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TIDES AND CURRENTS IN NEW YORK HARBOR

By
H. A. MARMER
Assistant Chief, Division of Tides and Currents

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PREFACE

This publication is a revision of the volume under the same title which was issued in 1925. Since that time there has been a very considerable increase in the tide and current data relative to New York Harbor. These not only develop more fully the local features in the tidal movement throughout the harbor, but serve also to bring out the changes in the tides and currents that have taken place in consequence of improvements in the harbor.

Quite apart from their importance to navigation, tides and tidal currents enter as important factors into a number of problems connected with the harbor and port of New York. In the maintenance of channels for the deep-draft vessels of modern commerce, in harbor improvement, in the disposal of the sewage of a large industrial center, and in related problems, a knowledge of the rise and fall of the tide and of the flood and ebb of the current becomes necessary.

In connection with various projects, tide and current observations have been made from time to time in the harbor. In 1922 and again n 1932 comprehensive tide and current surveys were carried out jointly by the Coast and Geodetic Survey and the United States Engineer Office, First District, New York. The present publication embodies the results of these surveys and also of previous tide and current observations. It is intended here to make available to the mariner, the engineer, the scientist, and the public generally, the tide and current data now in the files of the Coast and Geodetic Survey and the United States Engineer Office, First District, New York.

In connection with this publication, attention is directed to four other Coast and Geodetic Survey publications containing tide and current data for New York Harbor. These are: Tide Tables, Atlantic Ocean; Current Tables, Atlantic Coast, North America; Tidal Current Charts, New York Harbor; and Tidal Bench Marks, State of New York.

TIDES AND CURRENTS IN NEW YORK HARBOR

PART I—TIDES

TIDES, GENERAL CHARACTERISTICS

DEFINITIONS

The tide is the name given to the alternate rising and falling of the level of the sea which at most places occurs twice daily. The striking feature of the tide is its intimate relation to the movement of the moon. With but few exceptions the world over high water and low water at any given place follow the moon's meridian passage by a very nearly constant interval; and since the moon in its apparent movement around the earth crosses a given meridian, on the average, 50 minutes later each day, the tide at most places likewise comes later each day by 50 minutes, on the average. The tidal day, like the lunar day, therefore, has an average length of 24 hours and 50 minutes.

With respect to the tide, the "moon's meridian passage" has a special significance. It refers not only to the instant when the moon is directly above the meridian, but also to the instant when the moon is directly below the meridian, or 180° distant in longitude. In this sense, therefore, there are two meridian passages in a tidal day, and they are distinguished by being referred to as the upper and lower meridian passages or upper and lower transits.

The interval between the moon's meridian passage (upper or lower) and the following high water is known as the "high water lunitidal interval." Likewise the interval between the moon's meridian passage and the following low water is known as the "low water lunitidal interval." For short they are called, respectively, high water interval and low water interval and abbreviated as follows: HWI and LWI.

In its rising and falling the tide is accompanied by a horizontal forward and backward movement of the water, called the tidal current. The two movements—the vertical rise and fall of the tide and the horizontal forward and backward movement of the tidal current—are intimately related, forming parts of the same phenomenon brought about by the tidal forces of sun and moon.

It is necessary, however, to distinguish clearly between tide and tidal current, for the relation between them is not a simple one nor is it everywhere the same. At one place a strong current may accompany a tide having a very moderate rise and fall, while at another place a like rise and fall may be accompanied by a very weak current. Furthermore, the time relations between current and tide vary widely from place to place. For the sake of clearness, therefore, tide should be used to designate the vertical movement of the water and tidal current the horizontal movement.

It would be convenient to have a single term to designate the whole phenomenon which includes tides and tidal currents. Unfortunately no such distinct term exists. For years, however, "the tide" or "the tides" or even "flood and ebb" have been used in this general sense, and usually no confusion arises from this usage, since the context indicates the sense intended; but the use of the term "tide" to denote the horizontal movement of the water is confusing and is to be discouraged.

With respect to the rise and fall of the water due to the tide, high water and low water have precise meanings. They refer not so much to the height of the water as to the phase of the tide. High water is the maximum height reached by each rising tide and low water the minimum height reached by each falling tide.

It is important to note that it is not the absolute height of the water which is in question, for it is not at all infrequent at many places to have the low water of one day higher than the high water of another day. Whatever the height of the water, when the rise of the tide ceases and the fall is to begin, the tide is at high water; and when the fall of the tide ceases and the rise is to begin, the tide is at low water. The abbreviations HW and LW are frequently used to designate high and low water, respectively.

In its rising and falling the tide does not move at a uniform rate. From low water the tide begins rising, very slowly at first, but at a constantly increasing rate for about 3 hours, when the rate of rise is a maximum. The rise then continues at a constantly decreasing rate for the following 3 hours, when high water is reached and the rise ceases. The falling tide behaves in a similar manner, the rate of fall being least immediately after high water, but increasing constantly for about 3 hours when it is at a maximum and then decreasing for a period of 3 hours till low water is reached.

The rate of rise and fall and other characteristics of the tide may best be studied by representing the rise and fall graphically. This may be done by reading the height of the tide at regular intervals on a fixed vertical staff graduated to feet and tenths, plotting these heights to a suitable scale on cross-section paper and drawing a smooth curve through these points. A more covenient method is to make use of an automatic tide gage by means of which the rise and fall of the tide is recorded on a sheet of paper as a continuous curve drawn to a suitable scale. Figure 1 shows a tide curve for the Battery, New York Harbor, for the first 2 days of June 1933.

In figure 1 the numbers from 0 to 24, increasing from left to right, represent the hours of the day beginning with midnight. Numbering the hours consecutively to 24 eliminates all uncertainty as to whether morning or afternoon is meant and has the further advantage of great convenience in computation. The numbers on the left, increasing upward from 0 to 4, represent the height of the tide in feet as referred to a fixed vertical staff. The tide curve presents the well-known form of the sine or cosine curve.

The difference in height between a high water and a preceding or following low water is known as the "range of tide" or "range." The average difference in the heights of high and low water at any given place is called the "mean range."

THE TIDE-PRODUCING FORCES

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. 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

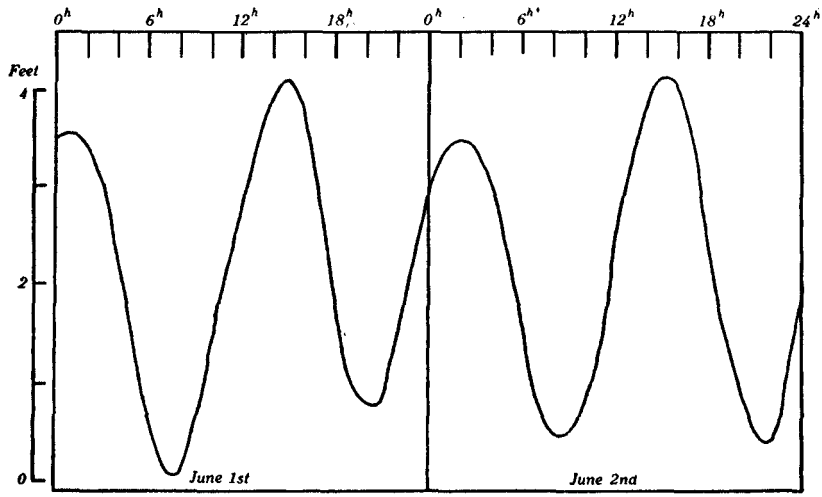

FIGURE 1.—Tide curve, the Battery, New York Harbor, June 1–2, 1933.

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 three classes: (*a*) Those having a period of approximately 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, as they actually occur, differ-

ing markedly at various places, but apparently with no regard to latitude.

The principal tide-producing forces are the semidiurnal forces. These forces go through two complete cycles in a tidal day, and it is because of the predominance of these semidaily forces that there are at most places two complete tidal cycles, and therefore two high and two low waters in a tidal day.

VARIATIONS IN RISE AND FALL

The rise and fall of the tide 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 rise and fall the tide 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, high water rises higher and low water falls lower than usual, so that the range at such times is greater than the average. The tides at such times are called "spring tides" and the range of the tide at these times is known as the "spring range." When the moon is in its first and third quarters, the tide does not rise as high or fall as low as usual, hence the range at such times is less than the average. The tide at such times is called the "neap tide" and the corresponding range is called the "neap range."

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 tides and the corresponding phases of the moon; that is, spring tides do not occur on the days of full and new moon, but a day or two later. Likewise neap tides follow the moon's first and third quarters after an interval of a day or two. This lag in the response of the tide, 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 rise and fall of the tide 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. When it is nearest the earth, or in perigee, the tide rises higher and falls lower than on the average, the tides being known as "perigean tides" and the corresponding range as the "perigean range." When the moon is farthest from the earth, or in apogee, the tide does not rise as high or fall as low as usual. These latter tides are called "apogean tides" and the corresponding ranges are "apogean ranges."

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 tides. The greatest rise and fall does not come on the day when the moon is in perigee, but a day or two later. Likewise, the least rise and fall does 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 rise and fall of the tide 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 two high waters of a day, and likewise the two low waters, do not differ much; in other words, at such times morning and afternoon tides resemble each other. As the declination increases, differences between morning and afternoon tides 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 tides small, the tides are known as "equatorial tides." At the times of the moon's maximum semimonthly declination, when the differences between morning and afternoon tides are at a maximum, the tides are called "tropic tides", since the moon is then near one of the tropics.

There are other variations in the rise and fall of the tides, but the three discussed above are the most prominent. These three variations are exhibited by the tide 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 tides that is the predominant variation.

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 27⅓ days in length. It follows, therefore, that very considerable variation in the rise and fall of the tide cocurs during a year due to the changing relations of the three variations to each other.

DIURNAL INEQUALITY

The difference between morning and afternoon tides is known as diurnal inequality. While this is a feature in the tide at all places where two high and two low waters occur in a day, it is more marked in some places than in others. On the Atlantic coast of the United States the tides exhibit but little diurnal ineuqality, but on the Pacific coast there is marked inequality. In figure 2 is shown the tide curve for San Francisco, Calif., for the last 4 days of May 1931. The horizontal line associated with the diagram represents mean sea level.

It will be noted the diurnal inequality in the tide curve of figure 2 is exhibited by both the high and the low waters, morning low waters being lower than the afternoon low waters, and morning high waters being lower than the afternoon high waters. But the inequality in the low waters is seen to be greater than that in the high waters. For the 4-day period shown the declination of the moon was increasing, and the inequality, likewise, is seen to have been increasing.

To distinguish the two tides of a day, definite names have been given to each of the two high and two low waters. Of the two high waters, the higher is called the "higher high water" and the lower the "lower high water." Likewise, of the two low waters of a day, the lower is called "lower low water" and the higher "higher low water." It is to be noted that the diurnal inequality in tides is featured not only in the heights but also in the time of the tide. Where there is considerable inequality in the heights of the tide, there will also be considerable inequality in the times. Thus, at San Francisco, the duration of rise, that is the time interval between low and high water, is 6.7 hours, on the average, while the duration of fall averages 5.7 hours. For the last day shown in figure 2, when there was considerable inequality in the tide the durations of rise and fall were as follows:

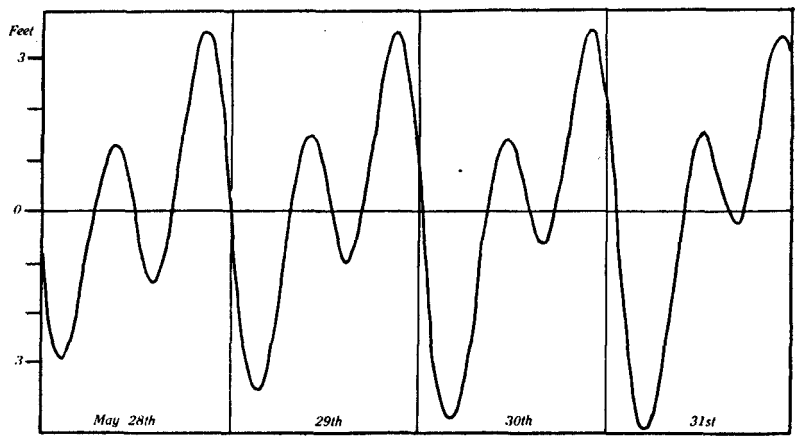

FIGURE 2.—Tide curve, San Francisco, Calif., May 28-31, 1931.

morning rise 7.4 hours, afternoon rise 5.9 hours; morning fall 7 hours, afternoon fall 4.4 hours.

Quite apart from the fact that the tides at different places differ in the degree of diurnal inequality exhibited, it is to be noted that the tides at different places differ also in the kind of inequality. At some places the inequality is exhibited principally by the high waters; at other places it is exhibited principally in the low waters; and at still other places it is a feature of both high and low waters. This matter, however, is advantageous to discuss in connection with types of tide.

TYPES OF TIDE

The tide at different places generally exhibits different features, in regard to time, range, or characteristics of rise and fall. Indeed, the tide at any place has certain features which distinguish it from the tide at other places. There is thus great variety in tides. It is convenient, however, to group all tides under three types, namely, semidaily, daily, and mixed. Instead of semidaily and daily, the terms semidiurnal and diurnal are frequently used.

The semidaily type of tide is one in which two high and two low waters occur in a tidal day, with but little diurnal inequality; that is, morning and afternoon tides resemble each other more or less close-

ly. Figure 1, illustrating the tide at the Battery, New York Harbor, may be taken as representative of this type of tide, and this is the predominant type found on the Atlantic coast of the United States.

In the daily type of tide, but one high and one low water occur in a day. Pensacola, Fla., may be cited as a place at which the tide is of the daily type. This type of tide is not widely distributed. Certain regions in the Gulf of Mexico, in Alaska, in the Philippine Islands, on the coast of China and in other scattered localities exhaust the list of places having this type of tide. Figure 3, which represents the tide at Pensacola for the last 4 days of May 1931, illustrates this type of tide. In the daily type of tide, the rise and the fall of the tide each have a duration of approximately half a day.

The mixed type of tide is one in which two high and two low waters occur during a day but with marked inequality. Figure 2, which represents the tide at San Francisco for a 4-day period may be taken as a representative of this type of tide. But as noted in the discussion

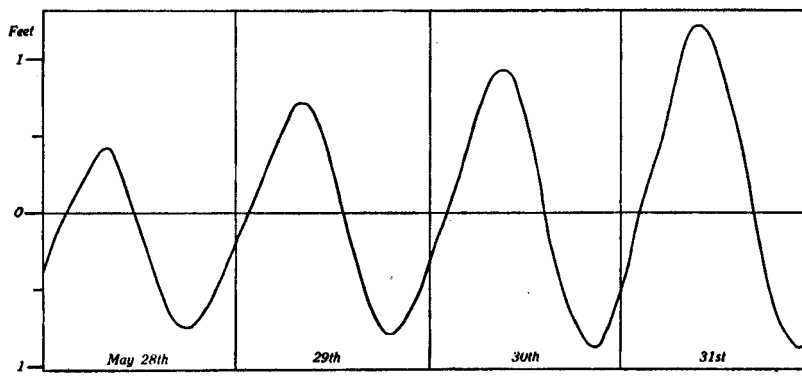

FIGURE 3.—Tide curve, Pensacola, Fla., May 28-31, 1931.

of diurnal inequality, the inequality may be featured principally by the high waters, principally by the low waters, or in approximately equal degree by both high and low waters. There are thus 3 different forms of the mixed type of tide, as illustrated in figure 4, which reproduces the tide curves for the last 4 days of May 1931 at Seattle, Wash., Honolulu, T. H., and San Diego, Calif.

At Seattle, as the upper diagram of figure 4 shows, the diurnal inequality is featured principally in the low waters. The two high waters of each day, for the period shown, do not differ much; but the low waters differ strikingly—by as much as 8 feet or more. It is of interest to note, too, that on the last 2 days the higher low water did not fall as low as sea level. At Honolulu conditions are the reverse of those at Seattle, for here the inequality is featured principally in the high waters. And at times, the lower high water here does not attain the height of sea level. At San Diego, on the other hand, the inequality is exhibited in approximately equal degree by both high and low waters.

In the mixed type of tide it is clear that as the diurnal inequality increases the difference between higher low water and lower high water becomes less and less and in the extreme case they merge, giving rise to a stand of the tide. Such tides occur at numerous places, as

for example at Galveston, Tex. and at Manila, P. I., tide curves for which for the last 4 days of May 1931 are shown in figure 5.

In connection with figure 5 it is to be noted that the moon was on the equator on May 26, so that the moon's declination was increasing thereafter until June 2, when it attained its farthest southerly declination. This is reflected in the tide curves shown in figure 5, by the increasing diurnal inequality in the tides. At Galveston on May 28 and 29 lower high water and higher low water differed by 0.2

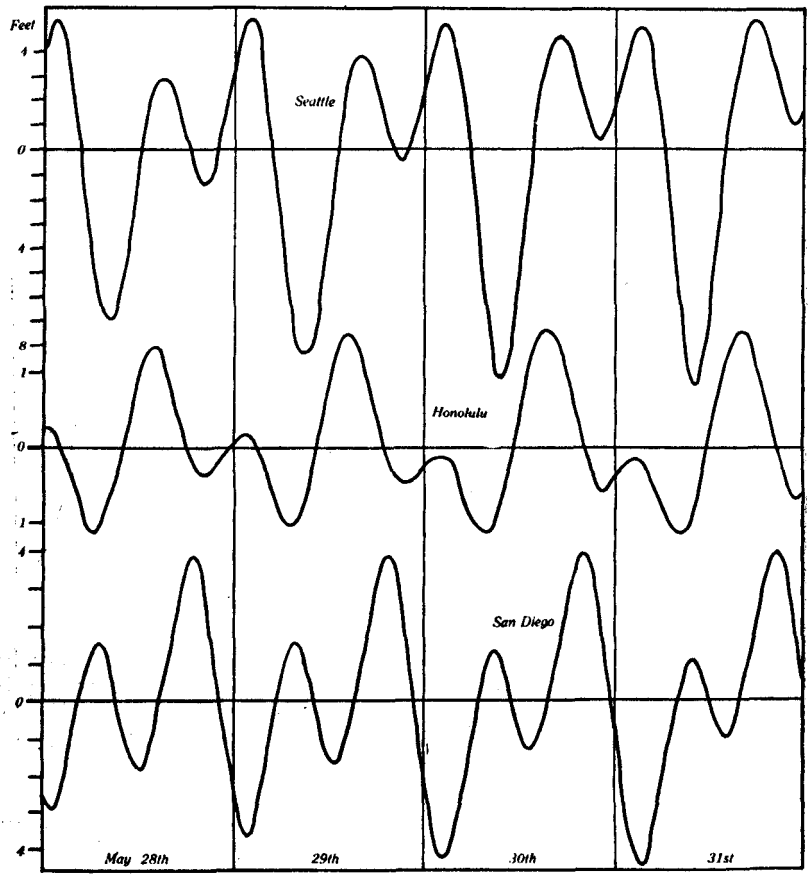

FIGURE 4.—Different forms of mixed type of tide: Seattle, Honolulu, and San Diego, May 28–31, 1931.

foot; on May 30 they both had the same height, thereby merging to form a stand of the tide of several hours. A similar state of affairs occurred at Manila in the evening of May 30.

When the tide at any place is designated as of a particular type, it refers to the characteristics of the predominating tide at that place. At the time of the moon's maximum semimonthly declination, the semidiurnal type exhibits more or less diurnal inequality and thus approaches the mixed type; and when the moon is on or near the equator the diurnal inequality of the mixed type is at a minimum, the tide at such times resembling the semidiurnal type. It is the characteristics of the predominating tide that determine the type of tide at any given place.

It can be shown easily that the different types of tide arise from the combination of daily and semidaily constituents having different ranges and different time relations. Thus, suppose that in a certain sea the tide-producing forces give rise to daily and semidaily constituents of the tides with different ranges. If the semidaily constituent has much the greater range, it is clear that within that sea the tide will be of the semidaily type, morning and afternoon tides differing but little. If the daily constituent has much the greater range, the tide will be of the daily type, with but one high and one low water in a day.

But suppose the two constituent tides have the same range, what then is the character of the resultant tide? The rise and fall of each of these constituent tides may be represented as in figure 6, the semi-

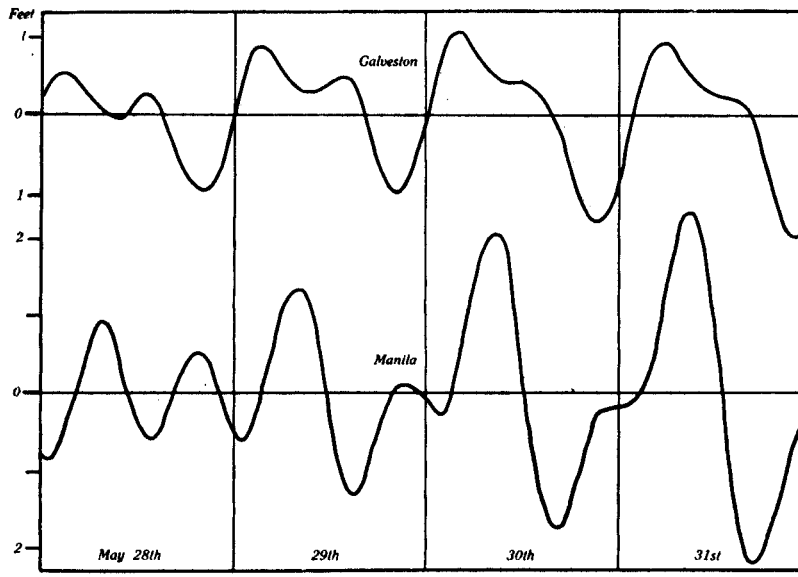

FIGURE 5.—Tide curves, Galveston and Manila, May 28–31, 1931.

daily constituent by the dotted curve and the daily constituent by the dashed curve. The height of the resultant tide at any moment is then clearly the sum of the heights of the constituent tides at that moment. In figure 6 the resultant tide is indicated by the heavy full-line curve.

The two constituent tides may combine in various ways as regards time. Three different cases are represented in figure 6. In the upper diagram the two constituent tides have such time relations that their low waters occur at the same time. The resultant tide in this case features the inequality wholly in the low waters, and resembles the tide at Seattle shown in figure 4. The middle diagram represents the case in which the high waters of the two constituent tides occur at the same time, and now the resultant tide exhibits the inequality wholly in the high waters, resembling the tide at Honolulu in figure 4. Finally, the lower diagram of figure 6 represents conditions resulting

when the two constituent tides are at sea level at the same time. Now the resultant tide exhibits the inequality in equal degree in both the high and the low waters, resembling the tide at San Diego in figure 4.

It is evident, therefore, that the mixed type of tide arises from a mixture of daily and semidaily constituents of approximately equal range. Furthermore, the different forms of the mixed tide arise from different time relations between the constituent tides.

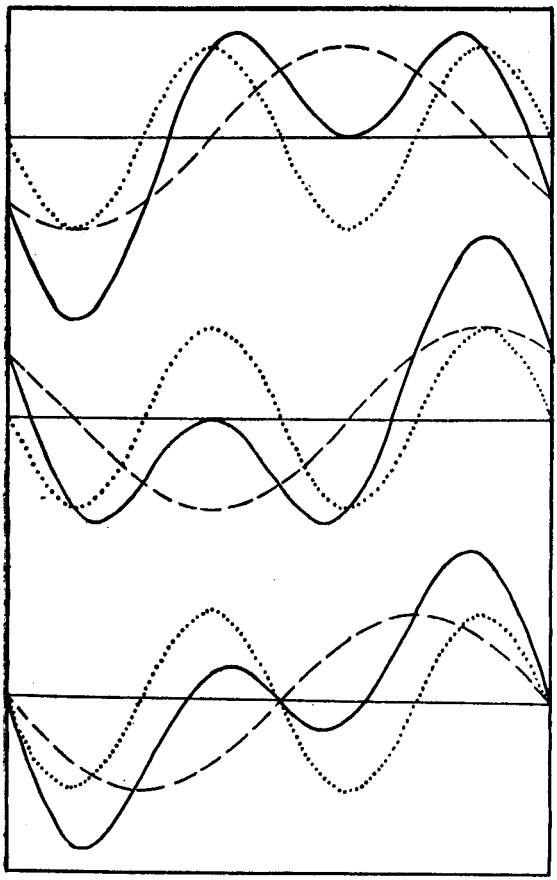

FIGURE 6.—Combination of daily and semidaily constituent tides.

Mixed tides in which a stand occurs, as at Galveston and Manila in figure 5, can be shown to be due to the combination of a daily and a semidaily constituent in which the former has twice the range of the latter. If in the case represented by the lower diagram of figure 6, we take the range of the daily constituent twice that of the semidaily, it is found that the resultant will have but one high and one low water in a day with a stand where the higher low water and the lower high water merge. And it is to be noted that both the daily and semidaily tide-producing forces vary in intensity from day to day, the former being greatest when the moon is at its semimonthly north or south declination, and the latter being greatest when the moon is over the equator. It is in this varying relation of the magnitudes of the daily and semidaily tide-producing forces through a fortnight that we find the explanation of tides which part of the time are of the mixed type and part of the time of the daily type.

By means of the harmonic analysis, the tide at any place may be resolved into its simple constituent tides. This analysis gives both the ranges and the phases or time relations of the constituent tides to each other. The data with regard to the range and phase of the constituent tides at any place are spoken of as the harmonic constants of the tide at that place.

HARMONIC CONSTANTS

Since the tide is periodic in character, it may be regarded as the resultant of a number of simple harmonic movements. In other words, if h be the height of the tide, reckoned from sea level, then for any time t, we may write $h=A \cos (at+\alpha)+B \cos (bt+\beta)+ \ldots$. In the above formula each term represents a constituent of the tide which is defined by its amplitude or semirange, A, B, etc., by an angular speed, a, b, etc., and by an angle of constant value, α, β, etc., which determines the relation of time of maximum height to the time of beginning of observation.

We may also regard the matter from another viewpoint and suppose the moon and sun as *tide-producing bodies* to be replaced by a number of hypothetical tide-producing bodies, each of which moves around the earth in the plane of the equator in a circular orbit with the earth as center. With the further assumption that each of these hypothetical tide-producing bodies gives rise to a simple tide, the high water of which occurs a certain number of hours after its upper meridian passage and the low water the same number of hours after its lower meridian passage, the oscillation produced by each of these simple tides may be written in the form $h=A \cos (at+\alpha)$ as above. The great advantage of so regarding the tide is that it permits the complicated movements of sun and moon relative to the earth to be replaced by a number of simple movements.

Each of the simple tides into which the tide of nature is resolved is called a component tide or simply a component. The amplitudes or semiranges of the component tides, together with the angles which determine the relation of the high water of each of these component tides to some definite time origin and which are known as the epochs, constitute the harmonic constants.

The periods of revolution of the hypothetical tidal bodies or the speeds of the various component tides are computed from astronomical data and depend only on the relative movements of sun, moon, and earth. These periods being independent of local conditions are therefore the same for all places on the surface of the earth; what remains to be determined for the various simple constituent tides is their epochs and amplitudes which vary from place to place according to the type, time, and range of the tide. The mathematical process by which these epochs and amplitudes are disentangled from tidal observations is known as the harmonic analysis.

The number of simple constituent tides is theoretically large, but most of them are of such small magnitude that they may, for all practical purposes, be disregarded. In the prediction of tides it is necessary to take account of 20 to 30, but the characteristics of the tide at any place may be determined easily from the 5 principal ones.

It is obvious that the principal lunar tidal component will be one which gives 2 high and 2 low waters in a tidal day of 24 hours and 50 minutes, or more exactly in 24.841 hours. Its speed per solar hour, therefore, is $\frac{2\times360^\circ}{24.841}=28^\circ.98$. This component has been given the symbol M_2. Likewise, the principal solar tidal component is one that gives 2 high and 2 low waters in a solar day of 24 hours. Its angular speed per hour is therefore $\frac{2\times360^\circ}{24}=30^\circ.00$. The symbol for this principal solar component is S_2.

Since the moon's distance from the earth is not constant, being less than the average at perigee and greater at apogee, the period from one perigee to another being on the average 27.55 days, we must introduce another hypothetical tidal body, so that at perigee its high water will correspond with the M_2 high water, and at apogee its low water will correspond with the M_2 high water. In other words, the tidal component which is to take account of the moon's perigean movement must, in a period of 13.78 days, lose 180° on M_2, or at the rate of $\frac{180°}{13.78}=13°.06$ per day. Its hourly speed, therefore, is $28°.98-\frac{13°.06}{24}=28°.44$. This component has been given the symbol N_2.

The moon's change in declination is taken account of by two components denoted by the symbols K_1 and O_1. The speeds of these are determined by the following considerations: The average period from one maximum declination to another is a half tropic month, or 13.66 days. The speeds of these two components should, therefore, be such that when the moon is at its maximum declination they shall both be at a maximum, and when the moon is on the equator they shall neutralize each other; that is, in a period of 13.66 days K_1 shall gain on O_1 one full revolution. The difference in their hourly speeds, therefore, is $\frac{360°}{24\times 13.66}=1°.098$. The mean of the speeds of these two components must be that of the apparent diurnal movement of the moon about the earth, or $\frac{360°}{24.84}=14°.49$. The speeds are therefore derived from the equations $\frac{K_1+O_1}{2}=14°.49$ and $K_1-O_1=1°.098$, from which $K_1=15°.04$ and $O_1=13°.94$.

It is customary to designate the amplitude of any component by the symbol of the component and the epoch by the symbol with a degree mark added. Thus M_2 stands for the amplitude of the M_2 tide and $M°_2$ for the epoch of this tide. The five components enumerated above are the principal ones. Between 20 and 30 components permit the prediction of the time and height of the tide at any given place with considerable precision.

From the harmonic constants the characteristics of the tide at any place can be very readily determined. The five principal constants alone permit the approximate determination of the tidal characteristics very easily. Thus, approximately, the mean range is $2M_2$, spring range $2(M_2+S_2)$, neap range $2(M_2-S_2)$, perigean range $2(M_2+N_2)$, apogean range $2(M_2-N_2)$, diurnal inequality at time of tropic tides $2(K_1+O_1)$, high water lunitidal interval $\frac{M_2°}{28.98}$. The various ages of the tide can likewise be readily determined. Approximately, the ages in hours are: Phase age, $S_2°-M_2°$; parallax age, $2(M_2°-N_2°)$; diurnal age, $K°_1-O°_1$. The type of tide, too, may be determined from the harmonic constants through the ratio $\frac{K_1+O_1}{M_2+S_2}$. Where this ratio is less than 0.25, the tide is of the semidiurnal type; where the ratio is between 0.25 and 1.25, the tide is of the mixed type; and where the ratio is over 1.25, the tide is of the diurnal type.

The periods of the various component tides, like the periods of the tide-producing forces, group themselves into three classes. The components in the first class have periods of approximately half a day and are known as semidiurnal components; the periods of the components in the second class are approximately one day, and these components are known as diurnal components; the components in the third class have periods of half a month or more and are known as long-period components. In shallow waters, due to the effects of decreased depth, the tides are modified and another class of simple tides is introduced having periods of less than half a day, and these are known as shallow-water component tides.

The class to which any component tide belongs is generally indicated by the subscript used in the notation for the component tides, the subscript giving the number of periods in a day. With long-period tides generally no subscript is used; with semidiurnal tides the subscript is 2; with diurnal tides the subscript is 1, and with shallow-water tides the subscript is 3, 4, or more. Thus Sa represents a solar annual component, P_1 a solar diurnal component, M_2 a lunar semidiurnal component, S_4 a solar shallow-water component with a period of one-quarter of a day, and M_6 a lunar shallow-water component with a period of one-sixth of a day.

TIDAL DATUM PLANES

Tidal planes of reference form the basis of all rational datum planes for elevations used in practical or scientific work. The advantage of the datum plane based on tidal determination lies not only in simplicity of definition, but also in the fact that it may be recovered at any time, even though all bench-mark connections be lost.

The principal tidal plane is that of mean sea level, which may be defined as the plane about which the tide oscillates, or as the surface the sea would assume when undisturbed by the rise and fall of the tide. At any given place this plane may be determined by deriving the mean height of the tide. This is perhaps best done by adding the hourly heights of the tide over a period of a year or more and deriving the mean hourly height. It is to be noted that in such a determination the mean sea level is not freed from the effect of prevailing winds, atmospheric pressure, and other meteorological conditions.

The plane of mean sea level must be carefully distinguished from the plane of half-tide level or, as it is frequently called, mean-tide level. This latter plane is one determined as the half sum of the high and low waters. It is, therefore, the plane that lies halfway between the planes of mean low water and mean high water. The plane of half-tide level does not, at most places on the open coast, differ by more than about a tenth of a foot from the plane of mean sea level, and where this difference is known the plane of mean sea level may be determined from that of half-tide level. Like all of the tidal planes, the plane of half-tide level should be determined by observations covering a period of a year or more.

For many purposes the plane of mean low water is important. This plane at any given place is determined as the average of all the low waters during a period of a year or more. Where the diurnal inequality in the low waters is small, as on the Atlantic coast of the United States, this plane is frequently spoken of as the "low-water

plane," or "the plane of low water"; but strictly it should be called the plane of mean low water.

Where the tides exhibit considerable diurnal inequality in the low waters, as on the Pacific coast of the United States, the lower low waters may fall considerably below the plane of mean low water. In such places the plane of mean lower low water is preferable for most purposes. This plane is determined as the average of all the lower low waters over a period of a year or more. Where the tide is frequently diurnal, the single low water of the day is taken as the lower low water.

The plane of mean high water is determined as the average of all the high waters over a period of a year or more. Where the diurnal inequality in the high waters is small, this plane is frequently spoken of as "the plane of high water" or "the high-water plane." This usage may on occasion lead to confusion, and the denomination of this plane as the plane of mean high water is therefore preferable.

In localities of considerable diurnal inequality in the high waters, the higher high waters frequently rise considerably above the plane of mean high water. A higher plane is therefore of importance for many purposes, and the plane of higher high water is preferred. This plane is determined as the average of all the higher high waters for a period of a year or more. Where the tide is frequently diurnal, the single high water of the day is taken as the higher high water.

The tidal planes described above are the principal ones and the ones most generally used. Other planes, however, are sometimes used. Where a very low plane is desired, the plane of mean spring low water is sometimes used, its name indicating that it is determined as the mean of the low waters occurring at spring tides. Another plane sometimes used, which is of interest because based on harmonic constants, is known as the harmonic tide plane and for any given place is determined as $M_2+S_2+K_1+O_1$ below mean sea level.

MEAN VALUES

Since the rise and fall of the tide varies from day to day, chiefly, in accordance with the changing positions of sun and moon relative to the earth, any tidal quantities determined directly from a short series of tidal observations must be corrected to a mean value. The principal variations are those connected with the moon's phase, parallax, and declination, the periods of which are approximately 29½ days, 27½ days, and 27⅓ days, respectively.

In a period of 29 days, therefore the phase variation will have almost completed a full cycle while the other variations will have gone through a full cycle and but very little more. Hence, for tidal quantities varying largely with the phase variation, tidal observations covering 29 days, or multiples, constitute a satisfactory period for determining these quantities. Such are the lunitidal intervals, the mean range, mean high water, and mean low water. For quantities varying largely with the declination of the moon, as, for example, higher high water and lower low water, 27 days, or multiples, constitute the more satisfactory period.

As will be seen in the detailed discussion of the tides in New York Harbor, the values determined from two different 29-day or 27-day periods may differ very considerably. This is due to the fact that these periods are not exact synodic periods for the different variations,

and to the further fact that variations having periods greater than a month are not taken into account. Furthermore, meteorological conditions, which change from month to month, leave their impress on the tides. For accurate results the direct determination of the tidal datum planes and other tidal quantities should be based on a series of observations that cover a period of a year or preferably 3 years. Values derived from shorter series must be corrected to a mean value.

Two methods may be employed for correcting the results of short series to a mean value. One method makes use of tabular values, determined both from theory and observation, for correcting for the different variations. The other method makes use of direct comparison with simultaneous observations at some nearby port for which mean values have been determined from a series of considerable length.

IRREGULARITIES IN RISE AND FALL

Thus far in the consideration of the various features characterizing the tide at different places, it has been tacitly assumed that the rise and fall of the tide is free from irregularities, and the tide curves illustrating the tide at different places have been shown as smooth curves. However, it is only in protected waters during periods of calm weather that the tide curve is a smooth curve; for various agencies are at work that tend to bring about irregularities in the rise and fall of the tide. The principal disturbing agency is the wind, its action being of a twofold nature.

In the first place the wind affects the height of sea level from which the rise and fall of the tide takes place. It is a well-known fact that onshore winds tend to raise the level of the water along the coast, while offshore winds tend to lower it. In other words, with onshore winds the heights of high water and low water are higher than usual, while with offshore winds they are lower. The extent to which the high and low waters are raised or lowered depends not only on the velocity and direction of the wind, but also on local hydrographic features. In general it may be said that the effect is greatest at places situated on shallow waters.

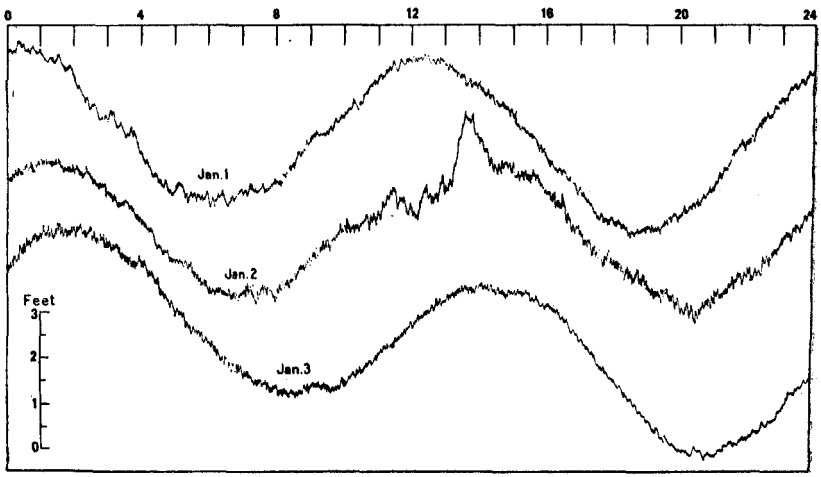

FIGURE 7.—Effect of wind on rise and fall of the tide.

The second effect of the wind on the regularity of the tide arises through the agency of waves. When the surface of the sea is disturbed by waves, the tide curves at nearby places are marked by numerous small "saw-teeth" as illustrated in the diagrams of figure 7, which are a reproduction of the tide curve for Atlantic City, N. J., for the period January 1–3, 1925. On these days there were heavy winds which gave rise to strong wave movement. The rapid changes in elevation of the surface of the sea due to these wind waves are recorded on the tide curve in the form of "saw-teeth."

The middle curve of figure 7, the tide curve for January 2, shows very pronounced irregularities in the rise and fall of the tide between 11 a. m. and 3 p. m. The oscillations of the surface of the sea between these times are of greater amplitude and longer period than those due to ordinary wind waves. These larger oscillations were brought about by a wind which a little before 1 p. m. attained a velocity of 78 miles per hour. These longer-period oscillations are not the effects of ordinary wind waves, but of stationary-wave oscillations known as seiches. They represent stationary-wave oscillations of some part of the wide embayment of the open coast upon which Atlantic City fronts.

The seiches shown in figure 7 were brought about by the wind. Seiches may also arise from rapid changes in barometric pressure, but more especially from seismic disturbances in the sea. When this seismic disturbance is near a coast a so-called "tidal wave" frequently inundates the coast. The waves resulting from seismic disturbances may also travel many miles across the sea and manifest themselves as seiches along distant coasts. An example of this is shown in figure

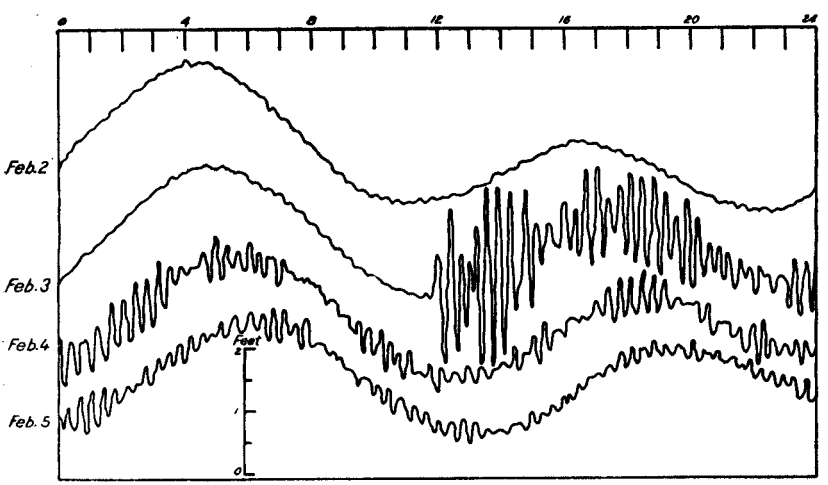

FIGURE 8.—Tide curves showing seiche movement, Honolulu, February 2–5, 1923.

8, which represents the tide curve at Honolulu, Hawaii, for the 4 days, February 2–5, 1923.

The upper curve of figure 8, for February 2, is a typical tide curve for that place, the slight irregularities being due to ordinary wind waves and swells. For the forenoon of the following day the curve is much like that on February 2; but a little before noon there is a

pronounced seiche movement, which continues with a more or less constant diminution in amplitude for the following 2 days. This seiche in the harbor of Honolulu resulted from an earthquake which occurred off the coast of Kamchatka on February 3, 1923, at 5:32 a. m. Hawaiian time. The seismic sea waves thus took a little more than 6 hours to travel the distance, in round numbers 2,500 miles, from Kamchatka to Honolulu.

THE HARBOR OF NEW YORK

COMPONENT PARTS

Most harbors are situated on a tidal river or bay, the harbor proper comprising a portion of the bay or river. New York Harbor differs in this respect from other harbors in that it consists of a number of bays and rivers that communicate with one another, thus forming a system of intercommunicating tidal waterways. And in another hydrographic respect does New York Harbor differ from other harbors, in that its communication with the open sea is through two independent passageways many miles apart. Figure 9 shows that the

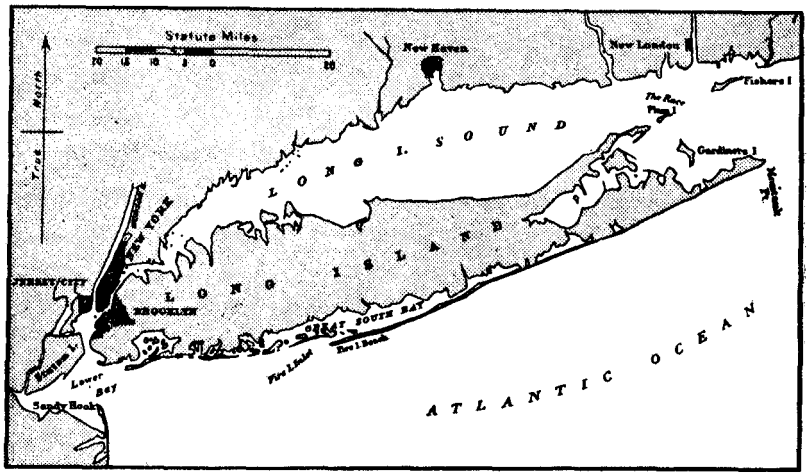

FIGURE 9.—New York Harbor, showing the two entrances from the open sea.

ocean tide comes to New York Harbor both from the south through Lower Bay and from the east, more than a hundred miles away, through Long Island Sound.

The principal entrance to the harbor is that through the southern gateway, through Lower Bay, the channel of which the largest ships afloat may navigate at any stage of the tide. New York Harbor is not only the most important seaport of the United States, but also one of the greatest commercial centers of the world. The area known as the port of New York extends east as far as Port Chester on Long Island Sound, north as far as Tarrytown on the Hudson, south as far as New Brunswick on the Raritan River, and includes the neighboring New Jersey shore of the Hudson as far as Newark and a little beyond. Within this area there is a population of very nearly 10 million people, according to the census of 1930.

The number of waterways that make up the harbor of New York depends on the limits assigned to the harbor. For the purposes of

this publication New York Harbor will be taken to comprise the following waterways: (1) Lower Bay (including Raritan and Sandy Hook Bays), (2) the Narrows, (3) Upper Bay, (4) Newark Bay, (5) Arthur Kill, (6) Kill Van Kull, (7) East River, (8) Hudson River (as far as Mount St. Vincent), (9) Harlem River. These waterways

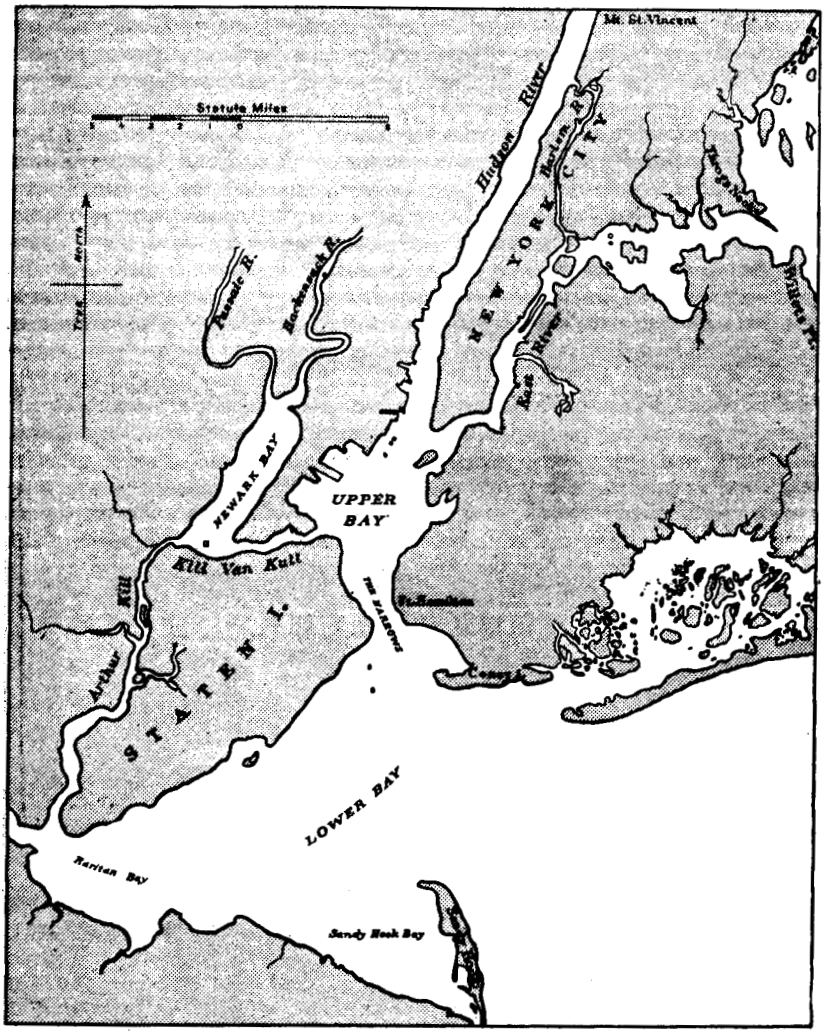

FIGURE 10.—New York Harbor, showing the relations of the component waterways.

are all included within the legally constituted port of New York. The relations of the component parts of the harbor to each other are shown in figure 10.

LOWER BAY

Into Lower Bay the ocean tide sweeps past the gateway between Sandy Hook and Coney Island. If we define the eastern limit of Lower Bay by a line running from the southwestern point of Coney

Island to the northwestern point of Sandy Hook, the entrance to the bay has a width of 7 statute miles. From this eastern limit Lower Bay extends to the Narrows on the north and to the mouth of Raritan River on the west, including thus Gravesend Bay, Raritan Bay, and Sandy Hook Bay. Within these limits Lower Bay covers an area of 118 square statute miles.

Through the bar extending across the entrance to Lower Bay a number of wide and deep channels give access to the bay and to the waterways connecting with it. Ambrose Channel, which leads into the Narrows, is the principal entrance to New York Harbor and has been dredged to a width of 2,000 feet and to a depth of 42½ feet below mean sea level. At its western end Lower Bay shallows considerably, but near its northern end, west of Coney Island, where it leads into the Narrows, the channel shows depths of over 100 feet. For the whole extent of its area within the limits assigned above Lower Bay has an average depth of 20 feet, reckoned from mean sea level.

At its northeastern end the tide from Lower Bay passes northward through the Narrows, while at its western end the tide is carried westward into Raritan River and northward into Arthur Kill. Through the Raritan River, Lower Bay receives the drainage waters from an area of about 1,100 square miles, while from the Narrows and Arthur Kill there drains into Lower Bay the waters from a territory having an area of approximately 15,000 square miles.

THE NARROWS

The Narrows is a short strait leading from Lower Bay into Upper Bay. It is a little more than 3 statute miles long, with a width of 1 mile at its southern end and 2 miles at its northern end. At its southern end where it meets Lower Bay the channel shows depths of 100 feet, but as it widens the depth of the channel decreases and at its northern end the greatest depth is 60 feet. At the southern end of the Narrows the deepest part of the channel lies nearer the eastern shore, but after a short distance the deeper part of the channel swings toward the western shore and continues parallel to it into Upper Bay. The area of 4¾ square miles which the Narrows comprises has an average depth of 49 feet, reckoned from mean sea level.

It is through the channel of the Narrows that the greater part of the commerce of New York Harbor passes, and it is through the same channel that the drainage waters of a region approximately 14,500 square miles in area find their way to the sea. For the tides, too, the Narrows is the principal channel to the highways of New York Harbor, affording a deep and commodious passage from Lower Bay.

UPPER BAY

From the Narrows the tide progresses into Upper Bay, a sheet of water a little more than 4 miles long and about 3½ miles wide, having an area of 14½ square miles. The main channel through Upper Bay, leading from the Narrows to the mouth of the Hudson, has a width of about half a mile with depths of 60 feet or more. The western part of the bay is occupied by extensive flats with depths of 8 feet or less, reckoned from mean sea level.

Three islands break the surface of Upper Bay near its northern end. Governors Island, the largest of these, is located near the eastern shore of the bay at the entrance to the East River. Bedloes Island and Ellis Island are situated near the west shore of the bay, and it is on Bedloes Island that the colossal bronze Statue of Liberty stands, the tip of the torch more than 300 feet above sea level.

From Upper Bay three tidal highways radiate—to the west Kill Van Kull leads into Newark Bay, to the northeast East River leads into Long Island Sound, and to the north the Hudson River furnishes a highway into the interior of the State. The channels leading into these three waterways have depths of 40 feet or more, but because of the extensive flats on the western side of the bay the average depth of the 14½ square miles covered by Upper Bay is about 25 feet, reckoned from mean sea level.

NEWARK BAY AND THE KILLS

Newark Bay lies to the west of Upper Bay, from which it is separated by a narrow tongue of land less than 1,200 yards wide in some places, on which the city of Bayonne, N. J., is located. It has a length of about 6 miles and an average width of a little more than a mile, comprising an area somewhat in excess of 8 square miles.

Two straits—Arthur Kill and Kill Van Kull—lead the tide into Newark Bay. From the south Arthur Kill brings the tide from the western end of Lower Bay and from the east Kill Van Kull carries the tide from Upper Bay. Arthur Kill has a length measured along its channel of 13 miles and covers an area of 4¼ square miles with an average depth of 18½ feet. Kill Van Kull is shorter than Arthur Kill, having a length of about 3 miles. It is about a third of a mile wide and comprises an area of almost exactly 1 square mile with an average depth, reckoned from mean sea level, of 28 feet. Being shorter, wider, and deeper, Kill Van Kull is the principal tidal inlet into Newark Bay.

Two rivers of considerable size—the Hackensack and the Passaic—empty into Newark Bay at its upper end, and it is principally through these two rivers that Newark Bay drains a territory with an area of nearly a thousand square miles. The Hackensack and the Passaic each carry the tide upstream a distance of about 15 miles. The greater part of Newark Bay is shoal, but a channel obtained partly by dredging leads through the bay to the entrance of the Hackensack and Passaic Rivers. For the 8 square miles comprising its area Newark Bay has an average depth of 9 feet.

EAST RIVER

From Upper Bay, East River carries the tide northeastward. Parenthetically, it may be remarked that East River is strictly not a river but a strait connecting Upper Bay and Long Island Sound, so that East River is subject not only to the tide coming northeastward from Upper Bay but also to the tide moving southwestward from Long Island Sound.

From the extreme tip of Manhattan Island on the southwest to Throgs Neck on the northeast East River has a length of 16 miles, but it is not at all uniform in its hydrographic features throughout this length. Hell Gate, which divides East River almost exactly in half, may be taken as separating the waterway into two parts possess-

ing different characteristics. Lower East River, lying southwestward of Hell Gate, is a relatively narrow and deep waterway, comprising an area of 4 square miles with an average depth of 38 feet. Eastward of Hell Gate the river widens and Upper East River covers an area of 9¾ square miles, with an average depth of 25 feet.

A number of islands lie scattered near the middle of East River, restricting the width of the waterway and giving rise to swift currents. It is to the stretch of water lying between the northern tip of Blackwells Island and the southern part of Wards Island that the name Hell Gate is applied. While the Dutch words "Helle Gat", from which its name is derived, have a totally different meaning than the English "Hell Gate", the Anglicised form was considered an appropriate designation, especially in the early days when the reefs of rock in the main passage, together with the swift currents and tortuous channel, rendered navigation dangerous at times. Since 1851 a considerable amount of rock has been removed, so that now the channel of Hell Gate is about 850 feet wide and very nearly 30 feet deep from mean sea level.

HUDSON RIVER

The Hudson River is one of the more important rivers of the Atlantic coast. From its mouth at the Battery, New York City, where it debouches into Upper Bay, it carries the tide from the latter body of water a distance of 150 miles until stopped by the dam at Troy. For a distance of 90 miles above its mouth the Hudson has a deep and unobstructed channel navigable for large vessels. Further upstream the depth lessens, but a project now under way will create a channel with a depth of 28 feet from mean sea level as far as Albany, 7 miles below Troy. The Hudson River also serves as a highway for the traffic of the New York State Barge Canal, which extends to the Great Lakes.

Near Mount St. Vincent, about 2 miles below Yonkers, runs the northern boundary of the city of New York, and it is the Hudson from the Battery to Mount St. Vincent—a distance of 16 miles—that is here included as forming a part of New York Harbor. For this distance the river has a width of very nearly a mile and covers an area of 14½ square miles, with an average depth, reckoned from mean sea level, of 33 feet.

It is the Hudson River that brings the greater part of the drainage waters into New York Harbor. Of the 15,000 square miles of territory that drain into the sea through the Narrows, the Hudson River contributes over 13,400 square miles, or more than 89 percent. Computations based on river gagings and rainfall bring out the fact that, on the average, about 26,000 cubic feet of fresh or nontidal water pass through the Narrows each second, of which the Hudson contributes 24,000 cubic feet. In other words, from the territory it drains, the Hudson pours each day into New York Harbor a volume of water equal to 2 billion cubic feet.

HARLEM RIVER

Harlem River is the narrow tidal waterway that joins the Hudson with the East River and makes an island of Manhattan by cutting it off from the mainland to the north. Like East River, Harlem River is a strait and not a true river. Its junction with the Hudson is at a

point 13½ miles above the mouth of the Hudson, and its junction with the East River is through three channels in the vicinity of Hell Gate, the principal channel lying between Manhattan and Wards Island.

Originally the Hudson River outlet of the Harlem was a tortuous narrow channel through a tidal marsh known as Spuyten Duyvil Creek, the designation "Harlem River" being applied to the rest of the waterway leading into East River. In 1895 a ship canal was completed through the tidal marsh, and now the Harlem is a continuous waterway from the East River to the Hudson, the channel having a length of 7 miles. It covers an area of three-quarters of a square mile, with an average depth of about 18 feet.

New York Harbor thus forms a system of waterways consisting of 3 bays, 5 straits, and 1 tidal river, through all of which the tide sweeps. From the ocean the tide enters the harbor through two inlets many miles apart, and this, together with the fact that the waterways of New York Harbor are intercommunicating, gives rise to the considerable variety in the rise and fall of the tide and in the flood and ebb of the current.

THE TIDE AT FORT HAMILTON

THE TIDE RECORDS

Of the tide observations in New York Harbor, those made at Fort Hamilton, on the east bank of the Narrows, constitute the longest continuous series. Begun in 1893, they are still being continued. From 1893 to 1920 the observations were made by the Coast and Geodetic Survey, the tide record being in the form of a curve drawn to a scale of 1:12 by a 3-roller standard Coast and Geodetic Survey automatic tide gage. The heights on the paper record are connected with a fixed zero by readings made on a fixed tide staff, these comparative readings being made several times a week.

On December 5, 1920, the wharf on which the tide house was located was destroyed by fire. On the reestablishment of the wharf early in 1921 the United States Engineer Office, War Department, installed a Gurley printing gage which records directly the height of the tide at 15-minute intervals. For the years 1921 to 1933, the data for Fort Hamilton are from the records of the United States Engineer Office.

Care was taken to maintain a fixed datum to which the heights of the tide curve were referred. This was accomplished by leveling with a wye level between the staff and substantial bench marks on the shore whenever it was necessary to renew the staff. In this way the zero of the staff was kept at a constant elevation throughout the period of observation.

TIME OF TIDE

The lunitidal intervals at Fort Hamilton, or the intervals by which high and low water follow the moon's meridian passage, vary somewhat from day to day. This variation is due principally to the variation in the positions of sun and moon relative to the earth; but changes in wind and weather also cause variations in the lunitidal intervals. However, when undisturbed by wind or other unusual meteorological conditions, it is only infrequently that these in-

tervals at Fort Hamilton vary by as much as 1 hour from the mean values.

The change in lunitidal intervals from day to day throughout a summer month is shown by the seventh and eighth columns of table 1, which list the high-water and low-water intervals for each day of June, 1919. It is to be noted, however, that for convenience in computation, the moon's transits across the meridian of Greenwich are taken, the necessary correction to refer these intervals to the local meridian being made to the average values determined for the month. For Fort Hamilton this correction is −0.11 hour. In the second column, the lower transits are inclosed in parentheses, and the values derived from them in the seventh and eighth columns are likewise inclosed in parentheses.

TABLE 1.—*High and low waters, Fort Hamilton, June 1919*

Date	Moon's transit, meridian of Greenwich	Time		Duration		Lunitidal interval		Height		Range	
		High water	Low water	Rise	Fall	High water	Low water	High water	Low water	Rise	Fall
	Hours	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Feet*
1	(2.5)	10.0	4.1	5.9	-------	(7.5)	(1.6)	9.4	3.4	6.0	-------
	14.9	22.2	16.1	6.1	6.1	7.3	1.2	10.0	4.1	5.9	5.3
2	(3.4)	10.9	4.9	6.0	6.7	(7.5)	(1.5)	9.2	3.7	5.5	6.3
	15.9	23.1	17.3	5.8	6.4	7.2	1.4	9.6	4.1	5.5	5.1
3	(4.3)	11.8	5.9	5.9	6.8	(7.5)	(1.6)	8.9	3.9	5.0	5.7
	16.7	-------	18.0	-------	6.2	-------	1.3	-------	4.2	-------	4.7
4	(5.1)	0.1	6.4	6.1	6.3	7.4	(1.3)	8.9	3.8	4.7	5.1
	17.4	12.9	18.8	6.5	5.9	(7.8)	1.4	8.5	4.4	4.7	4.1
5	(5.8)	0.6	7.5	5.8	6.9	7.2	(1.7)	8.3	3.8	3.9	4.5
	18.2	13.7	20.1	6.2	6.4	(7.9)	1.9	8.4	4.5	4.6	3.9
6	(6.5)	1.8	8.4	5.7	6.6	7.6	(1.9)	8.0	4.1	3.5	3.9
	18.9	14.4	21.0	6.0	6.6	(7.9)	2.1	8.5	4.7	4.4	3.8
7	(7.3)	2.7	9.1	5.7	6.4	7.8	(1.8)	7.9	4.0	3.2	3.9
	19.6	15.4	21.8	6.3	6.4	(8.1)	2.2	8.5	4.5	4.5	4.0
8	(8.0)	3.4	10.3	5.6	6.9	7.8	(2.3)	7.9	4.8	3.4	3.1
	20.3	16.3	22.9	6.0	6.6	(8.3)	2.6	9.1	5.3	4.3	3.8
9	(8.7)	4.2	11.2	5.3	7.0	7.9	(2.5)	8.3	4.7	3.0	3.6
	21.1	16.9	23.9	5.7	7.0	(8.2)	2.8	8.9	4.5	4.2	4.4
10	(9.4)	5.2	11.9	5.3	6.7	8.1	(2.5)	7.9	4.3	3.4	3.6
	21.8	17.4	-------	5.5	-------	(8.0)	-------	8.7	-------	4.4	-------
11	(10.2)	6.2	0.5	5.7	7.1	8.4	2.7	7.6	3.9	3.7	4.8
	22.6	18.5	12.2	6.3	6.0	(8.3)	(2.0)	8.7	4.1	4.6	3.5
12	(11.0)	6.7	1.5	5.2	7.0	8.1	2.9	7.9	4.0	3.9	4.7
	23.4	19.2	13.0	6.2	6.3	(8.2)	(2.0)	8.8	4.1	4.7	3.8
13	(11.8)	7.6	1.7	5.9	6.5	8.2	2.3	7.7	3.7	4.0	5.1
	-------	19.5	13.4	6.1	5.8	(7.7)	(1.6)	9.2	4.1	5.1	3.6
14	0.3	8.4	2.4	6.0	6.9	8.1	2.1	8.1	4.0	4.1	5.2
	(12.7)	20.3	13.8	6.5	5.4	(7.6)	(1.1)	9.1	4.3	4.8	3.8
15	1.1	8.6	3.1	5.5	6.8	7.5	2.0	8.2	3.8	4.4	5.3
	(13.5)	21.1	15.1	6.0	6.5	(7.6)	(1.6)	9.1	4.2	4.9	4.0
16	1.9	9.7	3.7	6.0	6.6	7.8	1.8	8.3	3.8	4.5	5.3
	(14.3)	21.6	15.5	6.1	5.8	(7.3)	(1.2)	9.2	4.4	4.8	3.9
17	2.7	10.1	4.3	5.8	6.7	7.4	1.6	8.4	3.9	4.5	5.3
	(15.1)	22.2	16.3	5.9	6.2	(7.1)	(1.2)	8.9	4.5	4.4	3.9
18	3.5	10.9	4.9	6.0	6.7	7.4	1.4	8.5	3.8	4.7	5.1
	(15.9)	23.3	17.3	6.0	6.4	(7.4)	(1.4)	8.8	4.5	4.3	4.0
19	4.3	11.7	5.8	5.9	6.5	7.4	1.5	8.5	3.8	4.7	5.0
	(16.7)	23.9	18.2	5.7	6.5	(7.2)	(1.5)	8.3	4.4	3.9	4.1
20	5.1	12.6	6.5	6.1	6.6	7.5	1.4	8.2	3.3	4.9	5.0
	(17.5)	-------	19.0	-------	6.4	-------	(1.5)	-------	4.0	-------	4.2
21	5.9	0.6	7.1	5.6	6.5	(7.1)	1.2	8.4	3.9	4.4	4.5
	(18.3)	13.7	19.9	6.6	6.2	7.8	(1.6)	8.9	4.4	5.0	4.5
22	6.8	1.9	8.3	6.0	6.4	(7.6)	1.5	8.2	3.7	3.8	4.5
	(19.2)	14.4	21.3	6.1	6.9	7.6	(2.1)	9.2	4.4	5.5	4.8
23	7.6	2.8	9.3	5.5	6.5	(7.6)	1.7	8.5	3.6	4.1	4.9
	(20.1)	15.4	22.3	6.1	6.9	7.8	(2.2)	9.0	3.7	5.4	5.3
24	8.6	3.8	10.5	5.5	6.7	(7.7)	1.9	8.3	3.3	4.6	5.0
	(21.1)	16.5	23.3	6.0	6.8	7.9	(2.2)	9.3	3.3	6.0	6.0

TABLE 1.—*High and low waters, Fort Hamilton, June 1919*—Continued

Date	Moon's transit, meridian of Greenwich	Time		Duration		Lunitidal interval		Height		Range	
		High water	Low water	Rise	Fall	High water	Low water	High water	Low water	Rise	Fall
	Hours	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Feet*
25	9.6	4.8	11.6	5.5	6.8	(7.7)	2.0	8.3	3.2	5.0	5.1
	(22.1)	17.4	-------	5.8	-------	7.8	-------	9.6	-------	6.4	-------
26	10.6	5.9	0.3	5.6	6.9	(7.8)	(2.2)	8.7	3.2	5.5	6.4
	(23.1)	18.4	12.4	6.0	6.5	7.8	1.8	9.8	3.3	6.5	5.4
27	11.7	6.9	1.4	5.5	7.0	(7.8)	(2.3)	8.8	3.0	5.8	6.8
	-------	19.4	13.4	6.0	6.5	7.7	1.7	9.8	3.1	6.7	5.7
28	(0.2)	7.9	2.3	5.6	6.9	(7.7)	(2.1)	9.1	3.1	6.0	6.7
	12.7	20.4	14.2	6.2	6.3	7.7	1.5	10.4	4.1	6.3	5.0
29	(1.1)	8.8	3.0	5.8	6.6	(7.7)	(1.9)	9.6	3.4	6.2	7.0
	13.6	21.1	15.4	5.7	6.6	7.5	1.8	10.0	4.0	6.0	5.6
30	(2.1)	9.8	4.1	5.7	7.0	(7.7)	(2.0)	8.8	3.3	5.5	6.7
	14.5	22.1	16.0	6.1	6.2	7.6	1.5	9.2	3.7	5.5	5.1
Sum	-------	-------	-------	341.2	372.8	446.8	105.6	508.3	229.1	279.2	273.4
Mean	-------	-------	-------	5.88	6.54	7.70	1.82	8.76	3.95	4.81	4.80

Since the variations in the lunitidal interval from day to day at Fort Hamilton are relatively small, the average values for these intervals as determined from a month of observations should not differ much from the values as determined from a considerable period of time. The variations in the intervals from month to month during 4 different years separated by 10 years each, are shown in table 2. The monthly means given in this table refer to the moon's transit across the meridian of Fort Hamilton.

TABLE 2.—*Lunitidal intervals, Fort Hamilton: Monthly means for 4 years*

Month	High-water intervals				Low-water intervals			
	1900	1910	1920	1930	1900	1910	1920	1930
	Hours	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
January	7.66	7.75	7.90	7.73	1.75	1.70	1.79	1.65
February	7.83	7.79	7.86	7.73	1.63	1.66	1.77	1.66
March	7.71	7.56	7.68	7.68	1.66	1.50	1.58	1.72
April	7.70	7.53	7.56	7.50	1.61	1.62	1.58	1.40
May	7.70	7.56	7.59	7.65	1.65	1.50	1.55	1.55
June	7.73	7.58	7.53	7.80	1.77	1.63	1.64	1.72
July	7.86	7.75	7.69	7.71	1.74	1.68	1.67	1.73
August	7.84	7.60	7.85	7.77	1.73	1.68	1.67	1.68
September	7.80	7.62	7.59	7.74	1.74	1.69	1.65	1.72
October	7.86	7.78	7.61	7.86	1.83	1.74	1.62	1.80
November	7.86	7.79	7.70	7.92	1.90	1.73	1.62	1.88
December	7.73	7.83	7.68	7.91	1.72	1.77	1.63	1.82
Sum	93.28	92.14	92.24	93.00	20.73	19.90	19.77	20.33
Mean	7.77	7.68	7.69	7.75	1.73	1.66	1.65	1.69

A glance at the values in table 2 gives evidence of a seasonal, or more accurately, of an annual variation in the lunitidal intervals. As a rule they are lower than the average in the spring months and higher than the average in the fall months. In any one year the accidental fluctuations from month to month tend to mask this variation, but if we average the corresponding monthly values over a number of years, the accidental fluctuations tend to balance out. In table 3

are given the monthly values of the high- and low-water intervals as derived from two groups of 19 years, namely, 1893–1911 and 1912–30. Nineteen-year groups are taken since in a period of 19 years the more important of the tidal variations will have gone through complete cycles. It is therefore customary to regard results derived from 19 years of observations as constituting mean values.

TABLE 3.—*Annual variation in lunitidal intervals, Fort Hamilton*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1893–1911:													
HWI	7.72	7.75	7.68	7.63	7.64	7.67	7.72	7.71	7.72	7.76	7.77	7.72	7.71
LWI	1.64	1.66	1.59	1.56	1.60	1.66	1.69	1.70	1.70	1.69	1.71	1.67	1.66
1912–30:													
HWI	7.69	7.65	7.59	7.53	7.60	7.59	7.65	7.65	7.69	7.67	7.70	7.71	7.64
LWI	1.62	1.61	1.55	1.52	1.58	1.62	1.64	1.67	1.69	1.67	1.68	1.67	1.63

The lowest intervals in both groups come in April. The highest intervals come in November for the first group and in September and December for the second group. The difference between the highest and lowest values is 0.16 hour for both the high-water and low-water intervals.

As determined from a year of observations, the lunitidal intervals give a close approximation to the mean values determined from a period of a number of years. The variation in the high-water and low-water lunitidal intervals from year to year is shown in table 4 under the headings HWI and LWI, respectively, the intervals being given in hours and decimals. For the years 1893–1912, inclusive, the values are from monthly groups, including every day of the month; from 1913–32, inclusive, the values are for monthly groups covering the first 29 days of each month.

TABLE 4.—*Lunitidal intervals, Fort Hamilton: Annual means, 1893 to 1932*

Year	HWI	LWI	Year	HWI	LWI	Year	HWI	LWI	Year	HWI	LWI
	Hrs.	*Hrs.*		*Hrs.*	*Hrs.*		*Hrs.*	*Hrs.*		*Hrs.*	*Hrs.*
1893	7.71	1.65	1903	7.66	1.63	1913	7.62	1.56	1923	7.69	1.67
1894	7.73	1.69	1904	7.70	1.66	1914	7.56	1.51	1924	7.65	1.64
1895	7.68	1.61	1905	7.72	1.69	1915	7.56	1.54	1925	7.62	1.63
1896	7.65	1.58	1906	7.76	1.72	1916	7.57	1.59	1926	7.62	1.65
1897	7.66	1.57	1907	7.69	1.68	1917	7.62	1.62	1927	7.65	1.62
1898	7.70	1.62	1908	7.74	1.68	1918	7.61	1.62	1928	7.63	1.69
1899	7.75	1.68	1909	7.73	1.66	1919	7.67	1.66	1929	7.65	1.61
1900	7.77	1.73	1910	7.68	1.66	1920	7.69	1.65	1930	7.75	1.69
1901	7.76	1.70	1911	7.66	1.62	1921	7.77	1.72	1931	7.66	1.57
1902	7.70	1.68	1912	7.63	1.60	1922	7.68	1.64	1932	7.71	1.65
Sum	77.11	16.51	Sum	76.97	16.60	Sum	76.35	16.11	Sum	76.63	16.42
Mean	7.71	1.65	Mean	7.70	1.66	Mean	7.64	1.61	Mean	7.66	1.64

Table 4 shows that the lunitidal intervals differ but little from year to year, generally by not more than a few hundredths of an hour. If we take the mean of the 40-year series we derive 7.68 hours for the HWI and 1.64 hours for the LWI. The extreme differences from these mean values of the yearly values are 0.12 hour for the HWI and 0.13 hour for the LWI, both of these being for the year 1914.

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The means for the 10-year groups in table 4 show slight differences. For the two middle groups, however, the differences are relatively large, 0.06 hour for the HWI and 0.05 hour for the LWI. Between these years apparently both the high water and low water became a little earlier. As will be seen later, the observations indicate also an increase in range between these years, both changes apparently being due to the deepening of the channels leading from the sea to the Narrows, and more especially to the improvement of Ambrose Channel between the years 1901 and 1914. If we take the 19-year period, 1912–30, as giving the best determination, we derive 7.64 hours for the HWI and 1.63 hours for the LWI.

DURATIONS OF RISE AND FALL

From the mean high and low water intervals at Fort Hamilton of 7.64 hours and 1.63 hours we derive the mean duration of the rise of tide to be 6.01 hours; and since the length of the tidal cycle is 12.42 hours (half the tidal day of 24.84 hours) the duration of fall is 6.41 hours. For individual tides the periods of rise and fall are obviously subject to somewhat greater variation than the corresponding lunitidal intervals. In general, however, when undisturbed by wind or weather, these periods at Fort Hamilton do not vary much from their mean values, as shown by the fifth and sixth columns of table 1, which give the consecutive durations of rise and of fall for a typical month.

From table 2 we may derive the monthly values of the durations of rise and fall for the 4 years given in that table. The values derived therefrom are given below in table 5.

TABLE 5.—*Duration of rise and fall, Fort Hamilton: Monthly means for 4 years*

Month	Duration of rise				Duration of fall			
	1900	1910	1920	1930	1900	1910	1920	1930
	Hours	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
January	5.91	6.05	6.11	6.08	6.51	6.37	6.31	6.34
February	6.20	6.13	6.09	6.07	6.22	6.29	6.33	6.35
March	6.05	6.06	6.10	5.96	6.37	6.36	6.32	6.46
April	6.09	5.91	5.98	6.10	6.33	6.51	6.44	6.32
May	6.05	6.06	6.04	6.10	6.37	6.36	6.38	6.32
June	5.96	5.95	5.89	6.08	6.46	6.47	6.53	6.34
July	6.12	6.07	6.02	5.98	6.30	6.35	6.40	6.44
August	6.11	5.92	6.18	6.09	6.31	6.50	6.24	6.33
September	6.06	5.93	5.94	6.02	6.36	6.49	6.48	6.40
October	6.03	6.04	5.99	6.06	6.39	6.38	6.43	6.36
November	5.96	6.06	6.08	6.04	6.46	6.36	6.34	6.38
December	6.01	6.06	6.05	6.09	6.41	6.36	6.37	6.33
Sum	72.55	72.24	72.47	72.67	76.49	76.80	76.57	76.37
Mean	6.05	6.02	6.04	6.06	6.37	6.40	6.38	6.36

The variation in the durations of rise and of fall from month to month are seen to be small, generally not more than a tenth of an hour. From table 5 it is not clear whether or not there is an annual variation in the durations of rise and fall. If we derive these durations from the values of table 3, in which the data are means for 19 years, it is found that there are indications of such a variation, the greatest duration of rise coming in the winter months and the smallest duration of rise in the summer months. But the range of this variation is small, being less than a tenth of an hour.

The yearly values of the durations of rise and fall may be derived from table 4. Since the duration of fall is 12.42 minus the duration of rise, it will be sufficient to take only the durations of rise. For each year of the 40-year period from 1893–1932 the duration of rise is given in table 6.

TABLE 6.—*Duration of rise, Fort Hamilton: Annual means, 1893 to 1932*

Year	Hours	Year	Hours	Year	Hours	Year	Hours
1893	6.06	1903	6.03	1913	6.06	1923	6.02
1894	6.04	1904	6.04	1914	6.05	1924	6.01
1895	6.07	1905	6.03	1915	6.02	1925	5.99
1896	6.07	1906	6.04	1916	5.98	1926	5.97
1897	6.09	1907	6.01	1917	6.00	1927	6.03
1898	6.08	1908	6.06	1918	5.99	1928	5.94
1899	6.07	1909	6.07	1919	6.01	1929	6.04
1900	6.04	1910	6.02	1920	6.04	1930	6.06
1901	6.06	1911	6.04	1921	6.05	1931	6.09
1902	6.02	1912	6.03	1922	6.04	1932	6.06
Sum	60.60	Sum	60.37	Sum	60.24	Sum	60.21
Mean	6.06	Mean	6.04	Mean	6.02	Mean	6.02

The values of the duration of rise from year to year show but little fluctuation. The mean for the last 20 years shows a slight decrease in the duration of rise in comparison with the mean for the first 20 years. Taking the 19 years 1912–30 as giving the best value, we derive 6.01 hours for the mean duration of rise, and therefore 6.41 hours for the mean duration of fall.

MEAN SEA LEVEL

Mean sea level may be defined as the surface the sea would assume if undisturbed by the rise and fall of the tide. With reference to a bench mark on the shore, the plane of mean sea level may be determined by averaging, over a considerable period of time, the hourly heights of the tide, as read on a fixed tide staff the zero of which has been connected with the bench mark by spirit levels. This is also accomplished by reading the hourly heights from an automatic tide gage record which is connected with a fixed staff by comparative readings.

For how long a period must the hourly heights of the tide be averaged to give a good determination of mean sea level? This question can best be answered by examining the results derived from observations of varying periods. Obviously, mean sea level determined from tidal observations extending over one day may be in error several feet, due to varying meteorological conditions. But even apart from the effects of wind and weather, it is to be borne in mind that the so-called "long period tides", brought about by the tidal forces having periods of half a month or more, introduce a variation in sea level from day to day.

The variation in sea level from day to day is shown in table 7 for the month of June 1919, a typical summer month. In this table the values of sea level were derived by averaging the 24 hourly heights of each day which are recorded in feet and tenths, and refer to the fixed tide staff to which all the observations at Fort Hamilton are referred.

TABLE 7.—*Daily sea level on staff, Fort Hamilton, June 1919*

Date	Feet	Date	Feet	Date	Feet
1	6.66	11	6.23	21	6.24
2	6.56	12	6.33	22	6.29
3	6.46	13	6.34	23	6.32
4	6.31	14	6.44	24	6.25
5	6.53	15	6.38	25	6.27
6	6.31	16	6.43	26	6.43
7	6.30	17	6.44	27	6.31
8	6.89	18	6.39	28	6.75
9	6.84	19	6.25	29	6.78
10	6.41	20	6.00	30	6.23
Sum	65.27	Sum	63.23	Sum	63.87
Mean	6.53	Mean	6.32	Mean	6.39

It will be observed that even in a summer month, when wind and weather conditions do not fluctuate much from day to day, sea level as determined from one day may differ from that on another day by as much as 0.9 foot. Table 7 also brings out the fact that sea level values derived from three consecutive 10-day groups during a month, when weather conditions were relatively stable, may differ from each other by 0.2 foot. During a winter month when heavy winds occur, sea level from one day may differ by as much as 2 feet from the next day, and within a single month the difference between the highest and lowest values of daily sea level may be as much as 4 feet.

