This manuscript may be cited as: Smith, N. P. (1990). An introduction to the tides of Florida's Indian River lagoon. Part II: Currents. *Florida Scientist, 53*(3), 216-225.

AN INTRODUCTION TO THE TIDES OF FLORIDA'S INDIAN RIVER LAGOON
II. CURRENTS

NED P. SMITH

Harbor Branch Oceanographic Institution, 5600 Old Dixie Highway, Fort Pierce, FL 34946

ABSTRACT: *Hourly current measurements recorded along the Atlantic Intracoastal Waterway are used to quantify amplitudes and local phase angles of the principal tidal constituents in Florida's Indian River lagoon. Twenty-seven study sites located between latitudes 27°10' and 28°17'N were occupied for periods of 1-2 months each during 1976-1988. Six principal tidal constituents (M_2, S_2, N_2, K_1, O_1, and P_1) have amplitudes greater than the precision of the measurements used to make the calculations. The semi-diurnal M_2 constituent dominates all other tidal constituents. M_2 amplitudes exceed 60 cm/s in the vicinity of Ft. Pierce Inlet; the amplitude just north of St. Lucie Inlet is approximately 45 cm/s. M_2 amplitudes are relatively small in the vicinity of Sebastian Inlet: Values of 11 and 19 cm/s are computed from data obtained at study sites approximately 3 km north and south of the inlet, respectively. M_2 amplitudes north of 28°11'N are less than 1 cm/s. A comparison of phase angles indicates that tidal wave forms propagate at speeds of 5-10 km/h. In the central parts of the central and southern segments of the lagoon, the time delay of any phase of the tide is 6.5 and 5 h, respectively, relative to Ft. Pierce Inlet.*

THE ebb and flood of the tide play a central role in the circulation of most estuaries by performing several important functions. At inlets and passes, they generally provide the dominant estuarine-shelf exchange mechanism. Within an estuary, tidal motions effect longitudinal, lateral, and vertical mixing, which serve to disperse pollutants and anything else that is dissolved or suspended in the water column. Tidal motions are thus of major importance in maintaining or restoring water quality.

The relative importance of tidal motions within an estuary varies according to the type of estuary. Coastal lagoons, in particular, have characteristically low tidal amplitudes because of the restrictive effect inlets and passes have on exchanges. Thus, even under unexceptional wind conditions, the ebb and flood of the tide in the interior of a lagoon may be dominated by the wind-driven component of the current. Nevertheless, tidal motions are important because they are as dependable as they are periodic, and thus predictable. Tidal processes can be enhanced greatly by nontidal forcing, but the baseline level of transport, mixing, and flushing they provide should be investigated and quantified.

Indian River lagoon lies along the Atlantic coast of central Florida. The lagoon is 195 km long, characteristically 2–4 km wide, and water depths are generally 1–3 m on both sides of the Atlantic Intracoastal Waterway (AIW). The lagoon is of the "restricted" type, according to the definitions suggested by Kjerfve (1986). The lagoon can be subdivided into three segments: The northern segment, north of Sebastian Inlet, is 113 km long; the central segment, between Sebastian and Ft. Pierce Inlets, is 45 km long; the southern segment, between Ft. Pierce and St. Lucie Inlets, is 37 km long. The landward side of the lagoon receives fresh water from natural creeks and rivers, from groundwater discharge (Pandit and El-Khazen, 1990), and from a series of man-made drainage canals that have added to drainage from the natural watershed of the lagoon.

This paper is the second of a two-part survey of the tides of Florida's Indian River lagoon. The first paper (Smith, 1987), using water-level data, showed that the M_2 constituent—the principal semi-diurnal constituent—is dominant throughout the lagoon. M_2 amplitudes in the northern, central, and southern segments are 0–5 cm, 5–10 cm, and 10–15 cm, respectively. The constricting effect of inlets, combined with the frictional damping of the tidal wave form, restricts significantly the portion of the lagoon that is influenced by tides. Thus, tidal ranges associated with diurnal and semi-diurnal period constituents decrease rapidly with distance inside each of the three inlets. Ft. Pierce Inlet, dredged to a depth of about 6 m, carries more water between the lagoon and the inner shelf than does either Sebastian Inlet or St. Lucie Inlet. As a result, tidal amplitudes in the lagoon are greatest in the northern part of the southern segment and in the southern part of the central segment.

