H Y D R O G R A P H I C

T I D A L M A N U A L

1969 EDITION

FOREWORD

Canada has some of the most interesting and peculiar tides. It also contains great bodies of inland waters and many important navigable rivers. Because of the vast extent of Canada's coastline, and the importance of the inland water systems, the hydrographer should obtain accurate reliable records whenever and wherever possible. On a survey, a major and immediate concern to the hydrographer is the establishment of a sounding datum to be used in reducing soundings. He also needs to establish a high water datum on which to base his heights. Subsequently this data must be verified to ensure that it is suitable for use on the published chart, tide and current tables, water level publications or water level bulletins.

This manual is intended to assist in the use of tide and water level recorders, levelling instruments, forms, and the application and usage of tidal or water level data in hydrographic surveys. The preliminary draft was prepared by Mr. R. Golding, and after being reviewed by field and office personnel, this edition was prepared by Mr. E. Brown. Both are hydrographers of the Canadian Hydrographic Service. The staff of the Tides, Currents and Water Levels Section contributed much of the information, and special credit is due Messrs. D. Cooper, H. Holdsworth, C. Langford, J. Mackenzie and G. Wade who prepared preliminary sections during his rotational period. Credit is also due personnel of the Regional Offices who submitted comments and suggestions.

G. Dohler,
Senior Tidal Officer.

Ottawa, November, 1965.

TIDAL FORCES

The main forces that cause our tides are the pull of the moon and the pull of the sun. Of these the pull, or attraction, of the moon is the more powerful—about twice that of the sun. The tidal rhythm is therefore generally in tune with the apparent rotation of the moon around the earth, or the "lunar day" of 24 hours and 50 minutes.

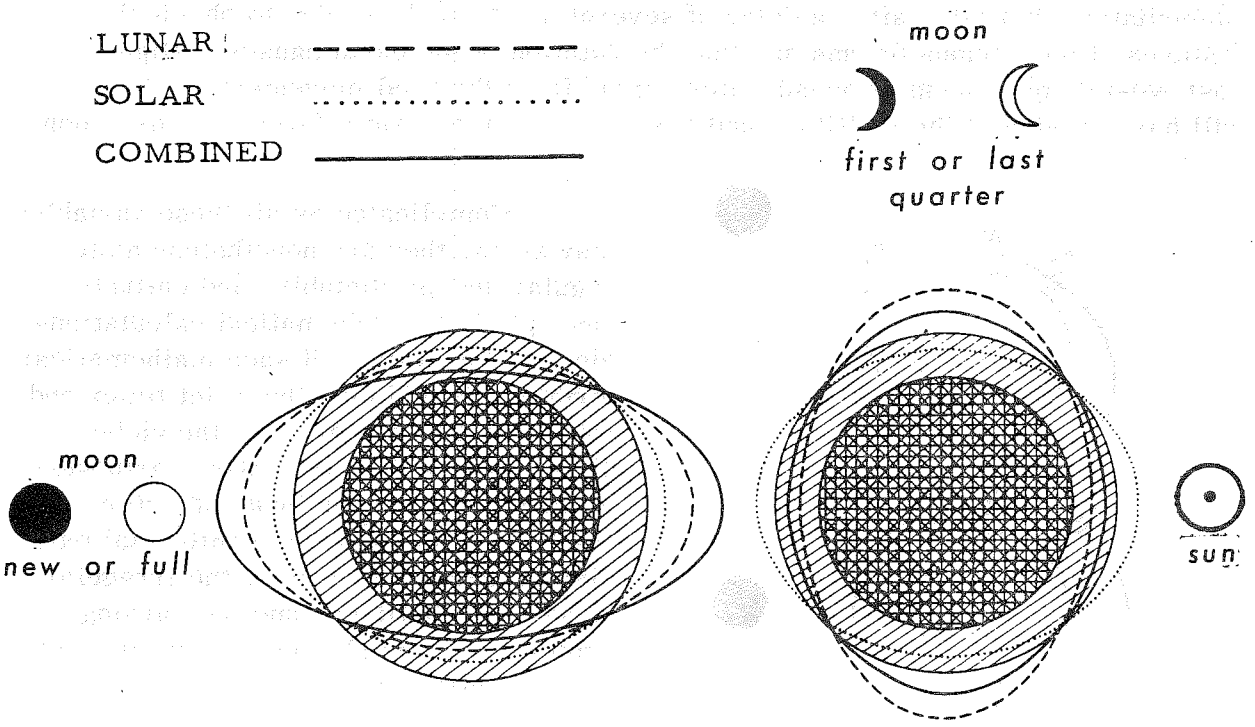


Figure 1. The solar and lunar tidal effect — phase of the moon.

The pull of the sun and the pull of the moon always affect two sides of the earth at the same time: on one side, the waters of the ocean are drawn away from the earth; on the other, the earth is drawn away from the water. The pull, and the resultant high tides, are naturally strongest when the attractions of the moon and the sun are added together; this occurs both at full and at new moon and we have "Spring Tides". The tides are least when the pull of the sun is counter-acting that of the moon, or when the sun and the moon are, so to speak, at right angles in relation to the earth; this occurs during the first and last quarter of the moon and we have

"Neap Tides" (Figure 1).

The attraction of the moon and sun also varies with the distance of these two bodies from the earth, since both the four-week revolution of the moon around the earth, and the annual revolution of the earth around the sun follow an elliptical course. The point where the moon is nearest to the earth is called "perigee"; the point where it is farthest is called "apogee". The force of the moon's attraction increases during perigee, and decreases by an equal proportion during apogee.

The apparent revolutions of moon and sun around the earth are not always along the plane of the equator, they are in phase when the moon has maximum declination, either north or south of the equator, and in opposition when the moon crosses the equator, therefore their tide-producing force at any given point on the earth does not repeat itself twice every lunar day. There tends to be sometimes one stronger and one weaker pull (Figure 2, h_1, h_2).

Add to this the fact that the tide does not respond to the phases of the moon immediately, but often after a delay of several hours or days, due to physical features of the various oceans and that the rotation of the earth causes a slight east-west displacement of ocean waters apart from the tidal movement, and you will have an idea of the multitude and complexity of the cosmic forces at work upon the tides.

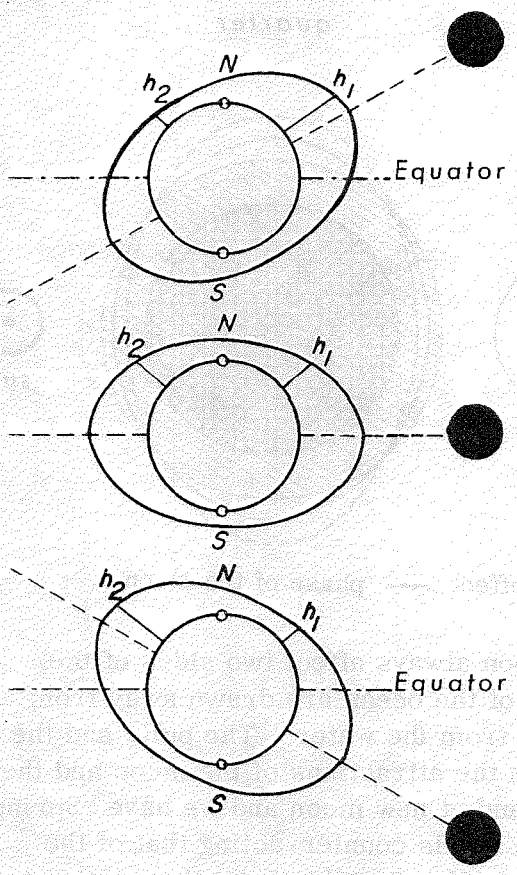


Figure 2. The solar and lunar tidal effect — declination.

Complicated as all these variables may seem, they are nonetheless quite regular and predictable, and entirely susceptible to mathematical calculations. Ideally, the results of such mathematical formulas should give the exact times and ranges of all tides all over the globe. This would be so if the entire earth were covered with an even layer of water. In reality, the existence of continental barriers between the oceans, the irregular shapes of coastlines, and the varying depths of oceans play havoc with theoretical assumptions.

To use a very much simpler illustration, we can safely predict that at any given point on earth there will be alternating periods of light and darkness (day and night); but we cannot predict just how much light will reach the spot without first finding out whether it is in a deep gorge or on an open plain.

There is no space here to describe the various theories used to explain the very wide variations of astronomical tides and their deviation from cosmic norms. The irregularities are sufficient to cancel out, at times, either the diurnal or the semi-diurnal component of the tide-producing force; in others, the height as well as the time of the tide may be increased or diminished out of all proportion by purely local conditions. Although astronomical factors must definitely be taken into account in tidal calculations, no accurate predictions of the tides at any given coastal point can be made without a long period of careful observations on the spot.

For practical purposes, as far as any particular coast is concerned, two basic questions present themselves to the tide observer:

a) How great is the range of the tide, i. e. , the difference between high and low water?

b) Are there one or two tidal cycles per day, i. e. , is the tide diurnal or semi-diurnal?

When we look for answers to these questions we soon find, from observations, that at only a few locations are the tides strictly diurnal, or strictly semi-diurnal. For example, although both high and low tide may occur twice within 24 hours, thus appearing semi-diurnal, the first high tide may be considerably greater than the second high tide.

For the sake of classification, we can divide tides into four groups: semi-diurnal; mixed, mainly semi-diurnal; mixed, mainly diurnal; diurnal.

The rise and fall of the tide in each of these groups can best be understood from the following graphs, each covering a period of one month.

Symbols: ● New ☽ First quarter S Max. decl. south Q At equator

○ Full ☾ Last quarter N Max. decl. north

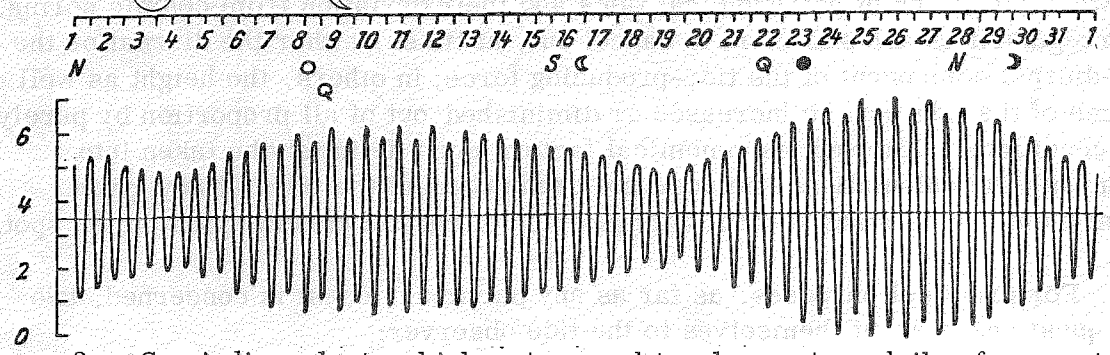


Figure 3a – Semi-diurnal: two high waters and two low waters daily of approximately the same height; the interval between the transit of the moon and the occurrence of high water is nearly constant.

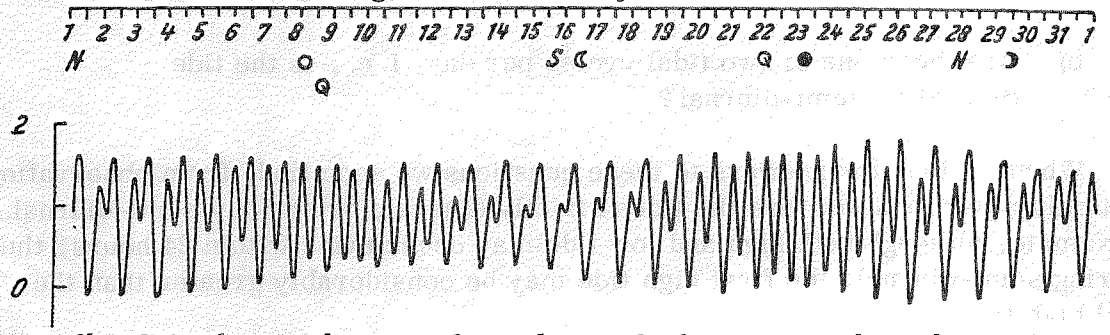


Figure 3b – Mixed, mainly semi-diurnal: two high waters and two low waters with inequalities in height and time reaching the greatest values when the declination of the moon has passed its maximum.

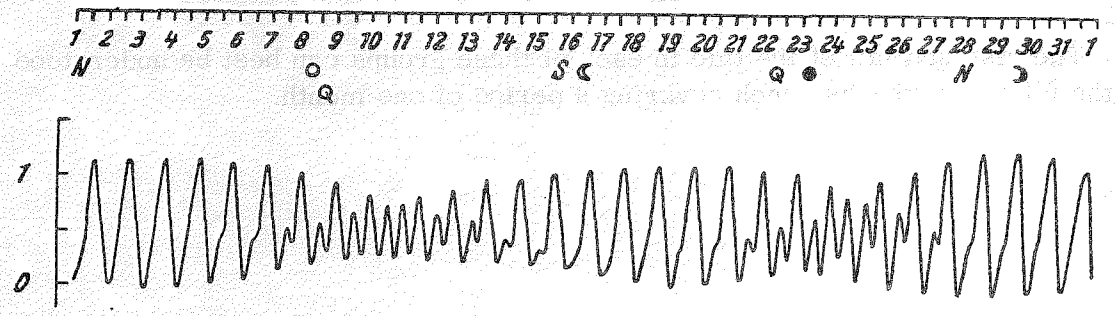


Figure 3c – Mixed, mainly diurnal: occasionally there is only one high and one low water a day, following the maximum declination of the moon; at other times there are two large inequalities in height and time, especially when the moon has passed over the equator.

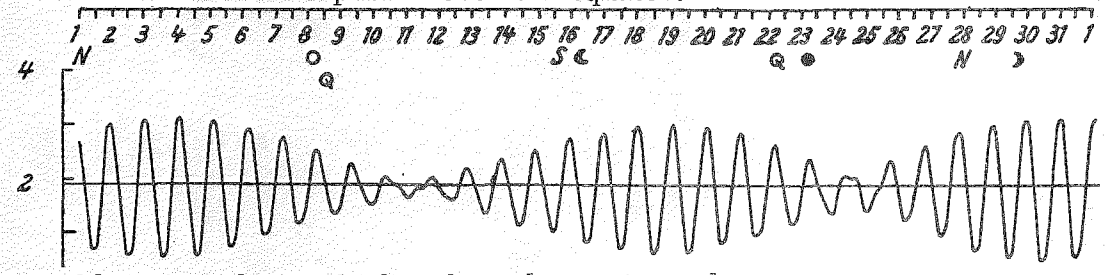


Figure 3d – Diurnal: one high and one low water a day.

TIDES IN CANADIAN WATERS

EAST COAST

South Coast of Newfoundland, Southeast Coast of Nova Scotia and the Bay of Fundy (Figures 4, 5, 6).

Along the Atlantic coast from Cape Race to Cap Ray, Nfld., across to Glace Bay, N.S., and along the shores of Nova Scotia and New Brunswick, the tide is semi-diurnal. High water occurs almost simultaneously along all coastal points from Placentia Bay, Nfld., to Shelburne, N.S. The tidal range is not very great, the difference between high and low water seldom exceeding 6 feet. Around the southern end of Nova Scotia, there are rapid changes both in the time at which high water occurs and in the range of the tide.

The most remarkable tide not only in Canada, but probably anywhere in the world, occurs in the Bay of Fundy, where the tidal range reaches over 40 feet. This is due entirely to a peculiar combination of geographical factors.

In the Petitcodiac River, which empties into the Bay of Fundy at Moncton, N.B., the tide comes in as a "bore", i.e., as an almost vertical head of water which may be as high as 4 feet or as low as a few inches. This strange phenomenon is caused by the current of the river and by friction.

At Saint John, N.B., the cycle of the tide and river current creates the famous Reversing Falls. This feature is caused by a narrow gorge a short distance upstream from the mouth of the St. John River. At low tide, the river level in a basin above the gorge is some 14 feet higher than the water in the bay, and a waterfall results. When the tide comes in, the sea level soon rises above the level of the water in the upriver basin. At one point the difference is as much as 12 feet - and, since the narrow channel cannot at once accommodate the heavy inflow, there is a waterfall "in reverse".

East Coast of Newfoundland and Labrador (Figures 4, 5, 6).

Along the east coast of Newfoundland, and along the Labrador coast as far as Cartwright, the tide is mixed but mainly semi-diurnal. Farther north it tends to become more and more semi-diurnal, being entirely so at Cape Chidley, Labrador's northernmost point. High water occurs simultaneously along the two coasts, and the tidal range is about 3 feet. However, towards the northern end of Labrador (Davis Strait) the range increases considerably.

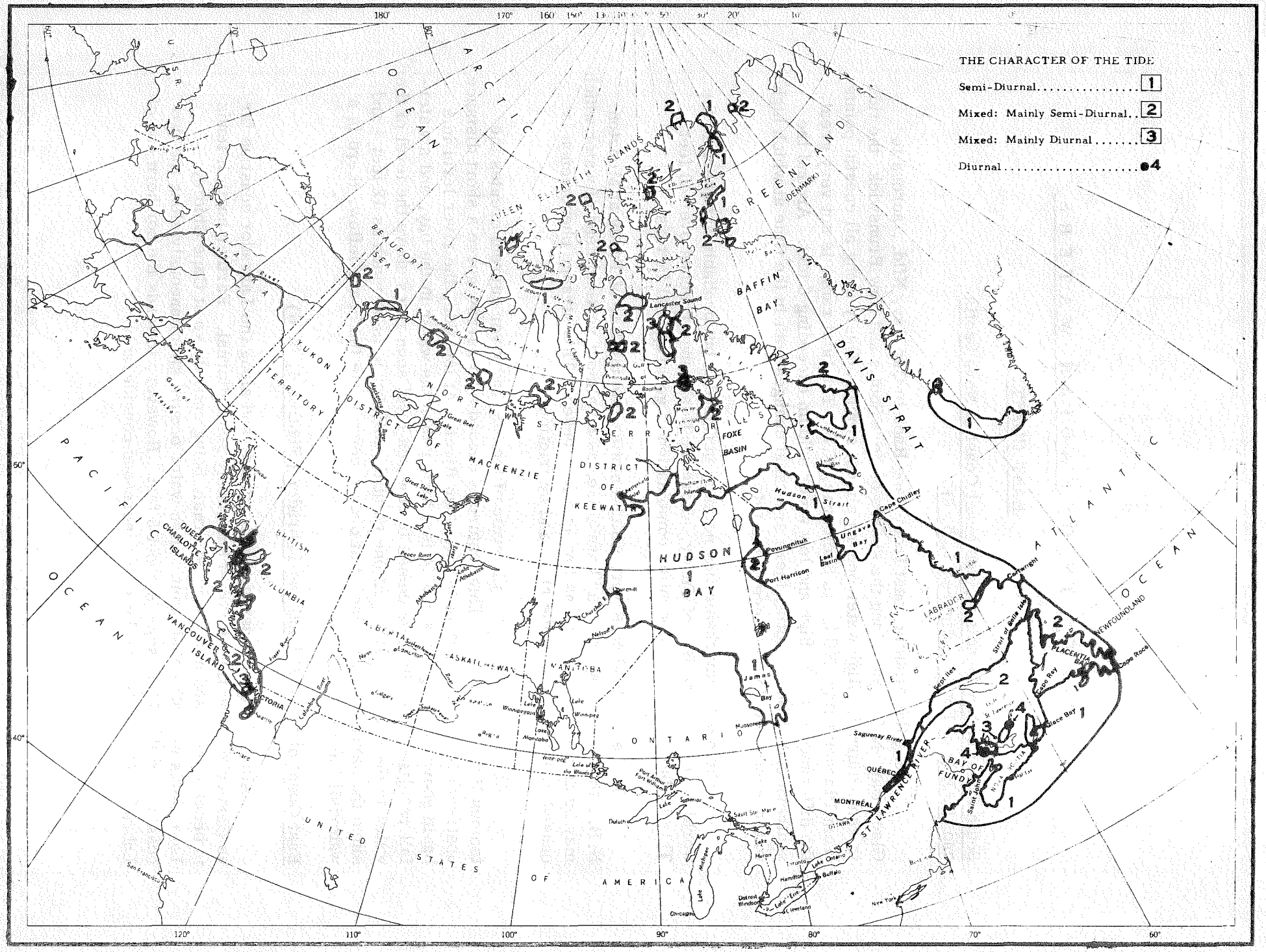


Figure 4. The character of Canadian tides.

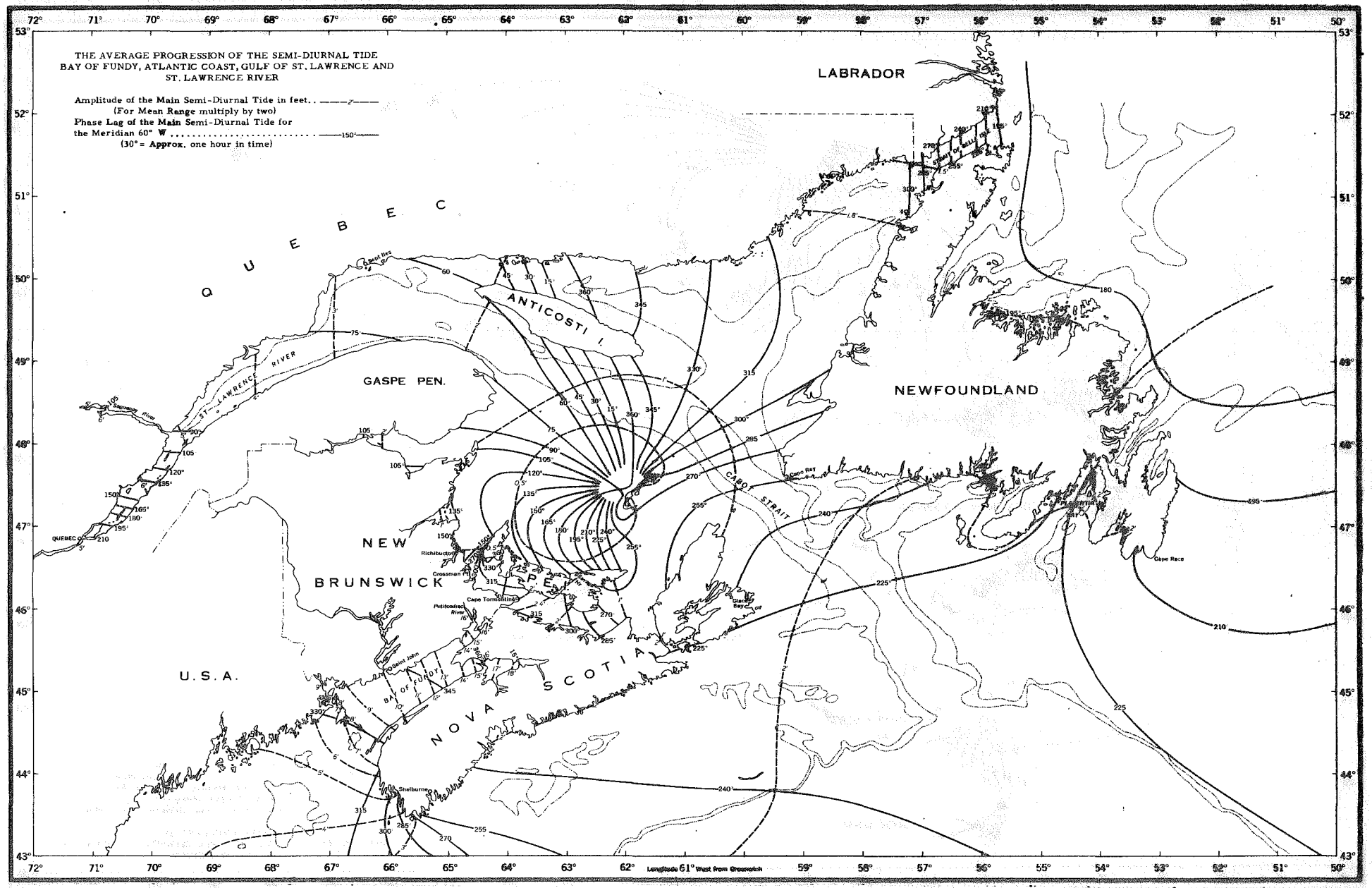


Figure 5. The average progression of the semi-diurnal tides in the Bay of Fundy, Gulf of St. Lawrence and St. Lawrence river, and on the Atlantic coast.

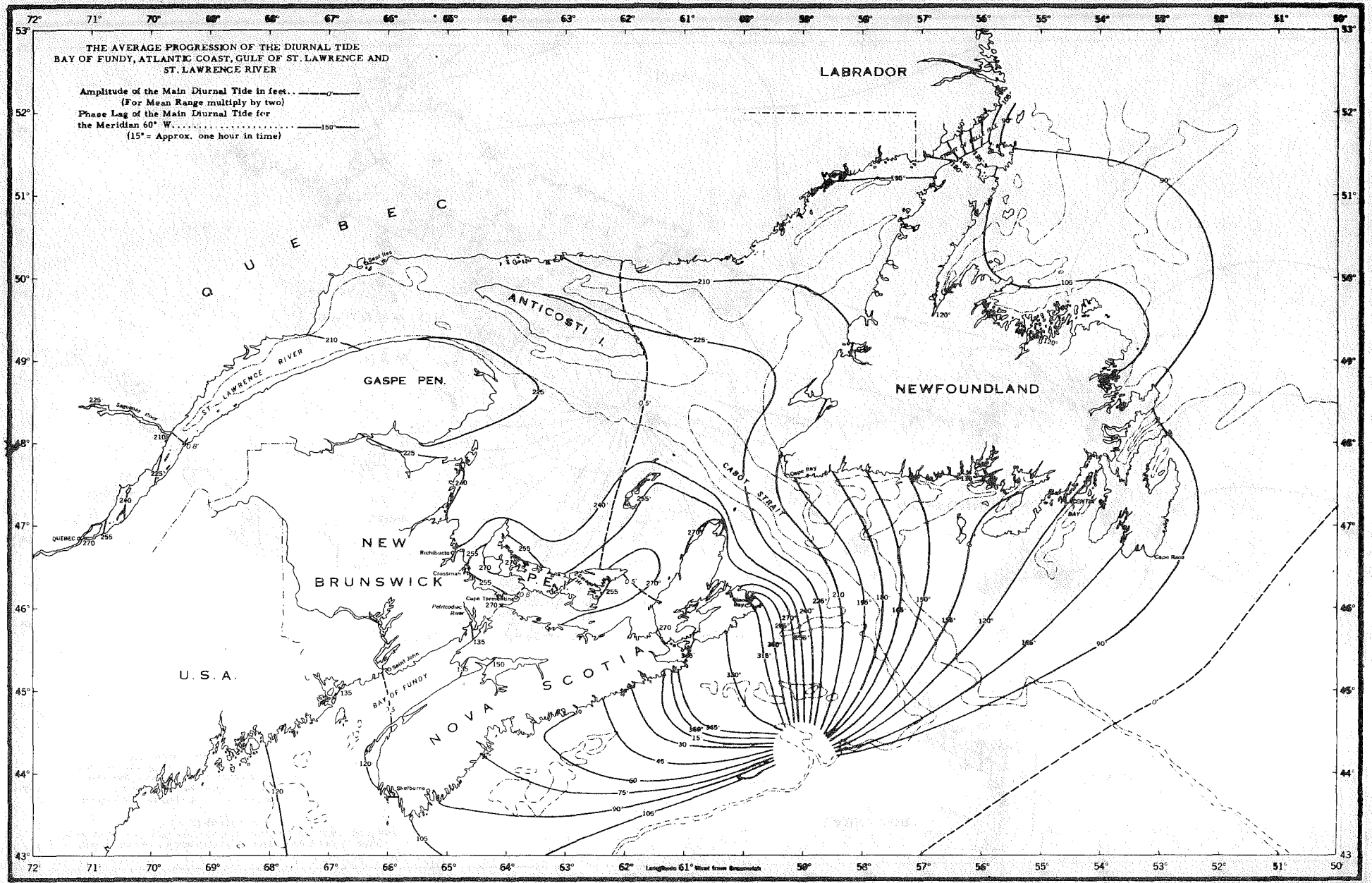


Figure 6. The average progression of the diurnal tide in the Bay of Fundy, Gulf of St. Lawrence and St. Lawrence river, and on the Atlantic coast.

Gulf of St. Lawrence (Figures 4, 5, 6).

The tide propagated through Cabot Strait and Belle Isle Strait into the Gulf of St. Lawrence is of a mixed type, but mainly semi-diurnal, except along the coast between Cape Tormentine and Richibucto, N.B., and near Savage Harbor, P.E.I., where diurnal inequalities dominate. At the southern tip of the Magdalen Islands and near Crossman Point, N.B., the tide is entirely diurnal, only one high and one low tide occurring every day. The range of the tide throughout the gulf is less than 8 feet.

St. Lawrence and Saguenay Rivers (Figures 4, 5, 6, 7).

The tide, entering the Gulf of St. Lawrence from the Atlantic Ocean, is further propagated up the St. Lawrence River, and its effect is easily observable as far as Lake St. Peter, some 400 miles up-river from Seven Islands. The tidal cycle repeats itself twice daily, and counting from Seven Islands, the crest of the tide takes about an hour to travel to the mouth of the Saguenay River, 5 hours to Quebec City, and 10 hours to Lake St. Peter. The range of the tide increases from about 7 feet at Seven Islands to twice that height at Quebec City, after which it diminishes, amounting to less than a foot at Lake St. Peter.

The tidal curve in the St. Lawrence River exhibits various peculiarities attributable to the narrowing and the slope of the river bed and to increasing friction, especially above Quebec City. One of these is that the tide, as in many other river estuaries, rises faster than it falls, i.e., the time from low water to high water is much shorter than the time from high water to low. Also, the high waters maintain almost the same absolute height, while the low waters show a considerable slope down-stream (Figure 8). Above Quebec City, low water level is higher when the moon is new or full (at spring tide) than when the moon is in one of its quarters (at neap tide). This is a reversal of the normal process and is found only in tidal rivers.