Sea level as determined from one day of observations clearly does not give a good determination of mean sea level. And even when determined from a month of observations the value of sea level may differ considerably from mean sea level. In table 8 are given the heights of sea level on the staff at Fort Hamilton as determined for each month of the 4 years, 1900, 1910, 1920, and 1930.

TABLE 8.—*Monthly sea level on staff, Fort Hamilton, for four years*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1900	5.28	5.38	5.53	5.75	6.02	6.14	6.03	6.20	6.14	6.16	5.85	5.76	5.85
1910	5.93	5.67	5.89	6.30	6.13	6.29	6.24	6.10	6.32	6.13	6.14	5.88	6.08
1920	5.75	5.95	5.52	6.30	6.31	6.46	6.19	6.34	6.30	6.32	6.25	6.07	6.15
1930	5.63	5.63	5.64	5.76	5.96	6.00	6.20	6.35	6.26	6.44	5.87	6.02	5.98
Mean	5.65	5.66	5.64	6.03	6.10	6.22	6.16	6.25	6.26	6.26	6.03	5.93	6.02

From table 8 it is evident that sea level as determined from a series of observations covering a period of a month is subject to considerable variation from month to month. Between the greatest and least values of the monthly means for the 4 years in the table the difference is 1.18 feet, and within the period of any one of these years the monthly means may differ by as much as 0.9 foot.

The monthly means for each of the years in table 8 gives evidence of the existence of an annual variation in the height of sea level at Fort Hamilton. Sea level is seen to be lowest in the winter months and highest in the fall months. For any one year this variation is somewhat irregular, but if the corresponding monthly heights are averaged over a number of years, this variation becomes quite regular, as is seen in figure 11, in which the heights of the monthly means of

sea level at Fort Hamilton for the two 19-year periods 1893–1911 and 1912–30 are plotted. The horizontal line in each diagram represents mean sea level as determined from the corresponding series of 19 years. The open circles represent the monthly heights of sea level as determined from the 19-year series.

The curves for the two periods agree closely except for the months of January and February, when the normal heights of the tide are frequently disturbed by winds. On the average, sea level at Fort Hamilton is below mean sea level in the winter and early spring months and above mean sea level in the summer and fall months. From the first 19 years of observations, lowest monthly sea level comes in February and highest in August and September with a difference of 0.68 foot. From the second series the minimum comes in January and the maximum in August, the difference being 0.63 foot.

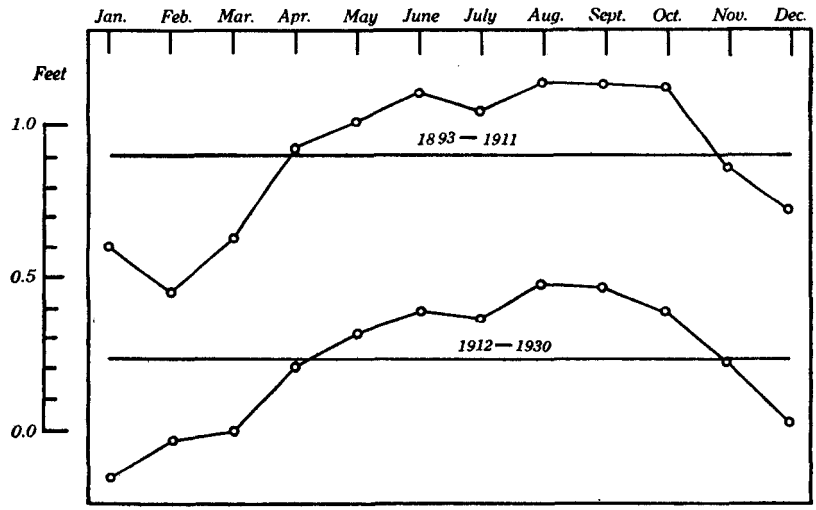

FIGURE 11.—Annual variation in sea level, Fort Hamilton.

An interesting feature is the secondary minimum in July, which both series exhibit. The average heights of monthly sea level on staff for the two 19-year periods, and the means for the 38-year period are given in table 9.

TABLE 9.—*Annual variation in sea level, Fort Hamilton*

Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1893–1911	5.67	5.52	5.69	5.99	6.07	6.17	6.11	6.20	6.20	6.18	5.93	5.80	5.96
1912–30	5.65	5.77	5.80	6.01	6.12	6.19	6.17	6.28	6.27	6.20	6.02	5.83	6.03
Mean	5.66	5.64	5.74	6.00	6.10	6.18	6.14	6.24	6.24	6.19	5.98	5.82	5.99

Sea level derived from a year of observations will obviously give a closer determination of mean sea level than that derived from a month of observations, for the annual variation will be eliminated, and the accidental fluctuations due to wind and weather tend to balance out. In table 10 are given the yearly values of sea level on the staff at Fort

Hamilton for the 40-year period 1893–1932. For the years 1893–1920 the values are derived by averaging the hourly heights of the tide. For the years 1921–32 the values are derived from half-tide level by adding the constant difference of 0.04 foot to the yearly values of half-tide level derived from the high and low waters.

TABLE 10.—*Yearly sea level on staff, Fort Hamilton: Annual means 1893 to 1932*

Year	Feet	Year	Feet	Year	Feet	Year	Feet
1893	5.86	1903	6.05	1913	5.90	1923	6.07
1894	5.90	1904	5.90	1914	6.03	1924	6.02
1895	5.83	1905	5.86	1915	6.08	1925	5.97
1896	5.91	1906	5.97	1916	6.04	1926	5.95
1897	5.98	1907	5.92	1917	6.07	1927	6.10
1898	6.00	1908	5.89	1918	6.05	1928	5.96
1899	5.99	1909	6.02	1919	6.22	1929	5.92
1900	5.85	1910	6.08	1920	6.15	1930	5.98
1901	6.08	1911	6.03	1921	6.16	1931	6.22
1902	6.12	1912	5.85	1922	6.06	1932	6.22
Sum	59.52	Sum	59.57	Sum	60.76	Sum	60.41
Mean	5.95	Mean	5.96	Mean	6.08	Mean	6.04

Table 10 shows that sea level at Fort Hamilton varies also from year to year. Generally this variation is but a few hundredths of a foot; but occasionally it may amount to as much as 0.2 foot, as for example between the years 1930 and 1931. Even the means for the 10-year groups in table 10 show differences of several hundredths of a foot, especially the two groups 1903–12 and 1913–22, the difference of whose means is 0.12 foot. The difference between the lowest and highest yearly sea levels for the 40 years represented in table 10 is 0.39 foot.

Changes in meteorological conditions are reflected by changes in sea level; and since meteorological conditions vary from year to year, the variations in height of yearly sea level brought out in table 10 must be ascribed, in large part at least, to variations in meteorological conditions. It is to be noted, however, that if the relation of land to sea is changing—whether as a result of the subsidence of the land or of the rise of sea level—this would be reflected in corresponding changes in the yearly heights of sea level. In fact the data furnished by the yearly heights of sea level over a considerable number of years will furnish conclusive proof whether the relation of land to sea is changing.

THE PLANES OF HIGH WATER

The height to which high water rises varies from day to day, principally in accordance with the varying positions of the moon relative to earth and sun. At times of new and full moon, when the so-called spring tides occur, high water rises higher than usual; and when the moon is in its first and third quarters the rise of high water is less than usual. Likewise at the times when the moon is in perigee high water rises higher than the average, while at the times of the moon's apogee the rise is lower than the average. Changes in the moon's declination also bring about a difference in the heights of the two high waters of a day. And apart from these variations due to astronomic causes there is also a variation brought about by wind and weather. We may therefore have various planes of high water—

spring high water, neap high water, perigean high water, apogean high water, higher high water, lower high water, mean high water, or some arbitrary storm high water. The term "high-water plane" by itself is not precise, for it does not indicate what high-water plane is referred to.

Of all the high-water planes, the one most readily determined is that of mean high water. This plane is defined as the average height of all the high waters at any place. Since high water varies from day to day, the question arises as to the period of time that tide observations must cover in order to give an accurate determination of mean high water. For any period less than a month, obviously, the average height of the high waters can give only a rough determination of mean high water, because of the periodic variations due to phase, parallax, and declination of the moon. Within a month these periodic variations tend to balance out.

In table 11 are given the monthly heights of high water at Fort Hamilton for 4 different years separated by 10-year intervals. It is seen that from one month to the next, high water frequently differs by several tenths of a foot, and may differ by as much as 0.8 foot. Within a year two monthly values of high water may differ by nearly a foot. Between the greatest and least values of the monthly means in table 11 the difference is 1.3 feet.

TABLE 11.—*Monthly high water on staff, Fort Hamilton, for 4 years*

Years	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Means
1900	7.55	7.67	7.88	8.10	8.31	8.41	8.30	8.53	8.46	8.49	8.18	8.13	8.17
1910	8.15	7.95	8.27	8.61	8.45	8.61	8.54	8.38	8.63	8.42	8.39	8.13	8.38
1920	8.11	8.30	7.93	8.73	8.71	8.82	8.61	8.72	8.67	8.69	8.58	8.48	8.53
1930	7.88	7.93	7.98	8.04	8.28	8.28	8.52	8.63	8.53	8.65	8.06	8.21	8.25
Mean	7.92	7.96	8.02	8.37	8.44	8.53	8.49	8.56	8.57	8.56	8.30	8.24	8.33

The means of the monthly values for the 4 years in table 11 give distinct evidence of an annual variation in the height of high water. If the corresponding monthly heights of high water for a number of years are averaged, the annual variation in high water at Fort Hamilton is found to follow closely, both in amplitude and in phase, the annual variation in sea level discussed on page 29. The secondary minimum in the variation of sea level, which occurs in July, is clearly brought out by the high waters. The annual variation in high water at Fort Hamilton is therefore due to the annual variation in sea level.

Within a year the annual variation in high water is eliminated and the fluctuation from month to month which arises from changes in wind and weather, will tend to balance out. A year of observations should therefore give a much closer approximation to mean high water. In table 12 are given the yearly heights of high water for the 40-year period, 1893–1932.

TABLE 12.—*Yearly high water on staff, Fort Hamilton: Annual means, 1893 to 1932*

Year	Feet	Year	Feet	Year	Feet	Year	Feet
1893	8.06	1903	8.42	1913	8.15	1923	8.46
1894	8.10	1904	8.29	1914	8.27	1924	8.44
1895	8.03	1905	8.23	1915	8.34	1925	8.36
1896	8.15	1906	8.31	1916	8.33	1926	8.31
1897	8.23	1907	8.27	1917	8.38	1927	8.42
1898	8.26	1908	8.21	1918	8.40	1928	8.27
1899	8.27	1909	8.33	1919	8.56	1929	8.22
1900	8.17	1910	8.38	1920	8.53	1930	8.25
1901	8.39	1911	8.30	1921	8.55	1931	8.48
1902	8.47	1912	8.12	1922	8.47	1932	8.47
Sum	82.13	Sum	82.86	Sum	83.98	Sum	83.68
Mean	8.21	Mean	8.29	Mean	8.40	Mean	8.37

From one year to the next the fluctuation in the yearly values of high water in table 12 is generally a few hundredths of a foot. Occasionally, however, it is as much as 0.2 foot. Several factors conspire to bring about this fluctuation. One of these, obviously, is the fluctuation in sea level from year to year, for it is about the plane of sea level that the tide oscillates. This fluctuation in high water may be eliminated by referring the height of high water to sea level, which is easily done by subtracting the heights in table 10 from the corresponding heights of high water in table 12. The results are given in table 13.

TABLE 13.—*Yearly high water above yearly sea level, Fort Hamilton*

Year	Feet	Year	Feet	Year	Feet	Year	Feet
1893	2.20	1903	2.37	1913	2.25	1923	2.39
1894	2.20	1904	2.39	1914	2.24	1924	2.42
1895	2.20	1905	2.37	1915	2.26	1925	2.39
1896	2.24	1906	2.34	1916	2.29	1926	2.36
1897	2.25	1907	2.35	1917	2.31	1927	2.32
1898	2.26	1908	2.32	1918	2.35	1928	2.31
1899	2.28	1909	2.31	1919	2.34	1929	2.30
1900	2.32	1910	2.30	1920	2.38	1930	2.27
1901	2.31	1911	2.27	1921	2.39	1931	2.26
1902	2.35	1912	2.27	1922	2.41	1932	2.25
Sum	22.61	Sum	23.29	Sum	23.22	Sum	23.27
Mean	2.26	Mean	2.33	Mean	2.32	Mean	2.33

The heights in table 13 show much less fluctuation from year to year than the corresponding heights in table 12. But a periodic variation is clearly evident in table 13; there is a gradual increase in height from 1893 to 1904, then a gradual decrease to 1914, after which an increase takes place to 1924, followed by another decrease. This periodic change, which is seen to have a period of about 20 years, is due to the variation in the longitude of the moon's node. This brings about a change in the inclination of the lunar orbit to the plane of the earth's equator which varies from 18°.3 to 28°.6, the average period of this variation being 18.6 years. The tidal forces are less than the average at the time of maximum inclination, and hence the rise of the tide is less than average at such times. Similarly, the tidal forces are greater than the average when the lunar orbit has its minimum inclination, and at such times the rise of the tide is greater than the average.

Factors may be derived for correcting the varying rise of high water, due to the variation in the longitude of the moon's node, to a

mean value.[2] If these factors are applied to the yearly values in table 13, we derive mean values for the rise of high water above sea level. These are given in table 14.

TABLE 14.—*High water above sea level, Fort Hamilton: Annual means corrected for longitude of moon's node*

Year	Feet	Year	Feet	Year	Feet	Year	Feet
1893	2.26	1903	2.30	1913	2.32	1923	2.32
1894	2.26	1904	2.32	1914	2.30	1924	2.36
1895	2.26	1905	2.31	1915	2.31	1925	2.34
1896	2.30	1906	2.29	1916	2.32	1926	2.34
1897	2.29	1907	2.32	1917	2.32	1927	2.32
1898	2.28	1908	2.32	1918	2.34	1928	2.34
1899	2.28	1909	2.33	1919	2.30	1929	2.35
1900	2.29	1910	2.34	1920	2.33	1930	2.33
1901	2.26	1911	2.32	1921	2.32	1931	2.33
1902	2.29	1912	2.33	1922	2.34	1932	2.32
Sum	22.77	Sum	23.18	Sum	23.20	Sum	23.35
Mean	2.28	Mean	2.32	Mean	2.32	Mean	2.34

Some disagreement in the yearly values of table 14 is to be expected from the nature of the observations and from the disturbing effects of wind and weather. Within each of the 10-year groups, however, the individual values do not depart by more than 0.03 foot from the mean for the 10-year group. In view of this, the difference of 0.04 foot between the mean of the first and second 10-year periods must be regarded as indicating an actual change in the plane of high water, which is to be ascribed to the improvement of the channel leading to Fort Hamilton between the years 1901 and 1914.

Since high water exhibits periodic variations with periods up to 18.6 years, it follows that an accurate determination of mean high water may be derived directly by averaging the high waters over a period of approximately 19 years. This will eliminate, practically, the periodic variations and will balance out the fluctuations due to fluctuations in sea level. If the plane of mean high water is to be determined from a shorter series, it may be derived by correcting the yearly values above sea level by the factors for the longitude of the moon's node and using the mean of these yearly values as applied to the value of mean sea level.

If we take the direct mean of the high waters for the first 19-year period at Fort Hamilton, that is, from 1893 to 1911, mean high water on the staff comes out as 8.26 feet; and for the second period, 1912 to 1930, it comes out as 8.36 feet. If we take the means of the yearly values of table 14, the first 19-year group gives 2.30 and the second gives 2.33. If we add 2.30 to the value of sea level for the first 19-year group from table 10, which is 5.96, we get for mean high water for that period 8.26 feet. Adding 2.33 to the sea level for the second 19-year group, we get 8.36 feet, which values agree with the direct means of high water for the two 19-year periods. Taking the result from the 19-year series, 1912–1930, as best representing present day conditions, mean high water at Fort Hamilton is 2.33 feet above mean sea evel.

The plane of mean high water being the average height of all the high waters, it follows that we may determine tidal high-water planes above and below the plane of mean high water. The planes of spring high water and neap high water are such planes. The plane of

[2] See Coast and Geodetic Survey Special Publication No. 135, p. 83.

spring high water is determined as the average over a considerable period of time of all the high waters that come at the time of the spring tides, and these tides, it is to be recalled, are the ones that occur a little after the times when the moon is full or new. The lag in the occurrence of spring tides with reference to new or full moon is known as the "phase age" of the tide, and the exact determination of this and the other "ages" of the tide will be taken up later. Here it will be sufficient to state that the phase age for Fort Hamilton is about 27 hours; that is, spring tides occur about a day after new or full moon.

For determining the heights of the spring high waters it is customary to take the two consecutive high waters which fall nearest the time given by adding the phase age of the tide to the times of new and full moon. This gives for any month four heights for the spring high water for that month. These heights, too, it is to be recalled, are affected by the moon's parallax, declination, and any accidental meteorological conditions. It is therefore obvious that the heights of the spring high waters, as determined from a month of observations, may differ considerably from that determined from another month. To determine this plane with any degree of precision from high and low water observations requires a series extending over a considerable number of years. From 17 years of observations—1893 to 1909, inclusive—spring high water on the Fort Hamilton staff read 8.68 feet. For this period table 10 shows the height of mean sea level on staff to have been 5.95 feet; hence, at Fort Hamilton the plane of spring high water is 2.73 feet above the plane of mean sea level.

The plane of spring high water may also be derived from the harmonic constants by means of the formulae developed by Harris.[3] When harmonic constants are at hand, this method is much less time-consuming than the method of direct tabulation, but the results from the harmonic constants generally differ somewhat from the results of direct tabulation. For Fort Hamilton there are at hand harmonic analyses for the years 1900 and 1904. From the 1900 analysis the plane of spring high water is 2.71 feet above sea level and from the 1904 analysis it is likewise 2.71 feet. This compares with 2.73 feet derived from the direct tabulation of the spring high waters from 1893 to 1909, and we may therefore take the plane of spring high water at Fort Hamilton as 2.72 feet above mean sea level as determined from the observations for the years 1893–1909.

The rise of mean high water above mean sea level for the above years is found from table 14 to be 2.29 feet. Hence the rise of spring high water above mean sea level is 18¾ percent greater than that of mean high water. The later observations at Fort Hamilton show that the rise of high water had increased somewhat owing to the improvement of the channels. The value for the rise of mean high water accepted as best representing present-day conditions is 2.33 feet. Hence, spring high water above mean sea level is to be taken as 18¾ percent greater than 2.33 feet, or 2.77 feet.

If in the preceding paragraphs relating to spring high water, we substitute for new and full moon the moon's first and third quarters, we derive the plane of neap high water. From direct tabulation of the series 1893–1909 this plane is found to be 1.87 feet above mean sea level and from the harmonic constants for the 2 years 1900 and

[3] Manual of Tides, part III, U. S. Coast and Geodetic Survey, Report for 1894, p. 144.

1904, 1.84 feet. A mean of the two results gives 1.86 feet, which we may take as giving the height of the plane of neap high water above mean sea level with sufficient accuracy. With respect to mean sea level, therefore, the rise of neap high water is 20 percent less than that of mean high water.

The periodic variation in the moon's distance from the earth gives rise to another set of tidal planes, namely, the planes of perigean and apogean high water. Perigean and apogean tides at Fort Hamilton come about 31 hours after the corresponding positions of the moon. The direct tabulation of the perigean high waters for the years 1893–1909 gives the plane of perigean high water as 2.97 feet above mean sea level, while the harmonic constants for 1900 and 1904 give, through Harris' formulae, 2.70 feet. The discrepancy between the two being considerable, it appears best to take a weighted mean, although it is difficult to assign other than arbitrary weights. Giving the result from the direct tabulation a weight twice that assigned to the result from the harmonic constants, we derive for the plane of perigean high water a height of 2.88 feet above mean sea level. For the plane of apogean high water the direct tabulation of the series 1893–1909 gives 1.86 feet above mean sea level, while the harmonic constants for 1900 and 1904 give 1.88 feet above. The mean of the two gives for the plane of apogean high water 1.87 feet above mean sea level. With respect to mean sea level, the rise of perigean high water is 24 percent greater, and the rise of apogean tides 19 percent less than that of mean high water.

The periodic fortnightly change in the moon's declination gives rise to four tidal high water planes, namely, the planes of higher high water, lower high water, tropic higher high water, and tropic lower high water. Since these datum planes depend on the moon's declination, they are called declinational planes. Of the two high waters of each day the average height of the higher over a considerable period of time determines the plane of higher high water, while the average height of the lower determines the plane of lower high water. The planes of tropic higher high and lower high water are determined, respectively, as the average heights of the higher high and lower high waters that occur at times of tropic tides; that is, the tides coming at the times of the moon's semimonthly maximum declination.

On the Atlantic coast the declinational datum planes are of relatively minor importance, since the diurnal inequality in the height of the tides is small. Like other high-water planes, the declinational planes exhibit annual variations, and when determined from observations extending over a period of a month or even a year must be reduced to a mean value. These declinational planes may also be derived from the harmonic constants. From 2 years of direct tabulation—1921 and 1922—the plane of higher high water lies 0.35 foot above the plane of mean high water, or 2.68 feet above mean sea level, while the harmonic constants from the analyses for 2 years (1900 and 1904) give 2.63 feet. We may therefore take the plane of higher high water as lying 2.65 feet above mean sea level. The plane of lower high water, it is obvious, lies as much below the plane of mean high water as the plane of higher high water is above. Hence, the plane of lower high water at Fort Hamilton lies 1.98 feet above the plane of mean sea level.

For the tropic higher high water plane there are at hand the direct tabulations of 17 years of observations—1893–1909—and the results

from the harmonic analyses for 2 years, 1900 and 1904. The plane of tropic higher high water from the former is 2.74 feet above mean sea level, while from the harmonic constants it is 2.66 feet. The mean of the two gives 2.70 feet, or a rise for the tropic higher high water of 16 percent greater than the mean high water. For the plane of tropic lower high water the direct tabulation gives 1.75 feet above mean sea level, while the harmonic constants give 1.67 feet. The mean of the two gives 1.71 feet, or a rise for the tropic lower high water of 26 percent less than mean high water.

Another high-water plane which is of importance is that of extreme or storm high water. This is not strictly a tidal datum plane, for the highest tides are generally due to storms. It is to be noted, however, that in raising the height of the water the effect of storms at times of spring or perigean tides, when the height of the water is above the average, will be greater than at times of neap or apogean tides. Hence, the datum plane of extreme high water must be somewhat arbitrarily defined. Any high water that is a certain adopted percentage above mean high water may be defined as an extreme high water, but it appears best to adopt a different basis of definition. Here we shall apply the term extreme high water to the highest tide of each month.

Under this definition, the plane of extreme high water for any year is determined as the average of monthly highest tides. In table 15 are given the yearly heights of extreme high water at Fort Hamilton for the 40-year period from 1893 to 1932, together with the date and height of the highest tide of each year.

TABLE 15.—*Extreme high water on staff, Fort Hamilton: Annual means and highest*

Year	Average	Highest		Year	Average	Highest	
	Feet	*Date*	*Feet*		*Feet*	*Date*	*Feet*
1893	10.01	Apr. 20	11.5	1903	10.26	Oct. 10	11.5
1894	10.20	Dec. 27	11.0	1904	10.13	Mar. 1	10.7
1895	9.73	Jan. 26	10.6	1905	10.00	Jan. 25	11.0
1896	10.08	Oct. 12	11.4	1906	10.21	Feb. 9	10.8
1897	10.08	Oct. 25	11.2	1907	9.89	Dec. 14	10.4
1898	10.18	Oct. 19	11.0	1908	10.13	Apr. 30	11.1
1899	10.02	Feb. 8	11.1	1909	10.29	Dec. 26	11.2
1900	9.91	Dec. 4	10.6	1910	10.17	Feb. 12	10.8
1901	10.17	Nov. 24	11.9	1911	9.92	Nov. 7	10.7
1902	10.40	Apr. 8	11.3	1912	10.01	Apr. 2	[1] 10.5
Sum	100.78		111.6	Sum	101.01		108.7
Mean	10.08		11.16	Mean	10.10		10.87

Year	Average	Highest		Year	Average	Highest	
	Feet	*Date*	*Feet*		*Feet*	*Date*	*Feet*
1913	9.96	Dec. 26	11.1	1923	10.27	Oct. 23	[4] 11.1
1914	10.25	Feb. 14	[2] 11.1	1924	10.34	Mar. 11	11.3
1915	10.22	Jan. 13	[3] 10.9	1925	9.94	Dec. 3	10.7
1916	9.99	June 16	10.5	1926	10.02	Feb. 10	[5] 10.5
1917	10.02	Oct. 24	11.2	1927	10.33	Feb. 20	12.1
1918	10.28	Apr. 11	12.1	1928	10.04	Sept. 19	10.6
1919	10.30	Nov. 8	11.5	1929	10.14	Apr. 16	11.3
1920	10.43	Feb. 5	11.7	1930	10.09	Aug. 23	11.7
1921	10.19	Nov. 29	11.0	1931	10.25	Mar. 8	11.6
1922	10.25	Jan. 29	11.2	1932	10.43	Nov. 10	12.3
Sum	101.89		112.3	Sum	101.85		113.2
Mean	10.19		11.23	Mean	10.18		11.32

[1] Same height on Nov. 24.
[2] Same height on Dec. 7.
[3] Same height on Jan. 14 and Feb. 2.
[4] Same height on Dec. 6.
[5] Same height on Oct. 20.

From the nature of its definition, and from the fact that but 12 values are used in its determination for any one year, it follows that the yearly heights of extreme high water will show relatively large fluctuations from year to year. But the means for the 10-year groups show surprising agreement. It is interesting to note, too, that as in the case of mean high water, an increased elevation is shown for the second half of the 40-year period. Taking the 19 years from 1912 to 1930 as the period from which to derive the accepted values of the datum, we find that the plane of extreme high water on the staff at Fort Hamilton has a value of 10.16 feet. Since mean sea level for the same period is 6.03 on the staff, the plane of extreme high water is 4.13 feet above mean sea level. The rise of extreme high water is therefore 78 percent greater than that of mean high water.

From the data in table 15 it is possible to determine a plane of highest high water by defining it as the average of the yearly highest high waters. For the 19-year period, 1912–30, the height of this plane is 5.13 feet above mean sea level. Its rise as compared with mean high water is therefore 120 percent greater. The highest high waters, as a rule, are due to storms and may therefore vary by relatively large amounts from year to year. But it is significant that like the rise of mean high water the rise of highest high water is greater for the second half of the 40-year period than for the first half.

THE PLANES OF LOW WATER

For each of the high-water datum planes discussed in the previous section there is a corresponding low-water datum plane. It will therefore be unnecessary to go into details of definitions and methods of determination of these datum planes. For Fort Hamilton the plane of mean low water is the most important of the low-water planes. This plane exhibits variations from day to day and from month to month much like that of high water. The variation from year to year is shown in table 16.

TABLE 16.—*Low water on staff, Fort Hamilton: Annual means 1893 to 1932*

Year	Feet	Year	Feet	Year	Feet	Year	Feet
1893	3.57	1903	3.59	1913	3.57	1923	3.60
1894	3.62	1904	3.45	1914	3.69	1924	3.52
1895	3.54	1905	3.42	1915	3.71	1925	3.49
1896	3.60	1906	3.55	1916	3.64	1926	3.51
1897	3.65	1907	3.49	1917	3.65	1927	3.69
1898	3.66	1908	3.48	1918	3.63	1928	3.56
1899	3.65	1909	3.66	1919	3.77	1929	3.53
1900	3.48	1910	3.71	1920	3.66	1930	3.64
1901	3.67	1911	3.66	1921	3.69	1931	3.88
1902	3.68	1912	3.49	1922	3.57	1932	3.88
Sum	36.12	Sum	35.50	Sum	36.58	Sum	36.30
Mean	3.61	Mean	3.55	Mean	3.66	Mean	3.63

The variation in the height of low water from year to year is seen to be generally only a few hundredths of a foot, but occasionally it may be as much as 0.2 foot. Like the yearly fluctuation in high water it is to be ascribed, in part, to the fluctuation in sea level from year to year. By referring the yearly heights of low water to the corresponding heights of sea level this variation in the height of low water is

eliminated. This may be done by subtracting the heights in table 16 from the corresponding heights in table 10. The results are shown below in table 17.

TABLE 17.—*Low water below sea level, Fort Hamilton: Annual means 1893 to 1932*

Year	Feet	Year	Feet	Year	Feet	Year	Feet
1893	2.29	1903	2.46	1913	2.33	1923	2.47
1894	2.28	1904	2.45	1914	2.34	1924	2.51
1895	2.29	1905	2.44	1915	2.37	1925	2.48
1896	2.31	1906	2.42	1916	2.40	1926	2.43
1897	2.33	1907	2.43	1917	2.42	1927	2.41
1898	2.34	1908	2.41	1918	2.42	1928	2.40
1899	2.34	1909	2.36	1919	2.45	1929	2.39
1900	2.37	1910	2.37	1920	2.49	1930	2.34
1901	2.41	1911	2.37	1921	2.47	1931	2.34
1902	2.44	1912	2.36	1922	2.49	1932	2.34
Sum	23.40	Sum	24.07	Sum	24.18	Sum	24.11
Mean	2.34	Mean	2.41	Mean	2.42	Mean	2.41

The values for the fall of low water below sea level in table 17 exhibit from year to year the variation found in the high waters in table 13, namely, a regular increase and decrease with a period of about 20 years. This periodic change in the fall of low water, like the corresponding change in the rise of high water, is due to the periodic change in the longitude of the moon's node which has a period of 18.6 years. The factors for correcting the yearly values of low water to a mean value are the same as for the high waters. The results derived by applying these factors to the values in table 17 are given in table 18.

TABLE 18.—*Low water below sea level, Fort Hamilton: Annual means corrected for longitude of moon's node*

Year	Feet	Year	Feet	Year	Feet	Year	Feet
1893	2.35	1903	2.39	1913	2.40	1923	2.40
1894	2.35	1904	2.38	1914	2.41	1924	2.45
1895	2.36	1905	2.37	1915	2.42	1925	2.43
1896	2.38	1906	2.37	1916	2.44	1926	2.41
1897	2.37	1907	2.40	1917	2.43	1927	2.41
1898	2.36	1908	2.41	1918	2.41	1928	2.43
1899	2.34	1909	2.38	1919	2.41	1929	2.44
1900	2.34	1910	2.41	1920	2.44	1930	2.40
1901	2.36	1911	2.43	1921	2.40	1931	2.41
1902	2.38	1912	2.43	1922	2.42	1932	2.41
Sum	23.59	Sum	23.97	Sum	24.18	Sum	24.19
Mean	2.36	Mean	2.40	Mean	2.42	Mean	2.42

As in the case of the rise of high water, a change in the fall of low water at Fort Hamilton appears to have occurred. The difference of 0.06 foot between the mean of the first 10 years and the means of the two last groups of 10 years must be taken to indicate an actual lowering of the plane of mean low water. Taking the 19 years from 1912 to 1930 as determining the plane of mean low water at Fort Hamilton, we derive a value of 2.42 feet below mean sea level.

The plane of mean high water from the same series of observations was determined as 2.33 feet above mean sea level. We therefore find that high water and low water at Fort Hamilton are not symmetrical with respect to mean sea level, the fall of low water being 0.09 foot greater than the rise of high water. This difference is to be ascribed to the fact that the curve representing the rise and fall of the tide at Fort Hamilton is not symmetrical, since it is made up of a number of simple cosine curves, some of which have fixed phase relations with respect to each other.

The determination of other low-water planes is carried out in a manner analogous to that for the corresponding high-water planes. Results are available from a direct tabulation of the 17-year series, 1893–1909, and from harmonic constants for 1900 and 1904. These results and the derived means are given in table 19. For comparison the plane of mean low water is included.

TABLE 19.—*Low water planes, Fort Hamilton: Distance below mean sea level*

Datum plane	Direct tabulation	Harmonic constants	Mean
	Feet	*Feet*	*Feet*
Mean low water	2.42	----------	2.42
Spring low water	2.85	2.81	2.83
Neap low water	1.96	1.84	1.90
Perigean low water	2.98	2.80	2.89
Apogean low water	1.98	1.98	1.98
Lower low water [1]	2.64	----------	2.64
Higher low water [1]	2.18	----------	2.18
Tropic lower low water	2.64	----------	2.64
Tropic higher low water	2.02	----------	2.02

[1] These values are derived from 3 years of direct tabulation (1904, 1921, and 1922), corrected to a mean value.

The plane of spring low water being of some importance, it is desirable to determine it as closely as possible. In table 19 the determination of this plane is based on the earlier years of the observations, and since an increase in the fall of mean low water occurred in the later years, the spring low water likewise must have changed. From the observations covering the years 1893–1909 the fall of spring low water is 19 percent greater than the fall of mean low water. We may therefore take the best determination of spring low water as 19 percent greater than the best determination of mean low water. Hence spring low water is $1.19 \times 2.42 = 2.88$ feet below mean sea level.

In consonance with the definition of extreme high water, we may define an extreme low water as the lowest low water of a month. The average height of these extreme low waters will then determine the plane of extreme low water. Table 20 gives the average of the extreme low waters and the date and distance below mean sea level of the lowest low water for each year from 1893 to 1932.

TABLE 20.—*Extreme low water on staff, Fort Hamilton: Annual means and lowest*

Year	Average	Lowest		Year	Average	Lowest	
	Feet	*Date*	*Feet*		*Feet*	*Date*	*Feet*
1893	2.08	Feb. 20	0.2	1903	2.06	Jan. 13	[2] 0.7
1894	2.12	Feb. 16	1.1	1904	2.04	Feb. 3	0.4
1895	1.86	Feb. 8	[1] 0.0	1905	2.02	Feb. 18	0.6
1896	2.09	Feb. 11	0.3	1906	2.04	Mar. 11	0.4
1897	2.19	Dec. 25	1.3	1907	2.04	Oct. 8	1.1
1898	2.08	Feb. 16	0.1	1908	1.78	Feb. 2	−0.5
1899	2.19	Feb. 11	0.1	1909	2.24	Feb. 25	0.6
1900	1.82	Jan. 26	0.2	1910	2.08	Dec. 16	0.0
1901	2.29	Feb. 5	1.0	1911	2.08	Mar. 16	0.6
1902	2.25	Feb. 3	1.1	1912	1.82	Jan. 6	[3] −0.3
Sum	20.97	Sum	5.4	Sum	20.20	Sum	3.6
Mean	2.10	Mean	0.54	Mean	2.02	Mean	0.36

Year	Average	Lowest		Year	Average	Lowest	
	Feet	*Date*	*Feet*		*Feet*	*Date*	*Feet*
1913	1.88	Jan. 4	0.0	1923	2.26	Feb. 15	1.1
1914	1.91	Jan. 13	−0.3	1924	2.08	Jan. 26	0.8
1915	2.17	Dec. 26	0.9	1925	1.70	Feb. 27	0.3
1916	2.13	Dec. 23	0.3	1926	2.12	Jan. 24	0.8
1917	2.12	Dec. 10	1.0	1927	2.30	Feb. 4	1.4
1918	2.08	Jan. 13	[4] 1.1	1928	1.94	Jan. 26	−0.3
1919	2.26	Mar. 28	0.8	1929	1.93	Jan. 20	1.0
1920	2.37	Mar. 8	1.2	1930	2.20	Feb. 16	1.2
1921	2.30	Jan. 25	1.1	1931	2.30	Dec. 8	1.1
1922	2.30	Jan. 16	1.3	1932	2.29	Mar. 8	0.0
Sum	21.52	Sum	7.4	Sum	21.12	Sum	7.4
Mean	2.15	Mean	0.74	Mean	2.11	Mean	0.74

[1] Same height on Feb. 9.
[2] Same height on Jan. 14.
[3] Same height on Feb. 22.
[4] Same height on Jan. 14.

While the yearly values of extreme low water are seen to vary by several tenths of a foot, the means for the 10-year groups are in fairly close agreement. In fact, excepting the 10-year period 1903–12, the means for the three other 10-year groups differ from each other only by a few hundredths of a foot. Taking the 19-year period 1912–30, the plane of extreme low water is determined as 2.10 feet on staff or 3.93 feet below mean sea level for the same period.

It will be recalled that the planes of mean high water and mean low water at Fort Hamilton are not symmetrical with regard to mean sea level, the fall of low water being 0.09 foot greater than the rise of high water. The planes of extreme high water and extreme low water, likewise, are not symmetrical with respect to mean sea level; but in this case it is the high water plane that is farthest from mean sea level, the rise of extreme high water being 0.20 foot greater than the fall of extreme low water. On a percentage basis, the fall of extreme low water, is 62 percent greater than that of mean low water, while the rise of extreme high water is 78 percent greater than that of mean high water.

From the data for the lowest tides of each year in table 20, the plane of lowest low water, that is, the plane defined as the average of the yearly lowest low waters, is found to be, for the 19-year period 1912–30, 0.71 foot on staff or 5.32 feet below mean sea level. As

compared to mean low water, therefore, the fall of lowest low water is 120 percent greater. As compared to the plane of highest high water, the distance of the plane of lowest low water from mean sea level is 0.19 foot greater than that of highest high water.

The highest and lowest tides of any year at Fort Hamilton generally occur with storms. As tables 15 and 20 show, these highest and lowest tides most frequently occur during the winter months. It will be of advantage, however, to take up later the discussion of this matter in connection with the consideration of the effects of wind and weather.

THE PLANE OF HALF-TIDE LEVEL

The plane of half-tide level or, as it is sometimes called, the plane of mean-tide level, is the plane lying exactly halfway between the planes of mean high and mean low water. If the rise of mean high water above sea level were exactly equal to the fall of mean low water below sea level, the planes of half-tide level and mean sea level would coincide. But for Fort Hamilton we found the fall of low water to be 0.09 foot greater than the rise of high water. Hence, it follows that the plane of half-tide level lies 0.045 foot below sea level or, to the nearest second decimal, we may take the plane of half-tide level to be 0.04 foot below mean sea level.

As determined from short series of observations, the relation between sea level and half-tide level may vary somewhat, for any cause that disturbs the regularity of the tide tends to change the relation between sea level and half-tide level. During disturbed weather conditions, therefore, half-tide level at Fort Hamilton determined from one day of observations may be derived as several tenths of a foot above sea level, instead of 0.04 foot below, as is derived from a long series of observations. Even from a month of observations during disturbed weather conditions, half-tide level may be derived as lying above sea level. But from a year of observations the relation between half-tide level and sea level at Fort Hamilton will not vary by more than 1 or at most 2 one-hundredths of a foot from the mean value of 0.04 foot.

From its definition it is obvious that half-tide level will exhibit the annual variation found in high water and in low water. And since the annual variation in these follows the annual variation in sea level, the annual variation in half-tide level likewise follows the annual variation in sea level.

Theoretically, the relation between sea level and half-tide level varies periodically through a period of 18.6 years. At places where the daily components of the tide are relatively large, this periodic variation may have a range of as much as a tenth of a foot. But at Fort Hamilton the daily components of the tide are relatively small, and hence this periodic variation becomes so small as to be negligible for practical purposes.

RANGE OF TIDE

The extent of rise and fall of the tide or the range of the tide varies from day to day, principally in accordance with the positions of sun and moon relative to the earth. Spring tides and perigean tides bring relatively large ranges, while neap tides and apogean tides bring

relatively small ranges of the tide. In fact, the various ranges of the tide may be classified in a manner similar to the datum planes. We thus have mean range, spring range, neap range, perigean range, apogean range, and several kinds of tropic ranges.

The variation in the range of the tide from day to day at Fort Hamilton for a typical summer month is shown in table 1. The variation from year to year may be derived by subtracting from table 12 the corresponding values in table 16, or by adding the values of table 13 to the corresponding values of table 17. The results are given below in table 21.

TABLE 21.—*Range of tide, Fort Hamilton: Annual means 1893 to 1932*

Year	Feet	Year	Feet	Year	Feet	Year	Feet
1893	4.49	1903	4.83	1913	4.58	1923	4.86
1894	4.48	1904	4.84	1914	4.58	1924	4.93
1895	4.49	1905	4.81	1915	4.63	1925	4.87
1896	4.55	1906	4.76	1916	4.69	1926	4.79
1897	4.58	1907	4.78	1917	4.73	1927	4.73
1898	4.60	1908	4.73	1918	4.77	1928	4.71
1899	4.62	1909	4.67	1919	4.79	1929	4.69
1900	4.69	1910	4.67	1920	4.87	1930	4.61
1901	4.72	1911	4.64	1921	4.86	1931	4.60
1902	4.79	1912	4.63	1922	4.90	1932	4.59
Sum	46.01	Sum	47.36	Sum	47.40	Sum	47.38
Mean	4.60	Mean	4.74	Mean	4.74	Mean	4.74

The range of the tide exhibits from year to year the variation found in the high and low waters; that is, a variation in a period of 18.6 years, which brings about greater ranges when the inclination of the lunar orbit is small, and smaller ranges when the inclination is large. The corrected mean range for each year is obtained by multiplying the range as directly obtained from the tabulations by factors to take account of the variation in the longitude of the moon's node. The corrected mean range may also be obtained by adding the values of table 14 to the corresponding values of table 18. The results are shown below in table 22, as derived by applying the factors to the yearly ranges in table 21.

TABLE 22.—*Range of tide, Fort Hamilton: Annual means corrected for longitude of moon's node*

Year	Feet	Year	Feet	Year	Feet	Year	Feet
1893	4.61	1903	4.69	1913	4.71	1923	4.72
1894	4.61	1904	4.70	1914	4.71	1924	4.81
1895	4.62	1905	4.68	1915	4.74	1925	4.78
1896	4.66	1906	4.66	1916	4.76	1926	4.75
1897	4.66	1907	4.72	1917	4.75	1927	4.73
1898	4.64	1908	4.72	1918	4.75	1928	4.76
1899	4.62	1909	4.70	1919	4.72	1929	4.78
1900	4.64	1910	4.75	1920	4.76	1930	4.73
1901	4.63	1911	4.75	1921	4.72	1931	4.73
1902	4.67	1912	4.76	1922	4.76	1932	4.72
Sum	46.36	Sum	47.13	Sum	47.38	Sum	47.51
Mean	4.64	Mean	4.71	Mean	4.74	Mean	4.75

The means of the 10-year groups bring out clearly an augmented rise and fall of the tide for the last decade of 0.11 foot. This increase was found reflected in a rise of 0.05 foot in the plane of mean high water and in a lowering by 0.06 foot of the plane of mean low water. Manifestly this increase in the range of the tide is to be ascribed to the deepening of the channels leading from the sea into the Narrows, especially the improvement of Ambrose Channel, which, between 1901 and 1914, was dredged to a width of 2,000 feet and to a depth at mean low water of 40 feet. If for the mean range of the tide at Fort Hamilton we adopt the value determined by the 19-year period, 1912–30, we derive 4.75 feet.

Each of the various ranges of the tide is easily determined as the distance between the corresponding datum planes discussed in the previous sections. The designations given to a number of these ranges are self-evident; as, for example, the mean, spring, neap, perigean, and apogean ranges. Some, however, require definition. Thus, the great diurnal range is the distance between the mean higher high water and mean lower low water, the small diurnal range is the distance between mean lower high water and mean higher low water, the great tropic range is the distance between tropic higher high water and tropic lower low water, the small tropic range is the distance between tropic lower high water and tropic higher low water, the extreme range is the distance between extreme high water and extreme low water, the greatest range is the distance between the highest observed high water and the lowest observed low water. In table 23 the various ranges for the tide at Fort Hamilton are given.

TABLE 23.—*Tidal ranges, Fort Hamilton*

	Feet		*Feet*
Mean range	4. 75	Small diurnal range	4. 17
Spring range	5. 65	Great tropic range	5. 34
Neap range	3. 76	Small tropic range	3. 73
Perigean range	5. 77	Extreme range	8. 06
Apogean range	3. 85	Greatest range	12. 8
Great diurnal range	5. 29		

HARMONIC CONSTANTS

Harmonic analyses of the hourly ordinates of the tide at Fort Hamilton have been made for each of the 3 years 1900, 1904, and 1928. The length of the series used in each case was 369 days, beginning with the first of January of the respective years. The analysis was carried out in the usual way, the effects of other components being eliminated. The results derived are given in table 24. The lesser components were derived by inference from the more important components, and not by direct analysis. Such inferred values are distinguished by being enclosed in parentheses. The amplitudes of the components are given in the columns headed H and the epochs in the columns headed κ.

TABLE 24.—*Harmonic constants, Fort Hamilton*

Component	1900		1904		1928	
	H	κ	*H*	κ	*H*	κ
	Feet	*Degrees*	*Feet*	*Degrees*	*Feet*	*Degrees*
J_1	(0.018)	(105.6)	(0.018)	(106.5)	(0.014)	(103.5)
K_1	0.320	103.1	0.324	104.0	0.316	102.5
K_2	0.148	244.1	0.132	235.8	0.120	252.1
L_2	(0.062)	(238.7)	0.103	231.9	0.066	227.8
M_1	0.008	86.8	0.007	123.0	0.012	123.0
M_2	2.212	221.3	2.208	220.7	2.256	220.7
M_3	0.026	202.1	----------	----------	0.031	192.4
M_4	0.028	333.4	0.030	345.3	0.055	313.6
M_6	0.051	35.8	0.053	34.9	0.063	26.8
M_8	----------	----------	0.013	80.1	0.004	113.5
N_2	0.459	203.9	0.496	204.5	0.473	202.1
$2N$	(0.061)	(186.5)	(0.066)	(188.3)	(0.063)	(183.5)
O_1	0.178	98.1	0.167	98.9	0.171	100.5
OO	(0.010)	(108.1)	(0.010)	(109.1)	(0.007)	(104.5)
P_1	0.102	102.7	0.095	109.1	0.096	108.8

Component	1900		1904		1928	
	H	κ	*H*	κ	*H*	κ
	Feet	*Degrees*	*Feet*	*Degrees*	*Feet*	*Degrees*
Q_1	(0.035)	(95.6)	0.031	87.1	0.039	106.8
$2Q$	(0.005)	(93.1)	(0.004)	(93.8)	(0.004)	(98.5)
R_2	(0.004)	(248.8)	(0.004)	(247.0)	(0.004)	(248.6)
S_1	0.044	68.5	0.036	58.6	0.050	60.1
S_2	0.440	248.8	0.450	247.0	0.461	248.6
S_4	0.035	75.8	0.042	63.9	0.030	59.8
S_6	----------	----------	0.004	140.8	0.009	207.6
T_2	(0.026)	(248.8)	0.110	156.9	(0.027)	(248.6)
λ_2	(0.015)	(234.1)	0.043	197.2	(0.016)	(233.6)
μ_2	(0.053)	(193.8)	0.061	235.2	(0.054)	(192.8)
ν_2	(0.089)	(206.2)	0.095	202.7	(0.092)	(204.6)
ρ_1	(0.007)	(96.0)	(0.006)	(96.7)	(0.006)	(99.6)
MS	----------	----------	0.046	293.3	----------	----------
Sa	----------	----------	0.303	132.0	----------	----------
Ssa	----------	----------	0.138	105.6	----------	----------

In the discussion, previously, of the time and range of the tide at Fort Hamilton, it was found that as between the first and last 10-year groups of the 40-year series, the time of high water had become 0.05 hour earlier, the time of low water 0.01 hour earlier, and the range 0.1 foot greater. These changes were interpreted as arising from the improvement in the channel leading to New York Harbor. Table 24 permits a comparison of the changes in the harmonic constants consequent on this improvement. Taking the larger semidiurnal components and comparing the results from the analyses for the years 1900 and 1928, it is found that the epochs from the latter year are smaller by 0°.6 for M_2, 1°.8 for N_2, and 0°.2 for S_2. Taking a mean for the three components, the epochs have become smaller by 0°.9.

The amplitudes of the three components from the same comparisons show increases of 0.044 foot for M_2, 0.014 foot for N_2, and 0.021 foot for S_2. Expressing these as percentage increases over the respective values of the amplitudes from the 1900 series, they are, respectively: M_2, 2 percent; N_2, 3 percent; S_2, 5 percent. For the three principal semidiurnal components, therefore, the increase averages 3 percent.

Taking the principal diurnal components, the epochs from the 1928 series are found to differ from those of the 1900 series as follows: K_1, 0°.6 less; O_1, 2°.4 larger; P_1, 6°.1 larger. Taking an average of the three values, the epochs of the three principal diurnal components have become larger by 2°.6. The amplitude of each of these three diurnal components is smaller from the 1928 series as compared with the 1900 series. Expressed as percentage decreases of the corresponding values from the 1900 series they are: K_1, 1 percent; O_1, 4 percent; P_1, 6 percent. This gives an average decrease of 4 percent.

The change in the diurnal components is thus in marked contrast to that in the semidiurnals. Whereas the former show an increase in epoch and a decrease in range, the latter show a decrease in epoch and increase in range. It is to be noted, however, that the quantities involved are relatively small. Furthermore, the epochs and amplitudes for any component derived from different series of observations generally differ, because of the nature of tide observations. Nevertheless, the difference in the changes as between the diurnal and semidiurnal components appears well marked and of a real rather than of an accidental character. Further analyses of observations in harbors which have been subjected to improvement will be of interest in this connection.

Since the components *Sa* and *Ssa* are chiefly meteorological, the values of the amplitudes and epochs derived from any one year of observations may differ by relatively large amounts from the values derived from another year. From 28 years of observations at Fort Hamilton, covering the period 1893–1920, the constants for *Sa* were determined as 0.295 foot and 135°.4, and for *Ssa* as 0.099 foot and 75°.6. These two components account for the larger part of the annual variation in sea level at Fort Hamilton. To determine what harmonics of these components may also be involved, the monthly heights of sea level from 1893 to 1920 were divided into two 14-year groups, 1893–1906 and 1907–1920. These were then analyzed for the following components: *Sa*, *Ssa* (or Sa_2), Sa_3, Sa_4, and Sa_6, that is components having periods respectively of a year, half year, 4 months, 3 months, and 2 months. The results are given in table 25.

TABLE 25.—*Harmonic constants, Fort Hamilton, derived from annual variation of sea level*

Component	1893–1906		1907–20	
	H	κ	*H*	κ
	Feet	*Degrees*	*Feet*	*Degrees*
Sa	0.309	135.1	0.281	135.8
Sa_2	0.113	78.7	0.085	72.5
Sa_3	0.043	120.3	0.033	158.1
Sa_4	0.053	72.1	0.005	119.5
Sa_6	0.052	143.3	0.053	140.8

The amplitudes of the components in table 25 are small, and hence the agreement between the amplitudes and epochs of the two groups cannot be expected to be as close as in the case of components with larger amplitudes. Nevertheless, with the exception of Sa_4, the agreement between the two groups is so close as to leave no doubt of the existence of these components in the tide at Fort Hamilton. And

it is of interest to note that the components, Sa_3 and Sa_6, for which no provision is made in tide-predicting machines, have amplitudes as large or even larger than a number of the components usually taken into account.

The astronomic or true tidal components giving rise to the annual or semiannual variations in mean sea level are very small. As derived from the harmonic analyses of the tidal observations the magnitudes of the components must be due largely to meteorological factors. To determine how much was due to variation in atmospheric pressure, the annual variation in barometric pressure at New York City was subjected to the harmonic analysis. Monthly mean barometric pressure was used and two groups—1893–1906 and 1907–1920—corresponding to the tidal observations were analyzed. The results are shown in table 26.

TABLE 26.—*Harmonic constants, New York City, derived from annual variation of barometric pressure*

Component	1893–1906		1907–20	
	H	*κ*	*H*	*κ*
	Inches	*Degrees*	*Inches*	*Degrees*
Sa	0.060	254.6	0.056	248.9
Sa_2	0.014	22.3	0.010	332.6
Sa_3	0.008	205.7	0.017	194.9
Sa_4	0.018	185.8	0.009	9.1
Sa_6	0.009	323.3	0.004	320.8

If the annual variation in sea level was due wholly to the variation in local barometric pressure, and if, further, the tidal basin in the vicinity of Fort Hamilton be considered as a negative water barometer, we should expect the corresponding terms of tables 25 and 26 to bear the following relations to each other: The amplitudes in table 25 in feet approximately equal to the amplitudes of the corresponding terms in table 26 in inches, and the epochs of the constants in table 26 greater by 180° than the corresponding epochs in table 25. A comparison of the amplitudes of corresponding constants in these tables shows that the annual variation in pressure can account for only a small portion of the annual variation in sea level, for the amplitudes in table 26 are much smaller than those in table 25. Furthermore, the relation between the epochs of the corresponding constants in the two tables departs in most cases considerably from the theoretical relation.

The harmonic constants of the tide in table 24 furnish data for deriving readily various characteristics of the tide at Fort Hamilton. The ages of the tide in hours may be derived from the following formulae: Phase age$=0.984\ (S_2{}^\circ-M_2{}^\circ)$, parallax age$=1.837\ (M_2{}^\circ-N_2{}^\circ)$, diurnal age$=0.911\ (K_1{}^\circ-O_1{}^\circ)$.

The phase age of the tide is the interval by which spring tides follow full or new moon, and thus likewise the interval by which neap tide follows the moon's first and third quarters. From the above formulae, substituting the values of the harmonic constants from table 24, we derive for the phase age of the tide at Fort Hamilton, 26.5 hours. At Fort Hamilton, therefore, spring tides come not on the days of new and full moon, but a day later.

The parallax age of the tide is the interval by which perigean and apogean tides follow, respectively, the corresponding positions of the moon. From the harmonic constants of table 24 we derive for the parallax age of the tide at Fort Hamilton, 30.9 hours. Perigean tides here, therefore, come a day and a quarter after the moon is in perigee.

The diurnal age of the tide is the interval by which the tropic tide follows the moon's semimonthly maximum north or south declination. From the harmonic constants of table 24 we derive for the diurnal age of the tide at Fort Hamilton, 4.6 hours.

The diurnal inequalities in the heights of the tide may also be derived from the harmonic constants. The mean high water inequality, which is the average difference in height between the higher high waters and mean high water, is found to be 0.35 foot at Fort Hamilton. The mean low water inequality which is the average difference in height between the lower low waters and mean low water is found to be approximately 0.1 foot. What little inequality there is in the tide at Fort Hamilton is thus featured principally in the high waters.

From the fact that the lunitidal intervals at Fort Hamilton only rarely vary by as much as an hour from the mean, and from the further fact that the diurnal inequality in the heights of high or low water is small, the tide here is of the semidaily type; but from the harmonic constants alone the type of the tide may be inferred, the ratio of K_1+O_1 to M_2+S_2 furnishing the criterion. As stated before, where the ratio is less than 0.25, the tide is of the semidiurnal type. For Fort Hamilton, from the constants of table 24, the ratio is 0.19.

Another characteristic which may be determined from the harmonic constants is the order of occurrence of the tides. The formulae for that are somewhat involved, and hence need not be reproduced here. These formulae show that at Fort Hamilton the order of the tides is as follows: Higher high water, lower low water, lower high water, higher low water.

EFFECTS OF WIND AND WEATHER

The average rise of extreme high water at Fort Hamilton above mean sea level was found to be 4.13 feet. That this rise is due not alone to tidal causes is evident from the following considerations. The average rise of high water is 2.33 feet; at times of spring tide this is increased 19 percent, at times of perigean tides it is increased 24 percent, and tropic higher high water shows an increase of 16 percent. Hence, the rise of the tide at the time of a tropic higher high water that occurs when the moon is full or new and at the same time is also in perigee should be $19+24+16=59$ percent greater than the average, or 3.70 feet. This, however, is about half a foot less than the average extreme high water, and we may therefore conclude that these extreme high waters are brought about by wind and weather.

For the extreme low water the average fall below mean sea level was found to be 3.93 feet, while the fall of mean low water is 2.42 feet. Spring tides fall 19 percent below mean low water, perigean tides 20 percent below, and tropic lower low water 10 percent below. Hence, the greatest fall below mean sea level due to tidal causes would occur with the tropic lower low water that came when the moon was full or new and also in perigee. At such times the low water should be $19+20+10=49$ percent lower than mean low water, or 3.60 feet below mean sea level. The average extreme low water, however,

falls about a third of a foot below this; and, as in the case of the extreme high water, we may conclude that extreme low waters are also brought about by wind and weather.

By noting the weather that prevailed on the days during which the highest and lowest tides of the various years occurred, as listed in tables 15 and 20, we find that the highest high waters generally came with northeasterly winds. Furthermore, the highest high waters almost invariably came with a falling barometer, while the lowest low waters came with a rising barometer.

It is important to note that the extreme tides due to wind and weather are brought about not by an augmented rise or fall of high or low water, but by an unusual rise or fall of sea level. In other words, it is the effect of wind and weather on sea level and not on the rise and fall of the tide that brings an extreme high or low water. This is evident from a consideration of the highest high water and lowest low water observed at Fort Hamilton during the period of observations.

The highest high water at Fort Hamilton during the years 1893–1932 occurred in the forenoon of November 10, 1932, when high water rose 6.3 feet above mean sea level, or 4 feet above mean high water. Insofar as the true or astronomic tide for that day was concerned, it should have been 2.5 feet above mean sea level. High water should have risen 4.8 feet from the preceding low water and fallen 4.7 feet to the succeeding low water. The tide gage record for Fort Hamilton shows that the morning high water on November 10, 1932, rose 3.4 feet from the preceding low water and fell 6.6 feet to the succeeding low water. The exceptional height of the high water on that day cannot, therefore, be ascribed to an exceptional rise of high water. If from the hourly heights of the tide we derive sea level for the forenoon of November 10, it is found to be 4.3 feet above mean sea level.

The lowest low water at Fort Hamilton for the period 1893–1932 occurred in the afternoon of February 2, 1908, when low water fell 6.5 feet below mean sea level, or 4.1 feet below mean low water. The true or astronomic tide on that day should have fallen 3.3 feet below mean sea level, or 37 percent more than the average, due to the fact that on February 1 the moon was in perigee and on the 2d the moon was new. The tide in question should have fallen 6.7 feet from the previous high water and risen 6.0 feet to the succeeding high water. The Fort Hamilton tide gage record for February 2, 1908, shows the tide to have fallen 6.8 feet from the previous high water and then to have risen 6.2 feet to the succeeding high water. The actual rise and fall, therefore, agrees closely with that derived from computation, and hence the abnormal depth to which low water fell must be looked for in an unusual subsidence of sea level. If we derive sea level for February 2, 1908, we find that it was 2.8 feet below its mean level.

In the two instances discussed above, wind and weather appear to have had but little effect on the range of the tide, the extreme tides in question appearing to be accounted for wholly by the change in sea level. It is evident, however, that with rapidly varying meteorological conditions, changes in sea level between the times of high and low water must bring about changes in the range of tide. In other words, while extreme tides are due to the effect of wind and weather on sea level, rapidly changing weather conditions will be reflected not only in change of sea level but also in a disturbance of the range of the tide.

Apart from the effects on the height of the tide, wind and weather bring about irregularities in the times of high and low water, disturbing the regularity of rise and fall. An example of this is brought out in figure 12, the upper curve of which represents the mean rise and fall of the tide for Fort Hamilton, while the lower curve represents the rise and fall of the tide at Fort Hamilton for December 13–14, 1917, on which days heavy northeast and northwest winds prevailed. To make the tide curves comparable in time, they are referred to the time of the moon's transit over the meridian of Fort Hamilton, zero hours being the instant of the moon's upper meridian passage. For the lower curve zero hours corrsponds to 11:10 a.m. on December 13, 1917.

Considering, first, the time of tide, it is seen that for the first 6 hours the two tide curves agree very closely. From that time on the

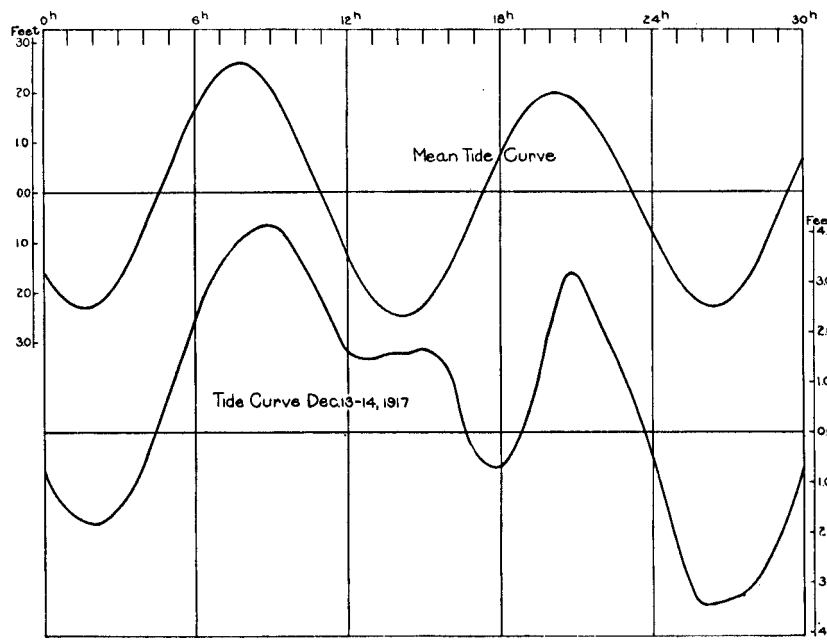

FIGURE 12.—Mean and storm tide curves, Fort Hamilton.

increasing velocity of the wind on December 13, 1917, is reflected in a disturbed condition of the tide, the high water being retarded by an hour and the following low water by 4 hours. This very considerable disturbance in the time of low water was evidently caused by a rapid rise of sea level between 12^h and 15^h (11 p.m. December 13 and 2 a.m. December 14, 1917). The weather record shows heavy northwesterly winds for the early hours of December 14 between 2 and 4 a.m., a wind velocity of 88 miles per hour being recorded. With less violent winds for the remainder of the day, the following high and low waters are seen to be much less disturbed in time. The change in time of tide brought about a marked change in the durations of rise and fall. The average duration of rise at Fort Hamilton is 6.01 hours and of fall 6.41 hours. The first rise shown by the tide curve for December 13–14, 1917, occupied a period of 6.9 hours.

This was followed by a fall of 9.1 hours, then a rise of but 2.9 hours, then a fall of 4.3 hours.

In regard to the height of the tide, it is to be noted that the zero line of heights for each of the tide curves represents mean sea level. A glance at the lower curve shows a very considerable elevation for sea level for the first half of the curve and a subsidence for the second half. For December 13, 1917, sea level stood 1 foot above its mean height, on the 14th it was 0.1 foot below its mean height, and on the 15th it was 1.3 feet below. Coincident with this rapid shifting in the height of sea level we find wide variations in the heights of the tide and consequently in the range of the tide. Beginning with the first low water shown in the curve, the undisturbed tide should have risen 4.3 feet, then fallen 4.1 feet, risen again 5.5 feet, and then fallen 5.9 feet. The effect of wind and weather was to give a rise of 6.0 feet, then a fall of 4.9 feet, followed by a rise of 4.0 feet and a fall of 6.7 feet.

The highest and lowest tides of any year at Fort Hamilton are brought about by wind and weather. It is therefore to be expected such tides will occur during the winter months. If the monthly distribution of the highest and lowest tides from tables 15 and 20 is compiled this is seen to be the case. The monthly distribution of these tides is given in table 27. The figures in the columns headed "Number" give the number of times the respective tides occurred during the corresponding month, while the figures in the column headed "Percent" give the monthly occurrence on a percentage basis.

TABLE 27.—*Month of occurrence of highest and lowest tides, Fort Hamilton, 1893 to 1932*

Month	Highest tides		Lowest tides	
	Number	Percent	Number	Percent
January	3⅔	9.2	11½	28.8
February	6⅓	15.8	16½	41.2
March	3	7.5	5	12.5
April	5½	13.8	0	0
May	0	0	0	0
June	1	2.5	0	0
July	0	0	0	0
August	1	2.5	0	0
September	1	2.5	0	0
October	6	15.0	1	2.5
November	5½	13.8	0	0
December	7	17.5	6	15.0

Table 27 shows that the highest tide of the year may occur during any of the months from October to April. The lowest tide of the year, however, occurs almost without exception in the winter months, and generally either in January or February.

SUMMARY OF TIDAL DATA

Since the observations at Fort Hamilton cover a longer period than at any other station in New York Harbor, it will be convenient to have the data relating to the principal features of the tide at Fort Hamilton assembled in one table, and this is done in table 28. The intervals, ranges, and principal datums are means for the 19-year series 1912–30. The other data are based on observations for various years as explained in the discussion of these data in the foregoing sections.

TABLE 28.—*Summary of tidal data, Fort Hamilton*

TIME RELATIONS		
High-water interval	hours	7. 64
Low-water interval	do	1. 63
Duration of rise	do	6. 01
Duration of fall	do	6. 41
Phase age	do	26. 5
Parallax age	do	30. 9
Diurnal age	do	4. 6
Sequence of tides is HHW to LLW.		
RANGES		
Mean range	feet	4. 75
Great diurnal range	do	5. 29
Small diurnal range	do	4. 17
Great tropic range	do	5. 34
Small tropic range	do	3. 73
Spring range	do	5. 65
Neap range	do	3. 76
Perigean range	do	5. 77
Apogean range	do	3. 85
Extreme range	do	8. 06
Greatest range	do	12. 8
Spring range÷mean range		1. 19
Neap range÷mean range		0. 79
Perigean range÷mean range		1. 22
Apogean range÷mean range		0. 81
Great diurnal range÷mean range		1. 12
Great tropic range÷mean range		1. 13
HEIGHT RELATIONS		
Mean high water above mean sea level	feet	2. 33
Mean higher high water above mean sea level	do	2. 65
Mean lower high water above mean sea level	do	1. 98
Tropic higher high water above mean sea level	do	2. 70
Tropic lower high water above mean sea level	do	1. 71
Spring high water above mean sea level	do	2. 77
Neap high water above mean sea level	do	1. 86
Perigean high water above mean sea level	do	2. 88
Apogean high water above mean sea level	do	1. 87
Extreme high water above mean sea level	do	4. 13
Highest high water above mean sea level	do	6. 3
Mean low water below mean sea level	do	2. 42
Mean lower low water below mean sea level	do	2. 64
Mean higher low water below mean sea level	do	2. 18
Tropic lower low water below mean sea level	do	2. 64
Tropic higher low water below mean sea level	do	2. 02
Spring low water below mean sea level	do	2. 88
Neap low water below mean sea level	do	1. 90
Perigean low water below mean sea level	do	2. 89
Apogean low water below mean sea level	do	1. 98
Extreme low water below mean sea level	do	3. 93
Lowest low water below mean sea level	do	6. 5
Half-tide level below mean sea level	do	0. 04

THE TIDE IN LOWER BAY

In connection with various operations, tides have been observed in Lower Bay at a number of places at various times. The stations at which the observations have been carried on for periods of sufficient length to determine with reasonable accuracy the time and other characteristics of the tide are shown in figure 13.

The consideration of the tide at Fort Hamilton in the preceding section brought out the fact that in order to derive mean values of the various tidal features directly from the observations, a series of 19 years in length is necessary. Such long series, however, are imprac-

tical at many places. To derive mean values, therefore, from short series of observations it is necessary to correct the results determined directly from the observations to mean values. The simplest method for this purpose is by means of comparison of simultaneous observations. This is best illustrated by means of an example.

Suppose that at Coney Island there is a series of observations covering the period, say, April 12–19, 1920, from which the lunitidal intervals are derived as 7.47 hours and 1.60 hours, and the range as 6.02 feet. Because of the periodic variations in these features and also because of the effects of wind and weather, these direct results may differ from mean values. But because of the nearness of Coney Island to Fort Hamilton it is clear that the variations in the tide at the two places must be much the same. Hence, from the observations at Fort Hamilton for the same period, April 12–19, 1920, the lunitidal intervals and the range are determined. The differences between these lunitidal intervals and the mean values at Fort Hamilton are then applied as a correction to the values determined from the observations at Coney Island. In the same way, the ratio of the range at Fort Hamilton for the period April 12–19, 1920, to the mean range is used as a factor for correcting the range derived from the observations at Coney Island.

THE TIDE AT SANDY HOOK

The longest series of observation in Lower Bay is that at station A in the Horse Shoe of Sandy Hook Bay. Short series of observations had been made prior to 1876, but in that year an automatic tide gage was installed, from the records of which tabulations for the following series are at hand: (*a*) 1876–81, (*b*) 1887–88, (*c*). 1890–92. Each of these series with the exception of (*c*) begins on the 1st of January and runs through to December 31. Series (*c*) begins on February 1 and ends on January 31. The lunitidal intervals and the mean range of the tide from these observations are shown in table 29. In this table the mean range of the tide has been corrected for the longitude of the moon's node. It is to be noted, too, that for the range the results for the years from 1887 through 1892 are at hand.

TABLE 29.—*Lunitidal intervals and mean range of tide, station A, Sandy Hook*

Series	Length	HWI	LWI	Range
	Years	*Hours*	*Hours*	*Feet*
(*a*) 1876–81	6	7.58	1.50	4.78
(*b*) 1887–88	2	7.61	1.48	----------
(*c*) 1890–92	2	7.60	1.43	----------
1887–92	6	----------	----------	4.68
Weighted mean	----------	7.59	1.48	----------

In view of the difficulties encountered in the operation of tide gages in the earlier years, we may consider the variations in the lunitidal intervals derived from the three series of observations as coming within the allowable limits of error. For the best determined values we may therefore take the weighted means, but for the mean range of the tide it is difficult to reconcile the values for the series 1876–81 and 1887–92. The probable explanation appears to be that there was an actual decrease in the rise and fall of the tide in the latter period brought about by the continual northward growth of Sandy Hook.

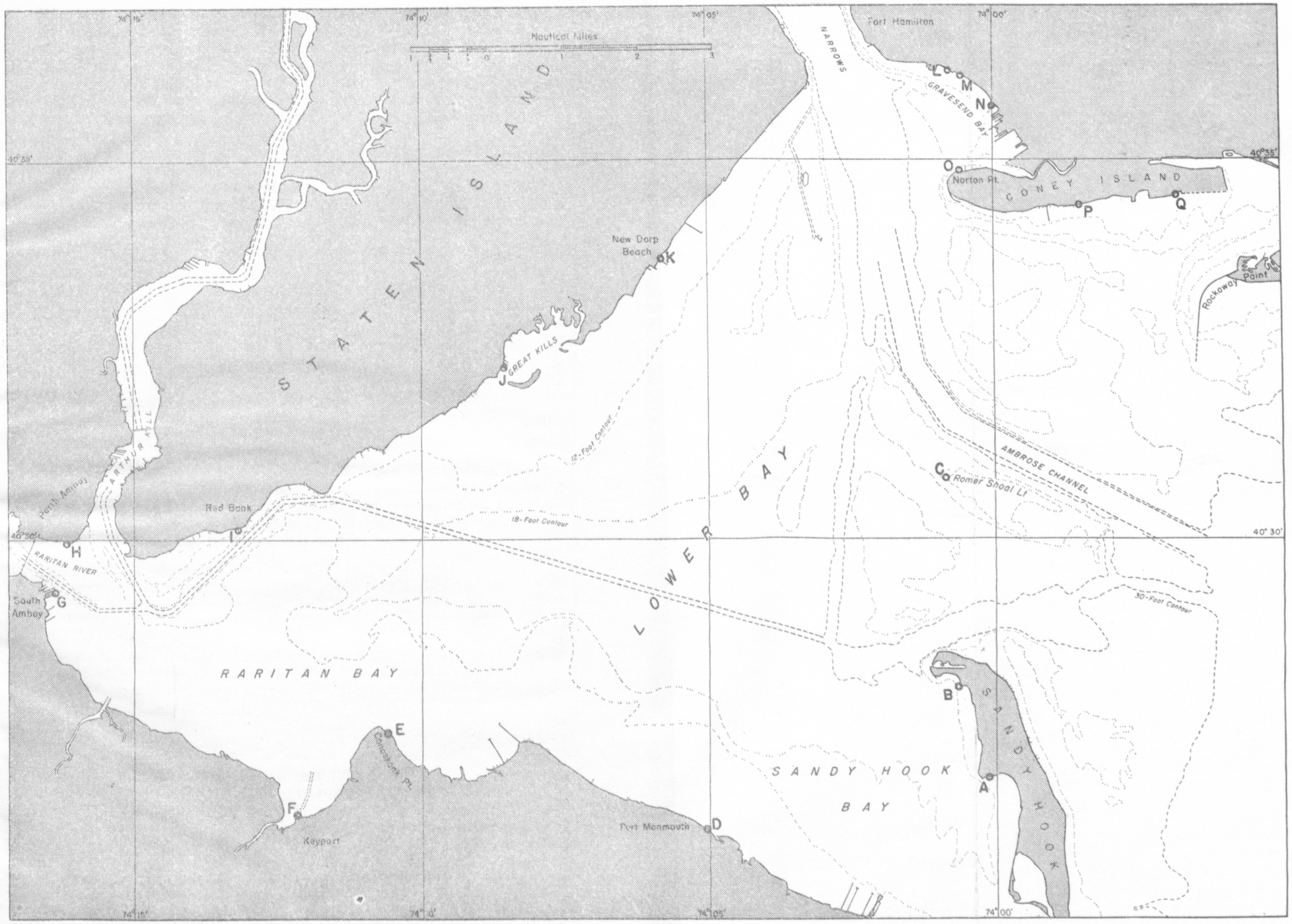

FIGURE 13.—Tide stations, Lower Bay.

Harmonic analyses have been made of the tidal observations at Sandy Hook for the years 1876–81 and 1887–88. The results of these analyses likewise give evidence of the decrease in the range of the tide for the later years. From the 6 years—1876–81—the amplitude of M_2 is 2.250 feet, while from the 2 years—1887–88—the amplitude is 2.188 feet. For the best determined range, therefore, the results from the series 1887–92 will be taken, which give a value of 4.68 feet.

In table 30 are given the harmonic constants for station A. In deriving the mean values of these constants the results from the series 1887–88 were given the same weight as those from the series 1876–81. The values inclosed in parentheses have been derived not by direct analysis, but by inference from the values of the principal components.

TABLE 30.—*Harmonic constants, station A, Sandy Hook*

Component	H	κ	Component	H	κ	Component	H	κ
	Feet	*Degrees*		*Feet*	*Degrees*		*Feet*	*Degrees*
J_1	(0.019)	(104)	$2N$	(0.067)	(184)	T_2	(0.025)	(246)
K_1	0.333	102	O_1	0.172	98	λ_2	(0.016)	(231)
K_2	0.123	243	OO	(0.010)	(105)	μ_2	0.068	226
L_2	0.110	203	P_1	0.105	105	ν_2	0.096	199
M_1	0.016	119	Q_1	0.032	110	ρ_1	(0.005)	(273)
M_2	2.219	218	$2Q$	(0.004)	(95)	Sa	0.254	143
M_4	0.026	336	R_2	(0.003)	(246)	Ssa	0.101	58
M_6	0.054	353	S_1	0.032	222			
N_2	0.503	201	S_2	0.426	246			

From the harmonic constants given in table 30, various characteristics of the tide have been determined. These are given in table 31, in which are included also for the sake of completeness the lunitidal intervals and the mean range of the tide, as determined from direct tabulation of the high and low waters.

TABLE 31.—*Tidal data, station A, Sandy Hook*

High-water interval	hours	7.59
Low-water interval	do	1.48
Mean range	feet	4.68
Spring range	do	5.57
Neap range	do	3.69
Great diurnal range	do	5.09
Phase age	hours	28.0
Parallax age	do	30.7
Diurnal age	do	3.1
Sequence of tides is HHW to LLW.		
Spring range÷mean range		1.19
Neap range÷mean range		0.79
Great diurnal range÷mean range		1.09

Between 1876 and 1884 the highest tide at station A occurred on January 31, 1878, when high water rose 2.9 feet above mean high water, or 5.2 feet above mean sea level. It is to be noted, however, that on September 12, 1882, a severe storm occurred, during which the height of the water was not recorded as the tide gage was swept away by the storm. The lowest tide between 1876 and 1884 occurred on January 23, 1882, when low water fell 3.3 feet below mean low water, or 5.6 feet below mean sea level. Between 1887 and 1891 the highest tide occurred on September 10, 1889, high water rising 6.2 feet above mean sea level. During this same period the lowest tide

occurred in 1890 on January 22, when low water fell 5.4 feet below mean sea level. The greatest range observed at Sandy Hook is therefore 11.8 feet, which compares with 12.8 feet at Fort Hamilton between the years 1893 to 1932.

For station B, about a mile and a half north of station A, there are at hand three series of observations between the years 1912 and 1933. The data derived from these series are given below in table 32, and are seen to agree with the values for station A. As compared with the tide at Fort Hamilton, the tide at Sandy Hook is about a tenth of a foot less in range and about 3 minutes earlier. In this connection it is to be noted, however, that in general, the direct difference between the lunitidal intervals at two stations does not give the difference in time of tide at the two stations. Only if the two stations have the same longitude does the direct difference of the intervals give the difference in the time of tide. If the stations have different longitudes, a correction must be applied. This correction is derived from the following considerations. Since the average period of the moon's apparent revolution about the earth is 24.84 hours, the time taken for the moon to travel 1° of longitude is $24.84 \div 360 = 0.069$ hour. Hence, the correction to be applied for the difference in longitude is $0.069\ (L_{\prime} - L_{\prime\prime})$, in which $L_{\prime}$ and $L_{\prime\prime}$ are the longitudes in degrees of the two stations. If both stations are in west longitude, the above correction may be added to the interval of the station having the greater longitude, and the difference in intervals will then give the difference in time of tides.

