TIDE AND TIDAL CURRENT PREDICTION BY HIGH SPEED DIGITAL COMPUTER

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Introduction

The Tide and Tidal Current Tables of the U. S. Coast and Geodetic Survey for 1966 have been computed and edited by a digital computer, the IBM 7094. Prediction by this method is found to be more economical and expedient than by the tide prediction machine in use since 1910.

The shift to digital predictions has been gradual. The first program was prepared in 1956 to predict hourly tide heights only, for use in storm surge research. The greatest advantage to digital prediction at that time was the elimination of the hour or more required to set up a new problem on the tide predicting machine, when highly accurate predictions were needed for many short periods. Later, as more efficient computers became available, this program was expanded to include the computation of highs and lows, editing the data in a form suitable for publication and the complete prediction and editing of the tidal current tables.

The existing program, to a large degree, reproduced the same calculations formerly made on the analogue tide predicting machine, and with comparable accuracy. The greater versatility of this system invites experimentation, not feasible with the analogue computer. Thus, it is expected that in the long run the switch to digital calculations will lead to an increase in the accuracy of the predictions for stations having complex tide problems.

The program grew through the years, and is not the most efficient that could be prepared today. Nevertheless, it appears doubtful that the improved efficiency would justify a complete revision. This report gives a general description of the program, the input data specifications and samples of the results.

The Mathematical Problem

The equation for the height of the tide at any time, as given by SCHUREMAN, is well suited to calculation by a digital computer and may be written:

$$h = H_0 + \sum_{n=1}^{37} f_n H_n \cos \left[a_n t + (V_0 + u)_n - K'_n \right] \qquad (1)$$

where

h = height of tide at any time t.
H_0 = mean height of water level above datum used for prediction.
H_n = mean amplitude of any constituent A_n.
f_n = factor for reducing mean amplitude to year of prediction.
a_n = hourly speed of constituent A_n.
t = time, in hours, reckoned from beginning of year of prediction.
$(V_0 + u)_n$ = Greenwich equilibrium argument of constituent A_n when $t = 0$.
K'_n = modified epoch of constituent A_n.

For the average station, 20 constituents are used in the prediction process. This means that the prediction of a complete year of 8760 hourly tide heights would require 175 200 cosines. Obviously a program which would require the calculation of that many cosines would be relatively inefficient. For this reason a table of cosines is supplied to the program and a table look-up procedure is used.

The Cosine Table

The accuracy of the tide calculation is determined by the length of the stored cosine table, but the amount of useful accuracy is sharply limited by physical considerations. In the United States, hourly observations, the input data for analysis, are tabulated in tenths of feet. Certainly it is sufficient, for practical purposes, to compute the tide predictions to the nearest 0.1 foot.

An angle can be expressed in the form $2n\pi + R$, where n is an integer. In the angles required for tide computation, we are interested only in the remainder "R" after dividing the required angle by 2π. The simplest method for obtaining this with a binary computer is to set 2π radians $= 2p$, where p is an integer. When this is done, the operation modula 2π can be carried out simply by shifting of the angle in the arithmetic register.

Because the program does not crowd the capacity of the available computer, a cosine table of 1024 (2^{10}) increments in one quadrant is used. The maximum difference in the cosines of this table between two successive entries is about 0.0016 which means that the maximum error of any constituent is about 0.0008 of the amplitude of the constituent. Therefore the cosine table with 1024 entries per quadrant and maximum error of each constituent of only 0.0008 of the amplitude is more than adequate for hourly tide predictions, to the nearest 0.1 foot.

The cosine table requirements for determining the time of extremes are different. In this problem it is necessary that the computed values of any constituent, which may determine the time of the extreme, be distinct when the computation times are separated by the smallest interval used in stating the time. The table of 1024 values per quadrant is sufficient for this purpose.