St. Lawrence River from Lake St. Peter to Montreal

A slight semi-diurnal tidal effect can be observed on tidal gauges upstream from Lake St. Peter. The range is very small - less than 6 inches. It is interesting to note however, that in each month there are several days when the daily mean values are below or above the monthly mean. These deviations correspond more or less to the phases of the moon (Figure 9).

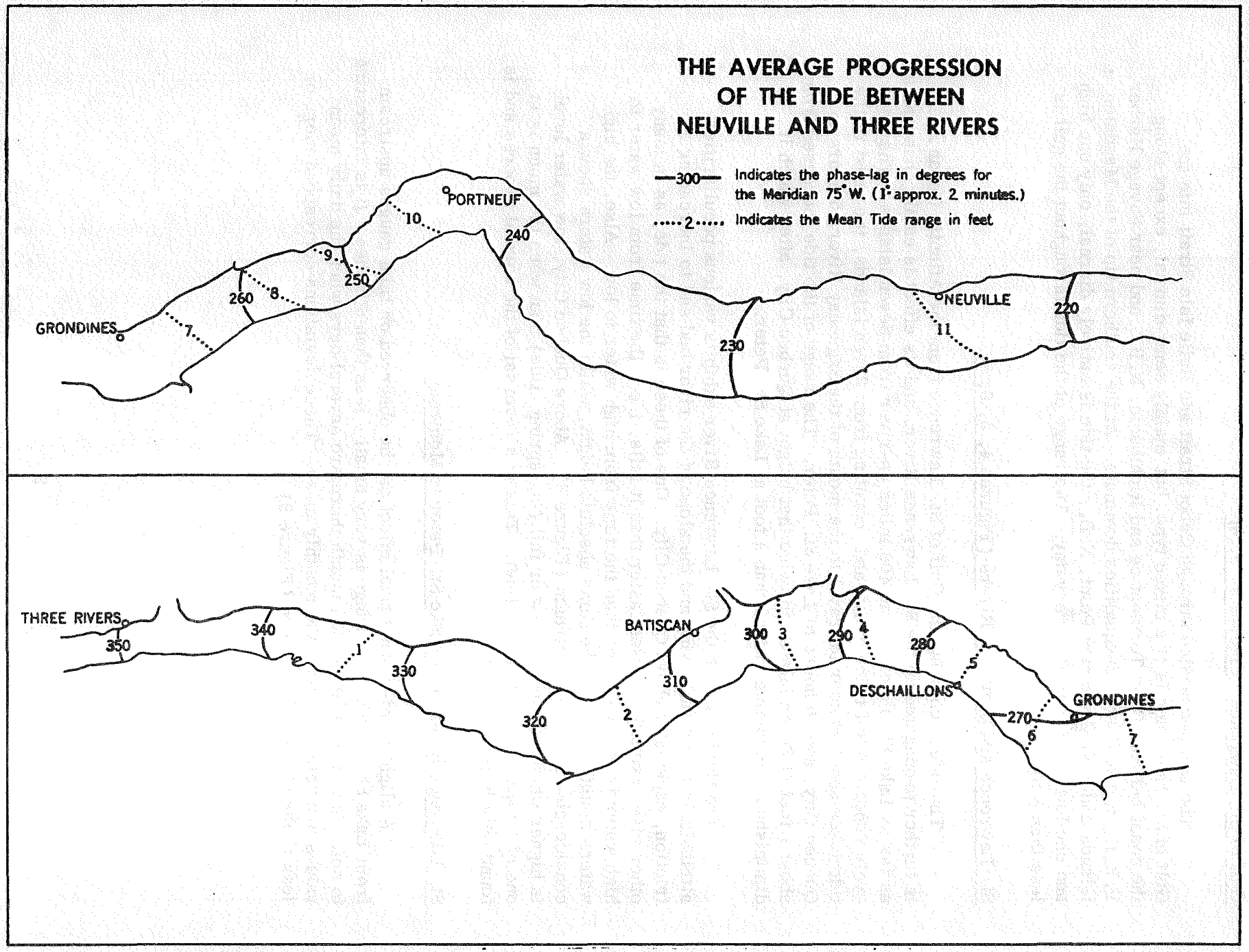


Figure 7. The average progression of the tide between Neuville and Three Rivers, Quebec.

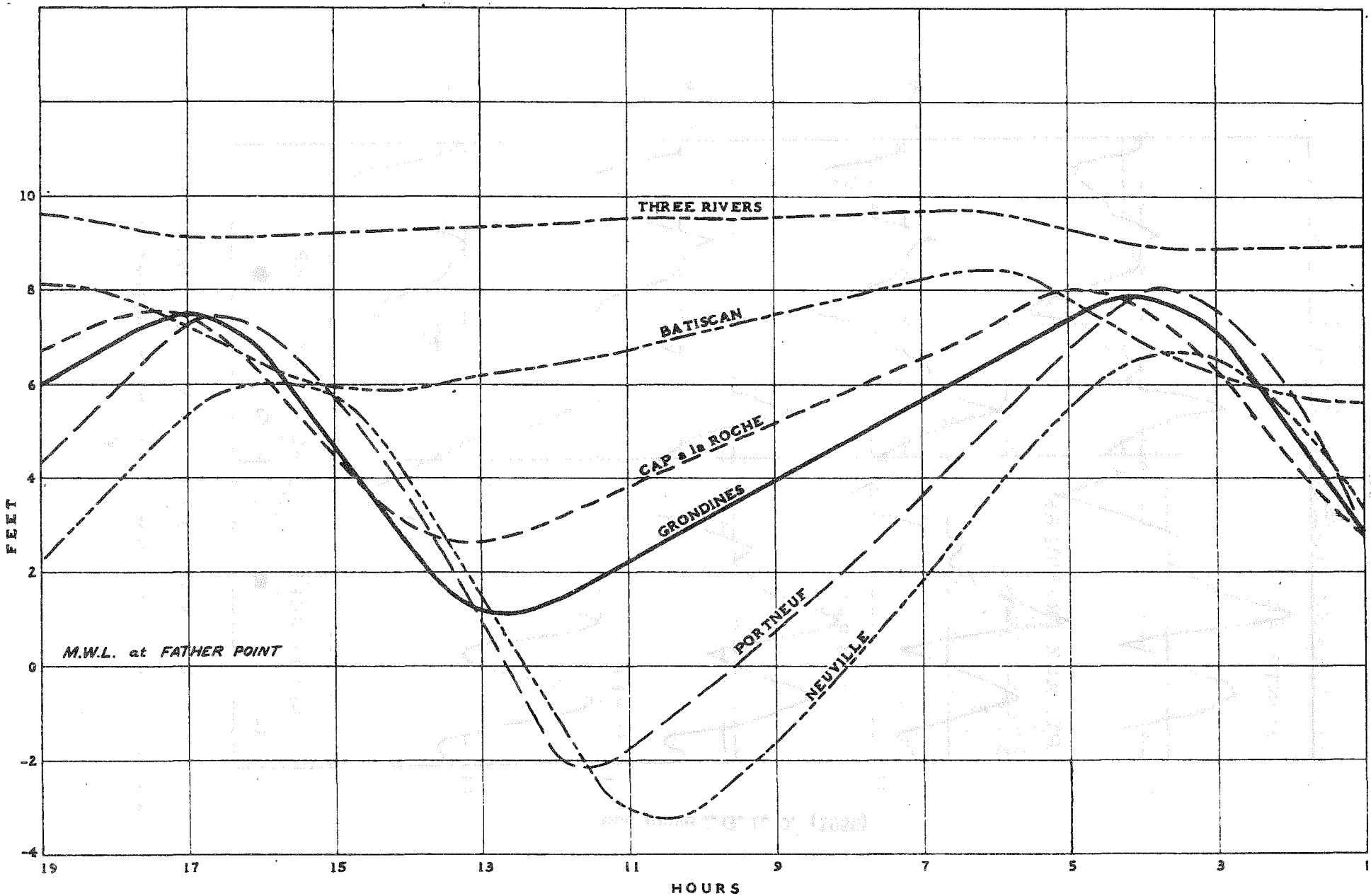
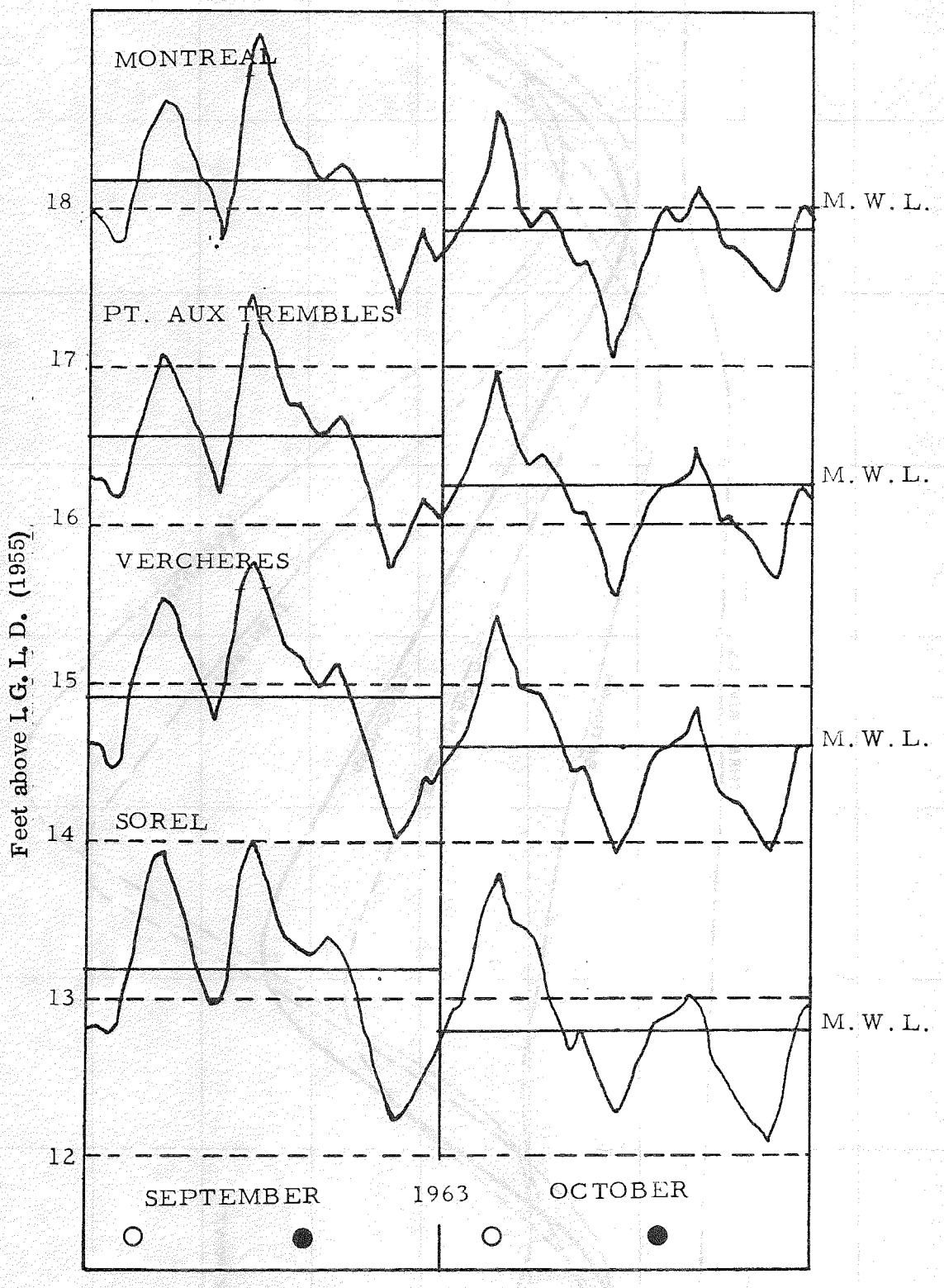
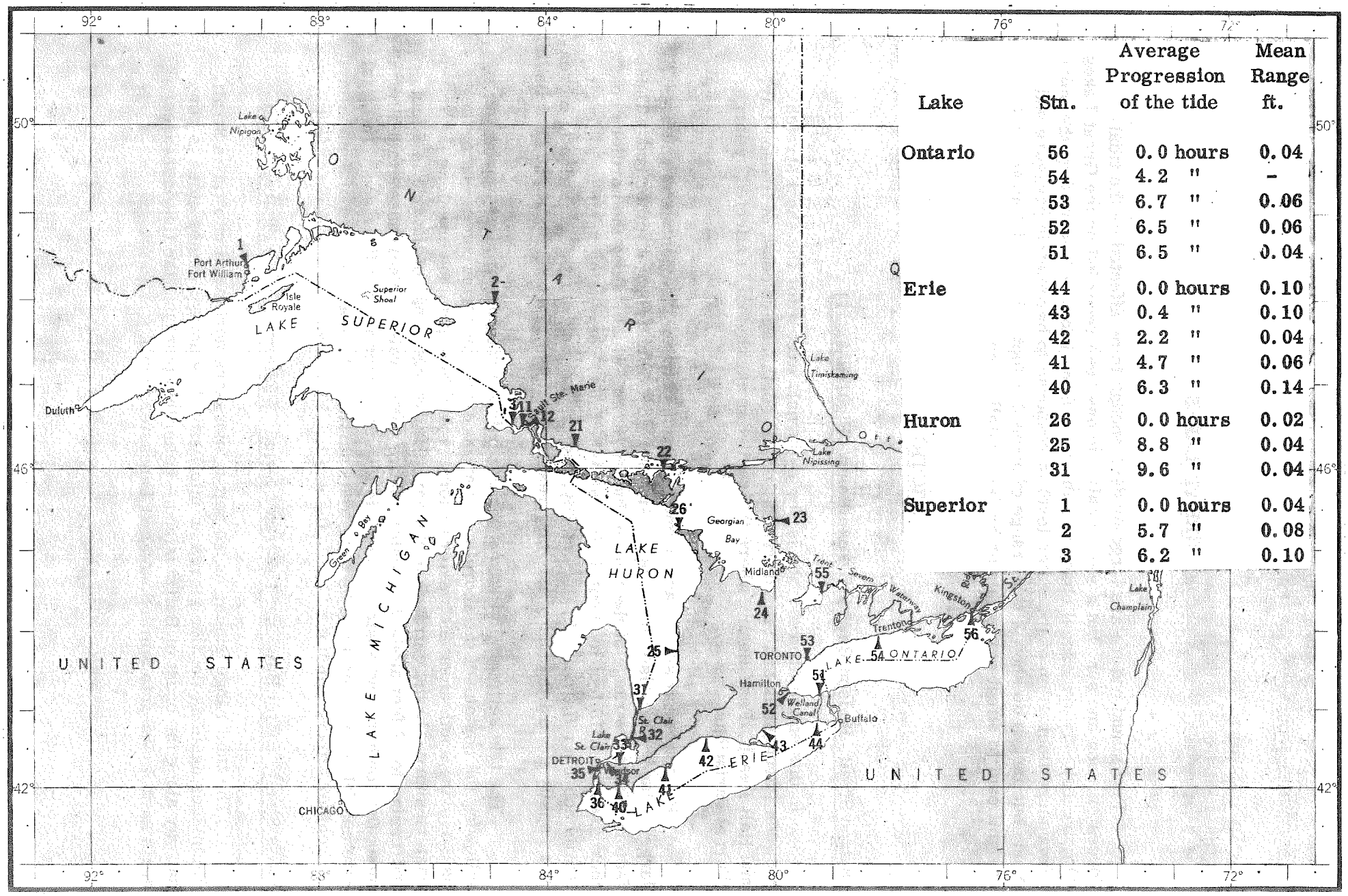


Figure 8. Simultaneous tidal observations at points between Neuville and Three Rivers, Quebec.



M. W. L. = MONTHLY MEAN WATER LEVEL

Figure 9. Water level fluctuations at points between Montreal and Sorel, Quebec.



Lake	Stn.	Average Progression of the tide	Mean Range ft.
Ontario	56	0.0 hours	0.04
	54	4.2 "	–
	53	6.7 "	0.06
	52	6.5 "	0.06
	51	6.5 "	0.04
Erie	44	0.0 hours	0.10
	43	0.4 "	0.10
	42	2.2 "	0.04
	41	4.7 "	0.06
	40	6.3 "	0.14
Huron	26	0.0 hours	0.02
	25	8.8 "	0.04
	31	9.6 "	0.04
Superior	1	0.0 hours	0.04
	2	5.7 "	0.08
	3	6.2 "	0.10

Figure 10. The very small tide recorded on the Great Lakes.

GREAT LAKES

Few inland waters are large or deep enough to be affected by the tidal forces of moon and sun, but a very small tide has been recorded on the Great Lakes (Figure 10). To the casual observer, the tide on the lakes is obscured by the more pronounced fluctuation of the water level in response to barometric pressure and wind, but gauges do show a tidal range of about 0.1 foot. This, of course, is too insignificant to affect navigation or harbor installations.

ARCTIC

Hudson Strait, Hudson Bay and Foxe Basin (Figures 4, 11)

In this entire area the tide is semi-diurnal, except for the short stretch between Povungnituk and Port Harrison, on the northeastern coast of Hudson Bay, and Hall Beach, Foxe Basin, where the semi-diurnal rhythm is affected by large diurnal variations.

Hudson Strait serves as a communication between the open ocean and a large "inland" sea; also, it is much narrower at its waist than at either end. These factors affect the range of the tide in Hudson Strait, which, along the northern coast, increases from 18 feet to about 30 feet at Ashe Inlet, decreasing again to 16 feet towards Schooner Harbor. In Ungava Bay, the tide coming in from the Atlantic increases rapidly toward the end of the bay, reaching a mean range of 40 feet at Leaf Basin.

The tide setting into Hudson Bay describes a roughly circular movement, following the contour of the shoreline, starting from the northwestern end of the bay, moving south along the western shore, and almost petering out along the eastern shore. In the entrance to the bay the average range of the tide is 6 feet, increasing to 12 feet along the western shore, after which it decreases gradually along the southern and eastern shores to about one foot at Port Harrison. The tidal rise and fall may sometimes be obscured, particularly near the head of James Bay, by weather effects which may cause the sea level to rise or fall by several feet.

Davis Strait, Baffin Bay and Lancaster Sound, Western Arctic (Figures 4, 12)

The tidal range which, as we noted, increases northward into Davis Strait, diminishes again as the tide moves on into Baffin Bay until it comes close to zero halfway along the coast of Baffin Island. From that point on, the tide increases again as it moves into Smith Sound and Lancaster Sound.

High water occurs almost simultaneously along the coasts of Davis Strait, but in Baffin Bay high water at the southern entrance coincides with low water at the northern end. In Smith Sound, the tidal range is about 10 feet, and in Lancaster Sound at Resolute, the mean range is 4 feet. The inlets leading off Lancaster Sound have a mean range under 6 feet.

In those portions of the western Arctic lying west of Barrow Strait the range of the tide is small, being no larger than the changes in water level caused by meteorological influences.

Although the Department of Mines and Technical Surveys is carrying on continuous exploration and surveying work in the Canadian Arctic, data on tides are still comparatively scanty. For this reason, the tidal characteristics shown on the map apply only to the few points where observations have been made.

WEST COAST

West Coast of Vancouver Island and Queen Charlotte Islands (Figures 4, 13)

Along the northern two-thirds of Vancouver Island's west coast - from Barkley Sound to Cape Scott - the tide occurs almost simultaneously and has a range of 10 feet. The range increases slightly as the tide moves up into the island's numerous inlets, without however being slowed down, except at Quatsino Narrows where, owing to the restriction of the channel, the tide occurs 45 minutes later than elsewhere on the coast.

Along the west coast of the Queen Charlotte Islands and along the mainland shores of Queen Charlotte Sound, high water occurs simultaneously about 30 minutes later than at Vancouver Island. The shallowness of the sound increases the range of the tide along the mainland, an effect that is further enhanced as the tide rolls up the deep inlets, where at the heads the tidal range reaches 16 feet.

Hecate Strait (Figures 4, 14)

The tide propagated into Queen Charlotte Sound sweeps northward into Hecate Strait, increasing in range with the shallowness of the passage. Around the northeastern spit of Graham Island the tide is slowed down, reaching Masset Inlet about an hour later than at Hecate Strait. On the mainland side of the Strait, both the time difference and the range of the tide increase from south to north; at Prince Rupert the tide arrives about an hour later than off Vancouver Island and has a range of 15 feet. The tide wave propagaged up the inlets reaches the end about 10 minutes later than the entrance, with a slight increase in range.

Juan de Fuca Strait and Strait of Georgia (Figures 13, 14)

It takes about 6 hours for the tide wave to travel up Juan de Fuca Strait and into the Strait of Georgia. The range increases from the entrance towards Victoria, where it is 7 feet, to 12 feet at the north end of the Strait of Georgia. The entire strait may be regarded as a single tidal basin, the time difference between any point along its shores and Point Atkinson at Vancouver not exceeding 30 minutes.

Queen Charlotte Strait and Johnstone Strait (Figure 13)

This narrow, island-strewn passage separating northern Vancouver Island from the mainland is host to two tidal currents - the one coming from Queen Charlotte Sound in the north, and the other from the Strait of Georgia in the south.

Since the tide from the north takes about three hours longer to reach the narrowest parts of the channel separating Vancouver Island and the mainland than the tide from the south, a furious alternating current is set up in the passage, especially at such narrows as Seymour, Okisollo, Surge, Hole-in-the-Wall, Yuculta and Arran Rapids. The range of the "northern" tide shows wide variations, owing to the highly irregular shape of the channel: at Alert Bay, the mean range is 14 feet, at Knight Inlet, 16 feet, decreasing again as the channel narrows.

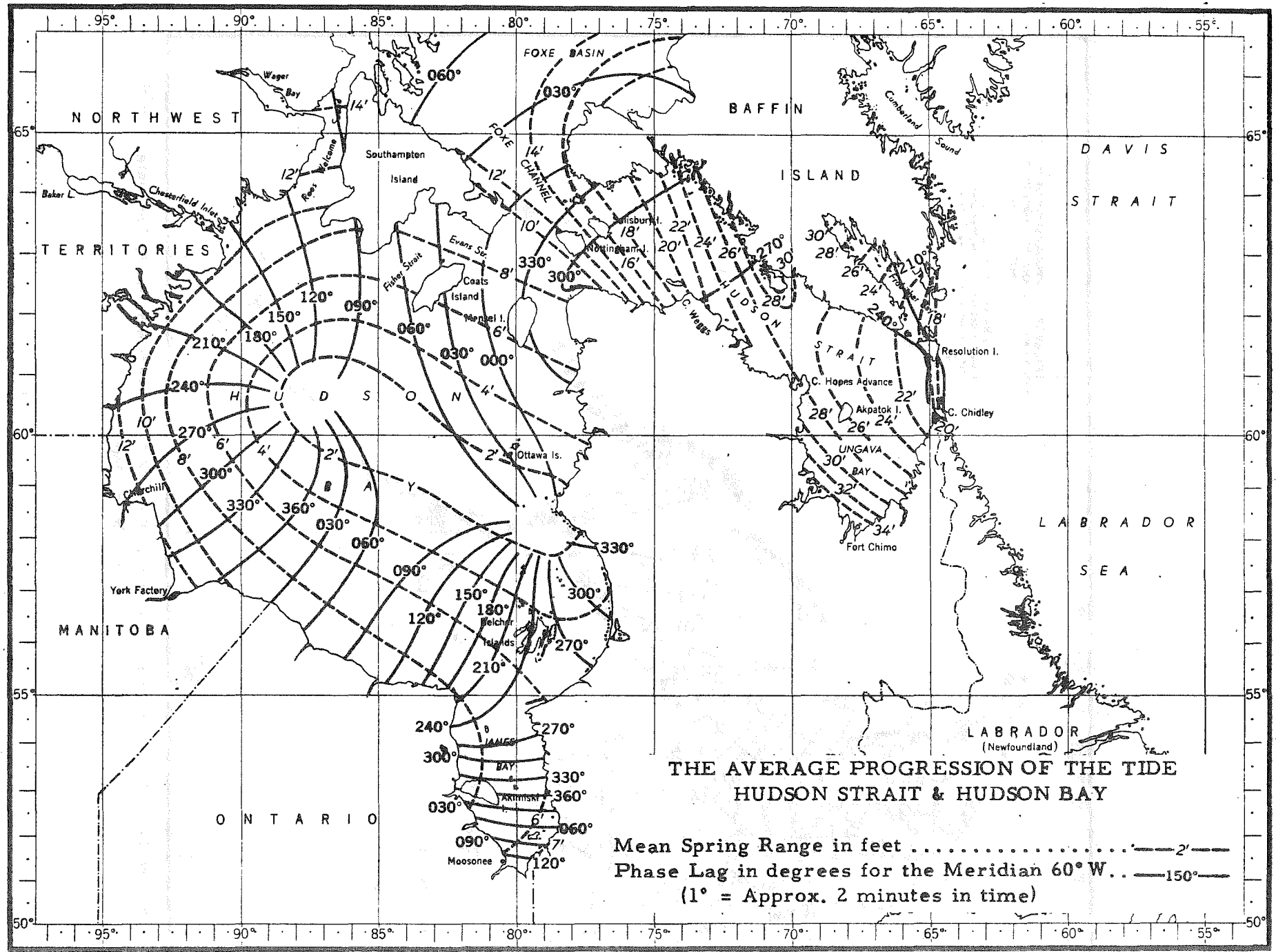


Figure 11. The average progression of the tide in Hudson Strait and Hudson Bay.

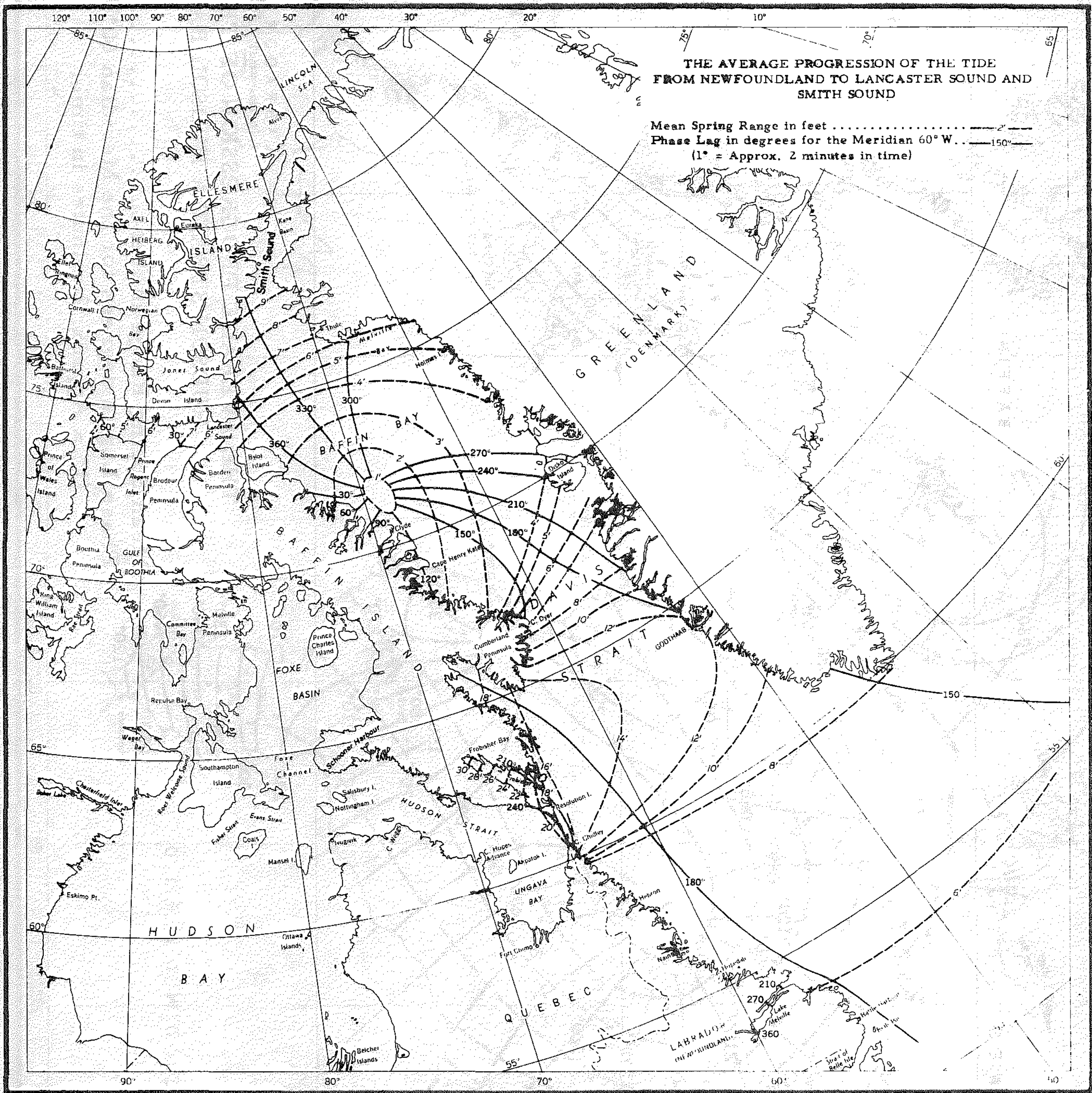


Figure 12. The average progression of the tide from Newfoundland to Lancaster Sound and Smith Sound.

