TIDAL CURRENTS

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TIDAL CURRENTS

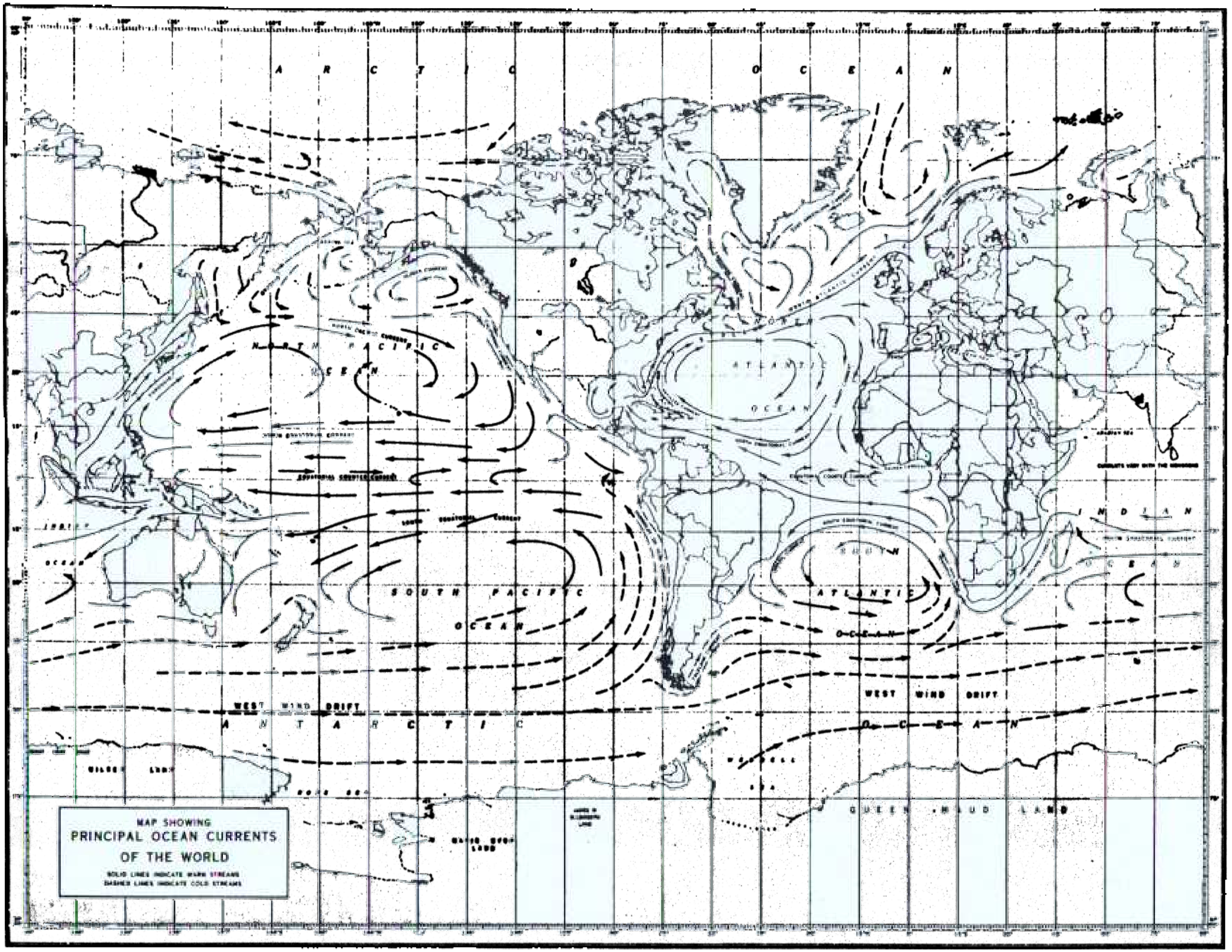
Man in his never ending search for knowledge and in his travels on the sea has long known about the ocean's tides and currents. Although he may not have fully understood the reasons for the movements of these waters, he was very much aware of their benefits and dangers to him. Today the study of the tide and current is still a major problem facing the oceanographer due to the increased needs of the scientist, engineer, military, and the general public.

In presenting a study of the ocean's tides and currents, the usual practice is to consider each separately. In this paper the primary emphasis is on tidal currents with only a brief reference to the tide. For a more complete discussion on the tide, the reader is referred to various C&GS manuals as well as the paper "Significant Aspects of The Tide."

Basically the current in the seas can be broken down into two parts, namely tidal and nontidal. Tidal currents are the horizontal movements of the water that accompany the rising and falling of the tide. The horizontal movement of the tidal current and the vertical movement of the tide are intimately related parts of the same phenomenon brought about by the tide-producing forces of sun and moon. Tidal currents, like the tides, are therefore periodic.

It is the periodicity of the tidal current that chiefly distinguishes it from other kinds of currents in the sea, which are known by the general name of nontidal currents. These latter currents are brought about by causes that are independent of the tides, such as winds, freshwater runoff, and differences in density and temperature. Currents of this class do not exhibit the periodicity of tidal currents. The permanent currents in the general circulatory system such as the Gulf Stream also fall into this grouping.

Tidal and nontidal currents occur together in the open sea and in inshore tidal waters, the actual current experienced at any point being the resultant of the two classes of currents. In some places tidal currents predominate and in others nontidal currents are stronger. Tidal currents generally attain considerable velocity in narrow entrances to bays, in constricted parts of rivers, and in passages from one body of water to another. Along the coast and farther offshore tidal currents



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are generally of moderate velocity; and in the open sea, calculation based on the theory of wave motion, gives a tidal current of less than one-tenth of a knot.

The Tide-Producing Forces

The gravitational forces of the various celestial bodies, principally the sun and the moon upon the rotating earth, result in the periodic changes in the sea. These forces are reflected in the vertical rise and fall of the sea called the tide and in its horizontal motion called the tidal current. Due to its nearness to the earth, the moon is the predominent tide-producing body.

The intensity with which the sun (or moon) attracts a particle of matter on the earth varies inversely as the square of the distance. For the solid earth as a whole the distance is obviously to be measured from the center of the earth, since that is the center of mass of the whole body. But the waters of the earth, which may be considered as lying on the surface of the earth, are on the one side of the earth nearer to the heavenly bodies and on the other side farther away than the center of the earth. The attraction of sun or moon for the waters of the ocean is thus different in intensity from the attraction for the solid earth as a whole, and these differences of attraction give rise to the forces that cause the ocean waters to move relative to the solid earth and bring about the tides and the tidal currents. These forces are called the tide-producing forces.

The mathematical development of these forces shows that the tide-producing force of a heavenly body varies directly as its mass and inversely as the cube of its distance from the earth. The sun has a mass about 27,000,000 times as great as that of the moon; but it is 389 times as far away from the earth. Its tide-producing force is therefore to that of the moon as 27,000,000 is to $(389)^3$, or somewhat less than one-half.

When the relative motions of the earth, moon, and sun are introduced into the equations of the tide-producing forces, it is found that the tide-producing forces of both sun and moon group themselves into classes: (a) Those having a period of approximately one half a day, known as the semidiurnal forces; (b) those having a period of approximately 1 day, known as diurnal forces; (c) those having a period of half a month or more, known as long-period forces.

The distribution of the tidal forces over the earth takes place in a regular manner, varying with the latitude. But the response of the various seas to these forces is very profoundly modified by terrestrial features. As a result we find the tides and the currents as they actually occur differing at various places but apparently with no regard to latitude. Other celestial bodies can be discounted because their size or distance from earth produces a pull that is almost nonexistent.

Variations in Velocity of the Tidal Current

The velocity of the tidal current at any place varies from day to day. In part this variation arises from changes in meteorological conditions, but in much larger part it is of a periodic character due to changes in the position of the moon relative to earth and sun. In its movements the tidal current clearly reveals the presence of three variations, each related to a particular movement of the moon.

The most noticeable variation, as a rule, is that related to the moon's phase. At the times of new and full moon, the speed of the current is stronger than usual and is called "spring current." When the moon is in its first and third quarters, the current flow is less than usual; hence the speed is less than the average. The current at such times is called "neap-current."

It is to be noted, however, that at most places there is a lag of a day or two between the occurrence of spring or neap currents and the corresponding phases of moon; that is, spring currents do not occur on the days of full and new moon, but a day or two later. Likewise neap currents follow the moon's first and third quarters after an interval of a day or two. This lag in the response of the current expressed in hours or days is known as the "age of phase inequality" or "phase age" and is generally ascribed to the effects of friction.

The second variation in the velocity of the current is related to the moon's varying distance from the earth. In its movement around the earth the moon describes an ellipse in a period of approximately 27½ days. The earth is at one of the foci of this elliptical orbit. Hence, during this period, the moon is at one time nearest the earth and at another time farthest away. When it is nearest the earth, or in perigee, the speed of the current is stronger than on the average, the currents being known as "perigean currents." When the moon is farthest from the earth, the speed of the current is weaker than usual. These latter currents are called "apogean currents."