The Computation Procedure

The input data to the program consist of several tables of constants and a date control card. The amplitude for each constituent (H_n) and the modified epoch of each constituent (K'_n) are constants determined for each location for which tide predictions are desired. The harmonic analysis of a series of tide observations made at each location determines these constants. These two tables therefore depend upon the station being considered. The node factor (f_n) is used to determine the true amplitude ($f_n H_n$) for each constituent depending upon the year. The equilibrium argument of each constituent $(V_0 + u)_n$ is usually the argument when t is taken to be midnight at the beginning of the year. These two sets of constants, node factor and equilibrium argument, therefore depend on the year for which tide predictions are being made. In addition there is a table of the speeds (a_n) of the constituents. Each of these five tables contains 37 constants and requires two cards. The date control card specifies for each desired period the month, the first day, and the number of days for which predictions are to be calculated. Several periods may be specified by each date control card. For a complete year the date control card specifies twelve periods, one for each month.

The program forms the prediction constants:

$$B_n = H_n \times f_n \tag{2}$$

$$D_n = (V_0 + u)_n - K'_n \tag{3}$$

and regroups them to omit all constituents for which $H_n = 0$. The prediction formula is now:

$$h = H_0 + \sum_{n=1}^{N} B_n \cos (a_n t + D_n) \tag{4}$$

Here t is the number of hours between 0000, January 1, and 0000 the first day of the computation period, and N is the number of non-zero constituents. The determination of t is with a table which gives the first hour number of each month, the beginning day of the computation period from the date control card, and a consideration of whether the year is a leap year or a non-leap year. The calculation for the first hour is carried out by the solution of equation 4. The argument $\theta_m(t) = (a_n t + D_n)_m$ is stored in a table for each constituent. For each succeeding hour the argument for each constituent is increased by the hourly speed : $\theta_m(t + 1) = \theta_m(t) + a_n$. The angles in the table (θ_m) are reduced to less than 2π before the cosine table look-up feature is used. This is accomplished by shifting the argument and losing the bits larger than 2π. Since the stored cosine table contains the 1024 values for only one quadrant, the quadrant of the desired angle must be determined. This is done by successive subtractions of $\pi/2$ and testing for the negative sign. The following definitions are used to determine cosine values in the four quadrants:

First quadrant	:	$\cos \theta = \cos \theta$	(5)
Second quadrant	:	$\cos \theta = -\cos (\pi - \theta)$	(6)
Third quadrant	:	$\cos \theta = -\cos (\theta - \pi)$	(7)
Fourth quadrant	:	$\cos \theta = \cos (2\pi - \theta)$	(8)

The tide calculation for the last hour of the time period is done twice, once in the usual manner by incrementing each constituent phase by the constituent speed each time period, and also by a completely independent calculation using equation 4 and substituting the correct value of t for the last hour. The two calculations are then compared and should be the same. No discrepancy has been found with this check in the several hundred times the program has been used.

After the program was completed to calculate hourly tide heights, several methods were considered to obtain the high and low tide predictions. The usual method of determining the time of high and low tide by setting the derivative of equation 1 equal to zero is not well adapted as the zero derivative would have to be approximated from an interpolation between points determined for fixed time intervals, or found more accurately by some type of iterative procedure. Polynomial interpolation of the two, three, four, or six highest or lowest hourly values was another possibility. This procedure is not satisfactory for stations where tides depart markedly from a sinusoidal character. At Galveston, for example, the highest tide may be the same to two significant digits for three consecutive hours. A more direct procedure would be to make several computations of tide height near the time of expected extreme tide and to select the extreme value of these computations as the tide maximum or minimum. Such a procedure would have difficulty in dealing with some of the Gulf of Mexico locations where relatively flat portions occur on the tide curve.

After further consideration the program was modified to scan the predicted hourly heights for extreme values. When an extreme is found, the program determines if it is examining hourly values near the time of a high or a low tide by comparing two successive hourly values. Then calculations are made at one-tenth hour intervals beginning one hour before the time of the extreme hourly value. To make calculations at one-tenth hour intervals, a new table of constituent speeds is generated and stored by dividing the table of hourly speeds by ten.