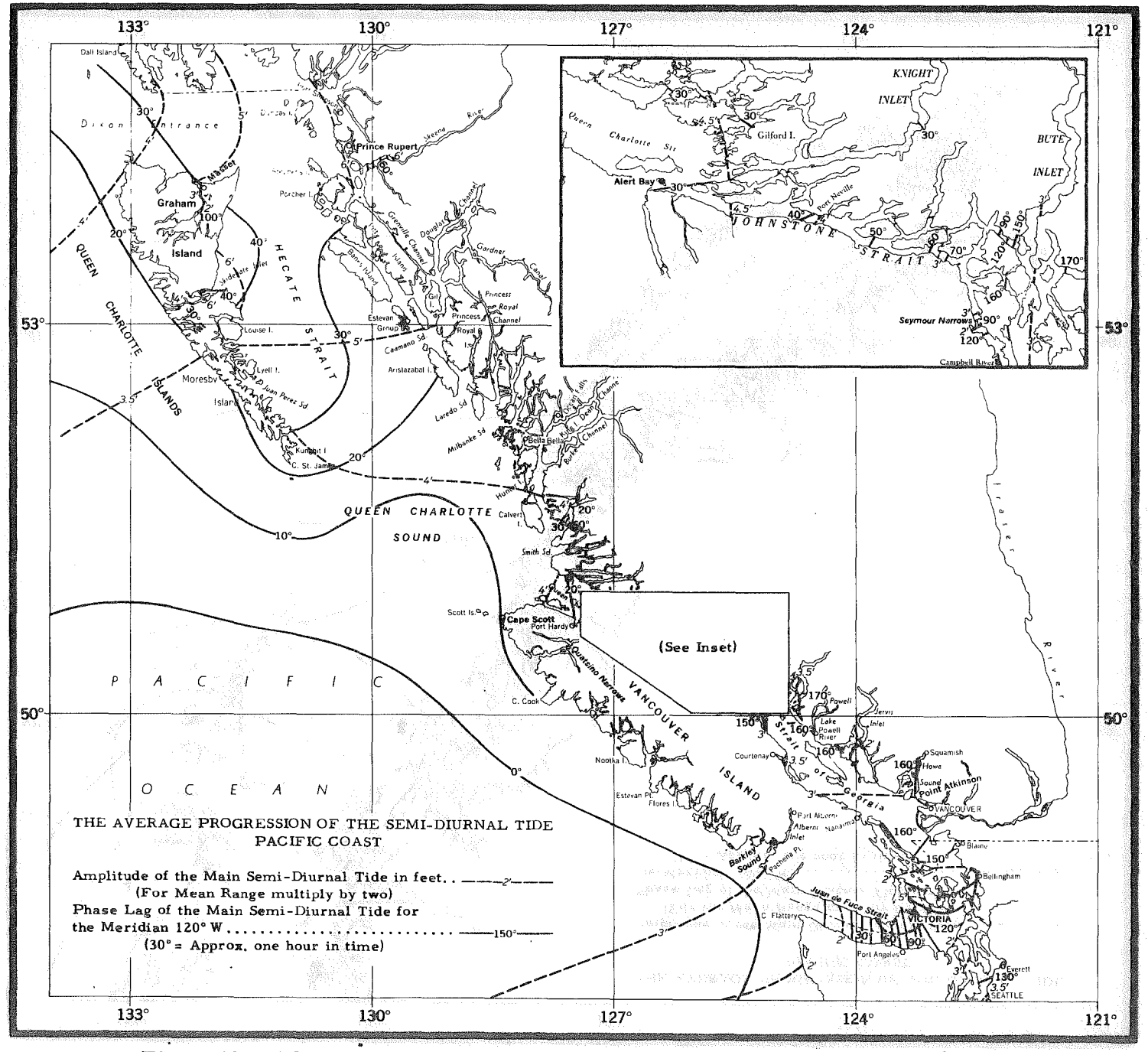


Figure 13. The average progression of the semi-diurnal tide on the Pacific coast.

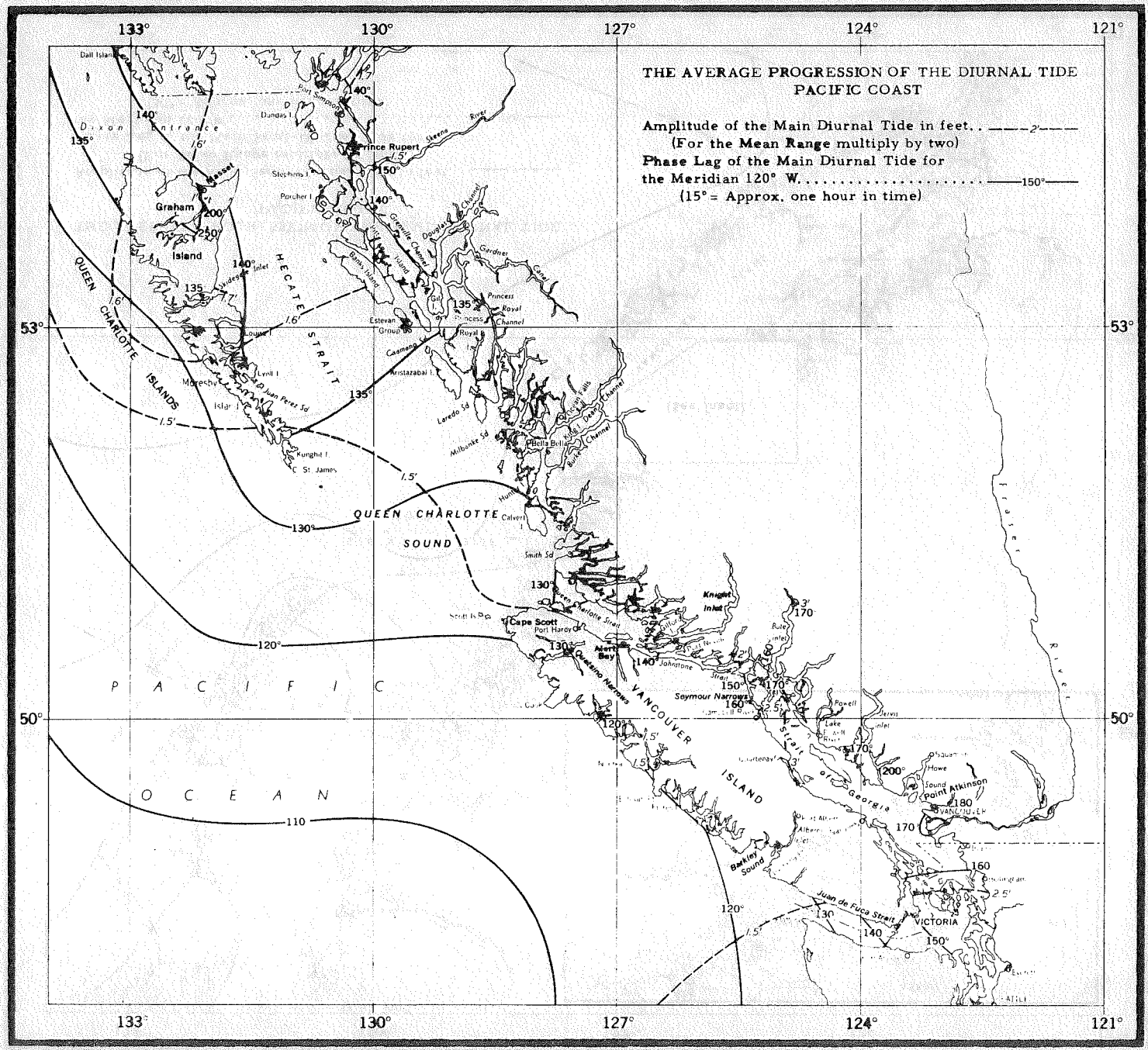


Figure 14. The average progression of the diurnal tide on the Pacific Coast.

TIDAL INSTRUCTIONS FOR CHARTING

The Canadian Hydrographic Service, Department of Mines and Technical Surveys, is the principal collecting agency of Tidal and Inland water level data obtained at permanent and temporary gauging stations. It has the responsibility of processing these records and it will, through the Regional Tides, Currents and Water Levels Sections, provide field officers with any of the following information:

1) Bench Mark descriptions and elevations.

2) The most suitable location for the establishment of tide recording equipment.

3) The most convenient place from which to transfer datum.

4) The most appropriate location for gauges along a non-tidal river and how to transfer datum from place to place along the river, using records obtained at the gauges.

5) The most suitable location for gauges along a tidal river and how to prepare graphs from records obtained at the gauges so that a datum for the river can be established.

If the officer-in-charge of a field survey finds on arrival at the survey area that the proposed locations are impracticable, he should make any changes he considers necessary.

In some cases, when circumstances permit, a field officer may be requested to establish a gauging station beyond his specific survey area so that tidal information and coverage may be extended over a larger area.

If the officer-in-charge of a hydrographic survey has any reason to doubt the reliability of information supplied to him concerning tides and water levels, he should contact the regional officer-in-charge of the Tides, Currents and Water Levels Section.

Hydrographers are invited to discuss verbally or by correspondence, any problem that might arise concerning tides, water levels, bench marks, recording equipment or records with the Tides, Currents and Water Levels Section.

TEMPORARY GAUGING STATIONS

General

Tidal observations should be taken by all surveying parties in areas where sounding is in progress. These observations may be taken by means of an automatic recording tide gauge, or by sight readings of a scale by an observer at frequent intervals. The gauging stations established and operated by the hydrographer in the field are classed as temporary.

Temporary stations include those which are operated over a very limited period of time – the observations in general extend over a period of a few months, and in some cases only a few weeks or days. Temporary stations are established for the purpose of obtaining tidal information for a locality and to obtain specific data for the reduction of soundings in connection with hydrographic surveys. Observations at a temporary station are not always sufficient for precise independent determination of tidal datum planes, but when combined with simultaneous observations at a suitable primary tide station, very satisfactory results are obtained. (NOTE: When practicable, observations at a temporary station should be continued over a period of not less than 29 days).

The two most commonly used tide recorders in the Canadian Hydrographic Service are the OTT and the OTTBORO. Other types of gauges are available but will only be issued on special request or due to a shortage of the regular supply. For the purpose of this manual, only the two most common gauges will be described in detail. Some of the Ott and Ottboro recorders have a slightly different mechanism than that described in this manual, but the general principle remains the same and for that reason, the differences will not be expanded.

Number of Stations Required

In some localities the tide may occur practically simultaneously with near equal range over a large area. In such a case a single tide station will serve the entire area. Differences in the range and time of the tide are frequently found to exist in places comparatively close together, therefore, when soundings have been carried a few miles along the coast, it should be assumed that there may be a change, and if so, another gauge may be required. For surveys of exposed channel approaches, where the depths are near the draft of vessels using the channel and where especially accurate soundings will therefore be required, for reductions of which the record from an inshore or distant tide station is not

sufficiently accurate, a transient station should be established. Several hours of tide observations obtained on a fixed tide staff simultaneous with the inshore or distant station would provide a means for height and time comparison calculations. In straits connecting two bodies of water having tides of different ranges and epochs of occurrence, it usually happens that in portions of the straits the tide varies from place to place. When sounding in such straits, tide stations should be established at frequent intervals, or if sufficient information is available, cotidal charts could be utilized to obtain the required reductions.

Location for Temporary Tide Stations

The selection of a location for a temporary or auxiliary tide station will depend upon the purpose for which it is to be established but existing facilities and the accessibility of the location to an observer must be taken into account. Wharfs, fish stakes or piles, present suitable locations for the establishment of a tide station (Figures 15, 16). When such facilities are not at hand, some means must be provided for the installation of the tide recording equipment. Stone filled cribs, spruce poles and wooden towers have been successfully used for this purpose.

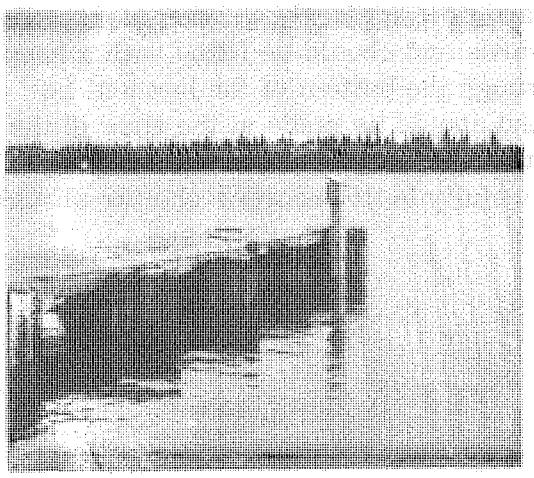


Figure 15. Float type water level recorder installed on a wharf.

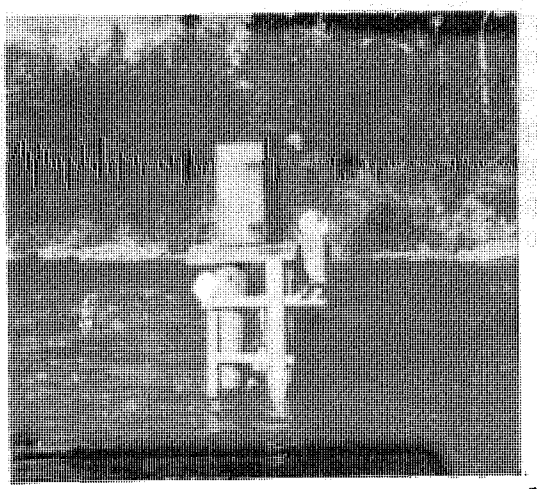


Figure 16. Pressure type water level recorder installed on piles.

Care should be taken to ensure that tide gauges are not set up in positions where the water is impounded near low water. This effect may not be noticeable at neaps and in certain cases, may only occur at extreme springs; impounding is easily noticed on the tide curve record, as the tide does not fall below a certain point and there is an apparent "stand" at low water. It is of the greatest importance to ensure that no impounding is taking place when transferring datum near Springs; the effect of such impounding would be to establish datum too high at the new gauge.

When the site for the gauge has been chosen as a wharf, care should be taken to ensure that the recorder shelter or stilling well will not be an obstruction to boats using the wharf.

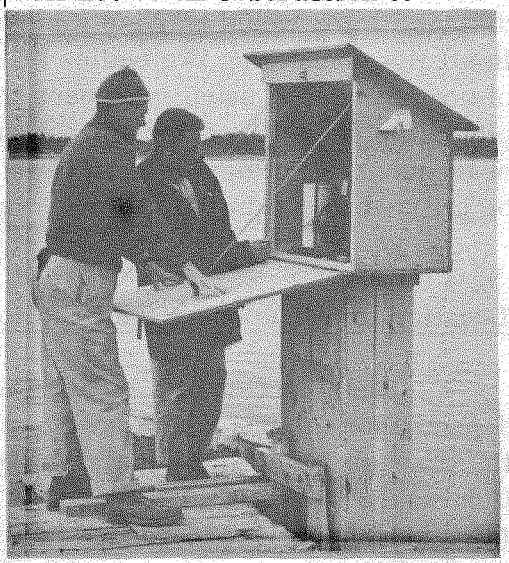


Figure 17. Recorder shelter.

Recorder Shelter

The recorder units, when installed in the field should be protected from the weather and inquisitive persons by a shelter. Both portable gauges issued to the hydrographic field parties are of the same dimensions, that is, 20 inches long, 16 inches high and 10 inches wide. The recorder shelter should be sufficiently large to accommodate the unit and provide storage for spare parts, extra graphs, stationery, instruction forms, etc. It is suggested that the shelter be 30 inches long, 20 inches high and 15 inches wide, with a roof sloped to the rear and overhanging four inches on all sides (Figure 17). If possible it should be built with plywood or dressed tongue and groove lumber and be completely weather tight. The door of the box should be hinged to open downwards and should be fitted with a hasp to accommodate a lock for security. Holes through the bottom of the box will be required for the capillary tube or float wires and should be made at the time of the installation of the equipment. The shelter should be neatly constructed and painted if possible to present a good appearance. A carefully built recorder shelter should provide many seasons of service.

THE TIDE STAFF

General

A tide staff consists of a graduated scale fastened vertically to a wharf or other suitable support from which the height of the tide can be read directly (Figure 18).

The staff used by the hydrographic service is 10 feet long, 8 inches wide and constructed of a plastic material. (This staff replaces the wooden one presently in use by the service). The staff is graduated in tenths of feet and numbered at the foot graduations from "0" to "9". The black block type figures are resting on the exact foot-mark designated by the figure; their tops indicate exactly 0.5 of a foot. Although the staffs are supplied in 10 foot lengths and should be perfectly square across the top and bottom, when two or more staffs are joined, the resultant total length should be checked against a tape. If it is necessary to shorten a staff for any reason, care should be taken to ensure that it is cut square and the exact length of the shortened staff should be checked. When there is no necessity for leaving a tide staff in a survey area after the completion of the survey, it should be removed and stored in a clean condition for future use.

Every tide staff installed should be connected by levels to three bench marks. The only exception to this is when subsidiary staffs are installed, provided that temporary marks are placed to assure that the zero of the staff has not moved during the period of observation. However, even in this case, if the locality presents open rock out-crop or other suitable sites, bench marks should be established if time permits.

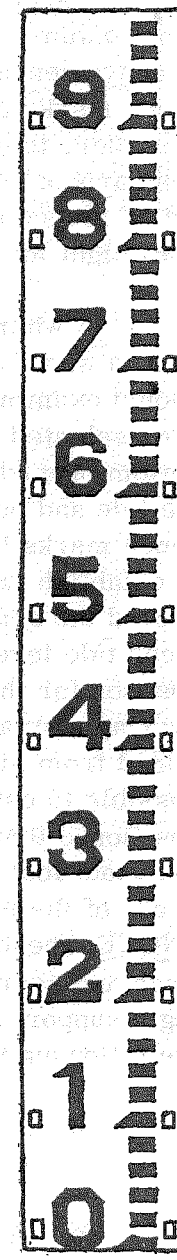


Figure 18. Tide staff.

Tide Staff Location

The selection of a suitable location in which to erect a tide staff is a matter of importance. It is obvious that, if possible, the zero of the staff should be below chart datum. In selecting the site for the tide staff, consideration should be given to convenience in taking water level readings and for levelling between the staff and bench marks ashore. If the staff is used in conjunction with an automatic tide recorder, they should be placed reasonably close together to provide accurate comparison readings between them, but, the staff and a float type recorder should not be placed on the same wharf piling, stone filled crib, stake or other structure that might move.

A wharf usually provides the most satisfactory position for the tide staff but when a wharf or other structure is not available for the installation, the hydrographer should examine the survey area thoroughly at low tide for a suitable location. The area selected should, if possible, be sheltered from storms, have a fairly level bottom of mud, sand or clay, be adjacent to the sounding area, yet be fully open to the tide and be relatively close to shore so that the zero of the staff can be tied to bench marks by levelling. When the range of the tide is great, it is often convenient to establish two tide staffs, one further seaward than the other; the seaward staff to record the readings between low and mean tide level, and the other to record between mean tide level and high water. This is particularly the case when the only available position for the staff is off a shelving beach. When two staffs are used, they must overlap a small amount in the vertical plane and there relative levels must be determined from simultaneous readings of the water level on both staffs. It might be possible to establish both staffs by levelling and if so, it is suggested that they be so positioned that an exact foot division of the outer staff be at the same elevation as the exact foot division of the inner staff. The ideal situation would be to have the zero of the inner staff at the same elevation as the top of the outer staff. (NOTE: The location of the seaward staff should be marked by a small buoy). Each and every survey will have different problems to be overcome when constructing a support for a tide staff when no wharf or other structure is available, therefore the following types of support are presented as a guide:

a) A stone filled crib with length and width dimension considerably greater than height.

b) A wooden tripod with ends pointed for penetration into the sea bed and some means of anchorage fitted to the legs.

c) A single wooden stake or pole driven into the bottom and fitted with wire guys to anchors.

Installation of the Tide Staff

Before establishing the tide staff in any location it should be fastened to a supporting timber with brass screws. Care must be taken to secure the staff in a vertical position, therefore it is suggested that a carpenter's level be used when plumbing the staff. The staff should be placed so that the graduations are clearly visible to the tide observer from an easily accessible position. Special attention should be given to placing it so that its elevation may be conveniently checked by levelling to bench marks, therefore there should be sufficient clearance above the staff to hold a levelling rod in a vertical position with its base on the top of the tide staff. Although a staff may be so located that it can be sighted upon directly from a level set up on the shore, this is not recommended because the tide staff is only graduated to 0.1 foot and there would be some difficulty in estimating readings to better than 0.02 feet. Sometimes it is advantageous to position a support for a levelling rod at any even foot division of the staff and level to a rod held on this support.

At the time of the original installation the exact elevation of the zero of the staff is usually unimportant, except that the zero be placed sufficiently low to prevent negative readings. After establishment by levels it is very important that the zero of the staff be maintained at a fixed elevation. Periodic checks should be made to ascertain whether there has been any displacement of the staff.

Where it is impossible to establish and maintain a tide staff for water level comparison readings, due to the nature of the foreshore or because of adverse natural elements such as ice, heavy seas or strong currents, some other means of checking the height readings must be used. Three suggested methods of checking the readings are:

1) Water level comparison readings can be obtained by levelling from an established bench mark to a level rod held at the water's edge. As the tide rises, the difference in elevation from bench mark to water's edge will decrease by the same amount as the gauge reading increases, and vice versa on falling tide.

2) Painted marks on a rocky foreshore, established by levelling, usually at half foot intervals would serve as a substitute tide staff. It is obvious that this method will provide an approximate check only.

3) An expansion of method 1 would be to set up a form of level in a permanent position and sight to a tide staff held at the water's edge (Figure 19). This level could consist of a level board approximately four feet long nailed to a tree, or a tripod constructed of 2 x 3 lumber and firmly anchored could be used to support the

board. In the example shown in figure 19, the staff reading plus gauge reading should always equal 14. 10 feet.

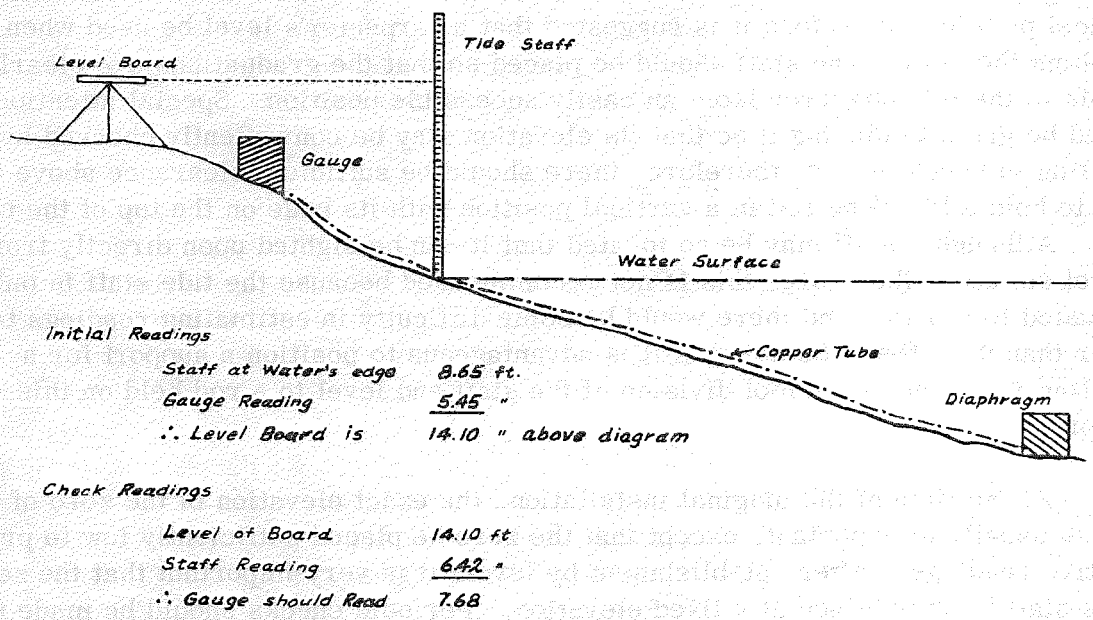


Figure 19. Checking the height readings on an automatic recorder by the "Level Board" method.

THE OTT XX STRIP CHART WATER LEVEL RECORDER

General

The Ott XX strip chart water level recorder, hereafter referred to as the Ott tide gauge or Ott, is a portable, float type tide gauge issued to hydrographic field parties (Figure 22).

The rise and fall of the tide is transmitted to the recorder by the action of a float, which is protected from the action of wind and waves by a stilling or float well. The float is attached to a wire which passes around a wheel on the recorder and is maintained at a constant tension by a counterweight. The vertical movement of the float, transferred through the float wheel, is reduced in scale by means of gearing and is finally communicated to a pen which traces this movement in the form of a curve on the clock-driven recording paper.

The Stilling Well

The float type recorder requires, in addition to the shelter, a stilling or float well. The well should be constructed of 1 x 12 planks, nailed together so that the internal measurements of the well are 12 x 10 inches. Planks the full length of the well should be used if possible. If this length is not available, shorter planks may be butt jointed, as long as the joints in adjacent planks are staggered. Horizontal cross braces can be added as required. The well should be long enough to reach from the floor of the recorder shelter to several feet below the lowest tide. No nails or other obstructions should extend into the inside of the box. Circumstances will dictate the number, position and type of mounting brackets required and these should, if possible, be fitted to the well at the time of construction. When the depth of the water is not too great, lengths of 2 x 4 could be fitted to extend below the well and into the sea bed as an additional support. A float wire inspection hatch, with an opening sufficiently large to permit the float to pass through, should be installed on one side and near the top of the well to allow access to the wires. A sloping bottom with an intake in one of the lower corners should be provided. The intake should be of sufficient size to permit free access of the tide while dampening down heavy seas. It should be large enough so that rough water on the outside will leave an unmistakable trace upon the graph. A single intake is more desirable than several smaller ones. The recommended size of intake for use with the "Ott" recorder is 1 inch diameter. Special care must be taken to keep the intake to the float well open, as even a partial clogging may create a lag in both time and height of the tide. When

considerable silting might take place, facilities should be provided for periodic cleaning of the intake. When sufficient depth is available, the well should be installed with the intake several feet below the lowest probable tide. It is desirable however, that there be sufficient water below the intake to make it unlikely that it will become covered by a shoaling of the water in the vicinity. Care must be taken to install the well truly vertical so that the float and counterweight will rise and fall freely without touching the sides of the well. When a wharf or similar structure is not available for the installation of the stilling well and recorder, it will be necessary to construct some other suitable support for the equipment. Each survey will have separate problems to overcome but the prime requirements of the installation of the support are: (a) it should be relatively free of vertical or horizontal movement; (b) it should be in sufficient water to read the low tides; (c) it should be sheltered from storms and (d) it should be adjacent to the sounding area.

The Float and Counterweight

The float supplied with the Ott recorder is a metal cylinder 8 inches long by 4 1/2 inches diameter, marked with a short horizontal line about 2 1/2 inches from the top. When the float is connected to the counterweight it should sink to this mark. The float is usually issued ready for use, that is, already filled with lead shot, but it is recommended that the float be tested in the field and adjusted if necessary by adding or removing lead shot or sand. The counterweight supplied is a lead rod 9 inches long by 3/4 inch diameter, weighing 18 ounces.

The Float Wheels

Although the reversing spindle mechanism employed on the Ott will permit the gauge to record tides of any magnitude, in actual practise it is preferred to limit the tide range recordings to the width of the paper supplied and for this reason the gauge is issued with two float wheels. The smaller 4 inch diameter wheel, stamped 1:12 is for a range of 0 to 10 feet, the larger 8 inch diameter wheel, stamped 1:24 is used for a range of 0 to 20 feet. The approximate tidal range for the area in which the gauge will be used should be ascertained and the relative float wheel fitted to the recorder before the gauge is installed. When changing the float wheel, care should be taken to be certain that the lock spring washer is between the float wheel and the bearing cover bushing. If these parts are not assembled in the proper sequence, slippage of the float wheel could result.

The Reversing Spindle

The float can be connected at either the front or rear of the recorder – but the pen must travel from LEFT TO RIGHT WHEN THE FLOAT COMES UP. There is one exception to this rule. When the tidal range exceeds the range of the graph, the reversing action of the spindle occurs (Figure 20). Example – if the gauge was set for a 10 foot range and the tide continued to rise to 11 1/2 feet, the recording head with pen assembly would move from left to right (normal action) to the 10 foot line or far right edge of the paper, where the reversing action would take place. Although the float continues to rise, the pen will move from right to left (backward to the normal movement) for 1 1/2 feet or to the 8 1/2 foot line. When the tide changes, the pen will move from left to right (backward to the normal movement) to the 10 foot line where a righting action will take place and the pen will record from right to left for a falling tide (normal action). A similar arrangement is provided for the low water recordings. Care must be taken when scaling such abnormal tide readings.

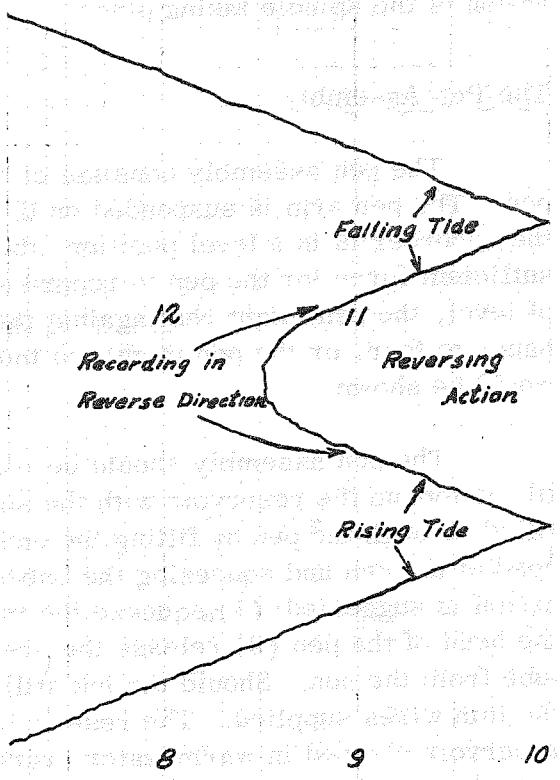


Figure 20. Reversing action of the spindle.

