.61	1.09	1.22	4 mos
872-0782	Sutherlands Still, Dunns Creek	84.8	8.23	9.32	0.79	0.91	4 mos
872-0855	Crescent City, Crescent Lake	104.5	- tidal influence negligible-				27 days
872-0767	Buffalo Bluff	89.2	7.85	8.95	0.93	1.03	5 mos
872-0832	Welaka	98.4	8.04	8.02	0.35	0.42	5 mos
872-0877	Georgetown	107.7	- tidal influence negligible -				4 mos

NOTES: A - APPROXIMATE DISTANCE FROM OCEAN ENTRANCE IN STATUE MILES
B - DIFFERENCE IN THE TIME OF HIGH WATER FROM THE OCEAN ENTRANCE IN HOURS
C - DIFFERENCE IN THE TIME OF LOW WATER FROM THE OCEAN ENTRANCE IN HOURS
D - MEAN RANGE OF TIDE (MEAN HIGH WATER -MEAN LOW WATER) IN FEET
E - MEAN DIURNAL RANGE OF TIDE (MEAN HIGHER HIGH WATER - MEAN LOWER LOW WATER) IN FEET
F - LENGTH OF DATA SERIES FROM WHICH TIDAL DATUMS WERE DETERMINED

All values computed relative to the 1960-78 National Tidal Datum Epoch

Figure 1. St. Johns River, Florida: Time Difference in High Water and Low Water from the River Entrance

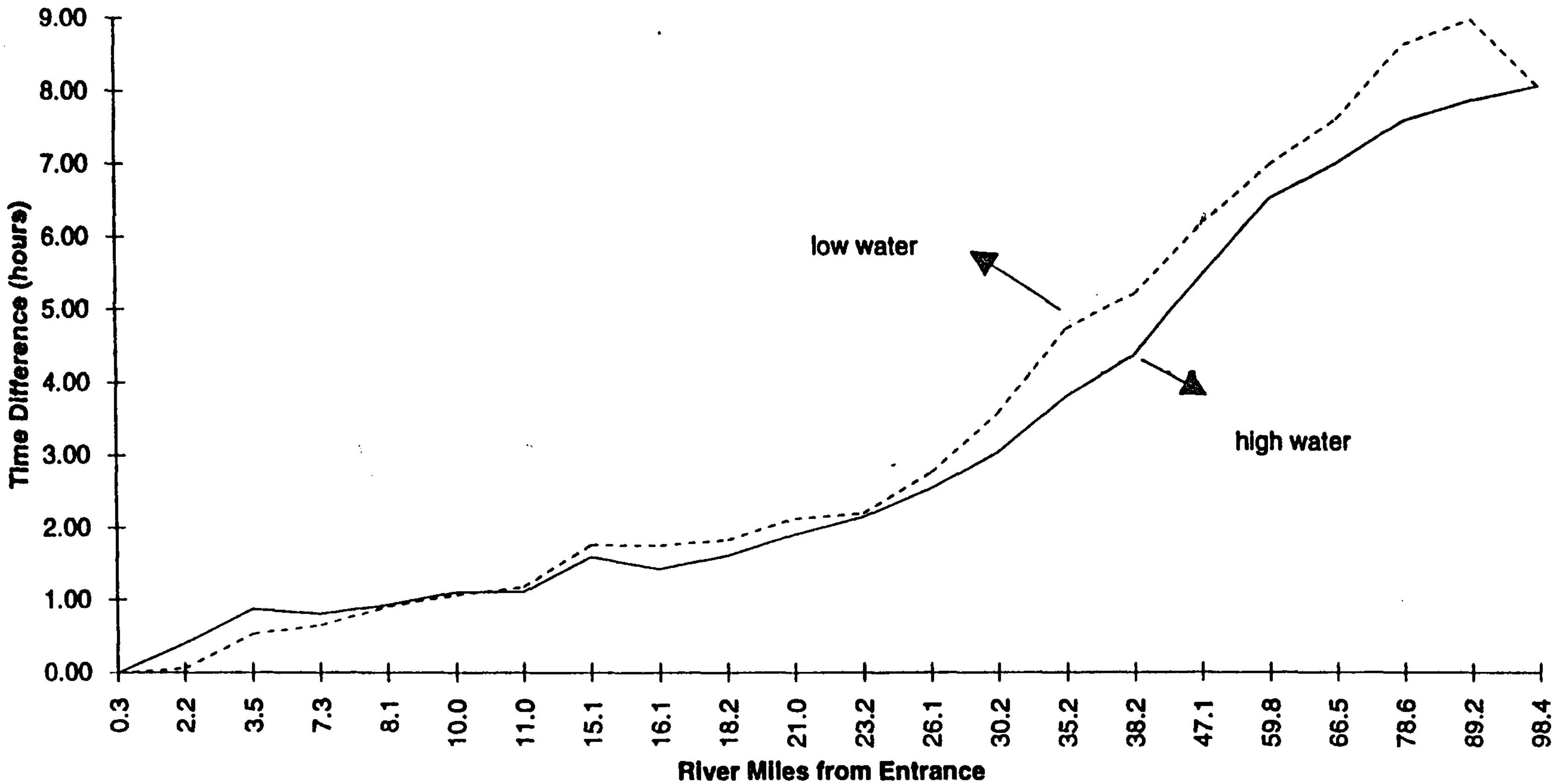
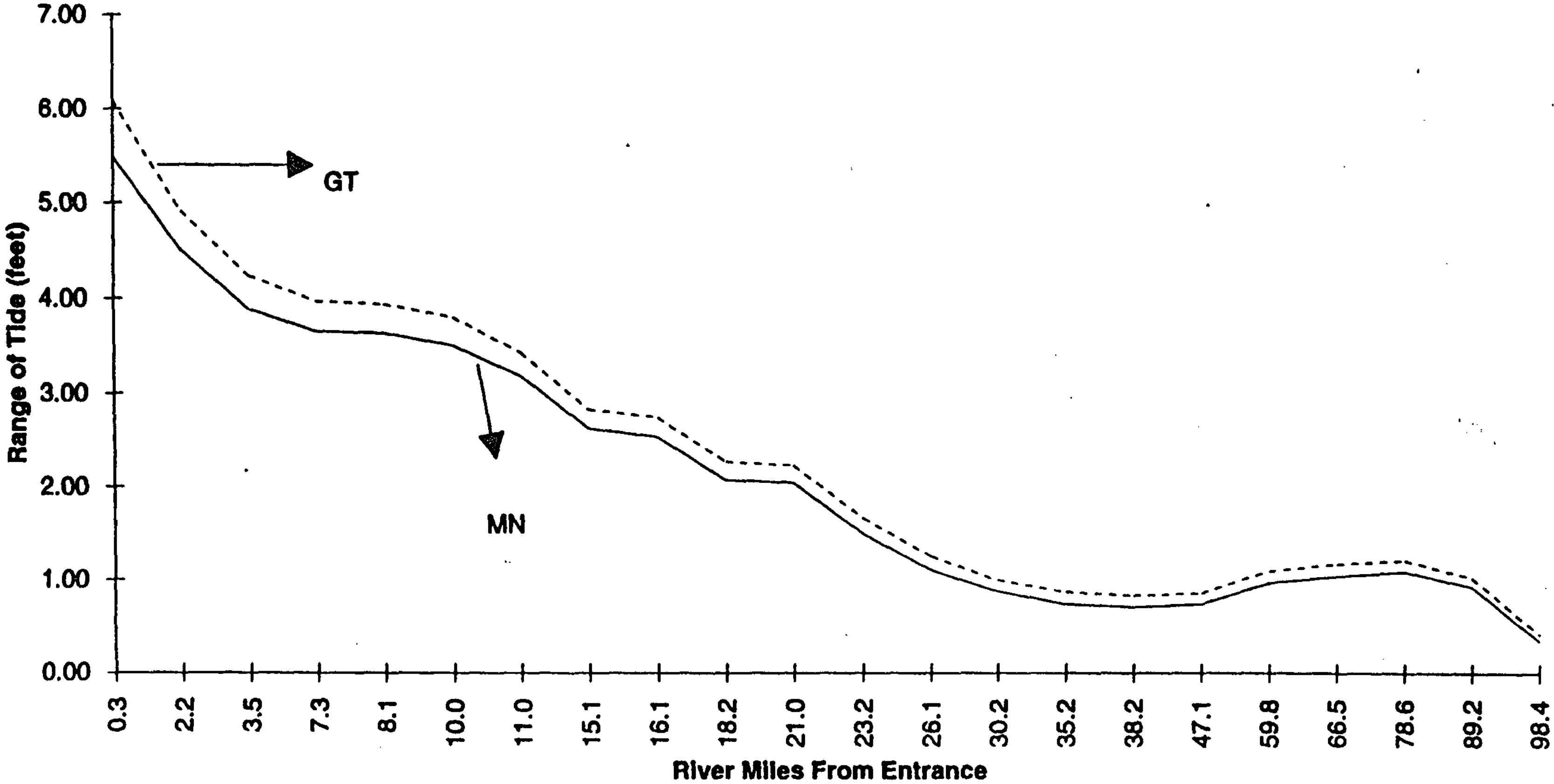


Figure 2. St. Johns River, Florida: Mean Range (MN) and Mean Diurnal Range of Tide (GT)



B. Harmonic Analyses

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 longer records of several months provides information on the contribution of tidal and non-tidal components to the total variability of the water level. Also, harmonic analysis provides the ability to more precisely predict the tidal variations at a particular location than the use of the time and range correctors found in Table 2. of the NOS Tide Tables.