Tidal-current amplitudes presented in this paper are also larger in the vicinity of inlets—especially Ft. Pierce Inlet. Spatial irregularities in phase angles are apparently attributable largely to differences in weather conditions and/or inlet cross-sections during the 13-yr period over which data were obtained.

THE OBSERVATIONS—Current data used to quantify tidal harmonic constants (amplitudes and local phase angles, referenced to Eastern Standard Time) of the principal diurnal and semi-diurnal constituents were recorded using General Oceanics Type 2010 film-recording inclinometers. Both inclination and azimuth angles were read to the nearest degree. Although the conversion from inclination angle to current speed is nonlinear, a precision of ±0.5° corresponds to about ±1.5 cm/s, within the inclination range commonly found in this study. The accuracy of the azimuth reading is ±5° for inclination angles greater than 10°, according to instrument specifications.

Data were collected in field studies conducted at irregular intervals from 1976 through 1988. Time series were typically 30–45 da long, but records from AIW Markers 57, 133, and 207 were 223, 175, and 102 d long, respectively. During the 1976 and 1977 field studies, current meters were attached to concrete blocks, and the midpoint of the current meter was approximately 1 m above the bottom at 0° inclination. In later studies, the mooring design was altered such that the current meter recorded the flow about 1.5 m above the bottom, or just below mid-depth.

All current-meter records were obtained from moorings in the AIW. Currents in the relatively shallow seagrass flats on both sides of the waterway are spatially variable because of the presence of spoil islands and local irregularities in bottom topography. By conducting field measurements in the AIW, results are more directly comparable, and the greater depth (3.5 m) reduces the possibility of vandalism and minimizes the contaminating effect of wind-wave motions.

The study focuses specifically upon semi-diurnal and diurnal tidal constituents. With the exception of data collected at AIW Marker 57 (27°52′N), current-meter records were not long enough to quantify the harmonic constants of fortnightly, monthly, and longer constituents. The Marker 57 data, however, suggest that amplitudes of the long-period tidal constituents are at or within the accuracy of the measurements and, thus, cannot be quantified with confidence.

METHODS—Because of the large length-to-width ratio of Indian River lagoon, and because currents in the AIW are constrained significantly by the channel, only the longitudinal, along-channel component of the current is used in the analysis. The along-channel direction was determined initially from NOAA Nautical Charts 11472 and 11485. In many instances, however, the indicated along-channel orientation was confirmed with polar coordinate plots of the raw data. "Along-channel" was defined by the line passing through the greatest concentrations of points representing flood and ebb current velocities.

Timing errors in the raw data were generally minimal. When the total number of observations did not correspond with the time interval between the known starting and ending times, however, the time series was "stretched" or "compressed" by fitting a natural cubic spline function through the data points and then interpolating or extrapolating along the curve to extract values at hourly intervals.

Tidal harmonic constants were computed from along-channel current components using the 29-d harmonic analysis computer program described by Dennis and Long (1971). Time series were usually long enough to permit several 29-d analyses, with each successive computation starting several days farther into the time series. When several harmonic constant pairs were available, they were vector-averaged, as suggested by Haurwitz and Cowley (1975), to provide the single value used to represent the study site. Vector probable errors provided a measure of the scatter about the vector mean. When the vector probable error exceeded 50% of the vector-averaged amplitude, the constituent was judged to be statistically insignificant at that location, and it was dropped from further consideration.