The Recording Head

The recording head of the gauge is moved in a horizontal direction by a spring loaded pin engaging in the endless groove of the reversing spindle. It is possible for this pin to be moved out of synchronization, therefore it should be examined to ensure that the recording head moves from left to right when the float moves up. Should it be found that the head moves in the wrong direction, the spring loaded pin should be disengaged, the recording head moved manually in either a right or left direction for a short distance to a neutral position and the float wheel turned in a counter-clockwise direction. This action should cause the pin to engage properly and the pen to move in the desired direction. On the inside of the case and at the extreme right end of the reversing spindle, a pen zeroing adjustment is incorporated and has been locked in position, therefore the hydrographer is instructed to not move the locking ring. To set the pen to some desired height on the graph, it is only necessary to slip the float wire over the float wheel until the pen reaches the required position. In actual practise the setting of the pen in an

exact relationship to the tide staff zero is unimportant, but it is desirable that the tidal movements be recorded within the width of the graph without the reversing action of the spindle taking place.

The Pen Assembly

The pen assembly consists of the pen arm, ink reservoir and glass capillary pen. The pen arm is suspended on the recording head in such a manner that when the recorder is in a level position the pen will bear against the paper with just sufficient force for the pen to record efficiently. If the recorder is positioned out of level, the pen might rest against the paper with too much force and cause the paper to tear, or the pen might not touch the paper and subsequently no recording would be shown.

The pen assembly should be removed from the spindle when it is necessary to fill or top-up the reservoir with the special ink supplied. The reservoir should be filled through the pen by fitting the end of the filling tube of the ink bottle over the head of the pen and squeezing the bottle. Should the ink fail to flow, the following action is suggested: (1) squeeze the ink bottle slightly (2) fit the filler tube over the head of the pen (3) release the pressure on the bottle (4) remove the filler tube from the pen. Should the ink still fail to flow, the pen should be cleaned with the thin wires supplied. The reservoir should be topped-up weekly and the pen and reservoir cleaned in warm water every three months or more often if the ink coagulates. A holder for the pen arm is located on the inside of the gauge door for use whenever the arm is removed from the spindle.

The Recording Paper

The recording paper for the "Ott" is supplied in rolls 35 feet long by 10. 6 inches wide. Both edges of the paper are perforated to fit over the drive sprockets. The dashed lines running down the length of the paper, serve no specific purpose when the paper is used with the Ott recorder. The hourly time intervals printed along the left edge of the paper are synchronized to a paper speed of 10 mm/h. At this paper speed one roll of paper should run for approximately 40 days under normal operating circumstances. A paper length indicator, in the form of a heavy diagonal line running from right to left, appears on the graph when 11 days' supply of paper remains on the roll.

The Paper Drive

The paper is driven by a hand-wound clock mechanism. Although the clock will operate for 28 days when fully wound, it is preferable that it be wound regularly once a week. The clock is provided with a "positive-stop" which prevents over-winding but the mechanism feels tight even when the clock is run down, so it should be wound until a definite resistance is felt. The "Start-Stop" lever for the clockwork

is situated near the lower right corner of the recorder, and should be in the "UP" position for the clock to operate. The sound of the clock operating can be heard when it is going. The regulator for the clock is of the "Advance-Retard" type, that is, if the clock is operating slow, the regulator should be moved in the direction of the letter "A" and vice versa. The regulator should be moved only a small amount to ensure that the error is not increased in the opposite direction. The selection lever for the two paper speeds 20-10 mm/h is situated midway on the left side of the recorder. It is possible for this lever to be moved to a neutral position during transit, therefore it should be inspected for proper gear mesh when the recorder is installed. The recommended paper speed for normal use in the field is 10 mm/h.

Lubrication

Normally no lubrication of the recorder is required by the field officer but should the grooves of the reversing spindle become dirty, it will be necessary to remove the spindle and clean the grooves. Varsol or equivalent should be used – DO NOT USE gasoline, alcohol or carbon tetrachloride.

Installation of the Gauge

It is assumed that a suitable location for the gauge has been selected, that the float well is installed, the shelter for the recorder has been constructed, the proper float wheel is on the recorder, and that the float has been checked for required ballast.

(1) Check to be certain that the top of the stilling well is level and modify if necessary.

(2) Position the shelter on top of the well but do not secure it in place.

(3) Position the recorder in the shelter and mark the location for the float wire openings.

(4) After removing the recorder and shelter from the well, cut the opening for the float wires. A slot 1/2 inch wide by 8 inches long or two holes at least one inch in diameter are suitable and will allow sufficient adjustment when finally positioning the recorder. If a 1/2 inch space has been left between the floor boards of the shelter, there is no need for drilling or cutting any holes.

(5) Remove the float wire inspection hatch from the stilling well.

(6) Replace the shelter on top of the well, and the recorder in the shelter.

(7) Pass an end of the float wire down through the slot in the bottom of the shelter and fasten the counterweight. It is suggested that the wire be brought through the inspection hatch and that the counterweight be fastened while it is outside of the well.

(8) Lower the counterweight to the bottom of the well then cut off an extra 5 feet of wire from where it passes through the floor of the shelter.

NOTE: Keep the wire taut to prevent kinking.

(9) Pass the free end of the wire, from front to rear, over the float wheel pulley, roller of adjusting arm and back through the opening in the floor of the shelter.

(10) Fasten the float at approximately 20 inches from the bottom of the shelter – the float should be at the back of the instrument. Again it is suggested that this be done while the float is outside of the well.

(11) Lower the float to the water by slipping the wire over the float wheel.

(12) Check to be certain that the float and counterweight will move freely in the stilling well. The position for the wire can be adjusted by the positioning arm if required.

(13) Secure the shelter in position with screw nails, and secure the recorder in a level position with the special bolts provided.

(14) Secure the float wire inspection hatch.

The recorder is now ready to be loaded with chart paper and set into operation.

Loading the Chart Paper in the Recorder

It is assumed that the recorder is installed in its shelter, the door is open and the pen is not in position on the recording head.

(1) Depress the platen retaining catches which will permit the platen and roll chart axle assembly to swing forward.

(2) Press the roll chart axle retaining spring clips forward, and remove the axle.

(3) Slip the roll chart axle through the chart roll from left to right, with the paper discharging with printed side up.

(4) Replace the roll chart axle complete with paper into position. The end plate of the axle must be on the left.

(5) Roll off approximately 9 inches of the graph.

(6) Lift the platen back into position over the retaining catches. A definite "click" will be heard when the catches engage.

(7) Raise the paper guide strips at both sides of the platen.

(8) Secure the end of the graph to the take-up spool with the metal clip or masking tape. Be certain that the printed side of the paper is exposed when it rolls on the take-up spool.

(9) Wind up any excess paper by turning either end of the take-up spool, making certain that the paper is fitting properly.

(10) Make certain that the hourly division lines on the graph are truly horizontal, and that the sprockets of the paper drive are engaged in the perforations at both edges of the paper.

(11) Close the paper guide strips on the platen.

NOTE: The above instructions also apply to the Ottboro recorder.

Setting the Recorder for Operation

It is assumed that the recorder is secured in position with the proper float wheel installed, the doors of the shelter and recorder are open, the correct paper speed is set and the clock is operating.

(1) Load the chart paper in the recorder.

(2) Fill the pen and install it on the recording head.

(3) Check to be certain that when the float rises, the recording head moves from left to right. Adjust it necessary.

(4) Set the chart to the true time by turning the graph advancing knob in a counter-clockwise direction. (To compensate for a play in the paper drive gearage, the diagram time should be set 10 minutes ahead of the desired time).

(5) By slipping the float wire over the float wheel, set the recorder at the desired height. (If there is reason to suspect that the tide will fall below datum, the zero of the graph should be considered to be at the one-foot mark or higher).

(6) After the play in the paper drive has been taken up, read and record the diagram time and true time on the comparison form.

(7) Read the tide staff and diagram and record the heights on the comparison form.

(8) Complete the comparison form records for wind and sea conditions.

(9) Close and secure the recorder and shelter.

NOTE: Operations 6 and 7 should be performed with very little time lapse.

Removing lengths of Graph

It is assumed that the door of the recorder is open, the graph has been read and the comparison form completed.

(1) Remove the pen assembly and place it on the bracket provided on the recorder door.

(2) Roll down the graph by turning the graph advancing knob in a counter-clockwise direction until the records are well clear of the platen.

(3) Cut off the paper, between the platen and take-up spool, with a knife or sharp pencil. DO NOT CUT ON THE PLATEN.

(4) Lift the take-up spool retaining catches and remove the take-up spool complete with paper.

(5) Remove the milled cap on the right-hand end of the take-up spool and slide the record off the spool. The small metal paper retaining clip must be retrieved for re-use.

(6) Replace the milled cap on the spool, then replace the take-up spool and secure the retaining catches.
Be certain that the drive gear is to the left.

NOTE: For further reloading instructions continue with instruction number (8) under the section on "Loading the chart paper in the recorder".

Daily Inspection of Recorder

The recorder should be inspected at least once a day when sounding operations are in progress and the following program carried out:

(1) Record diagram number, week day and date in columns 1, 2 and 3 of the comparison form (Figure 45).

(2) Make a short horizontal mark on the graph by moving the float wheel slightly, simultaneously noting the true time. Record diagram time, true time and any clock error in columns 4, 5 and 6 of the comparison form.

(3) Read the height on the tide staff and diagram, simultaneously noting true time. Record these observations in columns 7, 9 and 10 of the comparison form.

(4) Record the difference of wharf scale and diagram height in column 11.

(5) Complete the comparison form for wind and sea conditions. (A copy of the Beaufort Scale is available on the reverse side of the comparison form).

(6) Record the date and true time near the horizontal line on the graph (Figure 21).

(7) If the clock error is greater than 5 minutes, make the necessary adjustment on the clock regulator.

(8) Close and secure the shelter door.

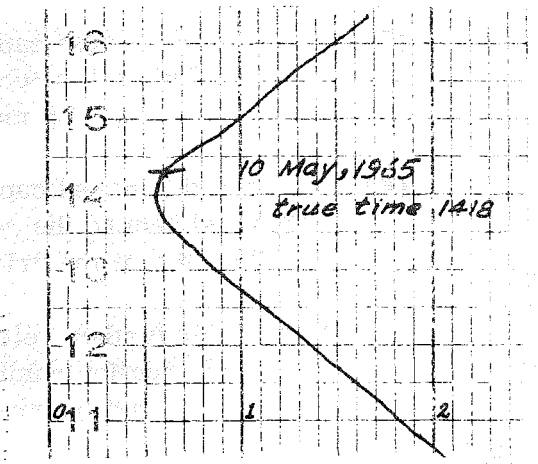


Figure 21. Daily comparison note on graph.

Weekly Inspection of Recorder

Similar to the daily inspection with the following additions:

(1) Wind clock.

(2) Top-up ink reservoir.

Trouble Shooting

(1) If the tide graph is flattened at the top or bottom, the float wire or stilling well might be too short.

(2) If the tide graph flattens only at the low tide, the gauge may be impounded.

(3) Jerky records might indicate kinks in the wire, or that the sides of the stilling well have opened up, or the float or counterweight is touching the side of the well.

(4) A variance in the height differences between the recorder and tide staff might indicate that the float wheel is slipping, or that the elevation of the staff is changing. This variance could also be caused by a partially clogged intake to the stilling well, creating a lag in both time and the height of the tide.

(5) No height record might indicate either a broken float wire, a loose float wheel or broken recorder head drive pin.

(6) No time record would indicate a stopped clock, disengagement of paper drive gears or disengagement of paper drive sprockets from the paper.

(7) Variance in true time and recorder time would indicate a faulty clock or that the clock is out of adjustment. It could also be caused by the paper being improperly aligned on the drive sprockets.

(8) A straight line instead of a curve might indicate that the float wire and counterweight wire have been tangled together.

Equipment Supplied

Each recorder will normally be supplied with:

(a) Clock keys (2)

(b) Capillary pens (4)

(c) Bottles of ink (1)

(d) Chart roll clips (2)

(e) Float wire (1 roll)

(f) Float (1)

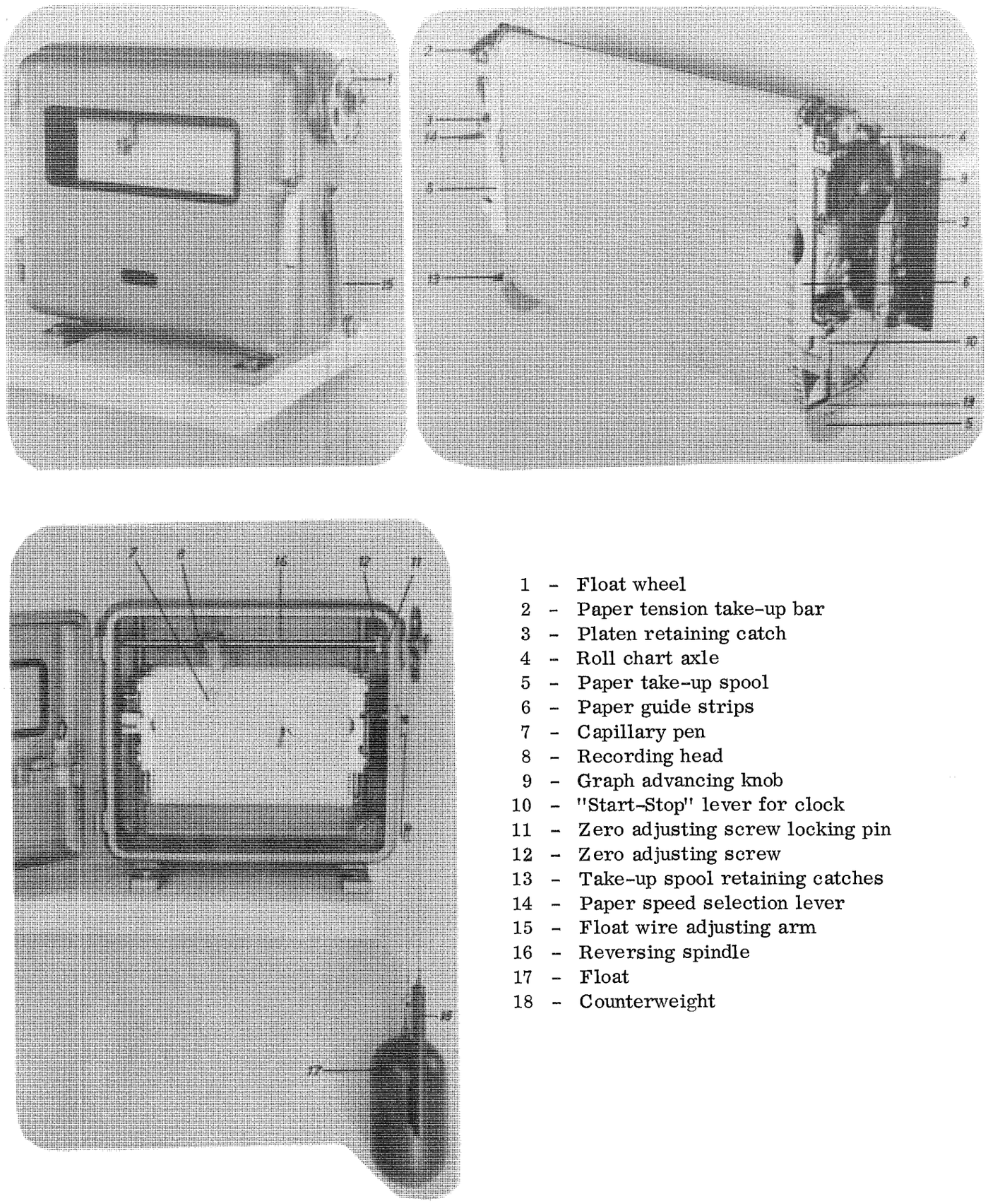
(g) Counterweight (1)

(h) Recorder securing and levelling bolts (4)

(i) Sufficient quantity of chart rolls, forms, etc.

(j) Pen cleaning wires

NOTE: In special cases, additional spare parts may be issued if required.



1 - Float wheel
2 - Paper tension take-up bar
3 - Platen retaining catch
4 - Roll chart axle
5 - Paper take-up spool
6 - Paper guide strips
7 - Capillary pen
8 - Recording head
9 - Graph advancing knob
10 - "Start-Stop" lever for clock
11 - Zero adjusting screw locking pin
12 - Zero adjusting screw
13 - Take-up spool retaining catches
14 - Paper speed selection lever
15 - Float wire adjusting arm
16 - Reversing spindle
17 - Float
18 - Counterweight

Figure 22. Ott float type water level recorder.

THE OTTBORO WATER LEVEL RECORDER

General

The "Ottboro" is a portable, pressure type water level recorder issued to hydrographic field parties (Figure 26).

The pressure at any fixed point below the surface of the sea is proportional to the height of the water above the point; the changes in pressure as the surface rises and falls consequently provides a means of measuring the range of the tide or water level.

In the pressure type gauge, the vertical movement of the water level is recorded by a change of pressure actuating a submerged rubber diaphragm joined by capillary tubing to a pressure-sensitive element. This element is connected by linkage to a pen assembly which traces the vertical oscillations of the water level in the form of a curve on the clock-driven recording paper.

The Ottboro gauge was developed by the Tides, Currents and Water Levels Section by combining the pressure assembly and pen mechanism of the Foxboro gauge with the paper drive and casing of the Ott. The gauge was developed primarily for use by hydrographic field parties for areas where the coastal formation is such that the establishment of a float gauge would be difficult or impossible and costly in time and labour.

The gauge consists of a diaphragm assembly, capillary tubing, pressure elements, a pen assembly and paper drive mechanism. NOTE: As the "Ottboro" utilizes the paper drive mechanism of the Ott gauge, and the instructions for loading the chart paper in the recorder are the same as for the Ott, these subjects will be omitted in this section and the operator is referred to the previous chapter.

The Diaphragm Assembly - (Figure 23)

The diaphragm box is a two section brass cylinder 5 inches in diameter by 3 1/2 inches in height. An adjustable opening is provided in the lower section; in areas of considerable marine traffic or heavy wave action and where silting is not present, the opening should be set at minimum, but where an appreciable amount of silting is liable to occur, the opening should be set at maximum. A synthetic rubber diaphragm sits in the lower section of the box with its edges firmly clamped between the flanges of the upper and lower sections to provide an airtight seal. The upper

section of the box houses one end of the capillary tubing which is protected against damage by a flexible sheath. The diaphragm box is mounted on a wooden bracket for installation at the selected site.

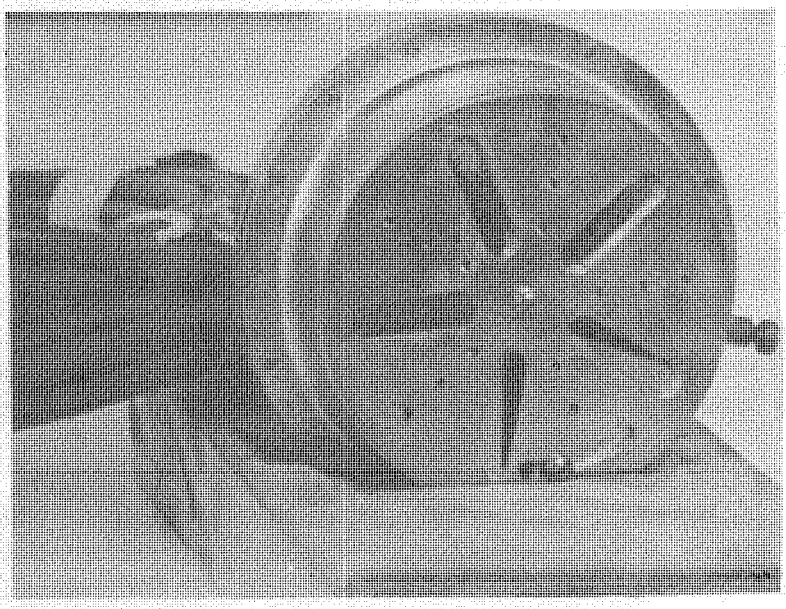


Figure 23. The diaphragm assembly.

The underwater unit should not be immersed in water until the capillary tubing is connected to the recorder element and all connections are tightened.

The Capillary Tubing

The diaphragm assembly is issued with 100 feet of attached capillary tubing which joins to the pressure element in the recorder or to additional lengths of tubing if required. The connection between the tubing and pressure element, or between lengths of tubing, is made by a union joint which encloses a rubber washer to make the joint completely air-tight.

To prevent damage to the solder joint between the tubing and union, two wrenches should be used when making the connections, one on the nut and the other across the flats of the union. The connection should be made taut but not overly tight; if the joints are connected too tight, the rubber washer will be flattened and consequently the air passage will be restricted or completely blocked off. The joints in the tubing are the most likely places at which leakage of air might occur so they should be inspected after an interval of 30 minutes, and again if feasible, 24 hours from the time of original connection. If, for any reason, air escapes from the system after the guage has been installed, any increase of pressure on the rubber diaphragm will cause it to move inwards and expel air until the diaphragm becomes inverted. When this occurs the air in the system will be at barometric pressure and the recorder will not register.

The capillary tubing is supplied in lengths of 100 feet, available with either . 080 or . 040 inch internal diameter. The . 080 inch diameter tubing should be used wherever possible because it provides a much better response when the water level changes rapidly. The final choice is determined by the range of the tide and length of tubing required (Figure 24). The . 040 inch diameter tubing is available only on special request and is marked by red paint, and the number 4 stamped on the union nut.

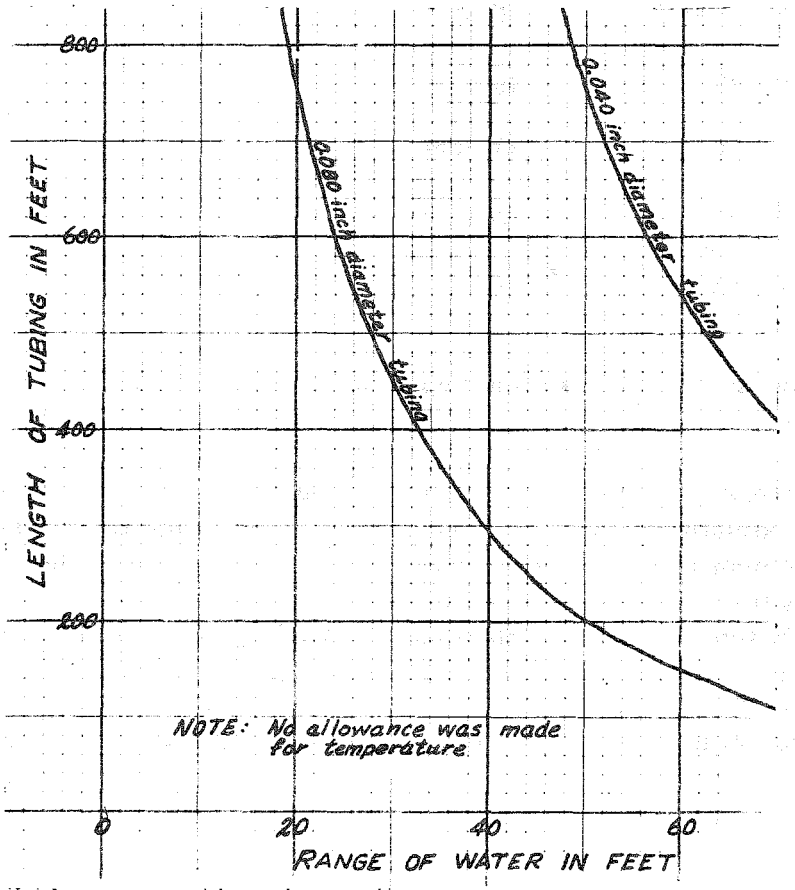


Figure 24. Maximum tubing length curve for water level gauges.

A certain amount of care should be taken when handling the tubing; it should never be kinked, no sharp turns should be used, metal cleats of proper size should be used for securing it during installation, it should be protected from traffic and it should not be used to lift or lower the diaphragm box. The tubing should be installed out of the direct rays of the sun as much as possible, therefore when it is necessary to have the tubing run across a drying foreshore, it should be covered or buried if practicable.

The Pressure Elements

Two bellows type pressure elements are fitted in each recorder to provide a two range selection. (In special cases the recorder may only be fitted with one pressure element). The two union connections for the elements are on the left side

of the recorder, and are so positioned that the upper one is always for the element of the higher range. To assist in making the correct connections, each union is colour coded to correspond with the colour code used on the pressure elements as listed below:

Range	Colour
0 - 10 feet	Black
0 - 20 "	Red
0 - 30 "	Orange
0 - 40 "	Yellow
0 - 50 "	White

The plastic union protection caps, supplied with the recorder, should always be retained and placed over the union whenever the capillary tubing is disconnected.

Each pressure element has been calibrated to within two percent of its range, therefore no adjustment to an element is necessary in the field. The possibility of a pressure element failing to operate properly is very remote, but if it should happen, the hydrographer is advised to use the second element on the recorder, and to order a complete recorder replacement. Although over-range protection is provided on each pressure element, that is, the pen will travel a small distance beyond the specified range, care should be taken to ensure that this does not happen as the gauge is calibrated only for the specified range. Should the range of an element be over-run, beyond the safety factor, the records would appear as a straight line and would not be the true height of the water level.

Pen Assembly and Linkage - (Figure 25)

The short movement of the bellows in the pressure element, caused by a change of pressure on the diaphragm, is expanded by linkage to the pen assembly. Two linkage arms are supplied with each recorder, one for each pressure element fitted and are correspondingly adjusted and colour coded to match an element. The pen assembly is provided with a height adjustment of approximately three inches of paper width. This adjustment is made by turning a slotted brass micrometer screw, situated on the pen drive shaft bracket where the linkage arm connects. This pen zeroing adjustment is the only adjustment required in the field. The pen assembly has compound shafting and a cam arrangement to convert an arcing movement into a straight line. The linkage arm clips at one end to the pressure element drive arm and at the other end to the pen drive arm. The arms have multiple holes but only the holes not painted are to be used. Only one arm is to be connected at a time, therefore a storage clip for the extra arm is provided on the door of the recorder.

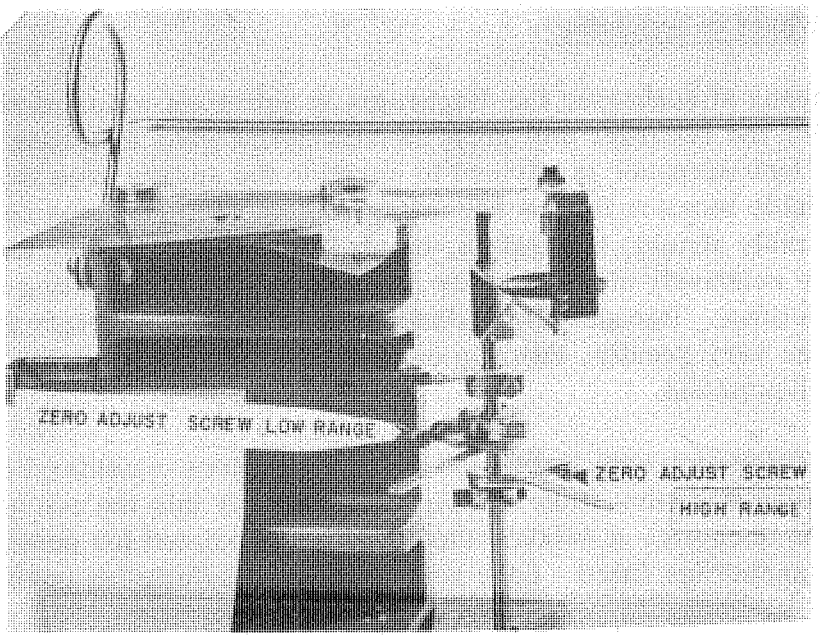


Figure 25. Plan view of the linkage mechanism.

The pen and ink reservoir is supplied as a single unit, and should be fitted in the lower of the two holes in the pen arm. A lifting arm for the pen is fitted so that the pen may be raised clear of the paper when changing or removing sections of the graph. Only the special ink supplied should be used, as any other ink will not flow freely through the small opening of the pen. It is recommended that the pen and reservoir be cleaned at least once a month.

The Recording Paper

The recording paper for the "Ottboro" is identical to the paper used for the "Ott" recorder (See Page 32). The Ottboro utilizes only the 5 inch section of paper which lies between the two dashed lines, therefore the dashed line on the left can be considered to be the graph zero.

Lubrication

No lubrication is required by the field officer. Should a recorder be required for an area of below freezing temperature it will be "winterized" with special lubrication.

Installation of the Gauge

Although the "Ottboro" was designed primarily for areas where it would be impractical to install a float type tide recorder, the "Ottboro" can be readily established on a wharf or other permanent structure. It is expected that nearly all temporary guaging stations will use the pressure type recorder in the future.

(A) When No Wharf is Available

Some means of anchoring the diaphragm in sufficient water to record the tides and a location for the recorder unit must be considered when installing the instrument. The hydrographer is advised to examine the survey area thoroughly at low water for a suitable location for the recording equipment. The area selected for the diaphragm assembly should, if possible, be sheltered from storms, have a fairly level bottom, be relatively close to shore, be adjacent to the sounding area and be fully open to the tides. Because the distance between the diaphragm and the recorder unit can vary greatly, there is considerable leeway available when selecting the site for the equipment.

A stone filled crib with length and width dimensions considerably greater than height - a single wooden stake or pole driven firmly into the sea bed and fitted with wire guys to anchors - a wooden tripod with ends pointed for penetration and some means of anchorage fitted - have been used successfully for positioning the diaphragm.

If the distance between the diaphragm and the shore is within the limits of the length of tubing available, a suitable location for the recorder unit should be established on shore. If the location of the diaphragm is not sufficiently close to shore, a wooden tower for the recorder must be constructed and anchored in open water. The recorder is sensitive to vibration, therefore a stable platform should be built for the unit.

