

THE TIDE PREDICTION CENTENARY OF THE UNITED STATES COAST AND GEODETIC SURVEY

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The golden years were from 1908 to 1918; for it was during this decade that you could have had your morning coffee with a group composed of no less than Rollin A. HARRIS, Leland P. SHIDY, Harry A. MARMER, and Paul SCHUREMAN. The only one missing would have been William FERREL who left in 1886; but Leland SHIDY, inventor of stencil summing, would have remembered him well since SHIDY's phenomenal 57 years of service with the Coast and Geodetic Survey extended from 1873 to 1930 (fig. 1). What would you have discussed; MARMER's intent to write "The Tide" [1] or "Tidal Datum Planes" [2] which weren't to be seen in print until 1926 and '27 respectively? Probably not, nor would Paul SCHUREMAN have had definite plans for his "A Manual of the Harmonic Analysis and Prediction of Tides" [3] of 1924 to discuss. It would most likely have been HARRIS' 1911 work on "Arctic Tides" [4] since his monumental "Manual of Tides" [5] was already completed by 1907. From tide data alone, HARRIS hypothesized the presence of an Arctic Ocean land mass or an area of shallow water. The hypothesis of a land mass was disproven, of course, but the Lomonosov Ridge and Fletcher Rise were subsequently discovered in a position corresponding to HARRIS' conjecture.

In addition, however, we would like to believe that the coffee discussions of these great men also included comments as to where the Survey had come in its prediction techniques in the preceding 50 years and where it would be going under their guidance, for this golden decade was midstream in the centenary of tide table publication which the Coast and Geodetic Survey is celebrating this year.

One hundred years ago the United States Coast Survey began publishing tide tables in essentially the same form as we know them today. By "essentially the same" is meant daily high and low water predictions at a number of control stations for a period of one year, published in advance in special tide table volumes. The use of empirical constants relating numerous secondary stations to the daily phase predictions at the control stations has also continued unchanged through the one hundred years.