Harmonic analyses have now been performed for the stations listed in Table 3 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 solved for directly and the amplitudes and phases of 15 other 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. Table 3 contains amplitude and phase information for the dominant 8 harmonic constituents found in the St. Johns River. In addition, some of the fundamental constituent amplitude and phase ratios and relationships are tabulated and can be used to describe the tidal characteristics of the river system.

The M2 constituent is the major semidiurnal lunar constituent due to 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.

Figures 3 through 6 show the variation of the constituent amplitudes and phases and their relationships in the river. The set of stations plotted is the same as in Figures 1 and 2. The amplitudes and phases are considered the "best set" and are derived from varying time periods and series lengths as dictated by the time period of the observations and the quality of the data. The plots are generally quite smooth considering the various averaging lengths and time periods used. The phases plotted are called the local phases or "kappas" by convention.

Figure 3, the plot of the constituent amplitudes, clearly shows that the M2 constituent is the dominant constituent, as it typically is for most of the east coast of Florida. The shape of the M2 amplitude curve is closely correlated with the plot of the mean range of tide (MN) found in Figure 1 and shows the same general features. The amplitudes of the other constituents tabulated are all below 0.50 foot in amplitude except for the amplitude of N2 outside at Little Talbot Island. The amplitudes generally slowly decrease proceeding upriver without any noticeable anomalies.

The plots of the constituent phases moving upriver are found in Figure 4. The phases are grouped into two bands, the semidiurnal and diurnal bands, and show a general linear trend of increasing phase with a noticeable curvature in the plots after river mile 36. The shape of the phase plots for the semidiurnal band constituents are closely correlated with the plots of the time differences found in Figure 2.

The ratios of the shallow water constituent amplitudes of M4 and M6 steadily increase as seen in Figure 5. The increase is more dramatic after river mile 80, and these constituents have a significant effect by distorting the sinusoidal waveform 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 ration of greater than 1.5 is a diurnal tide. Figure 6 shows that the ratios hold close to 0.25 until mile 30, where the jump in the ratio indicate 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. The relationships in Figure 6 show a slight shift 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 phase 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 semi-annual variation in mean sea level due 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 are also due to variations for seasonal changes in the river flow. The fact that the amplitudes and phases of these constituents are so similar at Mayport and Long Branch suggests that the seasonal sea level variations should be similar at the stations. This is confirmed in Section IV in the non-harmonic analysis of the long term data sets.

Table 3. St. Johns River, FL : Amplitudes and Phases of Harmonic Constituents - Main Stem

sta. no.	river mile	M2 amp.	M2 phase	N2 amp.	N2 phase	S2 amp.	S2 phase	K1 amp.	K1 Phase	O1 amp.	O1 phase	P1 amp.	P1 phase	M4 amp.	M4 phase	M6 amp	M6 phase	K1+O1/M2+S2	M4/M2	M6/M2	M2-K1-O1
194	00.3	2.62	215.2	0.61	195.1	0.42	239.7	0.37	110.5	0.26	119.4	0.12	111.2	0.05	063.3	0.02	356.0	0.207	0.019	0.008	-014.7
220	02.2	2.17	225.3	0.49	207.3	0.38	248.6	0.27	122.5	0.20	130.8	0.09	115.0	0.08	204.8	0.03	083.7	0.186	0.037	0.014	-028.0
232	03.6	1.88	236.2	0.34	223.9	0.23	258.8	0.29	145.6	0.19	130.6	0.10	144.5	0.05	257.9	0.04	091.9	0.227	0.027	0.021	-040.0
221	07.3	1.78	245.9	0.38	224.0	0.29	264.7	0.20	141.4	0.14	143.2	0.07	141.5	0.02	264.7	0.05	129.9	0.164	0.011	0.028	-038.7
198	08.1	1.76	243.4	0.36	230.0	0.24	266.9	0.22	145.1	0.15	136.3	0.07	144.4	0.03	054.8	0.06	142.7	0.165	0.017	0.034	-038.0
203	10.0	1.75	243.4	0.30	231.7	0.22	268.8	0.27	150.2	0.17	130.8	0.09	148.7	0.03	025.8	0.06	145.5	0.223	0.017	0.034	-037.8
219	11.0	1.58	247.2	0.30	236.0	0.21	272.9	0.19	151.8	0.14	146.2	0.07	151.5	0.03	350.1	0.07	166.4	0.164	0.019	0.044	-050.8
215	15.1	1.31	260.6	0.24	249.1	0.17	284.8	0.16	160.7	0.11	149.2	0.04	159.9	0.04	067.2	0.08	211.4	0.176	0.031	0.061	-049.3
225	18.1	1.28	264.7	0.24	257.4	0.17	288.4	0.16	163.5	0.11	155.2	0.05	162.8	0.05	108.3	0.07	220.7	0.189	0.040	0.056	-054.0
242	18.2	1.13	264.4	0.22	256.1	0.15	289.1	0.13	166.6	0.09	154.9	0.04	165.6	0.04	082.5	0.07	222.5	0.172	0.035	0.062	-057.1
274	21.0	1.02	268.4	0.19	258.6	0.14	292.6	0.13	170.0	0.09	151.0	0.04	168.5	0.04	119.4	0.05	222.8	0.190	0.039	0.049	-052.6
268	23.2	0.75	274.9	0.12	258.5	0.10	305.2	0.10	183.2	0.06	161.2	0.03	181.6	0.02	078.9	0.04	253.9	0.188	0.027	0.053	-089.5
296	26.1	0.53	286.1	0.08	270.1	0.07	317.9	0.08	201.8	0.04	169.7	0.02	199.4	0.03	190.8	0.04	298.9	0.200	0.057	0.075	-086.4
333	30.2	0.43	301.7	0.07	286.4	0.06	334.2	0.06	220.5	0.03	188.3	0.02	217.0	0.02	188.4	0.03	337.1	0.167	0.047	0.070	-108.1
374	35.2	0.38	322.6	0.06	316.2	0.06	341.8	0.08	206.1	0.04	202.3	0.02	207.7	0.03	244.0	0.03	032.5	0.279	0.079	0.079	-087.9
409	38.2	0.36	332.9	0.06	317.2	0.04	363.5	0.08	203.2	0.06	209.1	0.02	203.6	0.04	265.5	0.04	052.6	0.300	0.111	0.111	-079.4
498	47.1	0.36	363.9	0.06	348.5	0.04	347.3	0.06	216.8	0.05	220.8	0.01	213.4	0.03	283.5	0.03	108.5	0.275	0.083	0.083	-073.7
598	59.8	0.43	401.5	0.06	387.2	0.04	434.0	0.08	247.6	0.05	226.0	0.02	245.9	0.03	351.9	0.03	200.5	0.234	0.070	0.070	-072.1
653	66.5	0.49	413.4	0.08	394.7	0.02	449.7	0.06	238.4	0.05	237.8	0.02	238.4	0.03	028.3	0.03	253.7	0.216	0.061	0.061	-082.8
774	78.6	0.54	429.4	0.08	414.7	0.07	467.7	0.05	248.7	0.05	228.6	0.02	247.2	0.05	080.9	0.03	343.4	0.164	0.093	0.056	-047.9
787	89.2	0.44	449.3	0.07	442.8	0.04	465.8	0.03	263.7	0.02	256.8	0.01	263.2	0.02	123.2	0.04	061.4	0.104	0.045	0.091	-071.2
832	98.4	0.15	455.1	0.02	432.5	0.02	487.7	0.01	267.6	0.01	264.2	0.00		0.04	179.4	0.02	145.9	0.118	0.267	0.133	-096.7
877	107.7	0.02	562.0					0.01	337.6							0.01	215.6				