Before installing the gauge, the tidal range for the area should be ascertained and the recorder set for that range. Where chart datum is known, relative to a local bench mark, the height of sea level should be determined by levelling prior to placing the diaphragm box into position. The diaphragm box should then be secured in a depth of water at least one or two feet below datum; this will prevent any loss of records should the tide fall below datum. If chart datum is unknown, then the best time for positioning the diaphragm box is about three hours before or after high or low water, when the sea is near its mean level (semi-diurnal tides). The diaphragm should then be placed in such a depth of water that the pen on the recorder is near the middle of the height scale on the diagram. NOTE: The tide staff is usually established simultaneously with or prior to the tide gauge, therefore the water level readings on the staff provide a ready reference when positioning the diaphragm.

For the purpose of illustration let it be assumed that: the location for the diaphragm box and recorder has been selected, the recorder is secured in a level position in a shelter, a stone filled crib has been constructed for the diaphragm box and that a tide staff has been established in the immediate vicinity. Then the procedure for installing the gauge is as follows:

(1) Uncoil the capillary tubing and lay it flat to prevent any kinks from forming.

(2) Set the choke on the diaphragm box at a suitable opening. (For instructions on setting the choke see the section on "The Diaphragm Assembly", page 41).

(3) Secure the mounting bracket of the diaphragm box to the stone filled crib with brass screws. The opening of the diaphragm box should face downwards and be fastened so that its final position will be 3 to 6 inches from the sea bed. In areas where silting or marine growth might interfere, this distance should be increased.

(4) Connect the lengths of tubing together and the final end to the recorder. (For connecting instructions see the section on "The Capillary Tubing", page 42).

(5) Transport the crib, complete with diaphragm head in position, to its selected site and lower it to the sea bed with a length of attached rope. Do not permit any sharp turns or kinks to develop in the capillary tubing during this operation.

(6) If possible, cover or bury any tubing that would be exposed. Any surplus tubing should be lightly coiled and lashed under the recorder shelter out of the direct rays of the sun.

(7) The position of the crib and diaphragm should be marked with a buoy.

The recorder is now ready to be loaded with chart paper and set into operation.

NOTE: The installation should be inspected after an interval of 30 minutes and again after 24 hours.

(B) When a Wharf is Available

When a wharf is available at the proposed gauge location, the steps outlined in the previous section should be followed, except that instead of using a stone filled crib, the mounting bracket of the diaphragm box is secured to a length of 2 x 6, and after all connections have been made, is lowered into the water the required depth and fastened to the side of the wharf.

Setting the recorder for operation

It is assumed that the recorder is secured in position with the proper pressure element and linkage arm connected, the doors of the shelter and recorder are open, the correct paper speed is set and the clock is operating.

(1) Load the chart paper in the recorder.

(2) Fill the pen and install it on the pen arm.

(3) Set the chart to the true time by turning the graph advancing knob in a counter-clockwise direction. (To compensate for a play in the paper drive gearage, the diagram time should be set 10 minutes ahead of the desired time).

(4) By turning the zero adjusting screw, set the recorder at a desired height. (If there is reason to suspect that the tide will fall below datum, the zero of the graph should be considered to be at the one-foot mark or higher).

(5) After the play in the paper drive has been taken up, read and record the diagram time and true time on the comparison form.

(6) Read the tide staff and diagram and record the heights on the comparison form.

(7) Complete the comparison form records for wind and sea conditions.

(8) Close and secure the recorder and shelter.

NOTE: Operations 5 and 6 should be performed with very little time lapse.

Removing Lengths of Graph

It is assumed that the door of the recorder is open, the graph has been read and the comparison form completed.

(1) Lift the pen assembly from the paper with the pen lifting arm.

All other operations are to be followed as listed on page 36 (2-6).

Daily Inspection of Recorder

The recorder should be inspected at least once a day when sounding operations are in progress and the following program carried out:

(1) Record diagram number, week day and date in columns 1, 2 and 3 of the comparison form (Figure 45).

(2) Make a short curved line on the graph by lightly moving the pen arm from left to right, simultaneously noting the true time. Record diagram time, true time and any clock error in columns 4, 5 and 6 of the comparison form.

(3) Read the height on the tide staff and diagram, simultaneously noting the true time. Record these observations in columns 7, 9 and 10 of the comparison form.

(4) Record the difference of wharf scale and diagram height in column 11.

(5) Complete the comparison form for wind and sea conditions. (A copy of the Beaufort Scale is available on the reverse side of the comparison form).

(6) Record the date and true time near the short curved line on the graph (Figure 21).

(7) If the clock error is greater than 5 minutes, make the necessary adjustments on the clock regulator.

(8) Close and secure the recorder and shelter doors.

Weekly Inspection of Recorder

Similar to the daily inspection with the following additions:

(1) Wind clock.

(2) Top-up ink reservoir.

Trouble Shooting

(1) If the graph is flattened on the bottom, the diaphragm may not be set low enough and is exposed at low tide or the diaphragm box may be partially silted.

(2) If the graph is flattened on the top, the recorder might be set for the wrong range.

(3) If the graph is flattened between the bottom and top, there might be an air leak in the system, moisture in the tubing or the diaphragm may be partially inverted.

(4) No time record would indicate a stopped clock, disengagement of paper drive gears or disengagement of paper drive sprockets from the paper.

(5) If the graph is a continuous straight line, the capillary tubing may be damaged, the linkage arm may be stuck, the pressure element may not be operating or the union nut may be too tight consequently closing the hole in the rubber washer.

(6) If the graph is saw-toothed, the diaphragm opening might be set too large.

(7) Variance in true time and recorder time would indicate a faulty clock or that the clock is out of adjustment. It could also be caused by the paper being improperly aligned on the drive sprockets.

Equipment Supplied

Each recorder will normally be supplied with:

(a) Clock keys (2)

(b) Pens (3)

(c) Bottles of ink (1)

(d) Chart roll clips (2)

(e) Rubber washers (6)

(f) Rubber diaphragms (2)

(g) Capillary tubing (300 feet)

(h) Diaphragm box mounted on bracket c/w first length of tubing (1)

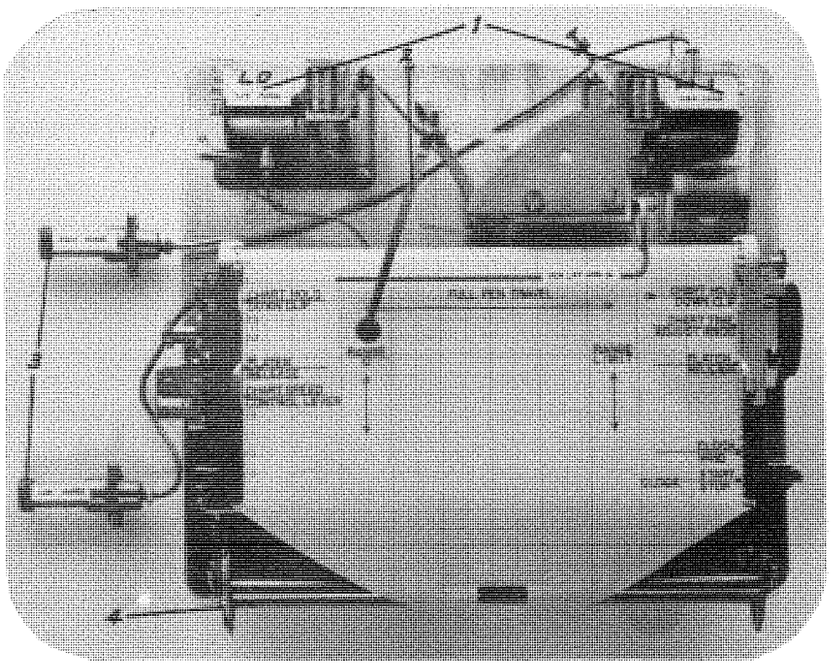
(i) Recorder securing and levelling bolts (4)

(j) Sufficient quantity of chart rolls, comparison forms, etc.

(k) Screwdriver

(l) Pen cleaning wires

NOTE: In special cases, additional spare parts may be issued if required.



1 - Pressure elements
2 - Linkage arm
3 - Union connections
4 - Paper take-up spool

Figure 26. Ottboro pressure type water level recorder - -removed from case.

L E V E L L I N G

General

It is essential that the datum of every sounding survey be referenced to at least three permanent bench marks so that an established datum may be recovered for use in subsequent surveys. This is done by levelling from the bench marks to the established tide staff at the time of installation and at intervals during the course of the survey.

Levelling is a very important phase of the hydrographer's field work, as on it depends the value of the established chart datum and consequently the height of all elevations and the depth of all soundings on the published chart. Because of the importance of good levelling, in this manual considerable space has been allotted to equipment and procedures of levelling.

Levelling Equipment

(1) Level: Levels used by field officers of the Canadian Hydrographic Service are Wild N2, Zeiss Ni2 and Cook, with the two former being most common.

(2) Tripod: Appropriate tripods are available for any of the above levels.

(3) Levelling Rod: The levelling rod most commonly used in hydrographic surveying is the Philadelpia rod.

(4) Rod Level: A rod level should be used during any levelling operation.

(5) Bench Mark Chisel: A bench mark chisel should be used to level to and from a bench mark set in a vertical face.

(6) Turning Points: Metal turning points should be used in any area where no other suitable turning points are available.

Care of Equipment

The levelling equipment should be treated with respect. Whenever the level is being transported out of its shipping case, in a launch, dory or motor vehicle, it

should be protected against accidental bumps. If possible someone should support the level. Although the level usually receives due care in handling, the same treatment is not always given the levelling rod and rod level. The rod should be handled properly and when not in use it should be stored in a protecting case or on a rack. Under no circumstances should the rod be used as a pushing pole, vaulting pole or seat.

Levelling Definitions (Figure 27)

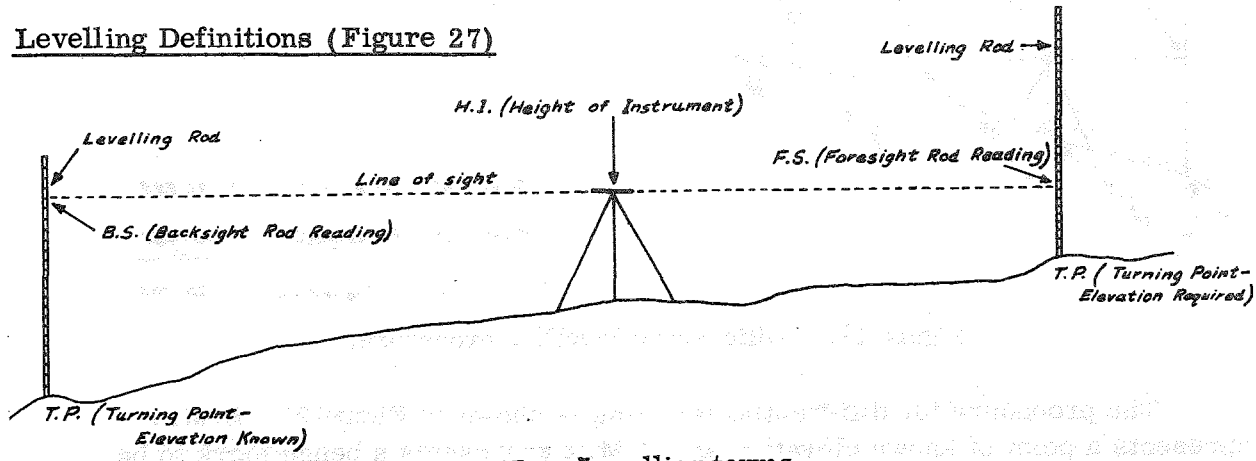


Figure 27. Levelling terms.

A Backsight (B.S.) is a rod reading taken on a point of known or assumed elevation.

A Foresight (F.S.) is a rod reading taken on a point whose elevation is to be determined.

The Height of Instrument (H.I.) is the elevation of the line of the telescope when the instrument is levelled.

A Turning Point (T.P.) is an intervening point between two bench marks, upon which foresight and backsight rod readings are taken. It may be any stable object or peg or metal plate which is carried forward by the rodman after observations have been made.

Levelling Procedure

The operation of direct levelling to determine the elevation of points some distance apart is called differential levelling. Differential levelling requires a series of set-ups of the instrument along a general route, and for each set-up, a rod reading back to a point of known or assumed elevation and forward to a point of unknown elevation.

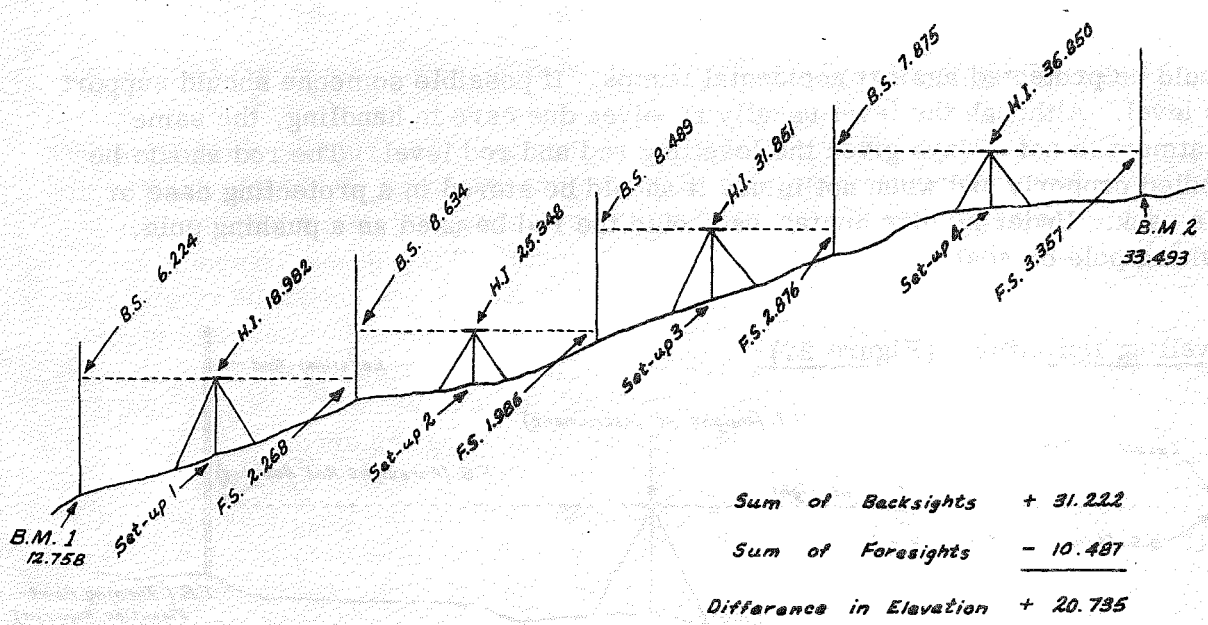


Figure 28. Differential levelling procedure.

The procedure for differential levelling is shown in Figure 28. B.M. 1 represents a point of known elevation and B.M. 2 represents a bench mark to be established some distance away. The rod is held at B.M. 1 and the level is set up in some convenient location, as set-up 1, along the general route B.M. 1 to B.M. 2. The level is placed in such a location that a clear rod reading is obtainable, but no attempt is made to keep on a direct line joining B.M. 1 and B.M. 2. A backsight is taken on B.M. 1. The rodman then goes forward and, as directed by the leveller, chooses a turning point T.P. 1 at some convenient spot within range of the telescope along the general route B.M. 1 to B.M. 2. It is desirable that each foresight distance be approximately equal to its corresponding backsight distance. The rod is held on the turning point, and a foresight is taken. The instrument man then moves the level to a point beyond T.P. 1 in the general direction B.M. 1 to B.M. 2 and sets up the instrument; set-up 2. A backsight is taken on the rod held at T.P. 1. The rodman then moves forward to establish a second turning point, T.P. 2, and so the process is repreated until finally a foresight is taken on the terminal point B.M. 2.

It is seen that a backsight added to the elevation of a point on which the backsight is taken gives the height of instrument, and that a foresight subtracted from the height of instrument determines the elevation of the point on which the foresight is taken. Also the difference between the backsight taken on a given point and the foresight taken on the following point is equal to the difference in elevation between the two points. It follows that the difference between the sum of all backsights and the sum of all foresights gives the difference in elevation between the bench marks. If, when levelling from one point to another point, the sum of the backsights is greater than the sum of the foresights, the elevation of the final point is higher than the original point, or vice versa.

Levelling Precision

Elevations of bench marks must be checked by re-running level lines between them or by completing a level circuit. A line of levels that ends at the point of origin or a line that is run between two previously established bench marks is called a level circuit. In a level circuit all bench marks should be employed as turning points, that is, no intermediate shots should be taken to a bench mark as there is no means of checking this elevation in the single circuit. It is recommended that all elevations be checked by re-running the level line, as this will supply a closure between each of the successive bench marks, and if an error has been made, less work is involved in locating the error.

When a line of levels makes a complete circuit, the final elevation of the initial bench mark as computed from the level notes will seldom agree with the initial elevation of this point. The difference between these two elevations is called the error of closure. The total error developed in a line of levels is composed partly of cumulative and partly of compensating error, but the more refined the procedure becomes, the more nearly will the former be eliminated. In levelling, adherence to the usual precautions, especially as regards equality of backsight and foresight distances and stability of turning points, prevents the propagation of serious cumulative error and experience shows that the closing error of ordinary careful work may be taken as obeying the law of accidental error. The total error is therefore proportional to the square root of the number of instrument stations. As the number of stations per mile will not vary greatly the error E, in feet, developed in a distance of M miles may be expressed as: $E = C\sqrt{M}$, where C is a constant. For hydrographic surveying $E = .035\sqrt{M}$ thus the maximum error allowed is as follows:

500 feet or less	0.010 feet
1000 " " "	0.015 "
2000 " " "	0.020 "
3000 " " "	0.025 "
4000 " " "	0.030 "

To obtain this accuracy in levelling it is essential that the hydrographer use the three wire method of observing. The three wire method can be applied whenever the reticle of the telescope level has stadia hairs. The rod is read at each of the three hairs and the average is used for the final result. The level bubble should be centred before each reading. (This is not necessary when the automatic level is used). The maximum difference between upper and lower intercepts should not exceed 0.006 feet for hydrographic surveying under normal or near normal conditions.

Sources of Error in Levelling

Numerous sources of error may affect the accuracy of a line of levels, but the precautions against them are of a simple nature, so that it is not difficult to obtain good results without delaying progress. The various errors and mistakes may be classified as:

(1) Instrumental Errors.

(2) Errors and Mistakes in Manipulation.

(3) Errors due to Displacement of Level and Rod.

(4) Errors and Mistakes in Reading.

(5) Mistakes in Booking.

(6) Errors due to Natural Causes.

(1) Instrumental Errors

The Level: The important requirement is that the line of collimation should be exactly parallel to the level tube axis, so that the line of collimation is horizontal when the bubble is at the centre of its run. The error introduced by non-adjustment is proportional to the length of sight, and is entirely eliminated between turning points by equality of the backsight and foresight distances. Considering the fact that no instrument is likely to be in perfect adjustment and further that the effect of curvature and refraction is not a negligible quantity, it is clear that for levelling of moderately high precision it is necessary to equalize backsight and foresight distances between bench marks; therefore these distances become a part of the levelling records. The effect of curvature and refraction cannot be entirely eliminated by making the sum of the foresight distances equal to that of the backsight distances, rather it is necessary that each foresight distance be made nearly equal to the corresponding backsight distance. For accurate levelling the total difference in backsight and foresight distances should not exceed 32 feet per mile, also the difference in corresponding backsight and foresight distances should not exceed 10 feet.

The Rod: It is advisable to test the graduations of a new rod by a steel tape (this is normally done by the equipment depot).

If the rod is worn uniformly on the bottom, an erroneous height of instrument is shown at each set-up, but the error in backsight is balanced by that in the following foresight and no error results in the elevation of the points.

(2) Errors and Mistakes in Manipulation

The Level: The most serious and common mistake in levelling is the omission to have the bubble centred at the instant of sighting.

The Rod: The rod level should always be used to hold the rod in a vertical position; if held off plumb, the resulting rod reading will be too great. Errors due to non-verticality of the rod tend to compensate at turning points, but if the backsight readings are consistently greater or smaller than the foresights, the error becomes cumulative. A further precaution to be observed by the rodman is to see that dirt does not accumulate on the foot of the rod, as this would cause a variable relationship between the zero of the graduation and the foot of the staff.

(3) Errors due to Displacement of Level and Rod

The Level: If the instrument is set up on soft ground, it may gradually settle from the moment of the backsight observation to that of the foresight. This will always make the foresight reading smaller than it should be. The error is cumulative, as every settlement of the instrument increases the reduced level of all subsequent observed points. It follows that the level should, whenever possible, be placed upon solid ground with the legs thrust in firmly and that no time should be wasted between the backsight and foresight observations. It sometimes happens that the level is accidentally distrubed, but as the mishap will be noticed, no error need result. If the position of the turning points have been distinctly marked it is only necessary to relevel the instrument and again backsight on the last turning point, substituting the new reading for the previous one. If turning points are not marked, it is necessary to return to the starting point.

The Rod: A serious and common error is that occasioned by the change of level of the rod at a turning point while the instrument is being carried forward. It is commonly caused by choosing unsuitable turning points. Soft ground should be avoided owing to the probability of the staff sinking between the foresight and backsight observations. The use of a peg or a metal turning point (available at the equipment depot) as a support in soft ground tends to prevent sinkage. If a peg or metal turning point is used in soft ground, the rodman should remove the rod from the turning point while the instrument is moved forward. Since any change of level of the staff will nearly always be in the direction of sinkage, the error is cumulative.

When rocks or boulders are used for turning points the exact position of the selected point should be marked so that the rod can be held in the same position for backsight and foresight observations. If only irregular or rounded boulders are available for turning points, the rod should be held on the highest point as at "a" in Figure 29; if the rod is held at "b" it is difficult to maintain the foot of the rod on the point while turning the rod to face the new instrument set-up.

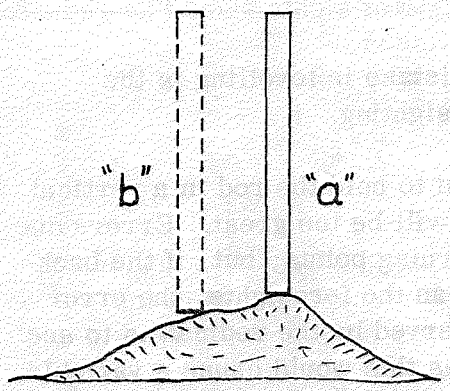


Figure 29. Selection of turning points.

It should be noted that the accuracy of levelling depends largely on the rodman, therefore he should be informed of the importance of his share of the work, particularly with regard to turning points and verticality of the rod.

(4) Errors and Mistakes in Reading

A large source of error is that of reading the wrong foot mark when all three wires fall within the same foot of the rod. This mistake cannot be detected in the levelling notes, so extra care should be taken by the observer.

Small compensating errors occur in the estimation of the decimal portion of the reading. The increased size of the image makes estimation easier with short sights than with long ones. The limit of sight depends upon the quality of the telescope as regards resolving power, the character of the staff graduation and the clearness of the atmosphere. Focusing should be carefully performed to eliminate parallax.

(5) Mistakes in Booking

Mistakes in booking include:

(a) Entering a reading in the wrong column.

(b) Omitting an entry.

(c) Noting a reading with digits interchanged.

To avoid any erroneous booking when the end of a line is reached, and check levelling is to be carried back along the line, the instrument position should be changed between the final foresight on the forward line and the initial backsight on the return line. To detect mistakes in recording, the best method is to read the staff and call out the readings to the notekeeper. The notekeeper should repeat all numbers and the instrument man should check these against the rod reading.

(6) Errors Due to Natural Causes

If levelling must be performed in a high wind, an endeavour should be made to shelter the instrument and readings with the rod extended should be avoided, owing to the difficulty of holding a long rod sufficiently steady and plumb. On hot sunny days the apparent vibration of the staff caused by irregular refraction makes

fine reading impossible. As a partial remedy, the length of sights should be reduced and sights on the lower two feet of the rod should be avoided.

Levelling Notes

No part of surveying is of greater importance, yet is more often neglected, than the field notes. These notes should constitute a permanent record of the survey with data in such form as to be interpreted with ease by anyone having a knowledge of surveying.

The record of every levelling survey should include the date, the weather conditions, the name of the surveyor and his assistants, and a title indicating the location of the survey. All field notes should be recorded in the field at the time the work is being done; notes copied from other field notes may be useful but they are not field notes. The recorder should realize that the notes will very likely be used by persons not familiar with the locality and must rely entirely upon what is recorded.

As an aid to field and office checking of the levelling records, it is desirable that the levelling between bench marks or between a bench mark and a tide staff, be considered as separate lines.

For hydrographic surveys, Forms L1 and L2 serve the requirements of good levelling records and should be used for all levelling operations (Figure 30). The forms are completely self explanatory and require only careful notekeeping to provide complete and accurate field records.

At first sight the form might appear to be cumbersome with all the arithmetic involved, but if it is closely followed, many common errors and mistakes can be detected. If an experienced notekeeper is employed the checks can be completed with very little extra time and when an error or mistake is detected, the time saved by not having to re-run the entire line could be considerable. It is left to the discretion of the officer-in-charge of the survey, as to whether or not H, K, L, F, and J are to be included in the field notes.

The space for general information on the back of the form should be completed in full. It is important that the surname of the observer be recorded so that any future query of the notes may be directed to the person concerned.

The record of levelling is so set out that for each instrument set-up the backsight and foresight readings and the computation of elevations are on the same horizontal block. Intermediate foresights are discouraged because there is no check on the elevation obtained. The sums of the backsights, foresights and stadia distances should be recorded in the spaces provided. When more than one page of

notes is required for a line of levels, the sums of the previous page should be entered immediately above the space for the sums on the second page, and so on, to provide a continuation of sums.

On the front of form L1, provision is made for a summary of the level line. The terms forward and backward refer to the direction of the line of levels. If the recommended procedure of separating the level circuit into individual lines of levels between bench marks is followed, the summary and comparison of forward and backward lines is simplified. As a check on the levelling summary, the difference in elevation as obtained from the difference of sum of backsights and sum of foresights, should equal the difference in the elevation of the bench marks as recorded in the "Elevations" column.

Form L2 is a continuation of form L1 without the summary and general information. Form L2 should be used in conjunction with form L1 where there are more than three instrument set-ups in the line of levels. When form L2 is used, the records on the bottom of the page must be completed. Whenever more than one page of notes is required for a line, they should be numbered consecutively to provide a check against loss or misplacement of pages.

BACK OF PAGE

Date June 6/63 — LEVELLING AT — Page 1 of 1

Inst. No. Wild N2 H.S.6 — Peg's Cove N.S. — Observer A.Smith

Weather Overcast — Recorder E.Brown

Visibility Good — Rodman D.Green

LINE B.M. #1 to B.M. #2 Forward

BACKSIGHTS			STATION	ELEVATIONS	SET-UP	FORESIGHTS		
A 8.266	D 123	F +.001	B.M. # 1	10.000		A 3.491	D 116	F −.001
B 8.143	E 121	G 8.144	B.S. +	8.144		B 3.375	E 120	G 3.374
C 8.022	L 244	J 8.144	H.I.	18.144	#1	C 3.255	L 236	J 3.374
H 24.431			F.S. −	3.374		H 10.121		
K 244			T.P. #1	14.770		K 236		
A 6.576	D 134	F +.002	T.P. #1	14.770		A 4.673	D 126	F +.002
B 6.442	E 128	G 6.444	B.S. +	6.444		B 4.547	E 120	G 4.549
C 6.314	L 262	J 6.444	H.I.	21.214	#2	C 4.427	L 246	J 4.549
H 19.332			F.S. −	4.549		H 13.647		
K 262			B.M. #2	16.665		K 246		
A	D	F	B.S. +			A	D	F
B	E	G	H.I.			B	E	G
C	L	J	F.S. −			C	L	J
H						H		
K						K		
Sums	506	14.588				Sums	486	7.923

A — Rod reading upper hair
B — Rod reading middle hair
C — Rod reading lower hair
Sums — Sums of L and Sums of J

$D = A - B$ $\quad E = B - C$ $\quad F = \frac{D - E}{3}$ $\quad G = B + F$ $\quad H = A + B + C$ $\quad J = \frac{H}{3}$ $\quad K = A - C$ $\quad L = D + E$

Checks: $K = L$; $G = J$; $D = E \pm .006$ (max.)

Form L1

FRONT OF PAGE

LOCATION PEG'S COVE N.S. — YEAR 1963

LEVELLING

LINE — DIFFERENCE OF ELEVATION

FROM	TO	FORWARD	BACKWARD	MEAN
B.M. 1	B.M. 2	+ 6.665		

	FORWARD	BACKWARD
SUM OF BACKSIGHTS	+ 14.588	+
SUM OF FORESIGHTS	− 7.923	−
DIFFERENCE OF ELEVATION	+ 6.665	

REMARKS

Figure 30. Hydrographic levelling notes - Form L1

WILD N 2 LEVEL

General

The Wild N 2 level (Figure 33) is a precise and compact instrument which is ideal for all levelling in hydrographic surveys.

The level has three foot screws and a small spherical level for approximate levelling of the instrument. A telescope level vial and magnifying optical-bubble viewer are contained in a housing on the left side of the telescope. A tilting screw, for final levelling of the telescope, is fitted directly below the telescope eye-piece. An azimuth tangent screw and azimuth locking screw is fitted directly below the objective end of the telescope. Some models are supplied with a graduated horizontal circle.

The telescope is internal focussing and is fitted with a black dioptric collar on the eyepiece for adjusting the focus of the reticle. The reticle is inscribed with stadia lines, set in a ratio of 1:100. Located underneath the telescope is a small spring loaded telescope locking pin, by releasing this pin, it is possible to turn the telescope 180 degrees on its longitudinal axis. If readings are taken with the telescope in the inverted and upright positions, errors of collimation are cancelled out. The telescope focussing screw is fitted on the right side of the telescope. The minimum focussing distance is 6 feet. The telescope presents an inverted image, with a magnification of 24 or 28 power depending on the lens used.