After each calculation at the one-tenth hour interval, comparison is made with the calculation for one-tenth hour earlier. This procedure is continued until the extreme tide is found. The time of extreme tide is readily obtainable by counting the number of calculations made at one-tenth hour intervals to determine the extreme height. Publishing predicted times in tenths of hours is a departure from present practice but it is felt that for practical purposes this accuracy is sufficient. It does represent an economy in digital computation. The tide extremes computed by this system are in close agreement with those calculated with the mechanical tide predicting machine. The time required for the computation of one year of hourly tide heights is about one-half minute on the IBM 7094. Computation of the high and low waters for a complete year requires about one minute.

Tidal Currents

Because the same periodic constituents are used in the prediction of tidal currents as in tide heights, and since the node factors (f_n) and arguments $(V_0 + u)_n$ are the same as for tide heights, the basic program is used for the prediction of tidal currents. Amplitudes are supplied in knots and hourly velocities are computed. The time and velocity of maximum current are computed in the same manner as for tide heights but a modification is necessary to search for the time of zero velocity (slack water).

MPTON ROADS, VA.
AR 1964 MONTH 5 DATUM 125 X .01 FEET NO. OF CONSTITUENTS 15

CLUDES SA AND SSA

0	64	5	125	15	0	0	0	0	0	0	0	0
1	25	23	18	13	7	4	2	3	6	11	15	19
1	20	19	16	12	7	4	3	4	9	12	18	22
2	24	24	21	16	11	7	4	3	5	8	12	16
2	19	19	18	15	11	7	4	4	6	9	14	18
3	22	23	22	19	15	10	6	4	4	6	9	13
3	16	19	19	17	14	10	7	5	4	6	10	14
4	18	21	22	21	18	14	10	6	4	4	6	9
4	13	17	19	19	17	14	10	7	5	4	6	10
5	14	18	21	22	21	18	14	9	6	4	4	6
5	10	14	18	20	20	18	15	11	7	4	4	5
6	9	13	18	21	23	21	18	13	9	5	3	3
6	6	10	15	19	22	22	20	16	11	6	3	2
7	4	8	13	18	22	23	22	18	13	8	3	1
7	2	5	10	16	21	24	24	21	16	10	5	1
8	0	2	7	13	19	23	24	23	18	12	6	1
8	-1	1	5	11	18	24	27	27	23	17	9	3
9	-1	-2	1	6	13	20	24	25	23	18	11	4
9	-1	-2	-0	5	13	21	27	30	29	24	16	8
0	1	-3	-4	0	6	14	21	26	26	23	17	9
0	2	-3	-4	-0	6	15	23	29	32	30	24	15
1	6	-1	-5	-4	-0	7	15	22	26	26	22	15
1	7	0	-4	-4	0	8	17	25	31	33	30	23
2	14	5	-2	-6	-5	1	8	17	23	27	26	21
2	14	5	-1	-5	-4	1	9	19	27	32	33	30
3	22	13	4	-3	-5	-4	2	9	17	24	26	25
3	20	12	4	-2	-5	-3	2	11	20	27	32	32
4	28	21	12	3	-3	-5	-3	3	11	18	23	26
4	24	18	11	4	-2	-4	-2	4	12	20	27	31
5	31	27	19	11	3	-2	-3	-1	4	11	18	23
5	24	23	18	11	4	-1	-2	-0	5	12	20	26
6	29	29	25	18	11	4	-0	-2	0	5	12	18
6	22	23	22	17	11	5	1	-1	1	5	12	18
7	24	27	27	23	18	11	5	1	-0	2	6	12
7	17	21	23	21	18	12	7	3	1	2	6	11
8	17	22	25	25	22	17	11	6	2	1	2	6
8	12	17	21	23	22	18	13	8	4	2	2	5
9	10	16	20	23	24	21	17	11	6	2	1	3
9	6	12	17	21	23	23	19	14	9	4	2	2
0	5	9	15	19	22	23	21	16	11	6	2	1
0	3	7	12	18	22	24	23	20	15	9	4	2
1	1	4	9	14	19	22	22	20	16	10	5	1
1	1	3	7	13	19	24	26	24	20	15	9	4
2	1	1	4	9	15	19	22	22	19	14	9	4
2	1	1	3	9	15	21	25	27	25	20	14	7
3	2	0	1	5	10	16	20	22	22	18	13	7
3	2	-0	1	5	11	17	23	27	27	24	18	12
4	5	1	-0	1	6	12	17	21	22	21	16	10
4	5	1	-0	2	7	13	20	25	28	27	23	16
5	9	4	-0	-0	2	8	13	19	22	22	19	14
5	8	3	-0	0	3	9	16	22	27	28	26	21
6	14	7	2	-1	0	4	10	15	20	22	21	17
6	12	6	2	-0	1	6	12	19	24	27	27	24
7	18	11	5	1	-0	2	6	12	17	21	22	20
7	15	10	4	1	1	3	8	15	21	25	27	26
8	21	15	8	3	0	0	3	8	14	18	21	21
8	18	13	8	3	1	2	5	11	17	23	26	26
9	24	19	12	6	2	1	2	6	11	16	19	21
9	19	16	11	6	3	2	4	8	13	19	23	25
0	25	21	16	10	5	2	1	3	8	12	17	20
0	20	18	14	10	5	3	3	5	10	15	20	24
1	25	23	19	14	8	4	2	2	5	9	14	18
1	20	19	17	13	9	5	3	4	7	11	16	21