Amplitudes (amp) in feet; Phases (kappas) in degrees

Figure 3. St. Johns River, FL : Changes in Harmonic Constant Amplitude

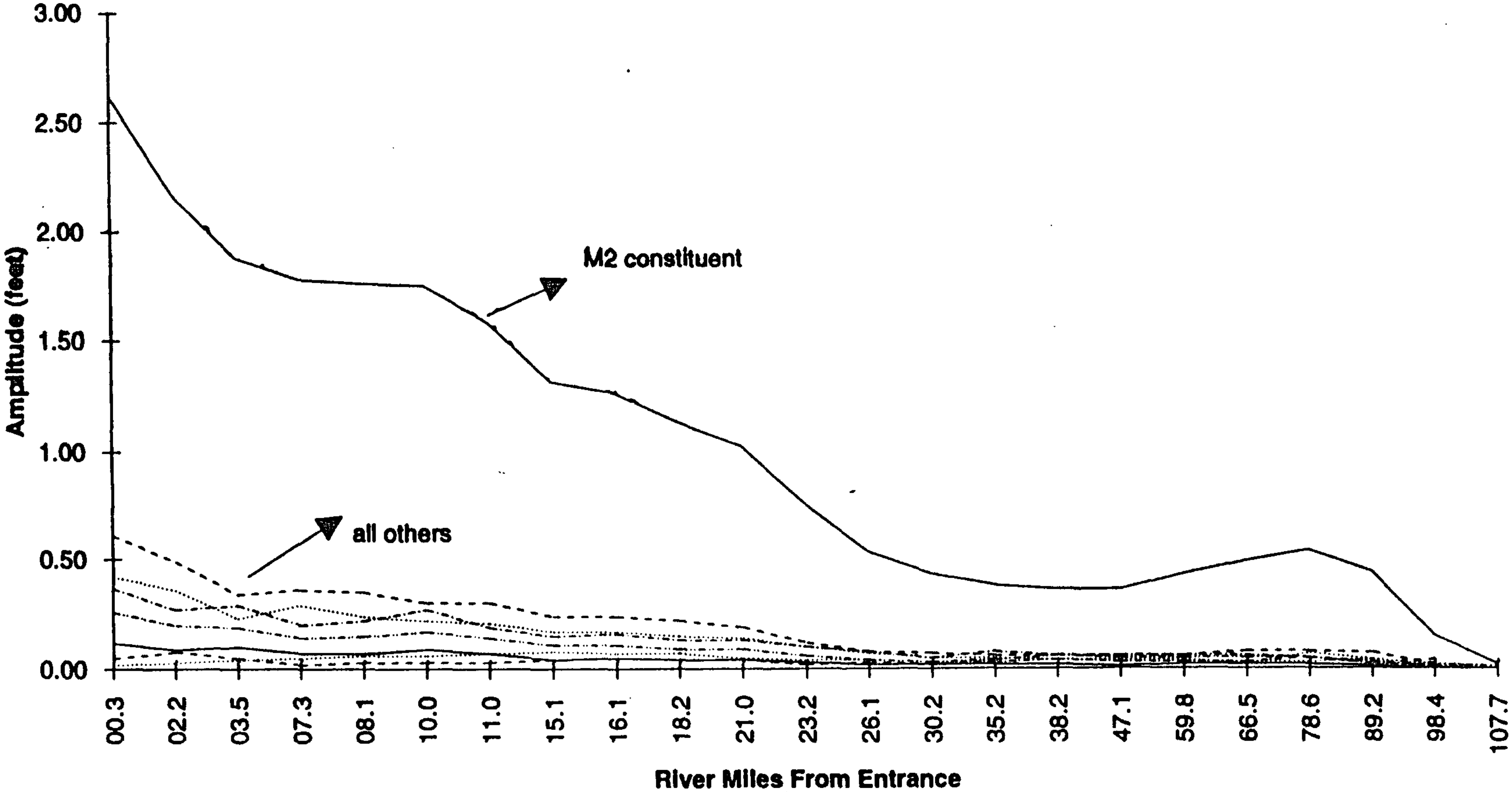


Figure 4. St. Johns River Fl: Changes on Phases of Harmonic Constituents

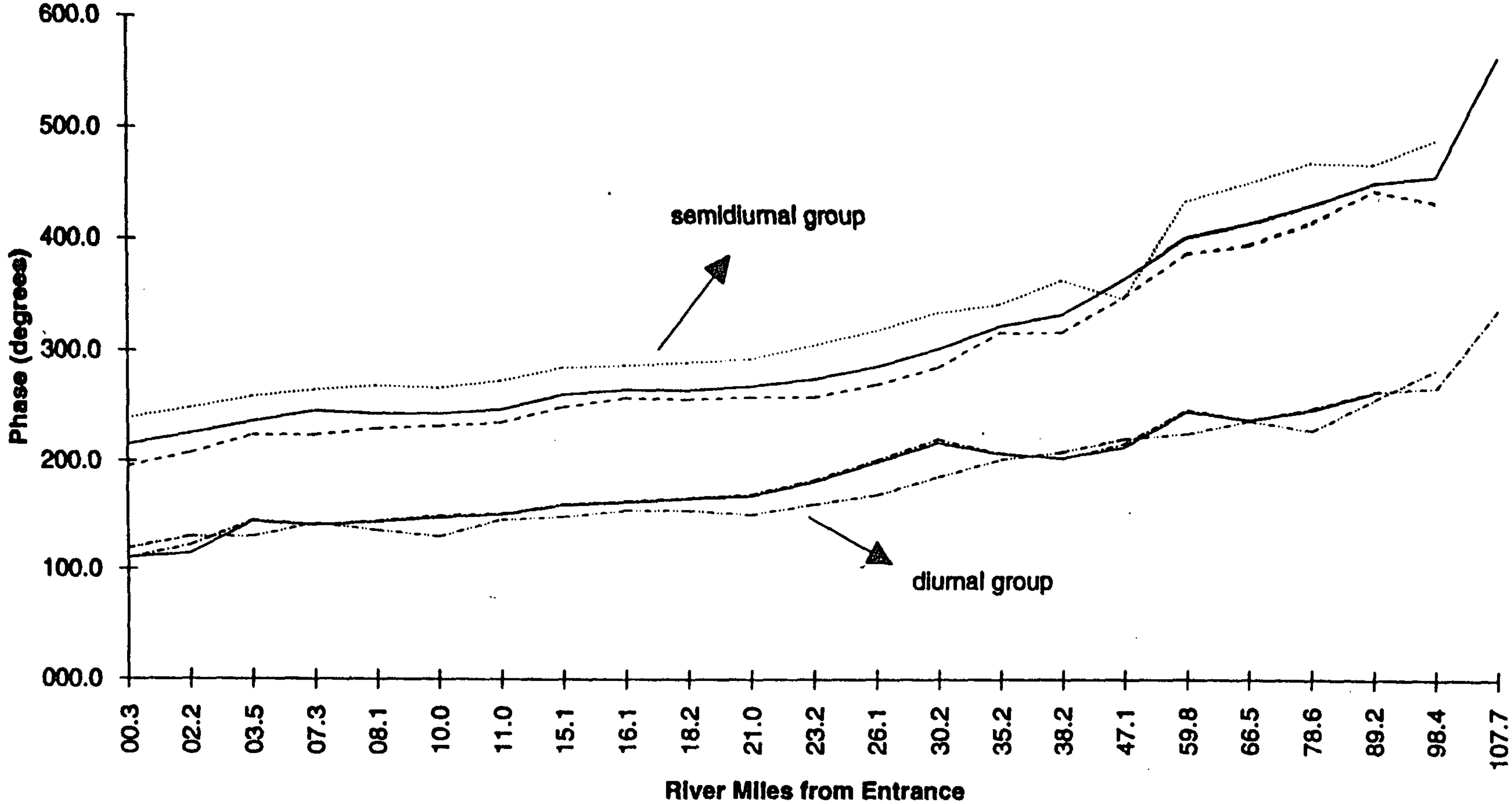


Figure 5. St Johns River, FL : M4/M2 and M6/M2 Amplitude Ratios

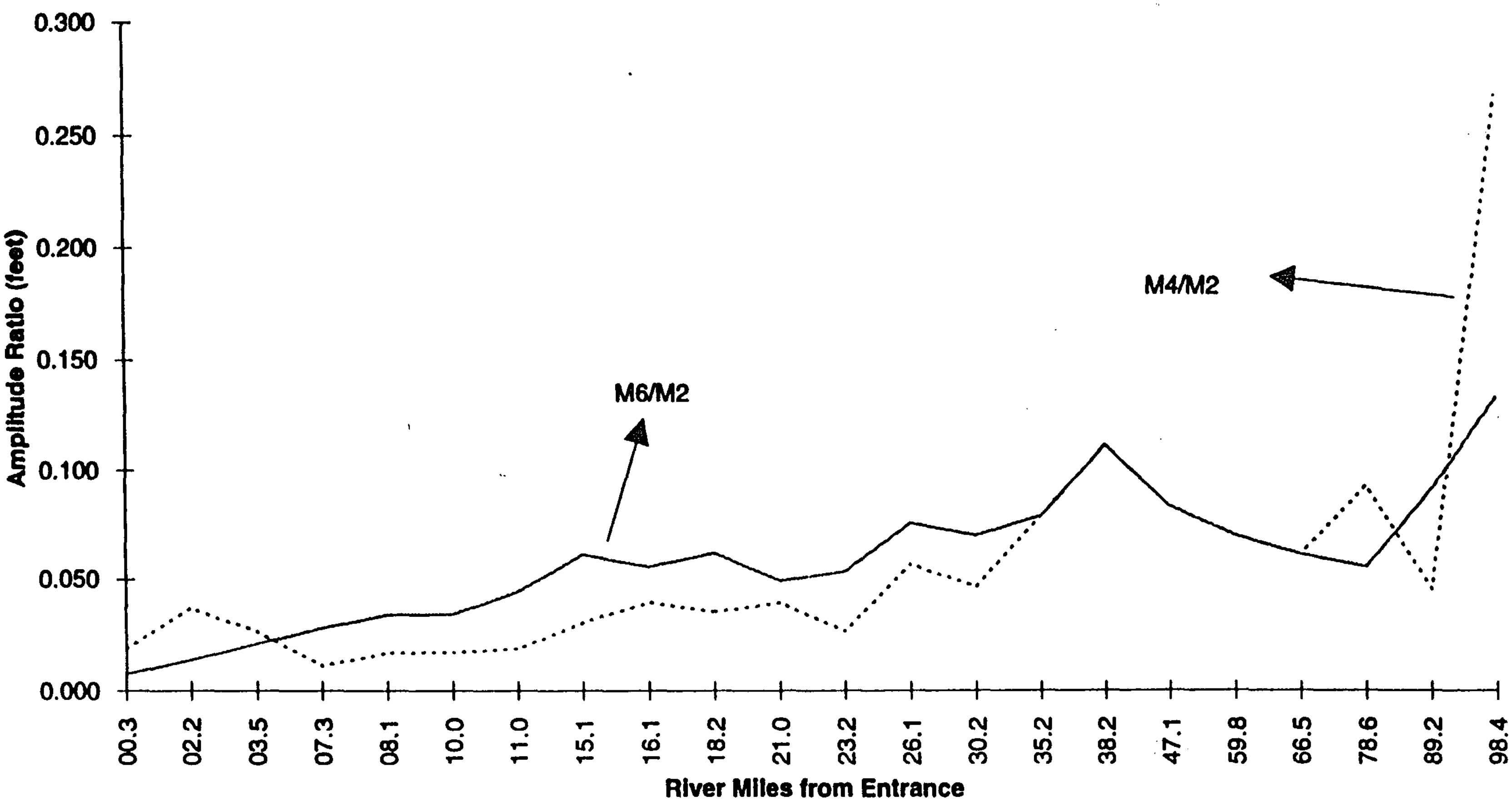
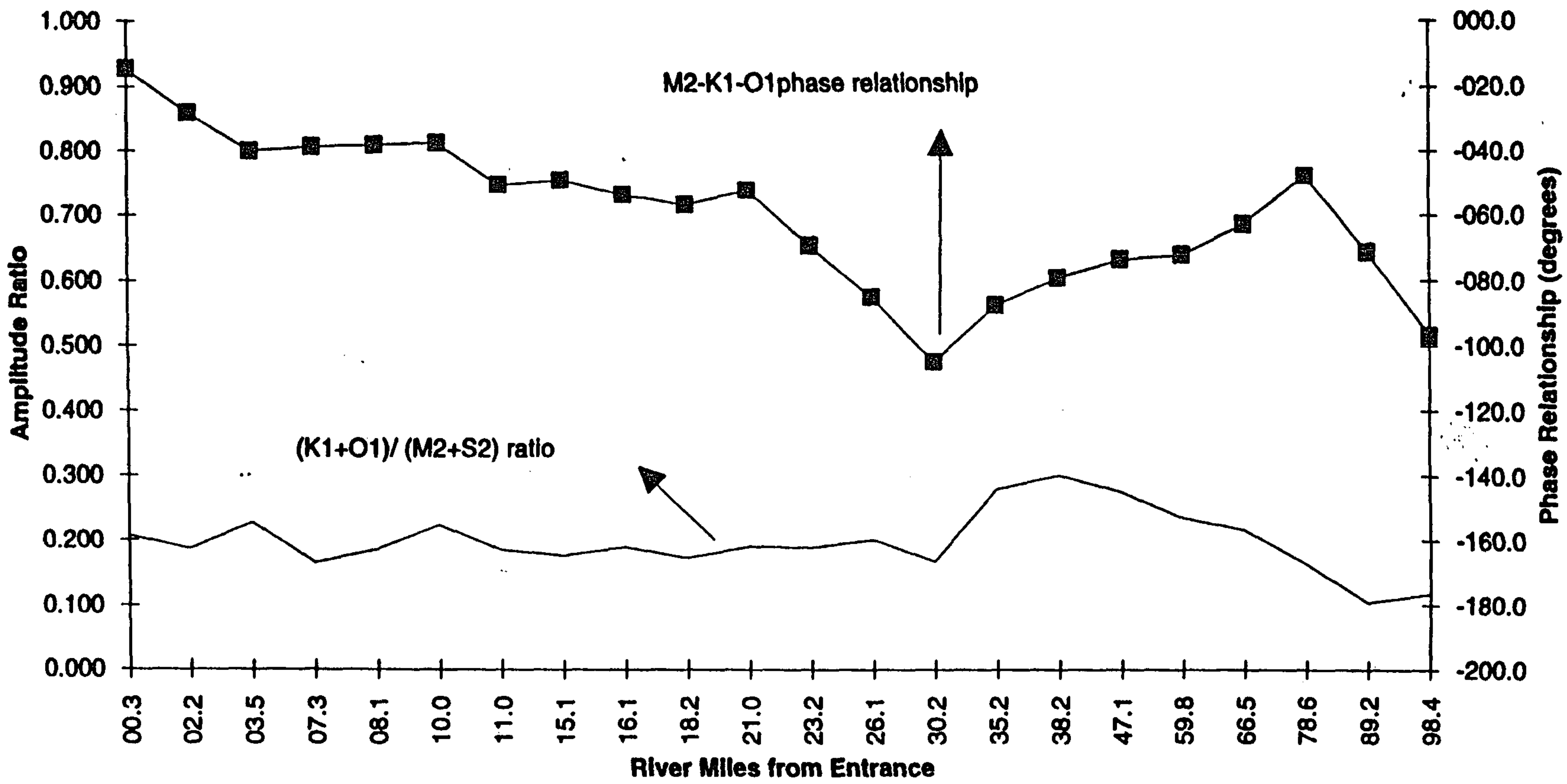


Figure 6. St. Johns River, FL : Changes in Harmonic Constant Ratios and Phase Relationships



C. Predicted and Observed Comparisons

Differences in predicted and observed tides can be due to a variety of factors. 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 due to the natural variability of the system caused by hydrological and meteorological variations and are also due to constraints imposed by the limited source of information from which to develop a tidal prediction. A comparative analysis 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 1991, the mean difference between the observed and predicted hourly heights was 0.29 foot with a 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. NOS predicted tides 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, hydrological 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 prediction. 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 from the harmonic analysis 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 as 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 standard deviation of 0.50 foot about the mean. Again, the 0.28 foot bias is because the 8-month mean sea level was 0.28 foot higher than the 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 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 0.57 foot at Welaka has much more impact because the uncertainty is greater then mean range of tide (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.

Due to the availability of digital tabulations, the times and heights of the observed and predicted tides can be compared for Mayport as seen in Table 4. The comparison is divided into 3-month segments to show seasonal variation and also shows statistics of 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 the 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 than the high water phases as evidenced by the larger standard deviations for each period.