Instructions for Use

(1) Setting-up. Set up the tripod at a convenient height with the tripod head approximately level. Remove the level from its case and fasten it to the tripod head by screwing up the central fixing screw moderately tight.

(2) Levelling the Instrument. Level the instrument approximately by turning the foot screws while observing the spherical level bubble. The more accurately this is done, the quicker will subsequent observations be taken.

(3) Focussing. Direct the telescope towards the sky and turn the black dioptric collar on the eyepiece until the cross hairs appear

perfectly sharp and black. Sharp focussing of the image is accomplished by turning the nickelled focussing screw, located on the right of the telescope. Test for parallax between the image and the cross hairs by moving the eye up and down in front of the eyepiece. Refocus if necessary until all parallax is removed.

(4) Observing.

(a) Sight on the levelling rod by using the peep sights located on top of the telescope.

(b) Tighten the azimuth locking screw.

(c) Sight through the telescope and bring the line of sight to the rod by using the azimuth tangent screw.

(d) Focus the rod image.

(e) Adjust the illuminating mirror of the tubular level.

(f) Turn the tilting screw until the two bubble-ends of the tubular level are in exact coincidence (Figure 31).

(g) For three-wire levelling, read on the rod the position of the three horizontal wires, checking the level bubble before and after each reading.
NOTE: If the bubble ends are not in coincidence after each reading, the observation should be repeated.

(5) Reading the Horizontal Circle. On instruments equipped with a horizontal circle, the reading microscope is situated to the right of and below the telescope. The scale is graduated in 10 minute intervals and may be accurately read to single minutes by estimation.

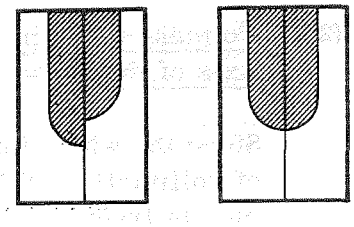


Figure 31. View of the level bubble.

Testing and Adjustments

Regardless of the precision of manufacturing, all levels in the process of use will require field adjustment, therefore it becomes an important duty of the hydrographer to test his instruments frequently. It is recommended that the equipment be field-tested after it has been shipped by public transport or whenever it might have received a severe blow.

When adjusting an instrument, be careful not to tighten up too drastically any antagonistic screws; tighten the screws only as far as is necessary to secure firmness without play. In any case do not operate the adjusting screws unless and until it has been proven that error exists.

Under normal conditions the following adjustments are the only two which will be required in the field.

(1) Adjustment of the Spherical Level

The spherical level is attached by pairs of appropriate push-and-pull screws, by which the level can be adjusted if necessary. First centre the bubble by means of the foot screws, then turn the instrument through 180 degrees about its vertical centre. If the bubble does not remain in the centre of the scribed circle, remove half the error by again making use of the foot screws, and correct the remaining error by means of the adjusting screws referred to above. For this adjustment it is recommended that the telescope be positioned directly over one of the foot screws. The adjustment should be checked by repeating the test.

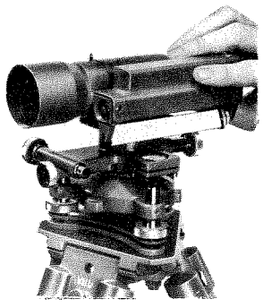
(2) To make the Line of Sight (Collimation Line) Parallel to the Axis of the Level Tube - Tilting Error

Since the whole function of a level is to furnish a horizontal line of collimation, this requirement is of prime importance and merits frequent examination.

A collimation error in the line of sight amounting to two or three tenths of an inch, over a distance of 300 feet, is of no account if foresight and backsight shots are taken at equal distances.

Before this test is carried out, the correct adjustment for the spherical level should be completed.

The tilting error would normally be found through a two-peg test, however, the Wild N 2 is fitted with means for inverting the telescope which simplifies the test considerably.



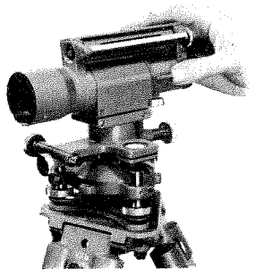
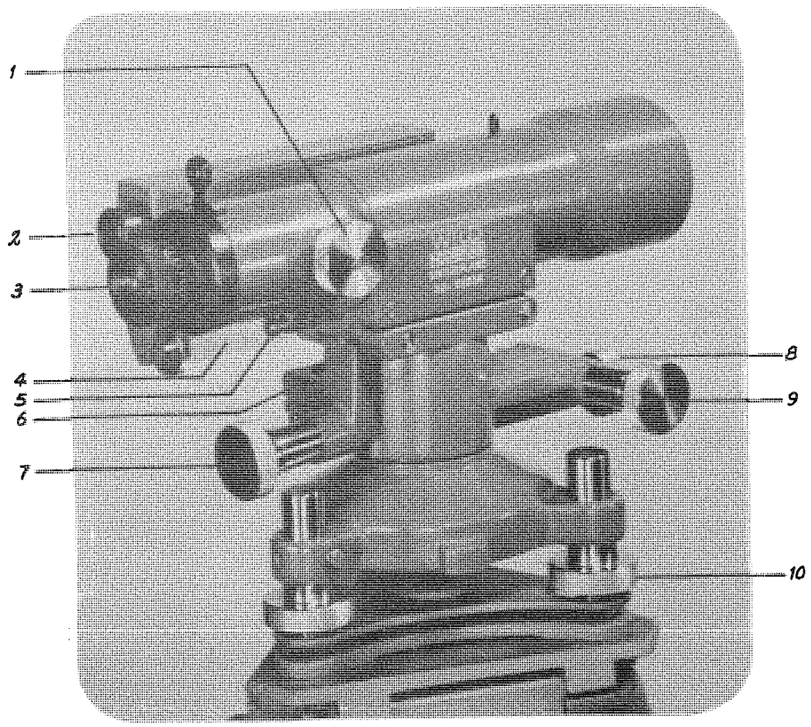


Figure 32. Rotating the telescope.

To verify tilting error, rotate the telescope on its longitudinal axis into the inverted position by releasing the pin located below the telescope eyepiece, simultaneously moving the telescope (Figure 32). Centre the bubble and read the rod, set up at a distance of approximately 150 feet. (NOTE: In the inverted position of the telescope, the bubble appears somewhat dull because it is read through the level and fluid). Next, rotate the telescope back to its normal position, centre the bubble and read the rod again. The mean of these two readings gives the true horizontal sighting. Set the cross hair to this mean value by turning the tilting screw, and then centre the bubble by means of the capstan head adjusting screws, situated at the objective end of the tubular level. Repeat the test to check adjustment.



1 - Focussing screw
2 - Eye-piece for tubular level
3 - Telescope eye-piece
4 - Level vial illuminator
5 - Telescope locking pin
6 - Spherical level
7 - Tilting screw
8 - Azimuth locking screw
9 - Azimuth tangent screw
10 - Foot screw

Figure 33. Wild N2 level.

ZEISS Ni2 LEVEL

General

The Zeiss Ni 2 level (Figure 36) is a precise and compact instrument which can be used for all hydrographic levelling.

The instrument may be termed "automatic" or "self levelling" because it is designed with a suspended prism or compensator which automatically aligns the line of sight in the horizontal plane. All that is necessary is to centre the bubble of the spherical level and then, in a fraction of a second, the compensator automatically adjusts the line of sight. The instrument has three foot screws and a spherical or box level for approximate levelling. The azimuth movement of the upper part of the instrument is controlled by spring friction and requires no locking screw. The exact azimuth is set with an endless tangent screw.

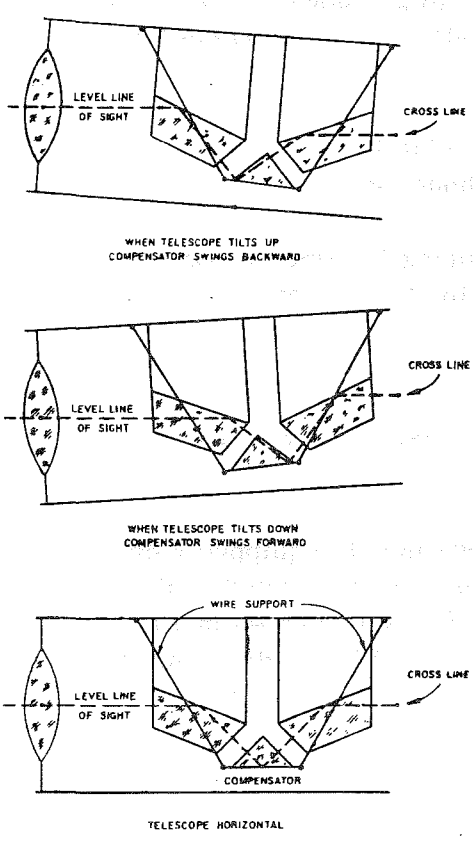


Figure 34. Suspended compensator.

The Telescope is internal focussing and has a dioptric collar for focussing the reticle, and a focussing knob on the top or side of the telescope for distance focussing. The reticle is inscribed with stadia lines to give a stadia ratio of 1:400 or 1:100. The minimum focussing distance is 11 feet. The telescope presents an upright image, with a magnification of 32 power.

The Compensator consists of three prisms, one of which is suspended on four wires of rustless and non magnetic alloy steel (Figure 34). This prism can swing freely, with its position in rest determined by gravitation. The swinging motion is frictionless and free from wear. An air cushion device quickly damps any tendency of prolonged oscillation. The compensator will operate when the telescope has been levelled by the foot screws to within plus or minus ten minutes off horizontal.

Instructions for Use

(1) Setting-up. Set up the tripod at a convenient height with the tripod head approximately level. Remove the level from its case and fasten it to the tripod head by screwing up the central fixing screw moderately tight.

(2) Levelling the Instrument. Level the instrument by turning the foot screws while observing the spherical level bubble.

(3) Focussing. Direct the telescope towards the sky and turn the black dioptric collar on the eyepiece until the cross hairs appear perfectly sharp and black. Sharp focussing of the image is accomplished by turning the focussing screw located on the top or side of the telescope. Test for parallax between the image and the cross-hairs by moving the eye up and down in front of the eyepiece. Refocus if necessary until all parallax is removed.

(4) Observing.

(a) Sight on the levelling rod approximately by viewing along one edge of the telescope housing.

(b) Sight through the telescope and bring the line of sight to the rod by using one of the azimuth tangent screws.

(c) Focus the rod image.

(d) For three-wire levelling, read on the rod the position of the three horizontal wires.

(5) Reading the Horizontal Circle. On instruments equipped with a horizontal circle, the reading microscope is situated to the left of the telescope eyepiece. The scale is graduated in 10 minute intervals and may be accurately read to single minutes by estimation. The horizontal circle can be oriented to any desired position.

Testing and Adjustments

Regardless of the precision of manufacturing, all levels in the process of use will require field adjustment, therefore it becomes an important duty of the hydrographer to test his instruments frequently. It is recommended that the equipment be field-tested after it has been shipped by public transport or whenever it might have received a severe blow.

When adjusting an instrument, be careful not to tighten up too drastically any antagonistic screws; tighten the screws only as far as is necessary to secure firmness without play. In any case to not operate the adjusting screws unless and until it has been proven that error exists.

Under normal conditions the following adjustments are the only two which will be required in the field.

(1) Adjustment of the Spherical Level

First centre the bubble accurately by means of the foot screws, then turn the instrument through 180 degrees about its vertical centre. If the bubble does not remain in the centre of the scribed circle, remove half the error by again making use of the foot screws, and correct the remaining error with the spherical level adjusting screws. Before tightening an adjusting screw, release the one on the opposite side accordingly. For this adjustment it is recommended that the telescope be positioned directly over one of the foot screws. The adjustment should be checked by repeating the test.

(2) To make the Line of Sight (Collimation Line) Parallel to the Axis of the Level Tube

Since the whole function of a level is to furnish a horizontal line of collimation, this requirement is of prime importance and merits frequent examination.

A collimation error in the line of sight amounting to two or three tenths of an inch, over a distance of 300 feet, is of no account if foresight and backsight shots are taken at equal distances.

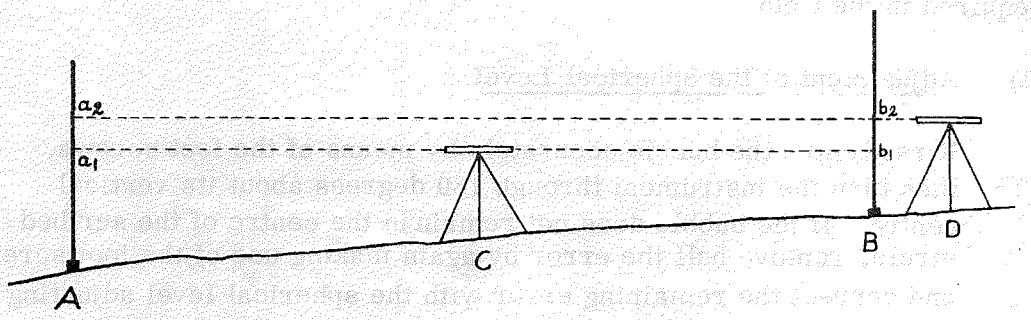
Before this test is carried out, the correct adjustment for the spherical level should be completed.

Two-peg test-(Figure 35)

(a) Set up and level the instrument at C, a point midway between two pegs A and B, about 200 feet apart.

(b) With the rod held at A, take rod reading a_1, and rod reading b_1 with rod held at B. If the instrument is exactly halfway between the two pegs, $a_1 - b_1 = d$ is the true difference in elevation between the pegs.

(c) Set up the instrument as near to one peg as clear focussing will permit (preferably beyond the peg as at D). Level the instrument and take rod readings b_2 and a_2. Then $b_2 + d$ should equal a_2 if the instrument is in adjustment. If this differs by more than 0.008 feet, the instrument requires adjusting.



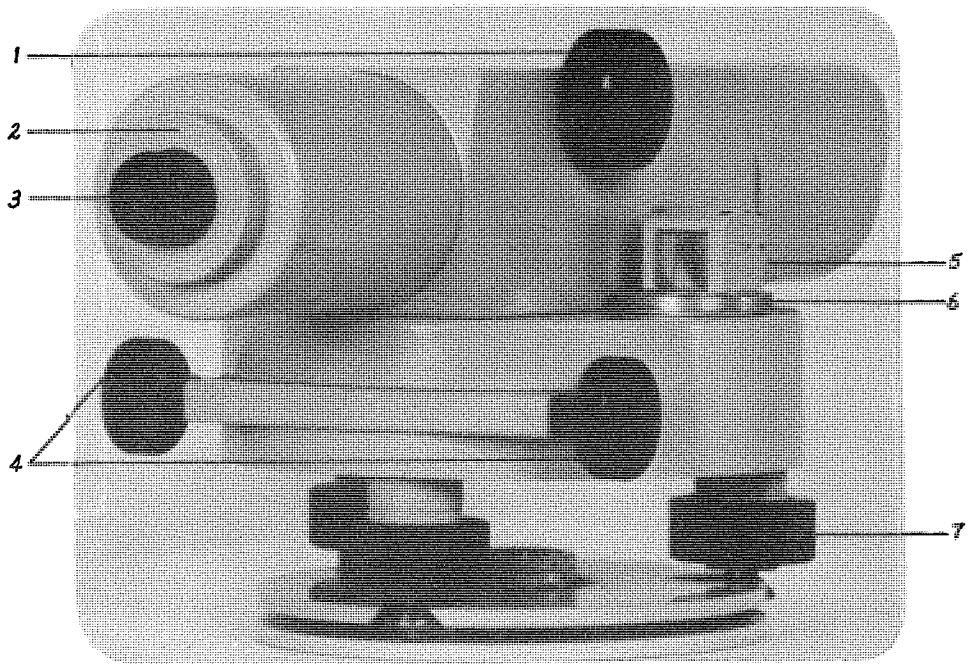
$a_1 - b_1 = d$ the true difference in elevation
then $b_2 + d$ should equal a_2

Example: $a_1 = 4.423$ $\quad b_2 = 3.486$
$- b_1 = 3.284$ $\quad + d = 1.139$
$d = 1.139$ $\quad$ then a_2 should be $\quad 4.625$

Figure 35. Two-peg test.

Adjustment:

In the Zeiss level, the collimation error is eliminated by adjusting the cross hairs. By means of the adjusting screw, which is accessible by unscrewing the protection cap, bring the cross hairs to the true reading $b_2 + d$. Repeat the test to check adjustment.



1 - Focussing screw
2 - Graticle screw protection cap
3 - Telescope eye-piece
4 - Azimuth tangent screws
5 - Viewing prism for spherical level
6 - Spherical level
7 - Foot screw

Figure 36. Zeiss Ni 2 level.

BENCH MARKS

General

It is essential that the datum of every sounding survey be referenced to at least three permanent bench marks, so that an established datum may be recovered for us in subsequent surveys.

A Bench Mark may be defined as a fixed point, whose elevation has been determined and whose position has been so described that it may be identified in the future. As the value of a line of levels depends upon the permanency and wise distribution of bench marks, it is highly desirable that this phase of hydrographic surveying receive the attention it deserves.

A bench mark is a visible record of the surveyor's and department's work, therefore, other agencies who might have reason to utilize such marks would surely assess the value of the survey from the appearance of the bench marks. A neat, well positioned mark would tend to create confidence in the survey, while a untidy mark in a poorly selected location would produce a feeling of doubt towards the value of the survey.

Bench marks established by hydrographic field parties are of two kinds; permanent and temporary.

It is of prime importance that these marks should be fixed points - no movement should take place in a bench mark during the period in which it is to be used. As the period during which a permanent bench mark will be used is expected to extend over an indefinite number of years, it is essential that it should be so located that it will hold its fixed position indefinitely.

Temporary bench marks will normally only be used for the season in which they are established.

Location for Bench Marks

Judgement and caution should be exercised in making the selection of bench mark sites; each B.M. should be set on a different plane, so that their elevations will not be disturbed by a common cause, and they should be separated by a horizontal distance of at least 200 feet.

Foundation of public buildings, post offices, churches, banks, concrete footings of water towers and bridges are usually good sites for bench marks; prior permission should be obtained for the use of such structures. When utilizing a building, the surveyor should be careful to select such a position for the bench mark that it will not be liable to destruction by addition or alterations to the building; as a general guide a bench mark in a building should be placed in a side facing a street and should be in one of the main walls. Any building resting on marshy ground, or where the foundation does not extend below the frost line should be avoided. In most cases tablets set in buildings will require the shank to be set horizontally.

Natural rock out-crop affords excellent locations for permanency of bench marks. Tablets set in such locations should be placed on high points, so that natural drainage will take place (Figure 37). If the bench mark is positioned in hollows or depressions, water might accumulate around the tablet and rot out the cement, or if the water froze, the mark might be lifted out of position.

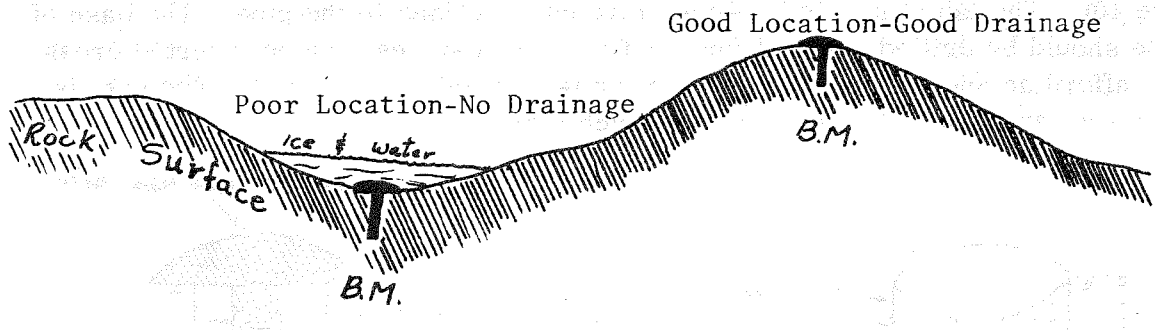


Figure 37. Location of bench marks.

If possible, all bench marks should be planted close to some point of reference so that their location can be definitely fixed and described. As there is often difficulty in describing bench marks set in rock outcrop, each mark should be carefully referenced to the other two, however, it is essential that each mark have an independent description in case the others cannot be found.

Due to the inherent instability of wharves the three reference bench marks should not be placed in these structures. An additional bench mark may, however, be planted on a wharf close to a tide gauge for convenience in levelling. It should be included in the bench mark description but should be clearly identified so that it will not be used as the controlling bench mark.

PERMANENT BENCH MARKS

C.H.S. Standard B.M.

The standard Canadian Hydrographic Service bench mark is a bronze tablet with a shank 2.5 inches long and 0.6 inches diameter, and a cap 2.2 inches in diameter (Figure 38). The cap has a horizontal slot to accommodate a bench mark chisel when the bench mark is set with its shank horizontal. The lower end of the shank is slotted to accommodate a fox wedge which should be used when setting the mark.

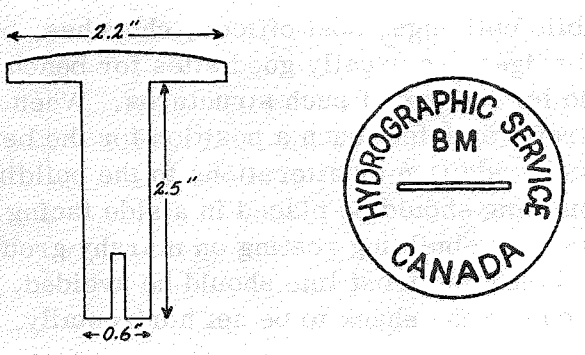


Figure 38. Canadian Hydrographic Service standard bench mark.

Soil Post

The soil post is a galvanized iron pipe of from 6 to 10 feet in length and of sufficient inside diameter to accommodate the shank of the standard bronze tablet (Figure 40). The tablet should be either riveted or welded to the pipe. The base of the pipe should be drilled, so that four or five 8-inch spikes may be inserted crosswise to afford an anchorage when the marker is embedded in the soil. The post is set in a similar manner to the iron pipe bench mark.

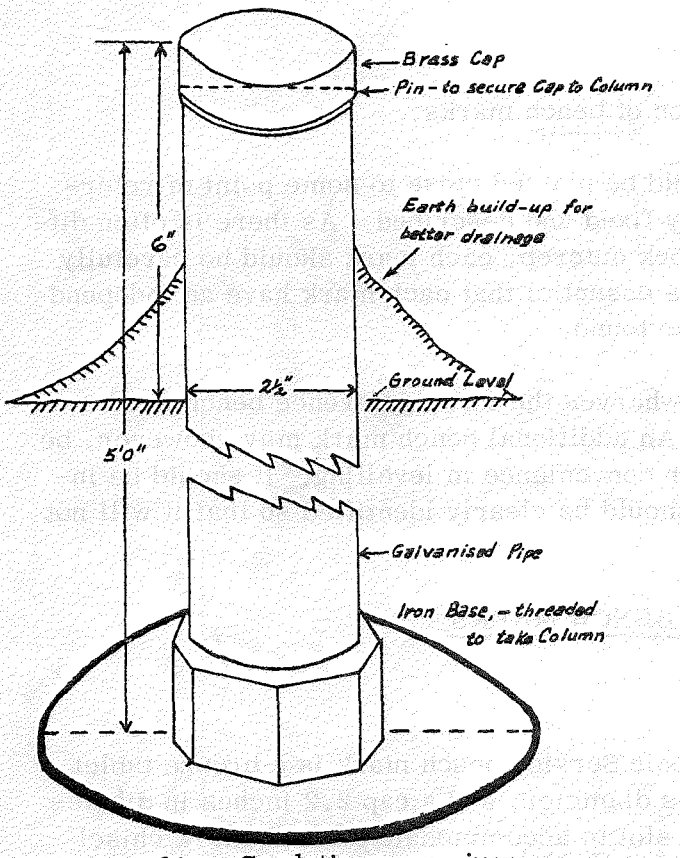


Figure 39. Geodetic survey iron pipe bench mark.

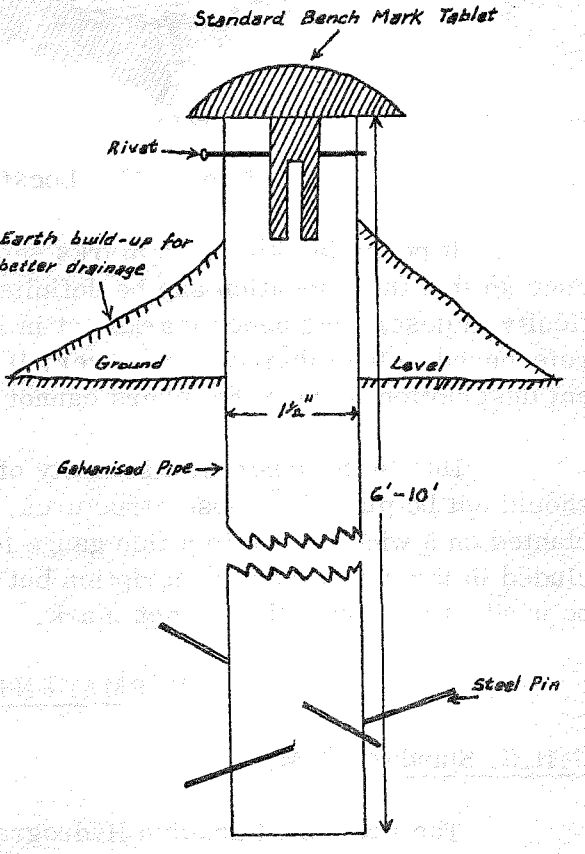


Figure 40. Soil post.

Iron Pipe B.M.

Iron pipe bench marks have been designed (at present for use by the Geodetic Surveys, but they could be made available for Hydrographic use) in order that permanent records of levelling may be left in areas where the standard bronze tablet would be unsuitable. The iron pipe bench mark (Figure 39) is constructed of 2 1/2-inch diameter iron pipe, 5 feet long; fitted with an iron baseplate and a brass cap inscribed similarly to the standard bronze bench mark. When setting the bench mark, a hole of sufficient diameter and depth is required to receive the pipe, so that only 5 to 9 inches of the marker remains above ground level. If it is practical a few shovels of cement should be deposited in the excavation, underneath and around the iron base place. The earth used for back-filling should be well tamped in and should be slightly rounded at the surface to allow for settlement and drainage.

Permafrost Bench Marks

The problem that has to be dealt with is to keep the bench mark isolated from the active zone which is the layer that is constantly moving. This is achieved by first embedding the bench mark in the permafrost and then isolating it from the active zone by a surrounding pipe (Figure 41). The area between the surrounding pipe and the bench mark is filled with axle grease to allow flexibility and to prevent water from entering this area.

From experience, the best means of digging in the permafrost is with a Bosch Hammer which is a high cycle, electric "jack" hammer.

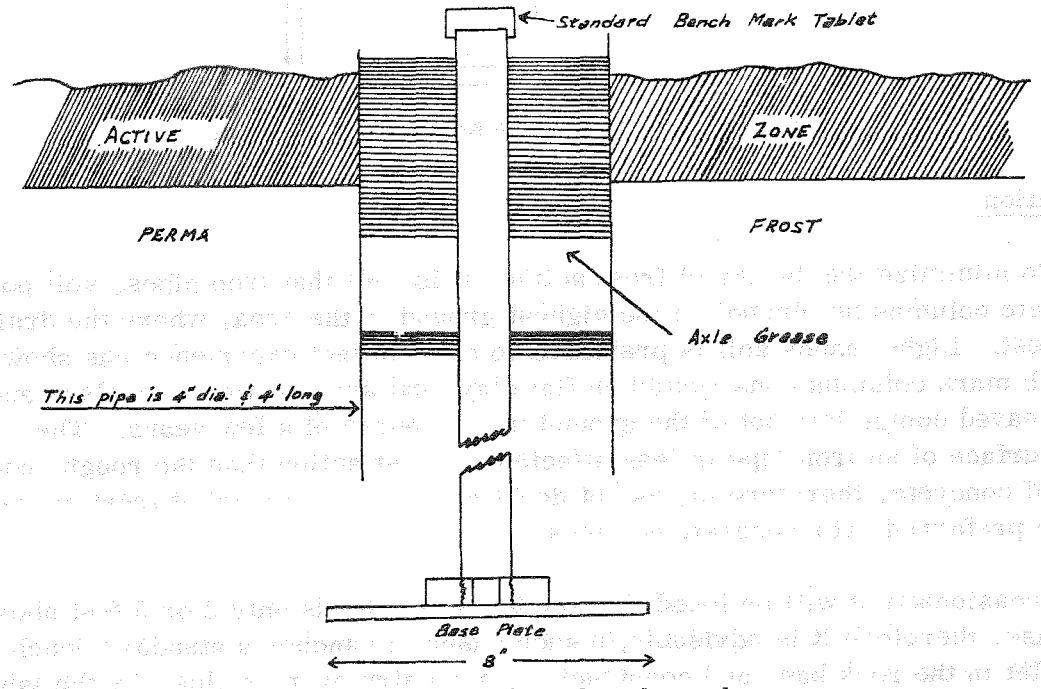


Figure 41. Permafrost bench mark.

Concrete B. M. Columns

Standard concrete bench mark columns are to be 1 1/2 feet square on top, the sides having a slight batter, and are to be reinforced with steel rods (Figure 42). The column should be 6 to 8 feet high, to go below frost level, and the upper portion should protrude 5 or 6 inches above ground level. A wooden form for the column will have to be constructed and it should not be removed for at least 48 hours to permit the concrete to set properly. The earth used for back-filling should be well tamped in and should be slightly rounded at the surface to allow for settlement and drainage.