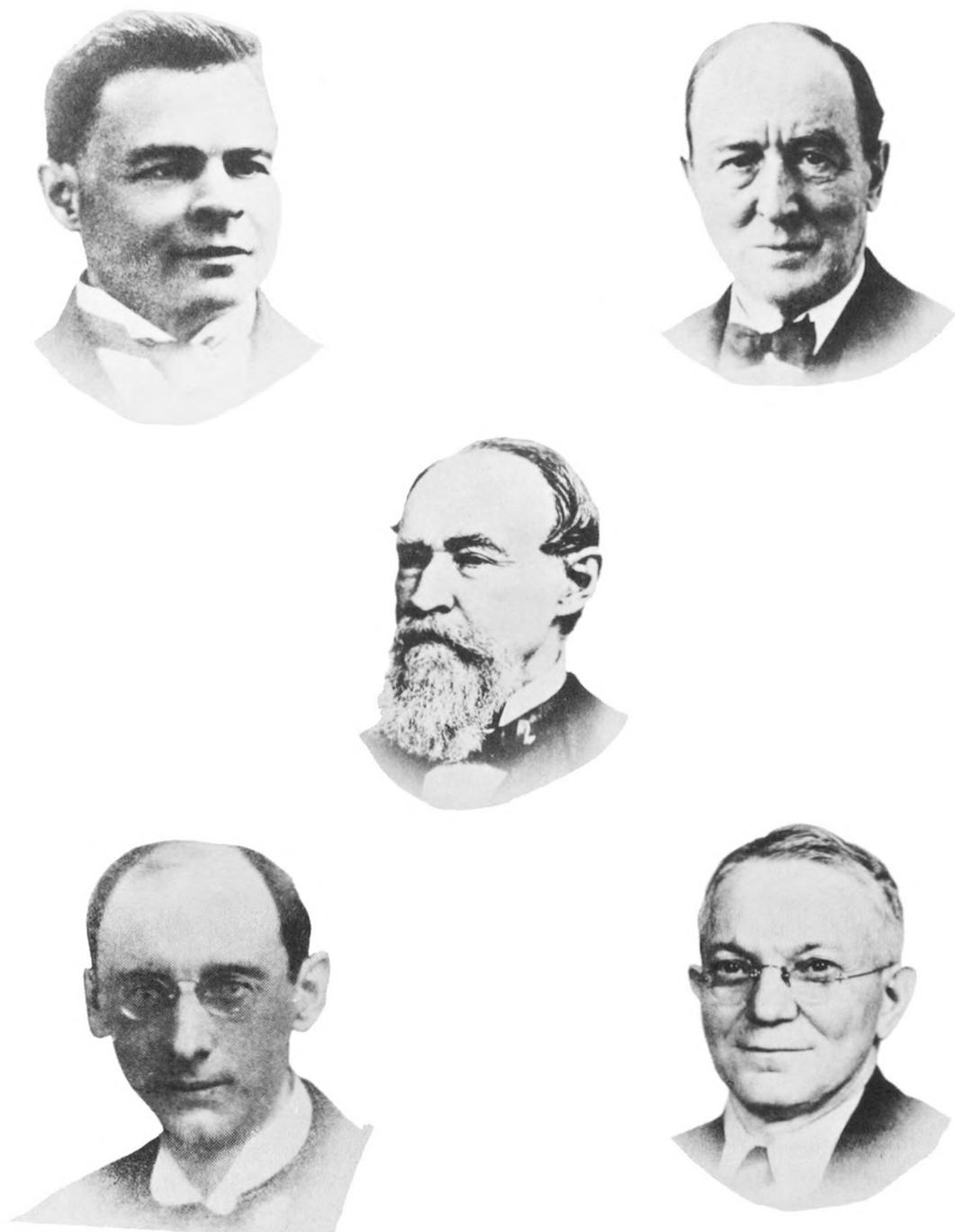


FIG. 1

From left to right, reading from the top : Rollin A. HARRIS (1863-1918), Leland P. SHIDY (1851-1935), William FERBEL (1817-1891), Paul SCHUREMAN (1876-1959), and Harry A. MARMER (1885-1953).

Even the table format has remained remarkably constant. The mariner of 1867 would find no difficulty whatsoever in using our present-day tables. In fact, only three major format changes have taken place. The first occurred in 1868 (*) when low water predictions were begun for stations along the west coast of Florida and the Pacific coast. Low water predictions for all stations were begun in 1887 (*). In 1892 (*) ('93 (*) for Atlantic) and 1958 (*) the practice of listing high and low water predictions in separate columns was changed to listing them sequentially, as had been done from 1867 (*) through 1891 (*) ('92 (*) for Atlantic) and from 1922 (*) through 1957 (*). The extreme constancy of format might lead one to believe that the prediction techniques themselves have enjoyed considerable stability. This assumption would be untrue. Many changes in technique have taken place over the years.

The nonharmonic lunital interval method was employed exclusively up through 1884 (*) while the harmonic method has been used ever since. The nonharmonic method was, to say the very least, exceedingly cumbersome. In its most advanced form, the method involved correcting lunital intervals and heights for the moon's phase and for the declination and parallax of the moon and sun.