Using harmonic constants from the stations listed, NOS can provide predicted tides as required to users. The predictions based on the harmonic constants are more precise than predictions based on the use of the time and range correctors found in Table 2 of the NOS tide prediction tables.

Mayport, FL : Differences between Observed and Predicted Tides - 1991

	Jan. 1 through Mar. 31		April 1 through Jun. 30		Jul. 1 through Sep. 30		Oct. 1 through Dec. 31	
TIME (hrs.)	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
High Water	0.0	0.2	0.0	0.2	0.0	0.2	0.1	0.2
Low Water	0.0	0.2	0.0	0.2	-0.1	0.3	0.0	0.2
HEIGHT (ft.)								
HHW	0.36	0.38	0.44	0.40	0.23	0.31	0.06	0.41
LHW	0.39	0.45	0.46	0.40	0.29	0.31	0.26	0.45
HLW	0.29	0.53	0.44	0.54	0.29	0.45	0.10	0.61
LLW	0.21	0.50	0.34	0.52	0.25	0.41	0.12	0.59
MSL	0.33		0.43		0.28		0.15	

HHW: Higher High Water
LHW: Lower High Water
HLW: Higher Low Water
LLW: Lower Low Water

MSL: Mean Sea Level

TABLE 4.

IV. TIDAL DATUM RELATIONSHIPS

The characteristics of the tide in the St. Johns River can also be illustrated by comparing the elevations of the tidal datums computed at each location to the local elevation of National Geodetic Vertical Datum (NGVD). The relationships of the tidal datums to geodetic datum are established by differential leveling between the local network of tidal bench marks and the closest geodetic bench marks.

Figure 7 is a plot of the relationships listed in Table 5. The asterisked (*) values indicate that the NGVD bench mark elevations are preliminary and have not been fully processed or adjusted by the National Geodetic Survey (NGS). However, although preliminary, they can be used to show that the tidal datum elevations have significant slopes relative to NGVD along the St. Johns River. Tidal datum elevation relationships to NGVD cannot be extrapolated over significant distances in the river. The localized relationships are generally dependent on the tidal range and the elevation of mean sea level (and mean tide level) above the geodetic datum at a given location. Figure 7 shows the most commonly used tidal datums of MHW, MSL and MLLW. The shape of the envelope formed by the relationships proceeding upriver is typical of tidal rivers. The elevation of MLLW is typically thought to be below that of NGVD, however, note that the elevation of MLLW transitions from negative to positive relative to NGVD near river mile 23.