FIG. 1. — Sample printout of predicted hourly heights, tenths of feet.

EASTPORT, MAINE, 1966

TIMES AND HEIGHTS OF HIGH AND LOW WATERS

JANUARY

DAY	TIME H.M.	HT. FT.	DAY	TIME H.M.	HT. FT.
1	0524	16.4	16	0012	1.0
SA	1148	2.2	SU	0624	17.9
	1748	15.8		1254	0.6
				1900	16.5
2	0006	2.2	17	0112	1.4
SU	0612	16.8	M	0724	17.7
	1242	1.7		1354	0.6
	1842	16.0		2000	16.4
3	0100	2.0	18	0212	1.6
M	0706	17.4	TU	0818	17.8
	1336	1.1		1448	0.4
	1936	16.5		2054	16.4
4	0154	1.5	19	0306	1.5
TU	0800	18.2	W	0912	17.9
	1430	0.2		1536	0.3
	2030	17.0		2142	16.5
5	0248	1.0	20	0354	1.4
W	0848	19.0	TH	1000	18.0
	1524	-0.6		1624	0.1
	2124	17.7		2224	16.6
6	0336	0.3	21	0436	1.3
TH	0942	19.8	F	1036	18.0
	1612	-1.5		1706	0.0
	2212	18.4		2306	16.8
7	0430	-0.3	22	0518	1.2
F	1030	20.5	SA	1118	18.1
	1706	-2.1		1748	0.0
	2306	18.9		2342	16.9
8	0518	-0.9	23	0600	1.2
SA	1124	20.9	SU	1154	18.1
	1754	-2.6		1824	0.1
	2354	19.3			
9	0612	-1.2	24	0018	17.0
SU	1212	21.0	M	0636	1.2
	1842	-2.7		1236	17.9
				1900	0.3
10	0048	19.5	25	0100	17.0
M	0700	-1.3	TU	0718	1.3
	1306	20.8		1312	17.7
	1936	-2.5		1936	0.6
11	0136	19.5	26	0136	17.0
TU	0754	-1.2	W	0754	1.5
	1400	20.2		1354	17.4
	2024	-2.0		2018	0.9
12	0230	19.3	27	0218	17.0
W	0854	-0.9	TH	0836	1.7
	1454	19.4		1436	16.9
	2118	-1.3		2100	1.4
13	0330	18.9	28	0300	16.8
TH	0948	-0.4	F	0918	1.9
	1554	18.4		1518	16.4
	2218	-0.4		2142	1.8
14	0424	18.5	29	0348	16.7
F	1048	0.0	SA	1012	2.0
	1654	17.6		1612	16.0
	2312	0.4		2230	2.2
15	0524	18.1	30	0436	16.7
SA	1148	0.4	SU	1106	2.0
	1800	16.9		1706	15.7
				2324	2.4
			31	0530	16.9
			M	1200	1.8
				1806	15.7