In the response to the moon's change in position from perigee to apogee, it is found that, like the response in the case of spring and neap tides, there is a lag in the occurrence of perigean and apogean currents. The stronger currents do not occur on the day when the moon is in perigee but a day or two later. Likewise, weak currents do not occur on the day of the moon's apogee but a day or two later. This interval varies somewhat from place to place, and in some regions it may have a negative value. This lag is known as the "age of parallax inequality" or "parallax age."

The third periodic variation in the speed of the tidal current is that associated with the moon's changing declination. Since the moon moves in an orbit inclined to the plane of the equator, its declination is constantly changing during the month. When it is on or close to the equator, the daily strengths of current do not differ much; in other words, at such times morning and afternoon currents resemble each other. As the declination increases, differences between morning and afternoon currents become pronounced and at the times of the moon's maximum semimonthly declination these differences are most marked. But like the response to changes in the moon's phase and parallax, there is a lag in the response to the change in declination, this lag being known as the "age of diurnal inequality" or "diurnal age." Like the phase and parallax ages, the diurnal age varies from place to place, being generally about 1 day, but in some places it may have a negative value.

When the moon is on or close to the equator and the difference between morning and afternoon currents small, the currents are known as "equatorial currents." At the times of the moon's maximum semimonthly declination, when the differences between morning and afternoon currents are at a maximum, the currents are called "tropic currents," since the moon is then near one of the tropics.

There are other variations in the speed of the currents, but the three discussed above are the most prominent. These three variations are exhibited by the current the world over but not everywhere to the same degree. In many regions the variation from neaps to springs is the principal variation; in certain regions it is the variation from apogee to perigee that is the principal variation, and in other regions it is the variation from equatorial to tropic currents that is predominant.

The month of the moon's phases (the synodic month) is approximately 29½ days in length; the month of the moon's distance (the anomalistic month) is approximately 27½ days in length; the month of the moon's declination (the tropic month) is approximately 27½ days in length. It follows, therefore, that considerable variation in the speed of the current occurs during a year due to the changing relations of the three variations to each other.

Reversing Tidal Currents

In the entrance to a bay or in a river and, in general, where a restricted width occurs, the tidal current is of the reversing or rectilinear type; that is, the flood current runs in one direction for a period of about 6 hours and the ebb current for a like period in the opposite direction. The flood current sets inland or upstream and the ebb current sets seaward or downstream. The change from flood to ebb gives rise to a period of slack water during which the speed of the current is zero. An example of this type of current is given in Figure 2 which shows the speed and direction of the current on a typical day.

Current speeds are given in knots, which is the unit generally used in measuring tidal currents, and represents a speed of 1 nautical mile per hour. Since a nautical mile has a length of 6,080 feet, knots may be converted into statute miles per hour by multiplying by 1.15, or into feet per second by multiplying by 1.69.

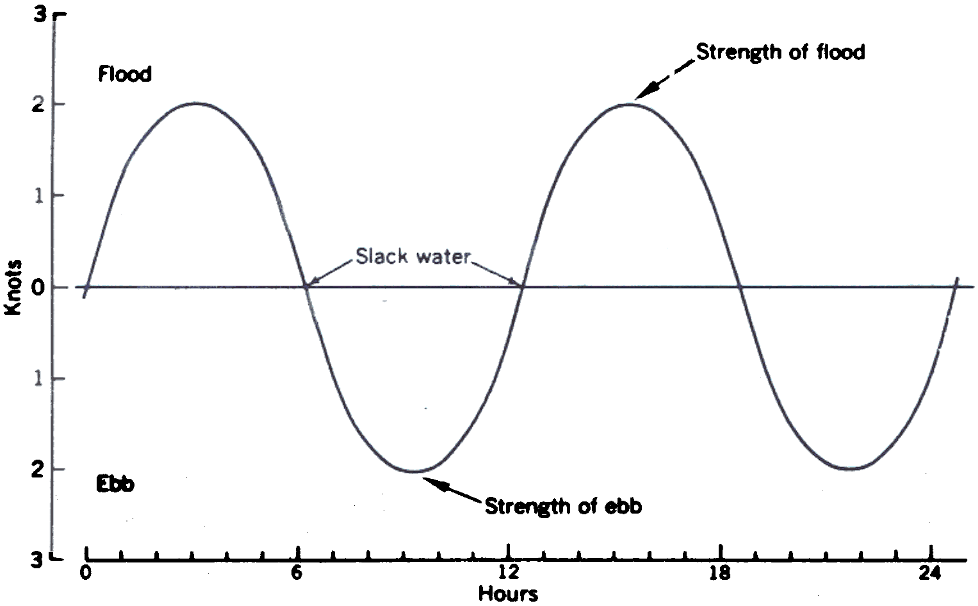


Fig. 2 - Example of a typical reversing current showing time vs. velocity for one day.

The curve depicting a reversing current resembles a tide curve. The maximum velocity of the flood current called the strength of flood corresponds to the time of high water in the tide curve, while maximum velocity of the ebb called the strength of ebb corresponds to the low water. Since the moon in its apparent movement around the earth crosses a given meridian on the earth on the average of 50 minutes later each day, the strength of current at most places likewise comes 50 minutes later each day. The current day, like the tidal day and the lunar day, has an average length of 24 hours and 50 minutes.

The current curve shown in Figure 2 represents the current near the surface in the axis of a channel. From observation and also from theory it is known that the tidal current extends from the surface to the bottom. In general it may be said that the velocity of the tidal current decreases from the surface to the bottom, the velocity near the bottom being about two thirds that at the surface. However, the effects of wind and fresh-water flow may bring about considerable variation in the vertical velocity distribution.

The current in a channel is also characterized by a variation in the horizontal distribution of velocity. In a rectangular channel of uniform cross-section, the velocity is greatest in the center of the channel, and decreases uniformly to both sides

Combining both the vertical and horizontal variations, it may be said that the average velocity of the current in a section of a regular channel is about three-quarters that of the central surface velocity.

Where the current is undisturbed by wind or fresh-water flow, the flood and ebb velocities, and the durations of flood and ebb are approximately equal. In this case, too, the characteristics of the current from the surface to the bottom are much the same. That is, the strengths of the flood and ebb currents, and also the slacks, occur at about the same time from top to bottom. If, however, nontidal currents are present, the characteristics of the tidal flow are modified considerably. The effect of nontidal currents on tidal currents may be derived from general considerations.

In Figure 3 a purely tidal current is represented by the curve, referred to the line AB as the line of zero velocity. The strengths of the flood and ebb are equal, as are also the durations of flood and ebb. In this case slack water occurs regularly 3 hours and 6 minutes (one-quarter of the current cycle of 12 hours and 25 minutes) after the times of flood and ebb strengths. If now a nontidal current is introduced which sets in the ebb direction with a velocity represented by the line CD, the strength of ebb will obviously be increased by an amount equal to CD and the flood strength will be decreased by the same amount. The current conditions may now be represented by drawing, as the new line of zero velocities, the line EF parallel to AB, and distant from it the length of CD.

Figure 3 now shows that the nontidal current not only increases the ebb strength while decreasing the flood strength, but also changes the times of slack water. Slack before flood now comes later, while slack before ebb comes earlier. Hence the duration of ebb is increased while the duration of flood is decreased.

If the velocity of the nontidal current exceeds that of the tidal current at time of strength, the tidal current in the opposite direction will be completely masked and the resultant current will set at all times in the direction of the nontidal currents. Thus, if in Figure 3 the line OP represents the velocity of the nontidal current, the new axis for measuring the velocity of the combined current at any time will be the line GH and the current will be flowing at times in the ebb direction. There will be no slack waters; but at period 6 hours 12 minutes apart there will occur minimum and maximum velocities represented, respectively, by the lines RS and TU.

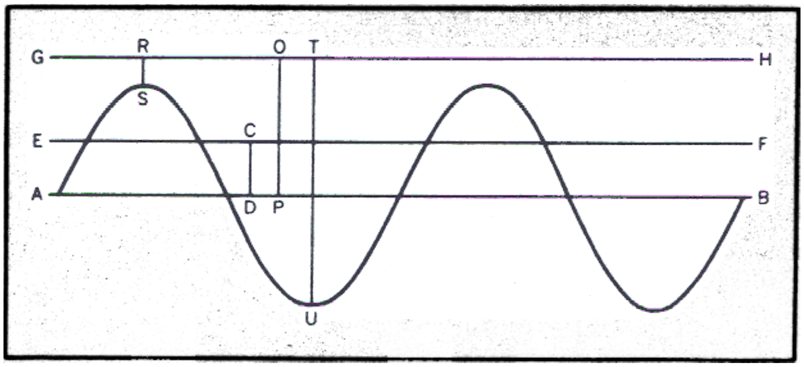


Fig. 3 - Effect of nontidal current on reversing current.