These relationships will be updated, along with relationships to the new North American Vertical Datum of 1988 (NAVD88), when NGS finishes the processing and adjustment procedures and NOS re-establishes the elevation relationships to the tidal bench marks and local station datums. This effort will be coordinated with FLDNR so that they will have the latest elevation relationships as they become available.

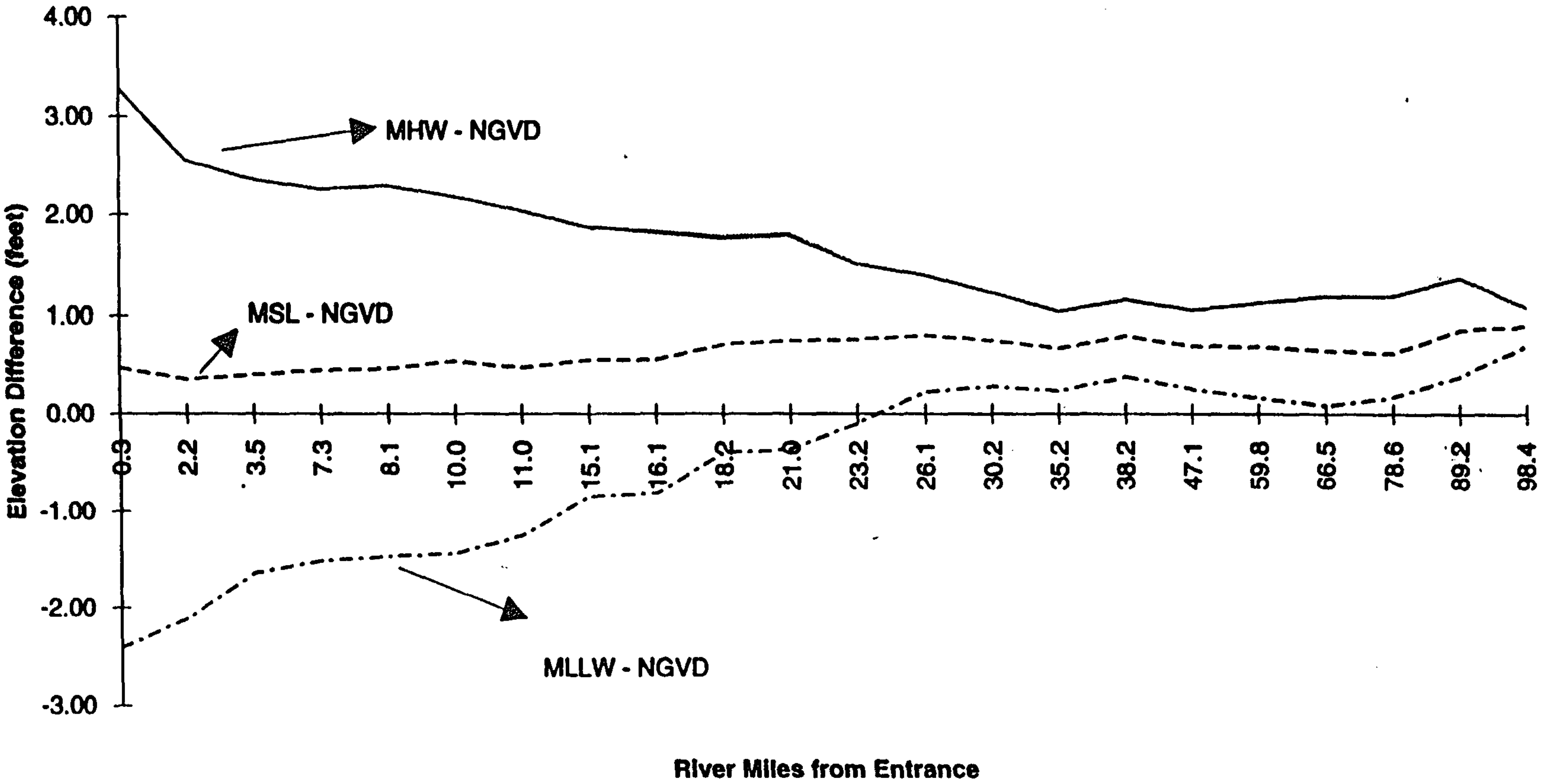
Table 5. St. Johns River, FL : Relationships of Tidal Datums to NGVD

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

Figure 7. St. Johns River, FL : Relationships of Tidal Datums to National Geodetic Vertical Datum (NGVD)



V. ANALYSIS OF LONG-TERM SEA LEVEL VARIATIONS

A. Seasonal Patterns and Variability

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. United States Geological Survey (USGS) river flow data has also been obtained through the District and can be included in the comparison. 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 are obtained by averaging the monthly mean values over each calendar year month for the 14-year period, 1954-1967. Figures 8 and 9 are the resulting average seasonal variations in mean sea level (MSL) and mean range (MN) for Mayport and Long Branch and the mean river flow (MRF) at Deland. The mean river flow plot is for the same data in each figure. The two stations 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 maxima in October, however the secondary maximum occurs in March and April, with a distinct minimum occurring in May and June.

The average seasonal variations in Figures 8 and 9 must also be put in context by looking at the year-to-year variabilities that went into the seasonal averages. Figures 10 and 11 show each of the time series of monthly means used. The monthly mean sea levels, monthly mean ranges, and monthly mean river flow all show significant year-to-year variability. The fall season of 1960 appears 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 has been run on the monthly time series shown in Figures 10 and 11. For the 14-year period 1954-1967, the correlation coefficients between the various combinations of parameters 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

These analyses simply quantify what is intuitively seen in the plots; variations in monthly MSL are highly correlated between Mayport and Jacksonville with variations in MN significantly correlated, but not highly correlated. Monthly MSL variations at Long Branch show higher correlation with variation of 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 noticeably 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 shown in Figures 8 and 9 for Mayport and Long Branch are extremely similar to the seasonal monthly MSL patterns found from Charleston, SC south to Miami, FL.

B. Long-Term Variations

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.

Figure 12 is a plot of the yearly mean sea level values for the entire series. All values have been referenced to the same station datum. The dominant features are the consistent upward trend and the noticeable degree of year-to-year variability in the values. The apparent secular trend in this series as determined from the slope of a 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 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, FL 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 as illustrated in the Mayport plot. 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.

Figure 13 is a plot of the yearly mean range of tide values for the entire series. The plot 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.

Figure 8. Mayport, FL : Average Monthly Mean Sea Level (MSL), Average Monthly Mean Range (MN), and Monthly Mean River Flow (MRF at Deland) : 1954 through 1967