FEBRUARY

DAY	TIME H.M.	HT. FT.	DAY	TIME H.M.	HT. FT.
1	0024	2.4	16	0148	2.4
TU	0630	17.2	W	0800	16.8
	1300	1.3		1424	1.3
	1906	16.0		2036	15.7
2	0124	1.9	17	0242	2.2
W	0730	17.9	TH	0848	17.1
	1400	0.5		1518	0.9
	2006	16.7		2124	16.1
3	0224	1.2	18	0330	1.8
TH	0824	18.9	F	0936	17.5
	1500	-0.6		1600	0.5
	2100	17.7		2206	16.5
4	0318	0.2	19	0418	1.3
F	0924	19.9	SA	1018	17.8
	1554	-1.6		1642	0.2
	2154	18.7		2242	16.9
5	0412	-0.8	20	0454	0.9
SA	1018	20.8	SU	1054	18.1
	1648	-2.5		1718	0.0
	2248	19.6		2318	17.3
6	0506	-1.7	21	0536	0.7
SU	1106	21.4	M	1130	18.2
	1736	-3.1		1754	0.0
	2336	20.2		2354	17.6
7	0554	-2.3	22	0612	0.5
M	1200	21.6	TU	1206	18.2
	1824	-3.3		1830	0.1
8	0030	20.6	23	0030	17.7
TU	0648	-2.5	W	0648	0.5
	1248	21.3		1242	18.0
	1912	-3.0		1906	0.3
9	0118	20.5	24	0100	17.8
W	0736	-2.3	TH	0724	0.7
	1342	20.6		1318	17.7
	2000	-2.3		1942	0.7
10	0206	20.1	25	0142	17.7
TH	0830	-1.7	F	0800	0.9
	1430	19.5		1400	17.3
	2054	-1.3		2018	1.2
11	0300	19.4	26	0218	17.5
F	0924	-0.9	SA	0842	1.2
	1530	18.3		1442	16.7
	2148	-0.1		2100	1.7
12	0354	18.5	27	0306	17.3
SA	1018	0.1	SU	0930	1.5
	1630	17.1		1536	16.2
	2242	1.0		2154	2.2
13	0454	17.7	28	0400	17.0
SU	1124	0.8	M	1030	1.8
	1730	16.1		1630	15.7
	2348	1.9		2248	2.6
14	0554	17.0			
M	1224	1.3			
	1836	15.6			
15	0048	2.4			
TU	0700	16.8			
	1324	1.5			
	1936	15.5			