Insofar as the effect of the nontidal current on the direction of the tidal current is concerned, it is only necessary to remark that the resultant current will set in a direction which at any time is the resultant of the tidal and nontidal currents at that time. This resultant direction and also the resultant velocity may be determined either graphically by the parallelogram of velocities or by the usual trigonometric computations.

Types of Reversing Currents

Since tides and tidal currents are merely different aspects of the tidal movement of the waters, the former being the vertical movement and the latter the horizontal movement, it is to be expected that tidal currents would show different types, corresponding to the different types of tide. Observations prove this to be the case. Reversing currents may be readily classed under three types: semidaily, daily, and mixed. The semidaily type is one in which 2 flood strengths and 2 ebb strengths occur in a tidal day with but little inequality between morning and afternoon currents. Figure 2 represents this type of current which is common along the East Coast of the United States.

The daily type of tidal current is characterized by 1 flood and 1 ebb in a day. The upper diagram of Figure 4, which represents the typical current in the entrance to Mobile Bay, Ala., exemplifies this type of current. The mixed type of tidal current exhibits 2 floods and 2 ebbs in a day with considerable inequality in their speed between the forenoon and afternoon cycles. The lower diagram of Figure 4, which represents the typical current in Rich's Passage, Puget Sound, Washington, illustrates this type of current.

In general, it may be said that with reversing currents a given type of current accompanies a like type of tide; that is, semidaily currents occur with semidaily tides, mixed currents with mixed tides, and daily currents with daily tides. But as noted in considering the variations in strength of current, the variations in the current that involve semidaily components will approximate corresponding changes in the range of the tide, while in those involving daily components the variation in the current is about half that in the tide. Hence the diurnal inequality in the current at any place is generally less than in the tide at that place.

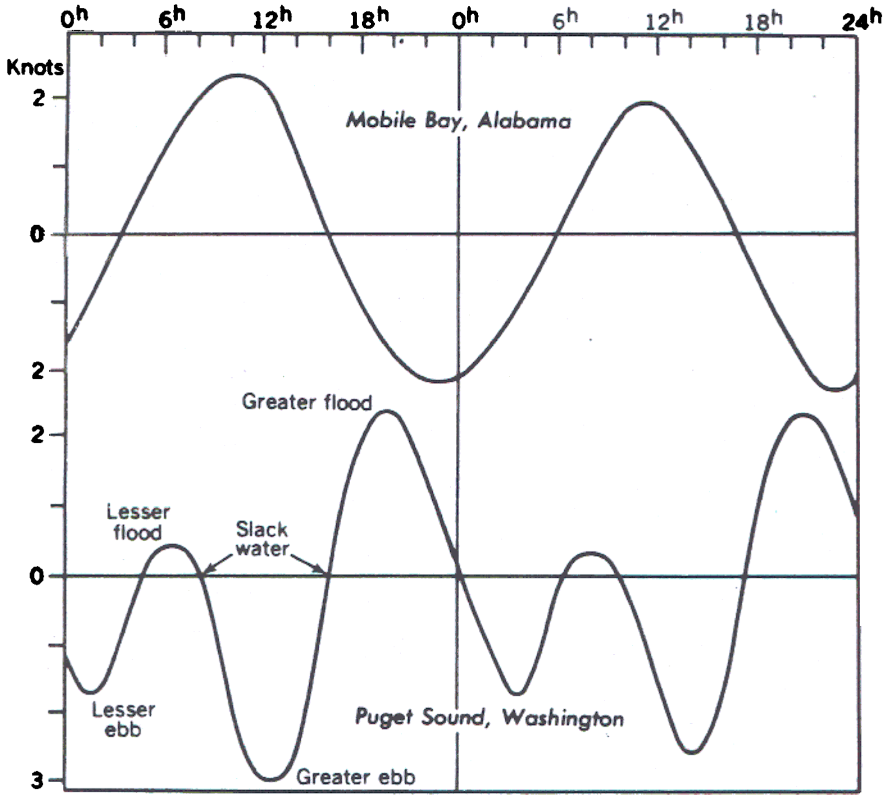


Fig. 4 · Typical current curves showing daily and mixed types of reversing currents.

Relation of Time of Current to Time of Tide

In simple wave motion the times of slack water and strength of current bear a constant and simple relation to the times of high and low water. The two principal types of tidal motion are progressive wave and stationary (standing) wave movements. A progressive wave is one whose crest advances horizontally; the times of high and low water progress from one end to the other. The time of slack water comes midway between high and low water and the time of strength of current at time of high and low water. A stationary wave is one in which the water surface oscillates vertically between fixed points called nodes without progression. The points of maximum vertical rise and fall are called antinodes. At the nodes there is no vertical motion and maximum horizontal motion (strength of current). At the antinodes the water has no horizontal motion (slack) and maximum vertical motion (high and low water).

Duration of Slack

In the change of direction of flow from flood to ebb, and vice versa, the reversing tidal current goes through a period of slack water or zero velocity. Obviously, this period of slack is but momentary, and graphically it is represented by the instant when the current curve cuts the zero line of velocities. For a brief period each side of slack water, however, the current is very weak, and in ordinary usage "slack water" denotes not only the instant of zero velocity but also the period of weak current. The question is therefore frequently raised, how long does slack water last?

To give slack water in its ordinary usage a definite meaning, we may define it to be the period during which the velocity of the current is less than one-tenth of a knot. Velocities less than one-tenth of a knot may generally be disregarded for practical purposes, and such velocities are, moreover, difficult to measure either with float or with current meter. For any given current it is now a simple matter to determine the duration of slack water, the current curve furnishing a ready means for this determination.

In general, regarding the current curve as approximately a sine or cosine curve, the duration of slack water is a function of the strength of current--the stronger the current the less the duration of slack--and from the equation of the sine curve we may easily compute the duration of slack water for currents of various strengths. For the normal flood or ebb cycle of $6^h\ 12.6^m$ we may write the equation of the current curve $y = A \sin 0.4831t$, in which A is the velocity of the current in knots at time of strength, 0.4831 the angular velocity in degrees per minute, and t is the time in minutes from the instant of zero velocity. Setting $y = 0.1$ and solving for t (this value of t giving half the duration of slack) we get for the duration of slack the following values: For a current with a strength of 1 knot, slack water is 24 minutes; for currents of 2 knots strength, 12 minutes; 3 knots, 8 minutes; 4 knots, 6 minutes; 5 knots, 5 minutes; 6 knots, 4 minutes; 8 knots, 3 minutes; 10 knots, 2 1/3 minutes. For the daily type of current with a given strength, the duration of slack is obviously twice that of a semidaily current with like strength.

Velocity of Current and Progression of Tide

In the tidal movement of the water it is necessary to distinguish clearly between the speed of the current and the progression or rate of advance of the tide. In the former case reference is made to the actual speed of a moving particle, while in the latter case the reference is to the rate of advance of the tide phase or the velocity of propagation of wave motion, which generally is many times greater than the velocity of the current.

It is to be noted that there is no necessary relationship between the velocity of the tidal current at any place and the rate of advance of the tide at that place. In other words, if the rate of advance of the tide is known we cannot from that alone infer the speed of the current, nor vice versa. The rate of advance of the tide in any given body of water depends on the type of tidal movement. In a progressive wave the tide moves approximately in accordance with the formula $r=\sqrt{gh}$, in which r is the rate of advance of the tide, g the acceleration of gravity, and h the depth of the waterway. In stationary wave movement, we have seen that the time of high water and low water occur at very nearly the same time over a considerable area. Thus, there is no progression of the wave present. When a combination of progressive and stationary wave movements occur, the relation between tide and current becomes quite complicated.

The velocity of the current, or the actual speed with which the particles of water are moving past any fixed point, depends on the volume of water that must pass the given point and the cross section of the channel at that point. The velocity of the current is thus independent of the rate of advance of the tide.

Rotary Tidal Currents

Within the channel of a bay or river, the current is compelled to follow the direction of the channel, upstream on the flood and downstream on the ebb. Out in the open sea, however, this restriction no longer exists, the current having complete freedom so far as direction is concerned. Offshore, therefore, tidal currents are generally not of the reversing type. Instead of flowing in the same general direction during the entire period of the flood and in the opposite direction during the ebb, the tidal currents offshore change direction continually. Such currents are therefore called rotary currents. An example of this type of current is shown in Figure 5, which represents the speed and direction of the current at the beginning of each hour of the forenoon for a typical day at Nantucket Shoals Lightship, stationed off the coast of Massachusetts.

The current is seen to have changed its direction at each hourly observation, the rotation being in the direction of movement of the hands of a clock, or from north to south by way of east, then to north again by way to west. In a period of a little more than 12 hours it is seen that the current has shifted in direction completely round the compass.

It will be noted that the tips of the arrows, representing the speeds and directions of the current at the beginning of each hour, define a somewhat irregular ellipse. If a number of observations are averaged, eliminating accidental errors and temporary meteorological disturbances, the regularity of the curve is considerably increased. The average period of the cycle is found to be $12^h\ 25^m$. In other words, the current day for the rotary current, like the tidal day, is $24^h\ 50^m$ in length.