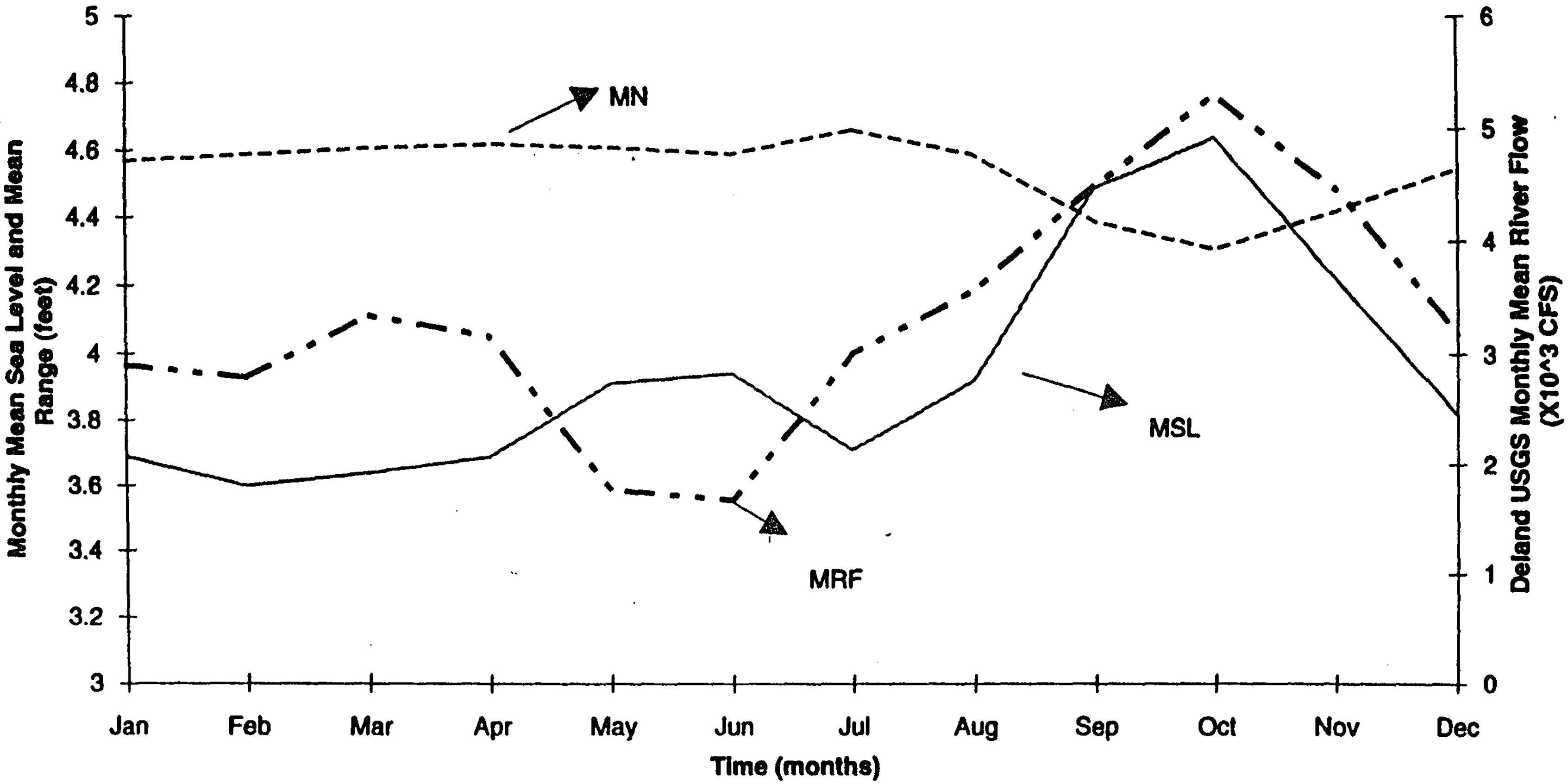


Figure 9. Long Branch, FL : Average Monthly Mean Sea Level (MSL), Average Monthly Mean Range (MN), and Average Monthly Mean River Flow (MRF) at Deland : 1954-1967

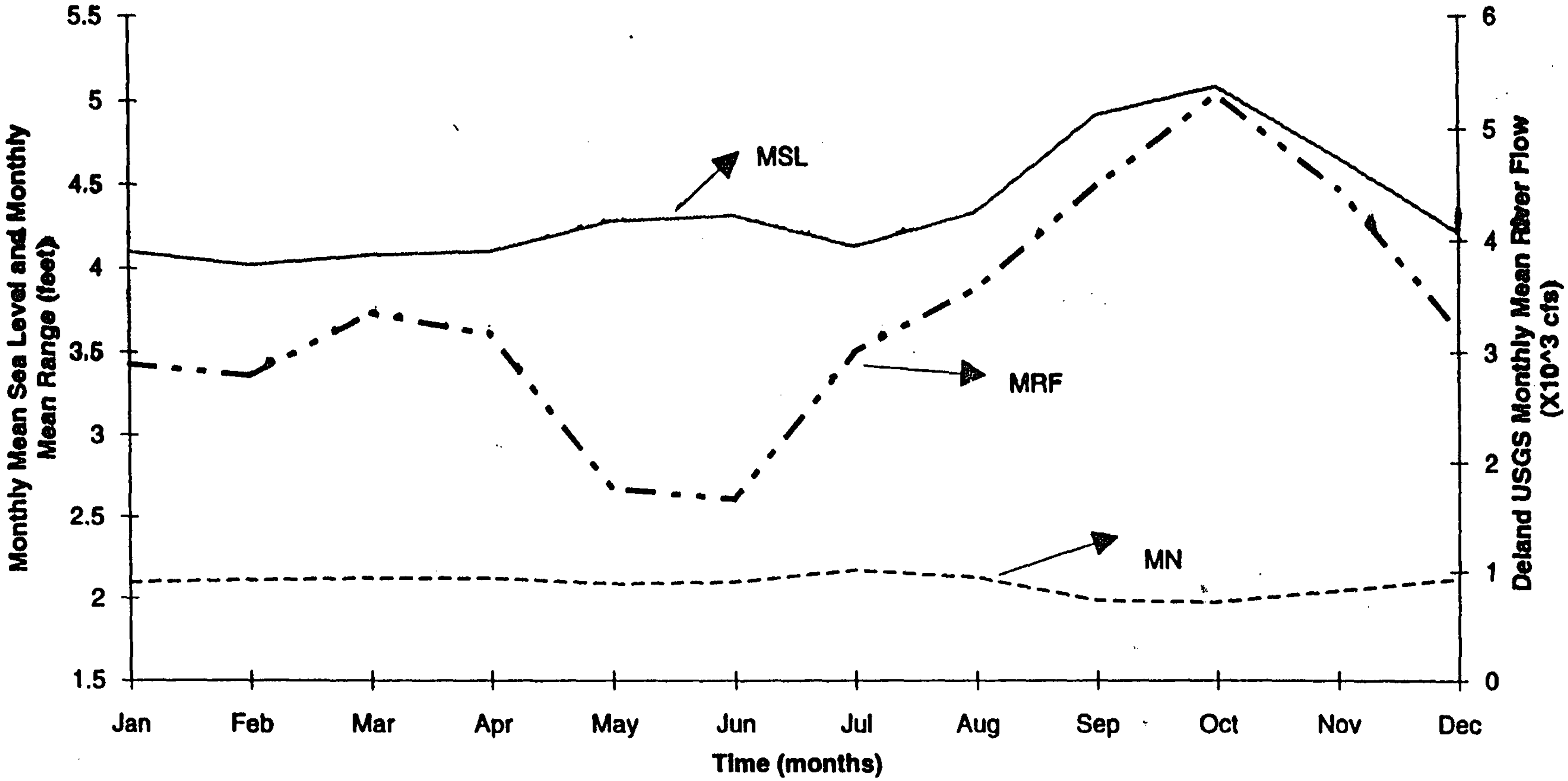


Figure 10. Mayport and Long Branch Monthly Mean Sea Level vs Deland Monthly Mean River Flow : 1954 - 1967

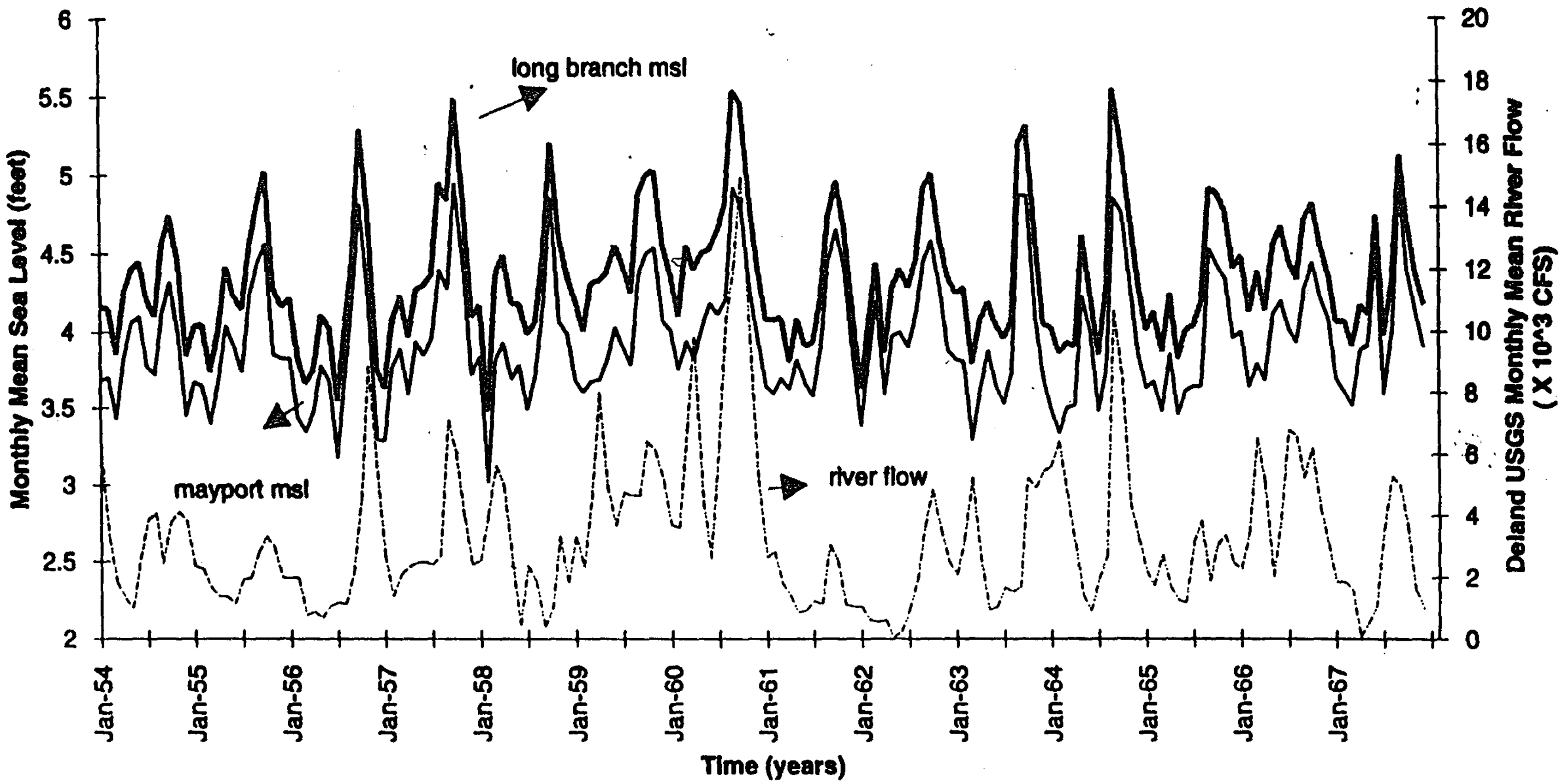


Figure 11. Mayport and Long Branch Monthly Mean Range vs Deland Monthly Mean River Flow : 1954-1967