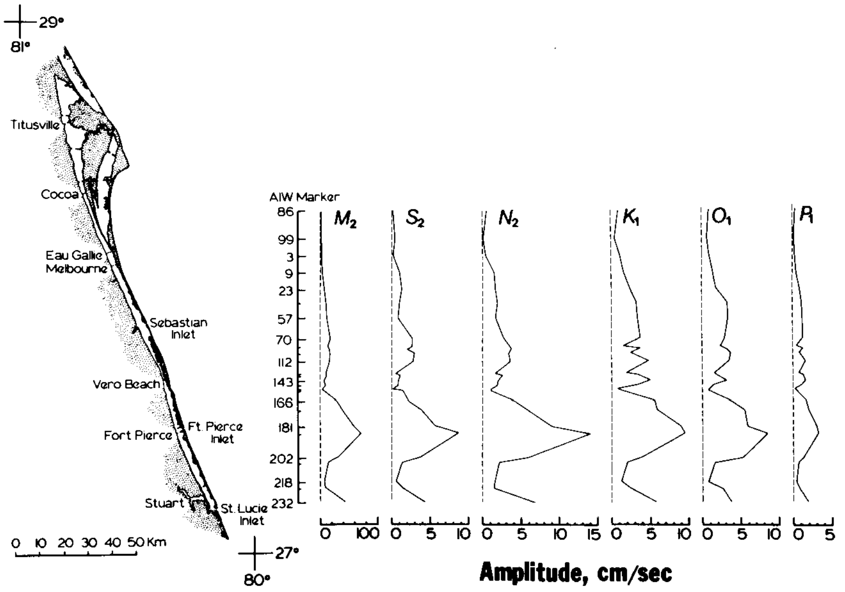

FIG. 1. Amplitudes of principal semi-diurnal and diurnal tidal constituents, in cm/s, recorded in Florida's Indian River lagoon between Atlantic Intracoastal Waterway (AIW) Markers 86 and 232. Note that the M_2 constituent amplitude has been plotted on a compressed axis. Major tick marks indicate labeled AIW marker numbers; minor tick marks represent intermediate markers listed in Table 1.

RESULTS—Harmonic constants of tidal constituents within the lagoon are listed in tabular form in Table 1 and shown in analog form in Figs. 1 and 2. Figure 1 shows tidal constituent amplitudes, in cm/s, along the longitudinal axis of the lagoon. The M_2 constituent was isolated and is presented above a compressed axis to the right of the lower-amplitude constituents. All constituents show locally higher amplitudes in the immediate vicinity of St. Lucie and Ft. Pierce Inlets. Amplitudes computed from data collected just inside Sebastian Inlet are not appreciably higher than those from adjacent study sites further north and south. The lower-amplitude constituents show locally higher amplitudes in the interior of the lagoon where constrictions reduce the cross-sectional area.

The M_2 constituent is best suited for determining where tidal motion and, therefore, tidal flushing are minimal. In the southern segment, between St. Lucie and Ft. Pierce inlets, lowest M_2 amplitudes of approximately 7 cm/s are computed from data collected at AIW Marker 218 (27° 16′N). In the central segment, between Ft. Pierce and Sebastian inlets, minimal amplitudes

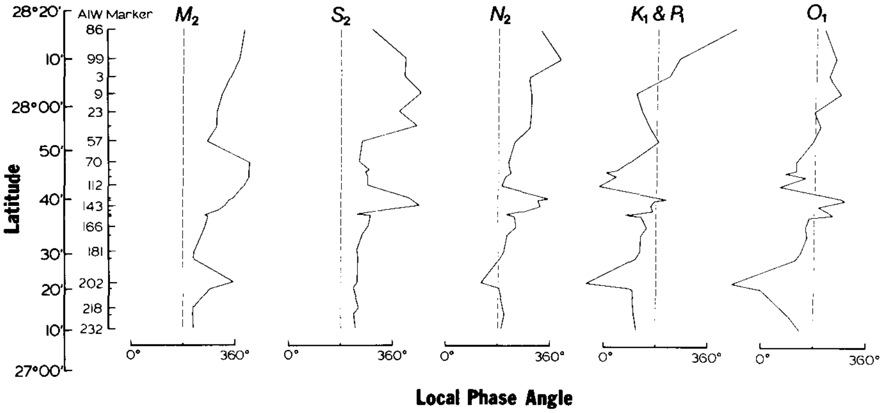

FIG. 2. Same as Fig. 1, except showing local phase angles. Note that the K_1 and P_1 constituents are represented by the same line.

occur in the vicinity of AIW Marker 154 (27°36'N), just south of Vero Beach. North of Sebastian Inlet, in the northern segment of the lagoon, amplitudes continue to decrease northward. M_2 amplitudes reach 1 cm/s at AIW Marker 99 (28°11'N). This appears to be a real value, even though it is at the precision of the measurements. Multiple, overlapping, harmonic analyses produce consistent phase angles. Still, the tidal excursion—the horizontal displacement associated with either the flood or ebb portion of the tidal cycle—is less than 150 m (the M_2 constituent tidal excursion is found by multiplying the amplitude by the 12.421-h period and dividing by π). Measurements were not made farther north, because tidal excursions on the order of 100 m are not physically important, even if the amplitudes are statistically significant.