A characteristic feature of the rotary current is the absence of slack water. Although the current generally varies from hour to hour, this variation from greatest current to least current and back again to greatest current does not give rise to a period of slack water.

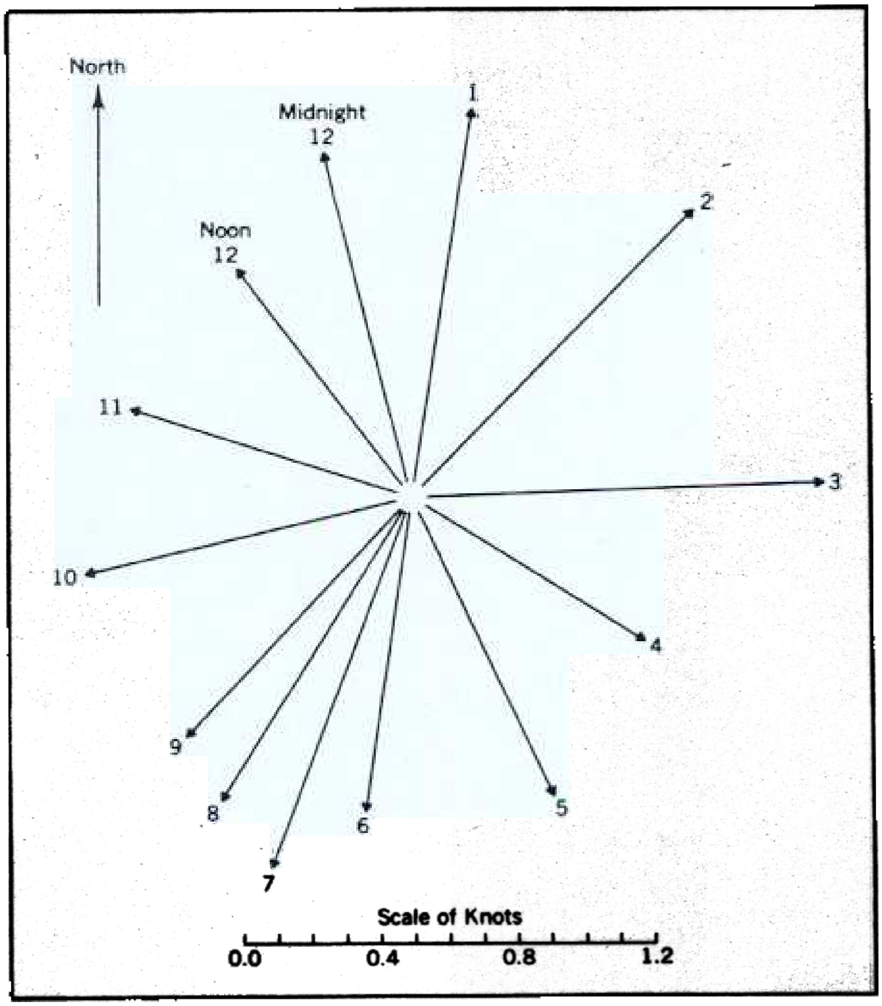


Fig. 5 - Example of a typical rotary current.

When the speed of the rotary tidal current is least, it is known as the minimum current, and when it is greatest it is known as the maximum current. The minimum and maximum speeds of the rotary current are thus related to each other in the same way as slack and strength of the rectilinear current, a minimum speed following a maximum speed by an interval of about 3 hours and being followed in turn by another maximum after a further interval of 3 hours.

With regard to the current curve, or current ellipse as it may be called, which represents the rotary tidal current at any place, the basic features are the relation of the major and minor axis which determine the ellipticity of the curve, the direction of rotation, and the direction of the major axis. If the major and minor axis are nearly equal the ellipse will be nearly circular; if they differ greatly the ellipse will be flattened. In the northern hemisphere the direction of rotation of the rotary current is, as a rule, with the hands of a clock, while in the southern hemisphere it is counter clockwise. But local hydrographic features may bring about a reversal of this general rule.

Rotary tidal currents are subject to the periodic variations found in tides and reversing currents. These variations are related to the changes in the phase, parallax, and declination of the moon. At times of full and new moon the velocity of the rotary current is greater than the average, while at the times of the moon's first and third quarters the velocities are less than the average. Likewise when the moon is in perigee, stronger currents occur, while when the moon is in apogee the currents are weaker. In general it may be taken that the percentage of increase or decrease in the velocity of the current in response to changes in phase and parallax is the same as the like increase or decrease in the local range of the tide.

In response to changes in the declination of the moon the rotary current exhibits diurnal inequality like the tide and reversing current. This manifests itself as a difference between morning and afternoon current ellipses. When the moon is on the equator the two current ellipses of a day are much alike; but when the moon is near its maximum semimonthly declination the two current ellipses exhibit differences, principally in velocity.

Like tides and reversing currents, rotary tidal currents may be grouped under the three types of semidaily, daily, and mixed. The semidaily type of rotary current is one which exhibits two full cycles within a tidal day, morning and afternoon currents differing but little. The daily type is one in which but one cycle occurs in a day, and the mixed type is one which exhibits two cycles within a day but with considerable differences between morning and afternoon currents. In addition to the periodic variations to which rotary tidal currents are subject, they also exhibit fluctuations arising from the effects of non-tidal currents.

Hydraulic Current

In addition to reversing and rotary currents, there is a third type called a hydraulic current. The term applies to a current in a strait or tidal river that is caused by a difference in head of water at the two entrances. When this difference in head results from tidal action that causes the water at one end to be alternately higher or lower than at the other, the movement is periodic and may be treated as a reversing type of current. The currents through the East River which connects New York Harbor with Long Island Sound are an example of hydraulic currents. When there is tidal action at each entrance to a strait, difference in the head will result partly from any difference in the range of tide and partly from any differences in the times of the high and low waters. Theoretically, the current speed will vary as the square root of the difference in head, will be a maximum when this difference is greatest, and will be zero or slack water when the difference is zero. Actually there will be a lag of several minutes in response of the currents to this difference in head due to inertia and friction in the waterway itself.

Harmonic Constants

The reversing tidal current, like the tide, may be regarded as the resultant of a number of simple harmonic movements, each of the form $y = A\cos(at+\alpha)$; hence, reversing tidal currents may be analyzed in a manner analogous to that used in tides and the harmonic current constants derived. These constants permit the characteristics of the currents to be determined in the same manner as the tidal harmonic constants, and they may also be used in the prediction of the times of slack and the times and velocities of the strength of current.

It can easily be shown that in inland tidal waters, like rivers and bays, the amplitudes of the various current components are related to each other, not as the amplitudes of the corresponding tidal components, but as these latter multiplied by their respective speeds; that is, in any given harbor, if we denote the various components of the current by primes and of the tide by double primes, we have

$$M'_2 : S_2 : N'_2 : K'_1 : O'_1 := m_2 M''_2 : s_2 S''_2 : n_2 N''_2 : k_1 K''_1 : o_1 O''_1$$

where the small italic letters represent, respectively, the angular speed of the corresponding components. This shows at once that the diurnal inequality in the currents should be approximately half that in the tide.

Rotary currents may likewise be analyzed harmonically, but in this case it is necessary to resolve the hourly velocity and direction of the current into two components, one in the north and south direction and the other in the east and west direction. Each set of hourly tabulations is then treated independently and analyzed in the usual manner. When the two sets of harmonic constants have been derived the like-named constants of the north and south and east and west directions may be combined into a single resultant, which will be an ellipse, either graphically or by means of the formula

$$\tan 2\theta = \frac{H_1^2 \sin 2\kappa_1 + H_2^2 \sin 2\kappa_2}{H_1^2 \cos 2\kappa_1 + H_2^2 \cos 2\kappa_2}$$

which may be derived by writing each harmonic constant in the form $u = H_1 \cos(\theta - \kappa_1)$ for the north and south component and $v = H_2 \cos(\theta - \kappa_2)$ for the east and west component.