TIDAL DATA, LOWER BAY

The tidal data for Lower Bay for the stations shown on figure 13 are given in table 32. With the exception of station A, the intervals and ranges given have been reduced to mean values by comparison with simultaneous observations at some stations like Fort Hamilton or Sandy Hook. For the sake of completeness the data for station A is also included.

TABLE 32.—*Tidal data, Lower Bay*

Station	Locality	Lunitidal intervals		Duration of rise	Mean range	Observations	
		HWI	LWI			Year	Length
		Hours	*Hours*	*Hours*	*Feet*		
A	Sandy Hook, N. J.	7.59	1.48	6.11	4.68	1876–92	12 years.
B	do	7.72	1.63	6.09	4.57	1912–16	5 years.
B	do	7.59	1.50	6.09	4.66	1921–22	2 years.
B	do	7.61	1.57	6.04	4.56	1932–33	1 year.
C	Romer Shoal Light, N. Y.	7.48	1.37	6.11	4.63	1922	3 months.
D	Port Monmouth, N. J.	7.53	1.78	5.75	4.65	1886	4 days.
E	Conaskonk Point, N. J.	7.57	1.63	5.94	5.02	1886	Do.
F	Keyport, N. J.	7.52	1.55	5.97	4.98	1870	14 days.
G	South Amboy, N. J.	7.75	1.83	5.92	5.07	1886	10 days.
H	Perth Amboy, N. J.	7.95	1.89	6.06	5.28	1873	1 month.
I	Red Bank, N. Y.	7.40	1.43	5.97	5.22	1886	Do.
J	Great Kills, N. Y.	7.50	1.53	5.97	5.07	1886	5 days.
K	New Dorp Beach, N. Y.	7.55	1.62	5.93	4.82	1919	3 days.
L	16th Ave., Brooklyn, N. Y.	7.61	1.53	6.08	4.71	1932	3½ months.
M	Gravesend Bay, N. Y.	7.52	1.60	5.92	4.64	1886–87	3 months.
N	do	7.67	1.48	6.19	4.53	1881–86	1 month.
O	Norton Point, N. Y.	7.45	1.23	6.22	4.87	1919	2 days.
P	Coney Island, N. Y.	7.65	1.33	6.32	4.92	1908	1 month.
Q	do	7.50	1.15	6.35	4.82	1920	3 months.

From the data of table 32 it is seen that the time of tide in Lower Bay changes but little, the difference between Romer Shoal Light and the entrance to Raritan River being less than half an hour. Toward the western end of the bay the tide exhibits to a greater degree the characteristics of river tides, as shown by the duration of rise becoming relatively shorter. Toward the western end, also, the range of the tide increases, and this obviously is to be ascribed to the rapidly converging shore lines which concentrate the energy of the tide in a smaller volume, and thus gives a greater rise and fall.

A comparison of the tidal ranges on the north and south shores of Lower Bay brings to light the fact that, relative to the axis of the bay, a point on the northern shore has a greater range than the corresponding point on the southern shore. Thus, stations A and B have ranges less than 4.7 feet, while stations O and P have ranges greater than 4.8 feet; the range at station D is 4.65 feet against 4.82 feet at station K.

This increase in range of tide on the northern shore is brought about by the rotation of the earth, as a consequence of which all moving bodies are impressed with a force deflecting them to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. On the rising tide the water moving into Lower and Raritan Bays is deflected to the right or northern shore. Hence, high water here is raised somewhat higher than on the southern shore. On the falling tide the moving water is again deflected to the right, but now it is the southern shore that is to the right of the moving water, and hence low water is somewhat higher on the southern than on the northern shore. The tide, therefore, rises higher and falls lower on the northern shore, giving a greater range here than on the southern shore.

It will be noted from tables 28 and 31 that the ratios of the spring, neap, and great diurnal ranges to mean range are practically the same at Fort Hamilton and at Sandy Hook. We may therefore assume that throughout Lower Bay the ratios of the various ranges to mean range are the same as at Fort Hamilton, and these ratios can thus be used for determining the various ranges at any of the stations listed in table 32. Apart from the range and lunitidal intervals the tide in Lower Bay is much like that at Fort Hamilton, and the features of the tide at the latter place may be taken as characterizing the tide also in Lower Bay.

THE TIDE IN THE NARROWS AND UPPER BAY

TIDAL DATA

On figure 14 are shown the stations at which tidal observations have been made in the Narrows and Upper Bay. The observations at station A, Fort Hamilton, were discussed in a previous section. At station N, Governors Island, observations were made over a period of 33 years at various times, from 1847 to 1879, an automatic tide gage being used from 1853; but because of the difficulties encountered in the operation of tide gages in the earlier years this series does not lend itself to a detailed discussion of the tidal data. From these observations at Governors Island there are at hand the results of the tabulations of high and low water for 19 years, from 1860 to 1879, and also the harmonic analyses of 3 years of observations. An harmonic

analysis has also been made of 1 year's observations at stations P and Q. The results from the tabulations of the high and low waters at the various stations in the Narrows and Upper Bay are given in table 33. With the exception of stations A and N (Fort Hamilton and Governors Island), the lunitidal intervals and ranges given in the table have been corrected to mean values by comparison with simultaneous observations at some nearby standard station, generally Fort Hamilton, Governors Island, or Sandy Hook.

TABLE 33.—*Tidal data, the Narrows and Upper Bay*

Station	Locality	Lunitidal intervals		Duration of rise	Mean range	Observations	
		HWI	LWI			Year	Length
		Hours	*Hours*	*Hours*	*Feet*		
A	Fort Hamilton, N. Y.	7.71	1.66	6.05	4.67	1893-1911	19 years.
A	do	7.64	1.63	6.01	4.75	1912-30	Do.
B	92d St., Brooklyn, N. Y.	7.76	1.65	6.11	4.62	1932	4 months.
C	83d St., Brooklyn, N. Y.	7.82	1.75	6.07	4.64	1932-33	7 months.
D	72d St., Brooklyn, N. Y.	7.85	1.78	6.07	4.62	1932-33	10 months.
E	66th St., Brooklyn, N. Y.	7.86	1.83	6.03	4.63	1932-33	7 months.
F	Bay Ridge, N. Y.	7.91	1.90	6.01	4.53	1886	3 days.
G	51st St., Brooklyn, N. Y.	7.90	1.88	6.02	4.63	1932	7 months.
H	Gowanus Canal, Brooklyn, N. Y.	7.95	1.93	6.02	4.65	1932-33	4 months.
I	Erie Basin (south side) Brooklyn, N. Y.	7.99	1.83	6.16	4.66	1932	½ month.
J	Van Dyke St., Brooklyn, N. Y.	8.04	1.97	6.07	4.67	1932-33	7 months.
K	Atlantic Basin, Brooklyn, N. Y.	8.07	2.02	6.05	4.60	1932-33	5½ months.
L	Hamilton Ave., Brooklyn, N. Y.	8.07	2.13	5.94	4.40	1856-65	10 years.
M	Governors Island, N. Y.	8.10	2.06	6.04	4.49	1932	1½ months.
N	do	8.10	2.25	5.85	4.45	1860-79	19 years.
O	do	8.21	2.13	6.08	4.45	1932	2 months.
P	The Battery, N. Y.	8.24	2.19	6.05	4.45	1921-26	6 years.
Q	do	8.11	2.11	6.00	4.52	1918-19	1 year.
R	Fort Wadsworth, Staten Island	7.73	1.65	6.08	4.56	1932	10 days.
S	do	7.77	1.67	6.10	4.46	1886	Do.
S	do	7.77	1.69	6.08	4.48	1931-33	9 months.
T	Rosebank, Staten Island	7.81	1.58	6.23	4.39	1932	6 days.
U	Clifton, Staten Island	7.81	1.72	6.09	4.48	1932-33	7 months.
V	Stapleton, Staten Island	7.76	1.75	6.01	4.48	1932-33	4 months.
W	do	7.88	1.76	6.12	4.47	1932	10 days.
X	St. George, Staten Island	8.07	2.07	6.00	4.34	1917-18	7 months.
X	do	7.90	1.85	6.05	4.48	1932	7 months.
Y	do	7.93	1.87	6.06	4.52	1932-33	7½ months.
Z	Bayonne, N. J.	7.95	2.03	5.92	4.52	1932	10 days.
Aa	Claremont, N. J.	8.05	1.94	6.11	4.41	1932	1 month.
Bb	Jersey City, N. J.	8.02	2.13	5.89	4.45	1871	2 days.

Table 33 gives for the difference in time of tide between Fort Hamilton and the mouth of the Hudson (stations A and Q) 0.47 hour for the high water and 0.48 hour for the low water, or a mean difference of 0.48 hour. The distance along the channel from Fort Hamilton to the mouth of the Hudson is 6 nautical miles, the waterway between these points having an average depth of 26 feet, reckoned from mean sea level. In the formula for the rate of advance of a progressive wave, $r=\sqrt{gh}$, if we substitute the depth above, we determine r to be 17.1 miles per hour. Hence, if the tidal movement through the Narrows and Upper Bay is of the progressive-wave type, the distance of 6 miles should, from the above value of r be traversed in 0.35 hour. This approximates 0.48 hour given by the tide, and we may therefore conclude that through the Narrows and Upper Bay the tidal movement is of the progressive-wave type.

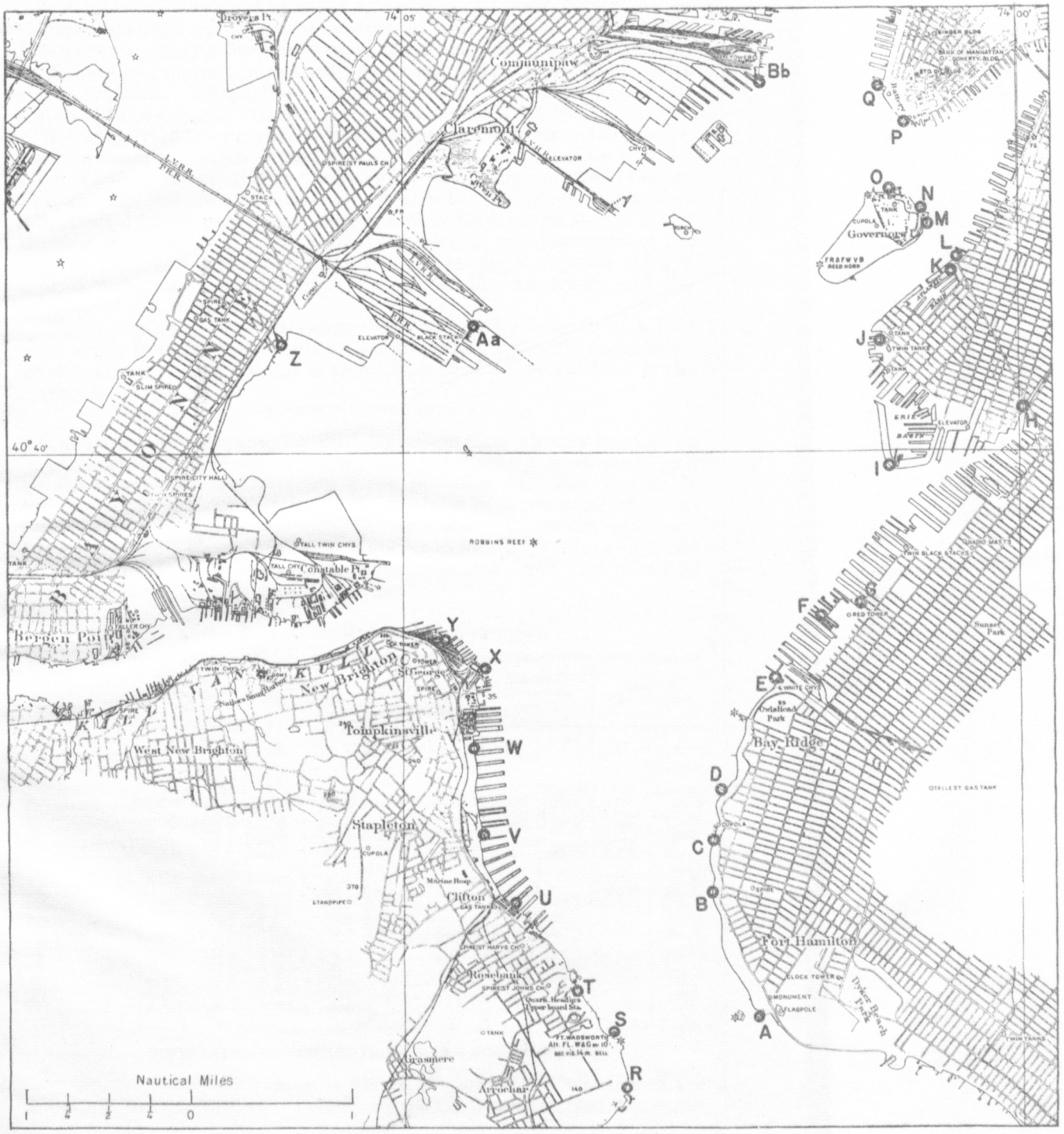

FIGURE 14.—Tide stations, the Narrows and Upper Bay.

The lunitidal intervals in table 33 show slight time differences as between stations on opposite shores of the channel. But these differences are only a few hundredths of an hour, and may be ascribed to difficulties inherent in determining mean values from short series of observations. Throughout this area the duration of rise is approximately 6 hours, giving the fall a duration of about 6.4 hours.

With regard to the range of tide, the data of table 33 show the eastern shore to have a greater range than the western shore. This is to be expected as a result of the deflecting force of the earth's rotation. Through the Narrows this difference is about 0.15 foot; in Upper Bay it is about 0.2 foot; and at the head of Upper Bay, in the mouth of the Hudson, it is 0.07 foot. As we shall see later, in the discussion of the tides in the Hudson River, the difference in range on opposite sides of a tidal waterway depends on the width of the waterway and the velocity of the current.

Within the Narrows, the range decreases about a tenth of a foot from south to north as a result of the gradually diverging shore lines. Within Upper Bay, the range is about a tenth of a foot less than in the Narrows.

HARMONIC CONSTANTS

The harmonic constants for Fort Hamilton have already been given in table 24. For Governors Island and the Battery (stations N and P) the harmonic constants are given in table 34. For station N the constants are derived from the analysis of 3 years of observations 1876–79—while the constants for station P are derived from 1 year of observations, beginning June 1, 1920. The values enclosed in parentheses have been derived by inference from the principal components and not by direct analysis.

TABLE 34.—*Harmonic constants, Upper Bay*

Component	Station N (Governors Island)		Station P (the Battery)		Component	Station N (Governors Island)		Station P (the Battery)	
	H	κ	H	κ		H	κ	H	κ
	Feet	*Degrees*	*Feet*	*Degrees*		*Feet*	*Degrees*	*Feet*	*Degrees*
J_1	(0.018)	(107.3)	(0.018)	(105.8)	Q_1	(0.031)	(103.3)	0.046	137.9
K_1	0.325	106.3	0.327	105.8	$2Q$	(0.004)	(102.3)	(0.005)	(105.8)
K_2	0.118	255.1	0.107	255.4	R_2	(0.003)	(257.1)	(0.003)	(259.0)
L_2	0.129	248.9	0.077	248.4	S_1	--------	--------	0.049	66.9
M_1	0.016	104.0	0.011	205.4	S_2	0.413	257.1	0.416	259.0
M_2	2.153	231.1	2.112	233.4	S_4	--------	--------	0.043	78.6
M_3	--------	--------	0.033	198.4	S_6	--------	--------	0.005	185.9
M_4	0.087	332.4	0.055	333.3	T_2	0.073	183.1	(0.025)	(259.0)
M_6	0.076	89.1	0.071	80.8	λ_2	0.025	186.0	(0.015)	(245.3)
M_8	--------	--------	0.012	85.6	μ_2	0.063	217.4	(0.051)	(207.8)
N_2	0.496	210.5	0.487	213.4	ν_2	0.093	241.0	(0.094)	(216.1)
$2N$	(0.066)	(189.9)	(0.065)	(193.4)	ρ_1	(0.006)	(103.4)	(0.007)	(105.8)
O_1	0.161	104.3	0.176	105.8	Sa	0.245	127.0	0.169	108.7
OO	(0.010)	(108.3)	(0.010)	(105.8)	Ssa	0.173	47.4	0.136	92.3
P_1	0.105	104.2	0.102	106.0					

TIDAL CHARACTERISTICS FROM HARMONIC CONSTANTS

From the harmonic constants above, various characteristics of the tide may be determined. It is to be noted, however, that the mean

range determined from harmonic constants is invariably smaller than that determined from high and low waters. It has been customary to use 1.02 as the factor to increase the range determined from the harmonic constants. It appears, however, that this factor is too small. At each of the three stations Fort Hamilton, the Battery, and Governors Island, comparisons between the results derived from high and low waters and from harmonic constants show that this factor should be 1.04 instead of 1.02. Table 35 gives the tidal data derived from the harmonic constants with the mean range modified by the factor 1.04. For the sake of comparison, the results from Fort Hamilton are also included.

TABLE 35.—*Tidal data from harmonic constants, the Narrows and Upper Bay*

		Station A (Fort Hamilton)	Station N (Governors Island)	Station P (the Battery)
Mean range	feet	4.75	4.50	4.45
Great diurnal range	do	5.29	4.83	4.79
Small diurnal range	do	4.17	4.17	4.11
Great tropic range	do	5.34	4.92	4.86
Small tropic range	do	3.73	3.66	3.58
Spring range	do	5.65	5.39	5.32
Neap range	do	3.76	3.53	3.50
Perigean range	do	5.77	5.40	5.38
Apogean range	do	3.85	3.88	3.68
Phase age	hours	26.5	25.6	25.2
Parallax age	do	30.9	37.8	36.7
Diurnal age	do	4.6	1.8	0.0
Spring range÷mean range		1.19	1.20	1.20
Neap range÷mean range		0.79	0.78	0.79
Perigean range÷mean range		1.22	1.20	1.21
Apogean range÷mean range		0.81	0.86	0.83
Great diurnal range÷mean range		1.12	1.07	1.08
Great tropic range÷mean range		1.13	1.09	1.09

The data of table 35 show a very close resemblance between tide at stations N and P and but little difference between the tide at these two stations and station A. It is of interest to note that with the exception of the apogean range at station N the various tidal ranges decrease from Fort Hamilton to the Battery, and that with the exception of the parallax age a similar decrease takes place in the ages of the tide. The ratios of the various ranges to mean range are practically the same at all three stations, and we may therefore use these ratios at Fort Hamilton for determining the various ranges at any of the stations in the Narrows and Upper Bay listed in table 33.

For the period 1847 to the end of 1878 the highest tide at Governors Island occurred on September 17, 1876, when high water stood 3.3 feet above mean high water, or 5.5 feet above mean sea level. For the same period the lowest tide at Governors Island occurred on December 22, 1876, when low water reached 3.7 feet below mean low water, or 5.9 feet below mean sea level. The greatest range of the tide at Governors Island for this period is therefore 11.4 feet. This compares with 11.8 feet at Sandy Hook for the period 1876–91 and 12.8 feet at Fort Hamilton for the period 1893–1932.

THE TIDE IN THE KILLS AND NEWARK BAY

ARTHUR KILL

The stations at which tide observations have been made in Arthur Kill are shown on figure 15. At no station in this waterway have observations been made for more than 3 months. To derive mean values, therefore, the observations in Arthur Kill have been compared with simultaneous observations at some primary station like Sandy Hook, Fort Hamilton, or Governors Island. The data from these observations are given in table 36.

TABLE 36.—*Tidal data, Arthur Kill*

Station	Locality	Lunitidal intervals		Duration of rise	Mean range	Observations	
		HWI	LWI			Year	Length
		Hours	*Hours*	*Hours*	*Feet*		
A	Perth Amboy, N. J.	7.95	1.89	6.06	5.28	1873	1 month.
B	do	7.72	1.82	5.90	5.15	1920	3 months.
B	do	7.95	1.96	5.99	5.07	1932	6 days.
C	Tottenville, N. Y.	7.93	1.70	6.23	4.98	1856	1 month.
D	Rossville, N. Y.	8.02	2.02	6.00	5.12	1856–86	2½ days.
E	Carteret, N. J.	8.38	2.37	6.01	5.18	1856	1 day.
F	do	8.30	2.36	5.94	5.16	1932	8 days.
G	Near Pralls Creek, N. Y.	8.52	2.42	6.10	5.25	1856	1 day.
H	Elizabeth, N. J.	8.22	2.45	5.77	5.00	1855–86	20 days.
I	do	8.47	2.33	6.14	4.99	1920	2 days.
I	do	8.62	2.62	6.00	4.75	1932	7 days.

The data in table 36 show the tide in Arthur Kill to become later from the Lower Bay to the Newark Bay entrance. Since the channel in this kill has been dredged at different times, we may use the results from the 1932 observations as best representing tidal conditions at the present time. From station B we may take the lunitidal intervals at the southern entrance as approximately 7.95 hours and 1.95 hours, respectively; while from station I we may estimate these intervals at the northern entrance as 8.65 hours and 2.65 hours. This gives a difference of 0.7 hour for the time of tide at the two entrances of Arthur Kill.

The length of Arthur Kill, measured along the channel, is about 11½ nautical miles, and while in 1932 there was a channel with a depth of 30 feet at mean low water, the average depth over the entire waterway was about 18½ feet measured from mean sea level. If the tidal movement through Arthur Kill is of the progressive-wave type—that is, progressing in accordance with the formula $r=\sqrt{gh}$—the tide should traverse this waterway from one end to the other in 0.8 hour. From the data in table 36, the difference is 0.7 hour.

The range of tide in Arthur Kill is greater at the southern entrance than at the northern entrance, being about 5.1 feet at the former and 4.8 feet at the latter. The duration of rise is approximately the same throughout the waterway having a value of about 6 hours. This makes the duration of fall 6.4 hours. The data are not sufficiently extensive to indicate with precision what changes in the tidal regime have taken place in Arthur Kill as a result of improvements in the waterway.

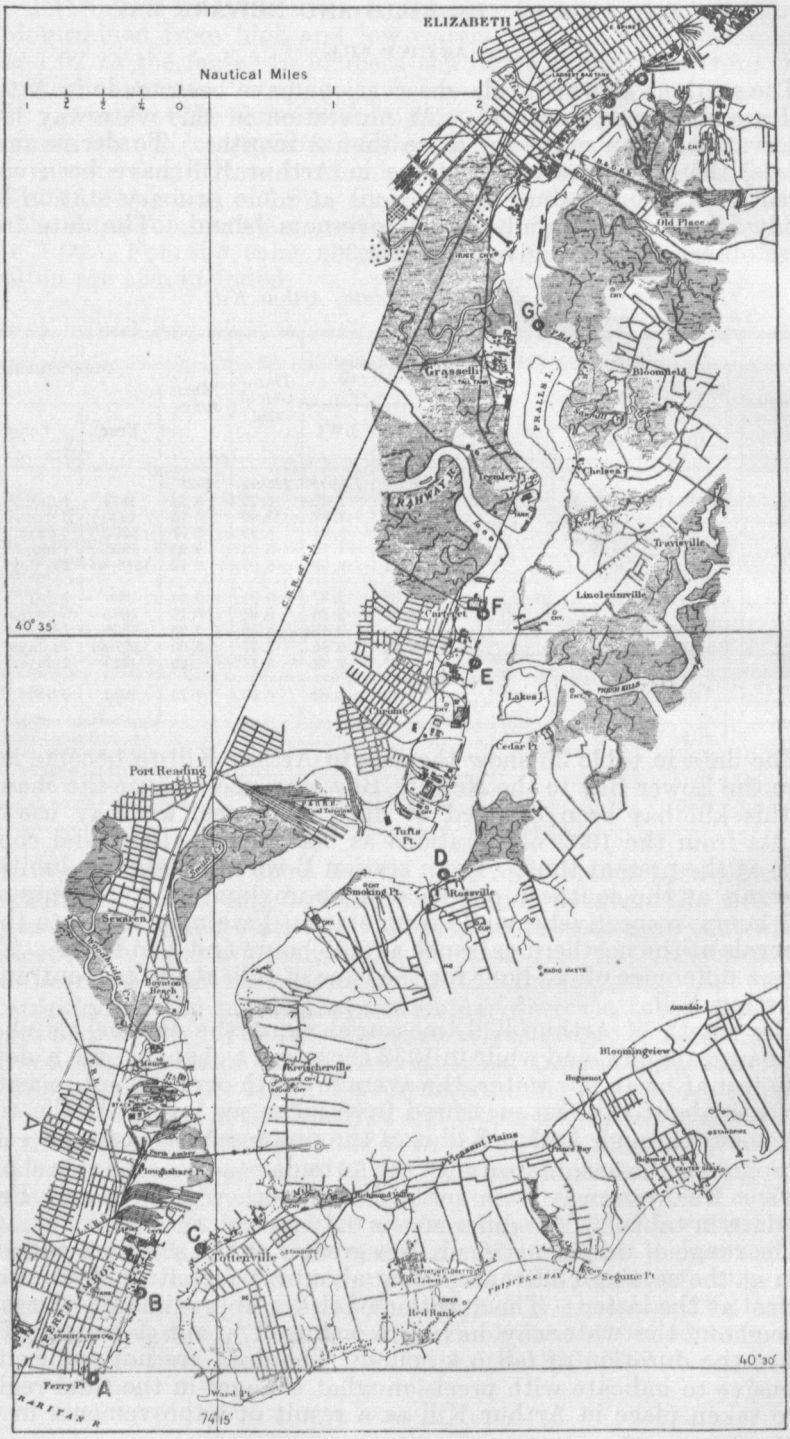

FIGURE 15.—Tide stations, Arthur Kill.

KILL VAN KULL

For Kill van Kull there are at hand observations at eight stations, the locations of these being shown on figure 16. In this waterway, as in Arthur Kill, the observations cover only short periods of time, the longest series being but 10 days in length. The tidal data derived from these observations are shown in table 37. In this table

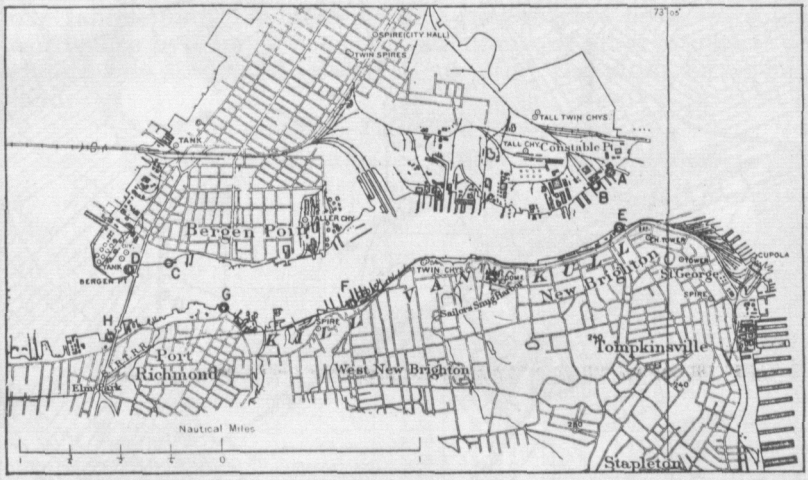

FIGURE 16.—Tide stations, Kill van Kull.

the lunitidal intervals and ranges have been corrected to mean values by comparison with simultaneous observations at some primary tide station.

TABLE 37.—*Tidal data, Kill van Kull*

Station	Locality	Lunitidal intervals		Duration of rise	Mean range	Observations	
		HWI	LWI			Year	Length
		Hours	*Hours*	*Hours*	*Feet*		
A	Constable Point, N. J.	7.97	1.99	5.98	4.47	1932	10 days.
B	do	8.12	1.95	6.17	4.50	1886	2 days.
C	Bergen Point, N. J.	8.28	2.32	5.96	4.64	1932	7 days.
D	do	8.35	2.13	6.22	4.64	1919	9 days.
E	New Brighton, N. Y.	8.03	1.87	6.16	4.48	1919	7 days.
F	West New Brighton, N. Y.	8.20	2.13	6.07	4.48	1919	2 days.
G	Port Richmond, N. Y.	8.38	1.87	6.51	4.48	1856	2½ days.
H	do	8.36	2.52	5.84	4.49	1885–86	6 days.

From the data in table 37, the tide at the eastern end of Kill Van Kull is seen to be about 20 minutes earlier than at the western end. The duration of rise throughout the waterway is approximately 6.1 hours, giving the duration of fall a period of 6.3 hours.

The range of the tide increases somewhat from the eastern entrance to the western entrance, the difference being a tenth of a foot. The northern shore appears to have a slightly greater range than the southern shore; if this is due to the deflecting force of the earth's rotation, the current must be flowing westerly on the rising tide, so that the

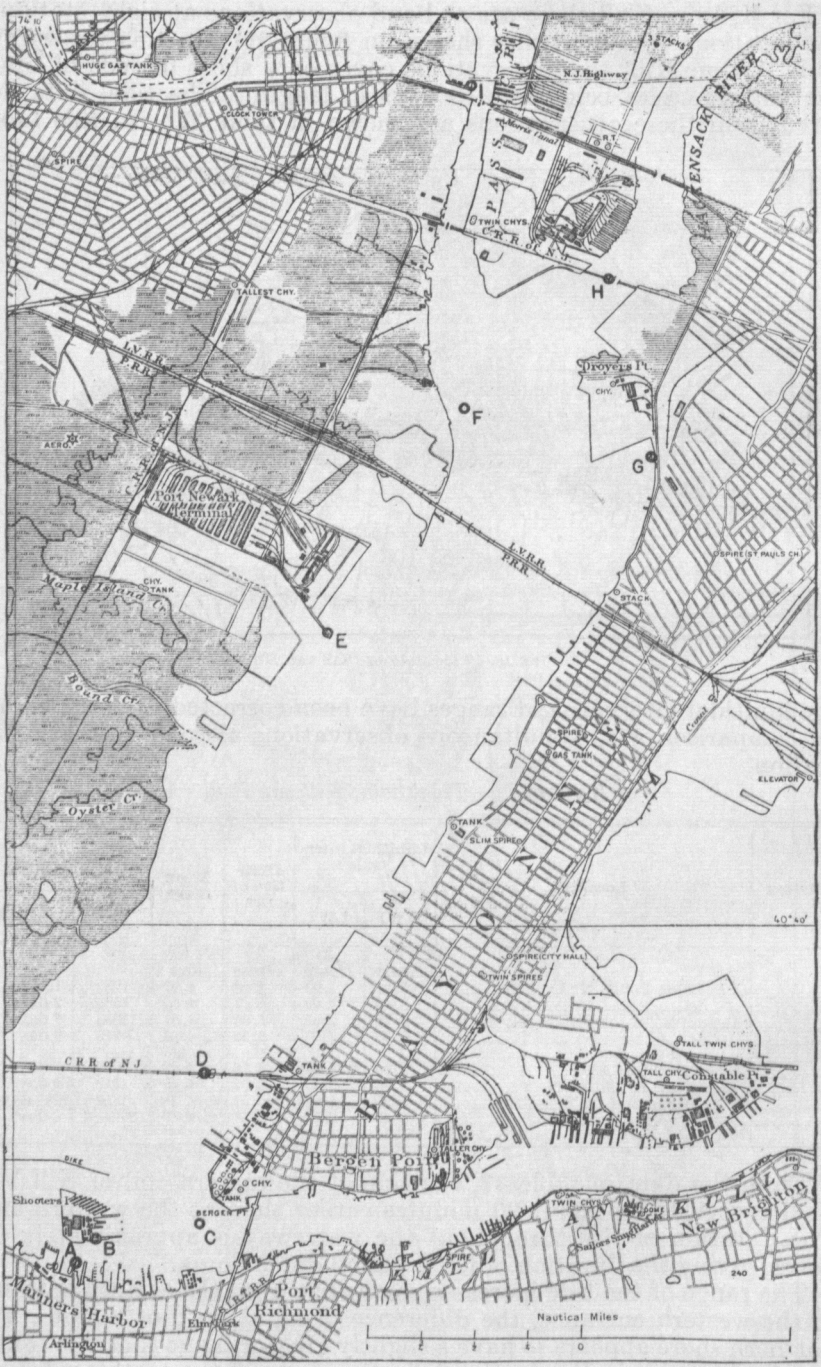

FIGURE 17.—Tide stations, Newark Bay.

northern shore is then to the right of the current movement. This, as we shall see later, the current observations show to be the case.

NEWARK BAY

The locations of the tide stations at which observations have been made in Newark Bay are shown on figure 17, and the data dervied from these observations are given in table 38. Here, as in the previous tables, lunitidal intervals and ranges have been corrected to mean values by comparison with simultaneous observations at some standard tide station like Sandy Hook, Fort Hamilton, or Governors Island.

TABLE 38.—*Tidal data, Newark Bay*

Station	Locality	Lunitidal intervals		Duration of rise	Mean range	Observations	
		HWI	LWI			Year	Length
		Hours	*Hours*	*Hours*	*Feet*		
A	Mariners Harbor, N. Y.	8.45	2.46	5.99	4.76	1920	3 months.
B	Shooters Island, N. Y.	8.32	2.43	5.89	4.59	1901	2½ months.
C	Bergen Point Light, N. J.	8.70	2.57	6.13	4.41	1856	1 day.
D	Off Bayonne, N. J.	8.40	1.83	6.57	4.42	1872	7 days.
E	Port Newark, N. J.	8.58	2.84	5.74	4.73	1919	5 months.
F	Off Newark, N. J.	8.54	2.71	5.83	4.93	1871–72	3 months.
G	Greenville, N. J.	8.70	3.00	5.70	4.58	1920	4 days.
H	Hackensack River, N. J.	8.48	3.25	5.23	4.58	1886	3 days.
I	Passaic River, N. J.	8.85	3.33	5.52	4.73	1920	2 days.

From the east, Newark Bay receives the tide from Kill van Kull with a range of 4½ feet, while from the west it receives the tide from Arthur Kill with a range of about 4¾ feet. And throughout Newark Bay the range of the tide approximates these figures.

With regard to time, the tide becomes later from south to north in Newark Bay. But it will be noted that while the times of high water at stations H and I are less than half an hour later than at the mouth of the bay, the times of low water are later by about three quarters of an hour. This difference arises from the fact that the bay is shallow, having an average depth of about 10 feet reckoned from mean sea level. With a range of tide of nearly 5 feet, the depth at the time of high water is about 50 percent greater than at the time of low water. And since the rate of advance of the tide depends on the depth, the high-water phase is propagated more rapidly than the low-water phase.

As a consequence of the different rates of advance of high and low water in Newark Bay, the duration of rise varies from mouth to head. In the lower part of the bay, the duration of rise is between 5¾ and 6 hours, while in the upper part, in the entrances to the Passaic and Hackensack Rivers, it is 5½ hours or less.

THE TIDE IN THE HUDSON AND HARLEM RIVERS

HUDSON RIVER

The stretch of the Hudson that is here considered as forming part of New York Harbor is that from the mouth to Mount St. Vincent, a distance of 14 nautical miles. The stations at which tide

observations have been made in this stretch are shown in figures 18a and 18b, and the data derived from these observations are given in table 39. For each station listed in this table the intervals and mean range have been reduced to a mean value by comparison with simultaneous observations at some standard tide station like Fort Hamilton or Governors Island.

TABLE 39.—*Tidal data, Hudson River*

Station	Locality	Lunitidal intervals		Duration of rise	Mean range	Observations	
		HWI	LWI			Year	Length
	EAST SHORE						
		Hours	*Hours*	*Hours*	*Feet*		
A	The Battery, Pier A	8.11	2.11	6.00	4.52	1918–19	1 year.
B	Chambers St	8.14	2.15	5.99	4.41	1932–33	11½ months.
C	Christopher St	8.19	2.20	5.99	4.40	1932–33	10 months.
D	20th St	7.80	2.18	5.62	4.31	1871	1 day.
D	22d St	8.28	2.25	6.03	4.40	1932–33	11 months.
E	28th St	7.92	2.10	5.82	4.55	1855	8 days.
F	41st St	8.28	2.30	5.98	4.16	1919	3½ months.
F	42d St	8.25	2.50	5.75	4.09	1885	9 days.
F	do	8.18	2.42	5.76	4.14	1886	6 days.
F	do	8.34	2.35	5.99	4.28	1932–33	11 months.
F	43d St	8.23	2.17	6.06	4.31	1875	1 day.
G	70th St	8.47	2.45	6.02	4.19	1932–33	10½ months.
H	96th St	8.27	2.48	5.79	4.11	1871	2 days.
I	98th St	8.58	2.57	6.01	4.05	1932–33	11½ months.
J	129th St	8.71	2.63	6.08	4.13	1932–33	10½ months.
K	155th St	8.43	2.62	5.81	4.28	1855	6 days.
K	156th St	8.80	2.77	6.03	3.97	1932–33	8½ months.
K	157th St	8.94	2.90	6.04	3.77	1930	27 days.
L	George Washington Bridge	8.79	2.74	6.05	4.15	1932	1 month.
M	Tubby Hook	8.57	3.13	5.44	3.96	1853	Do.
M	do	8.40	2.92	5.48	4.06	1855	1 day.
M	do	8.94	2.84	6.10	3.92	1932–33	10 months.
N	Spuyten Duyvil	9.16	2.90	6.26	3.69	1919	4 months.
N	do	9.23	3.11	6.12	3.73	1921–22	2 years.
N	do	9.22	3.06	6.16	3.78	1928–32	5 years.
O	Riverdale	8.67	2.87	5.80	3.94	1871	1 day.
O	do	8.94	3.09	5.85	3.86	1898	5 days.
O	do	9.40	3.09	6.31	3.71	1932	10 days.
	WEST SHORE						
P	Englewood				3.63	1932	1 month.
Q	Fort Lee	8.52	3.37	5.15	3.83	1837	2 days.
R	Edgewater				3.79	1932	4 months.
S	Weehawken	8.28	2.35	5.93	4.13	1872	2 days.
S	do	8.77	2.85	5.92	3.99	1885	11 days.
T	Hoboken				4.05	1932	3 months.
U	Jersey City	7.98	2.10	5.88	4.29	1873	7 days.
U	do	8.28	2.33	5.95	4.26	1874	9 days.
V	do	8.33	2.40	5.93	4.52	1854	8 days.
W	do	8.12	2.28	5.84	4.31	1885	12 days.
W	do				4.33	1932	1 month.
X	do	8.19	2.18	6.01	4.30	1860	4 days.
Y	do	8.02	2.13	5.89	4.45	1871	2 days.

In the use of lunitidal intervals for determining the difference in time of tide between 2 stations the correction to be applied is 0.07 hour for each degree of difference in longitude. But, since the Hudson River runs in an approximately north and south direction, the difference in longitude between any 2 stations for the stretch of 14 miles under consideration will be very small. Hence, the difference

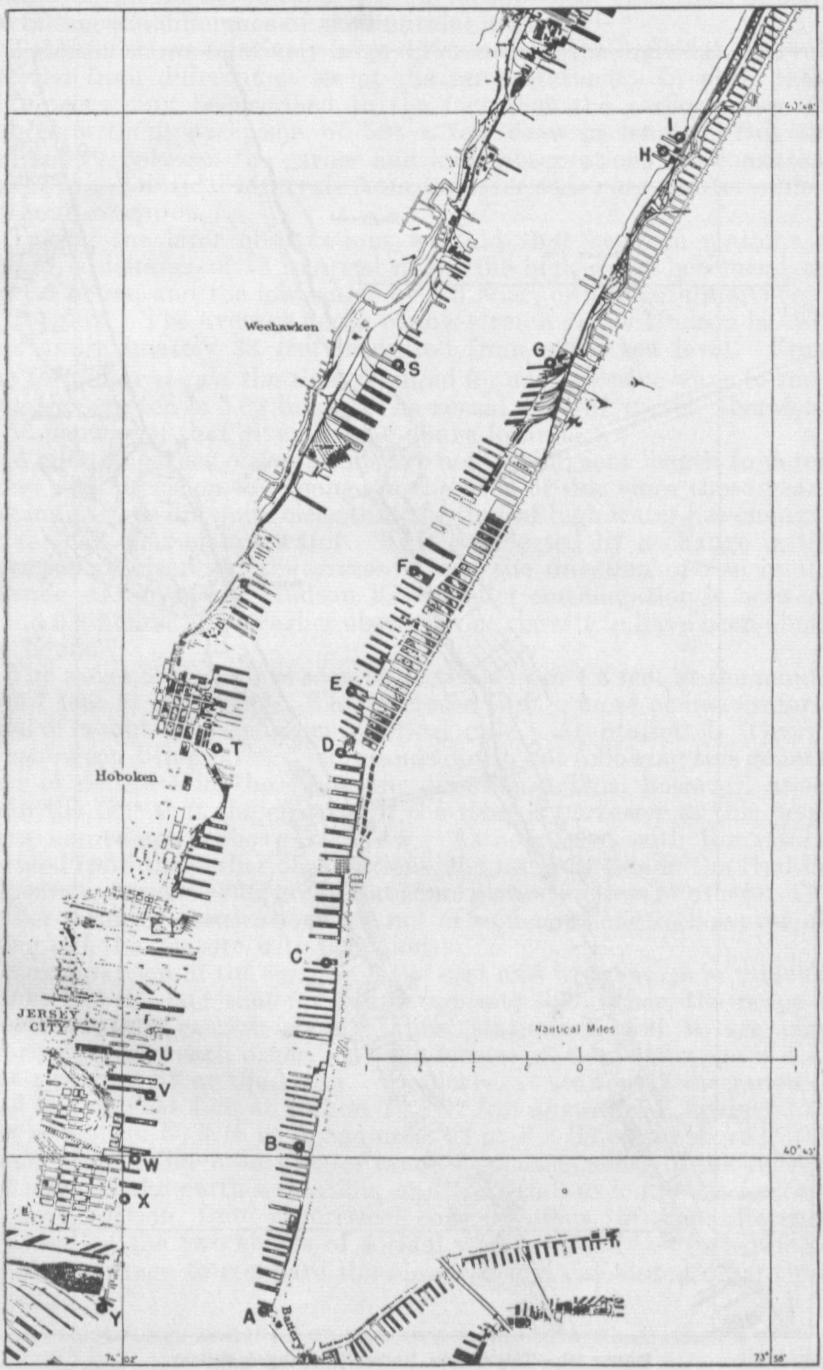

FIGURE 18a.—Tide stations, Hudson River (lower section).

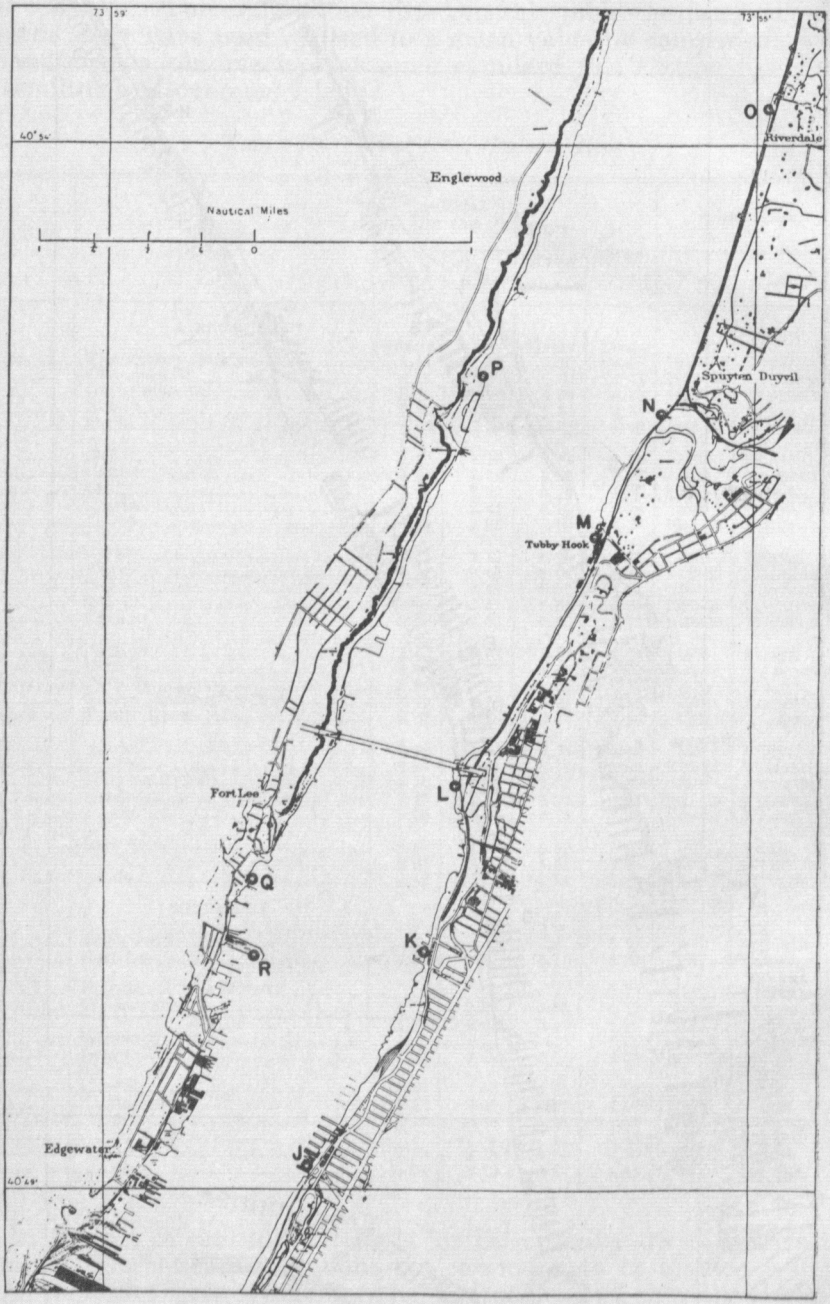

FIGURE 18b.—Tide stations, Hudson River (upper section).

in time of tide for the stations listed in table 39 may be derived directly by taking the difference of the lunitidal intervals.

Table 39 shows relatively large differences in the lunitidal intervals derived from different series at the same stations. In part, these differences may be ascribed to the fact that the earlier series are almost without exception of but a few days in length. But the differences between the earlier and later observations are consistent in that the lunitidal intervals from the later series are greater almost without exception.

Taking the later observations we find that between stations A and O, a distance of 13 nautical miles, the high water becomes later by 1.3 hours, and the low water by 1.0 hour, or a mean difference of 1.15 hours. The average depth of this stretch of the Hudson in 1932 was approximately 38 feet measured from mean sea level. From the formula $r=\sqrt{gh}$, the time required for a progressive wave to traverse this stretch is 0.63 hour. The actual rate of travel, therefore, is 55 percent of that given by the above formula.

While the earlier observations are not of sufficient length to determine with precision the change in the time of tide since those years, the indications are quite clear that the time of high water has changed more than that of low water. This is reflected by a change in the duration of rise. At the present time, the duration of rise in the 14-mile stretch of the Hudson River under consideration is between 6 and 6.3 hours. The earlier observations show it to have been about 5.8 hours.

The range of the tide is seen to decrease from 4.5 feet at the mouth to 3.7 feet at Riverdale. This decrease is at a more or less uniform rate of about 0.06 foot per nautical mile. At Station L (George Washington Bridge) the range stands out in not following this general rule of decrease in the upstream direction. This, however, arises from the fact that the channel of the river is narrower at this point than immediately above or below. As compared with the results derived from the earlier observations, the range of tide in the Hudson appears to have become greater at some places and less at others. The earlier series of observations are not of sufficient length, however, to bring out this feature with precision

A comparison of the ranges on the east and west shores in table 39 brings out the fact that for points opposite each other, the range is greater on the eastern shore. Thus, stations B and W are very nearly opposite each other. At the former station the range is 4.41 feet against 4.33 at the latter. Similarly, at station D the range is 4.40 feet against 4.05 at station T; 3.97 feet at station K against 3.79 feet at station R; 3.78 at N against 3.63 at P. The east shore of the Hudson should have the greater range as a consequence of the deflecting force of the earth's rotation, and the Hudson lends itself nicely to a calculation, from theoretical considerations, of the difference in range on the two shores of a tidal waterway. It will, therefore, be of advantage to compare the observed and calculated differences in range.

DIFFERENCE IN RANGE ON THE TWO BANKS OF A TIDAL STREAM

If v is the velocity with which a unit mass of water is moving, the deflecting force of the earth's rotation which acts on this unit mass is $2\,\omega\,v\,\sin\phi$, where ω is the angular velocity of the earth's rotation

and ϕ is the latitude. This force acts to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The transverse slope assumed by the surface of the water in response to this force is $\frac{2\omega\ v \sin \phi}{g}$, where g is the acceleration of gravity. If the strength of current occurs at the times of high and low water, the difference in level at such times between the surface of the water on the two banks of the tidal waterway will be $\frac{2\ \omega\ v\ d \sin \phi}{g}$, where d is the distance between the banks. Obviously, the difference in range will be twice the difference in level. Hence, since $\omega = 0.0000729$, if v is given in knots and d in nautical miles, the formula for the difference in range on the opposite banks of a tidal stream, expressed in feet, is $\frac{3\ v\ d \sin \phi}{g}$, approximately.

At stations B and W the width of the Hudson is, between pierheads, 0.6 nautical mile, and the velocity of the current near the surface at the times of high and low water averages about 1.7 knots in this section. For latitude 40°43′ the sine of the latitude is 0.65, and the value of g is 32.16 feet per second. Hence the difference in range between stations B and W should be, from the above formula, 0.06 foot with the east shore having the greater range. Table 39 gives a difference for these stations of 0.08 foot. As a result of the deflecting force of the earth's rotation, we may, therefore, take the range on the east bank of the Hudson to be about a tenth of a foot greater than on the west bank.

For stations D and T, which are almost exactly opposite each other, table 39 gives a difference of 0.35 foot in range. This is very much larger than the difference derived from the formula. But it will be noted that these stations are located at points where the river changes direction. On the flood, the two stations are situated about equally distant from the axis of the current, which is in the center of the channel. On the ebb, however, station T is much closer to the axis of the current than is D. As a result, there should be very little difference in the heights of the high waters, but a relatively large difference in the low waters. The observations at these stations show the high waters to be practically the same height, while the low waters differ by about a third of a foot.

It may not be amiss here to emphasize the fact that the deflecting force of the earth's rotation is independent of the direction of the movement of the water. At times one still meets with the erroneous assumption that it is only bodies moving in a north and south direction that are subject to the full effect of the deflecting force of the earth's rotation, while bodies moving in an east and west direction are not at all affected by it. It is to be noted that the formula for the deflecting force of the earth's rotation contains no term depending on the direction of the movement.

HARLEM RIVER

The locations at which tide observations have been made in the Harlem River are shown on figure 19, and the results derived from these observations, corrected to mean values by comparison with simultaneous observations at some standard station, are given in

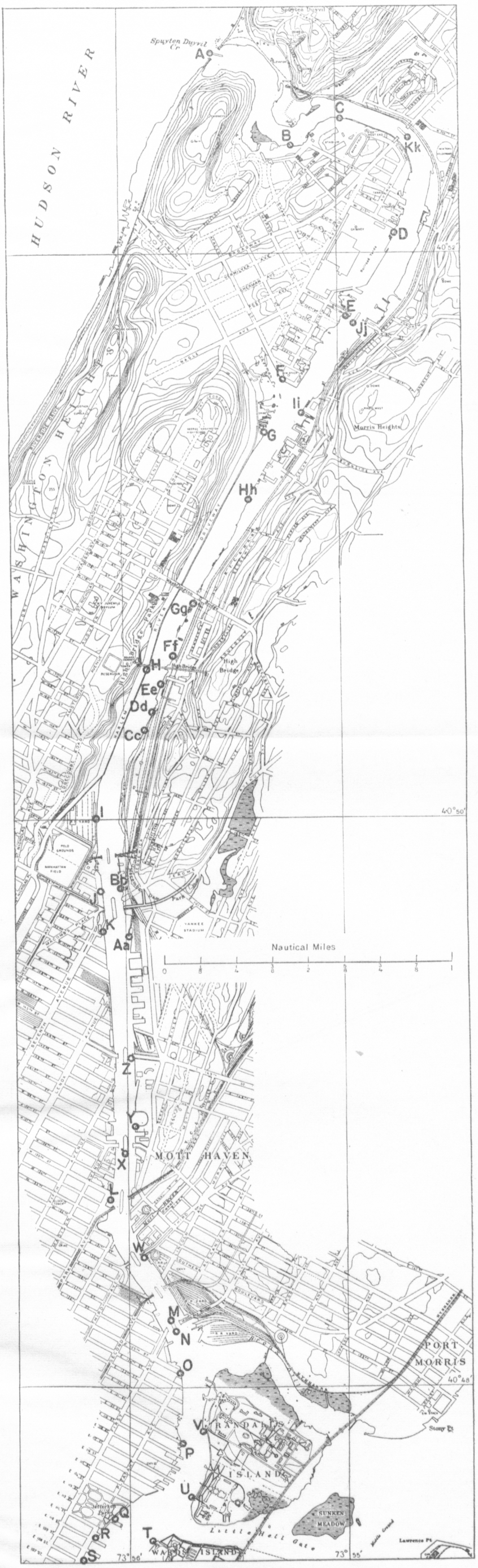

FIGURE 19.—Tide stations, Harlem River.

table 40. The latest data were derived during the tide survey of 1932–33 and give well determined means, since several months of observations were secured at a number of the stations. The earliest observations given in table 40 were made in 1856.

TABLE 40.—*Tidal data, Harlem River*

Station	Locality	Lunitidal intervals		Duration of rise	Mean range	Observations	
		HWI	LWI			Year	Length
		Hours	*Hours*	*Hours*	*Feet*		
A	Spuyten Duyvil, N. Y.	9.16	2.90	6.26	3.69	1919	4 months.
A	do	9.23	3.11	6.12	3.73	1921–22	2 years.
A	do	9.22	3.06	6.16	3.78	1928–32	5 years.
B	Opposite Johnson Iron Works	9.29	3.17	6.12	3.81	1932–33	5 months.
C	Off Seaman Ave	9.66	3.56	6.10	3.66	1919	1 day.
D	West 215th St	9.56	3.42	6.14	3.97	1932–33	5 months.
E	West 207th St	9.68	3.44	6.24	4.05	1932–33	3 months.
F	Sherman Creek	9.66	3.48	6.18	4.13	1932–33	7 months.
G	South of Sherman Creek	9.91	3.91	6.00	4.21	1919	1 day.
H	High Bridge	10.46	3.86	6.60	5.84	1886	2½ days.
I	North of Putnam railroad bridge	9.72	3.55	6.17	4.48	1932–33	6 months.
J	North of Central Bridge	10.21	3.96	6.25	4.96	1919	1 day.
K	South of Central Bridge	10.21	4.11	6.10	4.90	1919	Do.
L	Park Avenue Bridge	9.88	3.69	6.19	4.71	1932–33	7 months.
M	North of Willis Avenue Bridge	10.06	3.73	6.33	4.96	1921–22	2 years.
M	do	9.94	3.71	6.23	4.90	1932–33	11 months.
N	South of Willis Avenue Bridge	10.21	3.96	6.25	5.27	1919	1 day.
O	East 125th St	10.01	3.77	6.24	4.91	1932–33	8 months.
P	East 120th St	10.10	3.86	6.24	4.97	1932–33	3 months.
Q	East 112th St	10.13	3.81	6.32	4.97	1932–33	7 months.
R	East 110th St	10.25	3.73	6.52	4.98	1856–57	2 months.
S	East 108th St	10.14	3.81	6.33	5.08	1932–33	Do.
T	Wards Island	10.20	3.99	6.21	5.06	1932	1 month.
U	Randalls Island, Southwest pier	9.83	3.65	6.18	5.15	1932	5 days.
V	Randalls Island, opp. 122d St	9.98	3.74	6.24	5.06	1932	4 days.
V	do	10.19	3.63	6.56	5.24	1886	Do.
W	Third Ave. Bridge	10.13	4.06	6.07	4.81	1932	1 month.
X	Madison Ave. Bridge	10.11	4.11	6.00	5.09	1919	1 day.
Y	North of Madison Ave. Bridge	9.86	3.52	6.34	4.74	1932	1½ months.
Z	145th Street Bridge	9.76	3.63	6.13	4.62	1932–33	3 months.
Aa	South of Central Bridge	10.01	4.01	6.00	4.95	1919	1 day.
Aa	do	9.79	3.63	6.16	4.60	1932–33	5½ months.
Bb	North of Central Bridge	10.11	4.01	6.10	4.86	1919	1 day.
Cc	South of High Bridge	10.97	5.67	5.30	4.45	1856	½ day.
Dd	do	9.92	3.68	6.24	4.41	1927–32	6 years.
Ee	do	10.01	4.01	6.00	4.59	1919	1 day.
Ff	North of High Bridge	9.96	3.91	6.05	4.49	1919	Do.
Gg	Washington Bridge	9.73	3.57	6.16	4.29	1932–33	4½ months.
Hh	North of Washington Bridge	9.77	3.52	6.25	4.21	1932	1 month.
Ii	Opposite Sherman Creek	10.87	5.80	5.07	4.13	1856	1½ days.
Jj	West 207th St. Bridge	9.81	3.81	6.00	3.90	1919	1 day.
Kk	Broadway Bridge	9.16	3.60	5.56	3.96	1886	1½ days.
Kk	do	9.61	3.71	5.90	3.74	1919	1 day.
Kk	do	9.52	3.32	6.20	3.89	1932–33	6 months.

For the Harlem River the greatest difference in longitude between any two points is less than 0.2 degree. Hence, the difference in time of tide between any two points in the Harlem may be derived directly by taking the difference in the lunitidal intervals. The data of table 40 show that the tide is earliest at the Hudson River end and latest at the East River end, the difference between Spuyten Duyvil and Willis Avenue Bridge (stations A and M) being about 0.7 hour.

Throughout the Harlem the duration of rise is about 6.2 hours. But since the high water intervals change somewhat more rapidly

than the low water intervals, the duration of rise changes somewhat in the Harlem, becoming greater in going from the Hudson River end to the East River end. In the first half of the stretch, the duration of rise is about 6.19 hours, while in the second half it is about 6.23 hours. Throughout the Harlem the durations of rise and of fall of tide are approximately equal.

On comparing the results from the observations made in 1856 with those from the recent observations, it is seen that near the Hudson River end the tide has become considerably earlier, about an hour for the high waters and about 2 hours for the low waters. At the East River end, on the other hand, station R shows that there has been but little change in time. This change in time at the northern end is obviously to be ascribed to the improvements made in the Harlem and more especially to the opening up of the ship canal through the tidal marsh near the Hudson River end, which was completed in 1895. And since the change in the time of low water has been the greater, the duration of rise has become greater than it was in 1856.

With regard to the range of tide in the Harlem, the recent observations show that this increases at a very nearly uniform rate from 3.8 feet at station A to 5.1 feet at station S, or at an average rate of 0.2 foot per nautical mile. Compared with the results derived from the 1856 observations, there has been very little change in range. But the data for these early observations are based on but a few days of observations and are, therefore, inadequate for determining this point with precision. This statement likewise applies to the ranges derived from the observations made in 1886.

THE TIDE IN EAST RIVER

East River connects Upper Bay on the west with Long Island Sound on the east. The tide in Upper Bay has a range of about 4½ feet, the lunitidal intervals being approximately 8 hours for the high water and 2 hours for the low water. Toward the western end of Long Island Sound the range of the tide is 7 feet or more, the lunitidal intervals being 11 hours for the high water and 5 hours for the low water. East River, therefore, derives its tide from two bodies of water, the tides in which differ by 3 hours in time and by very nearly 3 feet in range.

This difference in the tides of the two bodies which it connects gives to the tidal movement in East River a character much less uniform than that in rivers with but one tidal entrance. As a result, numerous tidal observations have been made in the East River. It will, therefore, be convenient to divide these observations into two groups, the first covering the stretch of the East River from the Battery to Hell Gate, and the second covering the stretch from Hell Gate to Willets Point. This procedure may be justified, too, by the fact that Hell Gate divides East River into two very nearly equal parts having different hydrographic features—lower East River being a relatively narrow and deep waterway, while upper East River is wider and shallower.

LOWER EAST RIVER

On figure 20 are shown the locations of the stations at which tide observations have been made in lower East River. The data derived from these observations are given in table 41, following. The

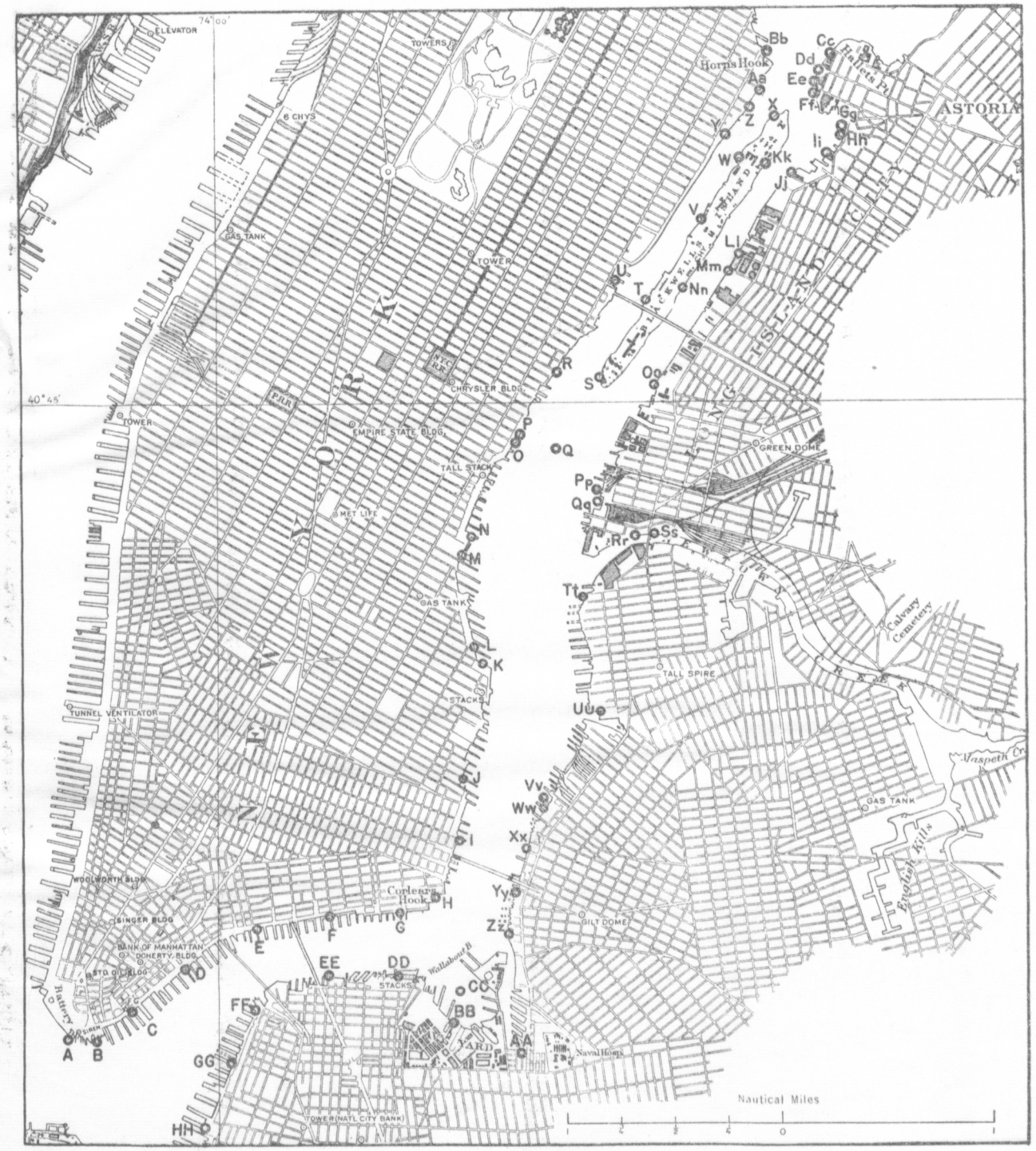

FIGURE 20.—Tide stations, lower East River.

lunitidal intervals and ranges given in this table have been reduced to mean values by comparison with simultaneous observations at some standard tide station like Governors Island or Fort Hamilton.

TABLE 41.—*Tidal data, Lower East River*

(Battery to Hell Gate)

Station	Locality	Lunitidal intervals		Duration of rise	Mean range	Observations	
		HWI	LWI			Year	Length
	WEST SHORE	*Hours*	*Hours*	*Hours*	*Feet*		
A	Barge Office Pier (Battery)	8.24	2.19	6.05	4.45	1921–26	6 years.
B	Whitehall St. (Battery)	8.29	2.19	6.10	4.41	1928–32	5 years.
C	Cuylers Lane	8.34	2.14	6.20	4.42	1932–33	7½ months.
D	Fulton St	8.46	2.26	6.20	4.41	1932–33	Do.
E	Catherine Slip	8.56	2.34	6.22	4.34	1932–33	Do.
F	Jefferson St	8.72	2.34	6.38	4.33	1932–33	5½ months.
G	Jackson St	8.99	2.43	6.56	4.32	1932–33	3½ months.
H	Corlears Hook	9.33	2.78	6.55	4.01	1886	5 days.
I	Rivington St	9.09	2.70	6.39	4.22	1932–33	5 months.
J	E. 5th St	9.19	2.83	6.36	4.18	1932–33	3½ months.
K	E. 17th St	9.35	3.06	6.29	4.22	1932–33	7 months.
L	E. 18th St	9.28	2.97	6.31	4.18	1875	12 days.
M	Bellevue Hospital	9.40	3.20	6.20	4.42	1885	8 days.
N	E. 29th St	9.37	3.12	6.25	4.23	1932–33	7 months.
O	E. 40th St	9.38	3.15	6.23	4.29	1932–33	Do.
P	E. 41st St	9.77	3.33	6.44	4.11	1874	21 days.
Q	Belmont Island	9.58	3.12	6.46	4.26	1921–22	2 years.
R	E. 49th St	9.46	3.18	6.28	4.36	1932–33	6½ months.
S	Blackwells Island (S.W. corner)	9.62	3.24	6.38	4.33	1932–33	1½ months.
T	Blackwells Island (N. of Queensboro Bridge).	9.63	3.32	6.31	4.42	1932–33	3¼ months.
U	E. 61st St	9.63	3.34	6.29	4.37	1932–33	5 months.
V	Blackwells Island (opp. 71st St.)	9.77	3.43	6.34	4.50	1932–33	3 months.
W	Blackwells Island (opp. 79th St.)	9.77	3.59	6.18	4.82	1932	3 days.
X	Blackwells Island (opp. 84th St.)	9.90	3.80	6.10	4.88	1932	Do.
Y	E. 80th St	9.84	3.58	6.26	4.79	1932–33	1¾ months.
Z	E. 84th St	10.10	3.87	6.23	4.90	1886	5 days.
Aa	E. 86th St	10.27	4.15	6.12	4.73	1857	1 month.
Aa	do	9.87	3.43	6.44	4.74	1868	4 days.
Aa	do	9.63	3.47	6.16	4.75	1875	9 days.
Aa	do	9.96	3.80	6.16	4.81	1920–22	2½ years.
Aa	do	9.90	3.79	6.11	4.85	1932–33	4½ months.
Bb	E. 90th St	10.08	3.43	6.65	4.77	1868	2 days.
Bb	do	10.05	3.85	6.20	4.90	1932–33	7 months.
	EAST SHORE						
Cc	Studio St. (Astoria)	10.01	3.82	6.19	4.98	1932–33	5½ months.
Dd	Astoria	8.87	3.12	5.75	4.82	1848	23 days.
Ee	do	9.90	3.62	6.28	4.80	1868	21 days.
Ee	do	10.01	3.78	6.23	4.89	1932–33	9 months.
Ff	do	9.17	3.40	5.77	3.94	1845	9 days.
Gg	Hallets Cove	8.98	3.08	5.90	5.29	1848	20 days.
Gg	do	9.73	3.37	6.36	4.75	1868	2 days.
Hh	do	10.03	3.81	6.22	4.86	1932–33	4 months.
Ii	do	9.95	3.80	6.15	4.91	1885	10 days.
Jj	Gibbs Point	9.92	3.76	6.16	4.76	1932–33	4 months.
Kk	Blackwells Island (opp. Gibbs Pt.)	9.70	3.56	6.14	4.86	1932	4 days.
Ll	Webster Ave. (Long Island City)	9.88	3.43	6.45	4.53	1886	5 days.
Mm	Freeman Ave. (Long Island City)	9.64	3.34	6.30	4.48	1932–33	6½ months.
Nn	Blackwells Island (opp. Harsell St.).	9.64	3.26	6.38	4.45	1932–33	3 months.
Oo	14th St. (Long Island City)	9.55	3.18	6.37	4.38	1932–33	Do.
Pp	3d St. (Long Island City)	9.39	3.06	6.33	4.29	1932–33	3½ months.
Qq	Borden Ave. (Long Island City)	9.72	3.31	6.41	4.14	1886	5 days.
Rr	Newtown Creek (Long Island City).	9.86	3.15	6.71	4.07	1915	1¼ months.

TABLE 41.—*Tidal data, Lower East River*—Continued

Station	Locality	Lunitidal intervals		Duration of rise	Mean range	Observations	
		HWI	LWI			Year	Length
	EAST SHORE—Continued						
		Hours	*Hours*	*Hours*	*Feet*		
Ss	Vernon Ave. (Long Island City)	9.64	3.61	6.03	3.95	1857	6 days.
Ss	do	9.42	3.03	6.39	4.14	1932	1¾ months.
Tt	Dupont St., Brooklyn	9.35	3.17	6.18	4.43	1855	2½ months.
Tt	do	9.39	3.01	6.38	4.25	1932	2 months.
Uu	Quay St., Brooklyn	9.26	3.01	6.25	4.11	1932	2½ months.
Vv	N. 3d St., Brooklyn	9.33	2.92	6.41	4.09	1921–22	2 years.
Ww	N. 2d St., Brooklyn	9.20	2.88	6.32	4.18	1932–33	1½ months.
Xx	S. 2d St., Brooklyn	9.41	2.68	6.73	4.09	1920	2 months.
Yy	S. 6th St., Brooklyn	9.02	3.29	5.73	4.02	1837	3 days.
Zz	S. 10th St., Brooklyn	8.86	2.73	6.13	4.25	1932–33	5 months.
AA	Fleeman St., Brooklyn	8.81	2.63	6.18	4.19	1932–33	4½ months.
BB	Navy Yard Basin, Brooklyn	8.80	2.70	6.10	4.10	1869	2 months.
CC	do	8.95	2.80	6.15	4.16	1855	5 months.
DD	Hudson Ave., Brooklyn	8.88	2.58	6.30	4.25	1932–33	7½ months.
EE	Adams St., Brooklyn	8.74	2.31	6.43	4.39	1932–33	5 months.
FF	Fulton St., Brooklyn	8.55	2.17	6.38	4.42	1932–33	5½ months.
GG	Clark St., Brooklyn	8.25	2.12	6.13	4.48	1932–33	Do.
HH	State St. Brooklyn	8.16	2.12	6.04	4.52	1932–33	7 months.

From the Battery to Hell Gate the greatest difference in longitude between any two points in the East River is about one-tenth of a degree. The difference in time of tide between any two points in East River may therefore be derived directly by taking the difference in the lunitidal intervals of table 41, since the correction for the difference of longitude of one-tenth of a degree is less than 0.01-hour.

Taking the results from the 1932–33 observations, it is seen that tne tide becomes later from the Battery to Hell Gate, the difference between stations A and Bb being 1.8 hours for the high water and 1.7 hours for the low water. This change is at an average rate of about 0.3 hour per nautical mile. But the data of table 41 bring out clearly the fact that for the first half of this stretch the change in time is at a more rapid rate than in the second half. Thus, between stations A and K, the high water changes at a rate of 0.37 hour per nautical mile, and the low water at a rate of 0.29 hour; between stations K and Bb the rates are 0.21 hour for the high water and 0.24 hour for the low water.

The distance between stations A and Aa is 6.3 nautical miles measured along the channel of East River. The average depth of this stretch, measured from mean sea level, is approximately 40 feet. For a progressive wave to traverse this stretch, the formula $r=\sqrt{gh}$ gives 0.3 hour as the time required. The observations give a time difference of 1¾ hours. It follows, therefore, that as regards the time of tide through the lower East River, the movement is not of the progressive wave type.

At the mouth of East River, the durations of rise and fall are very nearly equal. Going upstream the rise becomes somewhat the larger but at the entrance to Hell Gate the durations of rise and fall are again about equal.

The range of the tide in lower East River changes from 4.4 feet at the mouth to 4.9 feet at the entrance to Hell Gate; but this change

does not take place at a constant rate. In fact, for the first 2½-mile stretch from the mouth there is actually a decrease in range, from 4.4 feet to 4.2 feet, or a decrease of 0.08 foot per mile. For the following 3-mile stretch the range increases at the rate of 0.07 foot per mile. In the next stretch of 0.4 mile (from station V to station Y) the increase is 0.3 foot, or at the rate of ¾-foot per mile. In the last half-mile stretch the increase is again at a slower rate, about 0.2-foot per mile. With regard to range, therefore, as well as with regard to time, the tidal movement in the lower East River is not of the progressive-wave type. As will be seen later, the tidal movement in the East River is primarily of the hydraulic type, due to the instantaneous difference in head of water in the two bodies of water which it connects, Upper Bay and Long Island Sound.

For the determination of other ranges at the stations listed in table 41—as for example, the spring, neap, or perigean ranges—we may assume that these ranges at any station of table 41 have the same ratios to the mean range at that station as at Governors Island or at the Battery, given in table 35.

The earlier observations are in most cases of such short duration that exact comparisons with the results of the later series cannot be made. Nevertheless, the indications are clear that the improvements which have been made in the East River have tended to increase the range of the tide.

In Newtown Creek, the tidal waterway which enters East River about a mile south of Blackwells Island, the tide resembles that in East River. In addition to the two stations shown on figure 20, observations were made at two other stations during the 1932–33 survey. One of these was located at Greenpoint Avenue, and the other at Metropolitan Avenue. At these two stations the tide is about a tenth of an hour later than at Station Ss, and the range is about a tenth of a foot greater.

UPPER EAST RIVER

Upper East River, in this publication, is the designation applied to the stretch from Hell Gate to the western entrance of Long Island Sound, a distance of 7½ nautical miles, measured along the usually traveled channels. The stations at which tide observations have been made in this part of East River are shown in figure 21, and the data derived from these observations are given in table 42. The lunitidal intervals and ranges in this table have been corrected to mean values.

The data for the 1932–33 observations show that the time of tide becomes later from the southern entrance of Hell Gate to the eastern end of Rikers Island. In this stretch of 3½ nautical miles the tide becomes later by approximately 1½ hours. In the remaining 4-mile stretch, however, the tide becomes earlier, being about a quarter of an hour earlier at the entrance to Long Island Sound than at the easterly end of Rikers Island.

The durations of rise and fall of tide are approximately equal at the entrance to Hell Gate. But within Hell Gate and throughout the rest of upper East River, the duration of rise is less than that of fall, the values being approximately 5.7 hours and 6.7 hours respectively.