MARCH

DAY	TIME H.M.	HT. FT.	DAY	TIME H.M.	HT. FT.
1	0454	16.9	16	0018	3.
TU	1130	1.8	W	0630	16.
	1736	15.6		1254	2.
	2354	2.6		1912	15.
2	0600	17.1	17	0118	2.
W	1236	1.3	TH	0730	16.
	1842	16.0		1354	1.
				2006	15.
3	0100	2.1	18	0218	2.
TH	0706	17.8	F	0824	16.
	1336	0.5		1448	1.
	1942	16.8		2054	16.
4	0200	1.1	19	0306	1.
F	0806	18.8	SA	0912	17.
	1436	-0.6		1530	0.
	2042	18.0		2136	16.
5	0300	-0.2	20	0348	1.
SA	0906	19.9	SU	0948	17.
	1536	-1.8		1612	0.
	2136	19.2		2212	17.
6	0354	-1.4	21	0430	0.
SU	1000	20.9	M	1030	18.
	1624	-2.7		1648	0.
	2230	20.2		2248	17.
7	0448	-2.4	22	0506	0.
M	1048	21.5	TU	1106	18.
	1712	-3.2		1724	0.
	2318	21.0		2324	18.
8	0536	-3.0	23	0542	0.
TU	1142	21.6	W	1142	18.
	1800	-3.3		1800	0.
				2354	18.
9	0006	21.2	24	0618	-0.
W	0624	-3.2	TH	1218	18.
	1230	21.2		1836	0.
	1848	-2.8			
10	0054	21.0	25	0030	18.
TH	0712	-2.8	F	0654	0.
	1318	20.3		1254	17.
	1936	-1.9		1912	0.
11	0142	20.3	26	0106	18.
F	0806	-1.9	SA	0736	0.
	1406	19.1		1330	17.
	2024	-0.7		1948	1.
12	0230	19.3	27	0148	18.
SA	0854	-0.8	SU	0818	0.
	1500	17.8		1418	16.
	2118	0.6		2030	1.
13	0324	18.1	28	0236	17.
SU	0954	0.3	M	0906	1.
	1600	16.5		1506	16.
	2218	1.8		2124	2.
14	0424	17.1	29	0330	17.
M	1054	1.3	TU	1000	1.
	1700	15.6		1606	15.
	2318	2.6		2224	2.
15	0524	16.3	30	0430	17.
TU	1154	1.9	W	1106	1.
	1806	15.1		1712	15.
				2330	2.
			31	0536	17.
			TH	1212	1.
				1818	16.

TIME MERIDIAN 75° W. 0000 IS MIDNIGHT. 1200 IS NOON.
HEIGHTS ARE RECKONED FROM THE DATUM OF SOUNDINGS ON CHARTS OF THE LOCALITY WHICH IS MEAN LOW WATER.

FIG. 2. — Sample page, tide predictions.