The mechanical analog tide predicting machine was introduced in 1885 (*) in the United States. It was designed to handle the great quantity of constituent summations required in the harmonic method. The mechanical machine thus enabled the harmonic method to be used for standard yearly predictions on a practical basis. William FERREL's Maxima and Minima Tide Predictor [6] was the first one in the United States (1). Although summing only 19 constituents, the machine was a significant improvement over its English predecessors in that the predicted times and heights of the high and low waters could be read directly from the dial indicators. Rollin A. HARRIS and E. G. FISCHER (Chief, Instrument Division, C&GS) designed a 37 constituent machine [7] which was put into operation in 1912 (*) (2). "The Ferrel" was completely retired after 1914 (*). The Harris-Fischer machine consisted of two sides; a height side, and a time side 90° out of phase with amplitudes weighted by the constituent speeds. This arrangement made it possible to obtain both an analog trace and high and low water (as well as hourly) time and height predictions simultaneously. Its purely mechanical nature was somewhat altered in 1961 (*) with the addition of a motor drive and an automatic readout. The output was printed in a format suitable for direct reproduction in the published tide tables. Economics, speed, and accuracy did not dictate the bow of the mechanical analog machine to the electronic digital computer until 1966 (*) — a glorious testimony to its efficiency. In that year the electronic digital computer prediction program of D. Lee HARRIS, N. Arthur PORE, and Robert A. CUMMINGS [8] was first used for the standard published predictions.

(*) Date refers to tide or tidal current table volume containing predictions for the stated year.

(1) Ferrel's machine is presently on display in the Museum of History and Technology, Smithsonian Institution, Washington, D.C.

(2) The Harris-Fischer machine may be viewed at the Coast and Geodetic Survey, Rockville, Maryland.

The number of control stations for which standard predictions are prepared have, of course, increased during the 100 years. In addition, the number of tide table volumes and secondary stations (related to the control stations by empirical constants) has also increased significantly. For 1867 (*) there were two volumes [9] containing predictions for 19 control stations and 124 secondary stations. These numbers are in contrast with the 1967 (*) predictions which are published in six volumes [10], [11] (two for tidal currents) and contain a total of 251 control and 7822 secondary stations. Predictions are exchanged with other maritime nations through international agreement. Each country publishes the predictions prepared by the home country whenever available. The exchange practice, begun in 1896 (*), is followed by the majority of these nations in order to provide their own mariners with predictions : 1) in their own language, 2) in readily accessible volumes, 3) in familiar format, units, and terms, and 4) bound together for the geographical area of interest regardless of national boundaries.

Unlike almost all other oceanographic activities in the United States, tide and tidal current predictions are the responsibility of only one organization, i.e. the Coast and Geodetic Survey of the Environmental Science Services Administration. The parent organization is the U.S. Department of Commerce. Although the Survey is a nonmilitary agency in an organization devoted to commercial stimulation and assistance, it has tried to be particularly quick in its response to the needs of the Armed Forces in times of national emergencies. During the Civil War, for example, 1000 copies of the appendix to the annual Report of 1864 (containing the necessary tables for determining predictions by the nonharmonic lunital interval method) were printed in pamphlet form for distribution to Union naval forces.

World War II, with its huge amphibious assaults on numerous remote islands and atolls, presented unique tide prediction problems to the Survey. The accepted method requires observations of at least 15 days (preferably 29) at the location for which predictions are desired. Observations from the islands, let alone the specific landing beaches, were fragmentary for the Pacific theater of operations. In many instances, isolated bits of intelligence from captains of trading schooners, tourists, and coast watchers had to be put together for the "best possible" predictions. Special "restricted" (through 1946 (*)) tables were published for locations possessing acceptable harmonic constants. These included : Punta Gorda, Venezuela 1940 (*) (tides); Gilbert, Marshall, Caroline, and Mariana Is., 1944-48 (*) (tides); western Aleutians, Alaska and Kuril I., Japan, 1944 (*) (tides); Philippine Is., 1944-51 (*) (tides and tidal currents); Japan and China, 1945-51 (*) (tides and tidal currents); Unimak Pass, Alaska, 1943-44 (*) (tidal currents); Malacca Straits, 1944-48 (*) (tidal currents), and the Yangtze Kiang Entrance, 1945-46 (*) (tidal currents). In addition, numerous more highly classified reports were prepared.

The most successful wartime publication by far was the extremely useful and convenient Tide and Light Diagrams which supplemented special reports on tides and tidal currents in particular areas. Each Diagram page contained information for one month at a particular location.