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TABLE 42.—*Tidal data, upper East River*
(Hell Gate to Long Island Sound)

Station	Locality	Lunitidal intervals		Duration of rise	Mean range	Observations	
		HWI	LWI			Year	Length
	NORTH SHORE	*Hours*	*Hours*	*Hours*	*Feet*		
A	Mill Rock	10.05	3.78	6.27	4.93	1931–33	2 years.
B	E. 94th St	10.02	3.76	6.26	5.10	1932	18 days.
C	E. 100th St	10.15	3.82	6.33	4.99	1932–33	2½ months.
D	Wards I (near S. W. end)	9.97	3.65	6.32	5.11	1866	5 days.
D	do	10.17	4.00	6.17	5.06	1932	1 month.
E	Wards I (opp. E. 103d St.)	9.83	3.82	6.01	5.14	1932	5 days.
F	Wards I (opp. E. 108th St.)	9.77	3.75	6.02	5.07	1932	4 days.
G	Wards I (opp. E. 109th St.)	9.70	3.73	5.97	4.89	1932	7 days.
H	Wards I (Little Hell Gate)	9.79	3.51	6.28	4.74	1849	11 days.
I	Bronx Kill (near east end)	11.49	5.82	5.67	6.32	1932	Do.
J	Bronx Kill (east end)	11.81	5.61	6.20	6.80	1919	1 day.
K	Port Morris (E. 132d St.)	11.26	5.46	5.80	6.37	1932–33	4 months.
L	Port Morris (E. 133d St.)	11.59	5.86	5.73	6.32	1921–22	2 years.
M	Port Morris (E. 141st St.)	11.71	5.60	6.11	6.84	1886	4 days.
N	North Brother I (west side)	10.33	5.10	5.23	6.27	1847	1¼ months.
N	do	11.56	5.91	5.65	6.06	1883	4 days.
N	do	11.12	5.44	5.68	5.49	1887	2 days.
N	do	11.30	5.60	5.70	6.55	1932–33	3 months.
N	do	11.30	5.66	5.64	6.47	1933	1 month.
O	North Brother I (south side)	11.32	5.62	5.70	6.62	1932–33	2½ months.
P	Port Morris	11.38	5.55	5.83	6.55	1932–33	5 months.
Q	Rikers I (north end)	11.32	5.50	5.82	6.61	1932–33	4½ months.
R	Rikers I (northeast corner)	11.49	5.78	5.71	6.75	1932–33	1½ months.
S	Hunt Point	11.50	5.85	5.65	6.91	1932	Do.
T	Clason Point	11.34	5.59	5.75	7.01	1932	5 months.
U	Old Ferry Point	11.91	5.78	6.13	7.41	1886	5 days.
V	NE. of Old Ferry Point	11.08	5.68	5.40	7.19	1932	15 days.
W	NW. of Fort Schuyler	11.12	5.60	5.52	7.10	1932	10 days.
X	Fort Schuyler	10.50	5.22	5.28	6.96	1847	2 months.
X	do	11.26	5.67	5.59	7.10	1920–22	2 years.
X	do	11.27	5.58	5.69	7.18	1926–33	4 years.
	SOUTH SHORE						
Y	Willets Point	11.22	5.75	5.47	6.99	1886	1 month.
Y	do	11.30	5.27	6.03	7.09	1891–94	2½ years.
Y	do	11.29	5.53	5.76	7.10	1932–33	2 years.
Z	Whitestone	10.99	5.54	5.45	7.11	1856–86	3 days.
Z	do	11.16	5.49	5.67	7.12	1932	21 days.
Aa	Malba (Powell Cove)	11.17	5.50	5.67	7.01	1932	16 days.
Bb	Tallman I (north end)	11.44	5.61	5.83	6.76	1885	2 days.
Cc	College Point Dry Dock	11.35	5.63	5.72	6.97	1932	3¼ months.
Dd	College Point	11.71	6.84	4.87	6.85	1883	3 days.
Dd	do	11.43	5.70	5.73	6.85	1932–33	5¼ months.
Ee	do	11.85	6.17	5.68	7.21	1886	5 days.
Ee	do	11.72	6.04	5.68	6.64	1922	2 months.
Ee	do	11.64	5.90	5.74	6.67	1933	Do.
Ff	Flushing	11.43	5.66	5.77	6.82	1932–33	6½ months.
Gg	East Elmhurst	11.48	5.70	5.78	6.67	1932	15 days.
Hh	Sanford Point	11.17	5.72	5.45	6.72	1932	24 days.
Ii	North Beach	11.51	5.92	5.59	6.57	1932	7 days.
Jj	Lawrence Point	11.04	5.52	5.52	6.37	1932–33	7 months.
Kk	do	11.40	5.75	5.65	6.55	1868	17 days.
Ll	Winthrop Avenue	11.11	5.43	5.68	6.13	1932–33	4½ months.
Mm	Wolcott Ave	11.05	5.33	5.72	6.27	1886	5 days.
Nn	Ditmars Ave	9.40	3.84	5.56	5.56	1848	Do.
Oo	Wards I (opp. Wolcott Ave.)	10.51	5.56	4.95	6.35	1845	1 day.
Pp	Wards I (Hell Gate Bridge)	10.71	5.35	5.36	5.96	1932	1¼ months.
Qq	Wards I (opp. Potter Ave.)	10.46	5.68	4.78	5.54	1920–22	2½ years.
Rr	Wards I (Negro Point)	10.25	4.95	5.30	5.46	1932	1¼ months.
Ss	Pot Cove (Hoyt Ave.)	11.55	5.73	5.82	6.03	1857	1 month.
Ss	do	11.35	5.52	5.83	6.07	1868	17 days.
Ss	do	10.58	4.62	5.96	5.51	1875	9 days.
Ss	do	10.63	4.67	5.96	5.25	1932	4¼ months.
Tt	Pot Cove	11.06	5.01	6.05	5.63	1885–86	20 days.
Uu	do	10.51	4.56	5.95	5.35	1932	1 month.
Vv	Hallets Point	11.27	5.58	5.69	5.64	1857	14 days.

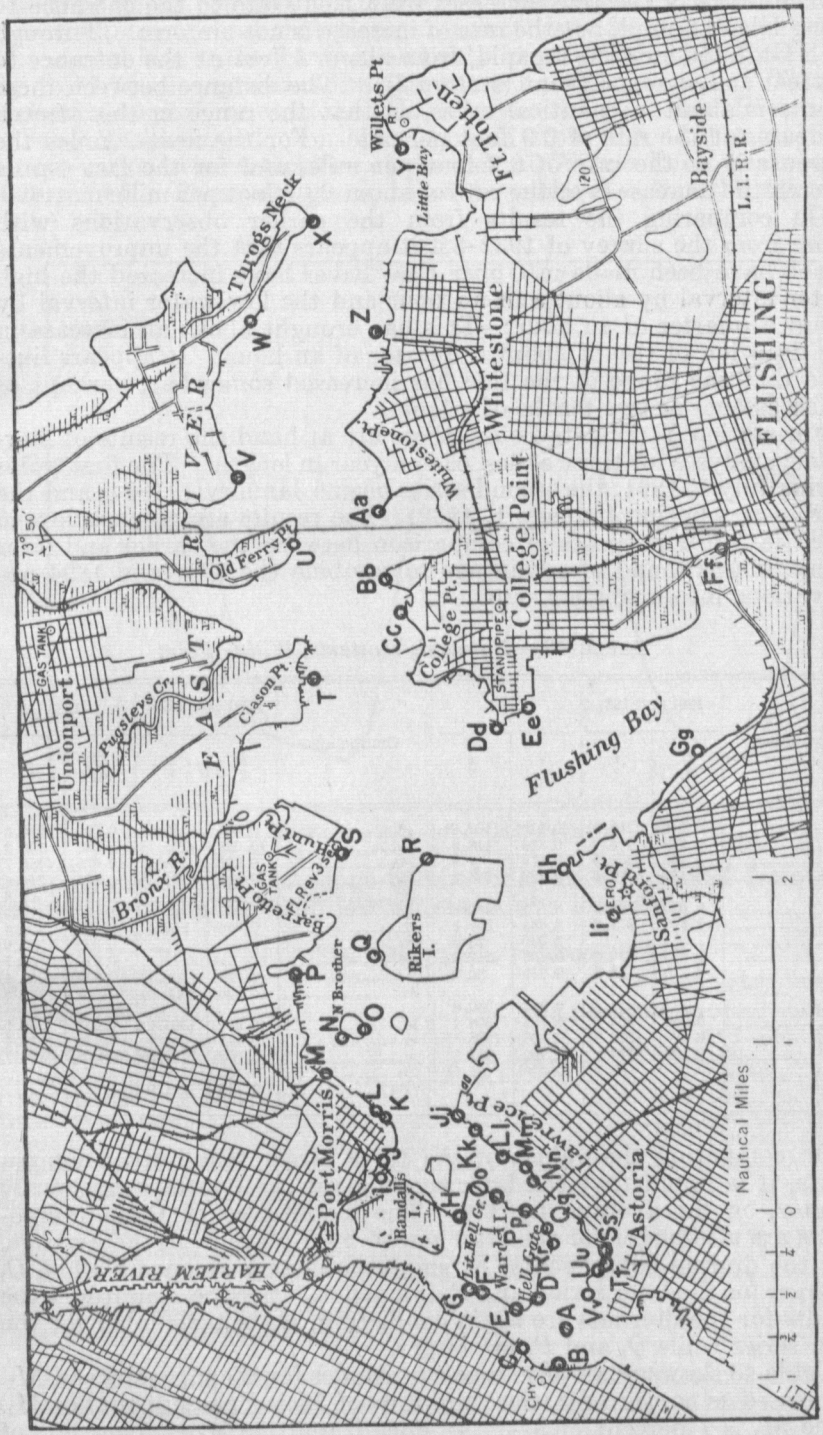

FIGURE 21.—Tide stations, upper East River.

The range of the tide increases from Hell Gate to the entrance to Long Island Sound, but the rate of increase is not uniform. Through Hell Gate the increase is rapid, from about 5 feet at the entrance to 6.4 feet at Lawrence Point (station Jj). The distance between these points is about 1½ nautical miles, so that the range in this stretch increases at the rate of 0.9 foot per mile. For the next 2 miles the increase is at the rate of 0.2 foot per mile, and for the last 4-mile stretch the increase is at the rate of about 0.07 foot per mile.

On comparing the results from the earlier observations with those from the survey of 1932–33, it appears that the improvements which have been made in Upper East River have increased the high water interval by about half an hour and the low water interval by about a quarter of an hour. This has brought about an increase in the duration of rise of about a quarter of an hour. It appears likewise that the range of the tide has increased somewhat, perhaps as much as one- or two-tenths of a foot.

For station Y (Willets Point) there are at hand the results of harmonic analyses for three series, each a year in length. The first series begins July 1, 1891; the second series begins January 1, 1894; and the third series begins January 1, 1932. The results are given below in table 43. For purposes of comparison between the earlier and later series, it was found of advantage to combine the 1891 and 1894 observations into a single group.

TABLE 43.—*Harmonic constants, Willets Point*

Component	1891 and 1894		1932		Component	1891 and 1894		1932	
	H ft.	κ °	*H* ft.	κ °		*H* ft.	κ °	*K* ft.	κ °
J_1	(0.016)	(103.5)	(0.016)	(102.2)	P_1	0.091	133.5	0.096	126.5
K_1	0.339	118.9	0.330	118.9	Q_1	(0.038)	(105.1)	0.056	136.3
K_2	0.146	359.0	0.171	1.9	$2Q$	(0.005)	(180.5)	(0.005)	(185.7)
L_2	0.300	2.6	0.222	323.3	R_2	(0.005)	(352.4)	(0.005)	(354.4)
					S_1	--------	--------	0.037	74.8
M_1	0.020	166.3	0.012	160.6					
M_2	3.649	328.6	3.686	329.3	S_2	0.644	352.4	0.659	354.4
M_3	--------	--------	0.030	23.8	S_4	--------	--------	0.012	222.9
M_4	0.096	210.6	0.106	217.0	S_6	--------	--------	0.010	102.1
M_6	0.210	83.8	0.249	80.2	T_2	(0.038)	(352.4)	(0.039)	(354.4)
					λ_2	(0.026)	(339.6)	0.077	1.8
M_8	--------	--------	0.022	330.9					
N_2	0.744	304.2	0.798	308.7	μ_2	(0.088)	(305.0)	0.010	296.5
$2N$	(0.099)	(279.8)	(0.106)	(288.1)	ν_2	0.112	312.4	0.178	311.4
O_1	0.198	149.7	0.202	152.3	ρ_1	(0.008)	(163.0)	(0.008)	(166.7)
OO	(0.008)	(88.1)	(0.009)	(85.5)	Sa	0.153	110.0	--------	--------
					Ssa	0.113	111.0	--------	--------

On comparing the values of the three larger semidiurnal components, it is found that the later series gives the epochs consistently greater, on the average by 2°.4. The amplitudes of these components are also larger for the later series, by 3 percent on the average. For the diurnal components, K_1 shows no change in epoch, while O_1 is larger for the later series, and P_1 is smaller. For the amplitudes the results for the diurnals are again conflicting, K_1 being smaller for the later series while O_1 and P_1 are larger.

Table 43 shows relatively large amplitudes for the harmonics of M_2. Expressed as percentages, the amplitude of M_4 is 3 percent that of M_2, while M_6 is 7 percent of M_2. At Fort Hamilton M_4 is 2 percent of

M_2 while M_6 is 3 percent. These large harmonics at Willets Point give the tide curve at that place a characteristic form, both the high waters and low waters having relatively long stands as illustrated by figure 22 which represents the tide curve for July 27, 1933. This is a characteristic feature of the tide throughout Upper East River.

From the harmonic constants derived from the 1891 and 1894 series, various characteristics of the tide at Willets Point have been determined. These are given below in table 44. For the sake of

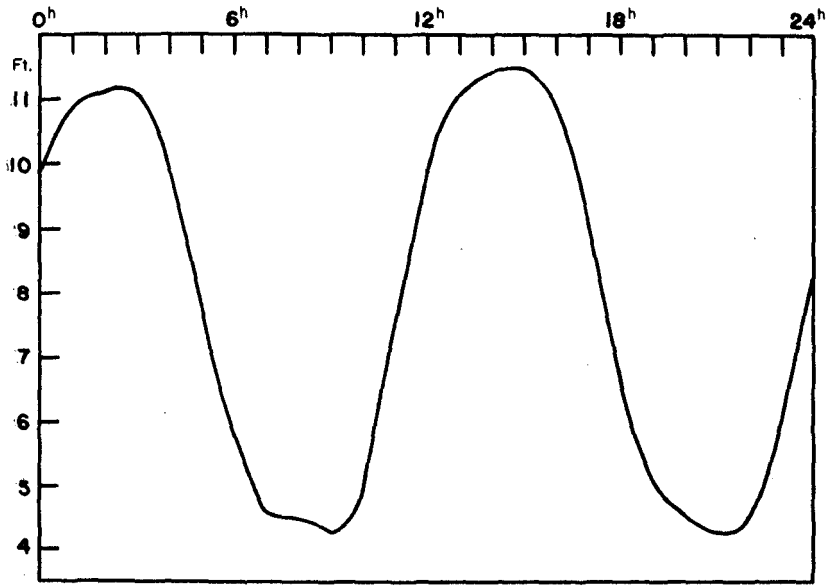

FIGURE 22.—Tide curve, Willets Point.

completeness the mean range of the tide, as determined from the tabulation of the high and low waters, is also included.

TABLE 44.—*Tidal data, Station Y (Willets Point)*

Mean range	feet	7.09
Spring range	do	8.46
Neap range	do	5.61
Perigean range	do	8.15
Apogean range	do	6.28
Great diurnal range	do	7.69
Great tropic range	do	8.21
Phase age	hours	23.4
Parallax age	do	44.8
Diurnal age	do	−28.1
Sequence of tides is HHW to LLW		
Spring range÷mean range		1.19
Neap range÷mean range		0.79
Perigean range÷mean range		1.15
Apogean range÷mean range		0.89
Great diurnal range÷mean range		1.08
Great tropic range÷mean range		1.16

Comparing the data of table 44 with the corresponding data of tables 31 and 35, it is seen that the ratios of the various ranges of the tide to the mean range are practically the same at Sandy Hook, Fort

Hamilton, Governors Island, the Battery, and Willets Point. Throughout New York Harbor, therefore, we may take the ratios of the various ranges at any place to the mean range at that place as follows: Spring range, 1.19; neap range, 0.79; perigean range, 1.20; apogean range, 0.85; great diurnal range, 1.09; great tropic range, 1.12. These are mean values for the five stations listed above. In this connection, however, it is to be noted that while at Sandy Hook, Fort Hamilton, Governors Island, and the Battery, the greatest range is the perigean range, at Willets Point the spring range is the greater.

THE TIDAL MOVEMENT THROUGH EAST RIVER

The discussion of the times and ranges of the tide in East River brings out clearly the fact that the tidal movement in East River is decidedly different from that in a true tidal river, like the Hudson for example. The reason for this is obviously to be found in the fact that the tide in East River comes from both ends, from Upper Bay on the west and Long Island Sound on the east. It has, therefore, been customary to ascribe the peculiar characteristics of the tidal movement in East River to the interference of two tide waves, one entering from Upper Bay and the other from Long Island Sound.

The mechanism of the tidal movement in East River can, however, be most readily understood by regarding the phenomena from the hydraulic point of view; that is, we may regard the changing height of the water in East River as brought about by the fact that part of the time the level of the water in Upper Bay is higher than in Long Island Sound, and part of the time it is lower. In other words, we may regard East River as a channel through which the water flows from the body having temporarily the higher level to the one having the lower level. The height of the water at any point in East River is therefore due to the relative elevations of the water at the two ends.

If we plot the simultaneous heights of the level of the water at the two ends of East River, the lines joining these simultaneous heights will represent the slope of the water surface in the river, and thus the height of the water at the different places along the axis of the river at these times. These slope lines will then permit the time and range of the tide throughout the river to be determined, since the time and height of the high water at any place will be represented by the highest point in the slope lines passing that place, while the time and height of the low water will be indicated by the lowest point in the slope lines.

In figure 23 the simultaneous heights of the water at the two ends of East River are represented for each lunar hour of the tidal rise and fall, time being reckoned from the instant of the moon's passage over the meridian of the Battery. On the vertical line to the left the hourly height of the tide at the Battery is plotted, while on the vertical line to the right the hourly height of the tide at Willets Point is plotted. In both cases the heights are measured from mean sea level, indicated by the heavy horizontal line, the scale of heights in feet being shown to the left. The figures along the vertical lines denote the hours in lunar time to which the indicated heights apply, hours and heights being placed to the left of each vertical line for the rising tide and to the right for the falling tide. The slope lines—the lines joining simultaneous heights—are drawn full when the slope is from Long

Island Sound to Upper Bay and dashed when the slope is in the reverse direction.

If the tidal movement in the East River is due, primarily, to the difference in elevation of the water at the two ends, then the slope lines of figure 23 should indicate the approximate high water and low water lunitidal intervals through the river and also the ranges of the tide. So far as the lunitidal intervals are concerned, the agreement between the data derived from the slope lines and those from tables 41 and 42 is only fair. But in this connection it is to be noted that the constriction of Hell Gate and the subsequent widening of the channel in Upper East River introduce complicating factors which the slope line diagram does not take into account. As regards the range of tide, however, the agreement must be considered very good. Figure 23 shows clearly a decrease in range of tide for a distance of

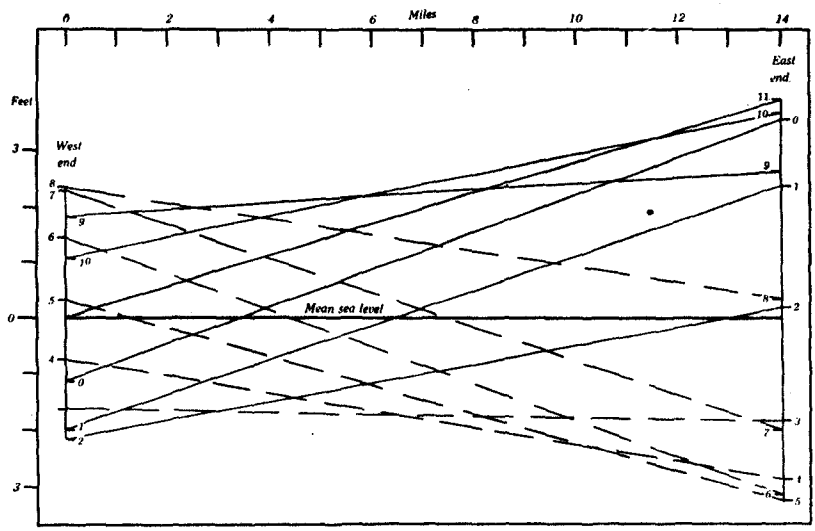

FIGURE 23.—Slope-line diagram, East River.

about 3 miles from the west end of East River, which is one of the peculiar features of the tide in this waterway.

It is obvious that the simple hydraulic considerations upon which figure 23 is based can give only a first approximation to the tidal conditions existing in the East River. The slope lines are drawn as if the channel from Governors Island to Willets Point ran straight for the stretch of 14 miles with unvarying width and depth. No account has been taken of the varying depths in the waterway, of the differences in width, changes in direction, nor of the effect of the water coming through Harlem River. These factors must obviously bring about modifications; but, notwithstanding this, it is seen that the principal tidal phenomena are easily derived by considering the movement of the water in East River as hydraulic. In the chapter devoted to the currents in the East River it will be seen that the characteristics of the current give further proof of the correctness of the view that the tidal movement in the East River is primarily hydraulic in character.

PART II—CURRENTS

TIDAL CURRENTS, GENERAL CHARACTERISTICS

DEFINITIONS

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, fresh-water run-off, and differences in density and temperature. Currents of this class do not exhibit the periodicity of tidal currents.

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 predominate. 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 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.

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 is the one that sets inland or upstream and the ebb current the one that sets seaward or downstream. The change from flood to ebb gives rise to a period of slack water during which the velocity of the current is zero. An example of this type of current is shown in figure 24, which represents the velocity and direction of the current as observed on August 8–9, 1922, in the Narrows, the entrance to New York Harbor.

The curve of figure 24 was drawn by plotting the velocity of the current as observed at the beginning of each hour and drawing a smooth curve that conformed as nearly as possible with the plotted velocities. The northerly setting or flood velocities were plotted above the line of zero velocity and the southerly setting or ebb velocities were plotted below this line. The velocities are given in knots, which is the unit generally used in measuring tidal currents, and represents a velocity 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.

The curve of the reversing current resembles the tide curve. The maximum velocity of the flood current, called the strength of flood, corresponds to the high water of the tide curve, while the maximum velocity of the ebb, called the strength of ebb, corresponds to the low water. The current day, like the tidal day, has a length averaging 24 hours and 50 minutes.

The current curve shown in figure 24 represents the current near the surface in the axis of the channel of the Narrows. 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. But 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

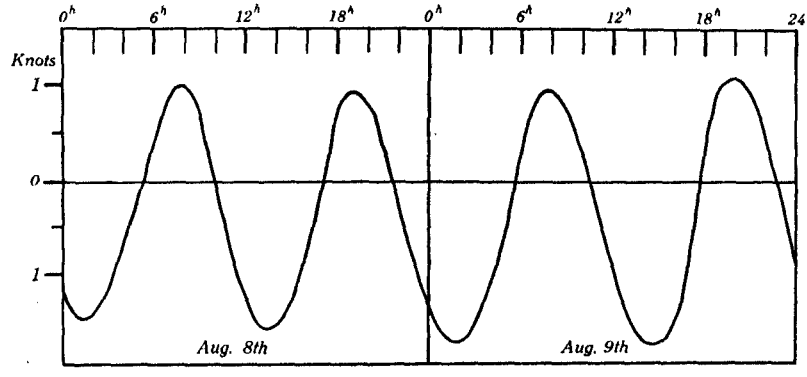

FIGURE 24.—Current curve, the Narrows, New York Harbor, August 8-9, 1922.

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 25 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 25 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 25 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 all times in the

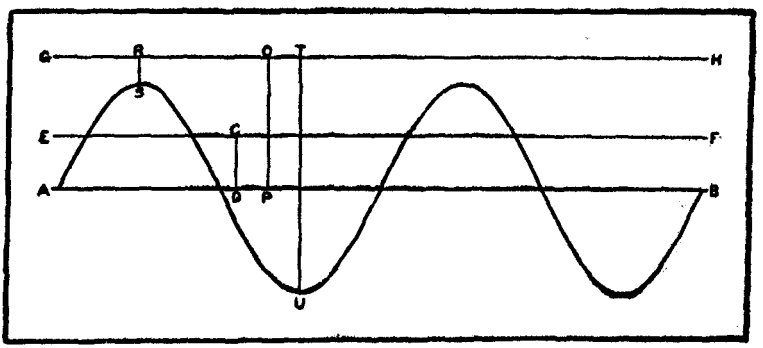

FIGURE 25.—Effect of nontidal current on reversing tidal current.

ebb direction. There will be no slack waters; but at periods 6 hours 12 minutes apart there will occur minimum and maximum velocities represented, respectively, by the lines *RS* and *TU*.

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.

VARIATIONS IN STRENGTH OF CURRENT

Tidal currents exhibit periodic changes in the strength of the current that correspond closely with the periodic changes in range exhibited by tides. Stronger currents than usual come with the spring tides of full and new moon and the weaker currents with the neap tides of the moon's first and third quarters. Likewise, perigean tides are accompanied by strong currents and apogean tides by relatively weaker currents; and when the moon has considerable declination, the currents, like the tides, are characterized by diurnal inequality.

As related to the moon's changing phases, the variation in the strength of the current from day to day is approximately proportional to the corresponding change in the range of the tide. The moon's changing distance likewise brings about changes in the velocity of the strength of the current which is approximately proportional to the corresponding change in the range of the tide; but in regard to the moon's changing declination, tide and current do not respond alike, the diurnal variation in the tide at any place being generally greater than the diurnal variation in the current.

The relations subsisting between the changes in the velocity of the current at any given place and the range of the tide at that place may be derived from general considerations of a theoretical nature. Variations in the current that involve semidiurnal components will approximate corresponding changes in the range of the tide; but for variations involving diurnal components the variation in the current is about half that in the tide.

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. And observations prove this to be the case. Reversing currents may be readily classed under the three types of 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 24, illustrating the current in the Narrows, New York Harbor, may be taken as representative of this type.

The daily type of tidal current is characterized by 1 flood and 1 ebb in a day. The upper diagram of figure 26, which represents the current as observed in the entrance to Mobile Bay, Ala., on May 2–3, 1918, exemplifies this type of current. The mixed type of tidal current exhibits 2 floods and 2 ebbs in a day with considerable inequality between the forenoon and afternoon cycles. The lower diagram of figure 26, which represents the current observed in Rich's Passage, Puget Sound, Washington, on March 29–30, 1917, 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.

RELATION OF TIME OF CURRENT TO TIME OF TIDE

In simple wave motion the times of slack and strength of current bear a constant and simple relation to the times of high and low waters. In a progressive wave the time of slack water comes, theoretically, exactly midway between high and low water and the time

of strength at high and low water; in a stationary wave slack comes at the times of high and low water, while the strength of current comes midway between high and low water.

The progressive-wave movement and the stationary-wave movement are the two principal types of tidal movements. A progressive wave is one whose crest advances, so that in any body of water that sustains this type of tidal movement the times of high and low water progress from one end to the other. A stationary wave is one that oscillates about an axis, high water occurring over the whole area on

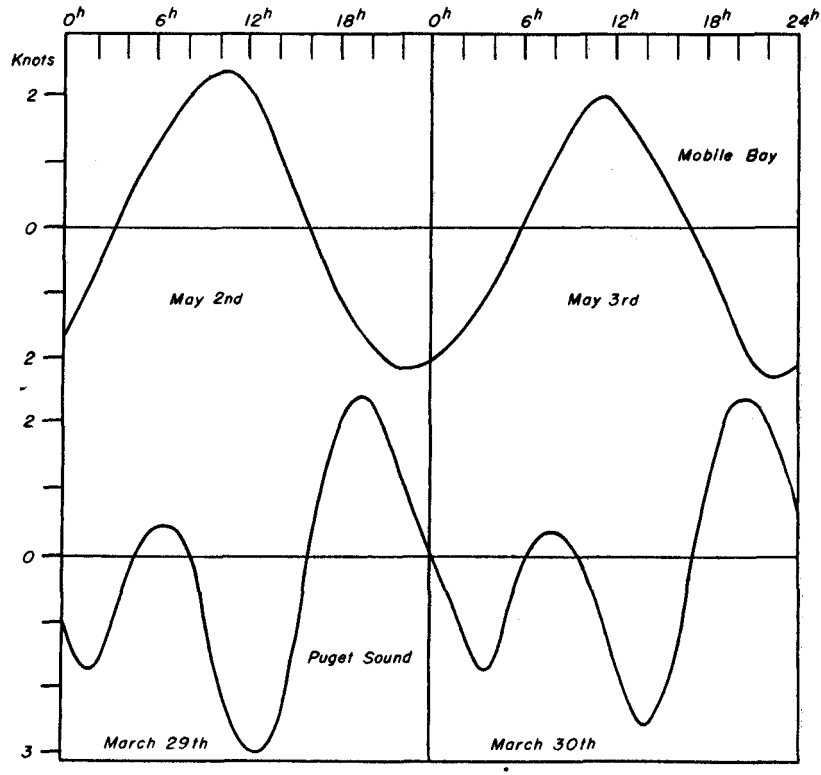

FIGURE 26.—Current curves of daily and mixed types of reversing currents.

one side of this axis at the same instant that low water occurs over the whole area on the other side of the axis.

The tidal movements of coastal waters are rarely of simple wave form; nevertheless, it is very convenient in the study of currents to refer the times of current to the times of tide. And where the diurnal inequality in the tide is small, as is the case on the Atlantic coast, the relation between the time of current and the time of tide is very nearly constant. This is brought out in figure 27, which represents the tide and current curves in the Narrows, New York Harbor, for August 8–9, 1922, the current curve being the dashed-line curve, representing the velocities of the current in the center of the channel, and the tide curve being the full-line curve, representing the rise and fall of the tide at Fort Hamilton, on the eastern shore of the Narrows.

The diagrams of figure 27 were drawn by plotting the heights of the tide and the velocities of the current to the same time scale and to such velocity and height scales as will make the maximum ordinates of the two curves approximately equal. The time axis or axis of X represents the line of zero velocity for the currents and of mean sea level for the tide, the velocity of the current being plotted in accordance with the scale of knots on the right, while the height of the tide reckoned from mean sea level was plotted in accordance with the scale in feet on the left.

From figure 27 it is seen that the corresponding features of the tide and current at this station bear a nearly constant time relation to each other. This approximate constancy in time relations between current and tide is characteristic of tidal waters in which the diurnal inequality is small, and permits the times of slack and of strength of the current to be referred to the times of high and low water. Thus, from figure 27 we find that the strengths of the current came about

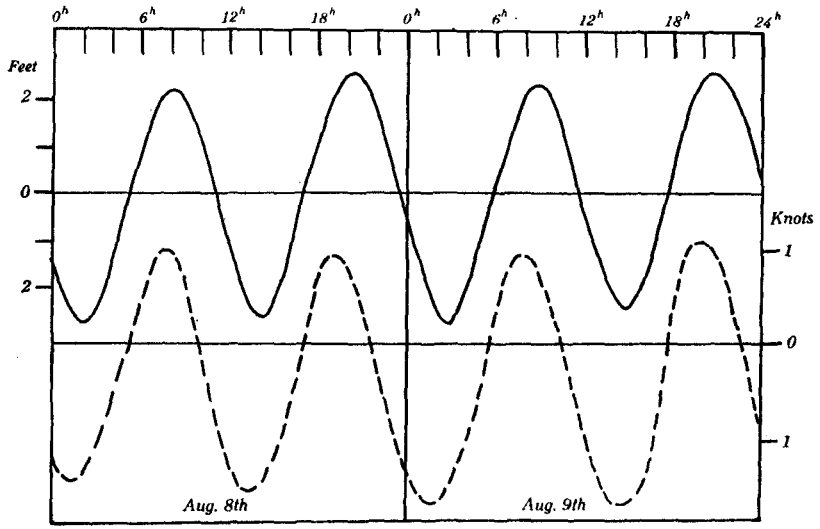

FIGURE 27.—Tide and current curves, the Narrows, New York Harbor, August 8-9, 1922.

an hour before the times of high and low water, while the slacks come about 1¾ hours after high water and 3 hours after low water. In this connection, however, it is to be noted that the time relations between corresponding phases of tide and currents at any place frequently vary in consequence of disturbing effects of wind, weather, and fresh-water run-off.

Quite apart from the disturbing effects of nontidal agencies, the time relations between current and tide are subject to variations in regions where the tide exhibits considerable diurnal inequality; as for example, on the Pacific coast of the United States. This variation is due to the fact, previously mentioned, that the diurnal inequality in the current at any given place is, in general, only about half as great as that in the tide. This brings about differences in the corresponding features of tide and current as between morning and afternoon. However, in such cases it is frequently possible to refer the current at a given place to the tide at some other place with comparable diurnal inequality.

DISTANCE TRAVELED DURING A TIDAL CYCLE

The vertical distance traveled by a floating object during the tidal cycle at any place can be easily determined from the tide curve at that place. For the tide curve represents the successive heights of the surface of the water during the tidal cycle. Hence the vertical distance on the tide curve between a high water and low water gives the vertical distance through which a floating object moved during that tidal cycle.

The close resemblance between the curve of the reversing current and the tide curve might lead one to conclude that from the current curve the horizontal distance traveled by a floating object can be as readily derived as the vertical distance is from the tide curve. The current curve, however, gives the successive speeds of the horizontal movement, and not the successive positions of a floating object. Hence the current curve does not give directly the horizontal distance traveled by a floating object.

If the velocity of the current during a tidal cycle were constant, the horizontal distance traveled by the water particles or by any object floating in the water would be given by multiplying the velocity by the period of duration. The velocity of the current, however, is not constant but changes continually throughout a tidal cycle. The distance traveled by the water particles is therefore the average velocity during the flood or ebb period in question, multiplied by the duration.

The average velocity of the current during any given interval may be determined in several different ways. By measuring the velocity on the current curve at frequent intervals, say every 10 or 15 minutes, the average velocity during the interval is easily derived. Or the area of the surface bounded by the current curve and the zero line of velocities may be determined by means of a planimeter and the average velocity derived by dividing this area by the length of the zero line included within the current curve.

The simplest method, however, consists in making use of the fact that the current curve approximates the cosine curve. And on the cosine curve it is known that the ratio of the mean ordinate to the maximum ordinate is $2 \div \pi$, or 0.637. Since the strength of the tidal current corresponds to the maximum ordinate, it follows that during any given flood or ebb period the average velocity will be the strength of the current multiplied by 0.637.

In the semidaily or mixed types of current the duration of a flood or ebb period approximates 6.2 hours. Hence, in the case of such a current which has a velocity at strength of one knot, a floating object will, during a flood or ebb period, be carried a distance of $0.637 \times 6.2 =$ 3.95 nautical miles, or 24,000 feet. In a daily current of the same strength the distance will be twice as great.

It may be noted that the formula made use of in the preceding calculation can give only approximate results. For not only is the average current derived through the cosine relationship approximate, but what may be even more serious, is the fact that in the formula it is assumed that the floating object during the various stages of its journey will experience the changes in velocity which occur at the

point where it started. Where more exact results are desired, corrections to the above approximate results can be applied.

If the durations of flood and ebb are equal, and also the strengths of the flood and ebb currents, a floating object would be carried a given distance downstream and a like distance upstream. The presence of fresh water in tidal waterways, however, makes both the strength and duration of the ebb greater than the flood, and therefore floating objects tend to be carried out to sea.

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, 2⅔ 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 velocity 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 velocity 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, since high or low water occurs at very nearly the same time over a considerable area, the rate of advance is theoretically very great; but actually there is always some progression present, and this reduces the theoretical velocity considerably.

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 28, which represents the velocity and direction of the current at the beginning of each hour of the forenoon of July 30, 1922, 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 of 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 velocities 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, from a considerable number of observations, 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.

When the velocity 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 velocities of the rotary current are thus related to each other in the same way as slack and strength of the rectilinear current, a minimum velocity following a maximum velocity by an interval of about 3 hours and being

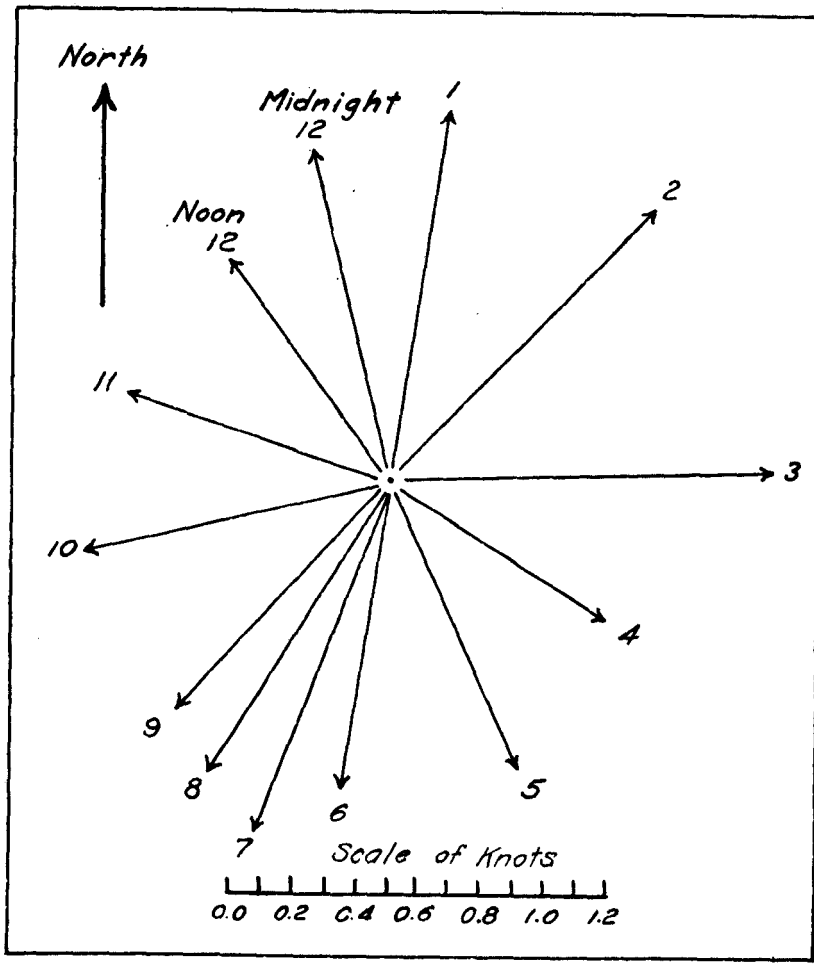

FIGURE 28.—Rotary current, Nantucket Shoals Lightship, forenoon of July 30, 1922.

followed in turn by another maximum after a further interval of 3 hours.

Since the current day corresponds to the tidal day, it is convenient, in determining the average hourly velocity and direction of the rotary current, to make use of the times of high and low water at some nearby place for purpose of reference. In figure 29 the average hourly velocity and direction of the tidal current at Nantucket Shoals Lightship is shown with reference to the times of high and low water at Boston, Mass., *H* standing for the time of high water, and *L* for the time of low water.

In figure 29 the velocity and direction of the current at the beginning of each hour is given by the length and direction of the line from the center of the ellipse to the hour in question. Thus at the time of high water at Boston the current at Nantucket Shoals Lightship has a velocity averaging 0.7 knot, setting N. 85° E.

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

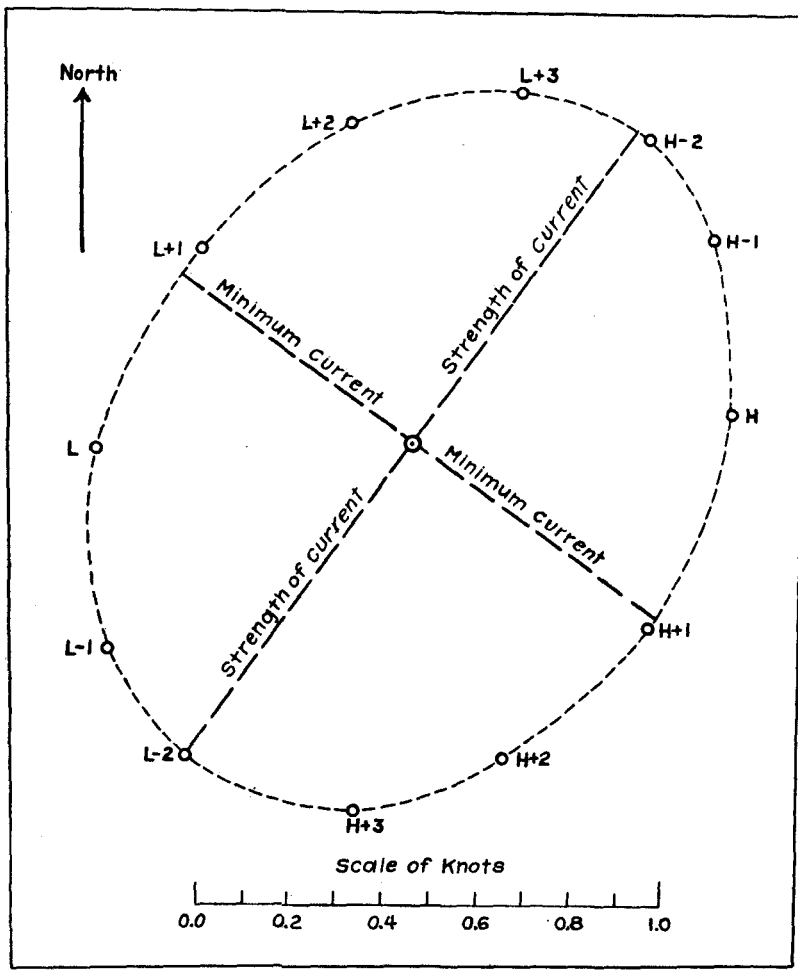

FIGURE 29.—Mean current curve, Nantucket Shoals Lightship.

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.

EFFECTS OF NONTIDAL CURRENTS ON ROTARY CURRENTS

In addition to the periodic variations to which rotary tidal currents are subject, they also exhibit fluctuations arising from the effects of nontidal currents. These effects can most conveniently be studied diagrammatically.

Figure 29 represents the purely rotary tidal current at Nantucket Shoals Lightship. Now suppose that on a given day a wind begins blowing from the northeast such that it produces a wind-driven current of half a knot in a southwesterly direction. For that day, obviously, the velocity and direction of the current at Nantucket Shoals Lightship will be different than represented in figure 29. At 2 hours before low water at Boston, for example, the tidal current sets southwesterly with a velocity of 0.85 knot on the average; but with a nontidal current due to the wind of 0.5 knot setting in the same direction, the velocity of the current now experienced will be $0.85+0.50=1.35$ knots, setting southwesterly. On the other hand, about 2 hours before high water, the current will be setting $0.85-0.50=0.35$ knot northeasterly.

The current conditions at this time may be completely represented by changing the origin of the hourly velocity and direction lines in figure 29 from the center to a point 0.5 knot northeasterly of its previous position. The lines drawn to the various hourly points on the ellipse from this new origin will now represent the velocity and direction of the tidal current as affected by the nontidal current.

The average velocity of the tidal current at the times of flood or ebb strength at Nantucket Shoals Lightship is 0.85 knot. If the

nontidal current due to the wind in the case just considered is greater than 0.85 knot, the origin of the velocity lines would lie outside the ellipse. In that case the current would throughout the day be setting either southeasterly or southwesterly, completely masking the rotary character of the tidal current. By plotting the observed hourly velocities and directions of the current, however, the tidal current would appear in its rotary character. This is illustrated in figure 30 for the current at Frying Pan Shoal Lightship under different wind conditions. This lightship is stationed off the coast of North Carolina about 20 miles southeasterly from Cape Fear. The hourly velocity and direction of the current here is referred to the times of high and low water at Charleston, S. C.

Observations made at this lightship show the tidal current here to be rotary clockwise, the average velocity at strengths of flood and ebb being about a third of a knot and setting northwest and southeast, respectively. During the 5-day period January 29–February 2, 1920, the wind was blowing steadily from the northeast with a velocity of about 30 miles per hour, and the current was observed to be setting at all times southwesterly with a velocity varying from a little less than one half a knot to a little more than three-quarters of a knot. Apparently the current here at this time was altogether nontidal. But if the hourly velocity and direction of the current during this period is plotted, the rotary character of the current is immediately apparent. The upper diagram of figure 30 represents the current conditions during this 5-day period, the velocity and direction of the current at the different hours being given by the length and direction of the arrows drawn from the point P.

Now, although the current at all times during this period set southwesterly, the diagram reveals clearly the existence of a rotary current with a strength of about a third of a knot in a northwest and southeast direction. Furthermore, the diagram shows that the current actually observed consisted of a tidal current which was masked by a nontidal current of greater velocity. In fact the diagram permits the evaluation of this nontidal current. For this must clearly be given by the line joining the point P with the center of the current ellipse, and this is found to have a length of about half a knot and a direction of S. 60° W. This nontidal current was brought about by the northeasterly wind during the 5-day period in question.

About 6 months later, throughout the 7-day period July 14–20, 1920, the current at Frying Pan Shoals Lightship was found to set easterly with velocities ranging from a little less than half a knot to more than a knot. On plotting the observations, as the lower diagram of figure 30 shows, the rotary character of the tidal current comes to light at once. During this 7-day period the wind was blowing steadily from the southwest with a velocity averaging approximately 30 miles per hour. This brought about a wind-driven current setting a little north of east with a velocity somewhat greater than half a knot, and this completely masked the tidal current.

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

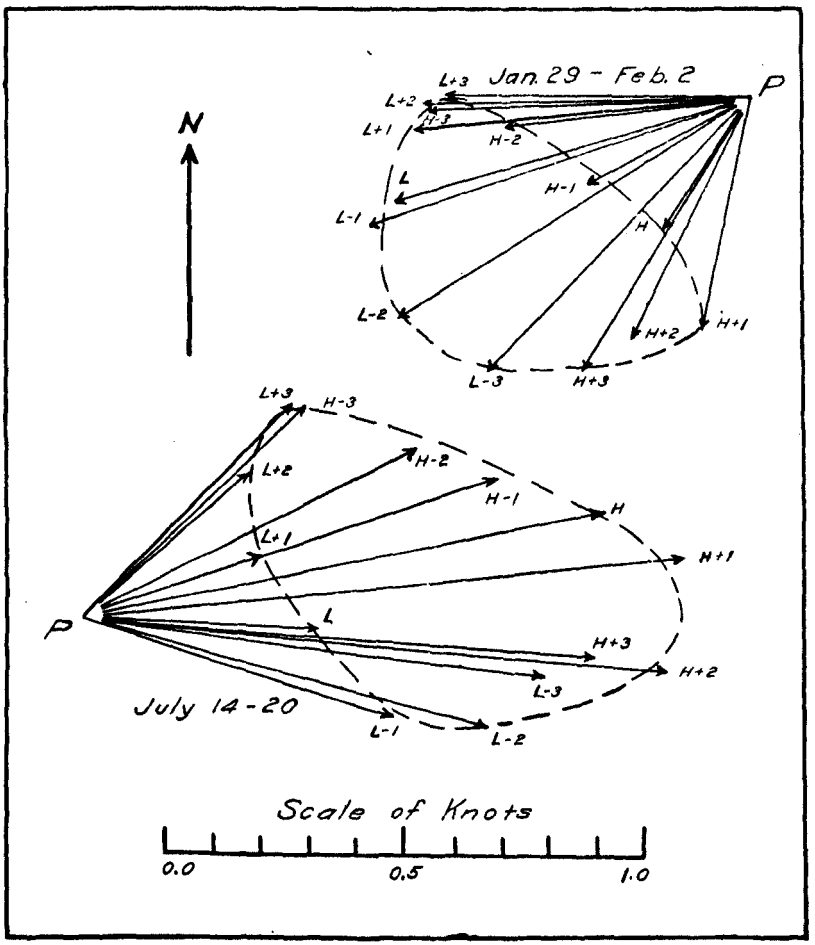

FIGURE 30.—Effect of nontidal current on rotary tidal current, Frying Pan Shoals Lightship.

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.

MEAN VALUES

In the nonharmonic analysis of current observations it is customary to refer the times of slack and strength of current to the times of high and low water of the tide at some suitable place, generally nearby. In this method of analysis the time of current determined is in effect reduced to approximate mean value, since the changes in the tidal current from day to day may be taken to approximate the corresponding changes in the tide; but the velocity of the current as determined from a short series of observations must be reduced to a mean value.

In the ordinary tidal movement of the progressive or stationary wave types the change in the strength of the current from day to day may be taken approximately the same as the variation in the range of the tide. Hence, the velocity of the current from a short series of observations may be corrected to a mean value by multiplying by a factor equal to the reciprocal of the range of the tide for the same period divided by the mean range of the tide. It is to be noted that in this method of reducing to a mean value, any nontidal currents must first be eliminated, and the factor applied to the tidal current alone. This may be done by taking the strengths of the tidal current as the half sum of the flood and ebb strengths for the period in question.

In some places the current, while exhibiting the characteristic features of the tidal current, is in reality a hydraulic current due to differences in head at the ends of a strait connecting two independent tidal bodies of water. East River and Harlem River in New York Harbor and Seymour Narrows in British Columbia are examples of such straits, and the currents sweeping through these waterways are not tidal currents in the true sense, but hydraulic currents. The velocities of such currents vary as the square root of the head, and hence in reducing the velocities of such currents to a mean value the factor to be used is the square root of the factor used for ordinary tidal currents.

THE CURRENT OBSERVATIONS IN NEW YORK HARBOR

The current observations discussed in this publication were made at different times beginning in the previous century. In the earlier observations, the methods used had not become standardized either with regard to instruments or procedure. After the beginning of the present century, however, a standard procedure was established

by the Coast and Geodetic Survey both with regard to observations by meter and by pole. This standard practice is described briefly below.

CURRENT METER

The current meter used is the Price meter with telephone attachment. Observations are made half-hourly at three depths, namely, 0.2, 0.5, and 0.8 of the depth at each station, except in very shallow waters or in water deeper than 100 feet. In water less than 20 feet in depth observations are generally limited to two depths, while in water over 100 feet in depth, the lowest depth for observations is generally limited to 80 feet.

At each of the three depths, the observation interval is 60 seconds, which period is determined by a stop watch. The meter is lowered to the 0.2 depth and the current measured for 60 seconds. It is then lowered to the 0.5 depth and observations made for 60 seconds. Finally, the observations are made at the 0.8 depth. Then before the meter is raised, the observation at the 0.8 depth is repeated; the meter is then raised to the 0.5 depth and a repeat observation made, and finally a repeat observation is made at the 0.2 depth. For each depth, therefore, there is a duplicate set of observations each half hour. In the survey of 1932, the United States Engineer Office adapted the Price meter to give a continuous curve of the velocity. This necessitated the use of three meters at each station, and this method was used at the stations occupied by the observers of the United States Engineer Office.

CURRENT POLE

The current pole used is a 15-foot pole of white pine, 2¾ inches in diameter, which is weighted with sufficient sheet lead at the lower end to submerge 14 feet of its length, leaving 1 foot floating out of water. To this upper end is attached the log line which is graduated for a run of 1 minute; that is, a length of 101 feet 4 inches of log line corresponds to a velocity of 1 nautical mile per hour or 1 knot. The log line is graduated to read tenths of knots, hundredths of a knot being estimated. Observations with the current pole are generally made every hour or every half hour.

Since the current pole is submerged 14 feet, the velocity derived by its use corresponds to the velocity at the depth of 7 feet. In water where the depth is less than 15 feet, a shorter pole is used.

DIRECTION OF CURRENT

With the current pole the direction of the current is determined by means of a compass. With the meter the direction of the current is not determined. In the current survey of 1922, the direction of the subsurface current was determined by means of a bifilar direction indicator.

Essentially the bifilar direction indicator consists of a pipe with a rudder attached at one end, which is suspended horizontally at the desired depth by two fine wires, these wires connecting with an upper horizontal bar that journals at its center in a ball-bearing joint which permits it to move in azimuth. The ball-bearing joint is fixed on an outrigger or davit of the observing vessel, and as the lower bar with its attached rudder takes the direction of the current at the depth to which it is lowered, the upper bar takes the same direction.

TABULATION OF THE CURRENT RECORD

The current observations, whether made with meter or pole, are plotted on cross-section paper to a convenient scale, flood velocities being generally plotted above the line of zero velocities, and ebb velocities below. A smooth curve is then drawn through the plotted points, and from this curve the times of the slack and strength of the current and the velocities at times of strength are then tabulated.

To make the results of the current observations obtained at different times in a given waterway comparable with each other, the times of slack and strength are referred to the times of high and low water at some nearby point. This, in effect, corrects the times of current to mean values approximately. In this publication the times of the current are referred to the times of high and low water at Sandy Hook, N. J.

The velocities of the flood and ebb strengths, as derived from a short series of observations, may differ very considerably from average or mean values. Since the change in the strength of the current is in general proportional to the change in range of tide, the factor for correcting the velocities obtained from a short series may be taken as the ratio of the mean range of the tide to the range of tide during the period of current observations.

It is to be noted, however, that it is the tidal current alone that is to be multiplied by this factor. The current as observed is the resultant of the tidal and nontidal currents, but since the effect of the nontidal current is to increase the ebb velocity by the same amount that it decreases the flood velocity we may eliminate the nontidal current by taking as the tidal current the half sum of the observed flood and ebb strengths, and it is this half sum which is multiplied by the correction factor. For the mean values of flood and ebb strengths, half the velocity of the nontidal current is then subtracted from the strength of flood and added to the strength of ebb.

THE CURRENT IN THE APPROACHES TO LOWER BAY

SURFACE CURRENTS

The stations at which currents were observed in the approaches to Lower Bay are shown on figure 31, and the data derived from these observations for the current near the surface are given in tables 45 and 46. In these tables, the surface current is taken to be the current within the first 7 feet from the surface. The times of slack and strength of current are given with reference to the times of high and low water at Sandy Hook, N. J. The velocities have been corrected to mean values as explained in the preceding section.

The data of table 45 show that the current turns earliest in the shallow regions near shore and latest in Ambrose Channel. South of Ambrose Channel the current sets almost due northwest on the flood, while to the north of the channel the direction of the flood current is a little more to the west. On the ebb, the current in the area south of the channel sets about S. 60° E., while to the north the direction of the ebb current is about S. 55° E.

Along the whole stretch from Sandy Hook to Rockaway Point, table 45 shows the ebb current to have a greater velocity than the flood current, the ebb averaging about 1.4 knots and the flood 1.0 knot. The duration of ebb likewise is greater than that of flood, the ebb

TABLE 45.—*Surface current data, approaches to Lower Bay*

[Referred to times of HW and LW at Sandy Hook]

Station no.	Location	Party of—	Observations		Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
1	Off Sandy Hook	T. A. Craven	November 1855	½	1.2	1.4	N. 70 W.	1.2	6.8	1.9	2.1	S. 65 E.	1.6	5.6
2	do	H. C. Denson	August 1922	1	0.7	3.8	N. 45 W.	1.5	6.0	0.6	2.5	S. 55 E.	1.7	6.4
3	do	do	do	2	1.1	1.8	N. 45 W.	1.1	6.0	1.0	2.8	S. 85 E.	1.9	6.4
4	Ambrose Channel	do	do	4½	1.6	2.4	N. 60 W.	1.8	5.8	1.3	1.6	S. 55 E.	2.3	6.6
5	do	H. L. Marindin	July 1887	½	1.1	2.3	N. 60 W.	1.4	5.8	0.8	1.8	S. 85 E.	1.7	6.6
6	South of Rockaway Point	do	do	¾		2.7	N. 75 W.	1.2		0.4	2.5	S. 75 E.	1.4	
7	do	H. C. Denson	August 1922	1¾	0.4	2.0	N. 80 W.	0.9	6.5	0.8	2.6	S. 40 E.	1.2	5.9
8	do	do	do	1¾	1.0	3.0	N. 50 W.	1.4	5.8	0.7	2.5	S. 40 E.	1.5	6.6
9	do	do	do	1½	0.6	3.1	N. 65 W.	1.1	6.0	0.5	3.0	S. 50 E.	1.6	6.4
10	do	J. M. Hawley	August 1885	½	1.4	2.0	N. 60 W.	0.9	5.7	1.0	2.1	S. 55 E.	1.3	6.7
11	do	do	do	1¼	1.7	2.0	N. 50 W.	0.6	5.0	0.6	2.0	S. 60 E.	1.0	7.4
12	Ambrose Channel	J. R. Goldsborough	October 1845	2	1.7	1.6	N. 40 W.	0.6	5.3	0.8	2.0	S. 70 E.	0.9	7.1
13	do	C. G. Hanus	August 1885	1¾	1.7	1.8	N. 45 W.	0.7	5.4	1.0	1.6	S. 70 E.	0.8	7.0
14	East of Sandy Hook	do	do	1¾	1.5	2.0	N. 45 W.	0.7	6.1	1.5	1.9	S. 60 E.	0.8	6.3
15	do	do	do	1½	1.2	1.7	N. 45 W.	0.6	6.4	1.5	1.5	S. 50 E.	0.7	6.0

averaging 6.5 hours, while the flood averages 5.9 hours. With regard to the time of current, it is seen that the strength of flood comes about 2¼ hours before local high water and strength of ebb about the same time before low water.

The observations listed in table 45 cover short periods of time from half a day to 4½ days. The results derived from such short periods of observations can, therefore, be considered only approximate and this explains the relatively large differences in the results for stations near each other made at different times. At stations 16 and 17, however, observations were made over a number of months, this being

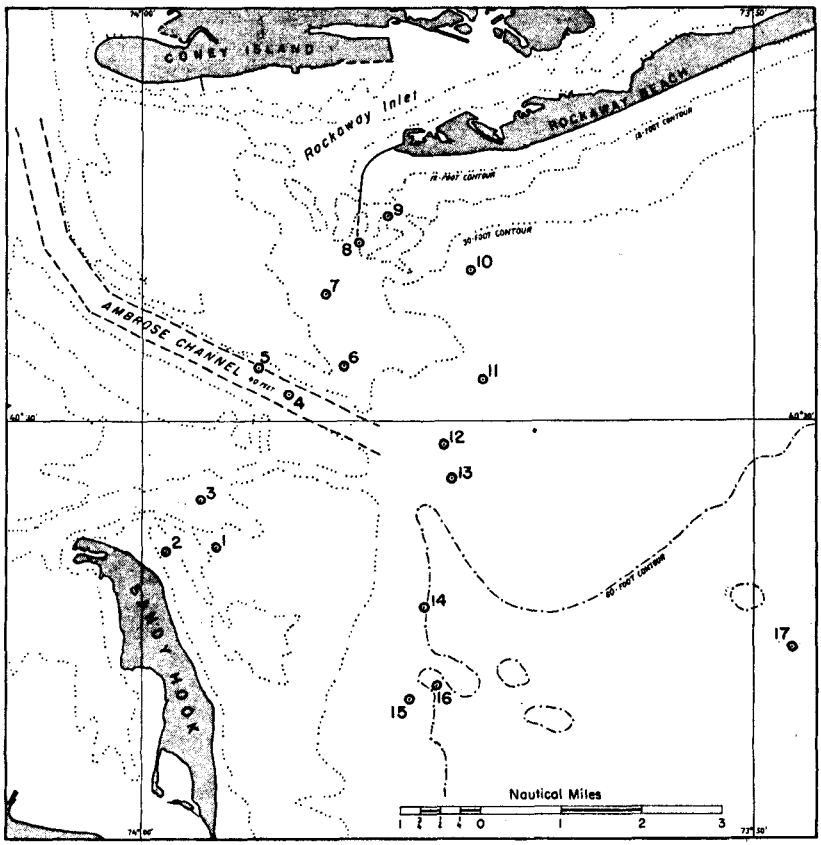

FIGURE 31.—Current stations, approaches to Lower Bay.

made possible by the fact that lightships were anchored at these stations. The results derived from these observations are given in table 46. At both stations the observations were made with a 15-foot pole, submerged for 14 feet of its length so that the data pertain to a depth of 7 feet below the surface of the water. The observations at the two lightships permit a more detailed analysis than is possible for the shorter series of observations at the other stations in the approaches to Lower Bay. By tabulating the hourly velocities and directions of the current, it is found that the current at both lightships is of a rotary character, so that instead of a slack current there is a minimum current.

TABLE 46.—*Current data, Scotland and Ambrose Lightships*

[Referred to times of HW and LW at Sandy Hook, N. J.]

SCOTLAND LIGHTSHIP (STATION 16)

Observations		Minimum before flood		Strength of flood			Minimum before ebb		Strength of ebb			Nontidal current	
Date	Length	Time	Velocity	Time	Velocity	Direction	Time	Velocity	Time	Velocity	Direction	Velocity	Direction
	Days	*Hours after LW*	*Knots*	*Hours before HW*	*Knots*	°	*Hours after HW*	*Knots*	*Hours before LW*	*Knots*	°	*Knots*	°
March–July 1921	140	2.3	0.26	2.1	0.31	N. 83 W.	1.3	0.08	0.7	0.76	S. 30 E.	0.18	S. 10 E.
July–October 1922	100	2.0	0.23	1.8	0.37	S. 85 W.	1.5	0.00	0.7	0.71	S. 32 E.	0.19	S. 1 W.
Weighted mean	--------	2.18	0.25	1.98	0.34	N. 88 W.	1.38	0.05	0.70	0.74	S. 31 E.	0.18	S. 5 E.
AMBROSE LIGHTSHIP (STATION 17)													
March–August 1921	150	2.4	0.03	1.0	0.17	N. 65 W.	1.2	0.03	0.9	0.36	East	0.09	N. 74 E.
July–October 1922	130	2.4	0.04	1.2	0.13	N. 57 W.	1.0	0.04	1.6	0.31	S. 88 E.	0.11	N. 75 E.
Weighted mean	--------	2.40	0.03	1.09	0.15	N. 61 W.	1.11	0.03	1.22	0.34	S. 89 E.	0.10	N. 74 E.

The data of table 46 were derived by tabulating the hourly velocities and directions of the current with reference to the times of high and low water at Sandy Hook, and deriving average values for each tidal hour. These average values were then plotted and the times, velocities, and directions of the minima and maxima determined from the plotted curves. For the minimum currents, however, the directions are not given in table 46, since these directions change rapidly at these times and are subject to wide variations on account of meteorological conditions that happen to prevail. The velocities in table 46 have been reduced to mean values.

It is to be noted that the velocities and directions for the currents at strengths and minima in table 46 are the resultants of both the tidal and nontidal currents. The nontidal current can be determined by averaging the hourly values of the current as observed. This is given in the last two columns of the table. By subtracting the nontidal current from the current strengths and minima, we derive the purely tidal current. At Scotland Lightship, the tidal current at the minima has a velocity of 0.15 knot, while at strength the velocity is 0.5 knot and sets N. 55° W. on the flood and S. 46° E. on the ebb. At Ambrose Lightship the velocity of the minimum tidal current is 0.03 knot and of the strength 0.23 knot, the flood setting N. 82° W. and the ebb S. 86° E.

A plotting of the hourly velocity and direction of the current shows that at Scotland Lightship the current turns clockwise, while at Ambrose Lightship it turns counter-clockwise. In the northern hemisphere, the effect of the deflecting force of the earth's rotation is such as to make the currents offshore rotary in a clockwise sense. The counter-clockwise rotation of the current at Ambrose Lightship must, therefore, be ascribed to its location. The current ellipse derived from the observations at Scotland Lightship for the period March–July 1921 is shown in figure 32. The point C gives the location of the average hourly value of the current; hence the line joining the origin with C gives the velocity and direction of the nontidal current during the period of observations.

For both these lightships there are available the results of an harmonic analysis of an 87-day series of observations made in 1912–13. These are given in table 47. For the harmonic analysis the hourly values of the current were resolved into two directions, magnetic north-and-south and magnetic east-and-west.

TABLE 47.—*Current harmonic constants, Scotland and Ambrose Lightships*

Component	Scotland Lightship, Nov. 6, 1912, to Jan. 31, 1913				Ambrose Lightship, Nov. 5, 1912, to Jan. 30, 1913			
	North-and-south (magnetic)		East-and-west (magnetic)		North-and-south (magnetic)		East-and-west (magnetic)	
	H	κ	H	κ	H	κ	H	κ
	Knots	*Degrees*	*Knots*	*Degrees*	*Knots*	*Degrees*	*Knots*	*Degrees*
M_2	0.350	201	0.383	348	0.045	157	0.197	2
M_4	0.068	263	0.034	54	0.007	58	0.012	147
M_6	0.038	316	0.023	152	0.008	135	0.106	318
S_2	0.044	181	0.053	358	0.039	188	0.044	8
S_4	0.009	83	0.018	158	0.009	314	0.011	196

The ellipse representing any one component can be derived from the harmonic constants above by plotting hourly values of the north-and-south and east-and-west components. The resultant strength of flood or ebb may be derived analytically by means of the formula given on page 94. Since M_2 is the principal component of the tidal current in New York Harbor, the current ellipse for M_2 should approx-

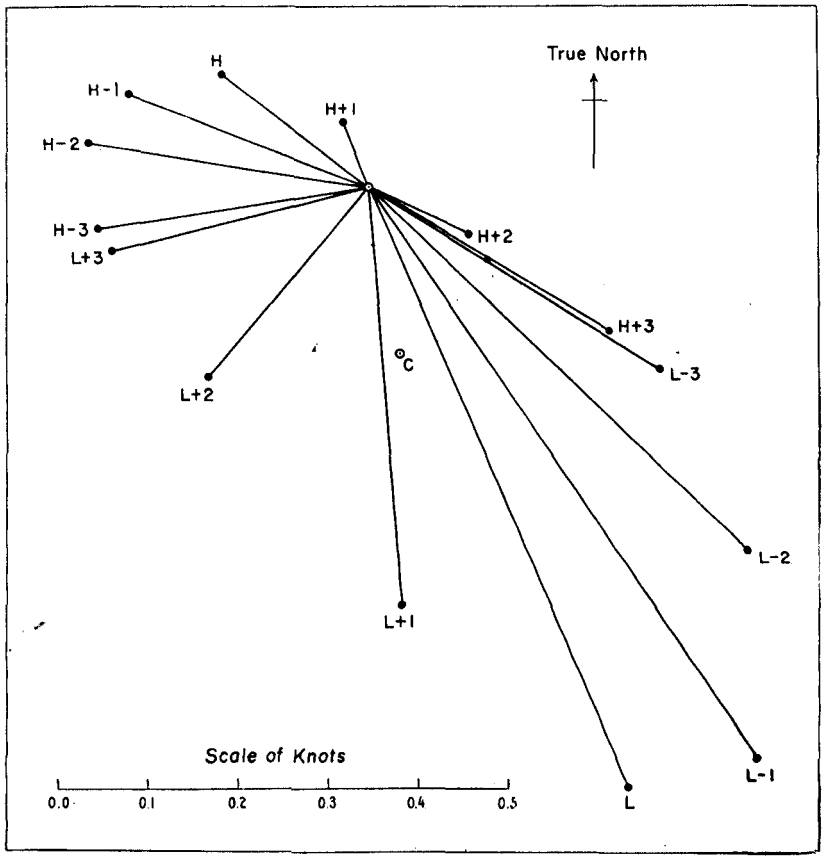

FIGURE 32.—Current ellipse, Scotland Lightship.

imate closely the ellipse derived by plotting the hourly velocities and directions of the current.

The current ellipse for M_2 for Scotland Lightship is shown in figure 33. From this ellipse it is seen that the M_2 component has its strength of flood 1.35 hours before the time of high water at Sandy Hook and sets N. 57° W. with a velocity of 0.50 knot, while the following minimum current, that is the minimum before ebb, comes 1.65 hours after the time of high water and sets N. 33° E. with a velocity of 0.15 knot. Since M_2 alone is taken into account in the current ellipse above, the strength of ebb has the same velocity as that of flood and sets in a direction exactly opposite, and a like relation holds between the two minima.

The current ellipse for M_2 at Ambrose Lightship is shown in figure 34. Here the current is seen to be rotary counter-clockwise, the strength of flood coming 1.2 hours before high water at Sandy Hook and setting N. 88° W. with a velocity of 0.2 knot. The minimum current is very weak, having a velocity of but 0.02 knot.

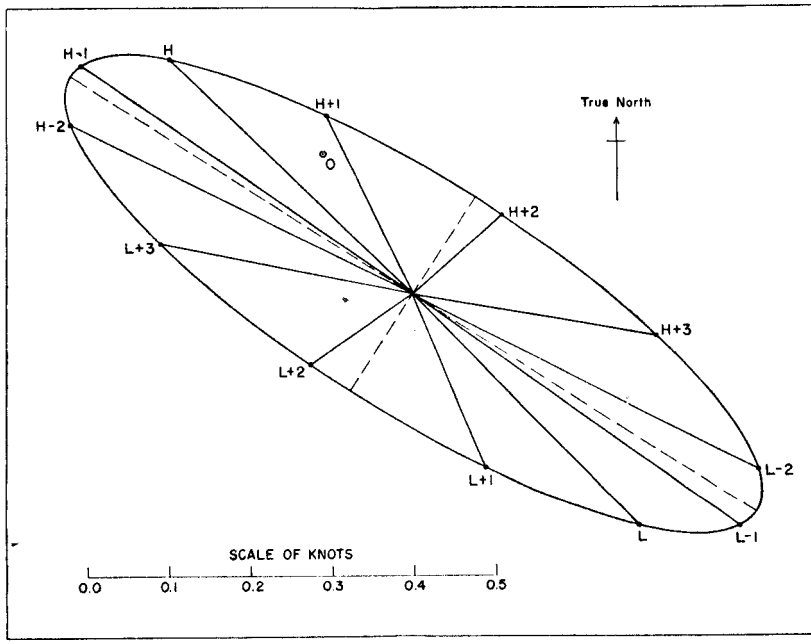

FIGURE 33.—Current ellipse for M_2, Scotland Lightship.

CURRENT DATA, VARIOUS DEPTHS

At several of the stations in the approaches to Lower Bay, current observations were also made with a current meter at 0.2, 0.5, and 0.8 of the depth at the stations. The results derived from these

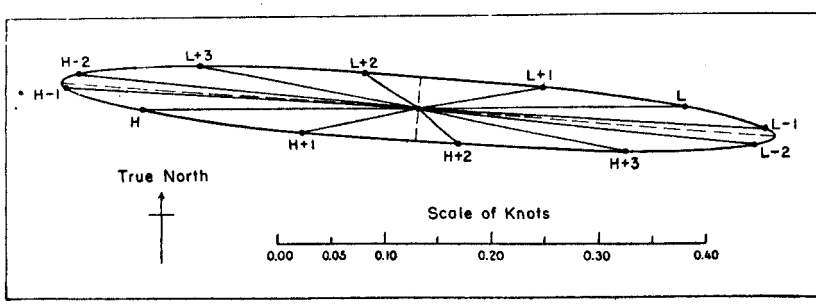

FIGURE 34.—Current ellipse for M_2, Ambrose Lightship.

observations are given in table 48. In this table the times and velocities are given to the second decimal place and the directions to the nearest degree in order to bring out any differences existing in the currents at the different depths. For the sake of comparison, too, data for the surface currents (7-foot depth) are included.

TABLE 48.—*Current data, various depths, approaches to Lower Bay*

[Referred to times of HW and LW at Sandy Hook]

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
2	Off Sandy Hook	H. C. Denson	Aug. 8–9, 1922	1	Pole	7	0.69	3.81	N. 42 W.	1.48	6.03	0.59	2.51	S. 56 E.	1.68	6.39
				1	Meter	6	0.59	3.61		1.93	6.18	0.64	2.51		1.70	6.24
				1	do	14	0.59	4.11		1.60	6.23	0.69	2.01		1.55	6.19
				1	do	24	0.59	3.91		1.27	6.23	0.69	1.96		1.20	6.19
3	do	do	Aug. 7–9, 1922	2	Pole	7	1.09	1.81	N. 46 W.	1.12	6.05	1.01	2.81	S. 83 E.	1.86	6.37
				2	Meter	7	1.06	2.01		1.30	6.06	0.99	2.61		1.99	6.36
				2	do	18	1.12	2.18		1.31	6.02	1.01	2.36		1.43	6.40
				2	do	29	1.12	2.25		1.27	6.02	1.01	2.26		1.10	6.40
4	Ambrose Channel	do	Aug. 8–12, 1922	4½	Pole	7	1.55	2.41	N. 60 W.	1.75	5.84	1.26	1.64	S. 55 E.	2.28	6.58
			Aug. 10–12, 1922	2½	Meter	9	1.89	2.27		1.54	5.76	1.52	1.55		2.50	6.66
				2½	do	20	1.79	2.35		1.38	5.78	1.44	1.57		1.86	6.64
				2½	do	32	1.73	2.57		1.27	5.84	1.44	1.95		1.41	6.58
7	South of Rockaway Point.	do	Aug. 7–9, 1922	1¾	Pole	7	0.39	2.03	N. 78 W.	0.90	6.51	0.77	2.61	S. 38 E.	1.25	5.91
				1¾	Meter	4	0.69	2.13		0.97	6.21	0.77	2.58		1.05	6.21
				1¾	do	10	0.69	2.21		0.91	6.46	1.02	2.26		0.93	5.96
				1¾	do	16	0.69	2.26		0.88	6.43	0.99	2.21		0.84	5.99
8	do	do	do	1¾	Pole	7	0.96	3.04	N. 51 W.	1.41	5.84	0.67	2.51	S. 40 E.	1.49	6.58
				1¾	Meter	5	0.64	3.06		1.60	6.08	0.59	2.74		1.53	6.34
				1¾	do	13	0.64	3.26		1.44	6.11	0.62	2.71		1.46	6.31
				1¾	do	21	0.64	3.46		1.38	6.08	0.59	2.78		1.32	6.34
9	do	do	do	1½	Pole	7	0.59	3.14	N. 66 W.	1.07	6.00	0.46	2.98	S. 48 E.	1.62	6.42
				1¼	Meter	5	0.74	3.31		1.17	5.95	0.56	2.91		1.71	6.47
				1¼	do	13	0.74	3.41		1.27	5.91	0.49	2.96		1.74	6.51
				1¼	do	21	0.74	3.41		1.27	5.91	0.49	3.11		1.54	6.51

The observations at the stations listed in table 48 are too short to determine with precision the differences in the currents at the different depths. In general, however, it appears that the time differences are small, the slacks and the strengths of the current occurring at practically the same time at the different depths. The velocities, likewise, exhibit but relatively small differences as between the different depths, although the strength of ebb appears to be greatest near the surface. At the majority of these stations the ebb strength is greater than the flood strength at all depths, but the difference becomes smaller in the greater depths.

THE CURRENT IN LOWER BAY

SURFACE CURRENTS

Lower Bay is here understood to be the whole body of water lying westward of a line drawn from the eastern tip of Coney Island to Sandy Hook and bounded on the north by the Narrows, on the northwest by Arthur Kill, and on the west by Raritan River. For this body of water figure 35 shows the locations of 48 stations at which observations have been made at various times. The data derived from these observations are given in table 49, and for each station these data refer to the current near the surface. Different methods of observation were employed at different times; but, in general, it may be taken that the data given in this table are based on observations made with a current pole and pertain to the currents at a depth of about 7 feet.

In the table above the times of slack and strength of current are given in hours and tenths and are referred to the times of tide at Sandy Hook, N. J., HW representing the time of high water and LW the time of low water. The velocity of the current is given in knots and tenths and the direction is given to the nearest 5°.

The data of table 49 show that from the entrance to Lower Bay the current becomes later in going northward toward the Narrows; but going westward toward Arthur Kill and Raritan River the current apparently becomes earlier for a short distance and then is very nearly simultaneous over the greater part of Lower Bay and Raritan Bay. Thus, taking the stations along the axis of the bay, the current at stations 14, 15, 19, and 20 comes to strength about 1½ hours before high and low water; at stations 16, 17, and 18 the value is 2⅔ hours; at 41 and 42 it is 2⅔ hours; and at 45, 47, and 48 near the western end of the bay it is likewise about 2⅔ hours.

In the entrance to Lower Bay the velocity of the current at strength averages between 1½ and 2 knots, but within the bay itself the current is much weaker, being less than a knot at strength. In general, the ebb velocity is somewhat greater than the flood, this being brought about by the fresh water draining into the bay. Where variations from these general conditions are shown by the data of table 49, the explanation is generally found in the hydrographic features. Thus, at station 33 the ebb current is greater than the flood current by more than a knot. A glance at the location of this station shows that the western point of Coney Island prevents the main stream of the flood current, which sets toward the Narrows, from embracing station 33 in its sweep; but on the ebb this station lies in the direct path of the main stream from the Narrows, and hence shows the current velocity belonging to that main stream.

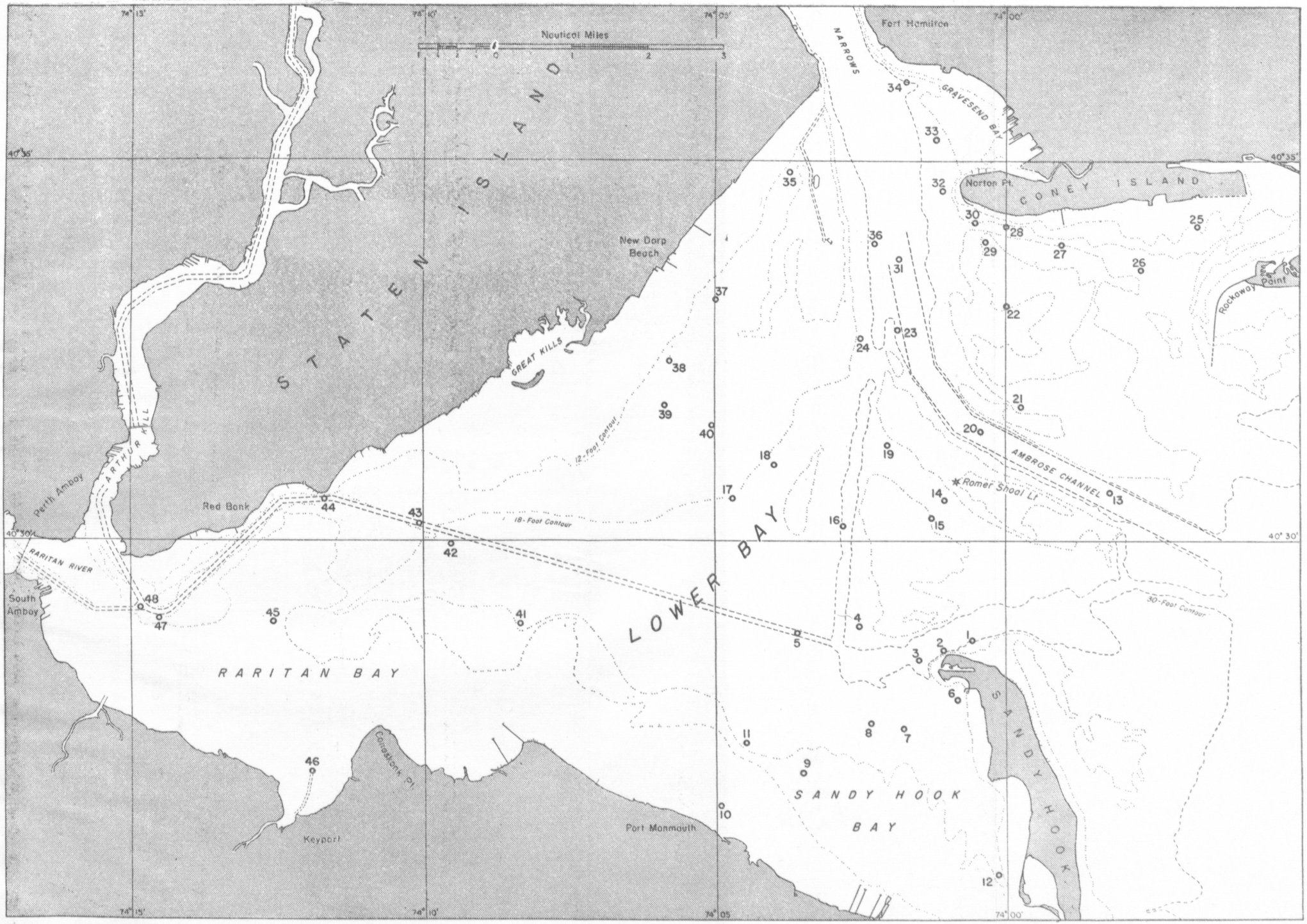

FIGURE 35.—Current stations, Lower Bay.