Local phase angles are shown in Fig. 2. The horizontal scale has been extended beyond a range of 0–360°, making it possible to offset curves that would otherwise overlap. In general, one would expect phase angles to be lower near inlets, thereby indicating a phase lead of flood, ebb, or slack water conditions. The M_2 constituent shows this best, because it is most prominent throughout the lagoon. Other constituents show greater spatial variability, because it is difficult to pinpoint the exact crest of a very low-amplitude sine wave.

M_2 constituent phase angles increase by approximately 140° between either St. Lucie or Ft. Pierce Inlet and the interior of the southern segment. This corresponds to a time delay of approximately 5 h. The phase lag in the interior of the central segment is somewhat greater, partly because the central segment is 8 km longer than the southern segment, and certainly because spoil islands in the interior decrease the speed of propagation. The 190° M_2 phase lag between Ft. Pierce Inlet and the area between AIW markers 75 and 112 (27°46' to 27°43'N) corresponds to a time lag of over 6.5 h. It is of interest to note that maximal phase lags occur at stations well north of the midpoint of the central segment and over 20 km north of where the lowest amplitudes occurred. It appears that northward moving tidal waves from Ft. Pierce Inlet are dominant through most of the central segment, while waves moving south from Sebastian Inlet play a dominant role only relatively close to the inlet. In the northern segment of the lagoon, a phase lag of 130° is calculated between AIW markers 57 and 86 (27°52' to 28°17'N). This corresponds to a time lag of about 4.5 h from Sebastian Inlet to just south of Cocoa.

TABLE 1. Harmonic constants of principal semi-diurnal and diurnal tidal constituents for Indian River lagoon. Amplitudes (η) in cm/s; local phase angles ($\varkappa$) in degrees. H is the height (m) of the current meter above the bottom. The date refers to the midpoint of the time series.

	Location					Constituent					
Mkr	N	W	H	Date		M_2	S_2	N_2	K_1	O_1	P_1
86	28°17.3′	80°41.5′	1.5	Apr 88	η	1.1	0.1	0.4	1.0	1.0	0.3
					$\varkappa$	028	332	347	088	207	088
99	28°10.8′	80°38.3′	1.5	Dec 87	η	1.0	0.4	0.1	0.4	0.6	0.1
					$\varkappa$	009	043	028	252	246	252
3	28°06.8′	80°36.4′	1.5	Sept 87	η	2.2	0.3	0.4	1.1	0.9	0.4
					$\varkappa$	339	038	281	222	221	222
9	28°03.3′	80°34.6′	1.5	Oct 86	η	2.8	1.0	1.5	1.6	1.4	0.5
					$\varkappa$	312	095	287	112	168	112
23	27°58.7′	80°32.2′	1.5	Jun 83	η	7.3	1.3	1.7	2.4	1.8	0.9
					$\varkappa$	295	017	290	140	177	140
41	27°55.3′	80°31.0′	1.5	Jun 83	η	10.4	1.0	2.0	3.3	3.3	1.1
					$\varkappa$	293	082	284	155	196	155
57	27°52.2′	80°29.1′	1.5	Sep 83	η	11.0	0.9	1.7	3.5	3.5	1.2
					$\varkappa$	259	253	232	187	173	187
70	27°47.9′	80°27.0′	1.5	May 80	η	18.7	2.8	2.8	3.8	2.9	1.3
					$\varkappa$	045	060	030	264	292	266
75	27°46.3′	80°25.8′	1.0	May 77	η	13.5	2.6	3.6	1.5	2.3	0.5
					$\varkappa$	042	095	033	226	297	226
80	27°45.8′	80°25.2′	1.0	Jul 76	η	15.6	2.1	3.8	3.8	3.1	1.3
					$\varkappa$	040	081	038	182	255	182
92	27°44.9′	80°24.2′	1.0	May 77	η	16.9	3.0	3.4	2.4	3.7	0.8
					$\varkappa$	041	090	019	220	329	220
112	27°43.1′	80°23.8′	1.0	Jul 76	η	16.1	2.8	3.7	4.9	3.5	1.6
					$\varkappa$	025	090	008	158	239	158
132	27°40.1′	80°23.0′	1.5	May 80	η	9.8	0.5	1.7	2.0	1.5	0.7
					$\varkappa$	348	050	348	215	269	215
134	27°39.8′	80°22.8′	1.0	May 77	η	11.0	1.1	2.6	3.5	1.8	1.2
					$\varkappa$	335	063	310	171	283	171
143	27°38.6′	80°22.3′	1.0	Jul 76	η	7.2	0.9	2.1	5.1	3.2	1.6
					$\varkappa$	319	090	319	159	192	159