The information included time and height of tide, daylight, three stages of twilight, darkness, moonrise and moonset, dim and bright moonlight, and monthly mean air and sea temperatures, and winds. Constants extended the tidal coverage to nearby places. Although the Diagrams were prepared for some strategic points in Europe, their greatest use was in amphibious operations in the Pacific. Over 1150 monthly Diagrams for 112 locations were constructed.

During times of peace, special tide tables have also been published occasionally to satisfy particular local needs. From 1955 (*) through 1961 (*), separate tables were published for selected places in Greenland, Canada, and Alaska for the Navy Department.

From 1928 (*) through 1932 (*) tide and tidal current predictions for a number of large ports were also published in small booklet form, $3\frac{1}{2} \times 5\frac{1}{2}$ inches in size. The ports were : New York, 1928-30 (*) (tides); Boston, 1930 (*) (tides); San Francisco, 1930-32 (*) (tides and tidal currents); Puget Sound, 1930-32 (*) (tides and tidal currents); Massachusetts Bay, 1931-32 (*) (tides and tidal currents), and New York, 1931-32 (*) (tides and tidal currents). From 1940 (*) through 1944 (*), in response to increased war traffic, the miniature tide table for New York Harbor and vicinity was again published.

Although very convenient and useful, the single port miniature tide table was discontinued by the Coast and Geodetic Survey in view of rising costs and the duplication in service by commercial firms. Abbreviated tables, based on predictions provided by the Survey, appear in private almanacs, calendars, and booklets, largely for advertising purposes. However, the four large "official" tide table volumes and two "official" tidal current table volumes, together with the tidal current charts and small craft chart predictions, are published by the United States Government.

Although this is primarily an account of tide table publication, it is to be noted that tidal current predictions were first published in 1890 (*) for New York Harbor and vicinity. They first appeared in volumes separate from the tide tables in 1923 (*) (Tidal Current Tables, Atlantic Coast, North America and Tidal Current Tables, Pacific Coast, North America).

From 1853 through 1864, tables were provided in the appendices of the annual reports which enabled the mariner to make his own predictions by the nonharmonic lunitidal interval method. Beginning in 1844, lunitidal intervals and ranges were included on nautical charts. The Map of New York Bay and Harbor and the Environs, Sheet No. 1 of 1844 contained the following tide note :

" Corrected Establishment of Sandy Hook	7 h 29 m
Rise of Highest Tide observed above the plane of refer- ence May 30, 1836 during a heavy gale from E.N.E.	8 ft 1 in
Height of mean Low Water above the plane of reference.	1 ft 0 in
Height of mean High Water above the plane of reference.	5 ft 9 in.6
Mean rise and fall of Tides	4 ft 9 in.6
Mean rise and fall of Spring Tides	6 ft 3 in.4
Mean rise and fall of Neap Tides	3 ft 9 in.8 "

Similar tide information was also provided for "New York Harbor observed at Governor's Island" on this same 1844 chart. Since 1939, only ranges have been printed on the conventional nautical charts.

Full circle has occurred with respect to tide prediction with the publication, begun in 1959 (*), of the Small Craft Chart series of the Coast and Geodetic Survey. This series, particularly directed toward the yachtsman, contains tide predictions for one year of chart issue at a control station, together with constants for numerous secondary stations in the area.

The lowest organizational unit in which all practical tidal activities are located in the Coast and Geodetic Survey is the Oceanography Division (fig. 2). The Oceanography Division, along with the Marine Chart Division and Research Group, comprise the Office of Hydrography and Oceanography, headed by an Associate Director of the Coast and Geodetic Survey.