TABLE 49.—*Surface current data, Lower Bay*

[Referred to times of HW and LW at Sandy Hook]

Station no.	Location	Party of—	Observations		Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
1	Off Sandy Hook	H. L. Marindin	July 1887	1	1.1	3.0		1.6	4.9	−0.1	3.8		2.2	7.5
2	do	I. E. Rittenburg	August 1932	2	0.9	3.2	S. 60 W.	1.4	4.6	−0.6	3.0	N. 60 E.	1.8	7.8
3	do	H. C. Denson	August 1922	1½	0.9	2.1	S. 50 W.	1.2	5.7	0.5	2.8	N. 10 E.	1.4	6.7
4	do	J. M. Hawley	August 1885	½	1.8	3.0	S. 65 W.	0.7	4.8	0.5	2.3	S. 85 E.	0.9	7.6
5	do	I. E. Rittenburg	September 1932	2	1.0	2.6	S. 80 W.	0.6	5.5	0.4	2.6	N. 85 E.	0.6	6.9
6	Sandy Hook Bay	do	June 1932	2	0.4	4.3	S. 40 E.	0.2	2.8	−2.9	4.6	N. 35 W.	0.4	9.6
7	do	H. Mitchell	July 1856	½	0.7	3.2	S. 40 E.	0.5	3.5	−1.9	3.9	N.	0.7	8.9
8	do	do	do	1½	0.9	3.1	S. 65 W.	0.4	3.8	−1.4	4.8	N. 70 E.	0.7	8.6
9	do	do	do	½	−0.1	1.4	N. 80 W.	0.5	6.5	0.3	3.6	S. 80 E.	0.3	5.9
10	do	do	do	½	−0.1	2.6	S. 85 W.	0.5	6.3	0.1	3.8	N. 25 E.	0.3	6.1
11	do	I. E. Rittenburg	August 1932	2	1.1	2.4	N. 80 W.	0.4	6.2	1.2	1.9	N. 85 E.	0.2	6.2
12	do	do	do	2	3.7	1.0	S.	0.1	2.9	0.5	0.3	N. 10 W.	0.5	9.5
13	Middle of Bay	H. L. Marindin	July 1887	1¾	1.5	2.2	N. 70 W.	1.3	5.6	1.0	1.6	S. 60 E.	1.8	6.8
14	do	do	do	1	1.3	2.0	N. 50 W.	1.6	5.9	1.1	1.0	S. 50 E.	1.5	6.5
15	do	T. A. Craven	August 1855	½	1.3	2.0	N. 50 W.	0.8	6.3	1.5	1.7	S. 60 E.	1.4	6.1
16	do	J. M. Hawley	August 1885	1½	0.6	3.0	S. 80 W.	0.7	6.0	0.5	2.4	E.	0.6	6.4
17	do	do	do	½	0.7	3.2	S. 70 W.	0.9	6.2	0.8	2.0	S. 80 E.	0.8	6.2
18	do	H. C. Denson	August 1922	1½	0.0	3.1	S. 70 W.	1.0	6.3	0.2	2.7	S. 80 E.	0.6	6.1
19	do	T. A. Craven	September 1855	½	1.8	1.3	N. 45 W.	0.8	6.1	1.8	1.7	S. 40 E.	0.8	6.3
20	do	H. L. Marindin	June 1887	2	2.0	1.7	N. 60 W.	1.5	5.5	1.4	1.1	S. 50 E.	1.6	6.9
21	do	do	do	2	1.1	2.3	N. 70 W.	1.5	6.1	1.1	1.3	S. 60 E.	1.6	6.3
22	do	W. G. Cutter	August 1885	1	1.1	2.5	N. 75 W.	1.2	6.2	1.2	1.5	S. 75 E.	1.6	6.2
23	do	do	do	1	2.5	1.7	N. 30 W.	1.0	4.7	1.1	0.3	S.	1.7	7.7
24	do	H. C. Denson	August 1922	1½	3.7	0.1	N.	0.9	5.0	2.6	−0.2	S. 10 W.	1.3	7.4
25	Off Coney Island	E. B. Thomas	September 1881	½	−0.3	3.4	N. 40 W.	0.4	6.0	−0.4	4.0	S. 85 E.	0.3	6.4
26	do	W. P. Elliot	May 1889	1	1.0	2.1	N. 70 W.	1.1	6.9	1.8	1.8	S. 70 E.	1.2	5.5
27	do	do	do	2½	0.4	2.7	N. 85 W.	2.0	7.2	1.5	2.3	S. 85 E.	1.8	5.2
28	do	H. Mitchell	August 1858	½	1.0	2.3	N. 85 W.	2.0	6.6	1.5	2.1	N. 85 E.	1.9	5.8
29	do	W. P. Elliot	May 1889	1	1.2	2.3	N. 75 W.	1.9	6.2	1.3	2.0	S. 70 E.	1.7	6.2
30	do	I. E. Rittenburg	October 1932	2	1.3	1.5	N. 70 W.	1.1	6.5	1.7	1.6	S. 80 E.	1.2	5.9

TABLE 49.—*Surface current data, Lower Bay*—Continued

Station no.	Location	Party of—	Observations		Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
31	Off Coney Island	H. Mitchell	August 1858	9	3.4	0.4	N. 10 W.	0.9	5.0	2.3	0.0	S. 10 E.	2.0	7.4
32	do	H. C. Denson	August 1922	1	2.2	2.1	N. 30 W.	1.1	4.8	0.9	0.8	S.	1.8	7.6
33	Gravesend Bay	do	do	1	3.6	0.8	N. 75 W.	0.5	3.4	0.9	0.6	S. 25 E.	1.7	9.0
34	do	I. E. Rittenburg	October 1932	½	0.7	2.0	N. 50 W.	0.9	6.4	1.0	2.9	S. 80 E.	0.7	6.0
35	Off Staten Island	H. C. Denson	August 1922	1	0.9	2.3	N. 20 E.	0.9	7.1	1.9	1.7	S. 30 W.	0.8	5.3
36	do	T. A. Craven	August 1855	½	2.4	0.5	N. 10 E.	1.2	5.8	2.5	−0.1	S. 15 W.	2.2	6.6
37	do	H. Mitchell	June 1859	1	1.8	0.7	N. 20 E.	0.4	7.2	2.9	0.1	S. 45 W.	0.3	5.2
38	do	I. E. Rittenburg	July, August 1932	2	−1.9	4.9	S. 45 W.	0.2	4.9	−3.1	5.9	N. 30 E.	0.7	7.5
39	do	H. Mitchell	July 1872	½	−1.8	4.5	S. 55 W.	0.4	5.9	−2.0	4.4	N. 70 E.	0.5	6.5
40	do	do	do	½	−1.0	1.9	S. 60 W.	0.3	7.3	0.2	2.8	N. 80 E.	0.4	5.1
41	Raritan Bay	I. E. Rittenburg	August, September 1932.	2	0.8	2.8	S. 85 W.	0.6	5.6	0.3	2.5	N. 70 E.	0.6	6.8
42	do	H. C. Denson	August 1922	2	0.4	2.9	W.	0.6	6.8	1.1	2.5	S. 85 E.	0.4	5.6
43	do	I. E. Rittenburg	August 1932	2	−0.1	2.5	N. 85 W.	0.5	7.4	1.2	2.9	N. 75 E.	0.5	5.0
44	do	do	September 1932	2	1.3	3.0	N. 85 W.	0.7	5.2	0.4	2.4	N. 80 E.	0.6	7.2
45	do	do	do	2	1.0	2.8	N. 80 W.	0.6	5.8	0.7	2.5	N. 80 E.	0.5	6.6
46	do	do	do	2	0.5	3.0	S. 25 W.	0.3	7.4	1.8	2.3	N. 15 W.	0.2	5.0
47	do	H. C. Denson	August 1922	1	0.9	2.9	N. 80 W.	0.7	6.5	1.3	1.9	E.	1.2	5.9
48	do	I. E. Rittenburg	June 1932	2	1.0	2.3	N. 75 W.	0.7	6.1	1.0	3.2	S. 65 E.	0.9	6.3

Between stations 37 and 38, off Staten Island, the flood and ebb currents change directions. At station 37 and in the region northward the flood sets northeasterly and the ebb southwesterly, while at station 38 and in the region southwestward the flood sets southwesterly and the ebb northeasterly. As the terms "flood" and "ebb" are ordinarily used, the flood current is the one that sets inland or upstream and the ebb current the one that sets seaward or downstream. In tidal rivers there can generally be no question as to which direction is upstream and which downstream; but in a case like that of the region in the vicinity of stations 37 and 38 the terms "upstream" and "downstream" or "inland" and "seaward" are no longer precise, and it therefore becomes necessary to define flood and ebb in terms other than that of direction.

From a consideration of the relation of current to tide both in the progressive-wave and stationary-wave types of tidal movement the flood current may be defined as the one that attains its strength on a rising tide, while the ebb current may be defined as the one that attains its strength on a falling tide. And it is to be noted that these definitions of flood and ebb, based on time relations of current to tide, agree with the ordinary use of these terms in cases where no ambiguity arises from the definition based on direction.

From table 32 it is evident that the time of tide in the vicinity of stations 37 and 38 is practically the same as that at Sandy Hook. Hence HW and LW in table 49 may be taken as representing not only the times of high and low water at Sandy Hook but also the times of local high and low water in the vicinity of stations 37 and 38, and the data of table 49 show that the strength of the northeasterly current comes on a rising tide at station 37 and on a falling tide at station 38. At the former station, therefore, the northeasterly current is the flood current, while at the latter station it is the ebb current.

Since the time of tide throughout Lower Bay differs but little from that at Sandy Hook, table 49 may be taken as giving directly the relations of the current at the various stations to local tide. For more accurate determinations use may be made of the data in table 32.

As regards the durations of flood and ebb in Lower Bay, table 49 shows that as a rule the ebb has the greater duration, and this was to be expected because of the fresh-water discharge through Lower Bay. Stations 26 to 30, near Coney Island, stand out markedly different with flood durations greater than the ebb. Here, too, it would appear that the location of the stations with respect to the main stream of the current explains this departure from the general conditions prevailing in Lower Bay. On the flood these stations are in the path of the main stream of the current, while on the ebb Coney Island cuts them off from the main stream issuing through the Narrows. A similar explanation probably accounts for the greater flood duration at stations 35 and 37. Within Sandy Hook Bay, near the shore of Sandy Hook, the ebb has an exceptionally long duration, about 9 hours, while the flood runs for but 3½ hours.

CURRENT DATA, VARIOUS DEPTHS

In the observations made in the years 1922 and 1932, the subsurface currents were also investigated, current meters being used for this purpose. These subsurface observations were made at three depths, 0.2, 0.5, and 0.8 of the depth at each station. The results of these observations, with the velocities reduced to mean values, are shown in table 50. The times are referred to high and low water at Sandy Hook, intervals and velocities being given to the second decimal place to bring out the differences existing in the current at the different depths.

TABLE 50.—*Current data, various depths, Lower Bay*

[Referred to times of HW and LW at Sandy Hook]

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
2	Off Sandy Hook	I. E. Rittenburg	Aug. 22-24, 1932	2	Pole	7	0.91	3.22	S. 59 W.	1.40	4.60	−0.62	2.99	N. 62 E.	1.80	7.82
				2	Meter	11	1.01	3.02		1.50	4.90	−0.22	2.99		2.00	7.52
				2	do	28	1.01	2.42		1.60	5.42	0.30	2.99		1.90	7.00
				2	do	44	0.51	2.42		1.60	6.32	0.70	2.69		1.70	6.10
3	do	H. C. Denson	Aug. 9-11, 1922	1½	Pole	7	0.89	2.06	S. 50 W.	1.15	5.73	0.49	2.81	N. 10 E.	1.38	6.69
				1½	Meter	11	0.96	2.06		1.42	5.63	0.46	3.24		1.43	6.79
				1½	do	26	0.92	2.61		1.25	5.93	0.72	2.78		1.35	6.49
				1½	do	42	0.89	2.71		1.10	6.00	0.76	3.24		1.27	6.42
5	do	I. E. Rittenburg	Sept. 12-14, 1932	2	Pole	7	1.01	2.62	S. 83 W.	0.60	5.52	0.40	2.59	N. 86 E.	0.60	6.90
				2	Meter	6	1.01	2.72		0.50	5.32	0.20	2.59		0.60	7.10
				2	do	15	1.01	2.72		0.60	5.32	0.20	2.59		0.50	7.10
				2	do	24	0.91	2.92		0.50	5.52	0.30	2.79		0.40	6.90
6	Sandy Hook Bay	do	June 20-22, 1932	2	Pole	7	0.41	4.32	S. 42 E.	0.20	2.80	−2.92	4.59	N. 37 W.	0.40	9.62
				2	Meter	5		4.52		0.20			4.09		0.40	
				2	do	12		4.42		0.30			3.79		0.40	
				2	do	20		3.92		0.40			3.09		0.40	
11	do	do	Aug. 24-26, 1932	2	Pole	7	1.11	2.42	N. 81 W.	0.40	6.22	1.20	1.89	N. 83 E.	0.20	6.20
				2	Meter	5		2.82		0.50			1.79		0.40	
				2	do	15		3.02		0.50			2.19		0.50	
12	do	do	do	2	Pole	3½	3.71	1.02	S. 2 E.	0.10	2.92	0.50	0.29	N. 9 W.	0.50	9.50
				2	Meter	4		0.52		0.40			0.29		0.50	
				2	do	16		0.52		0.40			0.29		0.40	
18	Middle of Bay	H. C. Denson	Aug. 9-11, 1922	1½	Pole	7	−0.01	3.11	S. 70 W.	0.95	6.33	0.19	2.71	S. 81 E.	0.57	6.09
				1½	Meter	5	−0.04	3.26		1.15	6.83	0.66	3.28		0.73	5.59
				1½	do	12	−0.04	3.27		0.98	6.83	0.66	3.28		1.00	5.59
				1½	do	19	−0.04	3.36		0.80	6.83	0.66	3.44		0.95	5.59
24	do	do	do	1½	Pole	7	3.76	0.11	N. 1 E.	0.85	4.99	2.62	−0.19	S. 10 W.	1.27	7.43
				1½	Meter	5	4.09	−0.06		0.83	4.46	2.42	0.01		1.28	7.96
				1½	do	12	4.02	0.34		0.65	4.40	2.29	0.31		1.05	8.02
				1½	do	19	3.86	0.54		0.55	4.36	2.09	0.84		0.77	8.06

TABLE 50.—*Current data, various depths, Lower Bay*—Continued

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
30	Off Coney Island	I. E. Rittenburg	Oct. 3-5, 1932	2	Pole	7	1.31	1.52	N. 67 W.	1.10	6.52	1.70	1.59	S. 78 E.	1.20	5.90
				2	Meter	6	1.51	1.12		1.20	6.32	1.70	1.69		1.20	6.10
				2	do	14	1.41	1.62		1.10	6.42	1.70	1.79		1.10	6.00
				2	do	22	1.51	1.32		1.00	6.32	1.70	1.49		1.00	6.10
32	do	H. C. Denson	Aug. 11-12, 1922	1	Pole	7	2.14	2.11	N. 28 W.	1.14	4.83	0.84	0.76	S.	1.76	7.59
				1	Meter	5	2.19	2.76		0.97	4.88	0.94	0.26		1.97	7.54
				1	do	12	2.19	2.21		1.33	5.08	1.14	1.01		1.75	7.34
				1	do	19	1.99	2.36		1.29	5.28	1.14	1.41		1.49	7.14
33	Gravesend Bay	do	do	1	Pole	7	3.59	0.81	N. 75 W.	0.47	3.38	0.84	0.61	S. 26 E.	1.70	9.04
				1	Meter	6	3.64	0.66		0.69	3.63	1.14	−0.09		1.61	8.79
				1	do	15	3.54	0.66		0.68	3.73	1.14	0.01		1.30	8.69
				1	do	22	3.49	0.66		0.74	3.88	1.24	0.16		1.01	8.54
34	do	I. E. Rittenburg	Oct. 5, 1932	½	Pole	7	0.71	2.02	N. 50 W.	0.90	6.42	1.00	2.89	S. 80 E.	0.70	6.00
				½	Meter	6		1.12		0.80			2.09		0.70	
				½	do	15		1.22		0.90			1.99		0.90	
				½	do	24		1.22		0.90			2.09		0.70	
35	Off Staten Island	H. C. Denson	Aug. 11-12, 1922	1¼	Pole	7	0.89	2.26	N. 18 E.	0.88	7.16	1.92	1.66	S. 30 W.	0.80	5.26
				1¼	Meter	4	1.24	2.51		0.88	6.71	1.82	1.76		0.80	5.71
				1¼	do	9	1.14	2.61		1.00	6.81	1.82	1.71		0.70	5.61
				1¼	do	14	0.84	2.46		0.89	6.98	1.69	1.86		0.62	5.44
38	do	I. E. Rittenburg	June 24-25, Aug. 26-27, 1932.	2	Pole	3½	−1.89	4.42	S. 44 W.	0.20	4.90	−3.12	5.29	N. 28 E.	0.50	7.52
				2	Meter	3		4.52		0.60			5.79		0.80	
				2	do	12		5.32		0.40			6.09		0.60	
41	Raritan Bay	do	Aug. 26-27, 31, Sept. 1, 1932.	2	Pole	7	0.81	2.82	S. 87 W.	0.60	5.62	0.30	2.49	N. 70 E.	0.60	6.80
				2	Meter	5	0.91	3.12		0.70	5.42	0.20	2.59		0.70	7.00
				2	do	15	0.91	3.32		0.60	5.52	0.30	2.79		0.50	6.90
42	do	H. C. Denson	Aug. 11-12, 21-22, 1922.	2¼	Pole	7	0.37	2.86	N. 88 W.	0.64	6.81	1.05	2.53	S. 84 E.	0.44	5.61
				2¼	Meter	5	0.56	3.06		0.74	6.28	0.71	2.63		0.62	6.14
				2¼	do	12	0.47	3.13		0.70	6.38	0.72	2.78		0.56	6.04
				2¼	do	19	0.42	3.36		0.62	6.43	0.72	2.79		0.44	5.99
43	do	I. E. Rittenburg	Aug. 22-24, 1932	2	Pole	7	−0.09	2.52	N. 84 W.	0.50	7.42	1.20	2.89	N. 77 E.	0.50	5.00
				2	Meter	6	−0.09	2.22		0.50	7.42	1.20	2.99		0.70	5.00
				2	do	15	−1.09	3.12		0.50	8.42	1.20	2.99		0.60	4.00
				2	do	24	−0.89	3.52		0.40	7.62	0.60	3.29		0.60	4.80
44	do	do	Sept. 12-14, 1932	2	Pole	7	1.31	3.02	N. 86 W.	0.70	5.22	0.40	2.39	N. 82 E.	0.60	7.20
				2	Meter	8	1.31	3.22		0.80	5.52	0.70	2.29		0.70	6.90
				2	do	19	1.01	3.12		0.80	5.92	0.80	2.29		0.60	6.50
				2	do	30	0.81	2.62		0.70	6.12	0.80	2.29		0.60	6.30
45	do	do	do	2	Pole	3	1.01	3.12	N. 82 W.	0.60	5.82	0.70	2.89	N. 79 E.	0.60	6.60
				2	Meter	5	1.01	2.82		0.50	5.92	0.80	2.59		0.60	6.50
				2	do	9	1.01	2.72		0.60	5.82	0.70	2.39		0.40	6.60
46	do	do	Sept. 14-16, 1932	2	Pole	3	0.31	2.92	S. 24 W.	0.20	7.52	1.70	2.29	N. 17 W.	0.10	4.90
				2	Meter	2	0.51	2.92		0.30	7.42	1.80	2.49		0.20	5.00
				2	do	6	0.51	3.02		0.30	7.42	1.80	2.29		0.20	5.00
47	do	H. C. Denson	Aug. 19-20, 1922	1	Pole	7	0.89	2.96	N. 78 W.	0.71	6.53	1.29	1.91	S. 88 E.	1.23	5.89
				1	Meter	4	1.24	2.76		0.91	6.11	1.22	2.36		1.06	6.31
				1	do	13	0.64	2.96		0.91	6.71	1.22	2.71		0.76	5.71
				¾	do	20	0.89	3.06		0.83	5.98	0.74	3.11		0.66	6.44
48	do	I. E. Rittenburg	June 23-25, 1932	2	Pole	7	1.01	2.32	N. 77 W.	0.70	6.12	1.00	3.19	S. 66 E.	0.90	6.30
				2	Meter	6	0.71	2.62		0.90	6.62	1.20	3.19		0.90	5.80
				2	do	15	0.41	2.52		1.00	6.92	1.20	2.99		0.80	5.50
				2	do	24	0.11	2.12		0.90	7.52	1.50	2.79		0.70	4.90

The observations on which the data of table 50 are based are from 1 to 2 days in length. In a day there are but 2 floods and 2 ebbs, so that slight differences in the results for the various depths derived from observations covering but a day or two may be due to accidental variations. In general, however, the data of table 50 indicate but little difference in the time of strength or of slack at the various depths. For the velocities, however, the differences between various depths are unmistakable.

The stations which are located outside the path of the current passing through the Narrows show, in general, a decrease in velocity with increase in depth, both on the flood and on the ebb. This is in accordance with the distribution of velocity in ordinary hydraulic flow and is evidenced by the data for station 3 off Sandy Hook, station 30 off Coney Island, and stations 42 and 43 off Staten Island. For these stations, too, it will be noted that the durations of the flood or ebb periods do not vary much for the different depths.

The stations located in the path of the current from the Narrows show a different vertical velocity distribution for flood and ebb. Station 32 is a good illustration of this. On the ebb the current at the different depths varies in accordance with the vertical velocity distribution of ordinary hydraulic motion, the velocity decreasing with increasing depth; but on the flood the velocity shows an increase from the surface downward for a considerable depth. At station 32 the flood strength at the two-tenths depth is less than at mid-depth or at the eight-tenths depth and at the latter depth is but little less than at mid-depth.

This difference in the vertical distribution of the current velocity evidently is due to the nontidal or fresh-water discharge from the Narrows. Having a density less than that of sea water, this fresh water tends to remain near the surface. On the ebb both tidal and nontidal water are moving in the same direction, and therefore the vertical velocity distribution is similar to that in water under hydraulic motion. On the flood the nontidal water near the surface tends to move seaward, and thus decreases the velocity of the tidal current near the surface. With increased depth the effect of the nontidal water diminishes, and hence the full velocity of the flood current is attained at some distance from the surface.

In consequence of the diminution of the flood strength near the surface by fresh water, an increase in the duration of the flood period may be expected with increasing depth. And while the data for station 32 are based on but 1 day of observations this increase in the flood period with increasing depth is shown unmistakably. The data for station 33, located similarly with regard to the current from the Narrows, give evidence of features similar to those for station 32.

THE CURRENT IN THE NARROWS AND UPPER BAY

SURFACE CURRENTS, THE NARROWS

For the Narrows there are at hand current observations at 33 stations, the locations of these being shown on figure 36. The data derived from these observations, with the velocities reduced to mean values, are given in table 51 and may be taken to pertain to the current at a depth of about 7 feet. The times of current are referred to the times of tide at Sandy Hook, HW standing for the time of high water and LW for the time of low water. The velocities have been reduced to mean values.

TABLE 51.—*Surface current data, the Narrows*

[Referred to times of HW and LW at Sandy Hook, N. J.]

Station no.	Location	Party of—	Observations		Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
1	Off Brooklyn	H. Mitchell	July, August 1858	4	3.3	0.1	N. 40 W.	1.1	4.4	1.6	0.6	S. 35 E.	1.9	8.0
2	do	I. E. Rittenburg	October 1932	2	0.6	0.7	N. 15 W.	1.2	7.6	2.1	2.6	S. 15 W.	0.9	4.8
3	do	H. C. Denson	August 1922	2½	3.2	0.2	N. 10 W.	1.5	5.0	2.1	0.8	S. 45 E.	1.9	7.4
5	do	H. L. Marindin	September 1885	1½	3.5	0.4		1.7	4.5	1.9	1.0		2.1	7.9
6	do	I. E. Rittenburg	August 1932	2¼	1.7	0.9	N. 10 E.	1.5	6.2	1.8	1.3	S. 20 W.	1.8	6.2
7	do	H. Mitchell	August 1858	½	3.5	0.0	N. 10 E.	1.3	5.1	2.5	−0.1	S. 40 W.	1.5	7.3
8	do	H. C. Denson	August 1922	1	2.4	0.9	N. 20 E.	1.4	6.1	2.4	1.4	S. 10 W.	1.6	6.3
9	do	I. Winston	October 1919	2	2.0	0.2	N. 15 E.	1.5	6.1	2.0	1.5	S. 25 W.	1.5	6.3
10	do	H. Mitchell	August 1872	1	1.9	1.9	N. 30 E.	1.2	5.8	1.6	1.9	S. 50 W.	1.3	6.6
11	Mid-channel	T. A. Craven	August 1855	½	2.9	0.8	N. 35 W.	1.2	5.3	2.1	1.1	S. 20 E.	2.3	7.1
12	do	H. C. Denson	August 1922	11	3.3	0.7	N. 20 W.	1.1	4.8	2.0	−0.1	S. 20 E.	1.9	7.6
13	do	I. Winston	October, November 1919	2	3.0	1.0	N. 25 W.	1.3	4.8	1.7	0.9	S. 20 E.	1.8	7.6
16	do	H. C. Denson	September 1922	1½	2.7	0.7	N. 20 W.	1.4	5.3	1.9	1.0	S. 15 E.	1.5	7.1
18	do	H. L. Marindin	September 1885	1½	3.1	1.0		2.1	4.9	1.9	0.9		2.4	7.5
19	do	C. G. Hanus	October 1886	2	3.1	0.4	N. 45 W.	1.5	5.3	2.3	0.8	S. 5 E.	1.8	7.1
20	do	U. S. S. *Amphitrite*	August-October 1917	87	2.4	0.7	N. 5 W.	1.1	5.9	2.2	1.0	S. 5 E.	1.4	6.5
21	do	H. Mitchell	August 1858	1	2.6	0.4	N. 10 W.	1.7	5.5	2.0	0.4	S. 5 E.	2.1	6.9
22	do	I. Winston	September 1919	2½	2.7	0.2	N. 5 W.	1.9	5.9	2.5	1.2	S. 10 W.	2.0	6.5
23	do	I. E. Rittenburg	August 1932	2¼	1.9	0.4	N.	1.5	6.6	2.4	0.7	S.	1.8	5.8
24	do	H. Mitchell	July 1859	1	2.7	0.2	N. 5 E.	1.4	5.5	2.1	0.6	S. 5 W.	1.5	6.9
25	do	T. A. Craven	August 1855	½	2.4	0.6	N. 20 E.	1.1	5.4	1.7	0.3	S.	2.0	7.0
26	do	I. Winston	September 1919	2	2.5	0.1	N. 5 E.	1.6	5.8	2.2	0.4	S. 15 E.	2.4	6.6
27	Off Staten Island	H. C. Denson	August 1922	2½	3.6	0.5	N. 25 W.	1.5	4.6	2.1	−0.3	S. 15 E.	2.3	7.8
29	do	H. L. Marindin	September 1885	1	3.0	0.9		1.6	4.7	1.6	1.5		2.0	7.7
30	do	H. C. Denson	September 1922	½	2.3	0.7	N. 5 W.	0.9	5.3	1.5	0.9	S. 15 W.	1.5	7.1
31	do	I. E. Rittenburg	August 1932	2¼	2.5	0.4	N. 5 E.	1.3	5.3	1.7	1.1	S.	1.6	7.1
32	do	H. C. Denson	September 1922	½	2.0	0.1	N. 15 E.	0.9	5.6	1.5	1.2	S. 10 W.	1.3	6.8
33	do	do	August-September 1922	1½	1.7	−0.2	N. 5 W.	1.2	6.4	2.0	1.5	S. 35 E.	1.6	6.0

From the data of table 51 it appears that through the Narrows slack before flood comes about 2½ hours after local low water, strength of flood half an hour before high water, slack before ebb 2 hours after high water, and strength of ebb 1 hour before low water. These time relations of current to tide are approximately those obtaining in progressive-wave motion, and the tidal movement through the Narrows deduced from the relation of current to tide is therefore of the progressive-wave type; and it is to be recalled that this conclusion was indicated by the behavior of the tides in the Narrows.

The greater velocity of the ebb current is clearly evident from the data in table 51. Only for station 2 is the flood velocity greater than the ebb; and for this station the times of the current likewise indicate special local features. In general, the strength of flood in the Narrows averages 1.4 knots and the strength of ebb 1.8 knots, this difference

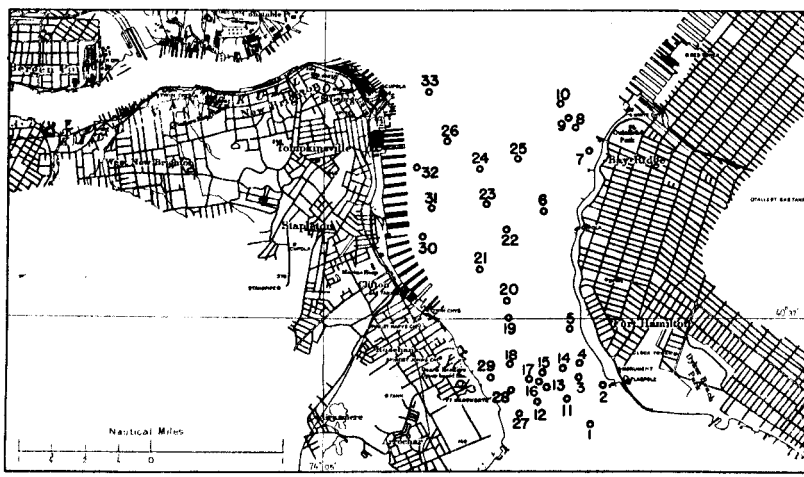

FIGURE 36.—Current stations, the Narrows.

arising from the very considerable amount of fresh water that drains through the Narrows.

At the southern end of the Narrows, the deepest part of the channel lies nearer the eastern shore; but after a short distance the deeper part of the channel swings toward the western shore and continues parallel to it into Upper Bay. And it is along this axis of the channel that the swiftest thread of the current is found. Thus, at stations 1, 11, and 26, the strength of ebb is 2 knots or more, against the average strength of ebb of 1.8 knots for the Narrows as a whole.

At the southern entrance to the Narrows the channel runs approximately N. 35° W. Further upstream the channel trends to the eastward, and near the upper end of the Narrows it runs approximately due north. The direction of the current in the Narrows changes in approximately the same way. At the southern entrance the flood sets about N. 35° W., while near the upper end the flood sets about N. 10° E. On the ebb the current near the southern entrance sets about S. 20° E., while near the upper end it sets about due south.

In consequence of the very considerable amount of fresh water draining through the Narrows, the surface currents have a longer

duration of ebb than of flood. Excepting station 2, the data of table 51, give an average duration for the ebb of 7 hours, and for the flood of 5.4 hours. In different parts of the channel, however, the durations differ noticeably from these average values. Thus for stations 6 to 10 which lie in or close to Bay Ridge Channel, and thus outside the sweep of the ebb current coming from the Hudson River, the duration of ebb averages 6.5 hours and of flood 5.9 hours; while for stations 11 to 13, which lie within the sweep of the main ebb current, these durations are respectively 7.4 hours and 5 hours.

The data for station 2 indicate peculiar conditions at that station. The flood velocity is greater than the ebb velocity, and the duration of flood is considerably greater than the duration of ebb. Examining figure 36, it is seen that this station is located between the island on which Fort Lafayette stands and the wharf at Fort Hamilton. It is thus sheltered from the sweep of the main ebb current. The island itself may also give rise to a reaction current on the ebb which lengthens the duration of flood.

CURRENT DATA, VARIOUS DEPTHS, THE NARROWS

At a number of stations shown on figure 36, subsurface current observations were also made by use of a current meter. Generally these observations were made at three depths—two-tenths, five-tenths, and eight-tenths of the depth of the station; and in addition to velocity observations the party of H. C. Denson in 1922 also determined the directions of the subsurface currents at the depths to which the meter was suspended. These directions were determined by means of the bifilar direction indicator described on page 96.

Table 52 gives the results of the subsurface current observations made in the Narrows in recent years. For comparison the observations made near the surface with log line and pole, which are given in table 51, are also included. To bring out the differences in the currents at the various depths, the times in table 52 are given to the second decimal of an hour, velocities to the second decimal of a knot, and directions to the nearest whole degree.

TABLE 52.—*Current data, various depths, the Narrows*

[Referred to times of HW and LW at Sandy Hook, N. J.]

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
2	Off Brooklyn	I. E. Rittenburg	Oct. 3-5, 1932	2	Pole	7	0.61	0.72	N. 17 W.	1.20	7.62	2.10	2.59	S. 14 W.	0.90	4.80
				2	Meter	5	0.51	0.92		1.10	7.82	2.20	2.79		0.90	4.60
				2	do	12	0.51	0.72		1.00	7.82	2.20	2.79		0.90	4.60
				2	do	20	0.51	0.12		1.10	7.82	2.20	2.79		0.70	4.60
3	do	H. C. Denson	Aug. 14-17, 1922	2½	Pole	7	3.21	0.21	N. 11 W.	1.49	4.96	2.04	0.81	S. 45 E.	1.89	7.46
				2½	Meter	14	3.49	0.23	N. 26 W.	1.41	4.85	2.21	0.53	S. 40 E.	1.65	7.57
				2½	do	36	3.45	0.59	N. 21 W.	1.24	4.89	2.21	0.56	S. 55 E.	0.94	7.53
				2½	do	58	3.27	0.43	N. 40 W.	0.88	5.11	2.25	0.59	S. 53 E.	0.78	7.31
4	do	U. S. Engineers	Aug. 18-25, 1932	6	do	7	2.70	0.31		1.40	5.33	1.90	2.56		1.61	7.09
				6	do	18	2.33	0.15		1.41	5.84	2.04	2.73		1.40	6.58
				6	do	29	1.97	0.33		1.69	6.09	1.93	2.79		1.37	6.33
6	do	I. E. Rittenburg	Aug. 17-20, 1932	2¼	Pole	7	1.71	0.92	N. 9 E.	1.50	6.22	1.80	1.42	S. 22 W.	1.80	6.20
				2¼	Meter	8	1.51	0.92		1.50	6.42	1.80	1.32		1.80	6.00
				2¼	do	20	1.51	0.92		1.40	6.42	1.80	1.22		1.60	6.00
				2¼	do	32	1.41	1.02		1.00	6.52	1.80	1.12		1.20	5.90
8	do	H. C. Denson	Aug. 17-18, 1922	1	Pole	7	2.44	0.86	N. 20 E.	1.39	6.13	2.44	1.46	S. 10 W.	1.64	6.29
				1	Meter	8	2.19	0.71	N. 22 E.	1.26	6.53	2.59	1.16	S. 18 W.	1.41	5.89
				1	do	21	2.04	0.76	N. 30 E.	1.41	6.33	2.24	0.61	S. 22 W.	1.31	6.09
				1	do	33	1.69	1.31	N. 30 E.	1.34	6.53	2.09	0.96	S. 20 W.	1.19	5.89
9	do	I. Winston	Oct. 1-3, 1919	1	Pole	7	1.97	0.24	N. 15 E.	1.51	6.13	1.97	1.54	S. 26 W.	1.51	6.29
				1	Meter	9	2.34	0.63		1.49	6.01	2.22	0.97		1.65	6.41
				1	do	22	2.27	0.69		1.56	5.87	2.01	0.97		1.40	6.55
				1	do	35	2.24	1.29		1.32	5.83	1.94	0.95		1.26	6.59
12	Mid-channel	H. C. Denson	Aug. 7-18, 1922	11	Pole	7	3.27	0.73	N. 20 W.	1.09	4.89	2.03	−0.09	S. 19 E.	1.86	7.53
				11	Meter	17	2.84	1.03	N. 17 W.	1.25	5.31	2.02	−0.17	S. 18 E.	1.81	7.11
				11	do	44	2.01	1.50	N. 27 W.	1.53	6.44	2.32	0.17	S. 23 E.	1.81	5.98
				11	do	70	1.08	0.39	N. 30 W.	1.75	7.11	2.06	1.38	S. 23 E.	1.27	5.31
13	do	I. Winston	Oct. 13-14, Nov. 12-13, 1919.	2	Pole	7	2.97	1.03	N. 25 W.	1.32	4.83	1.67	0.91	S. 20 E.	1.82	7.59
				2	Meter	18	2.57	1.19		1.18	5.51	1.95	1.11		1.57	6.91
				2	do	42	2.27	1.13		1.38	6.09	2.23	0.85		1.43	6.33
				2	do	60	1.84	1.11		1.60	6.38	2.09	0.93		1.53	6.04
14	do	U. S. Engineers	Sept. 2-9, 1932	7	do	16	2.77	0.44		1.39	5.44	2.08	1.35		1.45	6.98
				7	do	39	2.03	0.49		1.45	6.54	2.44	0.75		1.07	5.88
				7	do	62	1.69	0.81		1.71	6.76	2.32	0.82		1.08	5.66
15	do	do	Aug. 18-Sept. 16, 1932.	28	do	17	2.75	0.69		1.66	5.47	2.09	0.90		2.03	6.95
				28	do	42	1.79	0.57		2.03	6.85	2.51	0.57		1.76	5.57
				28	do	67	1.27	0.83		1.98	7.20	2.34	0.81		1.59	5.22
16	do	H. C. Denson	Sept. 5-6, 1922	1½	Pole	7	2.72	0.74	N. 22 W.	1.46	5.32	1.91	0.98	S. 13 E.	1.54	7.10
				1½	Meter	18	2.72	0.78	N. 29 W.	1.37	5.80	2.39	0.71	S. 19 E.	1.49	6.62
				1½	do	45	1.82	1.11	N. 24 W.	1.67	6.75	2.44	0.64	S. 47 E.	1.51	5.67
				1½	do	72	1.36	1.28	N. 26 W.	1.66	7.21	2.44	0.41	S. 42 E.	1.42	5.21
17	do	U. S. Engineers	Sept. 10-16, 1932	5	do	16	2.77	0.76		1.30	5.48	2.12	0.49		1.83	6.94
				5	do	40	2.42	0.93		1.36	5.99	2.28	0.28		1.57	6.43
				5	do	63	1.93	0.62		2.13	6.60	2.40	0.33		2.27	5.82
22	do	I. Winston	Sept. 17-18, 1919	2½	Pole	7	2.73	0.21	N. 6 W.	1.85	5.87	2.47	1.25	S. 10 W.	1.97	6.55
				2½	Meter	8	2.53	0.21		1.83	5.81	2.21	1.39		1.91	6.61
				2½	do	21	2.19	0.97		1.64	6.15	2.21	1.29		1.56	6.27
				2½	do	36	2.25	1.07		0.98	6.05	2.17	1.03		1.00	6.37
23	do	I. E. Rittenburg	Aug. 17-20, 1932	2¼	Pole	7	1.91	0.42	N. 2 E.	1.50	6.62	2.40	0.69	S. 1 W.	1.80	5.80
				2¼	Meter	9	2.01	0.52		1.60	6.42	2.30	0.59		1.90	6.00
				2¼	do	21	2.01	0.42		1.50	6.42	2.30	0.49		1.70	6.00
				2¼	do	33	2.01	0.82		1.40	6.32	2.20	0.69		1.70	6.10
26	do	I. Winston	Sept. 24-26, 1919	2	Pole	7	2.47	0.06	N. 6 E.	1.59	5.90	2.24	0.46	S. 17 E.	2.35	6.52
				2	Meter	12	2.79	0.41		1.55	5.38	2.04	0.46		1.97	7.04
				2	do	30	2.37	1.63		1.61	5.95	2.19	0.34		2.00	6.47
				2	do	48	2.07	2.43		1.30	6.12	2.06	0.24		1.64	6.30
27	Off Staten Island	H. C. Denson	Aug. 14-17, 1922	2½	Pole	7	3.55	0.51	N. 23 W.	1.52	4.67	2.09	−0.29	S. 17 E.	2.26	7.75
				2½	Meter	17	3.25	0.97		1.63	5.21	2.33	−0.39		2.41	7.21
				2½	do	42	2.03	1.19		1.47	5.77	1.67	0.97		1.89	6.65
				2½	do	67	1.51	2.71		0.92	6.13	1.51	1.59		1.55	6.29
28	do	U. S. Engineers	Aug. 25-Sept. 2, 1932.	8	do	15	2.71	1.11		1.25	5.55	2.13	0.39		1.73	6.87
				8	do	38	2.21	1.34		1.36	5.89	1.97	0.61		1.85	6.53
				8	do	60	1.86	1.12		1.21	5.92	1.65	0.81		1.76	6.50
30	do	H. C. Denson	Sept. 6, 1922	½	Pole	7	2.29	0.71	N. 7 W.	0.94	5.33	1.49	0.91	S. 13 W.	1.54	7.09
				½	Meter	10	2.39	0.31	N. 12 W.	1.18	5.43	1.69	1.01	S. 13 W.	1.63	6.99
				½	do	24	2.19	1.11	N. 25 W.	1.39	5.93	1.99	1.41	S. 2 E.	1.09	6.49
				½	do	38	1.19	0.51	N. 20 W.	0.62	6.93	1.99	1.61	S. 24 E.	0.62	5.49

TABLE 52.—*Current data, various depths, the Narrows*—Continued

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
31	Off Staten Island	I. E. Rittenburg	Aug. 17–20, 1932	2¼	Pole	7	2.51	0.42	N. 6 E.	1.30	5.32	1.70	1.09	S. 1 W.	1.60	7.10
				2¼	Meter	10	2.51	0.42		1.30	5.32	1.70	0.79		1.60	7.10
				2¼	do	25	2.41	1.62		1.60	5.92	2.20	0.79		1.40	6.50
				2¼	do	40	2.01	2.12		1.30	6.22	2.10	0.79		1.00	6.20
32	do	H. C. Denson	Sept. 6, 1922	½	Pole	7	1.99	0.11	N. 15 E.	0.94	5.63	1.49	1.21	S. 8 W.	1.34	6.79
				½	Meter	8	1.69	−0.09	N. 15 E.	1.08	6.03	1.59	1.41	S. 11 W.	1.73	6.39
				½	do	21	1.69	0.41	N. 2 E.	1.53	6.23	1.79	1.21	S. 8 W.	1.28	6.19
				½	do	34	1.69	0.61	N. 5 E.	1.34	6.23	1.79	1.01	S.	0.79	6.19
33	do	do	Aug. 17–18, Sept. 6, 1922.	1½	Pole	7	1.66	−0.22	N. 4 W.	1.19	6.46	1.99	1.54	S. 37 E.	1.59	5.97
				1½	Meter	10	1.52	0.01	N. 17 W.	1.55	6.85	2.24	1.94	S. 23 E.	1.48	5.54
				1½	do	24	1.99	1.14	N. 48 W.	1.77	6.58	2.44	0.68	S. 10 E.	1.34	5.80
				1½	do	38	1.82	1.48	N. 23 W.	0.98	6.62	2.31	0.48	S. 4 E.	1.01	5.86

At station 12 the observations covered a period of 11 days, while at station 15 they covered a period of 28 days. At these two stations, therefore, the characteristics of the current may be considered as well determined. At these two stations, the current is seen to differ at the different depths. The time of slack before flood becomes earlier with increasing depth. At both stations the decrease in time is at the rate of about 0.03 hour per foot. And while the data are not sufficiently extensive to give precise results, this decrease appears to be at an approximately uniform rate from the surface to near the bottom. These conclusions are also substantiated by the data for stations 4, 14, 17, and 28, where relatively long series of observations were made.

The slack before ebb behaves quite differently from the slack before flood. From the surface to mid-depth the slack before ebb becomes later, but from mid-depth towards the bottom it becomes earlier again. But the rate of change is small so that near the bottom the time of slack does not differ much from that near the surface. This difference in the behavior of the slacks is also evidenced at the other stations where relatively long series of observations have been obtained, namely stations 4, 14, 17, and 28.

This difference in the behavior of the slacks brings about a difference in the durations of flood and ebb at the different depths. For the surface currents, the data of table 51 gave an average duration for flood of 5.4 hours, and for ebb 7.0 hours. The data in table 52, almost without exception, indicate an increase in the duration of flood with increasing depth, and a corresponding decrease in the duration of ebb. At station 12 the duration of flood at the 7-foot depth is 4.9 hours; at 17 feet, 5.3 hours; at 44 feet, the mid-depth, 6.4 hours; and at 70 feet, 7.1 hours. At mid-depth, therefore, the duration of flood along the axis of the Narrows is greater than that of ebb, while at the 0.8 depth the flood runs for 1.8 hours longer than the ebb. The data for station 15 give much the same results. At the 0.2 depth, the duration of flood is 1.5 hours less than that of ebb, but at mid-depth the flood has the longer duration, and at 0.8 depth the flood runs 2.0 hours longer than the ebb.

The five stations along the section from Fort Wadsworth to Fort Hamilton, namely, stations 28, 17, 15, 14, and 4, were all occupied during the months of August and September 1932, and therefore permit comparison in regard to duration of flood and ebb across this section. For the 0.2 depth, which varies from 17 feet at station 15 to 7 feet at station 4, the duration of flood is practically the same at all 5 stations, averaging 5.45 hours. At the mid-depth there are decided differences, the duration of flood being greatest at the central station where the depth is greatest. The duration of flood decreases toward both shores, being least at station 4 where the depth is least; the difference in duration of flood at mid-depth between stations 15 and 4 being 1 hour. At the 0.8 depth the duration of flood is again greatest at station 15, and again decreases toward both shores, the difference in duration at this depth between stations 15 and 28 being 1.3 hours.

These differences in duration of flood or of ebb, mean that at certain times the current at the surface will be flooding, while below the surface it will be ebbing, and vice versa. Thus, at station 15 the

current near the surface will be flooding for about an hour, while at the mid-depth it will still be ebbing.

The large differences in the durations of flood and ebb at the different depths in the Narrows are characteristic only within the sweep of the main body of the ebb current. Thus, at stations 6, 8, and 9, which lie outside the path of the ebb current coming from the Hudson, the durations of flood and ebb are practically the same. Furthermore, these stations do not show notable differences in the durations as between the different depths.

Examining now the times of the strength of the current in the Narrows, the data of table 52 indicate that both for the flood and ebb strengths the times from the surface to the bottom do not differ much. This is to be expected if the difference in the durations of flood and ebb is brought about by the fresh water run-off.

The velocities of the current, however, exhibit relatively large differences at the different depths. In general, the data of table 52 show that the strength of ebb decreases with depth at the average rate of about 0.01 knot per foot. In the deeper central parts of the channel the rate is a little less, and in the shallower parts, near the shores, the rate is somewhat more. The change with depth in the velocity of flood is of a more complicated nature. In the deeper central parts of the Narrows, the velocity of flood increases from the surface to near the bottom at the rate of about 0.01 knot per foot, while near the shores the velocity decreases at a somewhat lesser rate. As a result, the difference between the ebb and flood velocities decreases with depth and in the deeper central parts of the Narrows the flood current at the 0.8 depth has a greater velocity than on the ebb.

The observations of the direction of the current below the surface are not sufficiently extensive to give precise results. At station 12 it is seen that both on the flood and on the ebb the direction changes somewhat from the surface to the bottom. Near the surface the direction is that of the channel, while in the deeper parts the current tends more westerly on the flood and more easterly on the ebb. If we examine a large scale chart of the Narrows, it will be seen that toward the bottom of the deeper parts of the channel, the contour lines run more nearly northwest and southeast than in the shallower parts, so that the current at any depth may be taken as running parallel to the direction of the channel at that depth.

CURRENT HARMONIC CONSTANTS, THE NARROWS

For the purpose of deriving harmonic constants for the prediction of the current in the Narrows, the pole observations at station 12 and the meter observations at the 17-foot depth at station 15 were submitted to harmonic analysis. The observations at station 15 covered a period of 28 days and these were analyzed in the usual manner. At station 12 there were available only 11 days of observations. To provide a 15-day series, 1½ days were extrapolated at the beginning, and 2½ days at the end of the 11 days of observations. This 15-day series was then analyzed in the usual manner. A simultaneous series of tidal observations at Fort Hamilton was also analyzed and the amplitude ratios and epoch differences between the components

at Fort Hamilton, derived from this short series, and those determined from the analysis of the series for the year 1904, were applied as corrections to the current amplitudes and epochs derived from the short series.

For both stations the harmonic analysis was carried out for the five principal components, namely, M_2 and harmonics, S_2, N_2, K_1, and O_1. The values of other components were then inferred from these principal components. The results are given in table 53, inferred values being enclosed in parentheses.

TABLE 53.—*Current harmonic constants, the Narrows*

Component	Station 12		Station 15		Component	Station 12		Station 15	
	H	κ	H	κ		H	κ	H	κ
	Knots	°	*Knots*	°		*Knots*	°	*Knots*	°
J_1	(0.01)	(102)	(0.01)	(68)	$2N$	(0.03)	(154)	(0.04)	(139)
K_1	0.20	78	0.16	72	O_1	0.09	29	0.11	80
K_2	(0.05)	(279)	(0.06	(217)	P_1	(0.07)	(78)	(0.05)	(72)
L_2	(0.04)	(223)	(0.05)	(229)	Q_1	(0.02)	(54)	(0.02)	(84)
M_1	(0.01)	(54)	(0.01)	(76)	S_2	0.19	279	0.24	217
M_2	1.34	200	1.66	199	T_2	(0.01)	(279)	(0.01)	(217)
M_4	0.04	340	0.09	55	λ_2	(0.01)	(237)	(0.01)	(207)
M_6	0.12	133	0.05	126	μ_2	(0.05)	(180)	(0.04)	(180)
N_2	0.25	177	0.28	169	ν_2	(0.03)	(121)	(0.05)	(173)

The epochs refer to the maximum velocity of the components in the northerly or flood direction. For M_2 both series give an epoch of about 200°; and since the epoch for M_2 of the tide at Fort Hamilton is 221°, the current harmonic constants show that the strength of flood in the Narrows comes 21° earlier or 0.7 hours before the time of local high water. Since M_2 is the principal component of the current, the above value should approximate the relation of the time of strength of flood to time of tide derived directly from the observations. From table 52, the time of strength of flood for stations 12 and 15 averages 0.65 hour before high water at Sandy Hook. And since the tide at Sandy Hook is about a tenth of an hour earlier than at Fort Hamilton, the agreement between the results from the harmonic constants and from the direct tabulation is very close.

SURFACE CURRENTS, UPPER BAY

For Upper Bay there are at hand current observations at 49 stations made at various times. Figure 37 shows the locations of these stations and table 54 gives the results derived from the observations near the surface which may be taken to pertain to the current at a depth of 7 feet below the surface. The times are referred to the times of high and low water at Sandy Hook, HW standing for the time of high water and LW for the time of low water. The velocities shown for the strengths have been reduced to mean values.

TABLE 54.—*Surface current data, Upper Bay*

[Referred to times of HW and LW at Sandy Hook, N. J.]

Station no.	Location	Party of—	Observations		Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
1	Off New Brighton	I. E. Rittenburg	August-September, 1932	2	1.1	3.3	N. 50 W.	1.1	5.7	0.7	2.7	S. 75 E.	1.3	6.7
2	In Channel	H. Mitchell	August 1872	1	3.0	−0.3	N. 10 E.	1.5	5.8	2.7	−0.3	S. 25 W.	1.5	6.6
3	Off Robbins Reef	I. E. Rittenburg	September 1932	2	1.0	0.4	N. 20 W.	0.9	7.4	2.3	1.9	S. 25 W.	0.7	5.0
4	In Channel	I. Winston	October 1919	2	2.9	0.3	N. 15 E.	1.3	5.3	2.1	0.5	S. 25 W.	1.8	7.1
5	do	H. Mitchell	July 1859	¾	3.9	−1.1	N. 5 E.	1.1	5.3	3.1	−1.1	S. 25 W.	1.4	7.1
6	do	T. A. Craven	August 1855	½	3.7	−0.7	N. 25 E.	1.1	5.8	3.4	−0.2	S. 10 W.	2.0	6.6
7	Off Brooklyn	I. E. Rittenburg	September 1932	2	2.4	1.4	N. 40 W.	1.0	5.0	1.3	1.6	S. 40 W.	1.1	7.4
8	do	H. Mitchell	August 1872	¾	2.0	1.5	N. 30 E.	0.9	6.0	1.9	1.0	S. 25 W.	0.7	6.4
9	Gowanus Bay	H. C. Denson	September 1922	½	−0.3	3.4	N. 45 E.	0.1	5.4	−1.0	3.8	S. 70 W.	0.1	7.0
10	Off Brooklyn	do	do	½	1.8	1.1	N. 30 E.	1.0	6.4	2.1	1.3	S. 5 E.	1.0	6.0
11	do	I. Winston	October 1919	2	1.7	1.1	N. 15 E.	0.8	6.3	1.9	1.5	S. 5 E.	1.3	6.1
12	do	H. L. Marindin	August 1872	1	2.4	1.6	N. 15 E.	1.4	6.1	2.4	0.9	South	1.0	6.3
13	do	I. E. Rittenburg	July-August 1932	2	1.9	1.5	North	1.3	6.3	2.1	1.2	S. 25 W.	1.3	6.1
14	do	H. Mitchell	August 1872	¾	3.6	0.9	N. 10 W.	1.3	4.7	2.2	1.4	S. 10 E.	0.8	7.7
15	do	do	do	1	3.0	0.9	N. 15 E.	1.3	5.8	2.7	0.2	South	1.1	6.6
16	In Channel	do	do	¾	3.5	0.2	N. 30 E.	0.9	4.8	2.2	0.3	S. 5 W.	1.3	7.6
17	do	I. E. Rittenburg	September 1932	2	2.9	0.2	N. 30 E.	1.0	5.6	2.4	0.2	S. 20 W.	1.6	6.8
18	do	H. Mitchell	August 1872	1	3.9	−0.1	N. 35 E.	0.8	4.3	2.1	0.2	S. 35 W.	1.4	8.1
19	do	H. C. Denson	August 1922	1	4.0	−0.6	N. 25 E.	1.2	4.8	2.7	−0.6	S. 15 W.	1.9	7.6
20	do	I. E. Rittenburg	July-August 1932	2	3.7	−0.2	N. 25 E.	1.4	5.3	2.9	−0.2	S. 25 W.	2.5	7.1
21	Off Bayonne, N. J	do	September 1932	2	2.7	0.2	N. 25 E.	1.0	6.0	2.6	0.6	S. 40 W.	1.2	6.4
22	do	do	August 1932	2	0.9	−0.4	N. 30 E.	0.6	7.4	2.2	2.8	S. 5 W.	0.6	5.0
23	In Channel	I. Winston	October 1919	2	3.4	−0.9	N. 25 E.	1.2	5.6	2.9	0.0	S. 25 W.	2.2	6.8
24	Off Governors I	T. A. Craven	July 1855	½	3.8	−1.4	N. 10 E.	1.5	4.9	2.6	−0.1	S. 25 W.	2.8	7.5
25	do	H. C. Denson	August 1922	1¼	3.8	0.0	N. 35 E.	1.5	5.2	2.9	−0.4	S. 25 W.	2.4	7.2
26	do	H. Mitchell	August-September 1858	3½	3.8	−0.3	N. 30 E.	1.0	5.3	3.0	−0.2	S. 25 W.	1.9	7.1
27	do	I. Winston	October 1919	2	3.9	−0.5	N. 20 E.	2.0	5.6	3.3	−0.4	S. 25 W.	2.6	6.8
28	do	I. E. Rittenburg	July 1932	2	3.9	−0.5	N. 40 E.	1.6	5.0	2.8	0.2	S. 25 W.	2.5	7.4
29	Off Brooklyn	H. C. Denson	September 1922	½	1.8	2.1	N. 25 E.	0.8	6.6	2.3				5.8
30	Buttermilk Channel	I. Winston	October 1919	1½	1.5	1.6	N. 45 E.	1.1	6.5	1.9	1.6	S. 55 W.	1.6	5.9
31	do	H. Mitchell	September 1872	½	2.3	0.5	N. 50 E.	1.5	6.3	2.5	1.1	S. 55 W.	2.4	6.1
32	do	I. E. Rittenburg	August 1932	2	2.4	0.9	N. 50 E.	1.6	5.9	2.2	0.9	S. 60 W.	2.3	6.5
33	do	H. C. Denson	July 1922	3¾	2.2	1.7	N. 50 E.	1.8	6.0	2.1	0.9	S. 45 W.	2.6	6.4
34	do	R. J. Auld	September 1920	¾	2.2	1.7	N. 45 E.	1.6	6.4	2.4	1.5	S. 40 W.	2.6	6.0
35	do	T. A. Craven	July 1855	½	2.0	0.7	N. 80 E.	1.7	6.9	2.8	1.1	S. 45 W.	2.4	5.5
36	do	H. C. Denson	September 1922	½	1.6	1.5	N. 40 E.	0.6	7.1	2.6	0.7	S. 35 W.	0.4	5.3
37	do	I. E. Rittenburg	July 1932	2	2.1	0.8	N. 35 E.	2.2	6.6	2.6	1.2	S. 15 W.	1.7	5.8
38	do	M. Woodhull	July 1854	½	1.9	1.2	N. 45 E.	1.4	6.9	2.7	1.7	S. 45 W.	1.3	5.5
39	do	I. E. Rittenburg	July 1932	2	2.5	1.7	N. 25 E.	0.9	5.8	2.2	0.6	S. 5 W.	2.6	6.6
40	do	H. L. Marindin	August 1872	½	1.6	0.8	N. 25 E.	1.6	6.7	2.2	1.4	South	1.2	5.7
41	Off Governors I	I. E. Rittenburg	July 1932	2	2.4	1.9	S. 75 E.	1.0	4.2	0.5	0.3	S. 45 W.	1.2	8.2
42	do	H. Mitchell	August 1872	½	1.8	0.3	N. 75 E.	1.5	6.9	2.4	0.6	S. 40 W.	1.8	5.5
43	do	H. C. Denson	July-August 1922	3½	2.2	0.7	S. 85 E.	1.2	6.0	2.1	0.6	West	1.7	6.4
43	do	H. Mitchell	September 1858	½	1.6	0.3	N. 85 E.	1.4	6.9	2.4	0.3	S. 70 W.	1.9	5.5
44	do	R. J. Auld	October 1920	1	1.9	1.1	N. 80 E.	1.2	6.2	2.0	0.3	S. 75 W.	2.4	6.2
45	Off Ellis I	H. Mitchell	August 1872	½	4.1	−0.7	N. 20 E.	0.9	5.5	3.5	−0.4	S. 10 W.	1.8	6.9
46	do	I. E. Rittenburg	June 1932	2	1.5	1.1	N. 60 E.	0.7	6.7	2.1	0.4	S. 50 W.	0.8	5.7
47	Off Jersey City, N. J	do	do	2	3.9	0.1	N. 20 E.	0.5	4.2	2.0	−0.2	S. 35 W.	1.8	8.2
48	do	H. Mitchell	September 1872	½	4.4	0.3	N. 10 E.	1.2	5.4	3.7	−0.5	S. 20 W.	1.3	7.0
49	do	I. Winston	October 1919	2¼	4.1	−0.3	N. 20 E.	1.6	5.3	3.3	−0.8	S. 20 W.	2.4	7.1

The data in table 54 show rather large differences. In part these may be ascribed to the nature of the observations and to the fact that the observations were made at different times. But in much the larger part these differences appear to be due to actual differences existing in different parts of the bay. Thus within the main channel leading to the Hudson the duration of ebb is considerably greater than the duration of flood, averaging 7.0 hours for the ebb against 5.4 hours for the flood. But along the eastern and western shores of the bay, the flood and ebb have very nearly equal durations.

Within the main channel the slack before flood comes about 3½ hours after low water at Sandy Hook, and strength of flood about

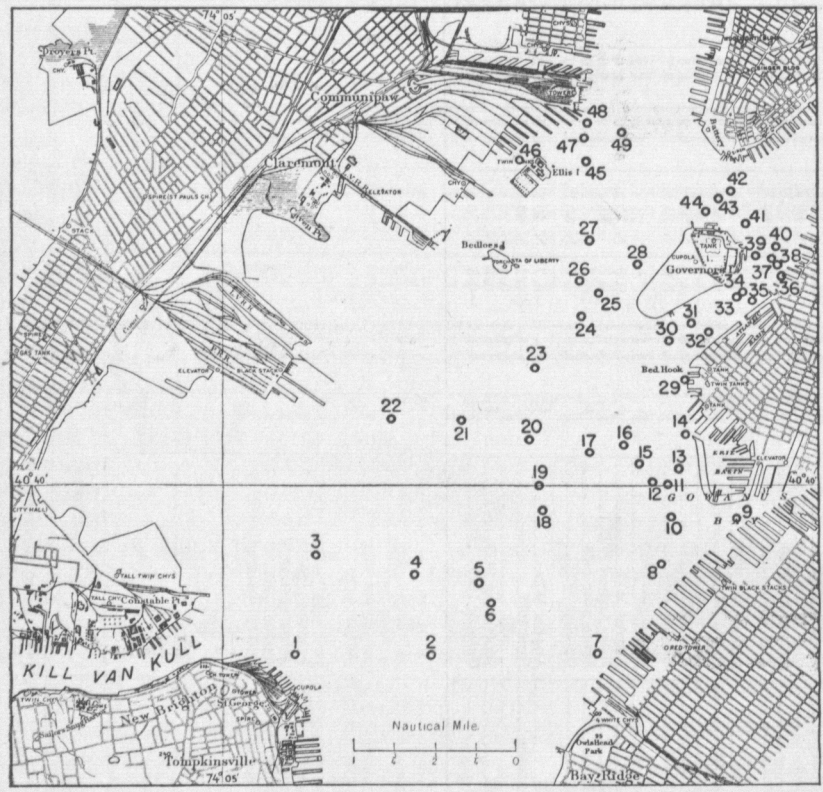

FIGURE 37.—Current stations, Upper Bay.

one-fourth of an hour after high water. Slack before ebb comes about 3 hours after high water and strength of ebb comes about one-fourth of an hour after low water. Since the time of tide in Upper Bay is about one-half an hour later than at Sandy Hook, the current in the main channel is at slack about 3 hours after local high and low water and at strength about one-fourth of an hour before local high and low water.

Along the Brooklyn shore the current is earlier than in the main channel, but the different phases of the current differ by different amounts. The strengths of the current along the Brooklyn shore come about 1½ hours earlier; slack before flood likewise comes 1½

hours earlier, but slack before ebb comes three-fourths of an hour earlier. These differences in the times of slack bring about the differences in the durations of flood and ebb as between the main channel and the regions near the shore noted above.

Along the main channel of Upper Bay, the ebb has also the greater velocity, averaging about 2¼ knots at strength of ebb, as against a little less than 1½ knots at flood strength. Along the Brooklyn shore the corresponding values are 1½ knots and 1¼ knots. In general, therefore, the ebb strength is very nearly a knot greater than the flood along the main channel, but only one-fourth knot greater along the Brooklyn shore. Within Buttermilk Channel, however, at certain locations, the ebb strength is less than that of the flood, as at station 37, for example, while at other locations the ebb has the greater velocity by more than 1½ knots, as at station 39. These deviations from the general conditions are obviously due to the locations of these stations with respect to the main threads of the flood and ebb in this channel.

For several of the stations listed in table 54 the values stand out markedly different from the values at the other stations. Thus for station 1, the times of the current are much earlier than for most of the other stations in Upper Bay. The directions of the flood and ebb strengths at this station show that the current here is in reality part of the current flowing into and out of Kill van Kull. And on comparing the values of the current at this station with the data for the stations in Kill van Kull listed in table 58, this is seen to be the case.

At station 9 the times of the current are very much earlier than at the other stations in Upper Bay. Instead of slack coming about 3 hours after the times of local tide, slack at station 9 comes near the times of high and low water; and the strength of the current, instead of coming about the times of high and low water, comes approximately midway between high and low waters. These differences find explanation in the location of the station. A glance at figure 37 shows that station 9 is located in Gowanus Bay. This bay is of such limited dimensions that there can be little progression of the tide beyond station 9. Hence, strength of flood and ebb must come when this restricted waterway is being filled most rapidly, namely, midway between high and low water, when the tide is rising or falling most rapidly. Similarly, the tidal movement should cease at the times of high and low water, when the rise or fall of the tide has ceased.

CURRENT DATA, VARIOUS DEPTHS, UPPER BAY

For 30 of the stations in Upper Bay, there are available current observations at three depths below the surface, namely, 0.2, 0.5 and 0.8 of the depth at the station. These observations were made with current meters, and the data derived are given in table 55. For comparison the results derived by use of the current pole, which are considered as pertaining to the surface, are also included.

TABLE 55.—*Current data, various depths, Upper Bay*

[Referred to times of HW and LW at Sandy Hook, N. J.]

Station no.	Location	Party of	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
1	Off New Brighton, N. Y.	I. E. Rittenburg.	Aug. 31–Sept. 2, 1932.	2	Pole	7	1.11	3.32	N. 48 W.	1.10	5.72	0.70	2.69	S. 73 E.	1.30	6.70
				2	Meter	7	1.01	3.32		1.10	5.82	0.70	2.59		1.40	6.60
				2	do	18	1.01	3.32		1.10	5.92	0.80	2.49		1.30	6.50
				2	do	29	0.91	3.32		1.20	6.02	0.80	2.49		1.10	6.40
3	Off Robbins Reef	do	Sept. 9–10, 14–15, 1932.	2	Pole	3	1.01	0.42	N. 21 W.	0.70	7.42	2.30	1.69	S. 24 W.	0.70	5.00
				2	Meter	3½	1.01	0.42		0.90	7.42	2.30	1.79		0.80	5.00
				2	do	9	1.01	0.42		0.90	7.32	2.20	1.99		0.60	5.10
4	In channel	I. Winston	Oct. 8–10, 1919	2	Pole	7	2.94	0.26	N. 16 E.	1.32	5.28	2.09	0.51	S. 24 W.	1.76	7.14
				2	Meter	15	3.14	0.56		1.20	5.17	2.18	0.43		1.52	7.25
				2	do	38	3.05	1.43		1.13	5.27	2.18	0.33		1.09	7.15
				2	do	60	2.94	1.53		0.95	5.37	2.18	0.49		0.55	7.05
7	Off Brooklyn	I. E. Rittenburg.	Sept. 9–10, 14–15, 1932.	2	Pole	7	2.41	1.42	N. 39 E.	1.00	5.02	1.30	1.59	S. 38 W.	1.10	7.40
				2	Meter	8	2.21	1.62		1.00	5.42	1.50	1.39		1.10	7.00
				2	do	21	2.01	1.52		1.10	5.82	1.70	1.29		1.00	6.60
				2	do	34	1.71	1.12		0.90	7.12	2.70	0.89		0.90	5.30
10	do	H. C. Denson	Sept. 5, 1922	½	Pole	7	1.79	1.11	N. 32 E.	0.96	6.43	2.09	1.31	S. 6 E.	0.96	5.99
				½	Meter	9	1.99	1.21	N. 8 E.	1.10	6.23	2.09	1.71	S. 5 E.	1.25	6.19
				½	do	23	1.49	1.51	N. 51 E.	1.01	6.73	2.09	1.71	S. 15 W.	0.71	5.69
				½	do	36	1.39	1.71	N. 12 E.	0.93	6.83	2.09	1.51	S. 1 W.	0.28	5.59
11	do	I. Winston	Oct. 15–17, 1919	2	Pole	7	1.71	1.13	N. 15 E.	0.82	6.26	1.84	1.53	S. 6 E.	1.26	6.16
				2	Meter	9	1.91	1.13		0.80	6.41	2.19	1.16		1.24	6.01
				2	do	21	1.74	1.18		0.89	6.58	2.19	1.39		0.83	5.84
				2	do	33	1.47	1.51		1.03	7.00	2.34	1.29		0.48	5.42
13	do	I. E. Rittenburg.	July 28–29, Aug. 5–6, 1932.	2	Pole	7	1.91	1.52	N. 2 E.	1.30	6.32	2.10	1.19	S. 23 E.	1.30	6.10
				2	Meter	6	2.01	1.42		1.10	6.32	2.20	1.09		1.30	6.10
				2	do	16	1.91	1.62		1.30	6.42	2.20	1.49		1.20	6.00
				2	do	26	1.71	1.92		1.20	6.62	2.20	1.69		0.80	5.80
17	do	do	Sept. 19–21, 1932	2	Pole	7	2.91	0.22	N. 29 E.	1.00	5.62	2.40	0.09	S. 21 W.	1.60	6.80
				2	Meter	5	2.91	0.32		1.00	5.42	2.20	0.49		1.30	7.00
				2	do	12	2.91	0.52		1.20	5.52	2.30	0.29		1.40	6.90
				2	do	19	2.31	0.82		0.90	6.12	2.30	0.89		1.00	6.30
19	In channel	H. C. Denson	Aug. 15–16, 1922	1	Pole	7	4.02	−0.59	N. 27 E.	1.17	4.75	2.64	−0.54	S. 16 W.	1.87	7.67
				1	Meter	6	4.07	−0.24		0.94	4.65	2.59	−0.54		1.84	7.77
				1	do	15	3.57	−0.04		1.20	5.02	2.46	−0.34		1.65	7.40
				1	do	24	3.07	0.71		0.95	5.52	2.46	−0.19		1.10	6.90
20	do	I. E. Rittenburg.	July 28–29, Aug. 5–6, 1932.	2	Pole	7	3.71	−0.20	N. 24 E.	1.40	5.32	2.90	−0.21	S. 26 W.	2.50	7.10
				2	Meter	10	3.51	0.00		1.40	5.42	2.80	−0.11		2.30	7.00
				2	do	24	3.51	0.12		1.70	5.82	3.20	−0.01		1.60	6.60
				2	do	38	2.51	0.42		1.40	6.92	3.30	−0.11		0.80	5.50
21	do	do	Sept. 19–21, 1932	2	Pole	7	2.71	0.22	N. 23 E.	1.00	6.02	2.60	0.59	S. 38 W.	1.20	6.40
				2	Meter	4	2.91	0.22		0.90	5.92	2.70	0.79		1.40	6.50
				2	do	15	2.71	0.32		1.20	6.12	2.70	0.59		1.20	6.30
22	Off Bayonne, N. J.	do	Aug. 15–17, 1932	2	Pole	3½	0.91	−0.50	N. 31 E.	0.70	7.52	2.30	2.79	S. 4 W.	0.50	4.90
				2	Meter	6	0.91	−0.40		0.60	7.42	2.20	2.79		0.60	5.00
				2	do	15	0.91	0.00		0.40	7.42	2.20	2.39		0.40	5.00
				2	do	24	1.01	0.52		0.40	7.32	2.20	2.29		0.30	5.10
23	In channel	I. Winston	Oct. 22–24, 1919	2	Pole	7	3.39	−0.94	N. 24 E.	1.23	5.68	2.94	0.04	S. 27 W.	2.22	6.74
				2	Meter	12	3.17	−0.54		1.34	5.87	2.91	0.33		1.99	6.55
				2	do	30	2.71	−0.29		1.62	6.36	2.94	0.33		1.45	6.06
				2	do	48	2.44	0.13		1.60	7.00	3.31	−0.09		1.00	5.42
25	Off Governors Island	H. C. Denson	Aug. 15–16, 1922	1¼	Pole	7	3.79	0.01	N. 35 E.	1.46	5.23	2.89	−0.42	S. 27 W.	2.36	7.19
				1¼	Meter	14	3.64	−0.39		1.39	5.35	2.86	−0.29		2.24	7.07
				1¼	do	35	3.19	−0.29		1.77	6.13	3.19	−0.29		1.67	6.29
				1¼	do	56	2.74	−0.44		2.09	6.61	3.22	−0.59		1.14	5.81
27	do	I. Winston	Oct. 29–31, 1919	2	Pole	7	3.89	−0.49	N. 20 E.	1.96	5.58	3.34	−0.41	S. 24 W.	2.60	6.84
				2	Meter	15	3.17	0.11		1.69	6.55	3.59	−0.01		2.24	5.87
				2	do	38	2.77	−0.19		2.02	6.90	3.54	−0.11		1.82	5.52
				2	do	60	2.37	0.11		2.02	7.33	3.57	−0.31		1.04	5.09
28	do	I. E. Rittenburg.	July 26–28, 1932	2	Pole	7	3.91	−0.50	N. 38 E.	1.60	5.02	2.80	0.19	S. 25 W.	2.50	7.40
				2	Meter	7	3.91	−0.50		1.80	5.02	2.80	0.29		2.40	7.40
				2	do	18	3.41	−0.40		1.80	5.42	2.70	0.39		2.30	7.00
				2	do	29	2.91	−0.20		1.40	6.02	2.80	0.29		1.60	6.40
29	Off Brooklyn, N. Y.	H. C. Denson	Sept. 3, 1922	½	Pole	7	1.79	2.11	N. 24 E.	0.80	6.63	2.29				5.79
				½	Meter	5	2.49	1.91	N. 20 E.	1.20	5.43	1.79				6.99
				½	do	12	2.39	1.51	N. 20 E.	1.05	5.43	1.69				6.99
				½	do	18	2.49	1.41	N. 24 E.	1.00	5.33	1.69				7.09
30	Buttermilk Channel	I. Winston	Oct. 27–28, Nov. 10–11, 1919.	1½	Pole	7	1.49	1.61	N. 44 E.	1.10	6.50	1.86	1.64	S. 53 W.	1.64	5.92
				1¾	Meter	8	1.52	1.33		1.15	6.58	1.97	1.76		1.50	5.84
				1¾	do	21	1.52	1.29		1.20	6.60	1.99	1.64		1.20	5.82
				1¾	do	34	1.39	1.01		0.85	6.78	2.04	1.61		0.90	5.64
32	do	I. E. Rittenberg.	Aug. 15–17, 1932	2	Pole	7	2.41	0.92	N. 50 E.	1.60	5.92	2.29	0.89	S. 59 W.	2.30	6.50
				2	Meter	6	2.41	0.92		1.50	6.02	2.39	0.89		2.30	6.40
				2	do	15	2.41	0.92		1.50	5.92	2.29	0.99		2.10	6.50
				2	do	24	2.41	1.02		1.30	5.92	2.29	1.09		1.90	6.50

TABLE 55.—*Current data, various depths, Upper Bay*—Continued

Station no.	Location	Party of	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
33	Buttermilk Channel	H. C. Denson	July 23–25, Aug. 13–15, 1922.	3¾	Pole	7	2.19	1.71	N 52 E.	1.80	6.00	2.06	0.89	S. 44 W.	2.60	6.42
				3¾	Meter	8	2.27	1.99		1.72	5.92	2.06	0.94		2.46	6.50
				3¾	do	20	2.32	2.03		1.73	5.87	2.06	0.84		2.43	6.55
				3¾	do	32	2.34	1.94		1.50	5.85	2.06	0.78		2.16	6.57
34	do	R. J. Auld	Sept. 29–30, 1920	¾	Pole	7	2.14	1.71	N. 44 E.	1.63	6.38	2.39	1.51	S. 40 W.	2.58	6.04
				¾	Meter	8	2.07	1.32		1.52	6.23	1.99	0.73		2.32	6.19
				¾	do	21	2.04	1.41		1.44	6.23	1.96	0.96		2.24	6.19
				¾	do	34	2.01	1.59		1.21	6.23	1.93	0.99		1.91	6.19
36	do	H. C. Denson	Sept. 2, 1922	½	Pole	7	1.59	1.51	N. 41 E.	0.55	7.13	2.59	0.71	S. 35 W.	0.40	5.29
				½	Meter	9	2.19	1.51	N. 43 E.	1.25	6.73	2.79	0.51	S. 41 W.	0.75	5.69
				½	do	22	2.19	2.11	N. 38 E.	1.25	6.63	2.69	1.31	S. 41 W.	0.40	5.79
				½	do	35	2.39	2.11	N. 28 E.	1.05	6.43	2.69	2.11	S. 37 W.	0.60	5.99
37	do	I. E. Rittenburg	July 22–23, 25–26, 1932.	2	Pole	7	2.11	0.82	N. 34 E.	2.20	6.62	2.60	1.19	S. 15 W.	1.70	5.80
				2	Meter	6	2.01	0.92		2.00	6.82	2.70	0.99		1.60	5.60
				2	do	16	2.01	1.12		1.90	6.72	2.60	1.49		1.50	5.70
				2	do	24	2.01	1.12		1.70	6.72	2.60	1.89		1.30	5.70
39	do	do	do	2	Pole	7	2.51	1.72	N. 27 E.	0.90	5.82	2.29	0.59	S. 6 W.	2.60	6.60
				2	Meter	7	2.51	1.42		0.80	5.82	2.29	0.79		2.20	6.60
				2	do	18	2.51	1.02		1.20	5.42	1.89	0.59		2.20	7.00
				2	do	29	2.51	0.92		1.50	5.32	1.79	0.59		2.30	7.10
41	Off Governors Island	do	July 26–28, 1932	2	Pole	6½	2.41	1.92	S. 75 E.	1.00	4.22	0.50	0.29	S. 45 W.	1.20	8.20
				2	Meter	4	2.41	1.92		1.40	5.12	1.40	0.49		1.30	7.30
				2	do	10	2.51	1.92		1.00	4.82	1.20	0.49		1.20	7.60
				2	do	16	2.51	1.62		0.80	4.92	1.30	0.59		1.00	7.50
43	do	H. C. Denson	July 23–24, Aug. 13–15, 1922.	3½	Pole	7	2.22	0.74	S. 86 E.	1.20	6.00	2.09	0.64	S. 89 W.	1.73	6.42
				3½	Meter	10	2.21	0.34		1.20	5.91	1.99	0.71		1.72	6.51
				3½	do	25	2.22	0.84		1.25	5.92	2.01	0.79		1.58	6.50
				3½	do	40	2.19	1.26		1.06	6.00	2.06	0.71		1.55	6.42
44	do	R. J. Auld	Oct. 8–9, 1920	1	Pole	7	1.89	1.11	N. 82 E.	1.18	6.23	1.99	0.31	S. 74 W.	2.43	6.19
				1	Meter	12	2.17	0.53		1.15	5.58	1.62	0.43		2.05	6.84
				1	do	30	2.19	2.16		0.68	5.48	1.54	0.31		2.08	6.94
				1	do	48	2.21	2.19		0.59	5.43	1.51	0.39		2.09	6.99
46	Off Ellis Island	I. E. Rittenburg	June 20–22, 1932	2	Pole	7	1.51	1.12	N. 59 E.	0.70	6.72	2.10	0.39	S. 50 W.	0.80	5.70
				2	Meter	6	1.51	1.32		0.70	6.82	2.20	0.49		0.50	5.60
				2	do	14	1.41	1.32		0.70	6.92	2.20	0.69		0.80	5.50
				2	do	22	1.51	1.02		0.70	6.82	2.20	0.89		0.50	5.60
47	Off Jersey City	do	do	2	Pole	7	3.91	0.12	N. 21 E.	0.50	4.22	2.00	−0.21	S. 35 W.	1.80	8.20
				2	Meter	6	4.01	0.42		0.60	4.32	2.20	−0.21		1.80	8.10
				2	do	15	3.51	0.42		0.50	4.92	2.30	−0.01		1.40	7.50
				2	do	24	2.01	1.92		0.80	6.92	2.80	0.29		0.90	5.50
49	do	I. Winston	Sept. 30, Oct. 20–21, Nov. 3–4, 1919.	2¼	Pole	7	4.12	−0.24	N. 21 E.	1.59	5.28	3.27	−0.76	S. 19 W.	2.37	7.14
				2½	Meter	8	4.11	−0.51		1.56	5.49	3.47	−0.66		2.11	6.93
				2½	do	20	3.44	½.51		1.92	6.41	3.72	−0.56		1.46	6.01
				2½	do	32	3.31	−0.10		1.58	6.33	3.51	−0.57		1.04	6.09

The relations of the current at the different depths in Upper Bay are much like those found in the Narrows. Within the main channel the slack before ebb becomes earlier from the surface downward. If for convenience we speak of the 7-foot depth as the surface and the 0.8 depth as the bottom, it appears that within the main channel of Upper Bay, as in the Narrows, the slack before flood comes earlier from the surface to the bottom at the rate of about 0.03 hour per foot. And as in the Narrows, this change in time of slack is to be ascribed to the effect of the fresh or nontidal water from the Hudson.