Table 1. Continued

Mkr	Location		H	Date		Constituent					
	N	W				M_2	S_2	N_2	K_1	O_1	P_1
146	27°37.6′	80°22.2′	1.0	May 77	η	9.4	0.8	2.0	3.4	1.3	1.1
					κ	298	322	273	167	225	167
152	27°36.7′	80°21.9′	1.0	Jan 77	η	3.6	0.2	1.1	0.8	0.9	0.2
					κ	249	232	205	069	241	069
154	27°36.4′	80°21.7′	1.0	Jan 77	η	7.4	1.4	1.1	1.1	0.7	0.4
					κ	266	279	233	128	163	128
166	27°34.0′	80°21.1′	1.0	Jul 76	η	30.5	2.2	4.4	5.7	3.8	1.8
					κ	253	274	240	153	152	153
171	27°32.2′	80°20.7′	1.5	May 79	η	38.9	3.9	6.1	6.0	5.6	2.0
					κ	240	251	208	129	135	129
181	27°28.6′	80°19.6′	1.0	Jul 76	η	59.2	5.7	9.2	9.0	5.8	3.0
					κ	216	232	196	123	135	123
188	27°27.1′	80°19.0′	1.5	Aug 81	η	70.8	8.4	14.2	9.5	8.6	3.2
					κ	032	056	005	291	295	291
202	27°21.3′	80°16.7′	1.5	Jul 81	η	31.3	3.8	6.1	4.0	5.3	1.3
					κ	352	053	297	119	075	119
207	27°20.1′	80°15.8′	1.5	Jan 87	η	13.8	1.4	2.2	2.1	1.6	0.7
					κ	272	041	360	273	188	273
218	27°15.6′	80°13.4′	1.5	May 88	η	7.2	0.6	1.5	1.3	0.7	0.4
					κ	212	243	200	094	136	094
222	27°14.1′	80°12.5′	1.5	Sept 87	η	8.8	1.4	1.5	2.3	2.5	0.8
					κ	211	224	200	103	095	103
232	27°10.4′	80°11.1′	1.5	July 81	η	43.1	4.3	6.9	5.8	3.8	1.9
					κ	212	228	189	112	134	112

When time lags such as those noted above are combined with distances separating stations, one can estimate phase speeds for any given tidal constituent. Again using the M_2 constituent as an example, in the southern segment, the nearly 5 h required for wave forms to move approximately 20 km translates into a phase speed of just over 4 km/h. In the central segment, wave forms moving north from Ft. Pierce Inlet to AIW Marker 70 in about 6.5 h indicate a phase speed of approximately 5 km/h. In the northern segment of the lagoon, the average phase speed of the M_2 constituent moving north from Sebastian Inlet to near Cocoa is just under 10 km/h.

DISCUSSION—Both the ebb and flood of the tide along the AIW and the rise and fall of water level in the lagoon arise fundamentally from tidal wave forms moving north to south along Florida's Atlantic shelf. As high and low tides pass by the inlets, water is alternately forced into and drawn out of the lagoon. But the transition from shelf tides to lagoon tides is quite different for currents than for water levels. Part I of this study (Smith, 1987) showed tidal amplitudes decreasing substantially in the immediate vicinity of each inlet. Frictional effects in the shallow water of the lagoon combine with the constricting effect of an inlet to decrease tidal-period variations in water level as tidal waves enter the lagoon. For example, M_2 amplitudes estimated from bottom pressure records obtained 1 km seaward of Ft. Pierce and Sebastian inlets are just over 50 cm. For comparison, the M_2 amplitude in the lagoon near both Ft. Pierce and St. Lucie Inlets was found to be 17 cm; it was 8 cm near Sebastian Inlet.