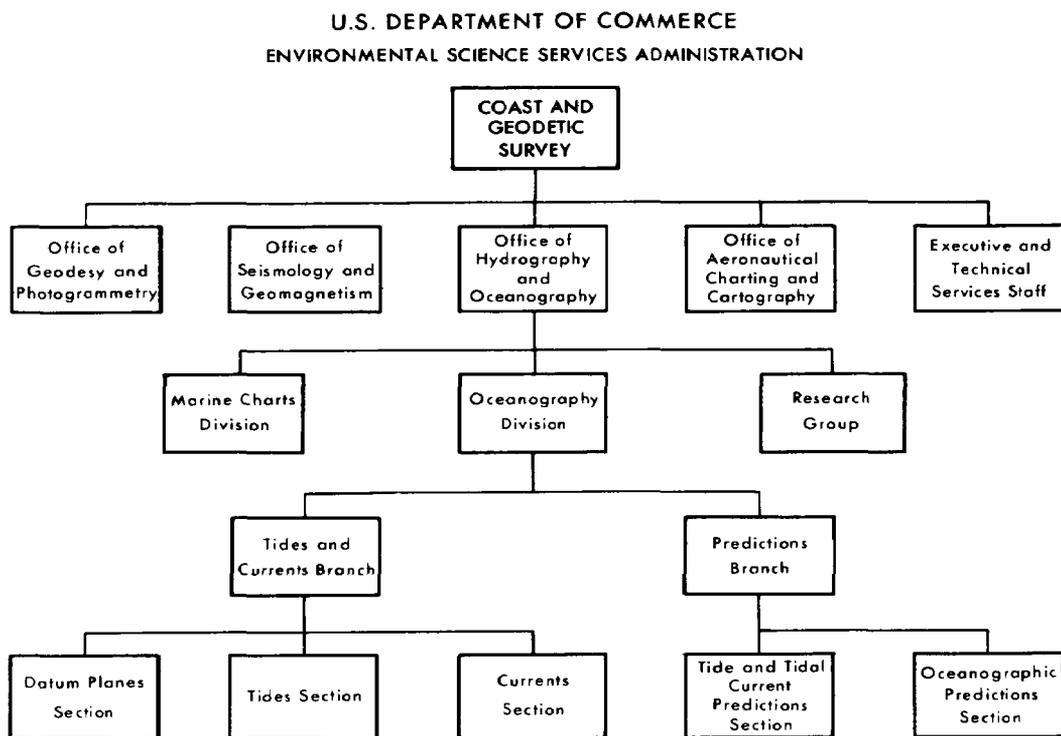


FIG. 2. — Abbreviated diagram illustrating organization of tidal activities only.

Within the Oceanography Division are the Tides and Currents, and Predictions Branches. The Tides and Currents Branch is composed of the Datum Planes, Tides, and Currents Sections, while the Predictions Branch contains the Tide and Tidal Current Predictions Section and Oceanographic (nontidal) Predictions Section.

The Division's origin can be traced to 1854 when it was first organized as the Tidal Division. Sixty-one years later its name was changed to Section of Tides and Currents. In December 1920 the Section was raised

to Division level [12]. The Division of Tides and Currents became the Marine Data Division in 1960 and finally the Oceanography Division in 1966. Before 1851, tide reductions were performed by the chiefs (mostly Naval officers on assignment to the Coast Survey) of the various hydrographic parties. In 1851 and '52, it appears that tidal work began to be done in the Washington Office. The group was referred to as a Tidal Party in the Report for 1853. The Division Chiefs, together with their dates of incumbency, are listed in table 1.

Basic research activities in tides are located in the Physical Oceanography Laboratory of the Institute for Oceanography, another component of the parent Environmental Science Services Administration. It is also planned to establish applied tidal research competence in the Research Group of the Office of Hydrography and Oceanography.