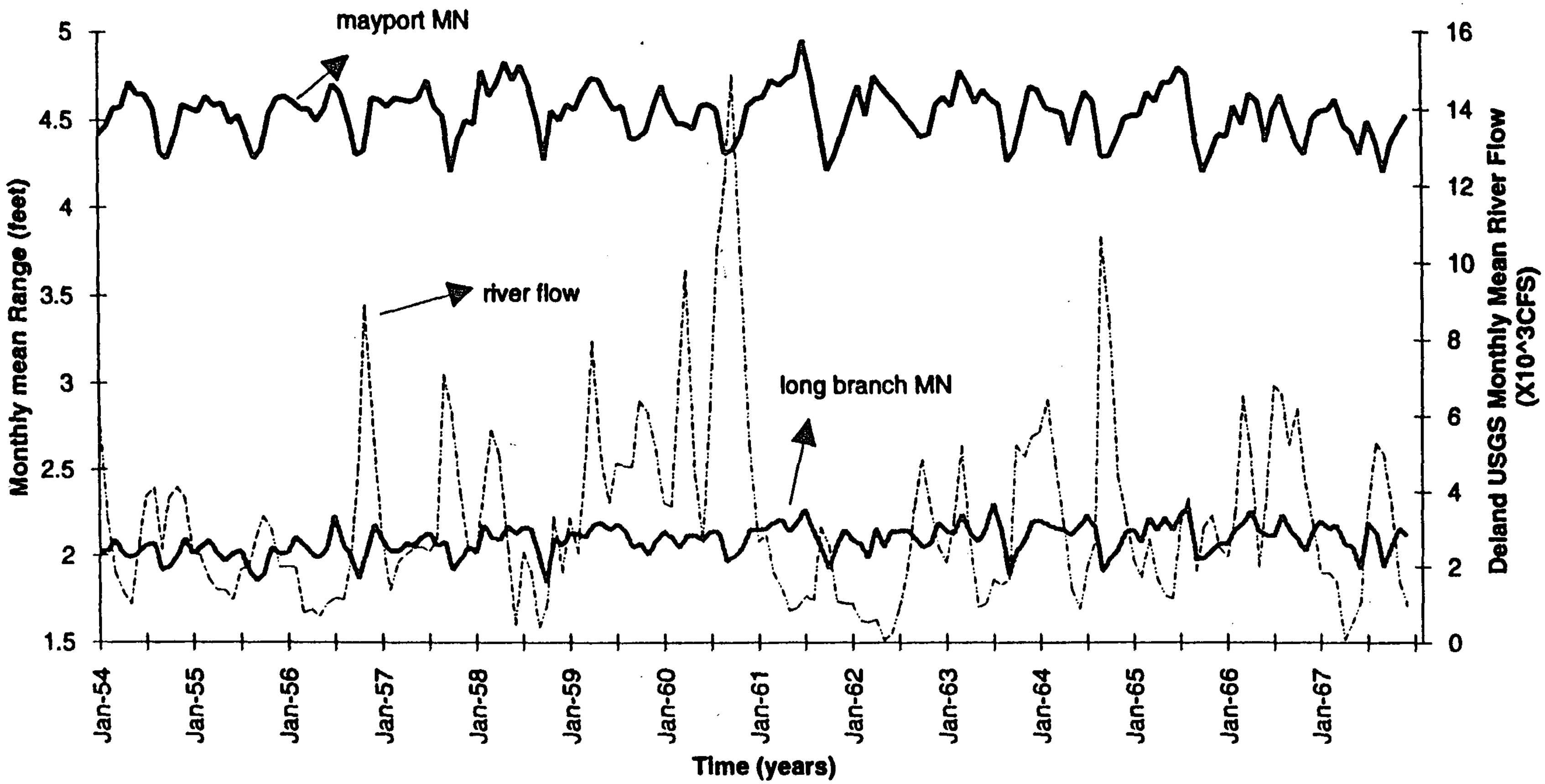


Figure 12. Mayport, FL : Long Term Yearly Mean Sea Level : 1929 - 1992

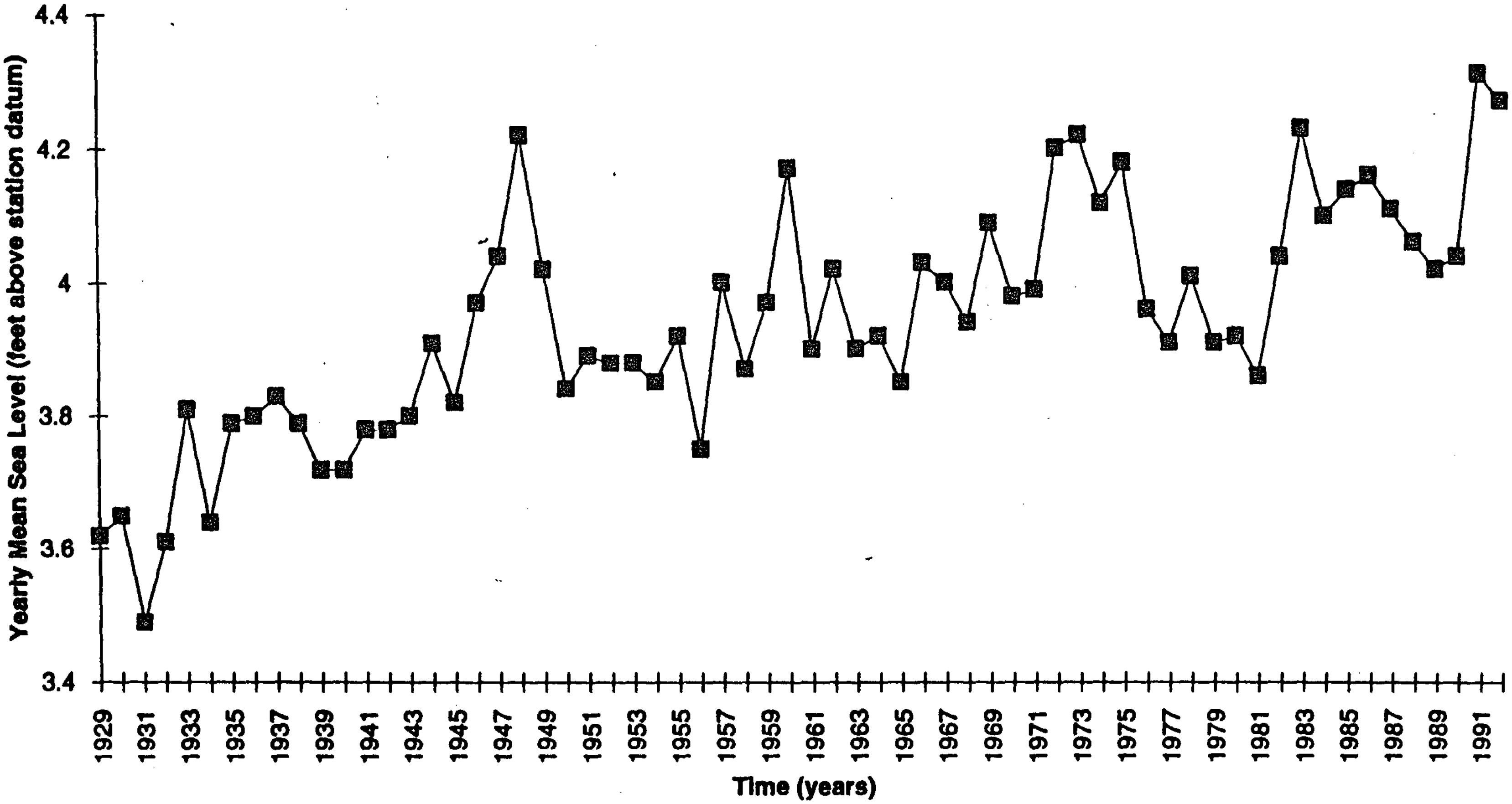
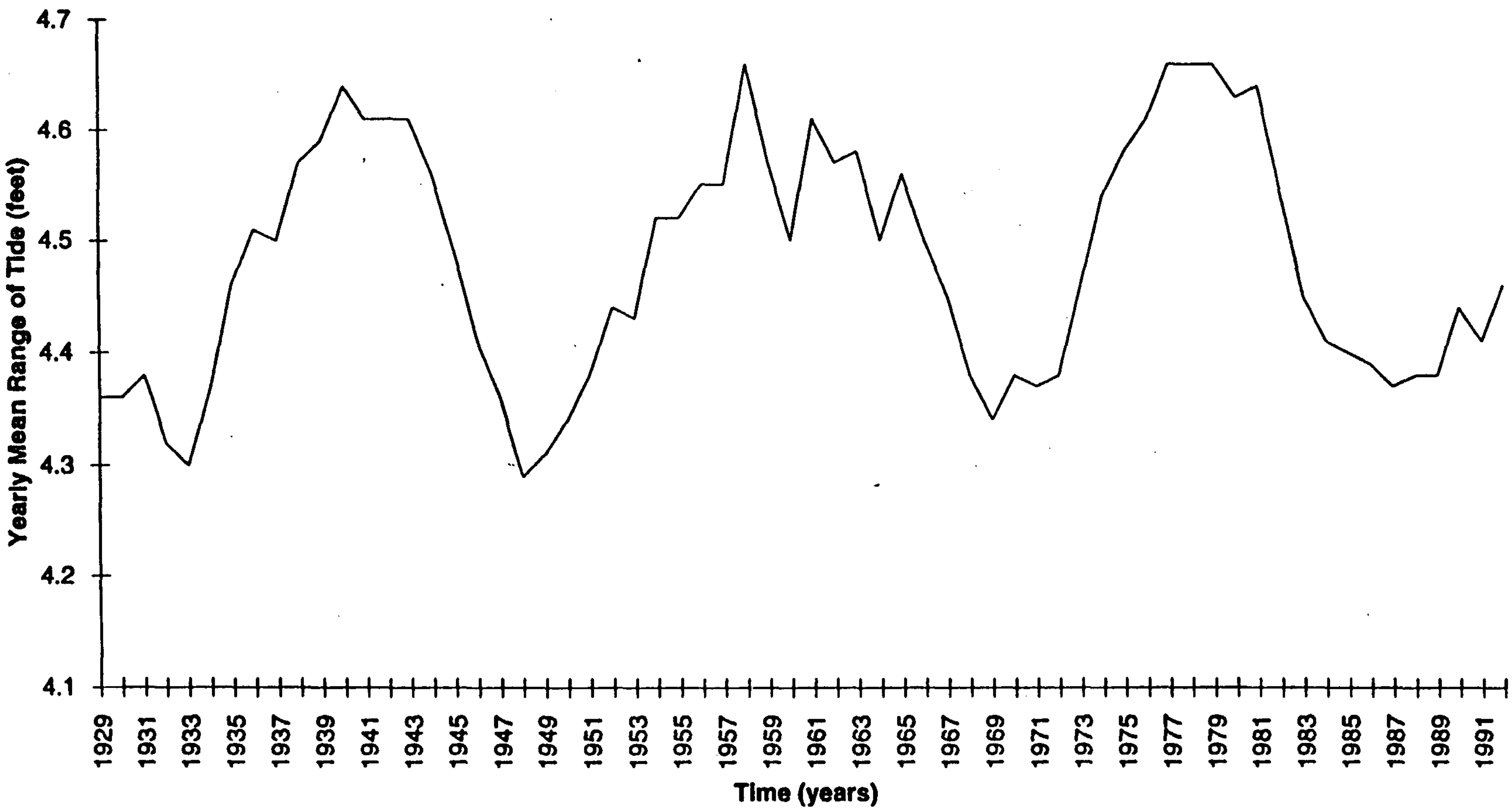