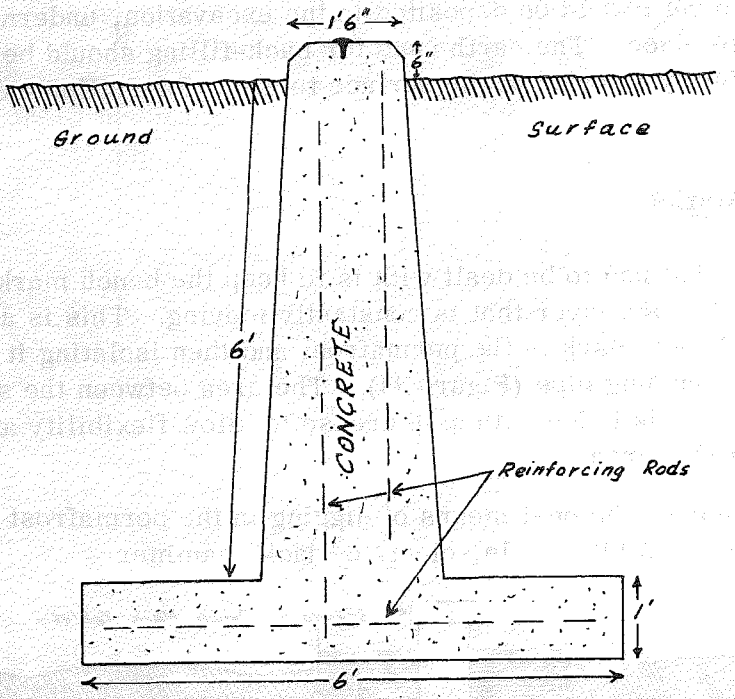


Figure 42. Standard concrete bench mark column.

Frost Action

To minimize the danger of frost action, it is well that iron pipes, soil posts or concrete columns be planted on the highest ground in the area, where the drainage will be best. Light sandy soil is preferred to clay; in fact experience has shown that bench mark columns constructed on flat clay land are practically useless and may be heaved completely out of the ground in the course of a few years. The smooth surface of an iron pipe is less affected by frost action than the rough uneven surface of concrete, therefore in case of doubt as to the likelihood of frost action, pipes are preferred over concrete columns.

Occasionally it will be found that the top soil extends only 2 or 3 feet above a rock base, therefore it is advisable, in such cases, to anchor a standard bench mark tablet in the rock base and construct a stone cairn over or close-by the tablet as a reference mark; such information should be carefully recorded in the description.

Concrete

The materials used in making concrete should be thoroughly mixed dry and again after the addition of water. Only sufficient water should be used to ensure a homogeneous mixture. The proportions of cement, sand and stone to be used depends to some extent upon the aggregate being of suitable quality: granted that this is the case, a 1:2:3 mixture is recommended.

Appearance of Bench Marks

When setting bench mark tablets in solid rock, masonry or concrete they should be fox-wedged and only sufficient cement should be used to imbed the shank of the tablet in the drill hole. The drill hole should be long enough to accommodate the tablet and should be slightly larger at the bottom to permit expansion of the shank when it is fox-wedged. Under no circumstances is the shank of the tablet to be shortened. The cap of the tablet should be set flush with the rock or concrete, as this will make it less subject to destruction or damage. The hydrographer should insure that the tablets are properly set; the horizontal line on the face of the tablet should be truly horizontal when the tablet is set in a vertical surface, and in no case should cement be permitted to adhere to the lettering on the face of the tablet.

Description of Bench Marks

Each bench mark should be stamped with dies, indicating the bench mark number and year established. Photographs of bench marks should be taken whenever possible. They may be invaluable in later years, especially in relatively featureless areas for recovering the position of bench marks; they are also valuable evidence when it is suspected that the original bench mark has been covered or destroyed. Normally two photographs of each bench mark should be taken, one being a close-up showing the bench mark clearly and the other being from some distance away to identify the general area. In the latter case, the bench mark should be indicated in the photograph by an assistant pointing to the position or by holding a level rod on the mark. The photographs are to be turned in to the Regional Offices.

A clear, concise description of all bench marks should be written at the time they are established. The descriptions should be distinct and sufficiently complete to enable the bench marks to be readily recovered and identified. If possible, the bench marks should be referenced by distance and direction to several prominent objects.

The descriptions of previously established bench marks should be carefully checked and revised if necessary.

Sketches of Bench Marks

A sketch showing the location of the bench marks should be shown on the Temporary Gauge History form T.W.L. 502 along with their description. The scale of the sketch will depend on the area but it should be sufficiently large to indicate as much detail as possible in the vicinity of the bench marks. While the sketch should be kept simple it is essential that the following be included: north direction, scale, high water line, drying areas and their type, (e.g. rock, sand, shingle), prominent objects or features, identified by name, with an approximate distance from the bench mark. It is not necessary that the sketch be drawn to high standards of draftsmanship as all are later redrawn by the chart compilation staff. The chart number should be indicated near the sketch. The sketch should not include large portions of the surrounding area. If, due to an unusual location this information is considered necessary, two separate sketches should be submitted.

Recovery of Bench Marks

When working in areas where bench marks have been previously established, the hydrographer is to make every effort to recover these marks. If it is impossible to find all or any of the old marks, new ones, as necessary to maintain three bench marks at each gauge site, should be established. The numbering of such new marks should be continuous from the last number used for the locality. As an example, if the hydrographer was able to recover only B.M. 1 and B.M. 3, then the new B.M. should be numbered 4, and dated for the year established. If an old bench mark cannot be found, or if it has been destroyed, the fact should be reported on Form TWL-502.

TEMPORARY BENCH MARKS

The hydrographer should at all times endeavour to find suitable locations for permanent bench marks, but in areas of extreme muskeg or semi-perma-frost, he will have to resort to the best means at hand for establishing temporary bench marks required for the duration of the survey. If it is necessary to use temporary marks, they should be as close to a permanent nature as possible. Railway spikes or ships nails (available at the equipment depot) driven into trees have been known to remain stable for a considerable number of years. When railway spikes are used in trees, they should be driven in nearly flush with just sufficient spike protruding on which the level rod can be rested vertically. If the bark of the tree is removed from the immediate vicinity of the spike, it will retard growth of the tree over the spike and would also aid to recover the mark in the future. A 6 or 8-inch lag screw could be used in the same manner as the railway spike for a temporary bench mark.

DATUM PLANES

General

When selecting a datum for soundings the following factors must be considered:

(a) The datum should be sufficiently low so that under normal weather conditions there will always be at least the charted depth of water.

(b) The datum should not be so low that it gives an unduly pessimistic impression of the least depth of water likely to be found.

(c) The datum should be in close agreement with those of neighbouring surveys.

The International Hydrographic Bureau recommends that chart datum should be a plane so low that the tide will seldom, if ever, fall below it. For tidal waters the Canadian Hydrographic Service has adopted the level of Lower Low Water Large Tides as its datum plane for chart datum, and Higher High Water Large Tides for its datum plane for elevations. For non-tidal waters the datum adopted for both chart datum and datum for elevations is the low water datum (see page 84).

Once chart datum has been established it is rarely, if ever altered, and then only if the whole area is to be resounded, as such a change would affect all the soundings and dredged depths and would involve alterations to the tide or water level data to which the height of wharves, bridges and other land features are referred.

It may sometimes occur, especially in areas where insufficient tidal or water level information is available, that the datum selected appears to be unsuitable; it may happen that the water level falls considerably below datum on one or more occasions; on the other hand, it may never fall to within several feet of the datum, and the temptation will be to alter the datum accordingly. In most cases however, an assessment of the suitability of the datum must await the analysis of the water level observations. The analysis may show that on the days when the water level fell below datum the cause was unfavorable weather conditions such as strong winds and a high barometer. Where the tide does not fall anywhere near datum, the reason may be that the astronomical conditions at that period did not

produce a large range of tide. This can be checked by comparing readings with those at the nearest Reference Port.

S. D. - Sounding Datum

Sounding datum is the plane to which soundings are reduced during the course of a hydrographic survey. It is the datum used when compiling the "Field Sheet". It may or may not be the same as chart datum.

C. D. - Chart Datum

Chart datum is the datum plane adopted for the published chart. It is a low water datum which by international agreement is so low that the water level will seldom fall below it. It is the level above which tidal predictions and water level records are based. The datum is only used within the gauge location and differs from place to place depending on the range of tide or water level, or on the level of a controlled water area.

G. S. C. Datum - Geodetic Survey of Canada Datum

Geodetic Survey of Canada Datum is based on the value of mean sea level prior to 1910 as determined from a period of observations at tide stations at Halifax and Yarmouth, N. S., and Father Point, Que., on the east coast, and at Prince Rupert, Vancouver, and Victoria on the Pacific Coast.

The average height of the sea is not constant; it is affected by wind, barometric pressure, temperature and salinity of the water, the discharge of rivers, and so on. Because of these factors, mean sea level varies from day to day, from season to season, and from year to year. It therefore cannot be used directly as a chart datum.

Information concerning Geodetic elevations and bench marks can be obtained through the Tides, Currents and Water Levels Section.

I. G. L. D. (1955) - International Great Lakes Datum (1955)

All water level and bench mark elevations in the area between Father Point, Quebec, and Port Arthur, Ontario, are referred to I. G. L. D. (1955). For this datum, dynamic instead of the standard orthometric elevations are used. Dynamic elevations take into account not only the measured linear height above the reference zero, but also the force of gravity at that particular point. The reference zero is the mean water level as computed for the years 1941 to 1956 at Father Point, which is defined as 7.486 feet above the zero of the gauge, or 12.444 feet below Geodetic bench mark 1248-G.

In the title, "1955" refers to the central year of the period during which the spirit levelling and water level transfers were carried out.

DATUM PLANES AND WATER LEVEL VARIATIONS IN TIDAL WATERS

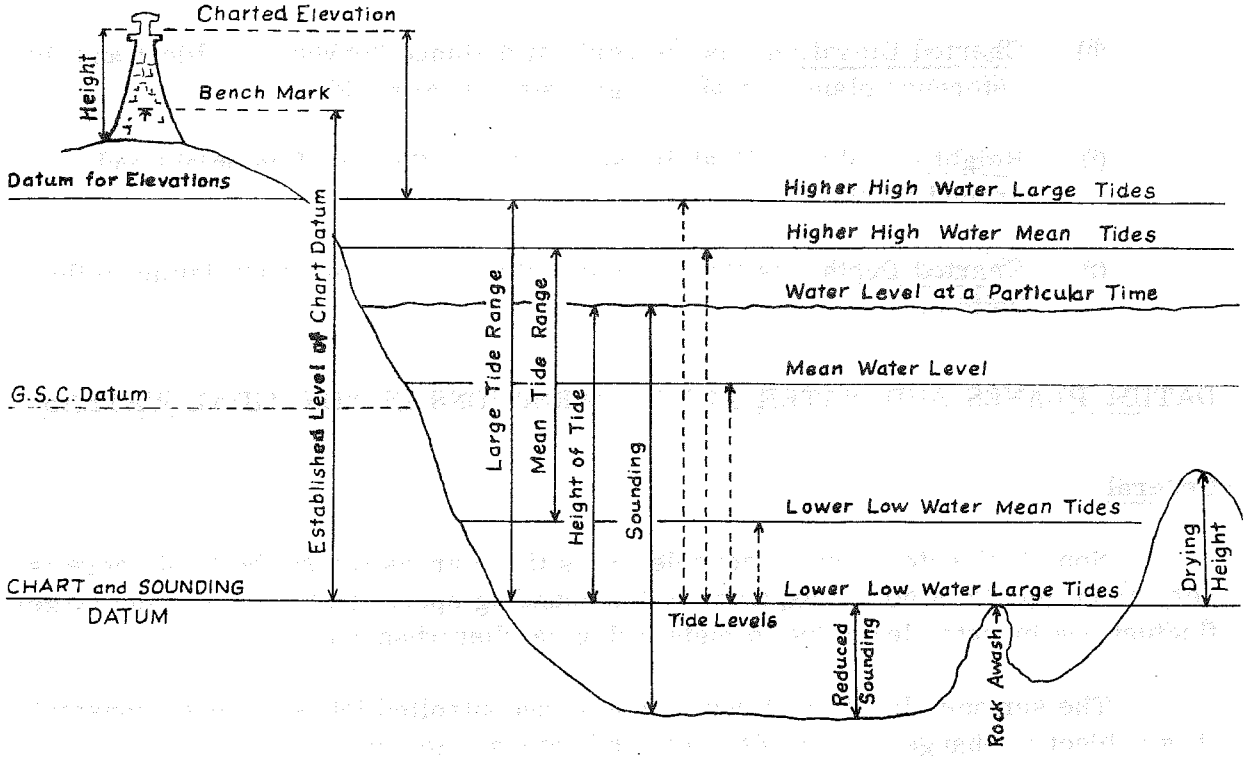


Figure 43. Datum planes in tidal waters.

Definitions

(a) H. H. W. L. T. - Higher High Water Large Tides - is the highest predictable tide from the available constituents, with the astronomical factor (f) close to unity.

(b) H. H. W. M. T. - Higher High Water Mean Tides - is the average of the predicted heights of the higher high waters of each day.

(c) L. L. W. M. T. - Lower Low Water Mean Tides - is the average of the predicted heights of the lower low waters of each day.

(d) L. L. W. L. T. - Lower Low Water Large Tides or Lowest Normal Tides (L. N. T.) - is the lowest predictable tide from the available constituents, with the astronomical factor (f) close to unity.

(e) M. W. L. - Mean Water Level - is the average of hourly water levels for a period of observations.

(f) M. S. L. - Mean Sea Level - is the average of hourly water levels for a period of several years of observations.

(g) M. T. L. - Mean Tide Level - is the average of all the high and low water heights over a period of observation.

(h) Charted Elevation - is the vertical distance between an object and the reference plane of higher high water of large tides.

(i) Height - is the vertical distance between the top of an object and ground level.

(j) Charted Depth - is the vertical distance from the chart datum to the bottom.

DATUM PLANES AND WATER LEVEL VARIATIONS IN NON-TIDAL WATERS

General

Non-tidal waters can be considered as those areas where the tidal range is very small and is of no consequence to the sounding operation because of the larger fluctuations in water level due to meteorological disturbances.

The surface elevation of controlled or uncontrolled lakes is never constant; it is subject to change from mechanical and natural agencies.

(1) Mechanical - Controlled inflow and outflow, artificial and deepened natural outlets, all affect the lake level.

(2) Natural - The general fluctuations of the lake level may be considered under the headings annual, monthly or seasonal, daily, and irregular.

(a) Annual - From year to year the mean surface elevation varies in relation to the balance between supply and discharge, natural or otherwise. The supply is the precipitation (less evaporation) over the lake and local drainage area, plus the outflow from a adjoining lake or river. The discharge is the outflow from the lake into adjoining rivers and lakes.

(b) Monthly or Seasonal - From month to month the lake elevation is constantly changing in relation to the seasonal balance between the supply and discharge.

(c) Daily - From day to day the lake level changes, first regularly in relation to the monthly range and secondly irregularly due to physical forces contributed to by winds, barometric pressures and lunar influences.

(d) Irregular - Surface oscillations are caused by differences in barometric pressure over the lakes. These irregular changes in level are called seiches and a pronounced increase over their normal range can indicate an approaching storm. At times the wind contributes a second irregular action by forcing the surface water to pile up on the shore faster than the under currents can return it. The lunar influence is a tide of very small range and of no practical value, but theoretically it is a very interesting phenomenon.

Chart Datum

In non-tidal waters the datum adopted for both chart datum and datum for elevations is a low water datum. This level is such that the daily mean water level will seldom fall below it during the normal season of navigation. Seldom in this definition is a variable factor depending on the number of years for which water level recordings have been made. It is obvious that the longer the period of observations available, the more accurate the established datum will be and consequently the daily mean water level will fall below chart datum fewer times.

In many areas the water levels are regulated according to a predetermined plan. In these cases the low water of the controlled level is used as chart datum. In areas where the water level is regulated throughout the year, but during the navigation season the water level is consistently above the controlled minimum, chart datum is derived by using water level heights for the navigation season only.

INSTRUCTIONS FOR COMPUTING DATUM IN TIDAL WATERS

The datum at any place has either already been established by some previous survey and can be recovered by levelling from the established bench marks, or it must be transferred from a suitable Reference Port. When transferring a datum, even though the range of the tide may differ between the two localities, when the tide falls to datum at the Reference Port, it will also fall to or close to datum at the place where it has been established.

Datums are computed in Section 1 of Form TWL-502 (see page 91). Section 1A is used when recovering a previously established chart datum. After levelling is completed and the elevation of the zero of the tide staff is known, the elevation of the zero on the automatic gauge is found by comparing simultaneous readings recorded on the comparison form.

Section 1B is used to transfer datum from a place where it has previously been established (Z). For this transfer it is essential to observe the high and low waters for a period of 24, or preferably 48 hours at the place where datum is unknown. The table should be completed using the days with the maximum tidal range available. The mean values of the high and low water heights are used to compute r, R, m and M.

r the mean range, i.e., the difference between the mean of the observed H.W. heights, and mean of the observed L.W. heights.

m the mean level above zero of the gauge, i.e., half the sum of the observed H.W. and L.W. heights.

The following are calculated from the observed or predicted H.W. and L.W. heights of those tides at the Reference Port which correspond to the ones observed at the place to which datum is to be transferred:

R the mean range, i.e., the difference between the mean of the H.W., heights, and the mean of the L.W. heights.

M the mean level above chart datum, i.e., half the sum of the H.W. and L.W. heights.

In order to correlate datum at the two places: z/M must equal r/R

Where z is the mean level above chart datum at the place to which datum is to be transferred.

d (the zero of the automatic gauge above (+) or below (-) sounding datum) = $z - m$

So the formula for finding d can be expressed as:

$$d = Mr/R - m$$

NOTE: At those places where the diurnal inequality is large, and there is a significant difference in elevation between the two daily high waters, or the two daily low waters, data should be computed by using only one tidal range daily. The same H.H.W., either immediately preceding or following the L.L.W. must be used for both the Reference Port and the place where datum is required.

In most areas it is possible to deduce a rough approximation of z from data at places in the vicinity. This information can be obtained by consulting the Tides, Currents and Water Levels Section. It is also essential to know which are the corresponding tides. If Time Differences for the place to which datum is to be transferred are given in the Tide Tables, then these differences will show which are the corresponding tides. In other cases it will be necessary to obtain an approximate time difference from the Tides, Currents and Water Levels Section.

The datum for elevations is also computed in section 1 B of Form TWL-502. The methods of computation are clearly described on the reverse side of the form (see page 94).

Datum Notes on Field Sheets

A copy of the complete datum note for a field sheet should be submitted from the region to the Tidal Section responsible for submitting datum notes for Chart Compilation. One copy will be returned to the Regional Hydrographer, one will be sent to the Dominion Hydrographer for information and one will be retained on file by the Tidal Section for use when submitting datum adjustments to chart compilation.

Format of Datum Notes on Field Sheets

Tidal Waters - The established system should be followed. e.g. Reduced to Sounding Datum which is "x" feet below B.M. "y".

I.G.L.D. Area - The established system should be followed. e.g. - Reduced to an elevation of 576.8 ft. I.G.L.D. (1955), which is "x" feet below B.M. "y".

All Other Inland Areas - The principal emphasis of the datum note should be to state the elevation of Sounding Datum below a bench mark. The actual G.S.C. elevation of Sounding Datum may be added as a supplementary note provided the year is also included.

e.g. - Reduced to a Sounding Datum which is "x" feet below B.M. "y". In 1968 the elevation of B.M. "y" was "z" ft. above (or below) G.S.C. datum.

TIDAL RECORDS

The purpose of operating tide gauges is twofold:

(1) To provide a continuous record of the tide heights so that the correct reduction can be applied to soundings.

(2) To obtain tidal records for a sufficient period so that the harmonic constituents of the tide may be computed or time and height differences obtained by comparison with the tides at a Reference Port.

The following forms are used in the preparation of tidal records and may be obtained from the Tides, Currents and Water Levels Section before leaving on a survey.

Form 105A - Comparison Form

Form L1 and L2 - Levelling Notes

Form TWL-501 - Tabulated Hourly Heights

Form TWL-502 - Temporary Gauge Data

Tide gauges may be operated on the most convenient time zone (e.g. Standard Time or Daylight Time or Ship Time) provided that the selected time is an exact number of hours different from Standard Time. The use of G.M.T. may be convenient in some cases. Thus in Standard Time Zone +4 the tide gauge may be operated on +3, +2 or +5, etc. But in Newfoundland and Labrador where the Standard Time is +3 1/2 the only acceptable tide gauge time zones are +2 1/2 or +4 1/2 etc., NOT +2, +3 or +4. Once the gauge is in operation the diagram time should not be altered even if the local time changes from Daylight to Standard Time or vice versa.

Form 105A - Comparison Form

During the period a tide gauge is operating the comparison form records should be completed daily or as frequently as possible. The purpose of the form is to provide a check on the accuracy of the times and heights recorded by the gauge. If the diagram time error exceeds five minutes the hydrographer should reset the diagram (indicating this on the diagram and comparison form) and adjust the clock regulator. The difference between the diagram height and the staff gauge height is used as explained on the bottom of Form 105A (Figure 45). This difference should remain constant, having regard to the impossibility of making consistently accurate staff gauge readings. If the difference does change it can

usually be traced to one of the following reasons:

(a) The diaphragm assembly has moved, or the float wire has slipped, as would be indicated by a step in the graph.

(b) The elevation of the tide staff has changed.

The hydrographer may reset a slipped float wire but a shift of the diaphragm assembly can only be corrected when scaling the diagram. If the tide staff has moved, it should be set in a more stable position and its new elevation ascertained by levelling.

The importance of wind and sea conditions should not be overlooked, as this may explain why a tide is extraordinarily high or low.

The foregoing shows the importance of noting all relevant information on the comparison form and diagram so that allowances can be made for any errors in order to make an accurate scaling of the diagram possible.

COMPARISON FORM

FORM NO. 105A

LOCALITY ..... PORTNEUF, QUE. ..... GAUGE TYPE ..... OTT ..... YEAR 19 ..... 65 .....

CHIEF OF PARTY ..... JOHN DOE ..... GAUGE NO. ..... 1234 ..... TIME USED ..... E.S.T .....

MONTH			TIME COMPARISON			HEIGHT COMPARISON					WIND AND SEA			
1 DIAGRAM NO.	2 WEEK DAY	3 DATE	4 DIAGRAM TIME	5 TRUE TIME	6 TIME ERROR	7 TRUE TIME	8 TAPE GAUGE	9 STAFF GAUGE	10 DIAGRAM	11 DIFF. *	12 WIND DIRECTION	13 WIND FORCE	14 STATE OF SEA	15 READ BY
1	MON	10 MAY	1420	1418	+2	1419		1.61	1.61	0.00	N.E.	1	CALM	J.D.

I HEREBY CERTIFY that the information given on this sheet and on the Automatic Gauge record, is correct and that I personally attended to the duties with the exception of the dates stated on the back of this report.

Signed .....
Gauge Attendant

* NOTE TO HYDROGRAPHERS. The average difference in column (11) is entered as (+) in section 1A or (−) in section 1B of Form TWL–502 if the reading on the staff gauge, column (9), is greater than on the diagram, column (10) and vice versa.

Figure 45. Comparison form records — Form 105A.

DEPARTMENT OF ENERGY, MINES & RESOURCES

TABULATED HOURLY HEIGHTS

SAMPLE

FORM T.W.L. 501
(Revised 1968)

KEY PUNCH OPERATOR'S INSTRUCTIONS
Duplicate Columns 2-14,
17-20 and 69, line 4 onwards.
DO NOT PUNCH Columns 71-80
line 3 onwards.

Place: LITTLE HARBOUR Time Zone of Observations: +4 (AST) Month & Year: JULY 1969 Page 1 of 3

LINE 1 S
LINE 2

TABULATED HOURLY TIDE / WATER LEVEL HEIGHTS

Card Code	STATION IDENTIFICATION STN. NO.	GAUGE ZERO	DATE DAY	MO	YR	01	02	03	04	05	06	07	08	09	10	11	12	DAILY TOTAL
						13	14	15	16	17	18	19	20	21	22	23	24	
LINE 3 1	1		1	07	69	06431	00010	98117	40936	07240	41001	38002	70157	04320	810			
LINE 4 2	1		1	09	27	10101	01809	25073	10462	01200	10200	57051	10805	09966				14699
1	2		2	11	05	10289	20673	04380	14801	26005	60476	07380	92912	63				
2	2		2	11	48	07390	43202	11005	6	ETC.			ETC.					14350
1	3																	
2	3																	
1	4																	
2	4																	
1	5																	
2	5																	
1	6																	
2	6																	
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2	8																	
1	8																	
2	9																	
1	9																	
2	0																	
1	0																	
2	1																	
1	1																	
2	1																	

PLEASE NOTE

1. Lines 1 and 2 - Leave blank
2. Station No. - Leave blank
3. Gauge Zero - Leave blank
4. Month and Year - Enter once only (Line 3)
5. Hourly Tabulation - Use four figure notation. Indicate negative values by bar over last digit e.g. $-2{\cdot}4 = 0240$
6. Periods of interpolated heights must be indicated by inserting minus signs (-) in col. 70, cards 1 and 2, of the days concerned.
7. Tabulation of heights should begin with the first hour of recorded data. Ensure the heights are placed opposite the correct day. Daily totals are not required for computer processing.
8. Insert the number, elevation, and datum of the controlling or most reliable Bench Mark.
   B.M. No. HS 1, 1962
   B.M. Elevation 10.00
   Elevation of B.M. is referred to CHART datum
9. If the tabulated heights are referred to the zero of the automatic gauge insert the "d" correction computed on form TWL 502. If the tabulated heights are referred to Sounding or Chart Datum insert "NIL" in place of the "d" correction. Processing of the data cannot be completed without this information.
   "d" = +.70

Survey Ship / Launch: CROW Tabulated by: M.D.O.
Chief of Party: R. SMITH Checked by: E.T.T.
Sum of Daily Totals: 2250.88
M.W.L. - So (mean of hourly readings) corrected by "d" 6.95

Figure 46. Tabulated hourly heights (Form T.W.L. 501)

DETAILED GUIDE FOR COMPLETING FORM TWL 501

INTRODUCTION

The purpose of this form is to enable the hydrographer to present automatic gauging data in a format readily convertible for use by the departmental electronic computer. A selection of programs has been prepared to enable the computer to plot, quality check and analyse the tidal records, and to compute the lunitidal intervals. Chart Datums can now be quickly established or confirmed and this information passed back to the hydrographer. The data is subsequently made available for chart construction, tide tables and water level publications.

REQUIREMENTS

The basic requirement for a tidal analysis is a complete 29 or 15-day period of hourly heights. If a slightly shorter period is available, tidal curves should be extrapolated for up to 1 1/2 days at the beginning and end of the record to complete the required period. Tidal curves should also be interpolated to fill gaps of up to 2 days in the record. To do this, compare the first High Water with the first High Water on the following day NOT with the second High Water on the same day. Proceed similarly for the other tides. Ensure that a minus sign (-) is placed in col. 70, cards 1 and 2, of any day containing interpolated heights. All available records should be tabulated even if the records contain gaps.

Hourly heights are entered from 0100 - 2400 each day. This requires two lines of figures. All the hourly tabulations for one day may be added and the total entered in the Daily Total column after the 2400 reading. Heights are always tabulated as four-figure groups i.e. 1.2 feet is 0120. Negative heights are permissible. They should be indicated by a bar over the final digit, e.g. -2.4 is tabulated as 0240. Heights are usually referred to the zero of the automatic gauge. The amount the zero of the automatic gauge is above (+) or below (-) Sounding or Chart Datum ("d" from form TWL 502) MUST be shown, otherwise processing of the data cannot be completed. If the heights are referred to Sounding or Chart Datum, a value of NIL must be shown in place of the "d" correction.

Tabulated heights should be referred to the same plane throughout the entire period of observations. Adjustments to readings, because of movement of the pressure head or slipping of the float wire, must be applied during tabulation of the data. Steps in the record, or a change in the difference between the record and staff gauge readings on the comparison form, normally indicate the need for such corrections. Adjustments due to time errors, which are indicated on the comparison form, must be made during tabulation of the data. These adjustments should be noted on the record.

A separate sheet should be used for each calendar month of data.

If the record available for a station covers less than a 12-day period, a harmonic analysis is not possible. Form TWL 516 (tabulated high and low waters) should therefore be completed and submitted with all other tidal data. This will enable the Tides and Water Levels Section to calculate approximate time and height differences, from a suitable reference port.

If the height of mean water level above Chart Datum is required prior to computer processing, the daily totals should be summed and divided by the number of hourly tabulations. This gives the value of So to which the value of "d" from form TWL 502 can be applied to obtain Mean Water Level.

This guide should also be followed for inland water surveys except that interpolation is not necessary. This data will be used for making water level transfers.

Lines 1 and 2 will be completed by the Tides and Water Levels Section. Col. 1 and 69 of form TWL 501 are for the attention of the keypunch operator only.

Please forward this form together with form TWL 502, via appropriate channels, to the Tides and Water Levels Section, Ottawa, for processing at the earliest opportunity. This will enable us to confirm the validity of your sounding datum and will ensure that your data reaches the public in the next edition of "Water Levels, Volume 3 - Temporary Gauges", in the next amendment to "Tides and Water Level Bench Marks" and, if appropriate, in the "Canadian Tide and Current Tables". It may not be possible to include data, received later than April 1 of the following year, in the Water Levels publication.

MINES AND TECHNICAL SURVEYS

FORM TWL-502

Temporary Gauge Data

LITTLE HARBOUR
Place

SECTION 1. DATUM COMPUTATIONS AND LEVELLING SUMMARY

SECTION 1A. BY RECOVERY OF PREVIOUSLY ESTABLISHED CHART DATUM.

Fundamental or reference bench mark 2 is 7.00 ft. above chart datum.