TABLE 1
Division chiefs

W. W. GORDON	April 11, 1851 to April 11, 1853
<i>Tidal Party and Tidal Division</i>	
Louis F. POURTALES	April 12, 1853 to June 14, 1866
<i>Tidal Division</i>	
Robert S. AVERY	June 15, 1866 to Sept. 30, 1885
Alexander S. CHRISTIE	Oct. 1, 1885 to April 19, 1893
Benj. A. COLONNA (Acting)	April 20 to May 8, 1893
George A. FAIRFIELD	May 9, 1893 to June 7, 1894
Leland P. SHIDY (Acting)	June 8, 1894 to July 17, 1895
E. B. LATHAM	July 18, 1895 to Feb. 24, 1896
Leland P. SHIDY (Acting)	Feb. 25 to March 4, 1896
Henry L. MARINDIN	March 5, 1896 to Nov. 16, 1897
Leland P. SHIDY (Acting)	Nov. 17, 1897 to May 16, 1898
Leland P. SHIDY	May 17, 1898 to Oct. 14, 1915
<i>Section of Tides and Currents</i>	
Leland P. SHIDY	Oct. 15 to Dec. 26, 1915
Robert F. LUCE	Dec. 27, 1915 to July 26, 1917
Leland P. SHIDY	July 27, 1917 to March 18, 1919
Robert F. LUCE	March 19 to July 19, 1919
Gilbert T. RUDE	July 24, 1919 to Dec. 14, 1920
<i>Division of Tides and Currents</i>	
Gilbert T. RUDE	Dec. 15, 1920 to Aug. 22, 1928
Paul C. WHITNEY	Aug. 23, 1928 to Aug. 27, 1942 [12]
Charles K. GREEN	Aug. 28, 1942 to Dec. 30, 1946
Cornelius D. MEANEY	Dec. 31, 1946 to March 31, 1950
Henry E. FINNEGAN	April 1, 1950 to Dec. 28, 1956
Kenneth G. CROSBY	Jan. 1, 1957 to Sept. 30, 1960
<i>Marine Data Division</i>	
Lindsay P. DISNEY (Acting)	Oct. 1 to Nov. 10, 1960
Kenneth S. ULM	Nov. 11, 1960 to May 31, 1964
William SHOFNOS (Acting)	June 1 to July 12, 1964
William D. BARBEE	July 13, 1964 to Dec. 19, 1965
William SHOFNOS (Acting)	Dec. 20 to 27, 1965
Steady D. HICKS (Acting)	Dec. 28, 1965 to Jan. 15, 1966
<i>Oceanography Division</i>	
Steady D. HICKS (Acting)	Jan. 16, 1966 to present.

William FERREL headed the first research group, which is said to have been entirely independent of the Tidal Division. From 1910 to 1915, Rollin

HARRIS was in charge of a Tidal Research Section which finally evolved into a current reduction and prediction section [12]. Although not heading a group, *per se*, Paul SCHUREMAN, in recognition of his significant accomplishments, was assigned full time to research in the latter years of his career. In 1963, a Research Group, headed by Bernard D. ZETLER, was formed under the Office of Oceanography. It consisted of four persons, three engaged in tidal research and one in geophysics. The Group was reformed into the present structure described above, with the reorganization of 1966.

It is probably dangerous to speculate as to the future of tide predictions. Nevertheless, at this 100th anniversary it is certainly called for. The greatest practical need is for short range advisories of departures from predicted astronomic tides due to meteorological effects. Of equal importance at river and up-estuary stations is the need for advisories of departures due to river stage and flow variations. Although the accuracy of the present empirical method is adequate for coastal stations, direct methods such as those under development by PEKERIS and HENDERSHOTT could foreseeably eliminate the necessity of prior *in situ* observations. In addition, predictions of tides in the deep sea will probably be needed. Plans are already well underway for an extensive tide observation program throughout the world's oceans. The Coast and Geodetic Survey and Institute for Oceanography plan to be the major U. S. participants in this international program sponsored by the International Association of Physical Oceanography of the International Union of Geodesy and Geophysics. Although primarily a basic research program, the observations could provide data for verification of prediction theories and for dynamic numerical prediction models.

Finally, the response method of MUNK and CARTWRIGHT [13] and the significant constituent identification technique of ZETLER and CUMMINGS [14] promise to be of considerable importance in the near future. The latter technique is extremely useful for shallow water stations. It has an advantage over the standard procedure in that it identifies additional frequencies in the spectrum which have significant energy at a particular station.