THE NARROWS, NEW YORK HARBOR, N.Y., 1966

F-FLOOD, DIR. 340° TRUE   E-EBB, DIR. 160° TRUE

JANUARY

DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS	DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS
1 A	0442 1142 1648 2342	0124 0806 1348 2018	1.5F 1.6E 1.1F 1.7E	16 SU	0542 1236 1748	0242 0854 1518 2106	1.8F 1.9E 1.2F 1.8E
2	0536 1236 1742	0218 0854 1448 2100	1.6F 1.8E 1.1F 1.8E	17 M	0036 0636 1336 1842	0348 0948 1624 2154	1.8F 1.9E 1.2F 1.8E
3	0030 0630 1336 1836	0312 0942 1548 2148	1.7F 1.9E 1.2F 1.8E	18 TU	0124 0730 1430 1930	0442 1042 1712 2242	1.9F 2.0E 1.3F 1.8E
4	0118 0718 1424 1924	0406 1036 1642 2236	1.9F 2.1E 1.3F 1.9E	19 W	0218 0812 1518 2018	0524 1130 1800 2330	1.9F 2.0E 1.3F 1.7E
5	0206 0812 1512 2012	0500 1124 1730 2330	2.1F 2.2E 1.5F 2.0E	20 TH	0306 0900 1600 2106	0606 1218 1836	1.9F 2.0E 1.3F
6	0254 0900 1600 2106	0548 1218 1818	2.3F 2.3E 1.6F	21 F	0348 0936 1642 2148	0024 0636 1300 1906	1.7E 1.9F 2.0E 1.3F
	0342 0948 1648 2200	0024 0630 1306 1900	2.1E 2.4F 2.4E 1.7F	22 SA	0430 1018 1724 2230	0106 0706 1342 1936	1.7E 1.8F 2.0E 1.3F
	0436 1036 1730 2254	0118 0718 1400 1954	2.2E 2.4F 2.5E 1.8F	23 SU	0512 1100 1800 2318	0148 0742 1418 2018	1.7E 1.8F 2.0E 1.4F
	0524 1130 1818 2348	0206 0812 1442 2048	2.3E 2.3F 2.5E 1.8F	24 M	0554 1136 1842	0230 0824 1500 2054	1.7E 1.7F 2.0E 1.4F
	0624 1218 1912	0300 0906 1530 2142	2.3E 2.2F 2.5E 1.8F	25 TU	0000 0636 1218 1918	0312 0912 1536 2142	1.7E 1.6F 1.9E 1.4F
	0042 0724 1312 2006	0354 1006 1624 2242	2.2E 2.0F 2.4E 1.9F	26 W	0042 0724 1300 2000	0348 0954 1612 2224	1.7E 1.5F 1.8E 1.4F
	0136 0824 1400 2100	0448 1100 1718 2336	2.1E 1.9F 2.2E 1.9F	27 TH	0130 0818 1342 2042	0436 1042 1654 2312	1.6E 1.4F 1.7E 1.5F
	0236 0930 1454 2154	0548 1200 1818	2.0E 1.7F 2.1E	28 F	0218 0918 1424 2130	0524 1130 1742	1.5E 1.3F 1.6E
	0336 1030 1548 2248	0030 0654 1254 1918	1.9F 1.9E 1.5F 1.9E	29 SA	0306 1012 1512 2212	0000 0624 1218 1836	1.5F 1.5E 1.2F 1.6E
	0442 1136 1648 2342	0130 0800 1406 2012	1.8F 1.9E 1.3F 1.9E	30 SU	0406 1112 1606 2300	0048 0730 1312 1936	1.5F 1.6E 1.1F 1.6E
				31 M	0500 1212 1706 2354	0142 0824 1412 2030	1.6F 1.7E 1.1F 1.7E

FEBRUARY

DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS	DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS
1 TU	0600 1306 1806	0236 0918 1512 2124	1.7F 1.9E 1.1F 1.8E	16 W	0106 0706 1406 1912	0418 1018 1654 2224	1.7F 1.8E 1.2F 1.7E
2 W	0048 0654 1400 1900	0342 1006 1618 2218	1.9F 2.0E 1.3F 1.9E	17 TH	0154 0748 1454 2000	0506 1106 1742 2312	1.7F 1.9E 1.3F 1.7E
3 TH	0142 0748 1448 1954	0436 1100 1712 2312	2.1F 2.2E 1.5F 2.1E	18 F	0248 0830 1536 2042	0548 1154 1818	1.8F 1.9E 1.4F
4 F	0236 0836 1536 2048	0530 1154 1800	2.3F 2.4E 1.7F	19 SA	0330 0912 1612 2124	0000 0618 1236 1842	1.7E 1.8F 2.0E 1.4F
5 SA	0330 0930 1624 2142	0006 0618 1248 1842	2.2E 2.4F 2.5E 1.9F	20 SU	0412 0954 1648 2206	0042 0648 1312 1912	1.8E 1.8F 2.0E 1.5F
6 SU	0424 1018 1706 2236	0100 0706 1336 1930	2.4E 2.4F 2.6E 2.0F	21 M	0448 1030 1724 2248	0124 0718 1348 1942	1.8E 1.7F 2.0E 1.5F
7 M	0512 1106 1754 2330	0154 0754 1424 2024	2.5E 2.4F 2.6E 2.1F	22 TU	0530 1106 1800 2330	0206 0800 1424 2024	1.9E 1.7F 2.0E 1.6F
8 TU	0606 1154 1842	0242 0848 1512 2118	2.5E 2.2F 2.6E 2.1F	23 W	0612 1148 1836	0242 0842 1500 2106	1.9E 1.6F 2.0E 1.6F
9 W	0024 0706 1242 1930	0330 0942 1554 2212	2.4E 2.0F 2.4E 2.0F	24 TH	0012 0654 1224 1912	0324 0924 1536 2148	1.8E 1.5F 1.9E 1.6F
10 TH	0118 0806 1336 2024	0424 1036 1648 2306	2.2E 1.8F 2.2E 2.0F	25 F	0054 0748 1306 1954	0400 1012 1612 2236	1.8E 1.3F 1.7E 1.6F
11 F	0212 0906 1424 2124	0524 1130 1742	2.0E 1.6F 2.0E	26 SA	0142 0842 1348 2042	0448 1100 1654 2324	1.7E 1.2F 1.6E 1.6F
12 SA	0306 1012 1518 2218	0000 0630 1230 1842	1.9F 1.9E 1.4F 1.8E	27 SU	0230 0942 1436 2130	0548 1154 1754	1.6E 1.1F 1.5E
13 SU	0412 1112 1618 2312	0100 0730 1336 1942	1.7F 1.8E 1.2F 1.7E	28 M	0330 1042 1536 2230	0018 0654 1242 1900	1.6F 1.6E 1.1F 1.5E
14 M	0512 1212 1718	0206 0836 1454 2042	1.6F 1.8E 1.1F 1.7E				
15 TU	0012 0612 1312 1818	0324 0930 1600 2136	1.6F 1.8E 1.1F 1.6E				