The slack before ebb does not change much with depth, and what change is exhibited is in the opposite direction to that of the slack before flood, for it apparently becomes later with increasing depth. But this change averages less than 0.01 hour per foot. As a consequence of this difference between the flood and ebb slacks there is a difference in the durations of flood and ebb at the different depths. Near the surface the average durations of flood and ebb within the main channel of Upper Bay are, respectively, 5.4 hours and 7.0 hours. At mid-depth (about 30 feet) the flood has generally the greater duration, about 6.3 hours against 6.1 hours for the ebb. And near the bottom the duration of flood is very nearly 7 hours against less than 5½ hours for the ebb.

Within the main channel of Upper Bay the vertical distribution of the velocity is much like that in the Narrows. The strength of ebb decreases with depth but at a greater rate than in the Narrows, being here about 0.03 knot per foot against 0.01 knot in the Narrows. The strength of flood at some stations indicates an increase with depth, at some stations practically no change, and at some stations a decrease. But these changes are much smaller than the corresponding changes in the vertical distribution of the ebb velocity.

As a result of the differences in the vertical distribution in the flood and ebb velocities within the main channel of Upper Bay, the relative velocities of flood and ebb are different at the different depths. Near the surface the ebb velocity is greater by nearly a knot. At mid-depth the flood is a little larger than the ebb, while near the bottom the flood strength is about half a knot greater than the ebb strength.

Outside the main channel of Upper Bay, the currents do not show such large differences between ebb and flood as within the channel. Near the western shore of the bay the times of slack water do not change much with the depth and hence the durations of flood and ebb do not change much at the different depths. The velocities likewise do not exhibit as great differences at the different depths as in the main channel.

Along the eastern shore, with the exception of Buttermilk Channel, the features of the current within the depths are much like those along the western shore. The duration of flood and ebb and the velocities at the different depths do not change much. In Buttermilk Channel the durations of flood and ebb do not change much with depth, but the velocities of both the flood and ebb currents decrease, as a rule, with increasing depth.

THE CURRENT IN THE KILLS AND NEWARK BAY

SURFACE CURRENTS, ARTHUR KILL

For Arthur Kill there are at hand current observations at 13 stations. The locations of these stations are shown in figure 38, and the data derived for the current near the surface are given in table 56. In general, the data refer to the current at a depth of 7 feet from the surface. The velocities of the current given have been reduced to mean values.

The data of table 56 show that the current becomes later in going up Arthur Kill from south to north. Both the slacks and the strength come later at the northern end than at the southern end by a little more than an hour, on the average. Taking the more recent observations, it is seen that this change is at an approximately uniform rate.

In the discussion of the tide in Arthur Kill (p. 59) it was found that the time of tide becomes later in going from south to north by about three-quarters of an hour. It follows therefore that the time relation between current and tide are approximately constant throughout this waterway. Since the tide here averages about three-quarters of an hour later than at Sandy Hook, it follows that the slacks in Arthur Kill come about 1¼ hours after the times of local high and low water and the strengths about 2 hours before the times of local high and low water.

In the channel of Arthur Kill the velocity of the current at strength is approximately 1 knot. At the southern entrance, and for the greater part of the Kill, the flood and ebb strengths have approximately equal velocities; but at the northern end the flood current has somewhat the greater velocity. For the Kill as a whole, the more recent observations, that is those taken in the present century, indicate a somewhat greater velocity of the current than the older observations. But this difference averages less than a tenth of a knot, and may therefore not be significant.

From the more recent observations the duration of flood in Arthur Kill is about half an hour less than that of ebb, averaging 5.9 hours for the flood and 6.5 hours for the ebb. The older observations give a somewhat smaller duration of flood, about 5.7 hours.

CURRENT DATA, VARIOUS DEPTHS, ARTHUR KILL

For seven of the stations listed in table 56 there are at hand also current observations made at 0.2, 0.5, and 0.8 depths. The results derived from these observations are given in table 57, in which are included also the data for the 7-foot depth for comparison.

TABLE 56.—*Surface current data, Arthur Kill*

[Referred to times of HW and LW at Sandy Hook]

Station no.	Location	Party of—	Observations		Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
1	Off Perth Amboy, N. J.	H. C. Denson	August 1922	5¼	1.4	1.9	N. 10 E.	0.9	6.0	1.3	2.4	S. 10 W.	0.9	6.4
2	Off Tottenville, N. Y.	H. Mitchell	August 1856	1	0.9	2.3	N. 60 E.	0.5	6.3	1.1	2.3	S. 35 W.	0.5	6.1
2	do	I. E. Rittenburg	August 1932	2	1.9	1.5	N. 25 E.	1.4	5.5	1.3	1.8	S. 60 W.	1.4	6.9
3	Off Tufts Pt., N. J.	do	September 1932	2	1.9	1.4	S. 70 E.	1.2	5.9	1.7	1.9	S. 85 W.	1.2	6.5
4	Off Rossville, N. Y.	H. Mitchell	August 1856	½	1.1	2.1	N. 65 E.	0.5	6.3	1.3	2.1	S. 45 W.	0.4	6.1
5	Off Carteret, N. J.	do	do	½	1.7	1.7	N. 55 E.	0.7	5.7	1.3	2.1	S. 30 W.	1.1	6.7
6	Off Linoleumville, N. Y.	H. C. Denson	August 1922	1¾	2.2	1.4	N. 15 E.	1.0	5.9	2.0	1.7	S. 15 E.	1.0	6.5
7	Off Tremley Pt., N. J.	I. E. Rittenburg	June, August, September 1932	2	2.1	1.2	N. 25 E.	1.1	6.3	2.3	1.5	S. 25 W.	1.4	6.1
8	Off Grasseli, N. J.	H. Mitchell	August 1856	½	2.5	1.1	N. 5 W.	1.3	5.5	1.9	1.9	S. 5 E.	1.0	6.9
9	Off Elizabeth, N. J.	do	September 1856	½	3.1	0.4	N. 5 W.	1.6	5.7	2.7	1.0	S. 5 E.	1.4	6.7
10	do	H. L. Marindin	July 1885	1	2.7	1.0		1.8	5.4	2.0	0.7		1.7	7.0
11	do	H. C. Denson	August 1922	4¾	2.8	0.9	E.	1.2	6.0	2.7	0.6	W.	0.8	6.4
11	do	I. E. Rittenburg	June 1932	2	2.9	0.9	E.	1.4	5.8	2.6	1.0	S. 75 W.	1.2	6.6
12	do	R. J. Auld	November 1920	2	2.4	0.7	N. 60 E.	1.0	6.2	2.5	0.6	S. 75 W.	0.5	6.2
13	do	H. Mitchell	August 1856	1	2.6	0.9	E.	1.2	5.9	2.4	0.5	S. 85 W.	1.0	6.5

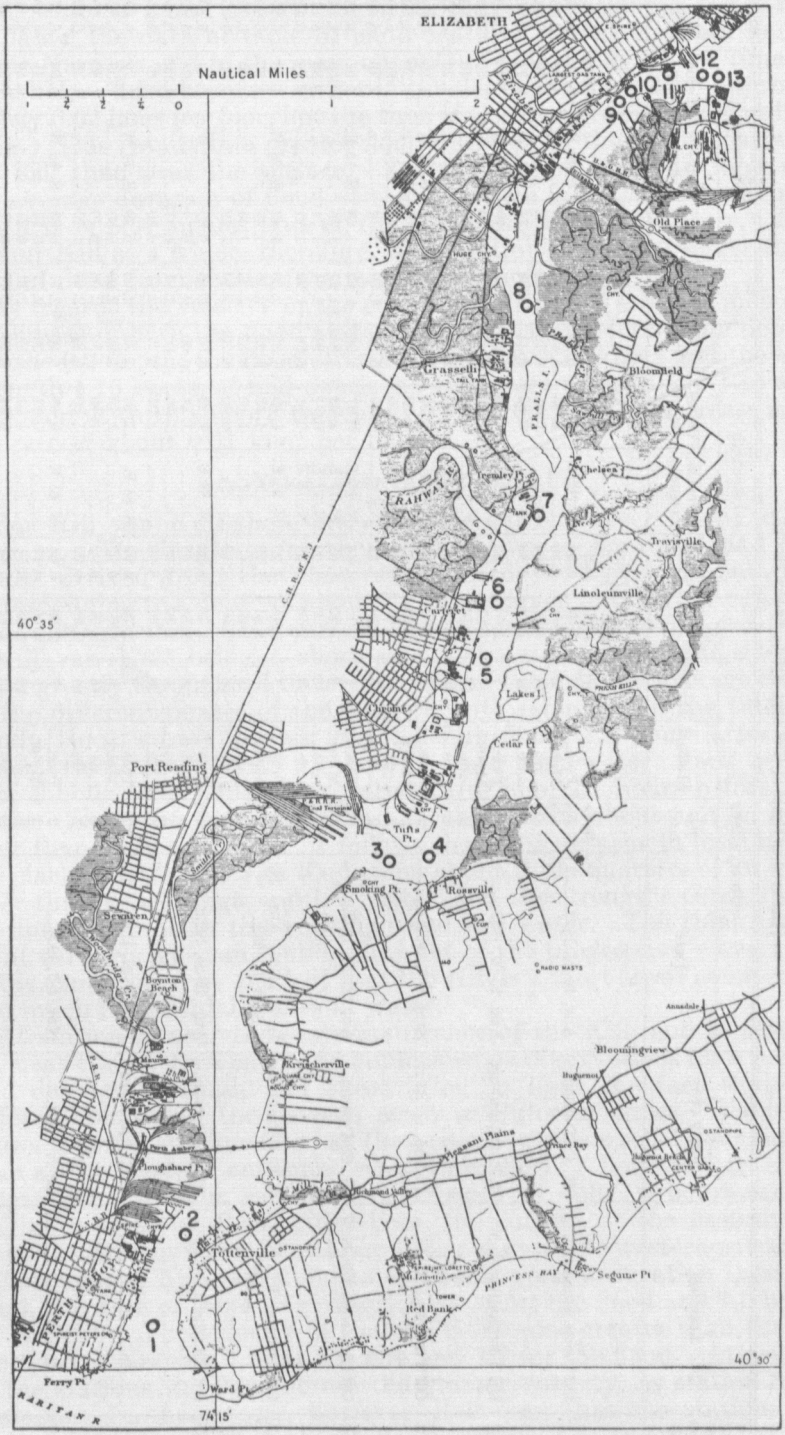

FIGURE 38.—Current stations, Arthur Kill.

TABLE 57.—*Current data, various depths, Arthur Kill*

[Referred to times of HW and LW at Sandy Hook]

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hrs.*
1	Off Perth Amboy, N. J.	H. C. Denson	Aug. 19-24, 1922	5¼	Pole	7	1.36	1.94	N. 12 E.	0.88	6.08	1.31	2.44	S. 10 W.	0.92	6.34
				5¼	Meter	5	1.52	1.88		0.95	5.97	1.36	2.88		1.08	6.45
				5¼	do	14	1.26	2.04		0.91	6.19	1.32	2.86		0.92	6.23
				5¼	do	21	1.06	1.89		0.82	6.41	1.34	2.74		0.71	6.01
2	Off Tottenville, N. Y.	I. E. Rittenburg	Aug. 25-27, 1932	2	Pole	7	1.91	1.52	N. 23 E.	1.40	5.52	1.30	1.79	S. 60 W	1.40	6.90
				2	Meter	7	1.91	1.82		1.40	5.42	1.20	1.79		1.50	7.00
				2	do	18	2.01	1.62		1.40	5.42	1.30	1.79		1.40	7.00
				2	do	28	2.01	1.92		1.30	5.32	1.20	1.79		1.20	7.10
3	Off Tufts Pt., N. J.	do	Sept. 6-8, 1932	2	Pole	7	1.91	1.42	S. 71 E.	1.20	5.92	1.70	1.89	S. 87 W.	1.20	6.50
				2	Meter	7	2.01	1.42		1.20	5.82	1.70	1.89		1.20	6.60
				2	do	17	2.01	1.12		1.10	5.82	1.70	1.79		1.30	6.60
				2	do	26	1.81	1.52		0.80	6.02	1.70	1.79		1.10	6.40
6	Off Linoleumville, N. Y.	H. C. Denson	Aug. 22-24, 1922	1¾	Pole	7	2.16	1.44	N. 16 E.	0.97	5.96	1.99	1.68	S. 15 E.	0.97	6.46
				1¾	Meter	6	2.22	1.51	N. 19 E.	1.03	5.88	1.97	1.58		0.95	6.54
				1¾	do	15	2.26	1.29	N. 17 E.	0.94	5.91	2.04	1.74		0.86	6.51
				1¾	do	24	2.26	1.36	N. 18 E.	0.84	5.86	1.99	1.21		0.74	6.56
7	Off Tremley Pt., N. J.	I. E. Rittenburg	June 24-25, Aug. 31, Sept. 1, 1932.	2	Pole	7	2.11	1.22	N. 26 E.	1.10	6.32	2.30	1.49	S. 24 W.	1.40	6.10
				2	Meter	6½	2.01	1.42		1.10	6.22	2.10	1.49		1.50	6.20
				2	do	16	2.01	1.42		1.10	6.32	2.20	1.49		1.40	6.10
				2	do	26	2.01	1.12		0.90	6.22	2.10	1.59		1.20	6.20
11	Off Elizabeth, N. J.	H. C. Denson	Aug. 19-24, 1922	4¾	Pole	7	2.76	0.89	N. 88 E.	1.22	6.03	2.66	0.65	W.	0.84	6.39
				5	Meter	6	2.84	0.68		1.38	6.00	2.71	0.79		0.94	6.42
				5	do	15	2.82	0.68		1.36	6.02	2.71	0.81		1.00	6.40
				5	do	24	2.67	0.99		1.25	6.17	2.71	0.80		0.87	6.25
11	do	I. E. Rittenburg	June 22-24, 1932	2	Pole	7	2.91	0.92	S. 88 E.	1.40	5.82	2.60	0.99	S. 74 W.	1.20	6.60
				2	Meter	6	2.91	0.92		1.40	5.82	2.60	0.89		1.20	6.60
				2	do	15	2.91	0.92		1.40	5.82	2.60	0.79		1.40	6.60
				2	do	24	2.91	0.92		1.20	5.82	2.60	1.29		1.30	6.60
12	do	R. J. Auld	Nov. 5-7, 1920	2	Pole	7	2.39	0.68	N. 61 E.	0.98	6.25	2.51	0.63	S. 76 W.	0.54	6.17
				2	Meter	5	2.66	0.14		0.93	6.24	2.77	0.73		0.41	6.18
				2	do	12	2.66	0.51		1.01	6.28	2.81	0.24		0.56	6.14
				2	do	19	2.62	0.44		0.94	6.28	2.77	0.41		0.50	6.14

At stations 1 and 11, at which the longest continuous series are available, the data of table 57 show features similar to those found in the Narrows and in the main channel of Upper Bay. The time of slack before flood becomes earlier in the depths at the rate of approximately 0.02 hour per foot, but the time of slack before ebb changes but little. This results in a greater flood duration in the deeper parts of the Kill than near the surface. For the seven stations in table 57, the average duration of flood at the 0.2 depth is 5.92 hours; at mid-depth it is 5.97 hours; and at the 0.8 depth it is 6.01 hours. For Arthur Kill as a whole, therefore, the duration of ebb is greater than that of flood from the surface to near the bottom.

As regards the velocity of the current, the data of table 57 indicate a decrease in both the flood and ebb strengths with increasing depth. For the 0.2 depth, the flood strength averages 1.17 knots and the ebb strength 1.10 knots, at mid-depth the values are respectively 1.15 and 1.10; and at the 0.8 depth they are 1.02 and 0.95. The decrease is at the rate of about 0.01 knot per foot.

SURFACE CURRENTS, KILL VAN KULL

For Kill van Kull there are available current observations at 10 stations. The locations of these are shown in figure 39 and the results derived from the observations made with the current pole corresponding to a depth of about 7 feet, are given in table 58. In this table the velocities of the current have been reduced to mean values.

Kill van Kull being a short strait, the time of current doesn't differ greatly throughout its length. From table 58 the average times of the different phases of the current, with reference to the tides at Sandy Hook are as follows: Slack before flood, 1.6 hours after low water; strength of flood, 2.1 hours before high water; slack before ebb, 1 hour after high water; strength of ebb, 2.1 hours before low water. Since the time of tide in Kill van Kull is about half an hour later than at Sandy Hook, it follows that with respect to local tides, the slacks within Kill van Kull come about three-quarters of an hour after the times of high and low water, and the strengths come about 2½ hours before the times of high and low water. The tidal movement through Kill van Kull is thus not of the progressive wave type but is conditioned by the fact that the Kill is a short strait connecting two much larger tidal bodies of water.

At station 2, near the eastern entrance of the Kill, and at station 10, near the western entrance, simultaneous observations for a period of 1 day are at hand, and these bring to light the fact that the different phases of the current occur at different times. Table 58 shows that slack before flood at the eastern entrance is 0.3 hour earlier than at the western entrance, strength of flood 1 hour earlier, slack before ebb 0.1 hour earlier, and strength of ebb 1.6 hours earlier. Taking a mean of these differences, the current at the eastern entrance is three-quarters of an hour earlier than at the western entrance.

Throughout Kill van Kull the ebb has a greater duration than the flood, the data of table 58 giving 5.4 hours for the flood and 7.0 hours for the ebb. The velocity of the ebb is likewise greater than that of the flood, averaging 1.8 for the ebb and 1.7 for the flood. At several of the stations the flood shows the greater velocity, as station 8 for example. In these cases, however, it is seen that the stations are located in the path of the main flood current, but to one side of the main ebb current.

TABLE 58.—*Surface current data; Kill van Kull*

[Referred to times of HW and LW at Sandy Hook]

Station no.	Location	Party of—	Observations		Slack	Flood strength			Flood Duration	Slack	Ebb strength			Ebb Duration
			Date	Period		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
1	Off New Brighton, N. Y.	I. Winston	November, December, 1919	1¾	1.6	2.3	S. 15 W.	1.4	5.1	0.6	2.8	N. 75 E.	1.9	7.3
2	do	H. C. Denson	August 1922	10¾	1.3	2.4	S. 30 W.	1.7	5.7	0.9	2.8	N. 40 E.	1.8	6.7
3	Off W. New Brighton, N. Y.	H. L. Marindin	July 1885	¾	1.8	3.0		1.2	4.6	0.3	2.0		1.4	7.8
4	Off Bergen Point, N. J.	do	do	¾	2.0	2.0		1.9	5.0	0.9	1.8		1.5	7.4
5	do	do	do	¾	1.8	2.7		1.9	5.3	1.0	2.0		1.5	7.1
6	do	I. Winston	November 1919	1¼	1.4	1.7	S. 65 W.	2.2	5.6	0.9	2.3	N. 80 E.	2.1	6.8
6	do	I. E. Rittenburg	June 1932	2	1.3	2.4	S. 60 W.	2.0	6.0	1.2	2.8	N. 75 E.	1.9	6.4
7	do	H. Mitchell	August 1856	1¼	1.9	1.3	S. 85 W.	1.4	5.3	1.1	2.0	N. 85 E.	2.2	7.1
8	Off Port Richmond, N. Y.	I. Winston	November 1919	1¾	1.3	2.0	S. 80 W.	2.3	5.7	0.9	2.6	N. 85 E.	1.9	6.7
9	Off Bergen Point Light, N. J.	H. Mitchell	August 1856	1¼	1.9	1.5	N. 85 W.	1.8	5.9	1.7	1.3	S. 50 E.	2.0	6.5
10	do	H. C. Denson	August 1922	1	1.6	1.4	N. 50 W.	1.2	5.5	1.0	1.2	S. 15 E.	1.7	6.9

CURRENT DATA, VARIOUS DEPTHS, KILL VAN KULL

For five stations in Kill van Kull there are available current observations at 0.2, 0.5, and 0.8 depths. The results of these observations are given in table 59, together with the results for the 7-foot depth derived from the observations with the current pole. For the sake of comparison the times are given to the second decimal of an hour, the velocities to the second decimal of a knot, and the directions to the nearest whole degree. Where directions are given for the current at the different depths, these directions were determined by means of the bifilar direction indicator.

The time of slack before flood shows the characteristic decrease with depth found in tidal waters carrying a considerable amount of fresh-water flow. The average decrease in time from table 59 is

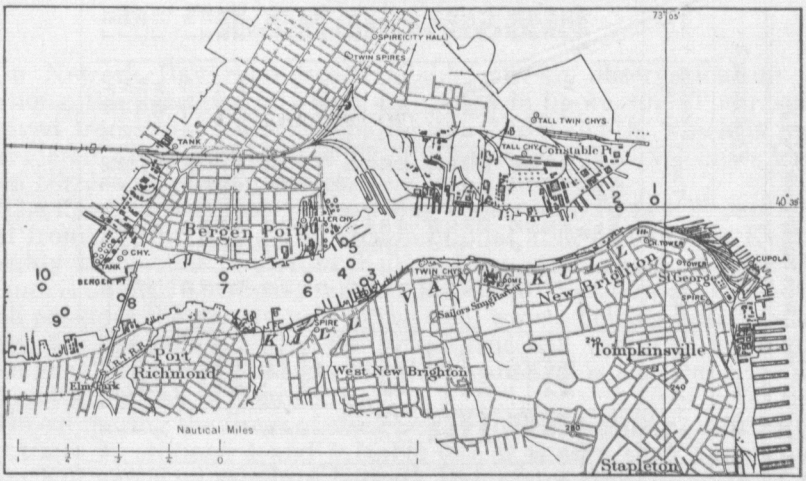

FIGURE 39.—Current stations, Kill van Kull.

about 0.01 hour per foot. The slack before ebb shows but little change with depth, a slight increase in time being indicated at most stations.

This difference in the behavior of the two slacks brings about the same difference in the durations of flood and ebb in Kill van Kull that was noted in the Narrows, Upper Bay, and Arthur Kill. At the 0.2 depth the duration of flood at the stations listed in table 59 is 5.74 hours, and for the ebb, 6.68 hours. At mid-depth the corresponding values are 5.98 hours and 6.44 hours. And at the 0.8 depth they are 6.23 hours and 6.19 hours. Near the bottom, therefore, the duration of flood in Kill van Kull is somewhat greater than that of ebb. In this regard the current in Kill van Kull differs from that in Arthur Kill, for in the latter the duration of ebb was greater for all three depths.

140597—35——10

TABLE 59.—*Current data, various depths, Kill Van Kull*

[Referred to times of HW and LW at Sandy Hook, N. J.]

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
1	Off New Brighton, N. Y.	I. Winston	Nov. 18-19, Dec. 2-3, 1919.	1¾	Pole	7	1.54	2.28	S. 75 W.	1.39	5.21	0.62	2.86	N. 75 E.	1.90	7.21
				1¾	Meter	8	1.31	2.23		1.16	5.51	0.69	2.71		1.83	6.91
				1¾	do	21	1.01	2.46		1.15	6.14	1.02	2.16		1.00	6.28
				1¾	do	34	0.54	2.09		1.12	6.75	1.16	2.11		0.37	5.67
2	do	H. C. Denson	Aug. 13-24, 1922	10¾	Pole	7	1.32	2.38	S. 30 W.	1.72	5.69	0.88	2.83	N. 41 E.	1.80	6.73
				10¾	Meter	10	1.39	2.46	S. 24 W.	1.73	5.75	1.01	3.04	N. 36 E.	1.73	6.67
				10¾	do	24	1.07	2.43	S. 24 W.	1.49	6.28	1.22	2.79	N. 32 E.	1.43	6.14
				10¾	do	38	0.62	2.18	S. 19 W.	1.30	6.63	1.12	2.56	N. 39 E.	0.89	5.79
6	Off Bergen Point, N J.	I. Winston	Nov. 25-26, Dec. 10-11, 1919.	1¾	Pole	7	1.39	1.71	S. 63 W.	2.24	5.58	0.84	2.28	N. 80 E.	2.14	6.84
				1¾	Meter	7	1.59	1.71		1.81	5.55	1.01	2.31		2.23	6.87
				1¾	do	16	1.59	1.71		1.62	5.55	1.01	2.23		1.99	6.87
				1¾	do	24	1.39	1.71		1.26	5.73	0.99	2.04		1.66	6.69
6	do	I. E. Rittenburg	June 22-24, 1932	2	Pole	7	1.31	2.42	S. 62 W.	2.00	6.02	1.20	2.79	N. 75 E.	1.90	6.40
				2	Meter	6	1.21	2.42		1.90	6.12	1.20	2.79		1.80	6.30
				2	do	16	1.11	2.52		1.70	6.22	1.20	2.79		1.60	6.20
				2	do	24	1.01	2.52		1.60	6.42	1.30	2.59		1.50	6.00
8	Off Port Richmond, N. Y.	I. Winston	Nov. 21-22, Dec. 5-6, 1919.	1¾	Pole	7	1.29	1.99	S. 82 W.	2.30	5.76	0.92	2.64	N. 86 E.	1.93	6.66
				2	Meter	7	1.41	2.21		2.24	5.91	1.19	2.43		1.66	6.51
				2	do	16	1.31	2.21		2.18	5.96	1.14	2.36		1.72	6.46
				2	do	24	1.27	2.29		1.93	6.05	1.19	2.19		1.63	6.37
10	Off Bergen Point Light, N. J.	H. C. Denson	Aug. 20-21, 1922	1	Pole	7	1.59	1.41	N 49 W.	1.15	5.53	0.99	1.16	S. 13 E.	1.72	6.89
				1	Meter	5	1.59	1.71	N. 53 W.	1.35	5.58	1.04	1.01		1.55	6.84
				1	do	12	1.54	1.46	N. 49 W.	1.33	5.73	1.14	1.26		1.39	6.69
				1	do	20	1.49	1.56	N. 49 W.	1.21	5.78	1.14	1.81		1.25	6.64

The strength of flood in Kill van Kull decreases with depth; on the average, a little less than 0.016 knot per foot. The ebb strength likewise decreases, but at a more rapid rate, the five stations in table 59 giving an average of 0.026 knot per foot. At the 0.2 depth the flood strength averages 1.70 knots and the ebb strength 1.80 knots. At mid-depth the corresponding values are 1.58 knots and 1.52 knots; and at the 0.8 depth they are 1.40 knots and 1.22 knots. From the surface to about mid-depth, therefore, the ebb has the greater velocity; but below that depth the flood has the greater velocity.

In regard to the relative velocities of flood and ebb at the different depths, Kill van Kull differs from Arthur Kill, for in the latter waterway the flood current had the greater velocity at all three depths. In Kill van Kull, on the other hand, the ebb had the greater velocity to near mid-depth, but below that the flood had the greater velocity.

SURFACE CURRENTS, NEWARK BAY

In Newark Bay there are available current observations at 12 stations, the locations of which are shown in figure 40. The results derived from these observations for the 7-foot depth, which is here considered as the surface, are given in table 60. The velocities have been corrected to mean values.

The flood current into Newark Bay comes both from Kill van Kull and from Arthur Kill. The cross-sectional area of Kill van Kull is roughly twice that of Arthur Kill and the strength of flood in the former is about 70 percent greater. It follows, therefore, that Kill van Kull provides the greater part of the tidal waters flowing into Newark Bay. On the ebb, likewise, the velocity in Kill van Kull is greater than that in Arthur Kill. So that Kill van Kull is also the principal outlet for the ebb of Newark Bay.

On comparing the times of slack before flood at stations 1 and 2 with the times at stations 4 and 5 (table 60), it is seen that the current from Kill van Kull sets into Newark Bay about three quarters of an hour earlier than from Arthur Kill. On the ebb, too, the current setting from Newark Bay into Kill van Kull is about an hour earlier than that setting into Arthur Kill.

As regards the change in time of current in Newark Bay, a comparison of the data for station 7 with those for the stations in Hackensack and Passaic Rivers shows that the current becomes later in going upstream by about three-quarters of an hour. The tide in Newark Bay is about an hour later than at Sandy Hook. It follows, therefore, from table 60 that the slacks in Newark Bay come about an hour after local high and low water, and the strengths about 2 hours before the times of local high and low water.

Throughout Newark Bay, the duration of flood for the current near the surface is somewhat less than that of ebb, averaging 6.0 hours for the flood against 6.4 hours for the ebb. In the main channel of the bay, the current at strength has a velocity of about 1¼ knots with but little difference between the flood and ebb velocities

In the Passaic and Hackensack Rivers, near their mouths, the currents have smaller velocities than in the main channel of Newark Bay. In the Passaic the velocity at strength is about half a knot, while in the Hackensack it is a little more than three-quarters of a knot.

TABLE 60.—*Surface current data, Newark Bay*

[Referred to times of HW and LW at Sandy Hook, N. J.]

Station no.	Location	Party of—	Observations		Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
1	Off Bergen Point Light, N. J.	H. Mitchell	August 1856	1¼	1.9	1.5	N. 85 W.	1.8	5.9	1.6	1.3	S. 50 E.	2.0	6.5
2	do	H. C. Denson	August 1922	1	1.6	1.4	N. 50 W.	1.2	5.5	1.0	1.2	S. 15 E.	1.7	6.9
3	Off Mariners Harbor, N. Y.	do	do	1	−1.0	3.4	N. 80 W.	0.7	7.8	0.7	3.8	N. 85 E.	0.5	4.6
4	Off Elizabeth, N. J.	H. Mitchell	August 1856	1	2.6	0.9	E.	1.2	5.9	2.4	0.5	S. 85 W.	1.0	6.5
5	do	R. J. Auld	November 1920	2	2.4	0.7	N. 60 E.	1.0	6.2	2.5	0.6	S. 75 W.	0.5	6.2
6	do	H. Mitchell	August 1856	½	3.1	1.1	N. 5 W.	0.7	4.9	1.9	0.4	S. 20 W.	0.7	7.5
7	Off Bergen Point, N. J.	R. J. Auld	November 1920	2	1.8	1.8	N. 40 E.	1.2	5.9	1.6	1.2	S. 30 W.	1.2	6.5
8	Off Bayonne, N. J.	H. C. Denson	August 1922	1	2.1	2.1	N. 45 E.	0.9	6.1	2.1	−0.6	S. 45 W.	1.4	6.3
9	Off Port Newark, N. J.	R. J. Auld	October 1920	2	1.7	1.7	N. 5 E.	1.5	6.0	1.6	1.3	S.	1.4	6.4
10	Passaic River	H. C. Denson	August 1922	1	2.4	0.5	N.	0.3	5.7	2.0	2.7	S. 10 E.	0.7	6.7
11	do	R. J. Auld	October 1920	2	2.1	1.1	N. 15 E.	0.6	6.2	2.2	1.8	S. 5 W.	0.4	6.2
12	Hackensack River	do	do	2	2.6	0.4	N. 15 E.	1.1	6.2	2.7	0.8	S.	0.9	6.2
12	do	H. C. Denson	August 1922	½	2.5	0.5	N.	0.7	6.2	2.6	0.2	S.	0.8	6.2

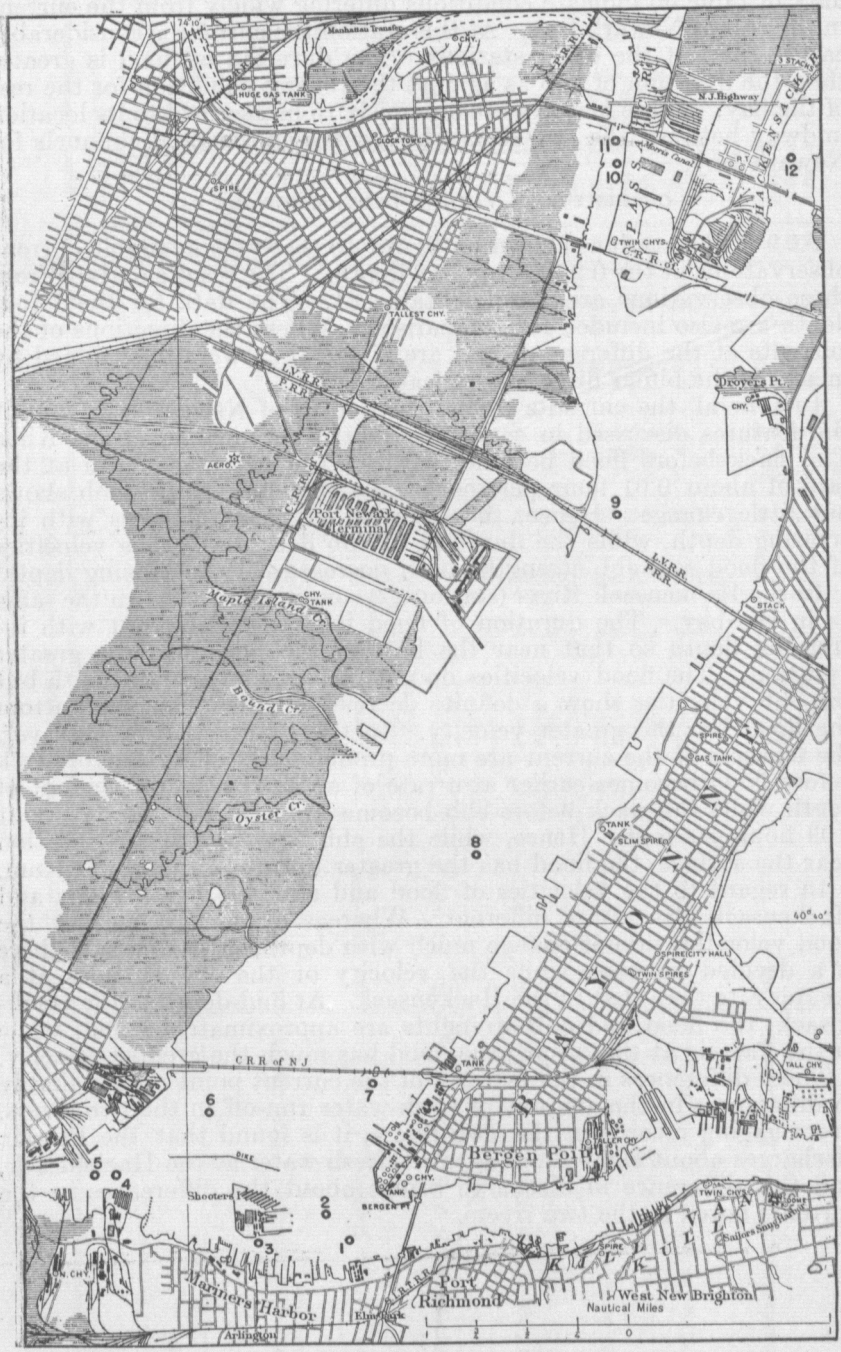

FIGURE 40.—Current stations, Newark Bay.

For station 3, between Mariners Harbor and Shooters Island, the data of table 60 indicate conditions differing widely from the current in the rest of Newark Bay. At this station the current is considerably earlier than at the other stations. The duration of flood is greater than the duration of ebb as against the reverse condition for the rest of the bay. These features are obviously to be ascribed to its location midway between the two Kills which serve as the tidal channels for Newark Bay.

CURRENT DATA, VARIOUS DEPTHS, NEWARK BAY

At 9 of the stations shown on figure 40 there are available current observations at the 0.2, 0.5, and 0.8 depths. The results derived from these observations are given in table 61. The data for the 7-foot depth are also included for comparison. Where the directions of the currents at the different depths are given, they were determined by means of the bifilar direction indicator.

In general, the currents within the depths of Newark Bay exhibit the features discussed in connection with the currents in the Kills. The slack before flood becomes earlier with increased depth at the rate of about 0.01 hour per foot, while the slack before ebb shows but little change. Hence, the duration of flood increases with increasing depth, while the duration of ebb decreases. The velocities of the flood and ebb strengths both decrease with increasing depth.

In the Hackensack River (station 12) conditions are much the same as in the bay. The duration of flood increases somewhat with increasing depth so that near the bottom the flood has the greater duration. The flood velocities do not change much with depth but the ebb velocities show a definite decrease so that near the bottom the flood has the greater velocity. In the Passaic River, however, the features of the current are more pronounced. The time of slack before flood becomes earlier at a rate of about 0.07 hour per foot of depth while the slack before ebb becomes later at the rate of about 0.03 hour per foot. Hence, while the ebb has the greater duration near the surface, the flood has the greater duration near the bottom.

In regard to the velocities of flood and ebb, too, the Passaic and Hackensack Rivers are different. Whereas in the Hackensack the flood velocities do not change much with depth, in the Passaic there is a decided increase while the velocity of the ebb changes at a greater rate than that in the Hackensack. At mid-depth in the Hackensack, the flood and ebb strenghts are approximately equal, while in the Passaic at that depth the flood has much the greater velocity.

These differences in the features of the current point unmistakably to differences in the amount of fresh-water run-off in the two rivers. From gaging records in the two rivers, it is found that the Passaic discharges about eight times as much fresh water as the Hackensack, and this difference in discharge brings about the differences in the currents noted in the two rivers.

TABLE 61.—*Current data, various depths, Newark Bay*

[Referred to times of HW and LW at Sandy Hook, N. J.]

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
2	Off Bergen Point Light, N. J.	H. C. Denson	Aug. 20-21, 1922	1	Pole	7	1.59	1.41	N. 49 W.	1.15	5.53	0.99	1.16	S. 13 E.	1.72	6.89
				1	Meter	5	1.59	1.71	N. 53 W.	1.35	5.58	1.04	1.01	S. 8 E.	1.55	6.84
				1	do	12	1.54	1.46	N. 49 W.	1.33	5.73	1.14	1.26	S. 9 E.	1.39	6.69
				1	do	20	1.49	1.56	N. 49 W.	1.21	5.78	1.14	1.81	S. 9 E.	1.25	6.64
3	Off Mariners Harbor, N. Y.	do	Aug. 19-20, 1922	1	Pole	7	−1.06	3.41	N. 79 W.	0.69	7.88	0.69	3.86	N. 83 E.	0.46	4.54
				1	Meter	6	−1.11	3.91	N. 86 W.	0.66	8.43	1.19	3.56	N. 84 E.	0.56	3.99
				1	do	15	−1.26	2.21	N. 85 W.	0.79	8.63	1.24	3.21	N. 85 E.	0.26	3.79
				1	do	24	−0.96	1.96	S. 89 W.	0.86	8.38	1.29	3.01	N. 85 E.	0.26	4.04
5	Off Elizabeth, N. J.	R. J. Auld	Nov. 5-7, 1920	2	Pole	7	2.39	0.68	N. 61 E.	0.98	6.25	2.51	0.63	S. 76 W.	0.54	6.17
				2	Meter	5	2.66	0.14		0.93	6.24	2.77	0.73		0.41	6.18
				2	do	12	2.66	0.51		1.01	6.28	2.81	0.24		0.56	6.14
				2	do	19	2.62	0.44		0.94	6.28	2.77	0.41		0.50	6.14
7	Off Bergen Point, N. J.	do	Nov. 3-5, 1920	2	Pole	7	1.79	1.81	N. 42 E.	1.25	5.90	1.56	1.21	S. 32 W.	1.19	6.52
				2	Meter	7	1.92	1.91		1.15	5.93	1.72	1.04		1.08	6.49
				2	do	18	1.79	1.91		1.18	6.00	1.66	1.38		0.93	6.42
				2	do	29	1.71	1.99		1.04	6.01	1.59	1.89		0.82	6.41
8	Off Bayonne, N. J.	H. C. Denson	Aug. 21-22, 1922	1	Pole	7	2.09	2.06	N. 46 E.	0.94	6.13	2.09	−0.54	S. 45 W.	1.41	6.29
				1	Meter	6	2.24	1.56	N. 54 E.	0.85	5.83	1.94	0.91	S. 37 W.	1.35	6.59
				1	do	16	2.14	2.21	N. 29 E.	0.90	5.93	1.94	0.96	S. 38 W.	1.30	6.49
				1	do	26	1.79	1.76	N. 27 E.	0.96	6.28	1.94	0.76	S. 41 W.	1.13	6.14
9	Off Port Newark, N. J.	R. J. Auld	Oct. 21-23, 1920	2	Pole	7	1.71	1.68	N. 5 E.	1.53	6.03	1.61	1.33	S.	1.43	6.39
				2	Meter	5	2.07	1.53		1.53	5.62	1.56	0.91		1.35	6.80
				2	do	12	2.04	1.79		1.50	5.71	1.62	0.98		1.07	6.71
				2	do	20	1.91	1.94		1.45	5.98	1.76	1.21		0.88	6.44
10	Passaic River, N. J.	H. C. Denson	Aug. 23-24, 1922	1	Pole	7	2.34	0.54	N. 1 W.	0.33	5.78	1.99	2.71	S. 8 E.	0.71	6.64
				1	Meter	5	2.49	0.91	N. 10 W.	0.42	5.28	1.64	2.91	S. 8 E.	0.62	7.14
				1	do	13	2.14	1.36	N. 2 W.	0.67	5.98	1.99	2.66	S. 4 E.	0.29	6.44
				1	do	21	0.99	0.88	N. 2 W.	0.74	7.33	2.19	3.56	S. 18 E.	0.07	5.09

TABLE 61.—*Current data, various depths, Newark Bay*—Continued

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*		*Knots*	*Hours*	*Hours after HW*	*Hours before LW*		*Knots*	*Hour*
11	Passaic River, N. J.	R. J. Auld	Oct. 28-30, 1920	2	Pole	7	2.11	1.11	N. 16 E.	0.64	6.21	2.19	1.83	S. 4 W.	0.42	6.21
				2	Meter	5	2.37	0.88		0.57	5.43	1.67	2.14		0.59	6.99
				2	do	10	2.16	1.11		0.82	5.85	1.88	1.78		0.32	6.57
				2	do	20	1.61	0.70		0.72	6.56	2.04	1.74		0.12	5.86
12	Hackensack River, N. J.	do	Oct. 25-27, 1920	2	Pole	7	2.64	0.43	N. 17 E.	1.07	6.13	2.64	0.79	S. 1 W.	0.88	6.29
				2	Meter	5	2.72	0.54		0.87	6.38	2.97	1.24		0.80	6.04
				2	do	13	2.66	0.46		0.88	6.49	3.02	1.34		0.71	5.93
				2	do	21	2.62	0.38		0.86	6.50	2.99	1.49		0.59	5.92
12	do	H. C. Denson	Aug. 23, 1922	½	Pole	7	2.49	0.51	N.	0.67	6.23	2.59	0.21	S.	0.79	6.19
				½	Meter	7	2.69	0.91		0.59	6.23	2.79	1.01		0.96	6.19
				½	do	18	2.59	0.71		0.73	6.33	2.79	1.01		0.78	6.09
				½	do	29	2.49	0.21		0.81	6.43	2.79	0.91		0.66	5.99

THE CURRENT IN THE HUDSON AND HARLEM RIVERS

SURFACE CURRENTS, HUDSON RIVER

The part of the Hudson here considered is the 14-mile stretch from the Battery to Mount St. Vincent. For this stretch, figures 41a and 41b show the locations of 84 stations at 78 of which currents were observed near the surface. Table 62 gives the data derived from these observations. The greater number of these observations were made by use of a 15-foot current pole submerged 14 feet so that the data of table 62 may be taken to pertain to a depth of 7 feet below the surface.

The data for the stations near the mouth of the Hudson show that, with reference to Sandy Hook tides, the time relations of the current are as follows: Slack before flood comes about 2.0 hours before high water, strength of flood 0.3 hour after high water, slack before ebb, 3 hours before low water, strength of ebb, 0.3 hour after low water. From tables 32 and 39 it is seen that the tide at the entrance to the Hudson is about half an hour later than at Sandy Hook. With respect to local tides, therefore, the current at the entrance to the Hudson River is slack halfway between high and low water, and at strength at about the times of high and low water.

A comparison of the time relations of the current at station 5 and at station 83 shows that in the 14-mile stretch the current becomes later by a little over 1 hour. In the discussion of the tide in this stretch of the river (page 67) it was found that the tide likewise became later by a little more than an hour. Throughout this part of the Hudson, therefore, the time relations of current to tide are practically constant, these time relations being the ones found in progressive-wave motion.

Taking the velocities given by the more recent observations, it is seen that along the axis of the channel the flood strength at the entrance to the Hudson averages about 1¼ knots. Further upstream, as the channel narrows towards Castle Point the velocity increases to a little over 1½ knots, and off Fort Washington Point it has its greatest velocity, namely about 2¼ knots. For the whole stretch the flood strength averages 1½ knots.

Along the axis of the channel the ebb has a greater velocity than the flood, the 14-mile stretch giving an average velocity of ebb strength of 2¼ knots against 1½ knots for the flood strength. Like the flood, the ebb is somewhat less than the average near the mouth of the river increasing to a little over 2½ knots off Fort Washington Point.

At station 71, the observations made in 1919 give much larger velocities on both the flood and the ebb than do the observations made at that same station in 1922 or in 1932. In the 1919 series, 4 floods and 4 ebbs were observed between September 2 and September 4, the flood strengths giving an average of 1.12 knots and the ebb strengths an average of 2.16 knots. Unusually small ranges of the tide prevailed on these days so that the correction factor for correcting the velocities to mean values from the ratio of ranges was 1.58. Apparently, the velocity of the current at this station does not vary in simple proportion to the range of tide, and the correction factor in this case is undoubtedly too large.

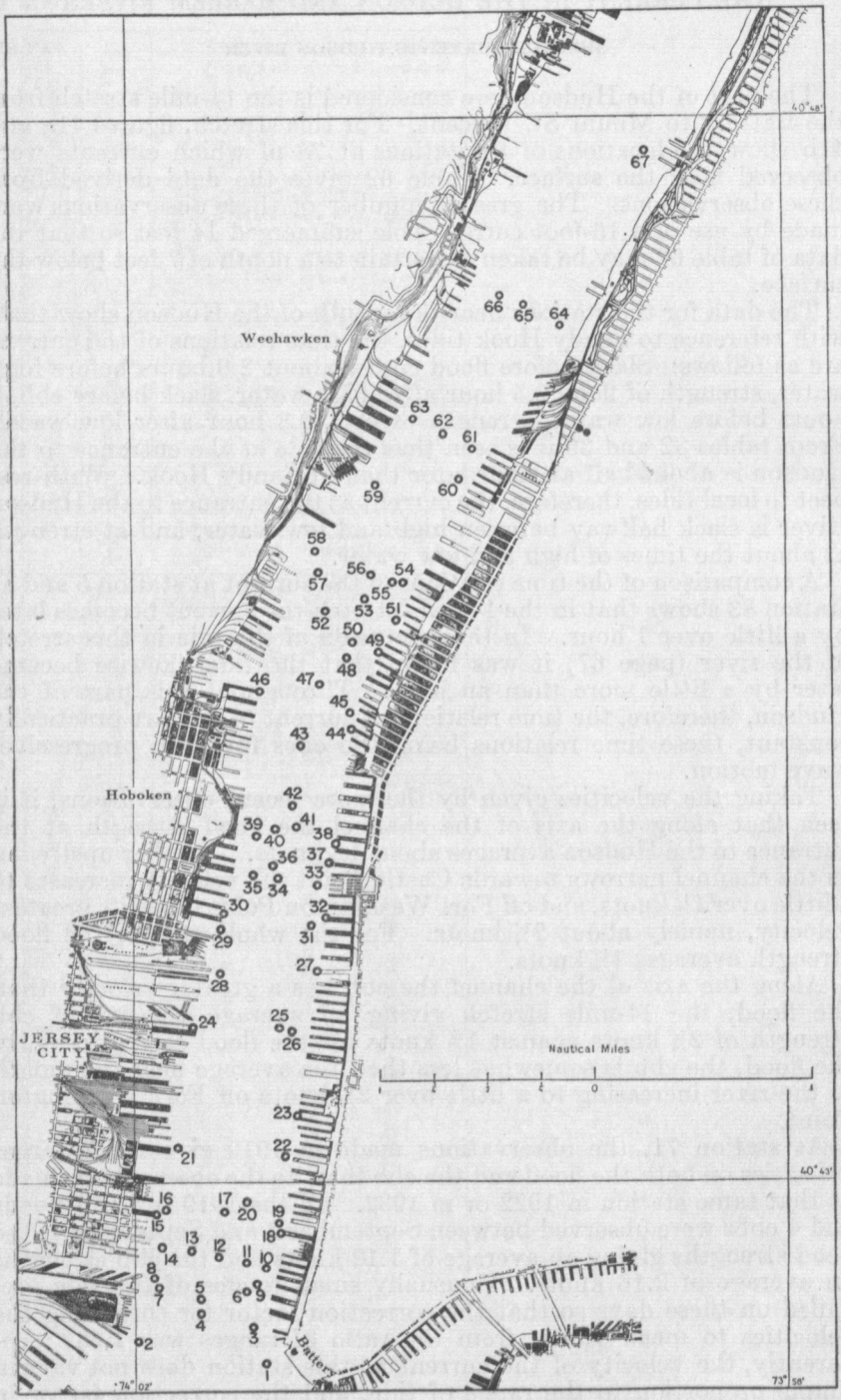

FIGURE 41a.—Current stations, Hudson River (lower section).

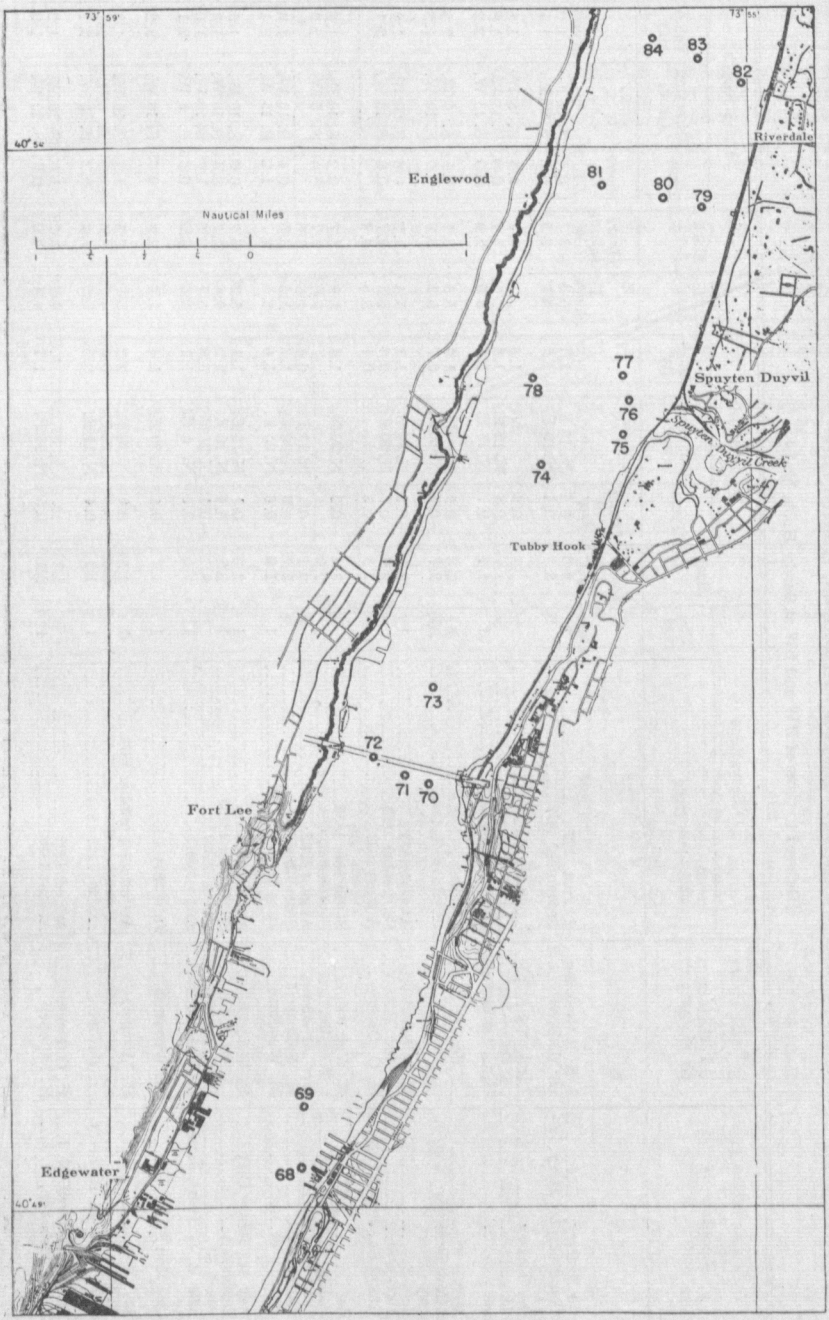

FIGURE 41b.—Current stations, Hudson River (lower section).

TABLE 62.—*Surface current data, Hudson River*

[Referred to times of HW and LW at Sandy Hook, N. J.]

Station no.	Location	Party of—	Observations: Date	Observations: Period	Slack	Flood strength: Time	Flood strength: Direction (true)	Flood strength: Velocity	Flood duration	Slack	Ebb strength: Time	Ebb strength: Direction (true)	Ebb strength: Velocity	Ebb duration
				Days	*Hours before HW*	*Hours after HW*	°	*Knots*	*Hours*	*Hours before LW*	*Hours after LW*	°	*Knots*	*Hours*
1	Off the Battery	I. E. Rittenburg	August 1932	2	2.0	0.6	N. 15 E.	1.1	5.2	3.1	0.1	S. 10 E.	1.0	7.2
2	Off Communipaw Ferry, Jersey City.	H. Mitchell	September 1872	½	2.1	−0.4	N. 10 E.	1.1	5.9	2.5	0.2	S. 20 W.	1.1	6.5
3	Off the Battery	do	do	½		0.4	N.	1.4		3.4	0.4	S. 5 W.	1.8	
4	do	do	do	½		0.6	N. 10 E.	1.4		3.1	0.0	S. 15 W.	1.8	
5	do	H. C. Denson	July, August 1922	31	1.7	0.7	N. 15 E.	1.2	5.0	2.9	0.9	S. 15 W.	2.2	7.4
6	Off Morris St	do	do	3	2.3	0.7	N.	1.4	5.5	3.1	0.5	S. 5 W.	2.2	6.9
7	Off Communipaw Ferry, Jersey City.	do	do	3½	2.7	−0.2	N. 15 E.	0.7	5.2	3.8	0.0	S. 10 W.	1.8	7.2
8	do	H. Mitchell	August 1873	1	2.3	−0.2	N. 15 E.	1.1	5.4	3.2	0.6	S. 20 W.	1.9	7.0
9	Off Morris St	do	September 1873	½	2.7	0.5	N. 20 E.	2.1	6.3	2.7	0.6	S. 10 W.	2.1	6.1
15	Off Grand St., Jersey City	H. C. Denson	August 1922	½	2.3	0.3		0.1	5.8	2.8				6.6
16	do	R. Wainwright	September 1855	½	3.2	−0.2	N. 20 E.	1.4	5.8	3.7	0.2	S. 10 E.	1.8	6.6
17	Off Fulton St	I. Winston	September, October 1919	2	2.0				5.6	2.7	0.5	S. 5 W.	2.3	6.8
18	Off Cortlandt St	H. C. Denson	August 1922	½	2.1	0.5	N. 15 E.	0.4	4.8	3.6				7.6
19	Off Fulton St	R. Wainwright	September 1855	½	2.7	0.0	N. 30 E.	1.3	5.5	3.5	0.1	S. 10 W.	1.6	6.9
20	Off Barclay St	M. Woodhull	June 1854	1	1.9	0.6	N. 25 E.	1.6	5.5	2.7	1.2	S. 15 W.	2.1	6.9
21	Off Bay St., Jersey City	H. Mitchell	August 1873	1	2.6	0.1	N. 10 E.	1.1	5.2	3.7	0.6	S. 10 W.	1.5	7.2
22	Off Duane St	do	September 1873	1	2.8	0.4	N. 10 E.	2.0	6.4	2.7	0.4	S. 10 W.	1.6	6.0
23	Off Beach St	H. C. Denson	August 1922	½	2.1	−0.1	N. 25 W.	0.8	5.7	2.6	1.7	S. 10 W.	1.0	6.7
24	Off Erie R. R. Piers, Jersey City.	H. Mitchell	August 1873	1	2.2	0.3	N. 5 E.	1.1	4.6	3.9	0.6	S. 5 W.	2.1	7.8
25	Off Charlton St	M. Woodhull	June 1854	1	1.7	0.6	N. 20 E.	1.4	5.2	2.8	0.7	S. 10 W.	2.2	7.2
26	do	H. Mitchell	August, September 1873	1	1.8	0.9	N. 20 E.	2.2	5.7	2.4	1.2	S. 10 W.	1.8	6.7
27	Off W. 10th St	R. Wainwright	September 1855	½	2.0	0.0	N. 20 E.	0.8	4.7	3.6	−1.0	S. 5 E.	2.1	7.7
28	Off D. L. & W. R. R. Ferry Jersey City.	do	do	1	1.1	0.4	N. 15 E.	0.8	3.2	4.2	0.2	S. 5 W.	2.1	9.2
29	Off 1st St., Hoboken, N. J	H. C. Denson	August 1922	½	1.7				4.8	3.2	1.0	S. 10 W.	1.2	7.[illegible]
30	Off 2d St., Hoboken, N. J	H. Mitchell	August 1873	1	2.1	0.5	N. 20 E.	1.1	4.4	4.0	0.8	S. 20 W.	1.9	8.[illegible]
31	Off Bank St	do	do	½	1.3	1.1	N. 10 E.	1.6	5.1	2.5	1.0	S. 5 E.	1.6	7.3
32	Off Bethune St	H. C. Denson	August 1922	½	1.2				3.0	4.5	−0.1	S. 25 E.	1.6	9.4
33	Off Gansevoort St	I.E. Rittenburg	July 1932	2	1.5	0.8	N. 10 E.	0.9	4.4	3.4	0.7	S.	2.0	8.0
34	do	do	August 1932	2	2.1	0.9	N. 10 E.	1.7	5.5	2.9	0.7	S.	2.4	6.9
35	do	do	July 1932	2	1.6	0.3	N. 25 E.	1.0	4.4	3.5	0.7	S. 10 W.	2.7	8.0
36	Off W. 13th St	I. Winston	September 1919	½	2.1	0.1	N. 15 E.	1.2	5.2	3.2				7.2
37	do	H. C. Denson	August 1922	½	2.7	−0.3	N. 15 E.	0.4	4.5	4.5	−0.1	S. 5 W.	1.2	7.9
38	Off W. 14th St	R. Wainwright	September 1855	½	2.4	1.0	N. 25 E.	1.0	5.3	3.3	−0.1	S. 5 W.	1.4	7.1
39	Off Castle Pt., N. J	do	do	½	1.8	0.8	N. 5 W.	1.8	5.5	2.6	1.0	S.	2.0	6.9
40	do	H. Mitchell	August 1873	½	1.5	0.8	N. 10 E.	1.1	5.1	2.7	1.2	S. 10 W.	1.7	7.3
41	do	H. C. Denson	July 1922	1	0.3	1.6	N.	0.7	3.6	3.0	1.6	S.	2.6	8.8
42	do	M. Woodhull	July 1854	1	1.6	0.7	N. 20 E.	1.2	5.1	2.8	0.5	S. 20 W.	2.2	7.3
43	Off W. 22d St	H. Mitchell	September 1871	½	2.7				5.9	3.1	0.4	S. 5 E.	1.6	6.5
44	Off W. 25th St	H. C. Denson	August 1922	½	1.3	0.0	N. 15 E.	0.6	4.0	3.6	1.1	S. 15 W.	0.9	8.4
45	Off W. 27th St	R. Wainwright	September 1855	½	2.0	−0.3	N. 40 E.	1.0	4.5	3.8	1.6	S. 15 W.	1.3	7.9
47	Off W. 28th St	I. Winston	September 1919	2	1.9	1.1	N. 15 E.	1.6	5.6	2.6	0.6	S. 25 W.	2.3	6.8
48	Off W. 32d St	M. Woodhull	July 1854	1	1.0	1.7	N. 20 E.	1.6	4.6	2.6	1.3	S. 45 W.	2.5	7.8
49	Off W. 34th St	H. C. Denson	August 1922	½	1.3	0.5	N. 15 E.	0.3	4.1	3.5	0.5	S. 35 W.	1.2	8.3
50	do	do	July 1922	1	1.3	1.2	N. 15 E.	1.5	4.9	2.7	1.0	S. 25 W.	2.4	7.5
51	Off W. 39th St	H. L. Marindin	August 1885	½						3.8	0.6		1.8	
52	Off W. 36th St	H. C. Denson	July 1922	1½	1.6	1.0	N. 10 E.	1.3	5.3	2.6	1.1	S. 25 W.	2.5	7.1
53	Off W. 39th St	H. L. Marindin	August 1885	3	1.7	0.7	N. 30 E.	1.7	5.4	2.6	0.8	S. 35 W.	2.9	7.0
54	Off W. 42d St	H. Mitchell	September 1872	1	1.9	0.5	N. 20 E.	0.9	4.6	3.6	0.4	S. 25 W.	2.5	7.8
55	Off W. 41st St	do	September 1858	1	2.3	0.5	N. 25 E.	1.4	5.9	2.7	0.7	S. 30 W.	2.2	6.5
56	do	do	September 1872	1	1.9	0.8	N. 40 E.	1.5	5.4	2.8	0.6	S. 35 W.	2.7	7.0
57	Off W. 39th St	H. L. Marindin	August 1885	½	2.5				5.6	3.2	−0.4		1.9	6.8
58	Off Weehawken, N. J	H. Mitchell	September 1872	1	2.6	0.5	N. 30 E.	1.2	6.4	2.5	0.2	S. 30 W.	1.4	6.0
59	Off Days Point	R. Wainwright	September 1855	½	2.8	1.0	N. 30 E.	1.5	6.2	2.9	0.0	S. 15 W.	1.7	6.2
60	Off W. 55th St	do	do	½	2.4	1.1	N. 50 E.	1.4	6.4	2.3	0.8	S. 20 W.	2.6	6.0
61	Off W. 57th St	I. E. Rittenburg	July 1932	2	1.9	0.6	N. 35 E.	1.4	5.4	2.8	1.0	S. 30 W.	2.8	7.0
62	do	do	July, August 1932	4	1.9	1.1	N. 30 E.	2.1	5.7	2.5	0.8	S. 30 W.	2.6	6.7
63	do	do	July 1932	2	2.1	0.8	N. 35 E.	1.9	5.6	2.8	0.4	S. 35 W.	2.5	6.8
64	Off W. 74th St	H. C. Denson	August 1922	½	1.8						0.3	S. 25 W.	1.8	
65	Off W. 75th St	do	July, August 1922	3½	1.3	1.2	N. 25 E.	1.8	5.0	2.5	1.5	S. 30 W.	2.5	7.4
66	Off W. 74th St	do	August 1922	½	1.4	1.0	N. 35 E.	1.5	4.6	3.1	0.0	S. 35 W.	2.2	7.8
67	Off W. 95th St	H. Mitchell	September 1871	1	2.4	1.0	N. 20 E.	1.3	6.0	2.7	0.7	S. 40 W.	1.5	6.4
68	Off W. 131st St	R. Wainwright	August 1855	1	0.4	2.7	N. 40 E.	0.6	4.0	2.6	1.9	S. 20 W.	2.2	8.4
69	Off W. 135th St	I. Winston	September 1919	2	1.6	0.9	N. 15 E.	2.0	5.4	2.6	0.9	S. 15 W.	2.0	7.0
70	Off Fort Washington Point	R. Wainwright	August 1855	½	1.6	1.1	N. 25 E.	1.0	5.2	2.6	1.1	S. 20 W.	2.4	7.2
70	do	I. E. Rittenburg	June, July 1932	2	2.0	1.4	N. 20 E.	2.4	5.8	2.5	1.0	S. 30 W.	2.7	6.6
71	do	I. Winston	September 1919	2	1.2	0.9	N. 15 E.	2.1	5.3	2.2	1.3	S. 25 W.	3.1	7.1
71	do	H. C. Denson	July 1922	2	1.3	1.0	N. 5 E.	1.2	5.2	2.4	1.4	S. 40 W.	1.9	7.2
71	do	I. E. Rittenburg	June, July 1932	4	1.8	1.2	N. 10 E.	1.5	5.8	2.3	0.9	S. 30 W.	2.4	6.6
72	do	do	do	2	1.6	1.1	N. 5 E.	1.5	5.8	2.1	1.0	S. 25 W.	2.4	6.6
73	Off Linwood, N. J	H. C. Denson	July 1922	2	1.6	1.0	N. 30 E.	1.7	5.8	2.2	1.3	S. 35 W.	2.0	6.6

TABLE 62.—*Surface current data, Hudson River*—Continued

Station no.	Location	Party of—	Observations		Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days	*Hours before HW*	*Hours after HW*	°	*Knots*	*Hours*	*Hours before LW*	*Hours after LW*	°	*Knots*	*Hours*
74	Off Tubby Hook	I. Winston	August 1919	2	2.2	0.7	N. 30 E.	1.8	6.4	2.1	1.2	S. 25 W.	2.0	6.0
75	Off Spuyten Duyvil	R. Wainwright	August 1855	½	1.1	1.7	N. 15 E.	1.4	4.7	2.7	1.0	S. 5 E.	2.5	7.7
75	do	I. E. Rittenburg	August 1932	2	1.7	0.2	N. 50 E.	1.5	4.7	3.3	1.7	S. 35 W.	2.1	7.7
76	do	H. C. Denson	July 1922	½	0.2	2.0	N. 30 E.	1.7	4.8	1.7	2.5	S. 15 W.	2.1	7.6
76	do	I. E. Rittenburg	August 1932	2	1.8	0.9	N. 40 E.	1.6	5.6	2.5	1.2	S. 30 W.	2.1	6.8
77	do	I. Winston	August 1919	2	1.3	1.3	N. 30 E.	1.6	5.4	2.2	1.4	S. 20 W.	2.2	7.0
78	do	H. C. Denson	July 1922	1½	1.0	1.6	N. 20 E.	1.2	5.3	1.9	2.0	S. 35 W.	1.8	7.1
79	Off Riverdale	H. E. Finnegan	August 1929	1	0.8	1.8	N. 15 E.	1.3	5.0	2.0	2.1	S. 30 W.	2.1	7.4
79	do	I. E. Rittenburg	June 1932	2	1.3	1.5	N. 25 E.	1.9	5.5	2.1	1.7	S. 20 W.	2.2	6.9
80	do	H. E. Finnegan	August, September 1929	2	1.4	1.4	N. 30 E.	1.5	5.2	2.5	1.4	S. 15 W.	2.1	7.2
80	do	I. E. Rittenburg	June, August 1932	4	1.2	1.3	N. 15 E.	1.4	5.3	2.2	1.9	S. 20 W.	2.0	7.1
81	do	H. E. Finnegan	August, 1929	1	1.3	1.4	N. 25 E.	1.1	4.4	3.2	0.9	S. 15 W.	1.9	8.0
81	do	I. E. Rittenburg	June 1932	2	1.0	0.7	N. 25 E.	1.2	4.3	3.0	1.8	S. 15 W.	2.1	8.1
82	do	H. C. Denson	July, August 1922	3½	1.2	2.0	N. 10 E.	1.6	5.5	2.0	1.6	S. 30 W.	2.1	6.9
83	do	do	do	6	0.7	2.1	N. 15 E.	1.3	5.2	1.8	1.9	S. 15 W.	1.9	7.2
84	do	do	do	3½	1.2	1.1	N. 5 E.	1.1	4.7	2.8	1.4	S. 25 W.	1.8	7.7

The difference in the flood and ebb velocities in the Hudson River is unquestionably due to the fresh water flow. This is reflected also in a greater duration of ebb flow. For the stations along the axis of the channel the flood duration averages 5.4 hours and the ebb duration 7.0 hours.

A comparison of the times of slack at the stations located in the axis of the channel with those located near the shore shows that the current turns earlier near the shore. Stations 5, 6, and 7, near the mouth of the river illustrate this nicely. These observations were practically simultaneous and show that in the axis of the channel the current turns about three-fourths of an hour later than near the shore. Stations 33, 34, and 35, bring out the same feature. Across this section, the stations near shore turn about half an hour earlier than at the station in midstream. Stations 61 to 63, and 64 to 66, likewise bring out this feature as do stations 82 to 84 near the end of the 14-mile stretch of river under consideration.

It will be noted, however, that there are also differences in time of current as between the two shores. Thus, taking the data for stations 5, 6, and 7, it is seen that at station 7 near the western shore the current is 0.6 hour earlier than at station 6 which is near the eastern shore. These observations were made in 1922, but the observations at stations 21 and 22, and 24 and 26, made about 50 years earlier likewise show the current to be earlier by half an hour near the western shore.

This feature is found to characterize the current for the 14-mile stretch of the Hudson under consideration. Between Castle Point and Guttenberg, however, a distance of about 3 miles, this feature is not so pronounced. In this reach the difference in time of current between the two shores is but one- or two-tenths of an hour as against half an hour for the remainder of the stretch. On examining a chart showing soundings in the Hudson River, it will be noted that the deepest part of the channel lies near the eastern shore except for the stretch from Castle Point to Guttenberg when the deep channel swings toward the western shore. The difference in time of current as between the eastern and western shores of the Hudson may, therefore, be ascribed to this difference in depth.

In regard to the velocity of the current across any section of the river, it is obvious that in a channel of uniform cross-sections the greatest velocity is to be found in the center of the channel where the effects of friction are least. While the cross-section of the Hudson is not uniform, this general principle is borne out by the data of table 62. But since the axis of the channel lies near the eastern shore rather than in midstream, the greatest velocities are generally found along the axis of the channel, that is to the eastward of midstream.

This feature is brought out well by stations located on a section across the river. Thus, at stations 5, 6, and 7, the strength of the tidal current—that is strength of the observed current freed from the effects of nontidal water, or half the sum of the flood and ebb strengths—is 1.7 knots for the midstream station, 1.8 knots for the station near the New York shore, and 1.2 knots for the station near the New Jersey shore. At this section the deeper channel is near the New York shore and here the velocity is greater than midstream.

Near Castle Point, the axis of the channel is approximately in midstream. And stations 33, 34, and 35, show the tidal current here to

be greatest at the midstream station. From Castle Point to Guttenberg, the axis of the channel lies more nearly in midstream and in this stretch the greatest tidal current is found in midstream as the data for stations 61, 62, 63, and stations 64, 65, 66 show. Since the axis of the channel lies near the New York shore, except for the stretch from Castle Point to Guttenberg, the current has a greater velocity near the New York shore than near the Jersey shore, except for the 3-mile stretch noted above.

The velocity of the nontidal current at any point in the river is given approximately by half the difference between the ebb and flood strengths. This nontidal current in the Hudson River depends primarily on the amount of fresh water coming down the river; hence it will be different at different times. We may, therefore, expect this nontidal current as determined from one series of observations to be different from that determined from another series at the same place.

If we derive the nontidal current for the different stations listed in table 62, it will be found that the stations near the western shore generally give greater values than the stations in midstream or near the eastern shore. Thus, for the section near the mouth of the river formed by stations 5, 6, and 7, the nontidal current for station 7, near the western shore is 0.55 knot; for station 5 midstream it is 0.5 knot; and for station 6 near the eastern shore it is 0.4 knot. For stations 33, 34, and 35, the nontidal current is, respectively, 0.55 knot, 0.35 knot, and 0.85 knot, the latter being for the station near the western shore. Similarly, for stations 82, 83, and 84, the station near the western shore gives a nontidal current of 0.35 knot, the midstream station 0.3 knot, and the station near the eastern shore 0.25 knot.

This greater velocity of the nontidal current along the western shore of the Hudson indicates a greater flow of nontidal water along that shore. This is undoubtedly to be ascribed to the effect of the deflecting force of the earth's rotation. This greater flow of nontidal water should also be reflected by a somewhat greater duration of ebb along the western shore. In general, this conclusion is borne out by the data of table 62. Thus, at station 7 the ebb duration is 0.3 hour longer than at station 6; and at station 81 it is 0.9 hour longer than at station 79.

With regard to the direction of the current in the Hudson, it may be said that in general it follows the direction of the channel. From the mouth to a little above Castle Point, the channel runs approximately N. 10° E., and table 62 shows that the currents in this stretch set approximately N. 10° E. on the flood and S. 10° W. on the ebb. Near the wharves the direction is more variable than further out in the channel, local features influencing the direction of the flood and ebb near the wharves.

A little above Castle Point, the channel swings farther eastward, the direction from that point to a point midway between Edgewater and Fort Lee, N. J., being N. 30° E. The direction of the current through this stretch changes to conform to the direction of the channel as the data for stations 47 to 69 show. The average direction of the flood strength for these stations is N. 27° E., and for the ebb S. 29° W. In general, the flood and ebb strengths set in approximately opposite directions throughout this stretch.

Between Edgewater and Fort Lee the channel swings about 5° to the west maintaining a direction of N. 25° E. as far as Spuyten Duyvil, after which there is another westward swing of 5° the direction in the last reach of the 14-mile stretch being N. 20° E. The direction of the current in these regions is seen to conform to these changes in the direction of the channel. Thus, the average direction of flood strength for stations 70 to 78 in the stretch from Fort Lee to Spuyten Duyvil is N. 23° E., while for the last stretch, stations 79 to 84, it is N. 18° E. For the ebb strength the direction from stations 70 to 78 is S. 26° W., and from stations 79 to 84 it is S. 21° W.

CURRENT DATA, VARIOUS DEPTHS, HUDSON RIVER

At a number of the stations in the Hudson River, subsurface current observations with current meters were made. Generally, these observations were made at three depths, 0.2, 0.5, and 0.8 of the depth at the station. For several of these stations the direction of the subsurface currents was determined by means of a bifilar direction indicator. The data derived from these observations are given in table 63. To bring out any differences existing in the currents at the different depths, times and velocities are given to the second decimal place and directions to the nearest degree. For comparison there are also given the data for these stations derived from the pole observations, which pertain to the 7-foot depth. The velocities given in table 63 have been corrected to mean values.

140597—35——11

TABLE 63.—*Current data, various depths, Hudson River*

[Referred to times of HW and LW at Sandy Hook, N. J.]