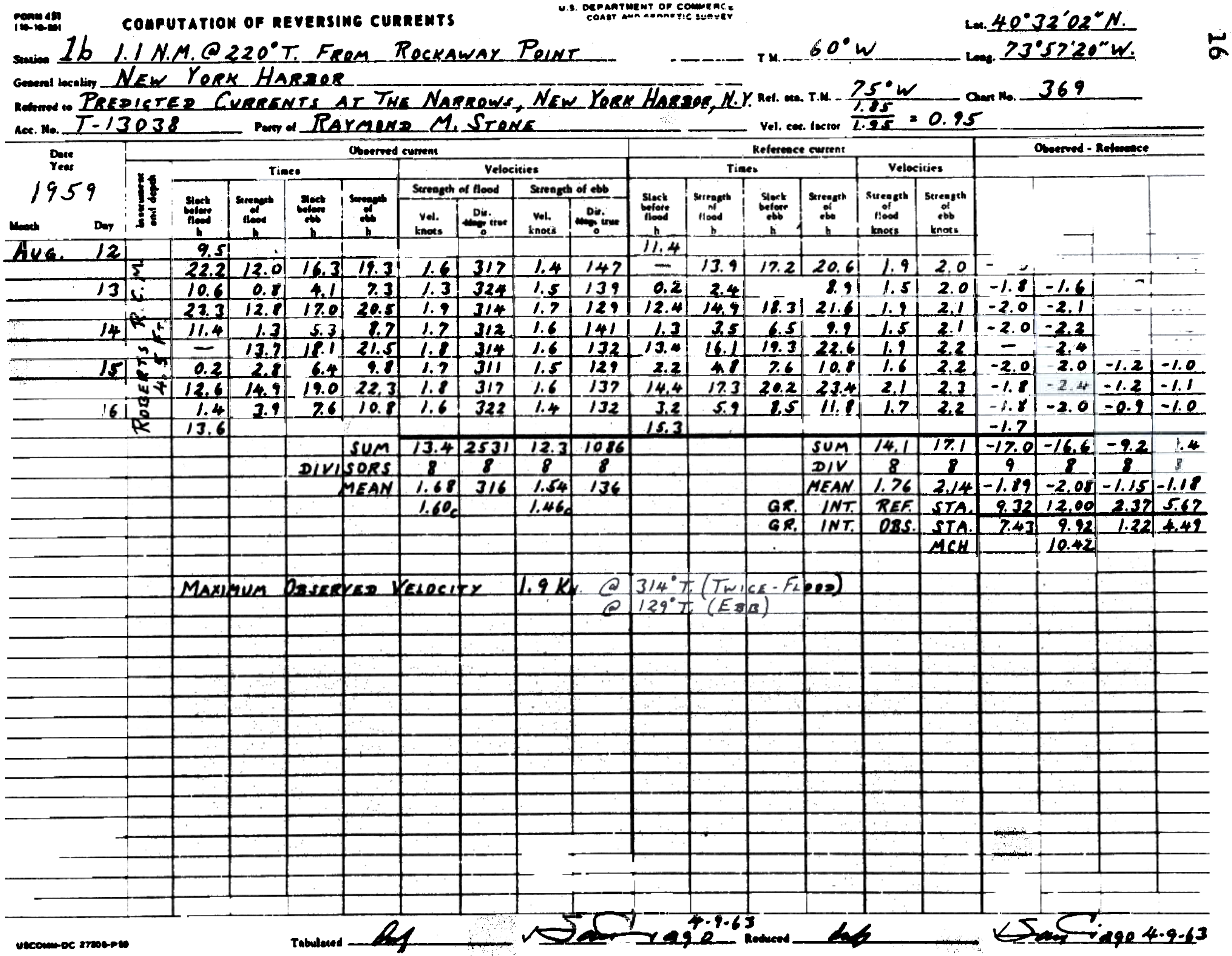
Reduction Methods and Results

The purpose in studying tidal currents is to determine their speed and direction through direct observations of the speed and direction of the current in a tidal body of water and to make such data available to the general public. Two types of reduction--harmonic and nonharmonic--are used in studying tidal currents. A harmonic analysis proceeds through several complicated mathematical procedures to determine harmonic constants which in turn are used in the prediction of the daily current at that place.

The mathematics involved is beyond the scope of this paper but is explained in detail in other C&GS manuals. "Harmonic Constants" has been defined in a previous section. A nonharmonic analysis determines the average speed and direction of the current and is a relatively simple reduction. A sample computation is shown in Fig. 6. Here the observed times of slack water and strengths of flood and ebb are compared to the predicted times of their respective phases at a nearby reference station. A reference station is a place for which daily predictions are given in the annual tidal current tables and the type of current is similar in times and velocities to the secondary stations being reduced.

Thus in selecting a reference station to which to refer any series of tidal current observations, its characteristics must be studied and compared with the secondary stations for which new data arc being reduced. If no suitable station is available in the survey area, one must be developed in order that the stations can adequately be reduced.

Likewise the observed speeds and directions of the current at a secondary station are summed and averaged for flood and ebb. The velocity of the observed tidal current may be reduced to a mean value by the application of a factor derived from the current velocity at the reference station. In using such a station,



FORM 451

COMPUTATION OF REVERSING CURRENTS

U.S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY

Lat. 40°32'02" N.

Station 1b 1.1 N.M. @ 220°T. FROM ROCKAWAY POINT T.M. 60°W Long. 73°57'20" W.

General locality NEW YORK HARBOR

Referred to PREDICTED CURRENTS AT THE NARROWS, NEW YORK HARBOR, N.Y. Ref. sta. T.M. 75°W Chart No. 369

Acc. No. T-13038 Party of RAYMOND M. STONE Vel. cor. factor $\frac{1.85}{1.95}$ = 0.95

Date Year 1959			Observed current								Reference current						Observed - Reference			
			Times				Velocities				Times				Velocities					
							Strength of flood		Strength of ebb											
Month	Day	Instrument and depth	Slack before flood h	Strength of flood h	Slack before ebb h	Strength of ebb h	Vel. knots	Dir. true °	Vel. knots	Dir. true °	Slack before flood h	Strength of flood h	Slack before ebb h	Strength of ebb h	Strength of flood knots	Strength of ebb knots				
AUG.	12		9.5								11.4									
		ROBERTS R.C.M. 45 FT	22.2	12.0	16.3	19.3	1.6	317	1.4	147	—	13.9	17.2	20.6	1.9	2.0				
	13		10.6	0.8	4.1	7.3	1.3	324	1.5	139	0.2	2.4		8.9	1.5	2.0	-1.8	-1.6		
			23.3	12.8	17.0	20.5	1.9	314	1.7	129	12.4	14.9	18.3	21.6	1.9	2.1	-2.0	-2.1		
	14		11.4	1.3	5.3	8.7	1.7	312	1.6	141	1.3	3.5	6.5	9.9	1.5	2.1	-2.0	-2.2		
			—	13.7	18.1	21.5	1.8	314	1.6	132	13.4	16.1	19.3	22.6	1.9	2.2	—	-2.4		
	15		0.2	2.8	6.4	9.8	1.7	311	1.5	129	2.2	4.8	7.6	10.8	1.6	2.2	-2.0	-2.0	-1.2	-1.0
			12.6	14.9	19.0	22.3	1.8	317	1.6	137	14.4	17.3	20.2	23.4	2.1	2.3	-1.8	-2.4	-1.2	-1.1
	16		1.4	3.9	7.6	10.8	1.6	322	1.4	132	3.2	5.9	8.5	11.8	1.7	2.2	-1.8	-2.0	-0.9	-1.0
			13.6								15.3						-1.7			
						SUM	13.4	2531	12.3	1086				SUM	14.1	17.1	-17.0	-16.6	-9.2	1.4
						DIVISORS	8	8	8	8				DIV	8	8	9	8	8	8
						MEAN	1.68	316	1.54	136				MEAN	1.76	2.14	-1.89	-2.08	-1.15	-1.18
							1.60_c		1.46_c				GR.	INT.	REF.	STA.	9.32	12.00	2.37	5.67
													GR.	INT.	OBS.	STA.	7.43	9.92	1.22	4.49
																MCH		10.42		

MAXIMUM OBSERVED VELOCITY 1.9 Kt. @ 314°T. (TWICE-FLOOD)
@ 129°T. (EBB)

USCOMM-DC 27808-P60

Tabulated 1290 4-9-63 Reduced 1290 4-9-63

Fig. 6 · Typical computation of reversing current.

the factor is obtained by dividing the best determined average speed at the reference station by the average speed for the period covered by the observations.