Current data presented here in Part II of this study reveal a quite different pattern. Tidal amplitudes increase dramatically at each inlet. Under frictionless conditions, phase speed is proportional to the square root of the water depth. As tidal waves enter the lagoon, the shallow water slows the speed of propagation substantially. As a result of the reduced phase speed, the wavelength becomes significantly shorter, the wave form is compressed, and the slope of the wave form ahead of and behind the crest increases. The pressure gradient associated with the surface slope is the primary driving force for the ebb and flood of the tide; and, thus, significantly higher current speeds result. The shallow water initially slows the tidal wave form much more than it decreases its amplitude, explaining the substantial, if local, increase in current speed.

Within the lagoon, the water depth and, therefore, wavelengths remain about the same, and wave forms are not compressed further. Frictional losses continue to decrease the tidal range, however. Thus, in the interior of the lagoon, the pressure gradient and resulting current speeds decrease appreciably. Figure 1 shows that at the midpoint of both the southern and central segments, M_2 current speeds are about 10 cm/s. In the northern segment, current amplitudes are reduced to less than 1 cm/s north of 28° 10′N. Farther north, tides are physically unimportant in both water-level and current-meter records.

Both Figures 1 and 2 show some significant differences in phase and amplitude at adjacent stations. Any of several different explanations may account for this. First, mass continuity considerations require that the amplitude vary inversely with the local cross-sectional area of the lagoon. The depth and width of the AIW are essentially constant along the length of the lagoon, but the width of the lagoon itself, as well as the mean depth outside the dredged channel, can vary by a factor of 2–3. Second, in view of the probability that the bottom friction layer extends through the entire water column, the indicated spatial variation in amplitude must reflect the mooring design used at the time the data were recorded. Specifically, at any given location, the amplitude of the tidal constituent in question may be directly but nonlinearly related to the height of the current meter above the bottom. This presents a problem when time series from many individual studies are combined. No attempt was made to correct for the position of the current meter above the bottom, but recent modeling work (Smith, in press) suggests that amplitudes computed from measurements made 1.5 m above the bottom in water 3 m deep are approximately 15% greater than amplitudes computed from measurements made 1 m above the bottom.

A third reason why neighboring amplitudes may differ significantly stems from the seasonal and certainly annual variation in the cross-sectional area of the nearest inlet. Ft. Pierce Inlet receives annual maintenance dredging; both Sebastian Inlet and St. Lucie Inlet are dredged less frequently. Because data collected for this study were collected over a 13-yr period, it is probable that tidal exchanges through Sebastian and St. Lucie inlets varied measurably and that this had a direct influence on tidal amplitudes in the lagoon. No long time series are available from outside the lagoon to determine whether these differences are a result of tidal exchanges through inlets or a result of changes in the constituents themselves during the study period.

Station-to-station variations in local phase angle along the axis of the lagoon (Fig. 2) may be influenced by any of several processes which influence the propagation speed of tidal wave forms. Both high-frequency wind-wave motions and low-frequency meteorological forcing can influence tidal conditions and thereby contribute noise to a composite which combines measurements separated in time and space. Grant and Madsen (1979) have shown that turbulence arising from oscillatory wave motions increases the effective bottom roughness and thus retards tidal wave propagation. Enhanced bottom stress might be especially important in the shallow waters of a coastal lagoon. Spatial variations in fetch from one study site to the next, together with temporal variations in mean wind speed from one study period to the next, can distort spatial patterns in local phase angles when results are compiled.

Over longer time scales, the propagation of tidal waves can be influenced directly by nontidal water-level variations. As noted above, the phase speed in shallow water is proportional to the square root of the water depth. In Indian River lagoon, where seasonal variations in water level have an average amplitude of 10 cm (Smith, 1987) and where meteorological forcing can raise or lower water levels an additional 0.5 m relative to the seasonal norm (Smith, 1986), the phase speed in water 1–2 m deep can vary on the order of ± 15–20%.