Acknowledgments

The author wishes to thank William A. STANLEY for discovering the unpublished manuscript by SHIDY [12] and both William SHOFNOS and William A. STANLEY for their assistance in determining the initial and ending dates for the publication of lunitidal intervals on nautical charts. William SHOFNOS also completed the table on the Division Chiefs. In addition, the author desires to express his appreciation for the additions, suggestions, and critical comments of: William SHOFNOS, Bernard D. ZETLER, William A. STANLEY, William D. BARBEE, Robert A. CUMMINGS, Donald C. SIMPSON, John J. GROTH, and Walter D. LAMBERT.

CHRONOLOGY (1)

- 1830 (*) Tide predictions for United States. Published in "The American Almanac" [15]. High water time predictions (one per day) for Boston, New York, and Charleston. Time differences for 96 other stations. Spring range predictions for 84 stations.
- 1844 Tide notes (including lunitidal intervals) on nautical charts begun.
- 1853 Tables for obtaining tide predictions by the nonharmonic lunitidal interval method first published in the Appendix to the annual report.
- 1854 Tidal Division formed.
- 1864 Last year of tables for lunitidal interval method. One thousand copies provided to Union naval forces.
- 1867 (*) First tide tables published.
- 1868 (*) Low water predictions begun for west coast of Florida and Pacific coast. William FERREL joined Coast Survey. First research group formed.
- 1873 Leland Perry SHIDY joined Coast Survey.
- 1878 Coast Survey became Coast and Geodetic Survey.
- 1885 (*) William FERREL's Maxima and Minima Tide Predictor introduced.
- 1886 William FERREL left Coast and Geodetic Survey.
- 1887 (*) Low water predictions included for all stations.
- 1890 (*) Tidal current predictions begun (New York Harbor and vicinity). Rollin A. HARRIS joined Coast and Geodetic Survey.
- 1896 (*) Extension of tables to include numerous ports throughout world.
- 1903 Paul SCHUREMAN joined Coast and Geodetic Survey.
- 1907 Harry A. MARMER joined Coast and Geodetic Survey.
- 1910 Tidal Research Section formed.
- 1912 (*) Harris-Fischer Tide Predicting Machine introduced.
- 1914 (*) Last year FERREL's Maxima and Minima Tide Predictor used.
- 1915 Tidal Division changed to Section of Tides and Currents.
- 1918 Rollin A. HARRIS died.
- 1920 Section of Tides and Currents changed to Division of Tides and Currents.
- 1922 (*) Format changed from sequential listing to separate columns for high and low waters.
- 1923 (*) Tidal current tables first published separately from tide tables (two volumes, Atlantic Coast and Pacific Coast, North America).
- 1928 (*) Single port miniature tables introduced.
- 1930 Leland Perry SHIDY retired.
- 1932 (*) Last year of single port miniature tables (revived from 1940 (*) through 1944 (*) for New York Harbor and vicinity only).
- 1940 (*) Special "restricted" tables for war effort begun.
- 1945 Paul SCHUREMAN retired.
- 1951 (*) Last year of special wartime and occupation tables.
- 1953 Harry A. MARMER retired.
- 1955 (*) Special tide tables for selected places in Greenland, Canada, and Alaska begun.
- 1958 (*) Format changed from separate columns for high and low waters to sequential listing.
- 1959 (*) Tide predictions added to Small Craft Chart series.
- 1960 Division of Tides and Currents changed to Marine Data Division.
- 1961 (*) Motor drive and automatic readout installed on Harris-Fischer machine. Last year of special tide tables for selected places in Greenland, Canada, and Alaska.
- 1963 Research Group formed.
- 1966 (*) Electronic digital computer introduced for predictions. Marine Data Division changed to Oceanography Division. Research Group activities transferred to Physical Oceanography Laboratory, Institute for Oceanography.

(1) Unless otherwise noted, all items refer to U.S. Coast and Geodetic Survey activities.

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