Figure 13. Mayport, FL : Long Term Yearly Mean Range : 1929-1992



VI. ASSESSMENT OF TIDAL DATUMS AND VERTICAL CONTROL

Tidal datum elevations have been published or issued for all of the stations listed in Table 2. (with exception of Georgetown and Crescent City which are defined as non-tidal). The FLDNR report contains relevant information as to the condition of the local tidal bench marks at each location and whether they can still be considered reliable for surveying and mapping applications. It is important for the bench marks to be maintained over time at all stations so that the tidal datum elevations can be accurately used in the field and so that future tidal datum updates and station reoccupations can be easily completed.

Based on the analyses presented in this report, 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 upriver to Mayport (river mile 2.2), 2) from Mayport upriver to Jacksonville, Acosta Bridge (river mile 23.2), 3) from Jacksonville upriver to Palatka (river mile 78.6) and 4) from Palatka upriver 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 extremely fast 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 this section 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; and there are changes in the M2 constituent amplitudes and the harmonic constant ratios. The river topography is partially responsible. The river channel is fairly constrained up to Jacksonville, Acosta Bridge, and the 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 as shown in Figure 14. 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 increasing dramatically at Welaka as seen in Figure 5. Although there is not a particular location where new tidal datums are required, a head of tide study would require additional short term stations to monitor the seasonal change in the transition zone.

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 a Primary (19-year) station, several secondary (1 to 5-year) stations and several 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 Welatka. 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. When stations are reoccupied, they should not be made randomly, but within the hierarchy system described above.

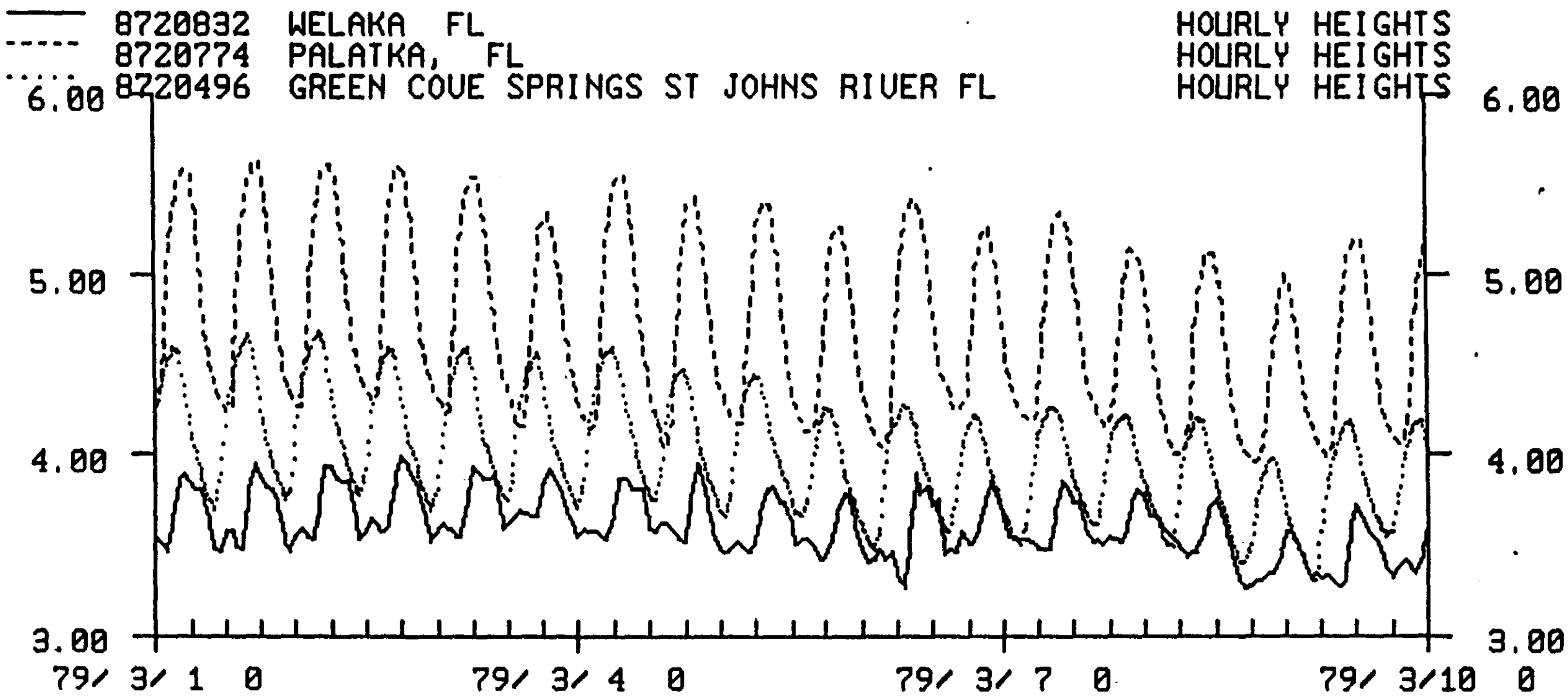


FIGURE 14. COMPARISON OF HOURLY HEIGHT TIME SERIES _ NINE DAY WINDOW

VII. SUMMARY

This final report represents Deliverables 2 and 3 of the cooperative agreement between the U.S. Army Corps of Engineers, Jacksonville District and the National Ocean Service for a tidal study of St. Johns River, Florida. The report should be reviewed in tandem with a draft final report being prepared by FLDNR.

This report provides a comprehensive review of the tidal characteristics of the St. Johns River based on non-harmonic and harmonic analyses using the latest tidal data. This effort has 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 National Geodetic Vertical Datum along the main stem of the 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 the discussion of tidal characteristics. A brief summary of expected uncertainty in predicted tides was completed using comparison of observed and predicted data. Using the harmonic analyses results, predicted tides can now be produced for individual stations that are more useful than using the Table 2 correctors found in the NOS tide tables.

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 to 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 all of the analyses, recommendations are made for the establishment of a secondary network of stations that would operate simultaneously from 1 to 5 years and supplemented with reoccupations of nearby tertiary stations as required. Mayport provides adequate primary control for datum determination for the river system. New locations requiring information have been identified in the river entrance, and between Welaka and Georgetown if a head of tide study is required.