Publishing the Results

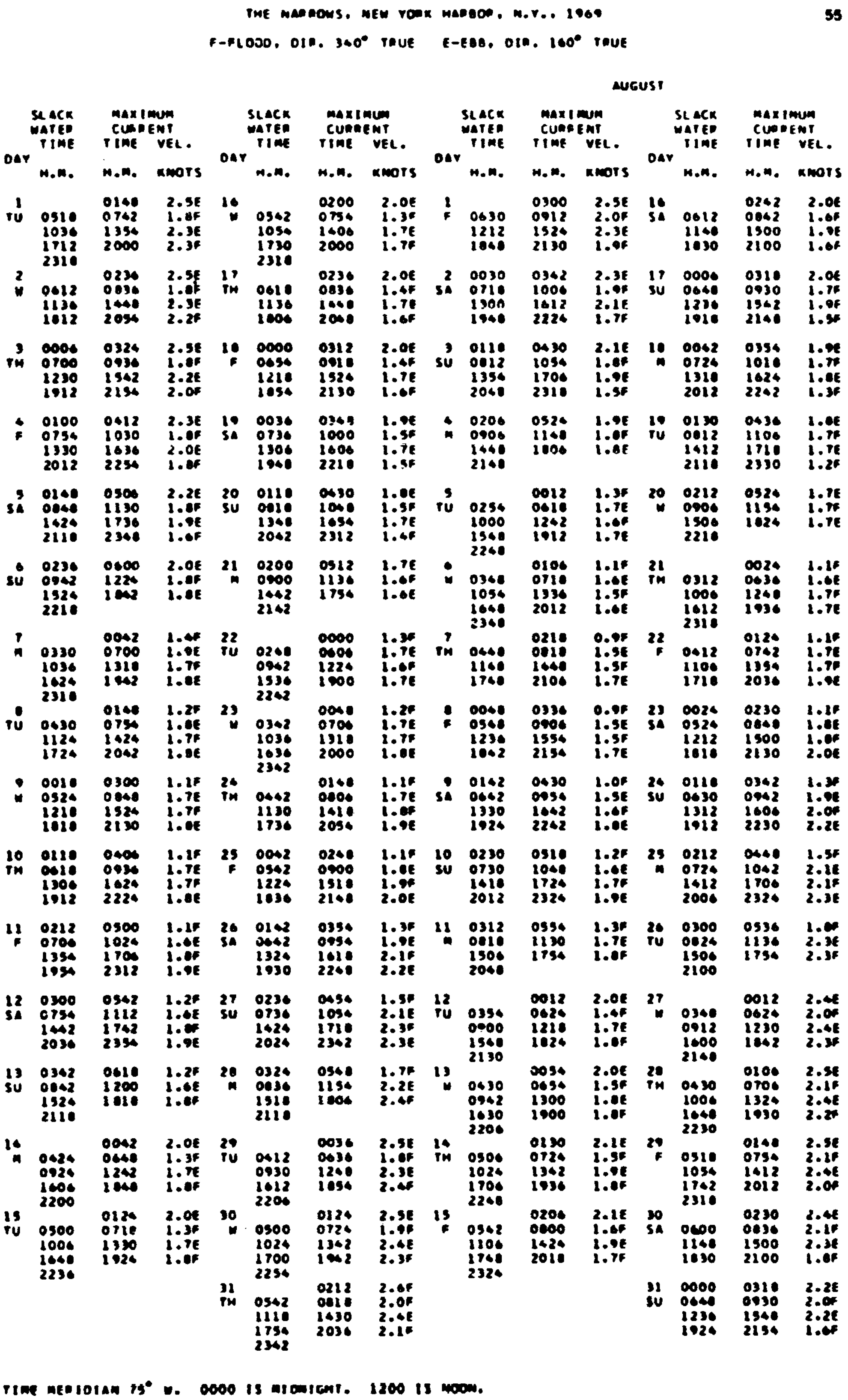
Two different types of publications are issued by the Coast and Geodetic Survey to include results of the tidal current surveys. Tidal Current Tables are published annually for both the Atlantic and Pacific Coasts of North America. The other is a series of Tidal Current Charts for various tidal estuaries on both Atlantic and Pacific Coasts. Each of these publications is based on observations obtained over many years of current surveys.

The Tidal Current Tables have been published annually since 1890. They first appeared as part of the Tide Tables and consisted of brief directions for obtaining the times of the current for a few locations. Later daily predictions of slack water were given. By 1923, the tables had so expanded that they were issued as a separate publication called "Current Tables, Atlantic Coast" and "Current Tables, Pacific Coast." A few years later, the daily predictions were extended to include the times and speeds of maximum current. Today, each Table is divided into several tables. Table 1 (Fig. 7) gives the predicted times of slack water and the predicted times and velocities of the maximum current--flood and ebb--for each day of the year for a number of places along the Atlantic and Pacific Coasts.

Table 2 (Fig. 8) furnishes data which will enable the user to determine the approximate time of slack water and the time and velocity of maximum current at numerous stations on both the Atlantic and Pacific coasts. Given for each station are time differences of slack water and maximum current and flood and ebb velocity ratios with respect to some stations for which daily predictions are also given. Finally the direction and average speed of maximum flood and ebb are also included in this section The Tidal Current Tables also contain data on rotary stations, Gulf Stream, wind driven currents, etc., all of which may be of interest to the mariner.

Each Tidal Current Chart (Fig. 9) gives a comprehensive view of the hourly speed and direction of the current throughout each of the tidal estuaries for which a chart has been published. Each chart also provides a means for determining the speed and direction of the current at various places covered by each chart.

Fig. 7 - Sample page of predictions for the Narrows, New York Harbor, N.Y.
Fig. 8 - Sample page of Table 2 showing several places referred to the Narrows.
Fig. 9 Sample page from a Tidal Current Chart.



THE NARROWS, NEW YORK HARBOR, N.Y., 1969 55

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

DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS
1		0148	2.5E
TU	0518	0742	1.8F
	1036	1354	2.3E
	1712	2000	2.3F
	2318		
2		0236	2.5E
W	0612	0836	1.8F
	1136	1448	2.3E
	1812	2054	2.2F
3	0006	0324	2.5E
TH	0700	0936	1.8F
	1230	1542	2.2E
	1912	2154	2.0F
4	0100	0412	2.3E
F	0754	1030	1.8F
	1330	1636	2.0E
	2012	2254	1.8F
5	0148	0506	2.2E
SA	0848	1130	1.8F
	1424	1736	1.9E
	2118	2348	1.6F
6	0236	0600	2.0E
SU	0942	1224	1.8F
	1524	1842	1.8E
	2218		
7		0042	1.4F
M	0330	0700	1.9E
	1036	1318	1.7F
	1624	1942	1.8E
	2318		
8		0148	1.2F
TU	0430	0754	1.8E
	1124	1424	1.7F
	1724	2042	1.8E
9	0018	0300	1.1F
W	0524	0848	1.7E
	1218	1524	1.7F
	1818	2130	1.8E
10	0118	0406	1.1F
TH	0618	0936	1.7E
	1306	1624	1.7F
	1912	2224	1.8E
11	0212	0500	1.1F
F	0706	1024	1.6E
	1354	1706	1.8F
	1954	2312	1.9E
12	0300	0542	1.2F
SA	0754	1112	1.6E
	1442	1742	1.8F
	2036	2354	1.9E
13	0342	0618	1.2F
SU	0842	1200	1.6E
	1524	1818	1.8F
	2118		
14		0042	2.0E
M	0424	0648	1.3F
	0924	1242	1.7E
	1606	1848	1.8F
	2200		
15		0124	2.0E
TU	0500	0718	1.3F
	1006	1330	1.7E
	1648	1924	1.8F
	2236		

DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS
16		0200	2.0E
W	0542	0754	1.3F
	1054	1406	1.7E
	1730	2000	1.7F
	2318		
17		0236	2.0E
TH	0618	0836	1.4F
	1136	1448	1.7E
	1806	2048	1.6F
18	0000	0312	2.0E
F	0654	0918	1.4F
	1218	1524	1.7E
	1854	2130	1.6F
19	0036	0348	1.9E
SA	0736	1000	1.5F
	1306	1606	1.7E
	1948	2218	1.5F
20	0118	0430	1.8E
SU	0818	1048	1.5F
	1348	1654	1.7E
	2042	2312	1.4F
21	0200	0512	1.7E
M	0900	1136	1.6F
	1442	1754	1.6E
	2142		
22		0000	1.3F
TU	0248	0606	1.7E
	0942	1224	1.6F
	1536	1900	1.7E
	2242		
23		0048	1.2F
W	0342	0706	1.7E
	1036	1318	1.7F
	1636	2000	1.8E
	2342		
24		0148	1.1F
TH	0442	0806	1.7E
	1130	1418	1.8F
	1736	2054	1.9E
25	0042	0248	1.1F
F	0542	0900	1.8E
	1224	1518	1.9F
	1836	2148	2.0E
26	0142	0354	1.3F
SA	0642	0954	1.9E
	1324	1618	2.1F
	1930	2248	2.2E
27	0236	0454	1.5F
SU	0736	1054	2.1E
	1424	1718	2.3F
	2024	2342	2.3E
28	0324	0548	1.7F
M	0836	1154	2.2E
	1518	1806	2.4F
	2118		
29		0036	2.5E
TU	0412	0636	1.8F
	0930	1248	2.3E
	1612	1854	2.4F
	2206		
30		0124	2.5E
W	0500	0724	1.9F
	1024	1342	2.4E
	1700	1942	2.3F
	2254		
31		0212	2.6F
TH	0542	0818	2.0F
	1118	1430	2.4E
	1754	2036	2.1F
	2342		