ME MERIDIAN 75° W.   0000 IS MIDNIGHT.   1200 IS NOON.

FIG. 3. — Sample page, tidal current predictions.

New routines are included for prediction of hydraulic currents and other special types. One year of predictions of tidal currents requires about one minute of computer time.

Program Output

On the computer system being used, the output is on magnetic tape which is printed on an off-line printer. The tide height output may include hourly heights or times and heights of high and low waters or both. The program has the option of making predictions either more or less frequently than once each hour. The hourly heights are printed six, twelve or twenty-four to a line, with the date included as shown in figure 1. The first row of figures on the page contains an assigned station number, year, month number, the value of mean sea level datum in the predictions, the number of constituents used and eight zeros. All other lines are arranged so that the first number is the date of the month and the other twelve numbers are tide predictions in tenths of feet. The first prediction of each day is for 0000 Local Standard Time.

There is a choice of format for the printing of high and low water. For research purposes all highs and lows are printed. For publication, the original tabulation of extremes is edited to provide a page format compatible with that now in use in the U. S. Coast and Geodetic Survey Tide Tables. A sample page is shown in figure 2. This page may be printed in the Metric system rather than the English system. The editing section of the program assumes there will be at least one tide extreme every day and makes proper allowances when two, three, or four occur. When there are five or more extremes in one day, only the first four are placed in the regular printed output to preserve the format. Listed elsewhere, to permit changes that may be necessary, are the times and heights of all the extremes for that day plus the last extreme on the day preceding and the first extreme on the day following. Hourly heights may also be printed to help determine which values will give the best representation of the tide during these unusual periods. For purposes of comparing one year with the next, predictions are listed for "December 32". Titles, headings, footnotes, days of the week, and dates of the month are provided by the program.

Two months of tidal current predictions are presented on a page which is complete and ready for photographing, with the exception of page numbers. The letters "E" and "F" are used to denote ebb and flood current. The direction of flow at time of maximum current is given at the top of the page. Figure 3 is a sample page of tidal current predictions.

Summary

The tide and tidal current tables of the United States Coast and Geodetic Survey are now produced by electronic digital computer. The development of this system began in 1956 and today is capable of producing the predictions in the standard format of the published tables. This method is more economical and expedient than that of using the analogue type tide

predicting machine, and has comparable accuracy. One year of calculations for one station requires about one minute of IBM 7094 time for each type of table, the tide tables and the tidal current tables.

Reference

SCHUREMAN, Paul (1958) : Manual of Harmonic Analysis and Prediction of Tides, Special Publication No. 98, U.S. Dept. of Commerce, Coast and Geodetic Survey, Washington, D.C., 317 pp.