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood Duration	Slack	Ebb strength			Ebb Duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours before HW*	*Hours after HW*	°	*Knots*	*Hours*	*Hours before LW*	*Hours after LW*	°	*Knots*	*Hours*
1	Off the Battery	I. E. Rittenburg	Aug. 1-3, 1932	2	Pole	7	2.02	0.60	N. 13 E.	1.10	5.22	3.09	0.11	S. 11 E.	1.00	7.20
				2	Meter	6	2.12	0.60		1.10	5.32	3.09	−0.39		1.10	7.10
				2	do	14	2.62	0.80		1.30	5.82	3.09	−0.69		0.70	6.60
				2	do	22	3.12	0.60		1.00	6.32	3.09	−0.19		0.60	6.10
5	do	H. C. Denson	July 15-Aug. 6, Aug. 11-18, 25-31, 1922.	31	Pole	7	1.70	0.70	N. 17 E.	1.19	5.06	2.93	0.93	S. 14 W.	2.22	7.36
				31	Meter	9	1.73	0.68		1.20	5.18	2.84	0.89		2.13	7.24
				31	do	24	2.52	0.62		1.56	6.23	2.58	0.52		1.52	6.19
				31	do	38	3.24	0.25		1.30	6.90	2.63	0.11		1.05	5.52
6	Off Morris St	do	July 23-25, Aug. 25-26, 1922.	3	Pole	7	2.33	0.74	N. 1 W.	1.42	5.52	3.10	0.46	S. 3 W.	2.20	6.90
				3	Meter	11	2.38	0.40		1.56	5.62	3.05	0.46		1.93	6.80
				3	do	27	2.81	0.40		1.57	6.19	2.91	0.46		1.50	6.23
				3	do	43	3.28	0.02		1.35	6.74	2.83	0.32		1.11	5.68
7	Off Communipaw Ferry, Jersey City.	do	July 23-27, Aug. 25-26, 1922.	3½	Pole	7	2.67	−0.23	N. 14 E.	0.66	5.18	3.78	−0.05	S. 12 W.	1.76	7.24
				3½	Meter	6	2.64	−0.68		0.72	4.91	4.02	−0.39		1.82	7.51
				3½	do	15	2.73	−0.55		0.72	5.32	3.70	−0.08		1.47	7.10
				3½	do	24	2.83	0.58		0.72	5.72	3.40	−0.03		1.11	6.70
10	Off Carlisle St	U. S. Engineers	July 29-Aug. 4, 1932	6	do	12	2.47	0.46		1.32	5.53	3.23	0.39		1.79	6.89
				6	do	30	2.95	0.21		1.78	6.44	2.80	0.23		1.30	5.98
				6	do	48	3.80	0.12		2.09	7.32	2.77	−0.34		0.95	5.10
11	do	do	Aug. 11-18, 1932	7	do	9	1.96	0.69		1.74	5.46	2.79	0.72		2.11	6.96
				7	do	24	2.53	0.50		1.86	6.19	2.63	0.60		1.41	6.23
				7	do	38	3.02	0.47		1.99	6.71	2.60	0.34		1.07	5.71
12	do	do	July 22-Aug. 18, 1932	27	do	10	1.67	0.80		1.76	5.15	2.81	0.83		2.52	7.27
				27	do	25	2.47	0.68		1.94	6.16	3.02	0.49		1.63	6.26
				27	do	40	3.03	0.54		1.50	6.54	2.78	0.27		0.90	5.88
13	do	do	Aug. 4-11, 1932	7	do	8	1.68	0.60		1.12	4.65	3.32	0.44		2.34	7.77
				7	do	20	2.34	0.83		1.43	5.65	2.98	0.42		1.77	6.77
				7	do	33	2.91	0.32		1.56	6.23	2.97	0.27		1.41	6.19
14	do	do	July 22-29, 1932	7	do	7	1.42	0.76		0.74	4.29	3.42	0.45		1.65	8.13
				7	do	17	2.33	0.42		1.12	5.32	3.30	−0.19		1.68	7.10
				7	do	27	3.02	0.61		1.31	6.00	3.31	−0.36		1.24	6.42
15	Off Grand St	H. C. Denson	Aug. 30, 1922	½	Pole	7	2.31	0.30		0.11	5.80	2.80				6.62
				½	Meter	8	2.41	0.30	N. 70 E.	0.41	5.00	3.70	0.29	S. 15 E.	1.11	7.42
				½	do	20	2.71	−0.30	N. 28 E.	0.51	5.50	3.50	0.29	S. 45 E.	1.01	6.92
				½	do	32	3.01	−0.50	N. 5 E.	0.93	5.80	3.50	0.29	S. 55 E.	0.93	6.62
17	Off Fulton St	I. Winston	Sept. 22-23, Oct. 6-7, 1919.	2	Pole	7	1.99				5.57	2.71	0.53	S. 3 W.	2.26	6.85
				2	Meter	9	1.95	0.61	N. 11 E.	1.73	5.50	2.74	0.41		2.36	6.92
				2	do	22	2.15	0.64		1.73	5.76	2.68	0.33		1.69	6.66
				2	do	35	2.27	0.61		1.37	5.90	2.66	0.48		1.10	6.52
18	Off Cortlandt St	H. C. Denson	Aug. 30, 1922	½	Pole	7	2.11	0.50	N. 14 E.	0.44	4.80	3.60				7.62
				½	Meter	9	2.21	0.50	N. 29 E.	1.15	5.60	2.90	−0.31	S. 47 W.	1.20	6.82
				½	do	22	2.61	−0.10	N. 20 E.	1.38	6.00	2.90	−0.11	S. 57 W.	0.63	6.42
				½	do	35	3.61	−1.10	N. 24 E.	1.28	7.00	2.90	−0.31	S. 37 W.	0.58	5.42
23	Off Beach St	do	Aug. 30, 1922	½	Pole	7	2.11	−0.10	N. 23 W.	0.83	5.75	2.65	1.69	S. 9 W.	1.03	6.67
				½	Meter	7	2.01	1.10	N.	0.84	5.50	2.80	0.79	S. 26 W.	1.29	6.92
				½	do	18	2.31	0.90	N. 9 E.	1.18	6.00	2.60	0.79	S. 44 W.	0.73	6.42
				½	do	28	2.61	−0.30	N. 7 E.	0.96	6.30	2.60	0.69	S. 11 W.	0.51	6.12
29	Off 1st St., Hoboken	do	Aug. 29, 1922	½	Pole	7	1.71				4.80	3.20	0.99	S. 11 W.	1.19	6.72
				½	Meter	9	1.71	0.20	N. 6 E.	0.58	4.50	3.50	0.49	S. 7 E.	1.58	7.92
				½	do	22	2.51	0.20	N. 34 E.	0.76	5.40	3.40	−0.41	S. 30 E.	0.86	7.02
				½	do	35	2.81	0.50	N. 13 E.	1.06	5.80	3.30	−0.91	S. 10 E.	0.66	6.62
32	Off Bethune St	do	Aug. 29-30, 1922	½	Pole	7	1.21				3.00	4.50	−0.09	S. 24 W.	1.62	9.42
				½	Meter	7	1.61	0.60	N. 16 E.	0.85	4.30	3.60	1.39	S. 22 W.	1.75	8.12
				½	do	18	2.41	0.60	N. 20 E.	1.03	5.40	3.30	1.09	S. 34 W.	1.13	7.02
				½	do	28	3.61	0.20	N. 13 E.	1.07	6.60	3.30	0.79	S. 12 W.	0.82	5.82
33	Off Gansevoort St	I. E. Rittenburg	July 18-20, 1932	2	Pole	6	1.52	0.80	N. 11 E.	0.90	4.42	3.39	0.71	S. 2 E.	2.00	8.00
				2	Meter	10	1.72	0.80		1.10	4.92	3.09	0.11		1.70	7.50
				2	do	25	2.22	1.00		1.70	5.92	2.59	0.11		1.20	6.50
				2	do	40	3.22	0.50		1.90	6.92	2.59	−0.09		1.00	5.50
34	do	do	Aug. 1-3, 1932	2	Pole	7	2.12	0.90	N. 9 E.	1.70	5.52	2.89	0.71	S.	2.40	6.90
				2	Meter	10	2.22	0.80		1.70	5.52	2.99	0.71		2.20	6.90
				2	do	26	2.62	0.80		1.80	6.32	2.59	0.61		2.00	6.10
				2	do	42	3.62	0.80		1.80	7.32	2.59	0.31		1.40	5.10
35	do	do	July 18-20, 1932	2	Pole	7	1.62	0.30	N. 25 E.	1.00	4.42	3.49	0.71	S. 7 W.	2.70	8.00
				2	Meter	9	1.72	0.40		0.90	4.92	3.09	0.71		2.40	7.50
				2	do	23	2.22	0.40		1.60	5.52	2.99	0.81		1.90	6.90
				2	do	36	2.72	0.00		1.60	6.12	2.89	0.91		1.60	6.30
36	Off W. 13th St	I. Winston	Sept. 10-11, 1919	½	Pole	7	2.07	0.14	N. 14 E.	1.16	5.20	3.16				7.22
				½	Meter	12	1.87	0.59		1.16	5.20	2.96				7.22
				½	do	30	1.97	0.61		1.54	5.56	2.70				6.86
				½	do	48	2.17	0.61		1.38	5.57	2.71				6.85

TABLE 63.—*Current data, various depths, Hudson River*—Continued.

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood Duration	Slack	Ebb strength			Ebb Duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours before HW*	*Hours after HW*	°	*Knots*	*Hours*	*Hours before LW*	*Hours after LW*	°	*Knots*	*Hours*
37	Off W. 13 St.	H. C. Denson	Aug. 29, 1922	½	Pole	7	2.71	−0.30	N. 15 E.	0.41	4.50	4.50	−0.06	S. 7 W.	1.21	7.92
				½	Meter	9	2.31	0.20	N. 4 E.	1.01	5.40	3.20	−0.01	S. 27 W.	1.29	7.02
				½	do	22	2.71	−0.30	N. 19 W.	1.01	5.80	3.20	0.09	S. 24 W.	0.96	6.62
				½	do	35	3.11	−1.00	N. 30 W.	0.96	6.30	3.10	−0.09	S. 23 W.	0.76	6.12
41	Off Castle Point, N. J.	do	July 19–21, 1922	1	Pole	7	0.31	1.55	N. 2 W.	0.67	3.63	2.97	1.59	S. 2 E.	2.64	8.79
				1	Meter	14	0.61	1.85		0.92	4.07	2.83	1.29		2.42	8.35
				1	do	36	1.86	1.65		1.38	5.78	2.37	0.59		1.43	6.64
				1	do	50	2.91	1.20		0.87	6.40	2.80	0.29		1.22	6.02
44	Off W. 25th St.	do	Aug. 28–29, 1922	½	Pole	7	1.31	0.00	N. 17 E.	0.57	4.00	3.60	1.09	S. 17 W.	0.87	8.42
				½	Meter	7	1.21	0.70	N. 29 E.	0.57	3.90	3.60	1.19	S. 24 W.	0.67	8.52
				½	do	18	1.71	−0.10	N. 18 E.	0.87	4.40	3.60	0.69	S. 24 W.	0.37	8.02
				½	do	29	1.81	−0.40	N. 4 E.	0.92	4.50	3.60	0.29	S. 54 W.	0.47	7.92
46	Weehawken Cove	do	do	½	do	7	1.61	0.60	N. 1 E.	0.50	4.10	3.80	0.59	S. 26 W.	1.75	8.32
				½	do	18	2.01	0.60	N. 11 E.	1.05	5.00	3.30	0.69	S. 22 W.	1.30	7.42
				½	do	28	2.51	−0.20	N. 10 E.	0.90	5.40	3.40	0.69	S. 47 W.	1.35	7.02
47	Off W. 28th St.	I. Winston	Sept. 15–17, 1919	2	Pole	7	1.92	1.06	N. 16 E.	1.60	5.65	2.56	0.55	S. 24 W.	2.26	6.77
				2	Meter	10	1.57	1.06		1.96	5.42	2.44	0.68		2.30	7.00
				2	do	24	1.90	1.04		2.14	5.60	2.59	0.71		1.92	6.82
				2	do	38	1.92	0.94		1.60	5.57	2.64	0.85		1.42	6.85
49	Off W. 34th St.	H. C. Denson	Aug. 28–29, 1922	½	Pole	7	1.31	0.50	N. 13 E.	0.27	4.10	3.50	0.49	S. 37 W.	1.22	8.32
				½	Meter	9	1.51	−0.20	N. 39 E.	0.47	4.30	3.50	0.09	S. 34 W.	1.17	8.12
				½	do	23	2.21	−0.30	N. 27 E.	0.62			−0.09	S. 33 W.	0.72	
				½	do	37	2.31	0.20	N. 36 E.	0.72			−0.01	S. 32 W.	0.62	
50	do	do	July 21, 23, 1922	1	Pole	7	1.34	1.23	N. 16 E.	1.46	4.96	2.67	1.02	S. 25 W.	2.36	7.46
				1	Meter	10	0.71	1.45		1.44	4.60	2.40	0.69		2.36	7.82
				1	do	25	1.51	1.45		1.39	5.30	2.50	0.69		1.52	7.12
				1	do	40	2.01	1.35		1.30	5.65	2.65	0.29		0.98	6.77
52	Off W. 36th St.	do	do	1½	Pole	7	1.63	1.03	N. 11 E.	1.26	5.32	2.60	1.06	S. 27 W.	2.51	7.10
				1½	Meter	9	1.99	1.20		1.25	5.65	2.63	0.89		2.10	6.77
				1½	do	23	2.29	1.20		1.55	6.11	2.47	0.79		1.98	6.31
				1½	do	37	2.44	0.15		1.19	6.03	2.70	0.89		1.72	6.39
61	Off W. 57th St.	I. E. Rittenburg	July 20–22, 1932	2	Pole	7	1.92	0.60	N. 34 E.	1.40	5.42	2.79	1.01	S. 29 W.	2.80	7.00
				2	Meter	9	2.12	0.60		1.50	5.82	2.59	1.01		2.40	6.60
				2	do	23	2.72	0.50		1.90	6.42	2.59	0.71		1.80	6.00
				2	do	36	3.22	0.50		1.50	7.02	2.49	0.71		1.70	5.40
62	do	do	July 20–22, Aug. 29–31, 1932.	4	Pole	7	1.92	1.10	N. 31 E.	2.10	5.72	2.49	0.81	S. 30 W.	2.60	6.70
				4	Meter	10	1.72	1.10		2.10	5.52	2.49	0.81		2.60	6.90
				4	do	24	2.22	0.90		2.20	6.02	2.49	0.71		2.00	6.40
				4	do	38	2.92	0.60		1.50	6.72	2.49	0.31		1.40	5.70
63	do	do	July 20–22, 1932	2	Pole	7	2.12	0.80	N 36 E.	1.90	5.62	2.79	0.41	S. 36 W.	2.50	6.80
				2	Meter	7	2.12	0.90		1.80	5.52	2.89	0.21		2.30	6.90
				2	do	18	2.62	0.90		2.00	6.42	2.49	0.21		1.70	6.00
				2	do	29	3.22	0.50		1.80	7.02	2.49	−0.39		1.20	5.40
64	Off W. 74th St.	H. C. Denson	Aug. 26–27, 1922	½	Pole	7	1.81						0.29	S. 27 W.	1.80	
				½	Meter	7	1.81	0.50	N. 41 E.	1.00	4.90	3.20	0.19	S. 27 W.	2.13	7.52
				½	do	17	2.61	0.00	N. 36 E.	1.10	5.70	3.20	0.04	S. 33 W.	1.68	6.72
				½	do	27	2.91	−0.30	N. 27 E.	1.12	6.20	3.00	−0.26	S. 36 W.	0.99	6.22
65	do	do	July 16–19, Aug. 26–27, 1922.	3½	Pole	7	1.26	1.20	N. 27 E.	1.75	5.06	2.49	1.46	S. 31 W.	2.53	7.36
				3½	Meter	11	1.30	1.31		1.81	5.15	2.44	1.39		2.58	7.27
				3½	do	27	2.01	0.91		2.11	6.00	2.30	1.01		2.17	6.42
				3½	do	43	2.98	0.21		1.62	6.57	2.70	0.80		1.63	5.85
66	do	do	Aug. 26–27, 1922	½	Pole	7	1.41	1.00	N. 37 E.	1.49	4.60	3.10	0.04	S. 35 W.	2.21	7.82
				½	Meter	10	1.81	1.00	N. 38 E.	1.76	5.40	1.70	−0.09	S. 36 W.	2.24	7.02
				½	do	24	2.31	0.90	N. 29 E.	1.95	6.00	2.60	−0.36	S. 38 W.	1.72	6.42
				½	do	38	2.71	0.80	N. 36 E.	1.24	6.40	2.60	−0.36	S. 33 W.	1.12	6.02
69	Off W. 135th St.	I. Winston	Sept. 8–10, 1919	2	Pole	7	1.65	0.89	N. 16 E.	2.03	5.38	2.56	0.91	S. 13 W.	2.04	7.04
				2	Meter	10	1.97	1.07		2.09	5.78	2.48	0.93		2.07	6.64
				2	do	24	2.39	0.69		1.90	6.28	2.40	0.84		1.53	6.14
				2	do	39	2.55	0.79		1.50	6.38	2.36	0.55		0.95	6.04
70	Off Ft. Washington Point.	I. E. Rittenburg	June 29–July 1, 1932	2	Pole	7	2.02	1.40	N. 20 E.	2.40	5.82	2.49	1.01	S. 30 W.	2.70	6.60
				2	Meter	24	2.12	1.20		2.20	6.42	1.99	1.01		2.20	6.00
				2	do	60	2.72	0.80		1.60	6.52	2.49	0.81		1.10	5.90
				2	do	96	2.22	0.70		1.40	6.72	1.79	1.81		0.80	5.70
71	do	I. Winston	Sept. 2–4, 1919	2	Pole	7	1.20	0.86	N. 17 E.	2.07	5.28	2.21	1.28	S. 26 W.	3.11	7.14
				2	Meter	8	1.67	0.84		1.84	5.52	2.44	1.31		2.74	6.90
				2	do	21	1.80	1.17		1.52	5.68	2.41	1.71		2.40	6.74
				2	do	33	2.07	1.06		0.89	5.87	2.49	0.86		1.61	6.55
71	do	H. C. Denson	July 21–23, 1922	2	Pole	7	1.33	1.02	N. 5 E.	1.16	5.22	2.40	1.39	S. 39 W.	1.94	7.20
				2	Meter	7	1.53	0.68		1.36	5.42	2.40	1.16		2.07	7.00
				2	do	18	1.91	0.40		1.37	5.52	2.68	0.86		1.83	6.90
				2	do	29	2.16	0.22		0.88	5.47	2.98	0.66		0.93	6.95

TABLE 63.—*Current data, various depths, Hudson River*—Continued

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood Duration	Slack	Ebb strength			Ebb Duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours before HW*	*Hours after HW*	°	*Knots*	*Hours*	*Hours before LW*	*Hours after LW*	°	*Knots*	*Hours*
71	Off Ft. Washington Point.	I. E. Rittenburg.	June 29–July 1, Aug. 29–31, 1932.	4	Pole	7	1.82	1.20	N. 9 E.	1.50	5.82	2.29	0.91	S. 32 W.	2.40	6.60
				4	Meter	7½	1.92	0.90		1.60	6.12	2.09	1.01		2.30	6.30
				4	do	19	2.12	1.00		1.50	5.92	2.49	0.91		1.90	6.50
				4	do	30	2.02	1.00		1.10	5.72	2.59	0.91		1.50	6.70
72	do	do	June 29–July 1, 1932	2	Pole	7	1.62	1.10	N. 6 E.	1.50	5.82	2.09	1.01	S. 24 W.	2.40	6.60
				2	Meter	4	1.72	1.20		1.60	5.92	2.09	1.11		2.30	6.50
				2	do	11	2.22	0.60		1.70	6.52	1.99	0.81		2.10	5.90
				2	do	18	2.12	0.20		1.40	6.42	1.99	0.61		1.60	6.00
73	Off Linwood, N. J.	H. C. Denson	July 21–23, 1922	2	Pole	7	1.63	1.05	N. 30 E.	1.70	5.77	2.15	1.27	S. 34 W.	2.02	6.65
				2	Meter	9	1.73	0.98		1.81	6.07	1.95	1.27		2.05	6.35
				2	do	22	2.23	0.60		1.62	6.34	2.18	1.04		1.52	6.04
				2	do	35	2.61	0.48		1.34	6.38	2.52	0.47		1.11	6.08
74	Off Tubby Hook	I. Winston	Aug. 28–30, 1919	2	Pole	7	2.25	0.66	N. 30 E.	1.75	6.40	2.14	1.18	S. 26 W.	2.04	6.02
				2	Meter	7	2.07	0.59		1.67	6.22	2.14	1.16		1.97	6.20
				2	do	17	2.45	0.41		1.53	6.60	2.14	0.68		1.50	5.82
				2	do	27	2.43	0.14		1.00	6.61	2.11	0.30		1.07	5.81
75	Off Spuyten Duyvil	I. E. Rittenburg.	Aug. 3–5, 1932	2	Pole	7	1.72	0.20	N. 50 E.	1.50	4.72	3.29	1.71	S. 34 W.	2.10	7.70
				2	Meter	8	1.62	0.40		1.30	4.72	3.19	1.81		2.10	7.70
				2	do	20	1.82	0.10		1.50	5.22	2.89	1.61		1.50	7.20
				2	do	32	1.72	0.10		1.30	5.92	2.09	0.71		1.40	6.50
76	do	H. C. Denson	July 20–21, 1922	½	Pole	7	0.21	1.95	N. 31 E.	1.74	4.80	1.70	2.49	S. 14 W.	2.09	7.62
				½	Meter	10	0.81						1.99		2.24	
				½	do	24	1.41									
76	do	I. E. Rittenburg.	Aug. 1–3, 1932	2	Pole	7	1.82	0.90	N. 39 E.	1.60	5.62	2.49	1.31	S. 32 W.	2.10	6.80
				2	Meter	7	2.12	0.90		1.60	5.92	2.49	1.41		1.90	6.50
				2	do	10	2.12	0.50		1.20	5.82	2.59	1.21		1.60	6.60
				2	do	29	2.22	0.30		1.00	6.02	2.49	0.51		1.40	6.40
77	do	I. Winston	Aug. 25–27, 1919	2	Pole	7	1.31	1.26	N. 32 E.	1.64	5.39	2.21	1.35	S. 21 W.	2.17	7.03
				2	Meter	8	1.47	1.12		1.63	5.52	2.24	1.65		2.07	6.90
				2	do	20	1.75	0.74		1.48	5.70	2.34	1.41		1.38	6.72
				2	do	32	2.45	0.84		1.12	6.40	2.34	1.01		0.83	6.02
78	do	H. C. Denson	July 19–20, 1922	1½	Pole	7	0.96	1.57	N. 18 E.	1.17	5.35	1.90	1.99	S. 33 W.	1.79	7.07
				1½	Meter	4	0.86	1.63		1.49	4.98	2.17	1.59		2.30	7.44
				1½	do	11	1.56	0.87		1.42	5.58	2.27	1.29		1.52	6.84
				1½	do	18	2.66	0.43		1.09	6.52	2.52	0.84		0.94	5.90
79	Off Riverdale	H. E. Finnegan.	Aug. 29–30, 1929	1	Pole	5	0.79	1.82	N. 15 E.	1.32	5.04	2.04	2.10	S. 30 W.	2.12	7.38
				1	Meter	11	1.04	1.67		1.62	5.29	2.04	1.75		2.17	7.13
				1	do	27	1.84	1.37		1.88	6.44	1.69	1.55		2.03	5.98
				1	do	43	2.24	1.17		1.77	6.84	1.69	1.55		1.97	5.58
79	do	I. E. Rittenburg.	June 27–29, 1932	2	Pole	7	1.32	1.50	N. 24 E.	1.90	5.52	2.09	1.71	S. 19 W.	2.20	6.90
				2	Meter	11	1.12	1.90		1.60	5.92	1.49	2.11		1.90	6.50
				2	do	27	1.72	1.30		2.00	6.52	1.49	1.31		1.40	5.90
				2	do	44	3.12	0.20		1.70	7.52	1.89	0.71		1.00	4.90
80	do	H. E. Finnegan.	Aug. 29–30, Sept. 19–20, 1929.	2	Pole	7	1.39	1.37	N. 30 E.	1.48	5.22	2.46	1.40	S. 17 W.	2.06	7.20
				2	Meter	7	1.36	1.29		1.56	5.41	2.24	1.55		2.24	7.01
				2	do	15	1.86	0.99		1.47	6.01	2.14	1.33		1.67	6.41
				1	do	15	1.59	1.27	N. 22 E.	1.23	5.54	2.34	1.35	S. 22 W.	1.53	6.88
				2	do	24	2.26	1.02		1.37	6.43	2.12	1.05		1.45	5.99
80	do	I. E. Rittenburg.	June 27–29, Aug. 29–31, 1932.	4	Pole	7	1.22	1.30	N. 17 E.	1.40	5.32	2.19	1.91	S. 22 W.	2.00	7.10
				4	Meter	6	1.22	1.70		1.30	5.42	2.09	1.71		1.90	7.00
				4	do	15	1.62	0.80		1.40	5.82	2.09	1.41		1.30	6.60
				4	do	24	3.12	0.20		1.00	7.32	2.09	0.71		0.80	5.10
81	do	H. E. Finnegan.	Aug. 29–30, 1929	1	Pole	7	1.34	1.37	N. 26 E.	1.14	4.39	3.24	0.90	S. 17 W.	1.94	8.03
				1	Meter	7	1.44	1.12		1.19	4.44	3.29	0.90		1.84	7.98
				1	do	16	2.54	0.47		1.05	5.64	3.19	0.80		1.05	6.78
81	do	I. E. Rittenburg.	June 27–29, 1932	2	Pole	7	1.02	0.70	N. 25 E.	1.20	4.32	2.99	1.81	S. 14 W.	2.10	8.10
				2	Meter	4	1.12	0.20		1.40	4.32	3.09	1.71		2.20	8.10
				2	do	16	2.12	0.20		1.20	5.82	2.59	0.71		1.20	6.60
82	do	H. C. Denson	July 16–19, Aug. 27–28, 1922.	3½	Pole	7	1.22	2.02	N. 11 E.	1.59	5.51	2.00	1.63	S. 30 W.	2.06	6.91
				3½	Meter	10	1.31	1.94		1.63	5.56	2.04	1.49		1.89	6.86
				3½	do	26	1.92	1.58		1.78	6.57	1.64	1.37		1.50	5.85
				3½	do	42	2.28	0.44		1.31	6.69	1.88	0.87		1.05	5.73
83	do	do	July 15–21, Aug. 27–28, 1922.	6	Pole	7	0.72	2.12	N. 15 E.	1.32	5.21	1.80	1.94	S. 13 W.	1.89	7.21
				6	Meter	8	0.64	2.10		1.56	5.18	1.75	2.01		2.07	7.24
				6	do	20	1.62	1.12		1.52	6.18	1.73	1.51		1.57	6.24
				6	do	32	2.58	0.36		1.12	6.69	2.18	0.67		1.05	5.73
84	do	do	July 16–19, Aug. 27–28, 1922.	3½	Pole	7	1.21	1.14	N. 6 E.	1.09	4.70	2.80	1.38	S. 26 W.	1.85	7.72
				3½	Meter	4	1.14	1.27		1.45	4.99	2.44	1.45		2.22	7.43
				3½	do	11	1.57	1.07		1.49	5.27	2.59	1.25		1.96	7.15
				3½	do	18	2.07	0.37		1.18	5.53	2.83	0.92		1.24	6.89

The subsurface current in the Hudson presents the features found in the subsurface current in the Narrows and Upper Bay. The slack before flood becomes earlier from the surface downward, while the slack before ebb occurrs about the same time from surface to bottom. The velocity of the flood strength decreases very slowly with increasing depth, or may even increase, while strength of ebb decreases at a relatively rapid rate. At the surface the ebb has the greater duration, but with increasing depth the duration of flood increases while the duration of ebb decreases, so that near the bottom the duration of flood may become the greater.

Taking up these features of the subsurface current in the Hudson in detail, the data of table 63 indicate that for the stretch of the Hudson here under consideration the acceleration in the time of slack before flood from the surface downward is approximately at the rate of 0.05 hour per foot against 0.03 hour per foot in the Narrows. At stations 5 and 12, where the observations were continued for about a month, the data may be regarded as well determined; and here the acceleration is at the rate of 0.05 hour per foot. In the upper part of the 14-mile stretch, the acceleration appears to be at a somewhat greater rate but the observations are not of sufficient length to determine this with precision. It is to be expected that this rate at any point would vary with the amount of fresh-water flow, but the rate of 0.05 hour per foot may be taken as obtaining during the summer months.

Stations 10 to 14, which lie along a cross-section of the channel, furnish data for determining whether there is any difference in the change of time of slack before flood with depth across a section of the channel. While the observations at these stations are not strictly simultaneous, they are very nearly so. The data in table 63 give the following changes in hours per foot: Station 10, 0.037; station 11, 0.037; station 12, 0.045; station 13, 0.049; station 14, 0.080. There is thus a very definite increase in the rate of change from the New York shore to the Jersey shore.

The data for other stations on sections of the river are not conclusive with regard to this feature. But in general they appear to substantiate the evidence of stations 10 to 14 that the rate of increase in time of slack before flood increases from the eastern to the western shore of the river.

The time of slack before flood becomes considerably earlier with increasing depth, while the time of slack before ebb becomes somewhat later. Taking stations 5 and 12, where the longest series of observations were obtained, it is found that as between the 9-foot depth and the 38-foot depth at station 5, the time of slack before ebb comes later by 0.21 hour, and at station 12 the difference between the 10-foot depth and the 40-foot depth is 0.03 hour.

This difference in the change of time of slack of the subsurface currents brings about a change in the duration of flood and ebb at different depths. Near the surface the ebb has the greater duration, but with increasing depth the ebb duration decreases and the flood duration increases. Station 5 brings out this feature for the current near the mouth of the river. At the 7-foot depth the duration of flood is 5.1 hours; at the 9-foot depth it is 5.2 hours; 24-foot depth, 6.2 hours;

38-foot depth, 6.9 hours. The increase in duration of flood is here at the rate of 0.06 hour per foot. At station 12, the rate is 0.05 hour per foot. At station 83 at the upper end of the 14-mile stretch under consideration, it is 0.06 hour per foot.

In midstream, the flood and ebb durations are approximately equal a little below mid-depth, and at the 0.8 depth the flood has the greater duration. This statement applies also to the current near the New York shore since the deep channel lies near the New York shore. Near the New Jersey shore, because of the relatively shallow depths prevailing, the ebb current has the greater duration even at the 0.8-foot depth.

For the 7-foot depth it was found that the current turned earlier near shore than along the axis of the channel. This feature is also characteristic of the current at lower depths. If we interpolate the values for any given depth from the data for stations 10 to 14, it is found that the current turns earliest near the shore and latest at station 12 in midstream. Stations 5, 6, and 7 give similar results as do also stations 82, 83, and 84. The discussion of the current at the 7-foot depth also brought out the fact that as a rule the current turns earlier near the western shore than near the eastern shore by about half an hour. This feature appears to be less pronounced for the current at the lower depths.

With regard to the vertical velocity distribution in the Hudson, the stations in the middle of the channel exhibit different features from those near the shores. Along the axis, the flood strength increases somewhat from the surface to mid-depth and then decreases to near the bottom. Near the shores the flood strength increases all the way from the surface to near the bottom. This is illustrated by the data for stations 10 to 14. At station 12, in midstream, the flood strength increases at the rate of about 0.01 knot per foot to mid-depth and then decreases at the rate of about 0.03 knot per foot, so that at the 0.8 depth the velocity is less than at the 0.2 depth. At stations 10, 11, 13, and 14, which are situated closer to shore, the flood strength increases from the surface downward to near the bottom, the rate being about 0.02 knot per foot.

The ebb strength in the Hudson decreases from the surface to near the bottom both in midstream and near the shores. The rate of decrease varies somewhat at the different stations but in general is about 0.05 knot per foot. The greatest ebb velocities are, therefore, found at the surface.

Along the axis of the channel, the flood and ebb velocities are, in general, approximately equal at mid-depth. As a general rule, too, the flood has the greater velocity at mid-depth near the New York shore, while near the New Jersey shore the ebb has the greater velocity at mid-depth.

Since the deepest channel of the river lies nearer the New York shore, mid-depth near the New York shore is deeper than along the New Jersey shore. If we interpolate for corresponding depths, from the data of table 63, it is found that for the same depth the ebb has the greater velocity along the New Jersey shore, as a rule. It appears, therefore, that the greater part of the fresh water that comes down the Hudson flows along the New Jersey shore.

CURRENT HARMONIC CONSTANTS, HUDSON RIVER

In connection with the prediction of currents in the Hudson, the pole observations at station 5 and the meter observations at the 10-foot depth at station 12 were submitted to harmonic analysis. The observations at station 5 covered a period of 21 days and at station 12 a period of 27 days. These were analyzed in the usual way except that the 21 days of observations at station 5 were divided into two overlapping 15-day series. Only the principal components were derived from the analysis, the others being inferred in the usual way, the inferred values being enclosed in parentheses.

TABLE 63a.—*Current harmonic constants, Hudson River*

Component	Station 5		Station 12		Component	Station 5		Station 12	
	H	κ	H	κ		H	κ	H	κ
	Knots	°	*Knots*	°		*Knots*	°	*Knots*	°
J_1	(0.01)	(68)	(0.01)	(86)	O_1	0.14	133	0.16	111
K_1	0.31	89	0.40	94	OO	(0.01)	(46)	(0.01)	(78)
K_2	(0.08)	(235)	(0.08)	(256)	P_1	(0.10)	(89)	(0.13)	(94)
L_2	(0.04)	(237)	(0.05)	(275)	Q_1	(0.03)	(154)	(0.03)	(120)
M_1	(0.01)	(111)	(0.01)	(103)	S_2	0.30	235	0.30	256
M_2	1.54	239	1.83	244	S_4	0.01	110	0.01	48
M_4	0.07	349	0.04	45	S_6	0.02	253	0.01	347
M_6	0.08	338	0.06	19	T_2	(0.02)	(235)	(0.02)	(256)
$M_{8\kappa}$	0.03	4	0.01	38	λ_2	(0.01)	(237)	(0.01)	(250)
N_2	(0.30)	(242)	0.40	213	μ_2	(0.04)	(244)	(0.04)	(231)
$2N$	(0.04)	(244)	(0.05)	(182)	ν_2	(0.06)	(241)	(0.08)	(217)

SURFACE CURRENTS, HARLEM RIVER

For the Harlem River there are available current observations at 16 stations, the locations of which are shown on figure 42. The data derived from these observations, for the current near the surface, are given in table 64. These data may be taken to pertain to a depth of 7 feet. The velocities of the flood and ebb strengths have been corrected to mean values.

Harlem River is in reality a strait connecting Hudson River with the East River. Upstream and downstream, therefore, have no precise meanings in the Harlem, and the designations of the flood and ebb currents here must be made with reference to the time relations between local current and tide.

From the data of table 40, the tide in the Harlem is about 2 hours later than at Sandy Hook. The strength of the southerly flowing current in the Harlem, as table 64 shows, comes about an hour before Sandy Hook high water, and hence about 3 hours before local high water. It follows, therefore, that the southerly flowing current attains its strength on a rising tide and is therefore the flood current. The northerly flowing current, from similar considerations, attains its strength on a falling tide and is, therefore, the ebb current.

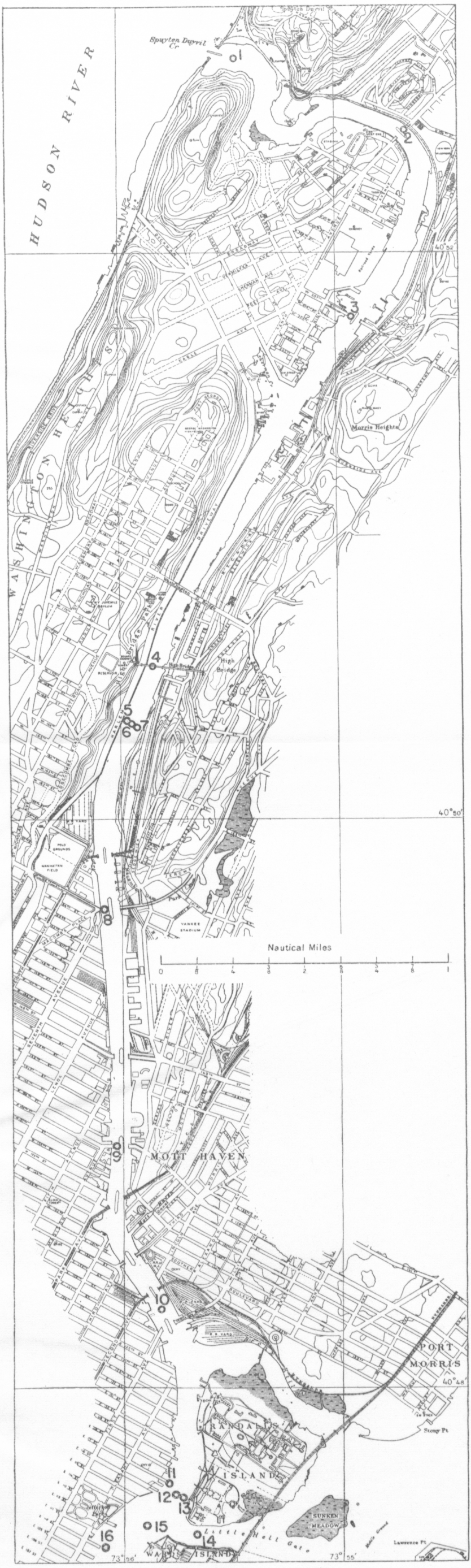

FIGURE 42.—Current stations, Harlem River.

TABLE 64.—*Surface current data, Harlem River*

[Referred to times of HW and LW at Sandy Hook, N. J.]

Station no.	Location	Party of—	Observations		Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
1	Off Spuyten Duyvil	R. J. Auld	November 1920	2	2.1	1.0	S. 75 E.	1.6	5.8	1.8	0.7	N. 75 W.	2.0	6.6
1	do	H. C. Denson	July 1922	22	1.9	0.5	S. 70 E.	1.3	6.2	2.0	0.7	N. 70 W.	1.8	6.2
1	do	I. E. Rittenburg	August 1932	2	2.1	0.5	S. 65 E.	1.5	6.1	2.1	1.0	N. 80 W.	2.2	6.3
2	Broadway Bridge	R. J. Auld	November 1920	2	2.1	0.5	S. 65 E.	2.1	5.8	1.8	1.4	N. 60 W.	2.4	6.6
3	W. 207th St. Bridge	I. E. Rittenburg	September 1932	2	2.0	0.8	S. 35 W.	2.0	6.3	2.2	0.9	N. 35 W.	2.0	6.1
4	High Bridge	R. J. Auld	November 1920	2	2.0	0.9	S. 10 W.	3.0	5.8	1.7	1.5	N. 15 E.	2.8	6.6
5	South of High Bridge	H. C. Denson	August 1922	¾	1.7	0.8	S. 35 W.	1.2	6.4	2.0	1.1		1.3	6.0
6	do	do	do	1½	1.9	1.0	S. 30 W.	1.4	6.2	2.0	1.3	N. 30 E.	1.5	6.2
7	do	do	do	¾	1.8	0.6	S. 25 W.	1.5	6.3	2.0	1.0	N. 20 E.	1.3	6.1
8	Central Bridge	I. E. Rittenburg	September 1932	2	2.1	1.1	S.	1.7	5.8	1.8	1.2	N.	1.4	6.6
9	Madison Ave. Bridge	do	do	2	2.0	1.0	S.	1.7	6.0	1.9	1.3	N.	1.6	6.4
10	Above Willis Ave. Bridge	H. C. Denson	August 1922	1¾	1.5	1.1	S. 35 E.	0.9	6.6	2.0	1.7	N. 40 W.	1.0	5.8
11	Off 117th St	I. E. Rittenburg	September 1932	2	2.2	0.2	S. 35 W.	0.5	5.9	2.0	1.0	N. 50 E.	2.2	6.5
12	Off 116th St	do	August 1932	2	1.2	0.6	S. 15 W.	1.3	7.6	2.7	1.5	N. 35 E.	0.2	4.8
13	Off South Pier, Randalls Island.	do	September 1932	2	------	0.9	S. 15 W.	1.2	------	------	1.0	S. 55 E.	−0.1	------
14	Between Randalls and Wards Islands.	H. C. Denson	August 1922	1	1.8	0.9	E.	2.3	6.0	1.7	2.0	S. 85 W.	2.3	6.4
14	do	I. E. Rittenburg	August 1932	2	2.0	0.4	S. 80 E.	3.1	5.9	1.8	1.3	N. 60 W.	2.9	6.5
15	Off Jefferson Park	T. A. Craven	August 1856	½	2.1	0.3	N. 55 E.	0.5	6.3	2.3	1.8	S. 50 W.	0.6	6.1
16	Off 110th St	C. H. Davis	June 1845	½	1.7	1.5	N. 40 E.	0.9	5.7	1.3	0.8	S. 5 W.	1.0	6.7

In the stretch of the river lying westward of Wards Island, the data for stations 15 and 16 show that it is the northerly flowing current that is the flood current, while the southerly flowing current is the ebb current. In a tidal sense, therefore, the Harlem River ends at the southern tip of Randalls Island.

The tide in the Harlem being 2 hours later than at Sandy Hook, the data of table 64 show that the slack waters in the Harlem come about the times of local high and low water, while the strengths come midway between high and low water. The tidal movement in the Harlem is, therefore, not of the progressive-wave type, being conditioned by the fact that it is a short strait connecting two larger tidal bodies of water. Because of this, the times and velocities of the current are subject to variations additional to those found in tidal rivers, for any relative changes in the heights of the water in the Hudson and East Rivers will introduce variations in the current of the Harlem.

In general, it is seen that the flood and ebb durations are approximately equal in the Harlem, although there are evidences that near the Hudson River end the ebb has somewhat the greater duration, while near the East River end the flood has the greater duration. In general, too, the strength of ebb has the greater velocity averaging about 1¾ knots against 1½ knots for the flood strength. In constricted passages between bridge piers the current attains its greatest velocity; under High Bridge, for example, the current has an average velocity at strength of 3 knots.

At stations 12 and 13, the flood strengths are much greater than the ebb. In fact, at station 13, there was no ebb at all, the current running flood throughout the 2 days of observations, the value −0.1 given for the ebb strength indicating that at the time corresponding to the ebb strength for the Harlem as a whole, the current was setting flood with a velocity of 0.1 knot.

The flood current at station 13 during the period when ebb is normally flowing in the Harlem appears to be due to the proximity of this station to Little Hell Gate. At the time of ebb strength in the Harlem, the current through Little Hell Gate is setting westerly and then southerly thus creating an eddy current in the vicinity of station 13. The effect of this is also felt at station 12 where the ebb strength is very small.

CURRENT DATA, VARIOUS DEPTHS, HARLEM RIVER

At 13 stations in the Harlem proper, subsurface current observations were also made with current meters at depths representing approximately two-tenths, five-tenths, and eight-tenths of the depth at each station. The data derived from these observations, with the flood and ebb strengths corrected to mean values, are given in table 65. For comparison, the results of the observations made with the current pole, which generally pertain to a depth of 7 feet, are also included. It is to be noted, however, that at a number of the stations listed in this table the observations were made with short poles so that the depths of the pole observations at these stations are less than 7 feet.

TABLE 65.—*Current data, various depths, Harlem River*

[Referred to times of HW and LW at Sandy Hook, N. J.]

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
1	Off Spuyten Duyvil	R. J. Auld	Nov. 14-16, 1920	2	Pole	7	2.11	0.99	S. 75 E.	1.57	5.83	1.81	0.69	N. 76 W.	2.00	6.59
				2	Meter	4	2.16	0.94		1.43	5.74	1.77	0.64		1.93	6.68
				2	do	10	2.24	1.11		1.31	5.65	1.76	0.38		1.84	6.77
				2	do	17	2.21	0.94		1.23	5.66	1.74	0.49		1.70	6.76
1	do	H. C. Denson	July 15-Aug. 7, 1922	22	Pole	7	1.91	0.49	S. 69 E.	1.28	6.23	2.01	0.69	N. 72 W.	1.76	6.19
				22	Meter	4	1.87	0.49		1.41	6.30	2.04	0.84		1.82	6.12
				22	do	11	1.98	0.54		1.25	6.17	2.02	0.56		1.85	6.25
				22	do	18	2.06	0.48		1.18	6.08	2.01	0.51		1.61	6.34
1	do	I. E. Rittenburg	Aug. 3-5, 1932	2	Pole	7	2.11	0.52	S. 67 E.	1.50	6.12	2.10	0.99	N. 78 W.	2.20	6.30
				2	Meter	5	2.01	0.62		1.30	6.32	2.20	0.79		2.00	6.10
				2	do	10	2.11	0.42		1.50	6.12	2.10	0.79		2.20	6.30
				2	do	16	2.11	0.52		1.40	6.22	2.20	0.49		1.80	6.20
2	Broadway Bridge	R. J. Auld	Nov. 18-20, 1920	2	Pole	7	2.09	0.51	S. 64 E.	2.14	5.85	1.81	1.43	N. 61 W.	2.38	6.57
				2	Meter	4	2.01	0.54		2.18	6.11	1.99	1.18		2.28	6.31
				2	do	10	2.02	0.36		2.07	6.07	1.96	1.31		2.23	6.35
				2	do	16	2.01	0.54		1.82	6.04	1.92	1.61		2.04	6.38
3	W. 207th St. Bridge	I. E. Rittenburg	Sept. 21-23, 1932	2	Pole	3½	1.71	0.72	S. 35 W.		6.62	2.20	1.29	N. 35 E.		5.80
				2	Meter	3	2.01	0.92		2.00	6.32	2.20	0.89		2.10	6.10
				2	do	13	2.01	0.72		1.90	6.32	2.20	0.89		2.00	6.10
4	High Bridge	R. J. Auld	Nov. 22-24, 1920	2	Pole	7	1.98	0.96	S. 9 W.	3.05	5.79	1.64	1.51	N. 15 E.	2.85	6.63
				2	Meter	4	2.06	0.74		2.75	5.56	1.49	1.61		2.59	6.86
				2	do	10	2.04	0.78		2.62	5.55	1.46	1.76		2.79	6.87
				2	do	16	1.96	0.88		2.23	5.66	1.49	1.81		2.30	6.76
5	South of High Bridge	H. C. Denson	Aug. 3, 1922	¾	Pole	1½	1.89	0.31	S. 37 W.	1.06	6.13	1.89				6.29
				¾	Meter	3	1.59	0.21		1.25	6.53	1.99	0.71		1.25	5.89
				¾	do	7	1.69	0.81		1.25	6.43	1.99	1.40		1.34	5.99
				¾	do	10	1.79	0.31		1.16	6.33	1.99	0.91		1.16	6.09

TABLE 65.—*Current data, various depths, Harlem River*—Continued

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
6	South of High Bridge	H. C. Denson	Aug. 2-4, 1922	1½	Pole	1½	1.89	0.78	S. 30 W.	1.36	6.25	2.01	1.04	N. 29 E.	1.36	6.17
				1½	Meter	4	1.96	0.88		1.40	6.13	1.96	1.41		1.48	6.29
				1½	do	11	1.89	1.04		1.33	6.20	1.96	1.16		1.48	6.22
				1½	do	17	1.89	1.08		1.19	6.20	1.96	1.09		1.30	6.22
7	do	do	Aug. 3-4, 1922	¾	Pole	1½	1.79	0.31	S. 26 W.	1.12	6.38	2.04	1.21	N. 20 E.	1.12	6.04
				¾	Meter	4	1.89	0.81		1.53	6.23	1.99	0.71		1.23	6.19
				¾	do	10	1.79	0.51		1.43	6.33	1.99	1.41		1.43	6.09
				¾	do	16	1.79	0.91		1.12	6.33	1.99	0.91		1.12	6.09
8	Central Bridge	I. E. Rittenburg	Sept. 8-10, 1932	2	Pole	3½	2.11	0.32	S.	1.80	6.12	2.10	0.69	N.	1.40	6.30
				2	Meter	3	2.01	1.12		1.80	5.92	1.80	1.19		1.50	6.50
				2	do	12	2.11	1.12		1.60	5.72	1.70	1.19		1.40	6.70
9	Madison Ave. Bridge	do	Sept. 6-8, 1932	2	Pole	3½	2.01	1.02	S.	1.70	6.02	1.90	1.29	N.	1.60	6.40
				2	Meter	4	2.01	1.02		1.90	5.92	1.80	1.29		1.80	6.50
				2	do	16	2.11	1.22		1.80	5.72	1.70	1.09		1.80	6.70
10	Above Willis Ave. Bridge.	H. C. Denson	Aug. 2-4, 1922	1¾	Pole	7	1.46	1.11	S. 33 E.	0.88	6.69	2.02	1.71	N. 41 W.	0.97	5.73
				1¾	Meter	4	1.52	0.58		0.80	6.70	2.09	1.91		1.07	5.72
				1¾	do	11	1.62	0.74		0.85	6.30	1.79	1.96		0.97	6.12
				1¾	do	17	1.62	0.91		0.73	6.03	1.52	1.76		0.87	6.39
11	Off 117th St	I. E. Rittenburg	Sept. 26-28, 1932	2	Pole	3½	3.01	−0.70	S. 37 W.	0.50	5.32	2.20	1.29	N. 50 E.	1.90	7.10
				2	Meter	4	2.41	−0.50		0.60	6.02	2.30	0.89		2.30	6.40
				2	do	14	2.01	0.82		0.30	5.72	1.60	1.09		2.10	6.70
12	Off Jefferson Park	do	Aug. 8-12, 1932	4	Pole	7	1.21	0.62	S. 17 W.	1.30	7.62	2.70	1.49	N. 37 E.	0.20	4.80
				4	Meter	4		0.72		1.30			1.39		0.30	
				4	do	15		0.62		1.20			1.59		0.40	
13	Off 110th St	do	Sept. 26-28, 1932	2	Pole	3½		0.42	S. 13 W.	1.20			0.89	S. 55 W.	−0.10	
				2	Meter	3		0.92		1.40			0.79		−0.10	
				2	do	13		0.82		1.10			1.29		−0.10	

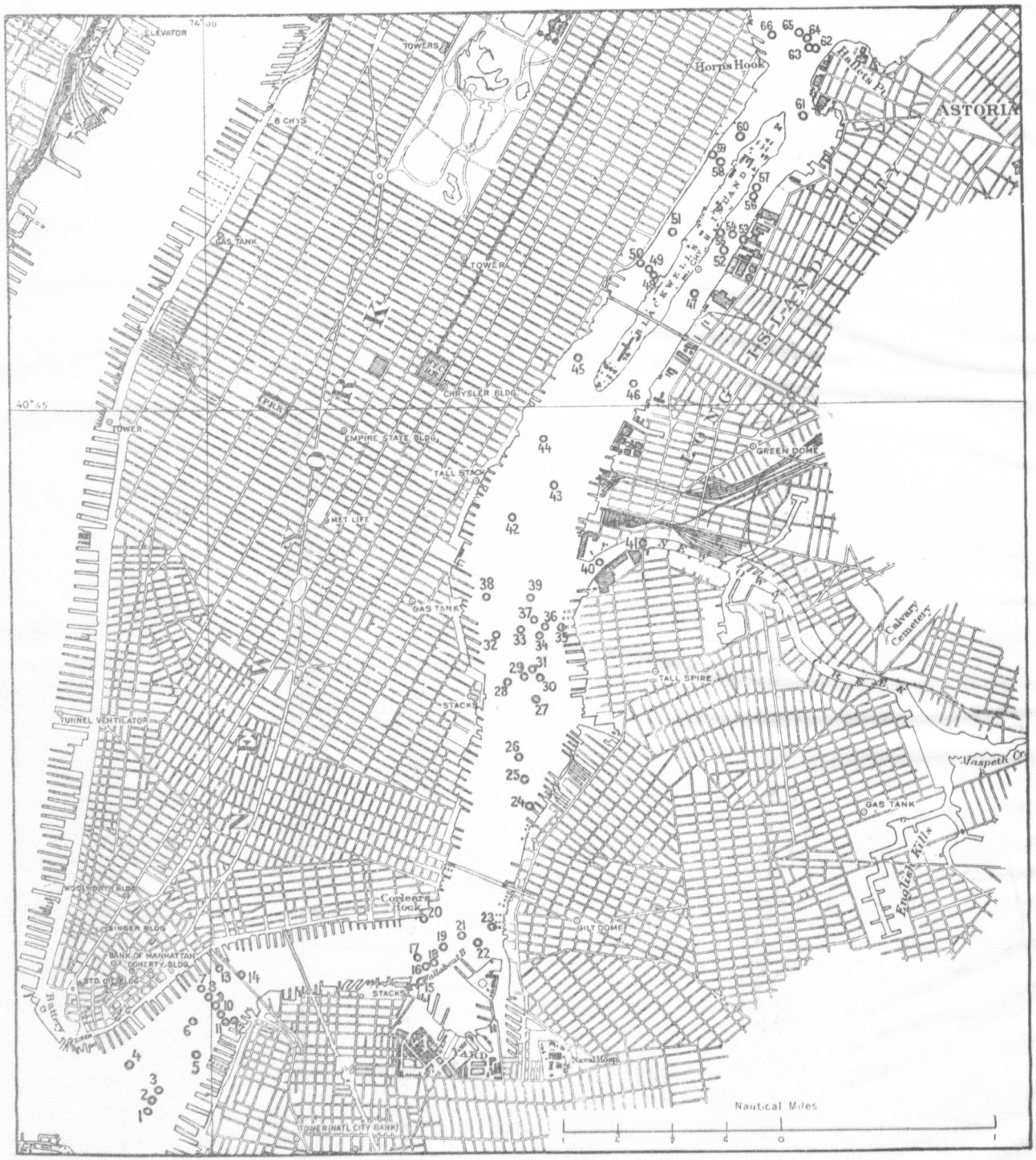

FIGURE 43.—Current stations, lower East River.

The observations made at station 1 in 1922 covered a period of 22 days and the results here may, therefore, be considered as well determined. The slack before flood appears to become somewhat later from the surface to the bottom, the rate being about 0.01 hour per foot. The slack before ebb, however, appears to occur at about the same time at all depths. This difference in the slacks causes the duration of flood to decrease with increasing depth. In this regard the current at the Hudson entrance to the Harlem reverses the condition found in the Hudson where it is the duration of ebb that decreases from the surface to the bottom.

The vertical velocity distribution at station 1 likewise differs from that in the Hudson. In the latter river it is the ebb strength that decreases rapidly in velocity, from the surface downward, while the flood strength in general increases. The data of table 65 show that in the Harlem, both the flood and ebb strengths decrease with increasing depth, the rate being between 0.01 and 0.02 knot per foot of depth.

Near the surface the ebb strength in the Harlem has the greater velocity. And since both flood and ebb strengths decrease at about the same rate with increasing depth, this preponderance of ebb over flood is characteristic of the Harlem at all depths. This is true at all stations except 12 and 13 where the flood has the greater velocity, for the same reason as explained on page 164 for the current near the surface.

THE CURRENT IN EAST RIVER

SURFACE CURRENTS, LOWER EAST RIVER

In the discussion of the current in East River it will be convenient to divide the river into two parts—lower East River, stretching from Governors Island to Hell Gate, and upper East River, stretching from Hell Gate to Willets Point. Lower East River, it is to be recalled, is a relatively narrow and deep waterway, while upper East River is wider and shallower.

On figure 43 are shown the locations of 66 stations at which current observations have been made in lower East River between the years 1845 and 1932. The results derived from these observations pertaining to the current near the surface are given in table 66. For the more recent years, these results are derived from observations made with a 15-foot pole submerged a distance of 14 feet, so that but 1 foot floated out of water. In general, the data of table 66 may be taken to refer to the current at a depth of about 7 feet.

The times of slack and strength of the current in table 66 are given in hours and tenths with reference to time of tide at Sandy Hook, N. J., HW standing for the time of high water and LW for the time of low water. For the flood and ebb strengths the directions are given to the nearest 5° and the velocities in knots and tenths. These velocities have been corrected to mean values by a factor derived from the range of tide. This correction factor for the current in East River is not the ratio of the mean range of tide divided by the range for the period of observation, as in the case of the Hudson River, but the square root of this ratio. This difference is due to the fact that the tidal movement in the East River is primarily hydraulic in character, as explained in the discussion of the tide in East River; and in hydraulic motion the velocity varies as the square root of the head or the difference in the height of water at the two ends of the channel.

TABLE 66.—*Surface current data, lower East River*

[Referred to times of HW and LW at Sandy Hook, N. J.]

Station no.	Location	Party of—	Observations		Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
1	Off State St., Brooklyn	H. L. Marindin	August 1872	1	2.0	0.7	N. 60 E.	1.3	6.5	2.4	1.7	S. 25 W.	1.8	5.9
2	Off Joralemon St., Brooklyn	T. A. Craven	July 1855	½	1.7	0.7	N. 60 E.	2.5	7.0	2.6	0.9	S. 50 W.	2.6	5.4
3	Off Montague St., Brooklyn	H. L. Marindin	August 1872	½	1.6	1.8	N. 70 E.	1.2	7.0	2.5	1.0	S. 25 W.	1.7	5.4
4	Off Coenties Slip, New York	I. E. Rittenburg	August 1932	2	2.3	0.4	N. 55 E.	2.1	6.1	2.3	0.9	S. 50 W.	2.5	6.3
5	Off Wall St., New York	H. Mitchell	July 1872	1	1.6	0.8	N. 50 E.	1.6	6.5	2.0	1.3	S. 30 W.	1.5	5.9
6	Off Fletcher St., New York	M. Woodhull	July 1854	½	2.1	1.1	N. 20 E.	2.2	6.4	2.4	1.0	S. 35 W.	3.4	6.0
6	do	H. C. Denson	August 1922	13	2.2	0.8	N. 45 E.	2.3	6.1	2.2	0.8	S. 40 W.	3.2	6.3
12	Below Fulton St., Brooklyn	do	September 1922	½	1.0	0.0	N. 40 E.	1.8	7.5	2.4	1.4	S. 55 W.	0.3	4.9
13	Off Dover St., New York	do	do	½	2.1	1.6	N. 45 E.	2.0	6.4	2.4	1.1	S. 40 W.	1.5	6.0
14	Midchannel, Brooklyn Bridge	R. J. Auld	September 1920	¾	2.1	0.2	N. 50 E.	3.2	6.7	2.7	0.4	S. 65 W.	3.8	5.7
15	Wallabout Bay	H. C. Denson	September 1922	½	1.9	1.0	N. 75 E.	0.8	6.2	2.0				6.2
16	do	M. Woodhull	July 1854	1	2.3	1.1	N. 80 E.	3.2	5.9	2.1	0.6	W.	3.5	6.5
17	Off Jackson St., New York	T. A. Craven	July 1855	½	2.4	0.8	S. 85 E.	5.3	5.7	2.0	0.9	S. 80 W.	4.2	6.7
18	Wallabout Bay	I. E. Rittenburg	October 1932	1	2.4	0.4	N. 50 E.	1.9	5.9	2.2	1.1	S. 75 W.	2.3	6.5
19	Off Corlear St., New York	R. J. Auld	September 1920	1	2.4	0.7	N. 55 E.	3.9	6.0	2.3	1.0	S. 60 W.	3.3	6.4
21	Off Corlears Hook, New York	T. A. Craven	July 1855	1	2.3	0.8	N. 65 E.	4.5	6.1	2.3	1.1	S. 45 W.	3.9	6.3
22	Wallabout Bay	M. Woodhull	July 1854	1	1.9	0.1	N. 35 E.	2.9	6.8	2.6	1.4	S. 40 W.	2.9	5.6
23	Off S. 9th St., Brooklyn	H. C. Denson	September 1922	½	1.9	0.3	N. 25 E.	1.6	6.2	1.9				6.2
24	Off N. 2d St., Brooklyn	do	do	½	3.4	−0.4	N. 15 W.	0.1	5.6	2.9	1.5	S. 45 W.	0.6	6.8
25	Off N. 4th St., Brooklyn	T. A. Craven	July 1855	½	2.5	0.4	N. 35 E.	4.8	5.7	2.1	0.6	S. 40 W.	3.9	6.7
26	Off N. 6th St., Brooklyn	M. Woodhull	July 1854	1	2.4	0.0	N. 25 E.	2.1	6.4	2.7	0.7	S. 20 W.	3.2	6.0
27	Off 17th St., New York	H. Mitchell	July 1859	1	2.3	0.0	N. 25 E.	2.5	6.2	2.4	1.0	S. 5 W.	1.3	6.2
28	Off 18th St., New York	H. C. Denson	July 1922	4¾	2.0	0.7	N. 10 W.	1.4	6.0	1.9	1.1	S. 10 E.	2.2	6.4
29	Off 19th St., New York	do	do	4¾	2.0	0.6	N. 5 W.	1.5	6.1	2.0	1.3	S.	2.0	6.3
30	Off 20th St., New York	do	do	4¾	1.9	0.6	N.	1.9	6.1	1.9	1.6	S. 10 W.	1.8	6.3
31	do	H. Mitchell	July 1858	¾	2.3	1.0		2.5	6.3	2.5	1.4	S. 20 E.	1.8	6.1
32	Off 21st St., New York	H. L. Marindin	August 1885	¼	2.1				6.0	2.0	0.9		2.5	6.4
33	Off 23d St., New York	do	do	1½	2.3	0.8		2.0	6.1	2.3	1.4		2.3	6.3
34	Off Huron St., Brooklyn	do	October 1886	3¼	2.4	0.8	N. 15 W.	2.1	6.2	2.5	1.1	S. 10 E.	2.3	6.2
36	Off Greene St., Brooklyn	do	August 1885	¼	2.1				6.0	2.0	1.2		2.1	6.4
37	do	R. J. Auld	August 1920	¾	2.1	0.9	N.	2.1	6.2	2.2	1.2	S. 15 E.	1.8	6.2
38	Off 25th St., New York	H. C. Denson	September 1922	½	2.3	1.4	N.	1.4	5.7	1.9	1.4	S.	1.7	6.7
39	Off 26th St., New York	M. Woodhull	July 1854	1	2.5	0.5	N. 5 W.	2.3	6.6	3.0	1.7	S. 15 W.	1.6	5.8
40	Newtown Creek entrance	R. J. Auld	October 1920	1	2.7	−0.1	N. 60 E.	0.3	5.6	2.2	1.2	S. 50 W.	0.3	6.8
42	Off 34th St., New York	H. C. Denson	September 1922	3¼	2.5	0.9	N. 25 E.	1.6	5.8	2.2	0.6	S. 35 W.	2.1	6.6
43	Off 39th St., New York	T. A. Craven	July 1855	½	2.1	1.1	N. 15 E.	2.3	5.4	1.4	0.2	S. 35 W.	1.5	7.0
44	Off 43d St., New York	do	do	½	2.8	0.7	N. 20 E.	2.5	6.0	2.7	0.6	S. 25 W.	4.1	6.4
45	Off 52d St., New York	H. Mitchell	July 1858	2¾	2.2	0.6	N. 25 E.	2.7	6.1	2.2	1.4	S. 30 W.	3.2	6.3
46	East Channel, Blackwells Island	do	do	½		0.7	N. 45 E.	1.6			0.5	S. 40 W.	2.5	
47	do	H. L. Marindin	July 1874	¼		1.0	N. 35 E.	2.7			0.6	S. 40 W.	2.7	
47	do	R. J. Auld	September 1920	1	1.8	0.4	N. 30 E.	2.6	6.6	2.3	1.2	S. 30 W.	1.9	5.8
48	West Channel, Blackwells Island	H. L. Marindin	July 1874	¼		0.5	N. 40 E.	3.7			0.7	S. 40 W.	2.3	
49	do	do	do	¼		0.2	N. 40 E.	4.1			0.4	S. 40 W.	4.9	
50	do	do	do	¼		0.5	N. 35 E.	4.0			0.4	S. 25 W.	3.1	
51	do	H. C. Denson	August 1922	2¾	2.3	1.0	N. 35 E.	3.6	5.9	2.1	1.0	S. 45 W.	4.7	6.5
52	East Channel, Blackwells Island	do	do	2¾	2.0	0.7	N. 25 E.	3.5	6.3	2.2	1.4	S. 30 W.	3.3	6.1
53	do	H. L. Marindin	July 1874	¼		1.2	N. 20 E.	2.9			1.2	S. 40 W.	1.6	
54	do	do	do	¼		1.2	N. 30 E.	4.0			1.2	S. 45 W.	3.9	
55	do	do	do	¼		0.7	N. 35 E.	3.5			1.0	S. 35 W.	3.5	
56	do	H. Mitchell	May, 1857	8¾	2.2	0.9	N. 35 E.	4.3	6.1	2.2	1.3	S. 35 W.	4.0	6.3
57	do	C. H. Davis	June 1845	½	2.5	0.5	N. 30 E.	3.0	6.3	2.7				6.1
58	West Channel, Blackwells Island	R. J. Auld	August 1920	1	2.1	1.1		4.8	6.3	2.3	1.4		5.0	6.1
58	do	C. H. Davis	June 1845	½	1.9	1.2	N. 35 E.	4.2	6.3	2.1	1.1	S. 40 W.	4.8	6.1
59	do	H. L. Marindin	July 1874	¼		0.4	N. 35 E.	3.9			0.6		2.8	
60	do	H. Mitchell	May 1857	7½	2.6	0.8	N. 40 E.	4.7	5.8	2.3	0.8	S. 40 W.	4.9	6.6
61	East Channel, Blackwells Island	R. J. Auld	September 1920	1	2.0	0.7	N. 10 W.	3.4	5.9	2.5	1.6	S. 15 E.	1.6	6.5
63	Hell Gate	C. H. Davis	June 1845	½	2.2	1.2	N. 20 E.	4.2	6.2	2.3	1.8	S. 60 W.	3.0	6.2
66	Off 92d St., New York	do	do	½	1.5	2.0	N. 25 W.	1.2	6.1	1.5	1.2	S. 20 E.	2.6	6.3

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In entering East River from Upper Bay it is natural to regard the current setting from Upper Bay into East River as the flood current; but East River may also be entered from Long Island Sound, from which body of water it is just as natural to regard the westerly setting current as the flood current. In East River, manifestly, upstream and downstream cannot be used for specifying the flood and ebb currents, and recourse must be had to the time relations between current and tide. From the tidal data of table 41 the tide in lower East River, from Governors Island to Hell Gate, is seen to be about 2 hours later than at Sandy Hook. Applying this difference to the data of table 66, the strength of the current setting into East River from Upper Bay is found to occur about 3 hours before local high water; that is, on a rising tide. Hence, the flood current in lower East River, and as we shall find later the flood current throughout the whole of East River, is the one setting from Upper Bay toward Long Island Sound, while the ebb current is the one that sets from Long Island Sound toward Upper Bay.

It is to be noted that since the current in East River is dependent on the relative heights of the water in Upper Bay and in Long Island Sound, short series of observations will not give as concordant results in this waterway as in a tidal river that has but one entrance for the tide. This may be taken to explain some of the comparatively wide divergences in the results for the different stations listed in table 66. In part, too, the differences result from the changes that have been made in the hydrographic features of this waterway.

In general, slack before flood throughout lower East River occurs about the same time, approximately 2 hours after the time of low water at Sandy Hook. Through this stretch, however, as the discussion of the tide observations brought out, the time of tide changes by 1¾ hours, becoming later in going from the Battery to Hell Gate. The time relations between tide and current in lower East River, therefore, changes from point to point. At the mouth of the river, slack before flood comes about 1½ hours after local low water, while in the channel near the northern end of Blackwells Island slack before flood comes about the time of local low water. This represents a change in the relation of current to tide of 1½ hours in a distance of about 6 miles. In the Hudson River, it will be recalled, the relation of time of tide to time of current was practically constant throughout the whole stretch of 14 miles from the mouth to Mount St. Vincent.

The slack before ebb likewise occurs about the same time throughout lower East River. So that a similar change in the time relations of current to local tide occurs with regard to slack before ebb as with regard to slack before flood. And this is true also of the strengths of flood and ebb which occur at about the same times, respectively, throughout lower East River.

Although lower East River is a relatively narrow waterway, the current turns somewhat earlier near shore than in midchannel. This is brought out by a comparison of the data for stations located on a cross section as, for example, stations 28, 29, and 30, and stations 32, 33, and 36. Throughout the stretch of lower East River the flood duration is approximately constant, averaging 6.1 hours against 6.3 hours for the ebb.

Since the channel of East River changes direction frequently, the flood and ebb directions are generally not directly opposite each other, the direction at any point being influenced by the direction of the channel below and above that point. This is well illustrated by station 14, for which table 66 gives the flood direction as N. 50° E. and the ebb direction as S. 65° W. The direction of the channel below this station is N. 45° E., and the flood current approximated this direction closely. Above the station the channel runs S. 80° W., and on the ebb the direction of the current is 20° farther westward than on the flood, thus indicating the influence of the direction of the channel above the station

The frequent changes in direction of the channel of lower East River have another consequence. In a straight stretch of the river the swiftest thread of the current lies in midchannel; but when the direction of the channel changes the swiftest thread of the current will be found not in midchannel but to one side. Thus, for stations 28, 29, and 30 it is obvious from the locations of these stations on figure 43 that on the flood station 30 will be in the path of the main stream of the flood current, although it is not in midchannel; and on the flood table 66 shows a greater velocity for station 30 than either for stations 28 or 29, notwithstanding the fact that the latter is a midstream station. On the ebb the turn of the channel southward in the vicinity of Newtown Creek makes the momentum of the moving stream continue its more westerly direction, and station 28 is now in the path of the main ebb stream, and the ebb velocities of table 66 show that the ebb strength at station 28 is now greater than either at stations 29 or 30.

The swiftest current in lower East River is found in the constricted passages of Blackwells Island and in Hell Gate, where the mean velocity of the current is 4 knots or more. In this connection it is to be noted that the more recent observations, in which improved methods and instruments were used, give lesser velocities than the observations made in 1855. For this reason the velocity of 5.3 knots on the flood listed in table 66 for station 17 is undoubtedly too great.

Through lower East River the ebb current has the greater velocity. This general rule is subject to modification by the location of the station, whether in the direct path of the ebb and flood current or not. This was illustrated in the previous paragraph by the currents at stations 28, 29, and 30 and is also illustrated by station 61, which shows a flood velocity of 3.4 knots and an ebb velocity of 1.6 knots, whereas from the general rule above the ebb velocity should be the greater. The location of this station is seen to be in the direct path of the flood current through the eastern channel of Blackwells Island but to one side of the main stream of the ebb current which sets from Hell Gate directly into the west channel of Blackwells Island.

The two channels of Blackwells Island show considerable differences. The data for stations 51 and 52 may be considered as fairly well determined, being based on recent observations extending over a period of very nearly 3 days. The velocity at station 51 in the western channel is somewhat greater on the flood and considerably greater on the ebb than at station 52 in the eastern channel. The observations at stations 45 and 46 were made in 1858, and these show the same differences between the two channels, the velocity

in the western channel being the greater; and the observations in 1874 at stations 47 and 49 likewise show the greater velocity for the western channel. A glance at a hydrographic chart of this region shows that the western channel of Blackwells Island is considerably deeper than the eastern channel and therefore offers a freer passage for the water. The direction of the channels likewise tends to bring the main flood and ebb streams through the western channel, and this is particularly the case on the ebb.

The fact that the ebb current has the greater velocity and the greater duration might be taken to indicate the presence of fresh-water flow toward Upper Bay, but the subsurface currents, to be discussed presently, do not bear this out. The reason for the greater velocity and duration of the ebb current must be sought in the character of the tidal movement in the East River.

An examination of figure 23 shows that on the assumption of hydraulic flow through East River, the slope lines would be horizontal about 2.9 hours and 8.7 hours, and that from 2.9 hours to 8.7 hours, or 5.8 hours, the current would be setting toward Long Island Sound or flooding. The hours of figure 23 are lunar hours and to convert them into solar or ordinary hours, they must be multiplied by 1.035. So that from the slope-line diagram the duration of flood is 6.0 hours, and of ebb 6.4 hours. These values are in fairly good agreement with the values of 6.1 hours and 6.3 hours derived directly from the observations.

Since the flow through East River is primarily hydraulic in character, it is to be expected that the time of current should be the same throughout the River. Furthermore, since the slacks should come about the time the slope lines are horizontal, it follows that the slack before flood should come about 2.9 hours and the slack before ebb about 8.7 hours. The hours of figure 23 are lunar hours reckoned from the time of transit of the moon over the meridian of the Battery. The lunitidal intervals at Sandy Hook are 7.6 for the high water and 1.5 for the low water. Hence from the slope line diagram, the slack before flood in lower East River should come 1.5 hours after low water at Sandy Hook, and slack before ebb 1.4 hours after high water. This is about half an hour earlier than the data in table 66 give. But part of this discrepancy is to be ascribed to the fact that in the slope-line diagram no allowance is made for the momentum of the moving mass of water; and obviously the effect of this momentum is to make slack water occur somewhat after the time the water at both ends of East River has attained the same level.

From the slope-line diagram, too, the time of strength of current can be derived, for the strength must occur when the slope lines have their greatest slope. Figure 23 shows these times to be about 6.5 hours for the flood and 0.5 hour for the ebb. With respect to the times of high and low water at Sandy Hook, therefore, strength of flood should come 0.9 hour before high water, and strength of ebb 1.0 hour before low water. From table 66 it is found that the strength of flood in lower East River, from the more recent data, comes 0.7 hour before high water, and strength of ebb comes 1.1 hours before low water. These values, again, are in fair agreement with the values derived from the slope-line diagram.

CURRENT DATA, VARIOUS DEPTHS, LOWER EAST RIVER

For a number of the stations in lower East River there are available also subsurface observations at three depths, namely, 0.2, 0.5, and 0.8 of the depth at each station. The results derived from these observations, with the velocities of the flood and ebb strengths corrected to mean values, are given in table 67. The observations with the current pole at these stations, which pertain to a depth of 7 feet and which have been given in a slightly different form in table 66, are included for purposes of comparison. For several of these stations the directions of the current were determined by means of the bifilar direction indicator.

TABLE 67.—*Current data, various depths, lower East River*

[Referred to times of HW and LW at Sandy Hook, N. J.]