AUGUST

DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS
1		0300	2.5E
F	0630	0912	2.0F
	1212	1524	2.3E
	1848	2130	1.9F
2	0030	0342	2.3E
SA	0718	1006	1.9F
	1300	1612	2.1E
	1948	2224	1.7F
3	0118	0430	2.1E
SU	0812	1054	1.8F
	1354	1706	1.9E
	2048	2318	1.5F
4	0206	0524	1.9E
M	0906	1148	1.8F
	1448	1806	1.8E
	2148		
5		0012	1.3F
TU	0254	0618	1.7E
	1000	1242	1.6F
	1548	1912	1.7E
	2248		
6		0106	1.1F
W	0348	0718	1.6E
	1054	1336	1.5F
	1648	2012	1.6E
	2348		
7		0218	0.9F
TH	0448	0818	1.5E
	1148	1448	1.5F
	1748	2106	1.7E
8	0048	0336	0.9F
F	0548	0906	1.5E
	1236	1554	1.5F
	1842	2154	1.7E
9	0142	0430	1.0F
SA	0642	0954	1.5E
	1330	1642	1.6F
	1924	2242	1.8E
10	0230	0518	1.2F
SU	0730	1048	1.6E
	1418	1724	1.7F
	2012	2324	1.9E
11	0312	0554	1.3F
M	0818	1130	1.7E
	1506	1754	1.8F
	2048		
12		0012	2.0E
TU	0354	0624	1.4F
	0900	1218	1.7E
	1548	1824	1.8F
	2130		
13		0054	2.0E
W	0430	0654	1.5F
	0942	1300	1.8E
	1630	1900	1.8F
	2206		
14		0130	2.1E
TH	0506	0724	1.5F
	1024	1342	1.9E
	1706	1936	1.8F
	2248		
15		0206	2.1E
F	0542	0800	1.6F
	1106	1424	1.9E
	1748	2018	1.7F
	2324		

DAY	SLACK WATER TIME H.M.	MAXIMUM CURRENT TIME H.M.	MAXIMUM CURRENT VEL. KNOTS
16		0242	2.0E
SA	0612	0842	1.6F
	1148	1500	1.9E
	1830	2100	1.6F
17	0006	0318	2.0E
SU	0648	0930	1.7F
	1236	1542	1.9F
	1918	2148	1.5F
18	0042	0354	1.9E
M	0724	1018	1.7F
	1318	1624	1.8E
	2012	2242	1.3F
19	0130	0436	1.8E
TU	0812	1106	1.7F
	1412	1718	1.7E
	2118	2330	1.2F
20	0212	0524	1.7E
W	0906	1154	1.7F
	1506	1824	1.7E
	2218		
21		0024	1.1F
TH	0312	0636	1.6E
	1006	1248	1.7F
	1612	1936	1.7E
	2318		
22		0124	1.1F
F	0412	0742	1.7E
	1106	1354	1.7F
	1718	2036	1.9E
23	0024	0230	1.1F
SA	0524	0848	1.8E
	1212	1500	1.8F
	1818	2130	2.0E
24	0118	0342	1.3F
SU	0630	0942	1.9E
	1312	1606	2.0F
	1912	2230	2.2E
25	0212	0448	1.5F
M	0724	1042	2.1E
	1412	1706	2.1F
	2006	2324	2.3E
26	0300	0536	1.8F
TU	0824	1136	2.3E
	1506	1754	2.3F
	2100		
27		0012	2.4E
W	0348	0624	2.0F
	0912	1230	2.4E
	1600	1842	2.3F
	2148		
28		0106	2.5E
TH	0430	0706	2.1F
	1006	1324	2.4E
	1648	1930	2.2F
	2230		
29		0148	2.5E
F	0518	0754	2.1F
	1054	1412	2.4E
	1742	2012	2.0F
	2318		
30		0230	2.4E
SA	0600	0836	2.1F
	1148	1500	2.3E
	1830	2100	1.8F
31	0000	0318	2.2E
SU	0648	0930	2.0F
	1236	1548	2.2E
	1924	2154	1.6F

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

Fig. 7 - Sample page of daily predictions for the Narrows, New York Harbor, N.Y.