While data assembled in this study provide a good overview of the ebb and flood of the tide along the longitudinal axis of the lagoon, results presented (Figs. 1 and 2) cannot be extrapolated laterally into the shallow waters of both sides of the AIW. A logical follow-up to this introduction to tides would involve the application of a lagoon-scale, two-dimensional hydrodynamic model. Once calibrated, the model could provide the time series necessary to construct co-tidal and co-range lines throughout the lagoon. *In situ* data might still be required to verify tidal conditions in areas of specific interest, but results of the model would improve considerably the one-dimensional picture presented here.

Current-meter data from within Indian River lagoon are put in perspective by noting tidal conditions in adjacent shelf waters. Unpublished current data were collected 1 km from the coast at a study site 15 km north of Sebastian Inlet between mid-July and mid-November, 1984. Computed harmonic constants include an M_2 amplitude of 1.5 cm/s in the along-shelf direction and 0.5 cm/s in the cross-shelf direction. Both values are well within the precision of the current-meter measurements used in the calculations. The associated along-shelf tidal excursion is less than 0.25 km. Thus, tidal currents over the inner shelf are physically unimportant for most practical purposes.

With the available data base, Indian River lagoon emerges as an unexceptional "restricted" type coastal lagoon. Tidal co-oscillations provide significant transport near each inlet. While tidal motions may stand out distinctly in current-meter records, they decrease substantially in importance in the interior of the lagoon. There, as in many coastal lagoons, tides provide a baseline level of transport and flushing but play an ancillary role to the local wind-driven circulation.

Acknowledgments—Any study that involves reading, key-punching, proofreading, and analyzing over 100,000 current speed and direction pairs will understandably require and benefit from the assistance of many individuals. Dr. Ortwin von Zweck directed the data collection and reduction during 1976 and 1977 under a consulting agreement with Harbor Branch Foundation while he was a member of the Florida Institute of Technology faculty. Dove W. Green painstakingly digitized many time series collected during that same time, including 11 used in this study. Lew Gilliland took over from 1979-80; Mark Sternberger continued in 1981–83, as the study expanded into the southern segment of the lagoon. Elizabeth Smith assisted in data collection and analysis during 1982–84. Patrick Pitts has been playing a central role in the data collection and reduction since mid-1984. He was in charge of field studies designed to fill gaps in the southern segment, and he worked with Paul Mikkelsen in 1986 to extend spatial coverage into the northern segment of the lagoon. In addition, Patrick Pitts worked with summer intern Rusty Tarver in 1987 to complete the important but onerous task of double-checking and editing time series during the final compilation of the 27 time series used in this paper. Harbor Branch Oceanographic Institution, Inc., Contribution Number 772.

LITERATURE CITED

DENNIS, R. E. AND E. E. LONG. 1971. A user's guide to a computer program for harmonic analysis of data at tidal frequencies. NOAA Tech. Rept. 41, U.S. Dept. Comm., Rockville, MD.

GRANT, W. D. AND O. S. MADSEN. 1979. Combined wave and current interaction with a rough bottom. J. Geophys. Res. 84:1797–1808.

HAURWITZ, B. AND A. COWLEY. 1975. The barometric tides at Zurich and on the summit of Santis. Pure Appl. Geophys. 113:355–364.

KJERFVE, B. J. 1986. Comparative oceanography of coastal lagoons. Pp. 63–81. *In:* WOLFE, D. A. (ed.), Estuarine Variability. Academic Press, New York.

PANDIT, A. AND C. C. EL-KHAZEN. 1990. Groundwater seepage into the Indian River lagoon at Port St. Lucie. Fla. Scient. 53(3a).

SMITH, N. P. 1986. The rise and fall of the estuarine intertidal zone. Estuaries 9:95–101.

———. 1987. An introduction to the tides of Florida's Indian River lagoon. I. Water levels. Fla. Scient. 50:49–61.

———. (in press) Computer simulation of residual tidal transport in a coastal lagoon. J. Geophys. Res.

From the *SECOND Indian River Research Symposium*, Marine Resources Council, 12-13 September 1988, at Florida Institute of Technology, Melbourne.

Florida Sci. 53(3):216-225. 1990.
Accepted: May 13, 1989.