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
4	Off Coenties Slip, New York.	L. E. Rittenburg.	Aug. 4–6, 1932	2	Pole	7	2.31	0.42	N. 56 E.	2.10	6.12	2.30	0.89	S. 51 W.	2.50	6.30
				2	Meter	9	2.41	0.42		2.10	5.92	2.20	0.99		2.40	6.50
				2	do	22	2.41	0.52		2.00	6.02	2.30	0.89		2.10	6.40
				2	do	35	2.51	0.42		1.60	5.82	2.20	0.89		1.80	6.60
6	Off Fletcher St., New York.	H. C. Denson	July 23–Aug. 16, 1922	13	Pole	7	2.20	0.77	N. 46 E.	2.28	6.13	2.20	0.85	S. 42 W.	3.22	6.29
				12½	Meter	10	2.16	0.64		2.30	6.16	2.19	1.01		3.25	6.26
				12½	do	25	2.16	0.62		2.09	6.15	2.18	1.02		3.03	6.27
				12½	do	40	2.18	0.57		1.81	6.13	2.18	0.89		2.77	6.29
7	Off Beekman St., New York.	U. S. Engineers	Oct. 26–Nov. 1, 1932	6	do	10	2.08	1.15		2.26	6.15	2.10	1.33		2.68	6.27
				6	do	25	2.19	0.88		1.75	6.02	2.08	1.20		1.88	6.40
				6	do	40	2.22	0.75		1.39	5.99	2.08	1.33		1.66	6.43
8	do	do	Nov. 2–5, 1932	3	do	11	2.30	0.54		3.11	6.09	2.26	0.93		3.55	6.33
				3	do	28	2.37	0.72		2.27	6.02	2.26	0.85		2.79	6.40
				3	do	44	2.33	0.56		2.24	6.00	2.20	0.83		2.91	6.42
9	do	do	Oct. 12–Nov. 5, 1932	24	do	11	2.16	0.71		2.80	6.23	2.26	1.18		3.45	6.19
				24	do	26	2.28	0.76		2.74	6.10	2.25	1.21		3.00	6.32
				24	do	42	2.32	0.70		2.16	6.01	2.20	1.13		2.49	6.41
9	do	do	Sept. 20–26, 1932	6	do	11	2.19	0.86		2.93	6.26	2.32	1.25		3.65	6.16
				6	do	27	2.27	0.86		2.89	6.18	2.32	1.25		3.20	6.24
				6	do	43	2.24	0.89		2.16	5.99	2.10	1.16		2.43	6.43
10	do	do	Oct. 19–26, 1932	6	do	11	2.12	0.54		3.09	6.63	2.62	1.07		3.41	5.79
				6	do	27	2.31	0.72		2.50	6.37	2.55	0.98		2.40	6.05
				6	do	43	2.42	0.76		1.52	6.19	2.48	1.07		1.56	6.23
11	do	do	Oct. 12–19, 1932	6	do	10	1.84	0.84		3.03	6.61	2.32	1.15		2.96	5.81
				6	do	24	2.04	0.87		2.19	6.35	2.26	1.10		2.15	6.07
				6	do	38	2.19	0.63		1.68	6.21	2.27	1.05		1.48	6.21
12	Below Fulton St., Brooklyn.	H. C. Denson	Sept. 2, 1922	½	Pole	7	0.99	0.01	N. 42 E.	1.77	7.53	2.39	1.41	S. 55 W.	0.27	4.89
				½	Meter	10	1.69	1.61	N. 39 E.	2.18	6.93	2.49	1.71	S. 59 W.	0.48	5.49
				½	do	24	1.69	0.31	N. 41 E.	1.92	6.93	2.49	1.51	S. 36 W.	0.37	5.49
				½	do	38	1.69	0.31	N. 38 E.	1.97	7.03	2.59	1.51	S. 41 W.	0.37	5.39
13	Off Dover St., New York.	do	do	½	Pole	7	2.09	1.61	N. 43 E.	2.03	6.43	2.39	1.11	S. 42 W.	1.53	5.99
				½	Meter	9	2.29	1.41	N. 36 E.	2.14	5.73	1.89	1.81	S. 42 W.	1.94	6.69
				½	do	23	2.19	1.31	N. 37 E.	1.43	5.83	1.89	1.71	S. 42 W.	1.73	6.59
				½	do	36	2.19	0.91	N. 41 E.	1.08	5.73	1.79	1.51	S. 21 W.	1.58	6.69
14	Mid-channel, Brooklyn Bridge.	R. J. Auld	Sept. 24–25, 1920	¾	Pole	7	2.14	0.21	N. 50 E.	3.20	6.68	2.69	0.36	S. 64 W.	3.75	5.74
				¾	Meter	13	2.17	0.83		3.19	6.53	2.57	0.63		3.64	5.89
				¾	do	33	2.19	1.16		2.77	6.48	2.54	0.66		3.27	5.94
				¾	do	53	2.21	0.70		2.55	6.23	2.31	0.04		2.80	6.19
15	Wallabout Bay	H. C. Denson	Sept. 1, 1922	½	Pole	7	1.89	1.01	N. 75 E.	0.83	6.23	1.99				6.19
				½	Meter	10	2.09	0.61	N. 74 E.	0.75	6.33	2.29	1.61	S. 78 W.	1.75	6.09
				½	do	24	2.19	0.91	N. 60 E.	1.00	6.23	2.29	1.91	S. 79 W.	1.45	6.19
				½	do	38	2.19	0.91	N. 72 E.	1.05	6.23	2.29	1.71	S. 74 W.	1.50	6.19
18	do	L. E. Rittenburg.	Oct. 5–6, 1932	1	Pole	7	2.41	0.42	N. 49 E.	1.90	5.92	2.20	1.09	S. 77 W.	2.30	6.50
				1	Meter	10	2.41	0.62		1.70	5.92	2.20	0.99		2.20	6.50
				1	do	25	2.41	0.32		2.20	6.02	2.30	0.89		2.10	6.40
				1	do	40	2.31	0.00		2.10	6.12	2.30	0.89		2.00	6.30
19	Off Corlear St., New York.	R. J. Auld	Sept. 21–22, 1920	1	Pole	7	2.34	0.71	N. 55 E.	3.87	6.13	2.34	1.01	S. 62 W.	3.32	6.29
				1	Meter	8	2.37	0.63		3.73	6.18	2.42	0.98		2.98	6.24
				1	do	25	2.34	0.51		3.44	6.18	2.39	1.16		2.84	6.24
				1	do	40	2.31	0.14		2.98	6.28	2.46	1.14		2.68	6.14
20	do	H. C. Denson	Sept. 1, 1922	½	do	7	2.69	0.81	N. 77 E.	0.40	5.43	1.99	1.16	S. 26 W.	2.23	6.99
				½	do	17	2.69	1.51	N. 50 E.	0.35	5.43	1.99	1.01	S. 25 W.	2.25	6.99
				½	do	27	2.69	1.71		0.35	5.43	1.99	1.11	S. 25 W.	2.25	6.99
23	Off S. 9th St., Brooklyn.	do	do	½	Pole	7	1.89	0.31	N. 24 E.	1.61	6.23	1.99				6.19
				½	Meter	10	1.09	0.81	N. 31 E.	1.14	7.83	2.79				4.59
				½	do	25	1.59	1.01	N. 45 E.	1.35	7.33	2.79				5.09
				½	do	40	1.69	1.01	N. 33 E.	1.30	7.23	2.79				5.19
24	Off N. 2d St., Brooklyn	do	Aug. 31–Sept. 1, 1922	½	Pole	7	3.39	0.11		0.10	5.63	2.89	1.51	S. 44 W.	0.62	6.79
				½	Meter	7	3.19	0.11	N. 17 W.	0.35	5.23	2.29	1.51	S. 39 W.	1.03	7.19
				½	do	18	3.24	0.11	N. 24 W.	0.34	5.18	2.29	1.11	S. 26 W.	1.19	7.24
				½	do	29	3.19	0.31	N. 22 W.	0.35	5.33	2.39	0.61	S. 23 W.	1.08	7.09
28	Off 18th St., New York	do	July 25–30, 1922	4¾	Pole	7	1.99	0.71	N. 12 W.	1.45	6.00	1.86	1.08	S. 12 E.	2.22	6.42
				4¾	Meter	6	2.07	0.44		1.59	5.89	1.83	0.88		2.54	6.53
				4¾	do	16	2.07	0.40		1.49	5.93	1.87	0.83		2.44	6.49
				4¾	do	26	2.06	0.43		1.36	6.02	1.95	0.98		2.12	6.40
29	Off 19th St., New York	do	do	4¾	Pole	7	1.97	0.60	N. 6 W.	1.48	6.15	1.99	1.33	S. 1 W.	1.97	6.27
				4¾	Meter	10	1.92	0.34		1.52	6.34	2.13	1.25		1.93	6.08
				4¾	do	25	2.06	0.23		1.35	6.22	2.15	0.94		1.79	6.20
				4¾	do	40	2.06	0.09		1.25	6.25	2.18	0.89		1.54	6.17

TABLE 67.—*Current data, various depths, lower East River*—Continued

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
30	Off 20th St., New York	H. C. Denson	July 25-30, 1922	4¾	Pole	7	1.90	0.57	N. 2 E.	1.87	6.16	1.93	1.57	S. 9 W.	1.75	6.26
				4¾	Meter	11	1.89	0.14		1.96	6.34	2.10	1.50		1.75	6.08
				4¾	do	27	2.04	−0.09		1.90	6.29	2.20	1.25		1.70	6.13
				4¾	do	44	2.05	−0.30		1.69	6.27	2.29	1.07		1.58	6.15
35	Off Greene St., Brooklyn.	do	Aug. 31-Sept. 1, 1922	½	do	8	1.89	1.16	N. 11 W.	1.10	7.03	2.79	0.01	S. 9 E.	0.54	5.39
				½	do	19	1.89	0.21	N. 9 W.	1.35	7.03	2.79	0.01	S. 9 E.	0.75	5.39
				½	do	30	1.89	0.21	N. 25 W.	1.45	6.83	2.59	0.41	S. 1 W.	0.80	5.59
37	do	R. J. Auld	Aug. 27-28, 1920	¾	Pole	7	2.09	0.96	N. 2 E.	2.12	6.23	2.19	1.21	S. 14 E.	1.82	6.19
				¾	Meter	7	1.99	0.51		1.82	6.23	2.09	1.91		1.62	6.19
				¾	do	18	2.02	0.59		2.07	6.28	2.17	1.84		1.72	6.14
				¾	do	28	2.06	0.98		2.12	6.38	2.31	1.48		1.82	6.04
38	Off 25th St., New York	H. C. Denson	Aug. 31-Sept. 1, 1922	½	Pole	7	2.29				5.73	1.89	1.41	S. 2 W.	1.73	6.69
				½	Meter	8	2.19	1.41	N. 2 W.	1.43	5.83	1.89	1.41	S. 5 W.	1.88	6.59
				½	do	21	2.19	1.51	N. 2 W.	1.17	5.83	1.89	1.41	S. 11 W.	1.87	6.59
				½	do	33	2.19	1.81	N. 2 W.	1.02	5.83	1.89	1.31	S. 11 W.	1.77	6.59
40	Newtown Creek entrance.	R. J. Auld	Oct. 14-15, 1920	1	Pole	7	2.69	−0.14	N. 58 E.	0.34	6.16	2.22	1.21	S. 49 W.	0.29	6.26
				1	Meter	4	2.17	−0.07		0.35	6.38	2.42	0.78		0.20	6.04
				1	do	9	2.24	0.16		0.25	6.13	2.24	0.36		0.20	6.29
				1	do	15	2.41	−0.06		0.30	5.93	2.21	0.69		0.25	6.49
41	Vernon Ave. Bridge, Newtown Creek.	H. C. Denson	Oct. 2, 1922	½	do	5	2.19	1.21		0.41	6.33	2.39	0.61		0.31	6.09
				½	do	13	2.29	1.41		0.31	6.03	2.19	0.11		0.21	6.39
				½	do	21	2.09	1.71		0.31	6.13	2.09	−0.19		0.31	6.29
47	East Channel, Blackwells Island.	R. J. Auld	Sept. 28-29, 1920	1	Pole	7	1.79	0.36	N. 32 E.	2.62	6.60	2.26	1.16	S. 32 W.	1.87	5.82
				1	Meter	6	1.82	0.43		2.52	6.62	2.31	1.73		1.92	5.80
				1	do	15	1.74	0.41		2.21	6.66	2.27	1.46		1.76	5.76
				1	do	24	1.71	0.34		2.17	6.66	2.24	1.49		1.47	5.76
51	West Channel, Blackwells Island.	H. C. Denson	Aug. 4-7, 1922	2¾	Pole	7	2.29	0.99	N. 35 E.	3.64	5.95	2.11	1.01	S. 43 W.	4.70	6.47
				2¾	Meter	15	2.12	1.29		3.58	6.07	2.06	1.33		4.52	6.35
				2¾	do	37	2.11	1.24		3.39	6.09	2.07	1.24		4.15	6.33
				2¾	do	58	2.12	1.04		3.08	6.03	2.02	1.41		3.72	6.39
52	East Channel, Blackwells Island.	do	do	2¾	Pole	7	2.01	0.66	N. 26 E.	3.50	6.33	2.21	1.41	S. 32 W.	3.30	6.09
				2¾	Meter	6	2.01	0.71		3.17	6.14	2.02	1.31		3.17	6.28
				2¾	do	16	1.99	0.88		3.13	6.16	2.02	1.61		2.98	6.26
				2¾	do	26	1.99	0.76		2.73	6.16	2.02	1.39		2.47	6.26
58	West Channel, Blackwells Island.	R. J. Auld	Aug. 27-28, 1920	½	Pole	7	2.04				6.38	2.29				6.04
				1	Meter	10	2.12	1.13		4.78	6.18	2.17	1.43		5.03	6.24
				1	do	25	1.99	1.11		4.64	6.33	2.19	1.31		5.24	6.09
				1	do	40	2.01	1.34		4.69	6.28	2.16	1.79		5.44	6.14
61	East Channel, Blackwells Island.	do	Sept. 19-20, 1920	1	Pole	7	2.04	0.66	N. 11 W.	3.35	6.53	2.44	1.56	S. 17 E.	1.65	5.89
				1	Meter	10	2.27	0.73		2.95	6.38	2.52	1.63		1.65	6.04
				1	do	18	2.24	0.76		2.65	6.33	2.44	1.46		1.50	6.09
				1	do	40	2.21	0.49		2.41	6.38	2.46	1.04		1.31	6.04
62	Hell Gate	U. S. Engineers	May 31-June 16, 1932	16	do	14	1.83	1.02		2.70	6.54	2.24	1.38		1.71	5.88
				16	do	35	2.00	1.00		2.61	6.37	2.24	1.27		2.42	6.05
				16	do	56	2.12	1.01		2.69	6.21	2.20	1.30		3.20	6.21
64	do	do	May 12-23, 1932	10	do	9	2.30	0.90		3.35	6.07	2.24	1.17		4.56	6.35
				10	do	22	2.30	0.91		3.00	6.07	2.24	1.13		4.11	6.35
				10	do	35	2.30	0.91		2.79	6.06	2.23	1.13		3.84	6.36
65	do	do	Apr. 25-May 7, 1932	12	do	8	2.56	0.84		3.32	6.04	2.47	0.87		4.39	6.38
				12	do	20	2.55	0.85		2.92	6.01	2.43	0.89		4.07	6.41
				12	do	32	2.58	0.89		2.50	5.94	2.39	0.92		3.65	6.48

At station 9 there are 2 series of observations totaling 30 days. The results here may, therefore, be considered as relatively well determined. The data of table 67 show that the slack before flood becomes somewhat later with increasing depth, while the slack before ebb becomes somewhat earlier. As a result, the duration of flood decreases while that of ebb increases.

Both flood and ebb strengths decrease in velocity with increasing depth, the rate of decrease at station 9 being 0.02 knot per foot for the flood and 0.03 knot for the ebb. At all three depths, however, the ebb has the greater velocity.

These features are also indicated by the observations at the other stations. But as found for the current near the surface, so in the subsurface currents, the conditions at certain stations may differ from the general conditions above. Thus at station 11, the flood strength has the greater velocity at all depths due to the fact that this station is located within the full sweep of the flood current but to one side of the main ebb current. Station 35 shows a longer duration for the flood than for the ebb which likewise is to be ascribed to its different location with regard to the main flood and ebb currents.

At stations 28 and 30 it will be recalled that, although located on the same cross section of the river, the current near the surface at the former station has the greater ebb velocity, while at the latter station the flood current has the greater velocity. The data of table 67 show this same condition to obtain at all depths.

CURRENT HARMONIC CONSTANTS, LOWER EAST RIVER

For the purpose of predicting the current in lower East River, the observations at three stations were subjected to harmonic analysis. At station 9 the meter observations at the 11-foot depth covering a period of 24 days were analyzed; at station 62 the meter observations at the 14-foot depth for a period of 15 days; and at station 64 the meter observations at the 9-foot depth over a period of 15 days. The harmonic constants are given in table 67a, the values enclosed in parentheses being derived by inference from the principal constants.

TABLE 67a.—*Current harmonic constants, lower East River*

Component	Station no. 9		Station no. 62		Station no. 64	
	H	κ	H	κ	H	κ
	Knots	°	*Knots*	°	*Knots*	°
J_1	(0.01)	(67)	(0.01)	(30)	(0.01)	(57)
K_1	0.06	52	0.06	32	0.11	39
K_2	(0.13)	(219)	(0.11)	(201)	(0.09)	(217)
L_2	(0.09)	(206)	(0.06)	(194)	(0.11)	(206)
M_1	(0.08)	(37)	(0.01)	(35)	(0.01)	(22)
M_2	3.21	192	2.22	186	3.83	192
M_4	0.18	129	0.23	33	0.16	161
M_6	0.29	28	0.15	2	0.23	70
M_8	0.08	332	0.04	258	0.04	56
N_2	(0.62)	(177)	(0.43)	(178)	(0.74)	(178)
$2N$	(0.08)	(162)	(0.06)	(170)	(0.10)	(165)
O_1	0.11	22	0.07	37	0.10	5
P_1	(0.02)	(52)	(0.02)	(32)	(0.04)	(39)
Q_1	(0.02)	(8)	(0.01)	(39)	(0.02)	(347)
S_2	0.47	219	0.42	201	0.32	217
S_4	0.03	199	0.04	75	0.01	285
S_6	0.03	81	0.04	52	0.05	226
T_2	(0.03)	(219)	(0.02)	(201)	(0.02)	(217)
λ_2	(0.02)	(204)	(0.02)	(193)	(0.03)	(204)
μ_2	(0.08)	(164)	(0.05)	(171)	(0.09)	(167)
ν_2	(0.12)	(179)	(0.08)	(179)	(0.14)	(180)

SURFACE CURRENTS, UPPER EAST RIVER

For upper East River there are at hand current observations for 67 stations, the locations of which are shown on figures 44 and 44a. These observations may be taken to pertain to the current at a depth of about 7 feet. The results derived from these observations, with the velocities of the flood and ebb strengths corrected to mean values, are given in table 68.

The tide in upper East River is about 3 hours later than at Sandy Hook. Applying this difference to the times given in table 68, it is seen that the easterly current in upper East River attains its strength about 4 hours before local high water and hence on a rising tide. The easterly current here is therefore the flood current and the westerly current the ebb current. This likewise was the case in lower East River, so that throughout the whole length of East River the current setting from Upper Bay toward Long Island Sound is the flood current, while the one setting from Long Island Sound toward Upper Bay is the ebb current.

Taking the southern end of upper East River as lying between Mill Rock and Hallets Point, the data of table 68 show that in the axis of the channel the time of slack before flood becomes earlier in going eastward as far as the section between Whitestone and Throgs Neck, the difference in time being about half an hour. The slack before ebb in the same stretch appears to become somewhat later. As a consequence, the duration of flood in this stretch increases from west to east. In Hell Gate the duration of flood averages about 6 hours, while in the section between Whitestone and Throgs Neck it averages about 7 hours. For upper East River as a whole, therefore, the flood has the greater duration, which reverses the conditions found in lower East River, where ebb has the greater duration.

The conditions described in the preceding paragraph apply only to the current in midchannel. Closer to shore, conditions are different being influenced by local hydrographic features. Thus, for station 48 the times of the current stand out strikingly different from the values at the nearby stations in midchannel. A glance at figure 44 shows that station 48 is located at the entrance to Flushing Bay. This bay is of a relatively restricted area and, therefore, there can be but little progression of the tide. Hence, the time of high and low water in Flushing Bay must occur but little later than in upper East River, and this is shown by the tidal observations listed in table 42. But the strength of the current in the entrance to Flushing Bay obviously must occur when the tide is rising or falling most rapidly—that is, about 3 hours before local high or low water—while the slack must come about the times of high and low water. In upper East River proper the current attains its strength 5 hours before local tide, hence, from the reasoning above, the current at station 48 should be about 2 hours later than in upper East River. The data in table 68 show the current at station 48 to be later by 2½ hours.

The velocity of the current in upper East River is much less than in lower East River, except for the stretch in the immediate vicinity of Hell Gate where velocities of 4 knots and over are encountered. In other parts of upper East River the velocities are less, generally between 1 to 3 knots at average strength. Another difference between lower and upper East River is that in the former the ebb generally has the greater velocity, while in the latter the flood generally has the greater velocity.

TABLE 68.—*Surface current data, upper East River*

[Referred to times of HW and LW at Sandy Hook, N. J.]

Station no.	Location	Party of—	Observations		Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
1	Between Randalls and Wards Islands.	H. C. Denson	August 1922	1	1.8	0.9	E.	2.3	6.0	1.7	2.0	S. 85 W.	2.3	6.4
1	do	I. E. Rittenburg	August 1932	2	2.0	0.4	S. 80 E.	3.1	5.9	1.8	1.3	N. 60 W.	2.9	6.5
2	Off Jefferson Park	T. A. Craven	August 1856	½	2.1	0.3	N. 55 E.	0.5	6.3	2.3	1.8	S. 50 W.	0.6	6.1
3	Off 110th St	C. H. Davis	June 1845	½	1.7	1.5	N. 40 E.	0.9	5.7	1.3	0.8	S. 5 W.	1.0	6.7
4	Off 108th St	T. A. Craven	August 1856	½	2.5	−0.4	N. 45 E.	0.7	6.4	2.8	1.2	S. 20 W.	0.8	6.0
5	Off 105th St	H. C. Denson	August 1922	2½	2.6	−0.6	N. 35 E.	0.6	5.9	2.4	1.6	S. 40 W.	0.8	6.5
6	Between Mill Rock and Wards Island.	I. E. Rittenburg	September 1932	2	1.8	0.9	S. 75 E.	2.6	6.2	1.9	1.8	N. 70 W.	0.5	6.2
7	do	C. H. Davis	June 1845	½	1.6	2.1	S. 85 E.	2.3	5.8	1.3	1.7	N. 55 W.	2.7	6.6
9	Hell Gate	do	do	½	2.1	1.3	N. 35 E.	2.4	5.5	1.5	1.9	S. 70 W.	4.2	6.9
14	do	R. J. Auld	October 1920	1	2.4	0.4	N. 70 E.	4.5	6.0	2.3	1.0	S. 85 W.	4.3	6.4
16	do	C. H. Davis	June 1845	½	1.5	1.4	S. 85 E.	5.7	6.0	1.4	1.7	N. 80 W.	4.6	6.4
17	Above Hell Gate Bridge	do	do	½	1.5	2.1	N. 35 E.	3.7	5.7	1.1	2.2	S. 40 W.	2.1	6.7
18	East of Wards Island	H. Mitchell	June 1857	7¾	2.5	0.8	N. 45 E.	3.2	6.3	2.7	1.3	S. 35 W.	2.3	6.1
19	do	J. R. Goldsborough	October 1846	½	2.4	0.5	N. 60 E.	2.6	6.2	2.5	0.6	S. 20 W.	2.4	6.2
25	Between Sunken Meadow and Wards Island.	I. E. Rittenburg	September 1932	2	0.9	0.7	S. 70 E.	1.5	7.6	2.4	2.2	N. 60 W.	0.6	4.8
26	Between Sunken Meadow and Randalls Island.	do	do	2	2.1	1.3	N. 50 E.	1.2	5.7	1.7	1.3	S. 45 W.	2.0	6.7
27	Off Lawrence Point	R. J. Auld	October 1920	1	2.6	1.1	N. 45 E.	3.0	5.8	2.3	1.0	S. 40 W.	3.3	6.6
28	do	H. Mitchell	July 1858	5½	2.3	0.8	N. 40 E.	3.1	6.2	2.4	1.4	S. 50 W.	2.4	6.2
29	do	H. C. Denson	August 1922	2	2.1	0.8	N. 45 E.	2.4	6.2	2.2	1.8	S. 40 W.	2.0	6.2
30	do	I. E. Rittenburg	August 1932	2	2.6	0.5	N. 45 E.	3.8	6.1	2.6	1.3	S. 45 W.	2.5	6.3
31	Bronx Kill Entrance	do	do	2	2.1	1.4	S. 80 E.	0.6	6.0	2.0	2.4	N. 75 W.	0.8	6.4
32	Bronx Kill, East end	R. J. Auld	September 1920	1	1.3	1.0	S. 65 E.	1.1	6.9	2.1	2.0	N. 50 W.	1.1	5.5
33	Bronx Kill	H. C. Denson	August 1922	1	1.7	0.5	S. 35 E.	1.6	6.4	2.0	1.6	N. 50 W.	1.9	6.0
34	West of North Brother Island.	I. E. Rittenburg	July 1932	2	2.5	0.7	N. 40 E.	2.1	6.3	2.7	1.0	S. 35 W.	1.7	6.1
35	South of North Brother Island.	do	September 1932	2	1.7	0.9	N. 65 E.	2.8	6.9	2.5	1.1	S. 75 W.	1.7	5.5
36	Southwest of Rikers Island	do	July 1932	2	2.5	0.7	S. 45 E.	1.1	5.8	2.2	0.9	N. 40 W.	1.3	6.6
37	Northeast of North Brother Island.	do	do	2	2.5	0.7	E.	2.0	6.4	2.8	1.0	S. 75 W.	0.6	6.0
38	North of Rikers Island	J. R. Goldsborough	October 1846	½	2.7	0.2	S. 30 E.	1.0	6.5	3.1	1.5	N. 50 W.	0.6	5.9
39	Off Barretto Point	R. J. Auld	September 1920	1	1.7	0.8	S. 70 E.	1.9	6.8	2.4	1.4	N. 80 W.	0.9	5.6
40	Off Hunt Point	I. E. Rittenburg	July 1932	2	2.4	1.0	S. 75 E.	1.9	6.3	2.6	1.3	N. 80 W.	1.3	6.1
41	do	H. C. Denson	July 1922	¾	1.7	1.7	N. 80 E.	1.1	7.1	2.7	1.4	N. 85 W.	1.6	5.3
42	Bronx River	I. E. Rittenburg	September-October 1932	2	3.7	−0.4	N. 55 W.	0.4	4.7	2.3	−0.4	S. 50 E.	0.3	7.7
43	Off Hunts Point	J. R. Goldsborough	October 1846	1	2.2	0.6	E.	1.3	6.2	2.3	1.1	N. 60 W.	1.1	6.2
44	East of Rikers Island	do	do	1	2.8	1.4	N. 50 E.	0.5	6.3	3.0	1.5	N. 45 W.	1.0	6.1
45	Off Sanford Point	H. C. Denson	July 1922	¾	1.9	1.5	N. 70 E.	1.1	6.1	1.9	1.6	S. 85 W.	1.0	6.3
46	do	I. E. Rittenburg	July 1932	2	2.1	1.1	S. 85 E.	1.2	6.0	2.0	1.0	S. 80 W.	1.3	6.4
47	Flushing Creek Entrance	do	September-October 1932	1	4.3	−1.2	N. 70 E.	0.4	6.6	4.8	−0.9	S. 85 W.	0.5	5.8
48	Off College Point	R. J. Auld	September 1920	1	4.9	−1.7	S. 45 E.	0.6	5.4	4.2	−1.0	N. 25 W.	0.5	7.0
49	Off Clason Point	I. E. Rittenburg	July 1932	2	1.9	1.4	N. 80 E.	1.6	6.6	2.4	1.3	S. 70 W.	1.4	5.8
50	Off Old Ferry Point	do	do	2	0.9	1.3	N. 75 E.	2.0	7.3	2.1	1.8	S. 45 W.	1.4	5.1
51	do	H. L. Marindin	August 1885	1	0.4	1.5		2.0	7.0	1.3	2.4		1.5	5.4
52	do	do	do	1½	0.9	1.6		1.5	6.8	1.6	1.9		1.3	5.6
53	do	H. C. Denson	July 1922	1	1.3	2.0	N. 65 E.	1.0	6.3	1.5	2.2	S. 80 W.	1.3	6.1
53	do	I. E. Rittenburg	July 1932	2	1.1	1.5	N. 80 E.	1.7	7.5	2.5	1.4	S. 65 W.	1.6	4.9
54	do	do	do	2	0.3	2.3	N. 85 E.	1.0	8.4	2.6	1.8	S. 70 W.	1.1	4.0
55	do	H. L. Marindin	August 1885	¾	0.6	1.7		0.9	6.8	1.3	2.4		1.1	5.6
56	Off Whitestone Point	J. R. Goldsborough	October 1846	1	1.0	1.6	S. 65 E.	1.4	6.9	1.8	1.6	N. 50 W.	1.1	5.5
57	Between Throgs Neck and Whitestone.	H. E. Finnegan	June 1929	1	0.3	1.4	S. 50 E.	2.0	8.5	2.7	1.6	N. 50 W.	0.9	3.9
58	do	I. E. Rittenburg	July 1932	2	0.1	1.7	S. 60 E.	1.8	8.3	2.3	2.3	N. 65 W.	1.1	4.1
59	do	do	do	2	1.8	1.5	S. 65 E.	1.5	6.6	2.3	2.0	N. 75 W.	1.5	5.8
60	do	H. E. Finnegan	June 1929	1	1.8	1.6	S. 70 E.	1.8	7.1	2.8	2.2	N. 75 W.	1.6	5.3
61	do	do	do	1	1.4	2.8	S. 75 E.	1.0	4.9	0.2	2.3	N. 70 W.	1.0	7.5
62	do	I. E. Rittenburg	July 1932	2	2.2	2.7	S. 85 E.	1.0	4.0	0.1	1.7	N. 60 W.	0.7	8.4
63	do	H. Mitchell	July 1858	6	0.6	0.9	E.	1.0	7.4	1.9	1.6	S. 85 W.	0.8	5.0
64	Between Throgs Neck and Willets Point.	H. C. Denson	July 1922	1	0.0	2.8	N. 55 E.	0.9	5.9	−0.2	1.8	S. 85 W.	0.6	6.5
65	do	do	do	11½	0.5	1.3	E.	1.2	7.2	1.6	2.3	S. 70 W.	0.5	5.2
66	do	R. J. Auld	September 1920	1	0.9	1.3	S. 85 E.	1.2	6.7	1.5	2.2	S. 80 W.	0.7	5.7
67	do	H. C. Denson	July 1922	1	−0.1	1.3	N. 80 E.	1.0	8.1	1.9	2.0	S. 70 W.	0.4	4.3

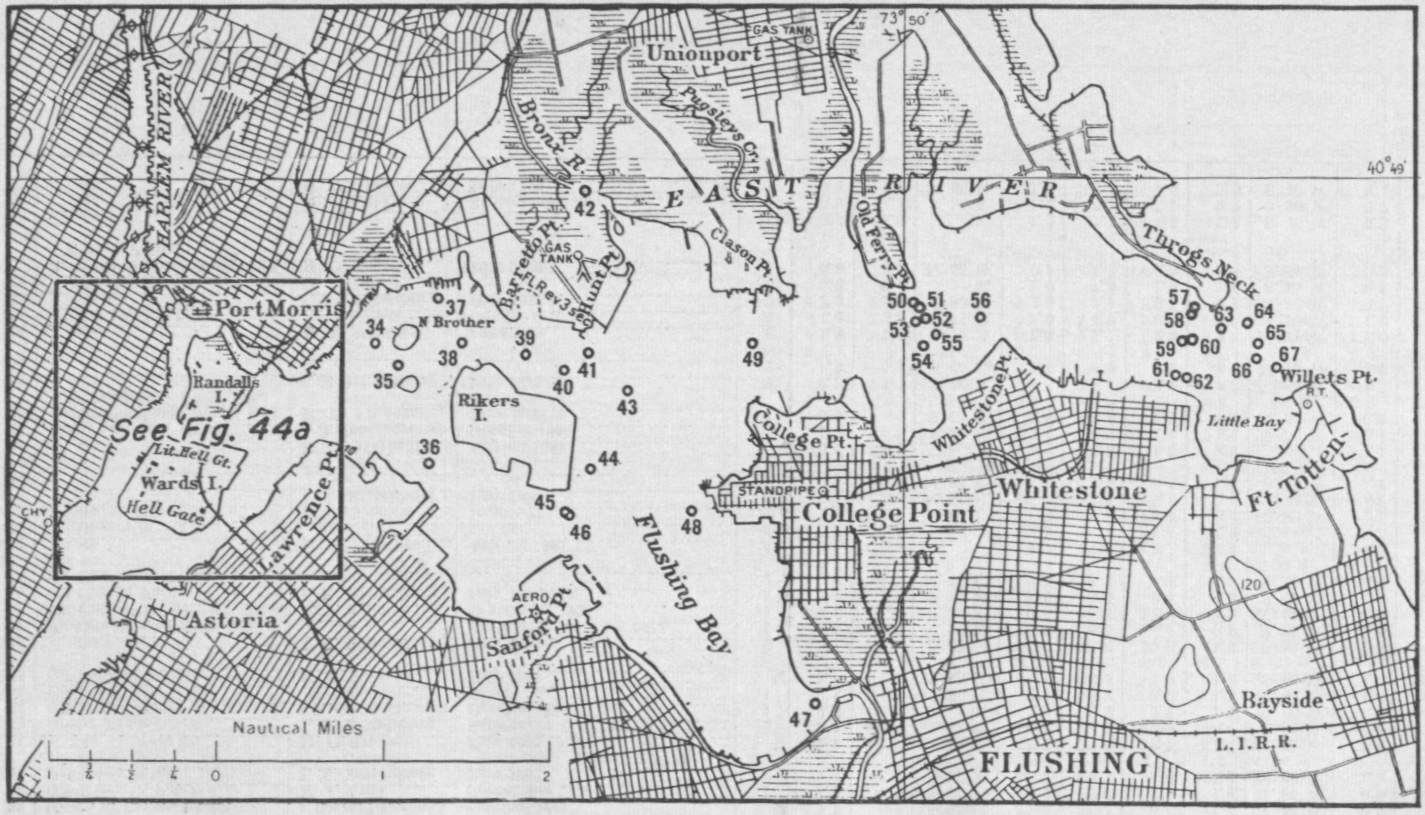

FIGURE 44.—Current stations, upper East River.

The fact that the velocities of the current in upper East River are less than in lower East River is obviously due to the greater width of the channel in upper East River; but the reversal of the relative magnitudes of the durations of flood and ebb and of the flood and ebb strengths cannot be accounted for on this ground. If we compare the current data for the Harlem River given in table 64 with the data of table 68, we find that the current in the Harlem is very nearly simultaneous with the current in upper East River. On the flood the Harlem is carrying the waters from the Hudson into East River, at which time the current is setting from lower East River into upper

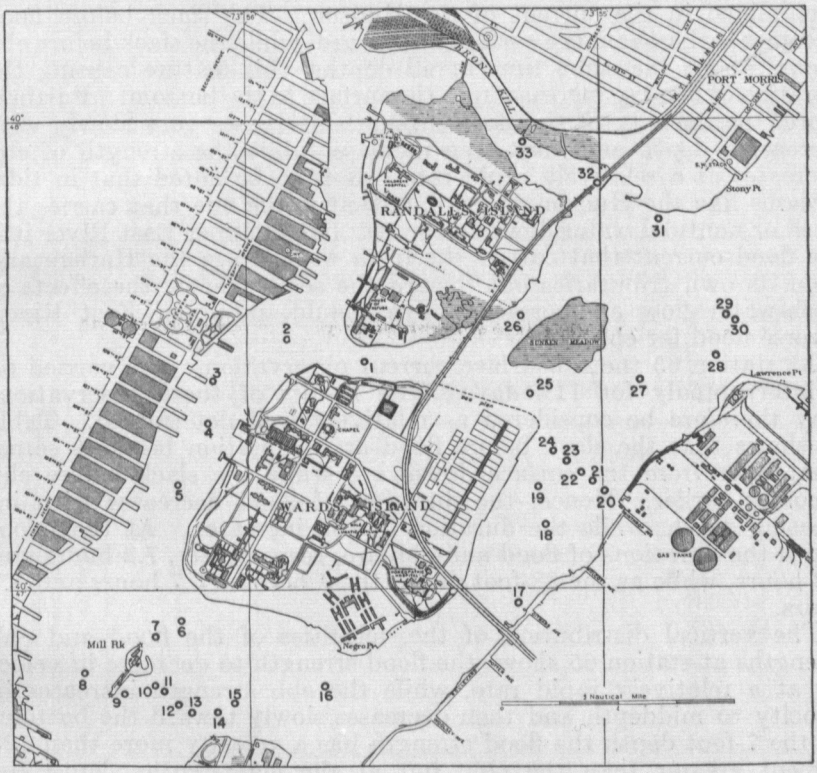

FIGURE 44a.—Current stations, Hell Gate.

East River. There should, therefore, be evidence in the current phenomena of upper East River of the effect of fresh-water flow both on account of the fresh water from the Hudson and also on account of the fresh water from the various streams tributary to upper East River. This evidence is found in the greater duration of the flood period and also in the greater velocity of the flood strength. We may also expect to find the vertical velocity distribution and the relative durations of flood and ebb from surface to bottom showing the effects of fresh-water flow, which effects, it is to be recalled, were absent in lower East River.

CURRENT DATA, VARIOUS DEPTHS, UPPER EAST RIVER

Subsurface current observations are at hand for a number of stations in upper East River. These observations were made with the current meter at three depths representing approximately two-tenths, five-tenths, and eight-tenths of the depth at each station. In addition, observations at a depth of 4 feet were made at station 66. The results derived from these observations, with the velocities of the flood and ebb strengths corrected to mean values, are given in table 69. For comparison the observations made with the current pole, which pertain to the current at a depth of 7 feet, are also included.

The characteristic effects of fresh-water flow in tidal streams are exemplified in the current of the Hudson. The slack before flood becomes earlier from the surface downward, while the slack before ebb occurs about the same time at all depths, this feature causing the duration of flood to increase from the surface to the bottom. Furthermore, the velocity of the flood strength decreases very slowly with increasing depth and may even increase, while the strength of ebb decreases at a relatively rapid rate. It is to be noted that in tidal streams like the Hudson the ebb current is the one that carries the fresh or nontidal water down to the sea; but in upper East River it is the flood current that carries the fresh water from the Harlem and from its own tributaries out toward the sea. Hence, the effects of fresh-water flow enumerated above should, in upper East River, reverse flood for ebb.

At station 65 the subsurface current observations were carried on uninterruptedly for 11½ days. The results of these observations may therefore be considered as relatively well determined. Table 69 shows that the slack before flood at this station becomes somewhat later from the surface downward while the slack before ebb becomes earlier. Hence, the duration of flood decreases with increasing depth, while the duration of ebb increases. At the 7-foot depth the durations of flood and ebb are, respectively, 7.2 hours and 5.2 hours, while at the 88-foot depth these become 6.7 hours and 5.7 hours.

The vertical distribution of the velocities of the flood and ebb strengths at station 65 shows the flood strength to decrease in velocity at a relatively rapid rate, while the ebb strength increases in velocity to middepth and then decreases slowly toward the bottom. At the 7-foot depth the flood strength has a velocity more than 125 percent greater than the ebb, but at the eight-tenths depth the ebb strength is only 12 percent greater. In upper East River, therefore, the effects of fresh-water flow are clearly evident in the current, while in lower East River it is to be recalled the current was free from such effects.

TABLE 69.—*Current data, various depths, upper East River*

[Referred to times of HW and LW at Sandy Hook, N. J.]

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
1	Between Randalls and Wards Islands.	H. C. Denson	Aug. 1-2, 1922	1	Pole	7	1.79	0.86	N. 89 E.	2.32	6.03	1.69	2.06	S. 87 W.	2.32	6.39
				1	Meter	4	1.74	0.66		2.12	6.28	1.89	1.66		2.72	6.14
				1	do	9	1.74	0.66		2.02	6.28	1.89	1.76		2.47	6.14
				1	do	15	1.64	0.51		1.73	6.48	1.99	2.16		1.93	5.94
1	do	I. E. Rittenburg	Aug. 10-12, 1932	2	Pole	3	2.01	0.42	S. 79 E.	3.10	5.92	1.80	1.29	N. 62 W.	2.90	6.50
				2	Meter	3	2.01	0.42		2.70	5.92	1.80	1.59		2.50	6.50
				2	do	9	2.01	0.52		2.90	5.92	1.80	1.29		2.70	6.50
5	Off 105th St	H. C. Denson	Aug. 4-7, 1922	2½	Pole	7	2.62	−0.57	N. 35 E.	0.55	5.88	2.37	1.60	S. 39 W.	0.79	6.54
				2¾	Meter	6	2.46	−0.96		0.65	5.99	2.32	2.13		0.89	6.43
				2¾	do	15	2.52	−0.61		0.57	5.68	2.07	1.83		1.03	6.74
				2¾	do	24	2.31	−0.47		0.43	5.79	1.97	1.31		1.05	6.63
6	Between Mill Rock and Wards Island.	I. E. Rittenburg	Sept. 28-30, 1932	2	Pole	7	1.81	0.92	S. 77 E.	2.60	6.22	1.90	1.79	N. 72 W.	0.50	6.20
				2	Meter	6	1.91	0.82		2.20	6.02	1.80	1.69		0.60	6.40
				2	do	15	2.01	0.72		2.20	5.92	1.80	1.59		0.60	6.50
				2	do	24	2.01	0.72		1.90	5.92	1.80	1.49		0.70	6.50
8	Off 94th St	U. S. Engineers	June 6-16, 1932	10	do	8	1.95	0.71		1.21	6.45	2.27	1.42		0.99	5.97
				10	do	20	1.93	0.74		1.00	6.37	2.17	1.42		1.01	6.05
				10	do	33	1.82	1.07		0.76	6.40	2.09	1.46		0.90	6.02
10	Hell Gate	do	Feb. 24-Mar. 7, 1932	11	do	6	2.40	0.69		3.16	5.99	2.26	0.81		3.57	6.43
				11	do	15	2.45	0.70		2.79	5.95	2.27	0.75		3.23	6.47
				11	do	24	2.57	0.64		2.72	5.76	2.20	0.83		3.10	6.66
11	do	do	Mar. 24-Apr. 8, 1932	12	do	8	2.58	0.73		3.42	5.95	2.40	0.88		3.59	6.47
				12	do	21	2.60	0.73		3.30	5.93	2.40	0.88		3.27	6.49
				12	do	33	2.60	0.71		3.01	5.94	2.41	0.88		2.95	6.48
12	do	do	Apr. 21-22, 1932	¾	do	8	2.40	0.68		3.58	5.73	2.00	1.19		4.77	6.69
				¾	do	20	2.40	0.68		3.23	5.73	2.00	1.09		4.15	6.69
				¾	do	32	2.40	0.63		3.04	5.73	2.00	1.09		4.11	6.69

TABLE 69.—*Current data, various depths, upper East River*—Continued

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
13	Hell Gate	U. S. Engineers	Apr. 12-15, 1932	3	meter	11	2.40	0.80		3.45	6.28	2.55	1.19	SW.[wd]	4.63	6.14
				3	do	28	2.48	0.75		3.41	6.13	2.48	1.21		4.17	6.29
				3	do	45	2.40	0.88		2.94	6.10	2.37	1.17		3.23	6.32
14	do	R. J. Auld	Oct. 6-7, 1920	1	Pole	7	2.34	0.41	N. 70 E.	4.53	6.05	2.26	0.96	S. 86 W.	4.31	6.37
				1	Meter	9	2.32	0.68		4.14	6.03	2.22	1.13		3.29	6.39
				1	do	22	2.34	0.76		4.04	5.98	2.19	1.06		3.49	6.44
15	do	H. C. Denson	Aug. 5-7, 1922	1½	do	9	2.29	1.01		4.40	6.00	2.16	1.28		4.20	6.42
				1½	do	22	2.34	1.04		3.85	6.01	2.22	1.31		3.85	6.41
				1½	do	34	2.29	1.01		3.59	6.03	2.19	1.34		3.49	6.39
20	Off Winthrop Ave., Astoria.	U. S. Engineers	July 8-15, 1932	6	do	16	2.21	0.73		3.45	6.32	2.40	1.48		2.46	6.10
				6	do	39	2.20	0.75		3.51	6.34	2.41	1.50		2.49	6.08
				6	do	62	2.21	0.75		4.14	6.33	2.41	1.41		2.96	6.09
21	do	do	June 30-July 8, 1932	8	do	16	2.34	0.82		3.90	6.28	2.49	1.19		2.68	6.14
				5	do	39	2.28	0.82		3.83	6.29	2.44	0.98		2.50	6.13
				8	do	62	2.33	0.84		3.87	6.23	2.43	1.38		2.47	6.19
22	do	do	June 16-July 15, 1932	24	do	15	2.35	0.88		3.42	6.08	2.30	1.29		2.47	6.34
				24	do	36	2.33	0.86		3.05	6.08	2.28	1.14		2.22	6.34
				24	do	58	2.31	0.89		2.85	6.05	2.23	0.95		2.31	6.37
23	do	do	June 16-23, 1932	6	do	9	2.44	0.82		2.34	5.85	2.16	1.11		2.69	6.57
				6	do	24	2.47	0.88		2.24	5.81	2.15	1.11		2.51	6.61
				6	do	38	2.39	0.91		1.96	5.76	2.02	1.23		2.72	6.66
24	do	do	June 23-30, 1932	7	do	11	2.31	2.70		1.44	6.12	2.30	0.94	SW.[wd]	2.70	6.30
				7	do	27	2.35	2.84		1.33	6.03	2.25	1.03		2.91	6.39
				7	do	43	2.38	2.97		1.29	6.00	2.25	0.99		2.77	6.42
25	Between Sunken Meadow and Wards Island.	I. E. Rittenburg	Sept. 21-23, 1932	2	Pole	3	0.51	0.62	S. 69 E.	1.50	8.02	2.40	1.89	N. 60 W.	0.30	4.40
				2	Meter	5	0.91	0.52		1.50	7.62	2.40	2.09		0.60	4.80
				2	do	10	0.91	0.82		1.40	7.62	2.40	2.29		0.70	4.80
26	Between Sunken Meadow and Randalls Island.	do	Sept. 6-8, 1932	2	Pole	3½	2.11	1.22	N. 50 E.	1.20	5.72	1.70	1.49	S. 43 W.	2.20	6.70
				2	Meter	3	2.11	1.32		1.10	5.72	1.70	1.39		1.90	6.70
				2	do	12	2.11	1.22		1.40	5.72	1.70	1.29		2.20	6.70
27	Off Lawrence Point	R. J. Auld	Oct. 5-6, 1920	1	Pole	7	2.54	1.06	N. 44 E.	2.98	5.83	2.24	1.01	S. 42 W.	3.28	6.59
				1	Meter	5	2.67	0.98		3.03	5.68	2.22	1.43		3.03	6.74
				1	do	12	2.69	0.76		2.73	5.63	2.19	1.46		2.73	6.79
				1	do	18	2.66	1.09		2.32	5.53	2.06	1.19		2.62	6.89
29	do	H. C. Denson	Aug. 1-2, 1922	2	Pole	7	2.04	0.86	N. 45 E.	2.43	6.25	2.16	1.78	S. 41 W.	1.97	6.17
				2	Meter	7	2.14	0.76		2.50	6.28	2.29	1.81		1.67	6.14
				2	do	18	2.17	0.81		2.15	6.25	2.29	1.58		1.60	6.17
				2	do	30	2.19	0.59		1.53	6.23	2.29	1.11		1.53	6.19
30	do	I. E. Rittenburg	Aug. 8-10, 1932	2	Pole	7	2.61	0.52	N. 45 E.	3.80	6.12	2.60	1.29	S. 45 W.	2.50	6.30
				2	Meter	10	2.51	0.62		3.50	6.22	2.60	1.49		2.30	6.20
				2	do	24	2.61	0.52		3.50	6.12	2.60	1.39		2.30	6.30
				2	do	38	2.61	0.62		3.20	6.12	2.60	1.09		2.10	6.30
31	Bronx Kill Entrance	do	do	2	Pole	7	2.11	1.42	S. 79 E.	0.60	6.02	2.00	2.39	N. 75 W.	0.80	6.40
				2	Meter	4	1.91	0.92		0.60	6.02	1.80	2.49		0.60	6.40
				2	do	11	1.91	1.32		0.60	6.02	1.80	2.29		0.70	6.40
				2	do	17	2.01	1.32		0.50	5.92	1.80	1.69		0.70	6.50
32	Bronx Kill, East End	R. J. Auld	Sept. 16-17, 1920	1	Pole	1½	1.94	0.86	S. 65 E.	1.28	6.23	2.04	1.91	N. 52 W.	0.84	6.19
				1	Meter	3	1.34	0.89		1.25	6.93	2.14	1.96		1.25	5.49
				1	do	9	1.36	1.19		0.86	6.88	2.11	1.99		0.86	5.54
33	Bronx Kill	H. C. Denson	Aug. 1-2, 1922	1	Pole	7	1.69	0.51	S. 35 E.	1.58	6.43	1.99	1.66	N. 49 W.	1.93	5.99
				1	Meter	4	1.59	0.71		1.83	6.63	2.09	1.81		1.78	5.79
				1	do	10	1.69	0.61		1.58	6.43	1.99	1.56		1.78	5.99
				1	do	15	1.84	0.96		0.93	6.08	1.79	1.51		1.68	6.34
34	West of North Brother Island.	I. E. Rittenburg	July 13-15, 1932	2	Pole	7	2.51	0.72	N. 38 E.	2.10	6.32	2.70	0.99	S. 33 W.	1.70	6.10
				2	Meter	7	2.51	0.72		1.80	6.32	2.70	0.99		1.50	6.10
				2	do	18	2.51	0.62		1.80	5.92	2.30	0.99		1.50	6.50
				2	do	29	2.51	0.62		1.60	5.92	2.30	0.99		1.40	6.50
35	South of North Brother Island.	do	Sept. 19-21, 1932	2	Pole	7	1.71	0.92	N. 66 E.	2.80	6.92	2.50	1.09	S. 73 W.	1.70	5.50
				2	Meter	6	1.81	0.92		2.50	6.72	2.40	1.39		1.80	5.70
				2	do	15	1.81	1.22		2.40	6.62	2.30	1.39		1.90	5.80
				2	do	24	1.91	1.12		2.00	6.52	2.30	1.29		1.50	5.90
36	Southwest of Rikers Island.	do	July 13-15, 1932	2	Pole	7	2.51	0.72	S. 44 E.	1.10	5.82	2.20	0.89	N. 41 W.	1.30	6.60
				2	Meter	5	2.51	0.82		1.10	5.82	2.20	1.09		1.20	6.60
				2	do	12	2.51	0.92		1.10	5.82	2.20	0.79		1.40	6.60
				2	do	19	2.41	0.92		1.00	5.82	2.10	0.59		1.40	6.60

TABLE 69.—*Current data, various depths, upper East River*—Continued

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
37	Northeast of North Brother Island.	I. E. Rittenburg.	July 13-15, 1932	2	Pole	7	2.51	0.72	S. 88 E.	2.00	6.42	2.80	0.99	S. 74 W.	0.60	6.00
				2	Meter	8	2.51	0.72		1.80	6.42	2.80	1.19		0.60	6.00
				2	do	20	2.51	0.82		1.80	6.32	2.70	1.09		0.80	6.10
				2	do	32	2.51	0.72		1.70	6.32	2.70	0.99		1.00	6.10
39	Off Barretto Point	R. J. Auld	Sept. 14-15, 1920	1	Pole	7	1.69	0.81	S. 71 E.	1.86	6.83	2.39	1.41	N. 78 W.	0.90	5.59
				1	Meter	10	1.92	1.03		1.88	6.38	2.17	1.48		0.98	6.04
				1	do	25	1.94	1.31		1.48	6.28	2.09	1.66		1.18	6.14
				1	do	40	1.81	1.44		1.11	6.33	2.01	2.09		1.06	6.09
40	Off Hunt Point	I. E. Rittenburg.	July 11-13, 1932	2	Pole	7	2.41	1.02	S. 73 E.	1.90	6.32	2.60	1.29	N. 82 W.	1.30	6.10
				2	Meter	9	2.51	0.92		1.90	6.22	2.60	1.29		1.30	6.20
				2	do	23	2.51	0.92		1.60	5.42	1.80	1.69		1.40	7.00
				2	do	36	2.41	0.92		1.50	5.52	1.80	1.59		1.20	6.90
41	do	H. C. Denson	July 31-Aug. 1, 1922	¾	Pole	7	1.69	1.76	N. 80 E.	1.09	7.13	2.69	1.41	N. 84 W.	1.59	5.29
				¾	Meter	11	2.14	1.36		0.99	6.48	2.49	1.51		1.34	5.94
				¾	do	29	2.29	1.01		0.89	6.23	2.39	1.81		1.24	6.19
				¾	do	45	2.19	0.96		0.69	6.23	2.29	1.51		1.09	6.19
42	Bronx River	I. E. Rittenburg.	Sept. 29-Oct. 1, 1932	2	Pole	3½	4.71	−0.60	N. 57 W.	0.30	3.72	2.30	−0.51	S. 49 E.	0.30	8.70
				2	Meter	2	4.51	−0.40		0.30	3.92	2.30	−0.61		0.20	8.50
				2	do	8	3.71	−0.40		0.40	4.72	2.30	−0.41		0.30	7.70
45	Off Sanford Point	H. C. Denson	July 31-Aug. 1, 1922	¾	Pole	7	1.89	1.51	N. 71 E.	1.09	6.13	1.89	1.61	S. 87 W.	1.04	6.29
				¾	Meter	9	1.99	1.21		1.09	6.13	1.99	1.21		0.99	6.29
				¾	do	22	2.04	1.41		0.99	5.88	1.79	1.71		0.89	6.54
				¾	do	35	2.14	1.21		0.89	5.58	1.59	1.51		0.69	6.84
46	do	I. E. Rittenburg.	July 11-13, 1932	2	Pole	7	2.11	1.12	S. 84 E.	1.20	6.02	2.00	0.99	S. 78 W.	1.30	6.40
				2	Meter	7	2.01	1.22		1.10	5.92	1.80	0.99		1.20	6.50
				2	do	18	2.41	1.42		1.10	5.02	1.30	1.29		1.40	7.40
				2	do	29	2.51	1.22		1.00	4.92	1.30	1.39		1.40	7.50
47	Flushing Creek Entrance.	do	Sept. 30-Oct. 1, 1932	1	Pole	3½	4.91	−1.20	N. 72 E.	0.50	6.12	4.90	−1.11	S. 86 W.	0.50	6.30
				1	Meter	3	4.91	−1.20		0.40	6.02	4.80	−1.11		0.40	6.40
				1	do	10	3.71	−1.10		0.40	7.12	4.70	−0.71		0.60	5.30
49	Off Clason Point	do	July 11-13, 1932	2	Pole	7	1.91	1.42	N. 79 E.	1.60	6.62	2.40	1.29	S. 70 W.	1.40	5.80
				2	Meter	12	2.01	1.32		1.50	6.32	2.20	1.29		1.50	6.10
				2	do	30	2.41	1.42		1.40	5.52	1.80	1.39		1.50	6.90
				2	do	48	2.51	1.62		1.20	5.32	1.70	1.29		1.30	7.10
50	Off Old Ferry Point	do	July 7-9, 1932	2	Pole	7	0.91	1.32	N. 75 E.	2.00	7.32	2.10	1.79	S. 44 W.	1.40	5.10
				2	Meter	16	1.41	1.42		2.00	7.02	2.30	1.99		1.60	5.40
				2	do	40	1.41	1.42		1.90	5.92	1.20	1.99		1.70	6.50
				2	do	64	1.51	1.42		1.30	5.32	0.70	1.89		1.90	7.10
53	do	H. C. Denson	July 30-31, 1922	1	Pole	7	1.29	2.01	N. 67 E.	1.01	6.30	1.46	2.26	S. 79 W.	1.31	6.12
				1	Meter	21	1.34	1.81		1.11	6.28	1.49	1.96		1.46	6.14
				1	do	53	1.44	2.21		1.17	6.05	1.36	1.91		1.07	6.37
				1	do	84	1.69	2.11		1.17	5.60	1.16	1.86		0.67	6.82
53	do	I. E. Rittenburg.	July 7-9, 1932	2	Pole	7	1.11	1.52	N. 81 E.	1.70	7.52	2.50	1.39	S. 67 W.	1.60	4.90
				2	Meter	17	1.41	1.32		1.60	6.92	2.20	1.49		1.60	5.50
				2	do	43	2.01	1.42		1.30	5.32	1.20	1.79		1.30	7.10
				2	do	69	1.91	1.32		0.90	5.42	1.20	2.09		1.20	7.00
54	do	do	do	2	Pole	7	0.31	2.32	N. 85 E.	1.00	8.42	2.60	1.79	S. 71 W.	1.10	4.00
				2	Meter	4	0.41	1.92		0.80	8.42	2.70	1.79		1.00	4.00
				2	do	12	1.01	2.42		0.90	7.42	2.30	1.89		1.10	5.00
57	Between Throgs Neck and Whitestone.	H. E. Finnegan.	June 24-25, 1929	1	Pole	7	0.27	1.35	S. 50 E.	1.98	8.56	2.70	1.65	N. 50 W.	0.88	3.86
				1	Meter	10	0.43	1.40		1.77	8.50	2.80	1.95		0.94	3.92
				1	do	24	0.43	1.60		1.50	8.30	2.60	2.25		0.80	4.12
				1	do	38	0.43	1.70		1.37	8.15	2.45	2.50		0.69	4.27
58	do	I. E. Rittenburg.	July 5-7, 1932	2	Pole	7	0.11	1.72	S. 60 E.	1.80	8.32	2.30	2.29	N. 63 W.	1.10	4.10
				2	Meter	9	0.01	1.62		1.60	8.42	2.30	2.29		1.00	4.00
				2	do	23	0.01	1.82		1.50	7.72	1.60	2.39		0.90	4.70
				2	do	36	−0.09	1.82		1.30	7.92	1.70	2.29		0.80	4.50
59	do	do	do	2	Pole	7	1.81	1.52	S. 66 E.	1.50	6.62	2.30	1.99	N. 77 W.	1.10	5.80
				2	Meter	12	1.51	1.42		1.50	6.82	2.20	1.99		1.10	5.60
				2	do	30	1.11	1.42		1.20	6.32	1.30	2.29		1.10	6.10
				2	do	48	1.41	1.72		0.90	5.52	0.80	1.99		1.00	6.90
60	do	H. E. Finnegan.	June 24-25, 1929	1	Pole	7	1.85	1.60	S. 69 E.	1.83	7.03	2.75	2.20	N. 74 W.	1.55	5.39
				1	Meter	12	1.80	1.75		1.48	6.98	2.65	2.00		1.33	5.44
				1	do	30	1.70	2.00		1.19	6.78	2.35	2.25		1.23	5.64
				1	do	48	1.60	2.25		0.94	6.73	2.20	1.95		0.99	5.69
61	do	do	do	1	Pole	7	1.45	2.75	S. 74 E.	1.05	4.88	0.20	2.30	N. 68 W.	1.05	7.54
				1	Meter	12	1.40	2.75		1.09	4.98	0.25	2.25		0.94	7.44
				1	do	30	1.35	2.85		1.00	4.48	−0.30	2.25		1.10	7.94
				1	do	48	1.20	2.65		0.57	4.43	−0.50	2.20		1.02	7.99

TABLE 69.—*Current data, various depths, upper East River*—Continued

Station no.	Location	Party of—	Observations				Slack	Flood strength			Flood duration	Slack	Ebb strength			Ebb duration
			Date	Period	Method	Depth		Time	Direction (true)	Velocity			Time	Direction (true)	Velocity	
				Days		*Feet*	*Hours after LW*	*Hours before HW*	°	*Knots*	*Hours*	*Hours after HW*	*Hours before LW*	°	*Knots*	*Hours*
62	Between Throgs Neck and Whitestone.	I. E. Rittenburg	July 5-7, 1932	2	Pole	7	2.21	2.72	S. 84 E.	1.00	4.02	0.10	1.69	N. 58 W.	0.70	8.40
				2	Meter	10	2.01	2.62		0.90	4.42	0.30	1.49		0.70	8.00
				2	do	25	2.01	2.62		0.70	4.22	0.10	1.49		0.90	8.20
				2	do	40	1.91	2.62		0.50	4.32	0.10	1.59		1.10	8.10
64	Between Throgs Neck and Willets Point.	H. C. Denson	July 30-31, 1922	1	Pole	7	−0.01	2.81	N. 53 E.	0.93	5.93	−0.21	1.81	S. 83 W.	0.58	6.49
				1	Meter	14	0.14	3.11		0.93	6.18	0.19	2.41		0.73	6.24
				1	do	35	0.34	2.66		0.78	5.38	−0.41	2.46		0.68	7.04
				1	do	58	0.49	1.96		0.72	5.18	−0.46	2.56		1.07	7.24
65	do	do	July 26-Aug. 7, 1922	11½	Pole	7	0.49	1.34	S. 88 E.	1.20	7.21	1.57	2.33	S. 68 W.	0.53	5.21
				11½	Meter	22	0.72	1.11		1.19	7.05	1.64	2.08		0.63	5.37
				11½	do	55	0.67	1.21		0.91	7.02	1.56	1.93		0.76	5.40
				11½	do	88	0.79	1.39		0.82	6.68	1.34	2.08		0.73	5.74
66	do	R. J. Auld	Sept. 10-11, 1920	1	Pole	7	0.89	1.26	S. 87 E.	1.24	6.73	1.49	2.21	S. 80 W.	0.68	5.69
				¾	Meter	4	0.72	1.48		1.50	6.93	1.52	2.53		0.50	5.49
				1	do	20	0.69	1.46		1.02	6.93	1.49	2.41		0.67	5.49
				1	do	50	0.76	1.64		0.79	6.68	1.31	2.24		0.74	5.74
				1	do	80	0.82	1.58		0.70	6.48	1.17	2.58		0.70	5.94
67	do	H. C. Denson	July 30-31, 1922	1	Pole	7	−0.06	1.31	N. 78 E.	1.03	8.03	1.84	1.96	S. 69 W.	0.38	4.39
				1	Meter	8	0.34	1.51		1.18	7.88	2.09	2.26		0.38	4.54
				1	do	20	0.44	1.41		0.98	7.63	1.94	1.51		0.48	4.79
				1	do	30	0.34	1.46		0.93	7.58	1.79	1.56		0.53	4.84

In this connection, it is instructive to compare the data from station 22, at which 4 days of observations were secured, with the data at station 65. At station 22 the duration of flood is practically constant at all depths and both flood and ebb strengths decrease in velocity with increasing depth. The conditions here are, therefore, different than at station 65. On glancing at figure 44a, it is seen that station 22 is outside of the sweep of the current from the Harlem which carries fresh water from the Hudson to upper East River.

CURRENT HARMONIC CONSTANTS, UPPER EAST RIVER

Harmonic analysis of the observations at two stations in upper East River were made in connection with the prediction of currents. At station 11 the meter observations at the 8-foot depth, covering a period of 15 days, were used. At station 22 the meter observations at the 15-foot depth, covering a period of 29 days, were used. The results are given in table 70, the values in parentheses being inferred from the principal components.

TABLE 70.—*Current harmonic constants, upper East River*

Component	Station 11		Station 22		Component	Station 11		Station 22	
	H	κ	H	κ		H	κ	H	κ
	Knots	°	*Knots*	°		*Knots*	°	*Knots*	°
J_1			(0.01)	(57)	O_1	0.03	101	0.09	41
K_1	0.04	218	0.04	52	P_1	(0.01)	(218)	(0.01)	(52)
K_2	(0.19)	(205)	(0.11)	(231)	Q_1	(0.01)	(43)	(0.02)	(36)
L_2	(0.10)	(202)	(0.08)	(218)	R_2	(0.01)	(205)		
M_1			(0.01)	(46)	S_2	0.71	205	0.39	231
M_2	3.56	199	2.89	194	S_4	0.06	145	0.02	112
M_4	0.10	73	0.37	38	S_6	0.01	209	0.01	314
M_6	0.15	117	0.20	82	T_2	(0.04)	(205)	(0.02)	(231)
M_8	0.06	283	0.01	209	λ_2	(0.02)	(202)	(0.02)	(211)
N_2	(0.69)	(195)	0.47	170	μ_2	(0.08)	(192)	(0.07)	(157)
2N	(0.09)	(191)	(0.06)	(147)	ν_2	(0.13)	(196)	(0.09)	(174)

THE TIDAL MOVEMENT IN THE HARBOR

The tables in the foregoing sections, which give in detail the results of the tide and current observations in the component waterways of New York Harbor, furnish the data for a comprehensive view of the tidal movement, including under this term both the rise and fall of the tide and the flood and ebb of the current, in the harbor. At any given instant the tidal movement may be represented in diagrammatic form by an arrow pointing in the direction of the current and by the letter R or F to indicate, respectively, a rising or a falling tide; but it is obvious that within the compass of a small diagram any schematic representation of the tidal movement over a large area, in which the times of tide and of current differ as much as in New York Harbor, can give only a generalized view without reference to details in the smaller bays and inlets fringing the main waterways of the harbor.

In the present section the tidal movement in New York Harbor is represented schematically at four different phases of the tide, namely, at low water, 3 hours after low water, at high water, and 3 hours after high water. Since the times of both tide and current in the tables of tide and current data have been given with reference to the time of tide at Sandy Hook, it will obviously be of advantage to refer the tidal movement to the time of tide at Sandy Hook. The

current arrows are to be taken as representing the general direction of the current near the surface.

Beginning with the time of low water at Sandy Hook, figure 45 represents the tidal movement in the harbor at that time. Excepting a few small indentations like Gowanus Bay, the current throughout the harbor is ebbing, the water flowing toward Lower Bay. And

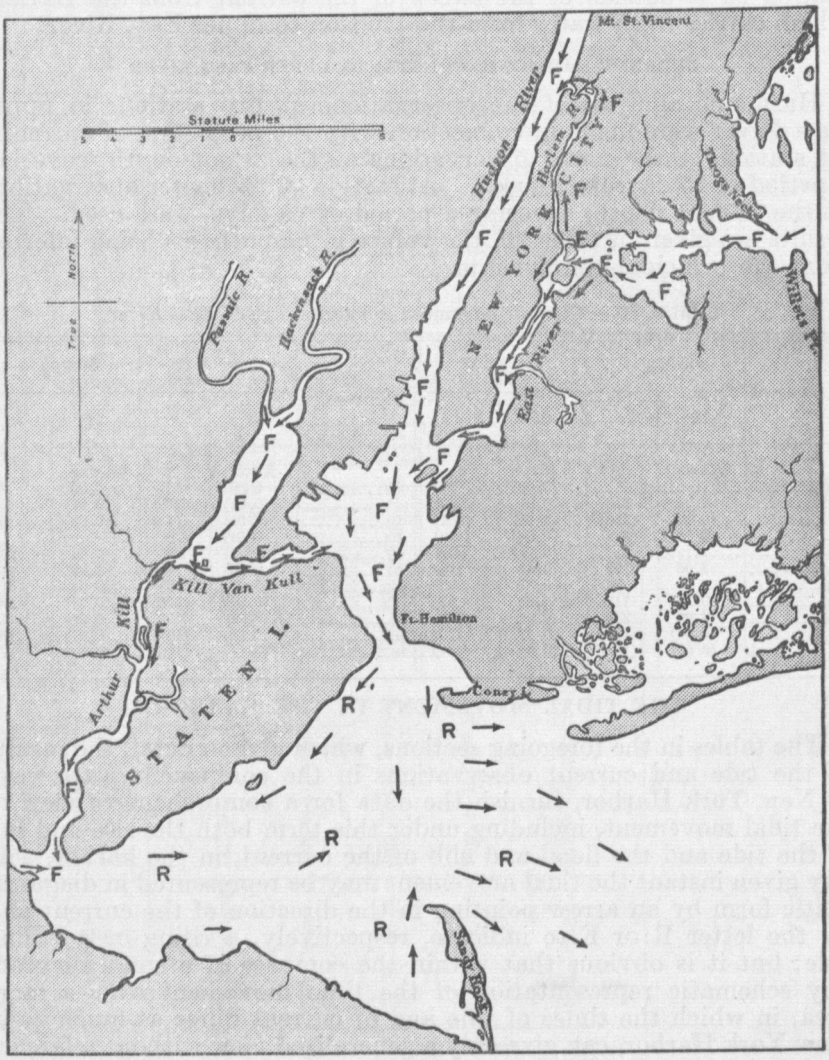

FIGURE 45.—The tidal movement at the time of low water at Sandy Hook.

with the exception of Lower Bay, the tide over the whole harbor is falling. In the Hudson the current is very nearly at its strength, while the tide is near low water, which is still 1 hour away. The Harlem is now carrying the water from East River toward the Hudson, the tide being below mean sea level and about 2 hours from its low water. Upper East River is bringing the water from Long Island

Sound toward Hell Gate, while its level is falling rapidly, being now 2 hours after high water. Through Hell Gate and lower East River the water is flowing toward Upper Bay at very nearly its strength, which was passed an hour ago, the level of the water being a little below mean sea level and falling rapidly.

At the time of low water at Sandy Hook, the current in Newark Bay has not yet attained its strength. The waters from Newark Bay are now pouring partly into Arthur Kill, but principally into Kill van Kull, which is carrying them into Upper Bay. In Upper Bay the current has passed its strength about half an hour previously, but it is still running with a velocity not far from strength and passing on the waters from the Hudson River, East River, and Kill van Kull into the Narrows. The level of the water in Newark Bay, Kill van Kull, and Upper Bay is still falling, but rather slowly, for low water is less than an hour away.

In the Narrows the strength of ebb comes about an hour before low water at Sandy Hook. At the time of low water at Sandy Hook, therefore, the current in the Narrows is still ebbing at nearly full strength. The tidal waters which are flowing into Upper Bay through the Hudson River, East River, and Kill van Kull, together with the nontidal waters from a territory having an area of nearly 15,000 square miles, are now pouring through the Narrows into Lower Bay at a rate of about three quarters of a million cubic feet per second. Arthur Kill, too, is flowing toward Lower Bay and from Lower Bay the waters are now passing out to sea although the strength of the current has already passed. In Arthur Kill the level of the water is falling slowly, low water being half an hour away; but in Lower Bay the water is beginning to rise very slowly, the low water having occurred a few minutes before this time.

Three hours later, or 3 hours after low water at Sandy Hook, the tidal movement in the harbor is represented by Figure 46. The tide and current conditions in the various waterways are now different. In the Hudson and Harlem Rivers the tide is rising rapidly, the current in the former ebbing while in the Harlem it is flooding. Through East River the current is flooding, being accompanied by a rising tide in lower East River and by a falling tide in upper East River. Through Upper Bay, the Narrows, Kill van Kull, Newark Bay, Arthur Kill, and Lower Bay, the tide is rising rapidly and through all these waterways with the exception of Upper Bay and the Narrows, the current is flooding. In the main channel of Upper Bay and the Narrows the current is under the influence of the ebb from the Hudson and is ebbing, but in the shallower regions near the shores the current has begun to flood.

At the time of high water at Sandy Hook or 3 hours after the conditions described in the preceding paragraph, the features of the tidal movement are represented in figure 47. The current throughout the whole harbor is now flooding, and with the exception of Lower Bay the tide over the whole area is rising. In Lower Bay the current is in the last hour of its flood, and, therefore, has only a small velocity. In the Narrows, however, the current is running at nearly full strength which occurred less than an hour previously; and in Upper Bay it is running at about full strength. In Arthur Kill the flood strength had occurred about an hour and a half previously so that the current now is running at a little more than half strength.

In Kill van Kull full strength had occurred about 2 hours previously; hence the current now is running at about half strength. And in Newark Bay, likewise, the current is at about half strength.

At the time of high water at Sandy Hook, the current in the Hudson is running at nearly full strength at the entrance, full strength coming about half an hour later; but at the end of the 14-mile stretch considered here as part of New York Harbor, the current is

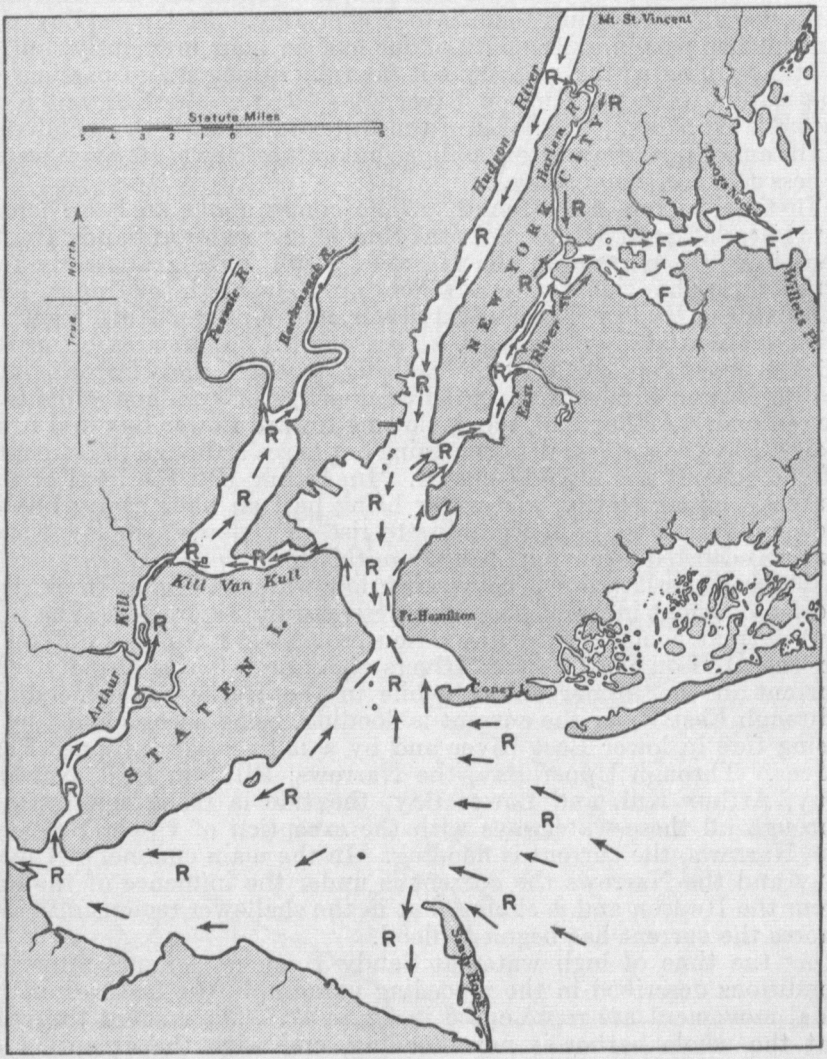

FIGURE 46.—The tidal movement 3 hours after low water at Sandy Hook.

running at half strength, full strength not coming till nearly 2 hours later. In the Harlem the water is flowing from the Hudson toward East River at a little more than three quarter strength, full strength having occurred about an hour previously. In East River the current is running at about three quarter strength, full strength having occurred about an hour previously.

The tide in Lower Bay at the time of high water at Sandy Hook has just completed its rise and is beginning to fall very slowly. In the Narrows and Upper Bay the tide is rising very slowly, having nearly reached high water which occurs about a quarter of an hour later. In Newark Bay and the Kills the tide is likewise rising slowly, with high water to come about three quarters of an hour later. In the

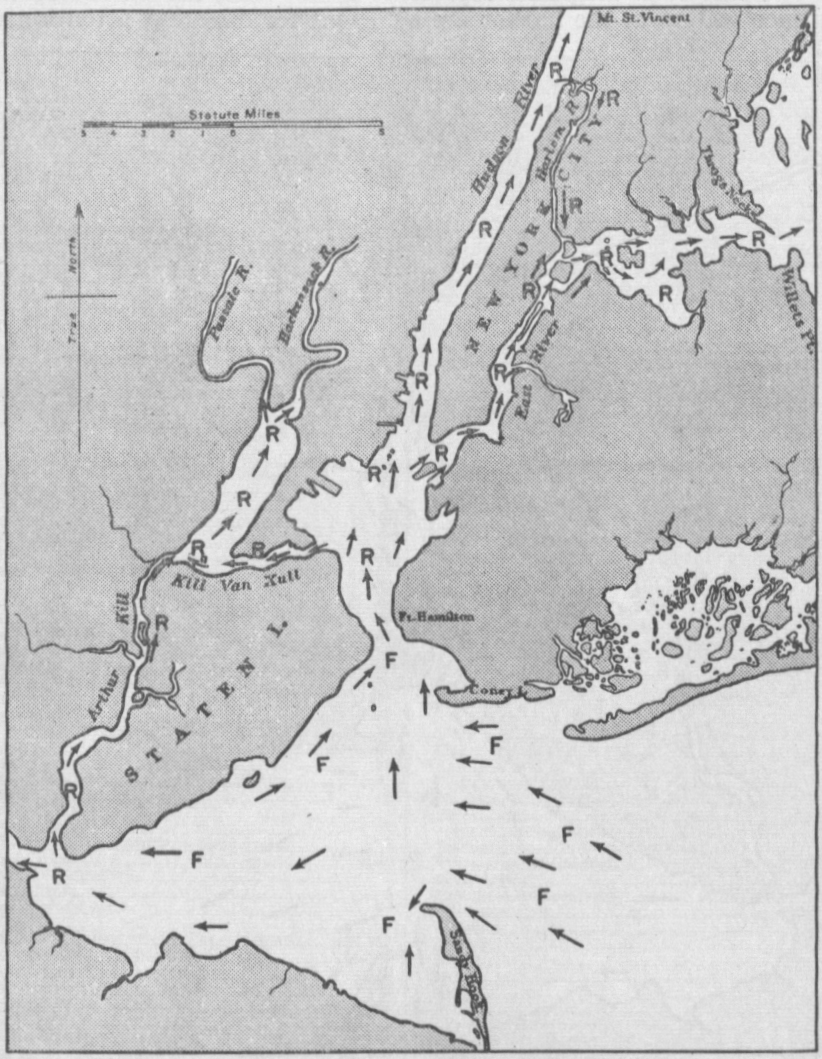

FIGURE 47.—The tidal movement at the time of high water at Sandy Hook.

Hudson the water is rising a little faster since high water is still an hour away. In the Harlem it is rising more rapidly, high water being 2 hours away. In lower East River the water is above mean sea level and still rising at a relatively rapid rate, high water being 2 hours away. In upper East River, the tide is rising at its most rapid rate, high water being 3 hours away.

Three hours after high water at Sandy Hook the tidal movement is represented in figure 48. Throughout the harbor, with the exception of upper East River, the tide is falling; and the current throughout the harbor, with the exception of the Hudson, is ebbing. In the latter waterway the current is flooding feebly, slack before ebb being an hour away.

The last four diagrams representing the tidal movement of the surface waters in the harbor are sufficient for directing attention to

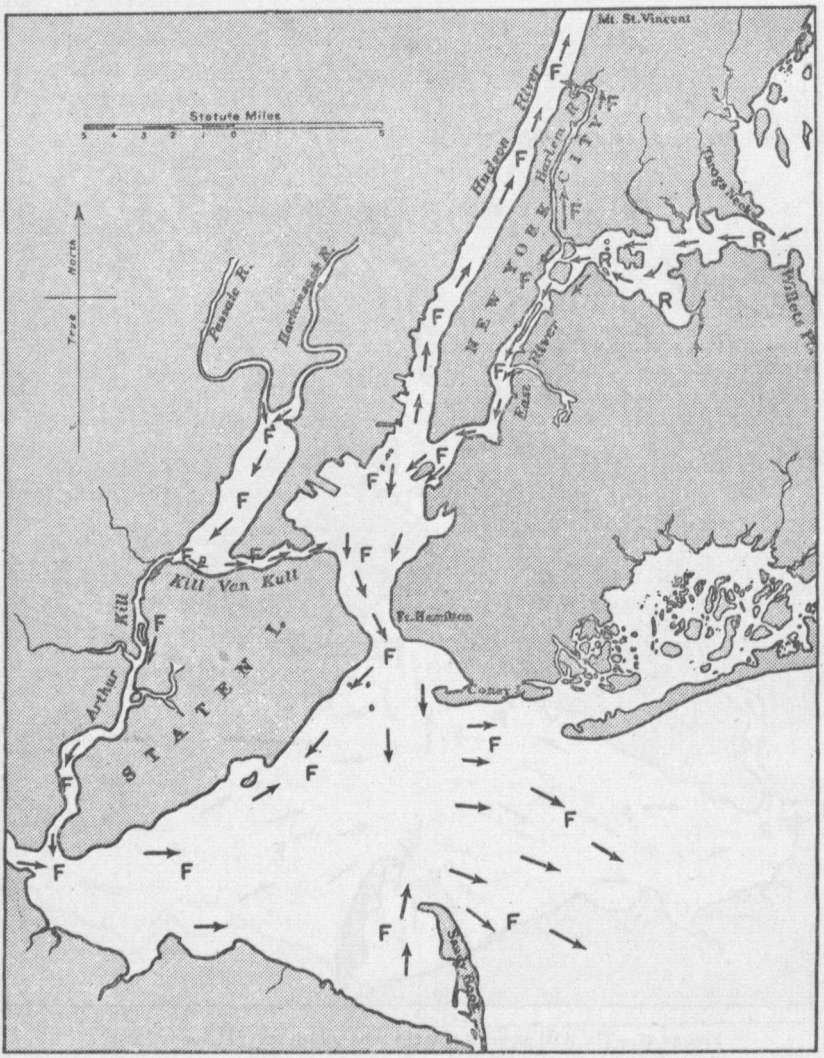

FIGURE 48.—The tidal movement 3 hours after high water at Sandy Hook.

the complexities of the tidal movement in New York Harbor at any given time. Actually, the movement is even more complex than indicated on the diagrams, for no account has been taken of the subsurface currents. The data given in the tables of this volume, however, furnish the data necessary for such a comprehensive view of this movement at any desired time.

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