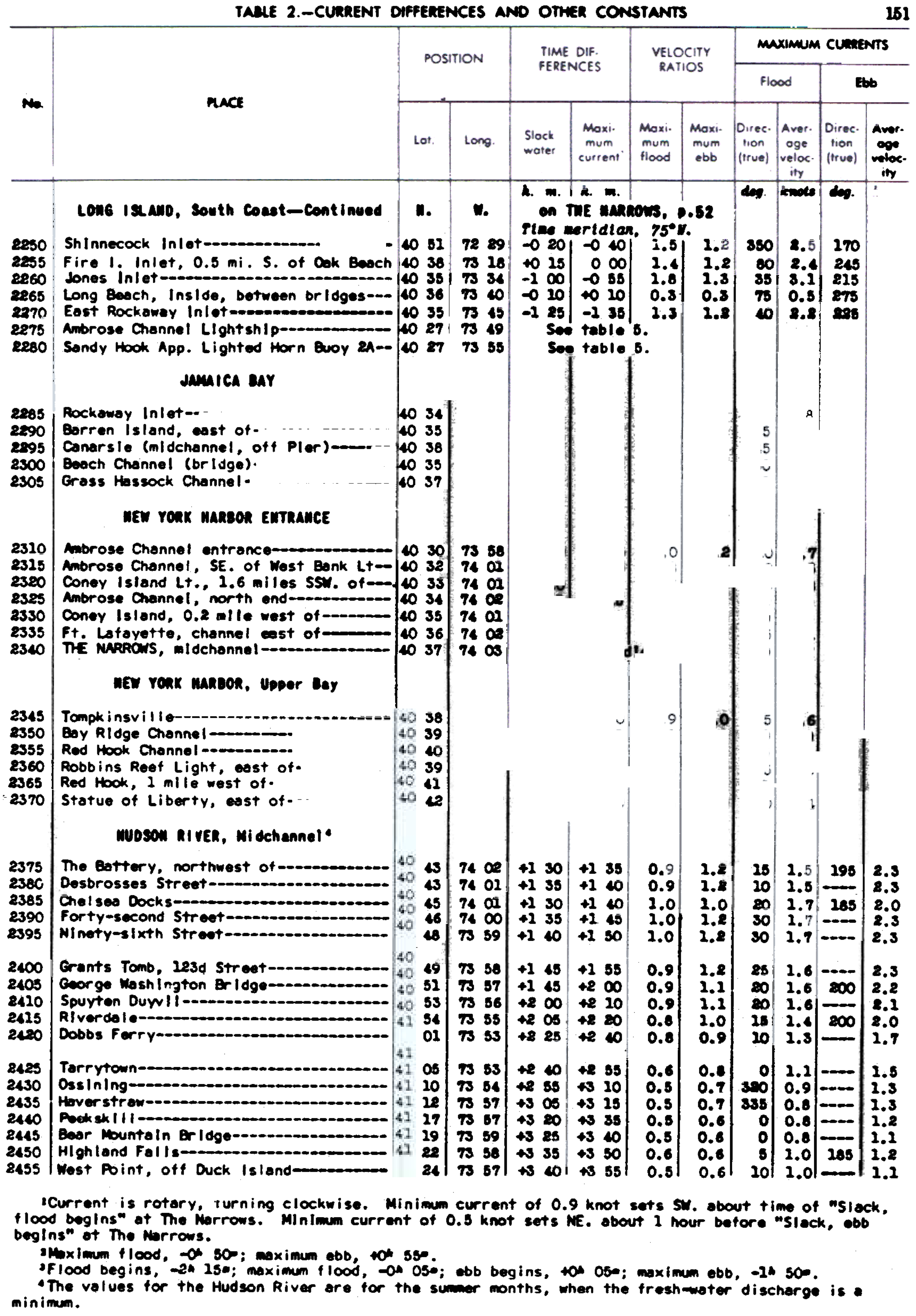


TABLE 2.—CURRENT DIFFERENCES AND OTHER CONSTANTS 151

No.	PLACE	POSITION		TIME DIFFERENCES		VELOCITY RATIOS		MAXIMUM CURRENTS			
								Flood		Ebb	
		Lat.	Long.	Slack water	Maximum current	Maximum flood	Maximum ebb	Direction (true)	Average velocity	Direction (true)	Average velocity
				h. m.	h. m.			deg.	knots	deg.	
	LONG ISLAND, South Coast—Continued	N.	W.	**on THE NARROWS, p.52** *Time meridian, 75°W.*							
2250	Shinnecock Inlet-------------	40 51	72 29	-0 20	-0 40	1.5	1.2	350	2.5	170	
2255	Fire I. Inlet, 0.5 mi. S. of Oak Beach	40 38	73 18	+0 15	0 00	1.4	1.2	80	2.4	245	
2260	Jones Inlet---------------------------	40 35	73 34	-1 00	-0 55	1.8	1.3	35	3.1	215	
2265	Long Beach, inside, between bridges---	40 36	73 40	-0 10	+0 10	0.3	0.3	75	0.5	275	
2270	East Rockaway Inlet------------------	40 35	73 45	-1 25	-1 35	1.3	1.2	40	2.2	225	
2275	Ambrose Channel Lightship------------	40 27	73 49	See table 5.							
2280	Sandy Hook App. Lighted Horn Buoy 2A--	40 27	73 55	See table 5.							
	JAMAICA BAY										
2285	Rockaway Inlet--	40 34									
2290	Barren Island, east of-	40 35						5			
2295	Canarsie (midchannel, off Pier)------	40 38						5			
2300	Beach Channel (bridge)-	40 35									
2305	Grass Hassock Channel-	40 37									
	NEW YORK HARBOR ENTRANCE										
2310	Ambrose Channel entrance--------------	40 30	73 58			.0	.2		.7		
2315	Ambrose Channel, SE. of West Bank Lt--	40 32	74 01								
2320	Coney Island Lt., 1.6 miles SSW. of---	40 33	74 01								
2325	Ambrose Channel, north end-----------	40 34	74 02								
2330	Coney Island, 0.2 mile west of--------	40 35	74 01								
2335	Ft. Lafayette, channel east of--------	40 36	74 02								
2340	THE NARROWS, midchannel--------------	40 37	74 03								
	NEW YORK HARBOR, Upper Bay										
2345	Tompkinsville------------------------	40 38				9	.0	5	.6		
2350	Bay Ridge Channel----------	40 39									
2355	Red Hook Channel-----------	40 40									
2360	Robbins Reef Light, east of-	40 39									
2365	Red Hook, 1 mile west of-	40 41									
2370	Statue of Liberty, east of-	40 42									
	HUDSON RIVER, Midchannel[4]										
2375	The Battery, northwest of------------	40 43	74 02	+1 30	+1 35	0.9	1.2	15	1.5	195	2.3
2380	Desbrosses Street--------------------	40 43	74 01	+1 35	+1 40	0.9	1.2	10	1.5	----	2.3
2385	Chelsea Docks------------------------	40 45	74 01	+1 30	+1 40	1.0	1.0	20	1.7	185	2.0
2390	Forty-second Street------------------	40 46	74 00	+1 35	+1 45	1.0	1.2	30	1.7	----	2.3
2395	Ninety-sixth Street------------------	40 48	73 59	+1 40	+1 50	1.0	1.2	30	1.7	----	2.3
2400	Grants Tomb, 123d Street-------------	40 49	73 58	+1 45	+1 55	0.9	1.2	25	1.6	----	2.3
2405	George Washington Bridge-------------	40 51	73 57	+1 45	+2 00	0.9	1.1	20	1.6	200	2.2
2410	Spuyten Duyvil-----------------------	40 53	73 56	+2 00	+2 10	0.9	1.1	20	1.6	----	2.1
2415	Riverdale----------------------------	40 54	73 55	+2 05	+2 20	0.8	1.0	15	1.4	200	2.0
2420	Dobbs Ferry--------------------------	41 01	73 53	+2 25	+2 40	0.8	0.9	10	1.3	----	1.7
2425	Tarrytown----------------------------	41 05	73 53	+2 40	+2 55	0.6	0.8	0	1.1	----	1.5
2430	Ossining-----------------------------	41 10	73 54	+2 55	+3 10	0.5	0.7	350	0.9	----	1.3
2435	Haverstraw---------------------------	41 12	73 57	+3 05	+3 15	0.5	0.7	335	0.8	----	1.3
2440	Peekskill----------------------------	41 17	73 57	+3 20	+3 35	0.5	0.6	0	0.8	----	1.2
2445	Bear Mountain Bridge-----------------	41 19	73 59	+3 25	+3 40	0.5	0.6	0	0.8	----	1.1
2450	Highland Falls-----------------------	41 22	73 58	+3 35	+3 50	0.6	0.6	5	1.0	185	1.2
2455	West Point, off Duck Island----------	24	73 57	+3 40	+3 55	0.5	0.6	10	1.0	----	1.1

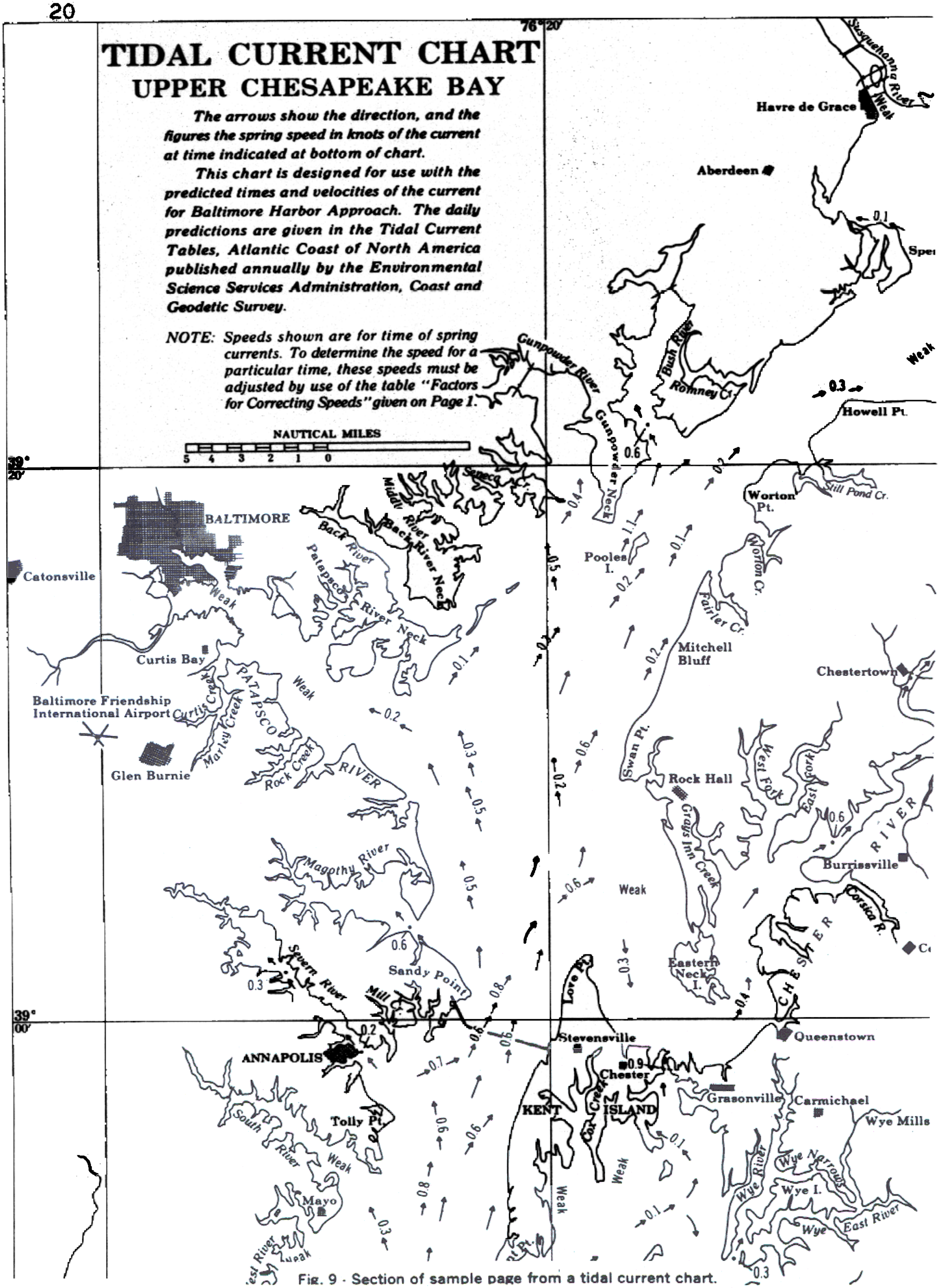
[1] Current is rotary, turning clockwise. Minimum current of 0.9 knot sets SW. about time of "Slack, flood begins" at The Narrows. Minimum current of 0.5 knot sets NE. about 1 hour before "Slack, ebb begins" at The Narrows.

[2] Maximum flood, -0h 50m; maximum ebb, +0h 55m.

[3] Flood begins, -2h 15m; maximum flood, -0h 05m; ebb begins, +0h 05m; maximum ebb, -1h 50m.

[4] The values for the Hudson River are for the summer months, when the fresh-water discharge is a minimum.

Fig. 8 - Sample page of Table 2 showing places referred to the Narrows.



TIDAL CURRENT CHART
UPPER CHESAPEAKE BAY

The arrows show the direction, and the figures the spring speed in knots of the current at time indicated at bottom of chart.

This chart is designed for use with the predicted times and velocities of the current for Baltimore Harbor Approach. The daily predictions are given in the Tidal Current Tables, Atlantic Coast of North America published annually by the Environmental Science Services Administration, Coast and Geodetic Survey.

NOTE: Speeds shown are for time of spring currents. To determine the speed for a particular time, these speeds must be adjusted by use of the table "Factors for Correcting Speeds" given on Page 1.

Fig. 9 - Section of sample page from a tidal current chart.

References

Following is a partial list of references for additional information on tidal currents:

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