BM(a) 2 above chart datum	7.00	BM(a) 2 above chart datum	7.00
BM(b) 3 above/~~below~~ BM(a)	+ 5.02	BM(b) 4 above/~~below~~ BM(a) 2	+ 2.00
BM(b) 3 above chart datum	12.02	BM(b) 4 above chart datum	9.00
BM(a) above chart datum		BM(a) above chart datum	
BM(b) above/below BM(a)		BM(b) above/below BM(a)	
BM(b) above chart datum		BM(b) above chart datum	

BM 2 above chart datum	+	7.00
Zero of staff gauge below BM 2	−	8.00
∴ Zero of staff gauge + above/− below chart datum	−	1.00 *
Zero of automatic gauge + above/−below zero of staff gauge		0.00 **
∴ Zero of automatic gauge + above/− below chart datum	−	1.00 ***

SECTION 1B. BY TRANSFER OF A PREVIOUSLY ESTABLISHED CHART DATUM AT BIG ISLAND (Z)

MONTH	OBSERVED HEIGHTS AT TEMPORARY GAUGE		OBSERVED OR PREDICTED HEIGHTS AT (Z)	
DAY	H.W.	L.W.	H.W.	L.W.
15	10.00	2.00	16.00	4.00
15	10.00	2.00	16.00	4.00
16	10.00	2.00	16.00	4.00
16	10.00	2.00	16.00	4.00
17	10.00	2.00	16.00	4.00
17	10.00	2.00	16.00	4.00
SUM	60.00	12.00	96.00	24.00
MEAN	10.00	2.00	16.00	4.00
	(1)	(2)	(3)	(4)

(1)−(2)=r= 8.00 (2)+ ½r=m= 6.00

(3)−(4)=R= 12.00 (4)+ ½R=M= 10.00

DATUM FOR SOUNDINGS REFERRED TO ZERO OF AUTOMATIC GAUGE = d = Mr/R − m

= (M 10.00 xr 8.00 /R 12.00) − m 6.00

= 6.70 − m 6.00 = d = + 0.70 ***

DATUM FOR HEIGHTS IS HIGHER HIGH WATER (large tides)

HHW (large tides) at (Z) 21.00 xr 8.00 /R 12.00

Datum for heights 14.00 above Sounding Datum

Zero of automatic gauge + above/− ~~below~~ sounding datum (d)	+	0.70 *
Zero of staff gauge + ~~above~~/− below zero of automatic gauge	−	0.20 **
Zero of staff gauge + above/− below sounding datum (e)	+	0.50
BM 1 above zero of staff gauge	+	9.50
Zero of staff gauge + above/− below sounding datum (e)	+	0.50
BM 1 above sounding datum	+	10.00

BM(a) 1 above sounding datum	10.00	BM(a) 2 above sounding datum	7.00
BM(b) 2 ~~above~~/below BM(a) 1	− 3.00	BM(b) 3 above/~~below~~ BM(a) 2	+ 5.00
BM(b) 2 above sounding datum	7.00	BM(b) 3 above sounding datum	12.00
BM(a) 1 above sounding datum	10.00	BM(a) above sounding datum	
BM(b) 3 above/~~below~~ BM(a) 1	+ 2.00	BM(b) above/below BM(a)	
BM(b) 3 above sounding datum	12.00	BM(b) above sounding datum	

* use appropriate signs. ** From comparison Form 105-A. *** enter on Form TWL-501.

NAME LITTLE HARBOUR VICINITY WIDE BAY

GENERAL LOCALITY N.S. LATITUDE 45° 00.'0 N. LONGITUDE 65° 00.'0 W.

FIELD SHEETS AFFECTED F.S. 4380 L-1 & 4359 S.C. AUG. 26 - OCT. 15, '63

TIME ZONE OF OBSERVATIONS + 4 OR A.S.T. PERIOD GAUGE IN OPERATION: FROM ~~AUG. 29~~ TO ~~OCT. 10, '62~~

O.I.C. R. SMITH SURVEY ESTABLISHMENT ~~"CROW"~~ "RAVEN"

NAME AND TYPE OF GAUGE: OTTBORO float ☐, pressure ☑, staff ☐. TYPE OF DIAGRAM: strip ☑, or ☐

RANGE OF GAUGE 10 ft. ☑ 20 ft. ☐ 30 ft. ☐ 40 ft. ☐ 50 ft. ☐

SECTION 3. TYPE OF RECORD OBTAINED AND LOCATION OF GAUGING SITE.

Year 1962 TYPE OF RECORD: Continuous ☑ Or Staff gauge readings: hourly ☐ or ____ times daily ☐

The gauge was located On the eastern side of the Government wharf at Little Harbour. (Poor location due to silting)

Year 1963 TYPE OF RECORD: Continuous ☑ Or Staff gauge readings: hourly ☐ or ____ times daily ☐

The gauge was located on the western side of the Government wharf at Little Harbour.

Year ____ TYPE OF RECORD: Continuous ☐ Or Staff gauge readings: hourly ☐ or ____ times daily ☐

The gauge was located ____

Year ____ TYPE OF RECORD: Continuous ☐ Or Staff gauge readings: hourly ☐ or ____ times daily ☐

The gauge was located ____

SECTION 4. METHOD BY WHICH BENCH MARK ELEVATIONS WERE ORIGINALLY ESTABLISHED AND WERE MAINTAINED DURING THE PERIODS OF OPERATION OF THE GAUGE SITE.

Year 1962 : Sounding Datum established by water level transfer from Big Island B.M.'s levelled into Sounding Datum.

Year 1963 Levelling run from controlling B.M. No. 2

Year

Year

SECTION 5. TABULATION OF OBSERVED BENCH MARK ELEVATIONS

Date	O.I.C.	Establishment	B.M. No. 1	B.M. No. 2	B.M. No. 3	B.M. No. 4	B.M. No.	Datum Used
6/9/'62	R. Smith	"CROW"	10.00 *	7.00	12.00			S.D.
5/9/'63	R. Smith	"RAVEN"		7.00 *	12.02	9.00		C.D.

SECTION 6. DATUM FOR HEIGHTS 14.00 above Sounding Datum 14.00 above Chart Datum

SECTION 7. BENCH MARK DESCRIPTIONS

B.M. NO. 1 A C.H.S. (agency) bronze tablet stamped 1, 1962 set

Sounding datum 10.00 ft. below.
Chart datum ft. below.
G.S.C. elevation
IGLD (1955) elev.
BM condition DESTROYED 1963

in the south concrete foundation of the General Store at the Little Harbour Government wharf. It is 1 foot above ground and 1 foot from the southwest corner.

DESTROYED

correct ☐ amended ☑

B.M. NO. 2 A C.H.S. (agency) bronze tablet stamped 2-1962 set

Sounding datum 7.00 ft. below.
Chart datum 7.00 ft. below.
G.S.C. elevation
IGLD (1955) elev.
BM condition Good 1963

in the concrete foundation of the fish plant close by the Little Harbour Government wharf. It is 1 foot from the northwest corner and is on the west side of the plant.

correct ☑ amended ☐

B.M. NO. 3 A C.H.S. (agency) bronze tablet stamped 3-1962 set

Sounding datum 12.00 ft. below.
Chart datum 12.00 ft. below.
G.S.C. elevation
IGLD (1955) elev.
BM condition Good 1963

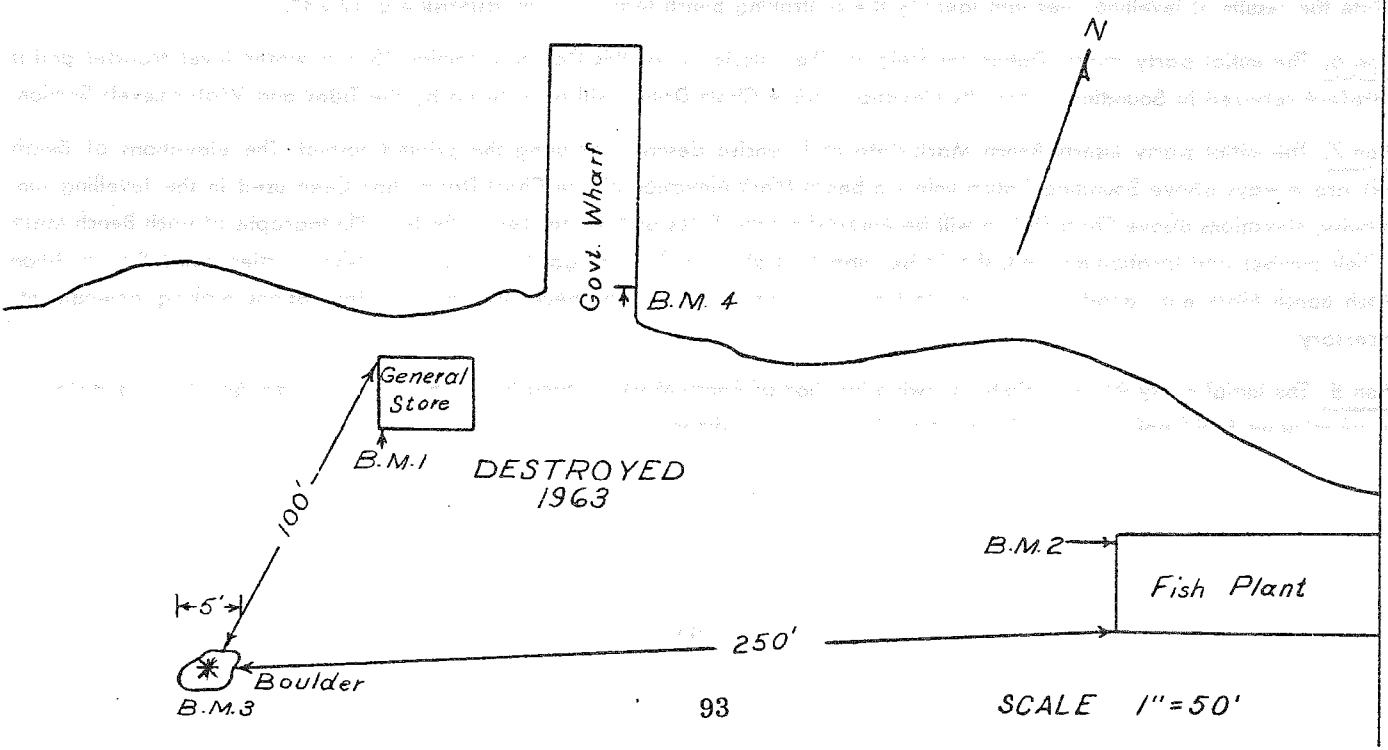
in the top of a large boulder located 250 feet west of wharf at Little Harbour, ~~and 100 feet southwest of the northwest corner of the genera store~~

See additional sheet for B.M.4

correct ☐ amended ☑

SECTION 8. SKETCH

correct ☐ amended ☑



Form TWL-502

Temporary Gauge Data

This form combines a computation sheet for datums and Bench Mark elevations, a gauge history for past and present data and a Bench Mark sketch with descriptions along with detailed instructions for standardizing its use. The gauge history will be supplied along with Bench Mark data when required.

Section 1. This section is for computing the elevation of all Bench Marks and the zero of the automatic gauge relative to chart or sounding datum. The Bench Marks should follow the pattern indicated by the letters a and b, and the convention + above and − below should be used throughout *having careful regard to the exact context.*

Section 1A. is used by successive parties when the elevation of Chart Datum below a Bench Mark is known. The elevation of all Bench Marks in the net and the zero of the staff gauge are related to Chart Datum. The zero of the automatic gauge relative to the zero of the staff gauge is found by comparing simultaneous readings recorded on the comparison form and hence the zero of the automatic gauge relative to Chart Datum.

Section 1B. This section is used by the initial party to transfer Chart Datum from a place (Z) where it has already been established. The table should be completed using the days with the maximum tidal range available. The mean values are used as indicated to compute r,R,m,M, and hence "d" the amount the zero of the automatic gauge is above (+) or below (−) Sounding Datum. The zero of the staff gauge relative to the zero of the automatic gauge is found by comparing simultaneous readings recorded on the comparison form and hence the zero of the staff gauge is found relative to Sounding Datum. The elevation of all Bench Marks in the net are then computed above Sounding Datum. The Higher High Water (Large Tides) datum for heights can be calculated using the Higher High Water (Large Tides) at (Z) and r/R as indicated. The Higher High Water (Large Tides) at (Z) is found by applying the Higher High Water (Large Tides) height difference at Z to the Higher High Water (Large Tides) height at the appropriate reference port. If this data is not published, it will be supplied by the Tides and Water Levels Section.

Section 2. All parties insert or check appropriate data (In sections 3, 4 and 5 all parties complete one section of each).

Section 3. Check type of record and insert a brief description of the site.

Section 4. Insert a brief description of the method used for establishing the Bench Mark elevations e.g. water level transfer from "Z" or levelling run from Geodetic Bench Mark No. "CCX". Similarly for successive years e.g., levelling run from controlling Bench Mark No. 1.

Section 5. The elevations of Bench Marks are accepted as those computed by the party which establishes them. Successive parties tabulate the results of levelling lines and identify the controlling Bench Mark with an asterisk e.g. 12.23*.

Section 6. The initial party inserts Datum for Heights. The calculation of this Datum in section 1B is a water level transfer and it is therefore referred to Sounding Datum. Its elevation above Chart Datum will be entered by the Tides and Water Levels Section.

Section 7. The initial party inserts Bench Mark data and concise descriptions using the printed format. The elevations of Bench Marks are always above Sounding Datum unless a Bench Mark elevation above Chart Datum has been used in the levelling run. Otherwise, elevations above Chart Datum will be entered by the Tides and Water Levels Section. Photographs of each Bench Mark with their number and location marked, should be submitted along with other gauge data. Successive parties insert the condition of each Bench Mark e.g., good, unreliable, destroyed or not located, and check accuracy of descriptions making amendments if necessary.

Section 8. The initial party draws a sketch showing location of Bench Mark, automatic gauge and staff gauge, showing distances from conspicuous fixed points. Successive parties check for amendments if necessary.

Form TWL-501 Tabulated Hourly Heights

The purpose of this form is to enable the hydrographer to present the gauge recordings in a format usable for the electronic computer.

Form TWL-501 should be kept up-to-date by tabulating the hourly tidal heights each time the tide graph is removed. Detailed instructions are given on the back of the form (page 90).

Form TWL-502 Temporary Gauge Data

All data from and about a temporary gauge is entered on Form TWL-502. The form combines a computation sheet for datums and bench mark elevations, a gauge history for past and present data, and a bench mark sketch with descriptions, along with detailed instructions for standardising its use. The Tides, Currents and Water Levels Section will transfer new data supplied by successive parties to the original form submitted by the initial party. This will create a history of each gauge site which will be supplied along with all bench mark data to successive hydrographic parties surveying in the area.

The use of Sections 1A and B has been explained in the chapter on datum (page 84).

The following sample of Form TWL-502 contains two seasons data. Section 1B was used during the first season and 1A during the second. The alterations in Section 2 are for the purpose of this sample only, in all other sections each seasons work is dated.

INSTRUCTIONS FOR SUBMITTING TIDAL DATA

When a specific survey project has been completed, or operations ceased on a project for any reason, the following are to be submitted promptly to the Tides, Currents and Water Levels Section, Regional Offices.

(1) Form TWL-501

(2) Form TWL-502

(3) Levelling Notes

These should not be held for submission at the end of the season. If the survey officer wishes to keep records of any of the above items for his own information, he should retain a duplicate copy. The original notes must be submitted to the Regional Office.

The analysis of tidal data submitted on Form T.W.L. 501 will not be carried out until a completed copy of Form T.W.L. 502 is received.

At the conclusion of the field season, the following are to be submitted to the Tides, Currents and Water Levels Section, Regional Offices:

(1) Automatic gauge records

(2) Comparison form 105A

(3) Bench mark photographs

An early return of the records is most desirable in order that any queries raised by the Tides, Currents and Water Levels Section may be discussed while the details are still fresh in the mind of the Hydrographer.

PROCESSING OF TIDAL RECORDS

Form TWL-501 is sent for keypunching, where the data is transferred to punched cards. These cards and a special programme are fed into the Department's electronic computer, which in a few minutes produces the harmonic constituents of the tide at the gauge site. This data is further processed to produce tidal ratios or characteristics, and lunitidal intervals and heights. A suitable Reference Port with similar characteristics is selected and their lunitidal intervals and heights compared. The difference between them are filed for insertion in the Secondary Ports tables of the next edition of the Tide Tables. The lunitidal heights are also filed for inclusion under Tidal Information on new or revised charts. The Harmonic Constants are made available through the International Hydrographic Bureau to all participating nations.

Levelling notes, datum computations, and levelling summaries are carefully checked. If the calculation of the lunitidal intervals and heights shows that the height of LLW large tides is within plus or minus 1 foot of zero, sounding datum is accepted as chart datum. If it exceeds this amount, the sounding datum is raised or lowered accordingly, and the survey party is notified so that a note to that effect can be put on the field sheet.

Form TWL-502 is completed with the bench mark elevations and HHW datums above chart datum. New data or information is transferred to the original on file so that it is available whenever required. The automatic gauge records and comparison forms are stored at the Public Archives and are available for future study if required. All other information is filed in the Regional Offices.

ACCURACY OF RECORDS

In most cases the predictions for Reference Ports are based on the analysis of long period observations, recorded by tide gauges under the control of the Tides and Water Levels Section. In other cases, particularly in Arctic waters, it may not be feasible to obtain long period observations, and the predictions must be based on the comparatively short period observations obtained in the course of hydrographic surveys.

The responses of the sea to the various changes in astronomical conditions can only be completely separated, and subsequently predicted, by the analysis of continuous observations for the period of a year. For any shorter period, assumptions must be made and the shorter the period of observation the greater the number of assumptions. The shortest period which can be analysed harmonically is 15 days of continuous observations, but the relative value of such observations is only a quarter of that of a period of 29 days continuous observations. With observations for a year there is a reasonable expectation that casual errors will cancel out but with a short period their effects may be cumulative, with a very adverse effect upon the subsequent analysis and in consequence upon any predictions which may be made in the future. It is essential therefore that care should be taken to ensure that the records are as accurate as possible.

Apart from their possible use in making predictions for a Reference Port, the most general purpose for which the tidal observations are required is to enable time and height differences, between the tide at the place of observation and that at the most suitable Reference Port, to be calculated for use by the navigator. The accuracy of the predictions is very dependant on the similarity between the characteristics of the tides. These characteristics are determined by:

(1) The age of the semidiurnal tide, that is the interval between new and full moon and the occurrence of spring tides, and the degree of variation in range between springs and neaps.

(2) The age of the diurnal tide, that is the interval between the moon's maximum declination, north or south of the equator, and the occurrence of tropical spring tides and the degree of variation in range between tropical springs and neaps.

(3) The interval between the arrival of the crests of the semi-diurnal and diurnal tides and the relative magnitudes of the two tides.

These characteristics can only be determined by the harmonic analysis of continuous observations for at least 15 days and the selection of the most suitable Reference Port for any particular place is based on a comparison between the characteristics of the tide at that place and those at a variety of Reference Ports. In those areas where there already exists a close network of tidal stations at which harmonic data is available, the characteristics of the tide at intermediate

places can reasonably be inferred. Part-day observations, or observations of the times and heights of high and low water only, are valuable in calculating time and height differences on a Reference Port. In the Arctic, or in other areas where no close network exists, observations of that type would be quite useless.

Another important reason for accuracy in tidal observations is that it will never be possible to obtain tidal observations at every point on the coast, and in the less habitable areas they will always be very scanty. Therefore it is essential that at those places where observations are obtained, they should be of the greatest accuracy, for it is impossible to foresee future developments, either commercial or strategic, and there may arise quite suddenly a vital need for tidal data at a place where no observations have been obtained. The only way in which that information can be supplied is by inference, usually with the aid of cotidal charts, from the information available elsewhere in the same area. The reliability of the inferences will be directly related to that of the observations previously obtained.

It is very important that a tide gauge station and all the relevant records be maintained with the aim of obtaining the highest degree of reliability and precision that is practicable. It is essential that the information supplied to the Tides, Currents and Water Levels Section is in accordance with the instructions of this manual in order to ensure that correct information as to tidal levels and chart datum is provided for charts and tide tables.

COTIDAL CHARTS

General

The accumulation of tidal and inland water level data has made it possible to construct temporary cotidal charts for the hydrographer's use. Hydrographers are encouraged to use cotidal charts for the reduction of off-shore soundings.

Cotidal charts are based on the analyses of data collected by Hydrographic surveys along the coast, and from tidal and current surveys in open waters. The longer the periods of observation, the more accurate are the analyses and thus the more precise the positioning of the cotidal lines on the chart.

A cotidal chart, in areas with a predominently semi-diurnal tide, is formed by joining points at which high water occurs at the same time and the range of the tide is equal. Normally the heights are calculated in proportion to those of a Reference Port. These charts will be supplied by the Regional Tidal Offices for any area where their use would be beneficial.

Use of Cotidal Charts

The cotidal chart is divided into time and height zones related to the zone containing the controlling tide gauge (Figure 47). These time and height zones are distinguished from one another by using solid lines to mark time zones, and pecked lines to mark height zones. Heights are tabulated in relation to the gauge heights used for the survey and should be used after the proper time corrections have been applied to the gauge times. The tabulated values must be revised for every gauge location having a different mean range.

The formula used for calculating these heights is termed the height ratio, and is expressed as follows:

$$\text{Height Ratio: } \frac{\text{Mean range at ship}}{\text{Mean range at reference gauge.}}$$

where the mean range at the ship is obtained from the cotidal chart and may be checked at certain locations by a series of echo soundings over a 24-hour period.

The following example using the Bay of Funday as an operational area illustrates the procedure to be followed.

First the curves plotted on the cotidal chart must be transferred to the field sheet or boat board to enable the hydrographer to ascertain when plotting the positions of his soundings, as to which zones they fall in. If the curves are plotted on the boat board, the notes can be kept up-to-date during sounding operations by recording the respective zone and time correction.

The solid curves are time adjustment curves and indicate the correction to be applied to the true tide gauge time. There is no time correction in the zero zone contained between the solid lines on either side of Deep Cove, N.S. where the reference gauge is set up for this operation. Moving to the northeast of Deep Cove and crossing the first solid line, 10 minutes, after crossing the second solid line, 20 minutes, and so on, must be added to true gauge time.

Having applied these time corrections to the true gauge diagram times, the corrected gauge heights are referred to the tabulated values according to the zones in which the soundings lie (Figure 48). These zones are marked by pecked curves and represent steps of one-foot intervals.

For example, a sounding in zone -6 would have a minus correction of 10 minutes to true gauge diagram time. The gauge reading for this new time may be, say 10.0 feet. Now, going to the tabulated values for zone -6, the proper reading would be 7.09 feet; for zone + 6 the reading would be 12.91 feet. These would be the proper reductions for soundings in these zones.

The use of cotidal charts is only suitable in areas where the tide is predominantly semi-diurnal and where a good coverage of tidal data is available. Furthermore the sounding area should not be located too far from the gauge location as meteorological conditions could be quite different between the two locations.

Cotidal charts are not meant to replace the present method of establishing gauges. They are however very useful for obtaining accurate reductions on off-shore sounding operations.

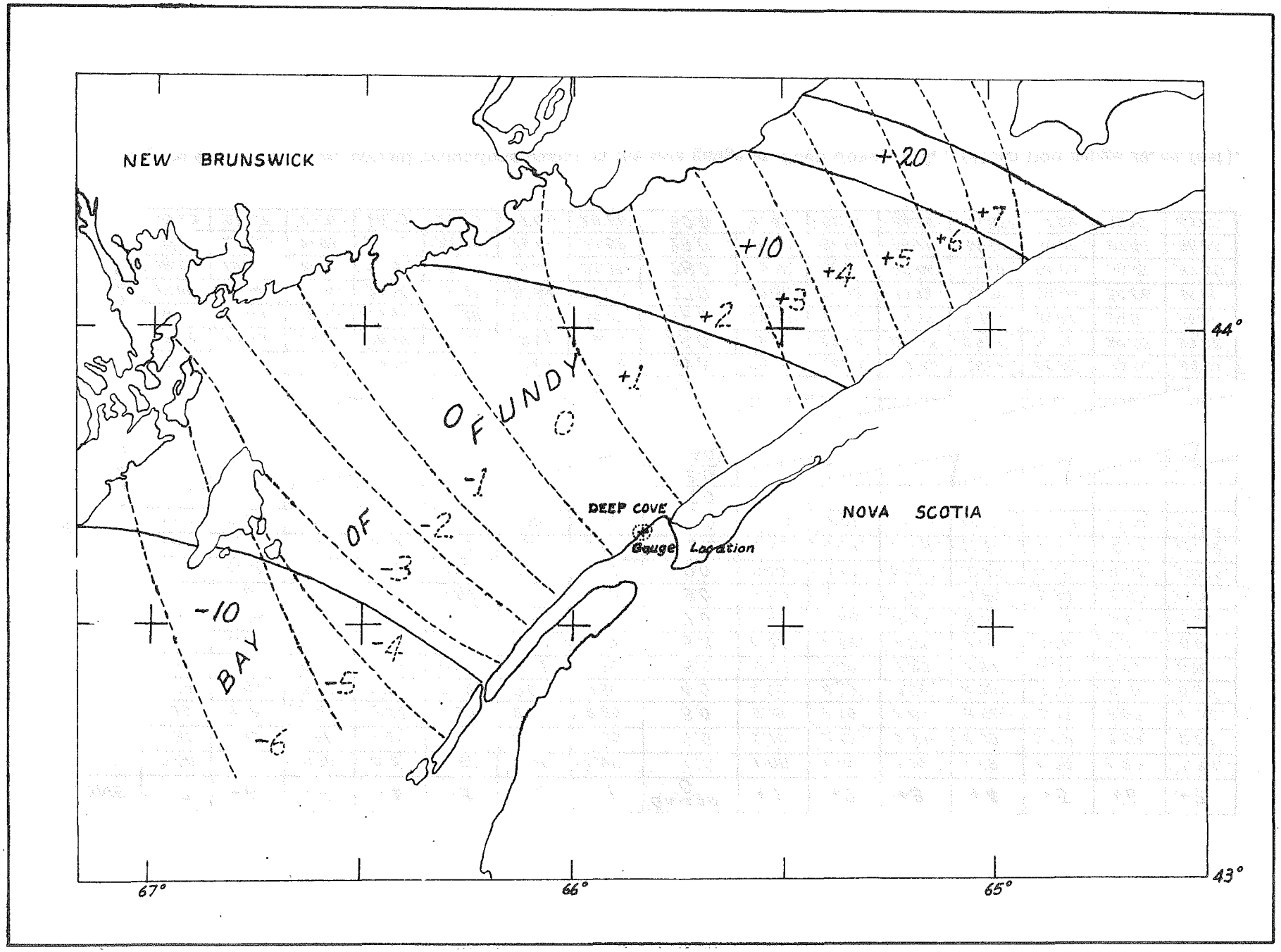


Figure 47. Cotidal chart —— Bay of Fundy.

REDUCTIONS (in feet)

ZONE	-7	-6	-5	-4	-3	-2	-1	Gauge 0	+1	+2	+3	+4	+5	+6	+7
	0.66	0.71	0.76	0.81	0.86	0.90	0.95	1.0	1.05	1.10	1.15	1.19	1.24	1.29	1.34
	1.32	1.42	1.51	1.61	1.71	1.81	1.90	2.0	2.10	2.19	2.29	2.39	2.49	2.58	2.68
	1.98	2.13	2.27	2.42	2.57	2.71	2.85	3.0	3.15	3.29	3.44	3.58	3.73	3.87	4.02
	2.64	2.84	3.03	3.22	3.42	3.61	3.80	4.0	4.20	4.39	4.58	4.78	4.97	5.16	5.36
	3.31	3.55	3.79	4.03	4.28	4.52	4.76	5.0	5.25	5.49	5.73	5.97	6.22	6.46	6.70
	3.97	4.25	4.54	4.84	5.13	5.42	5.71	6.0	6.29	6.58	6.87	7.16	7.46	7.75	8.03
	4.63	4.96	5.30	5.64	5.99	6.32	6.66	7.0	7.34	7.68	8.02	8.36	8.70	9.04	9.37
	5.29	5.67	6.06	6.45	6.84	7.22	7.61	8.0	8.39	8.78	9.16	9.55	9.94	10.33	10.71
	5.95	6.38	6.81	7.25	7.70	8.13	8.56	9.0	9.44	9.87	10.31	10.74	11.19	11.62	12.05
	6.61	7.09	7.57	8.06	8.55	9.03	9.51	10.0	10.49	10.97	11.45	11.94	12.43	12.91	13.39
	7.27	7.80	8.33	8.87	9.41	9.93	10.46	11.0	11.54	12.07	12.60	13.13	13.67	14.20	14.73
								12.0							
								13.0							
								[illegible]							
								[illegible]							
	15.86	17.02	18.17	19.34	20.52	21.67	22.82	24.0	25.18	26.33	27.48	28.66	29.83	30.98	32.14
	16.53	17.73	18.93	20.15	21.38	22.58	23.78	25.0	26.23	27.43	28.63	29.85	31.08	32.28	33.48
	17.19	18.43	19.68	20.96	22.23	23.48	24.73	26.0	27.27	28.52	29.77	31.04	32.32	33.57	34.81
	17.85	19.14	20.44	21.76	23.09	24.38	25.69	27.0	28.32	29.62	30.92	32.24	33.56	34.86	36.15
	18.51	19.85	21.20	22.57	23.94	25.28	26.63	28.0	29.37	30.72	32.06	33.43	34.80	36.15	37.49
	19.17	20.56	21.95	23.37	24.80	26.19	27.58	29.0	30.42	31.81	33.21	34.63	36.05	37.44	38.83
	19.83	21.27	22.71	24.18	25.65	27.09	28.53	30.0	31.47	32.91	34.35	35.82	37.29	38.73	40.17

Figure 48. Tabulated cotidal reductions based on the tide gauge at Deep Cove, N. S., (Mean tide range 20. 64 feet).

AIDS FOR SCALING GAUGE RECORDS

H. W. K. Gauge Reader

Instructions for the use of the H. W. K. Tide Recorder, as shown in Figure 49, have not been included in this manual as the gauge is only issued on special request. When the recorder is issued to field parties, detailed operating instructions will be included.

Because the need of a tide graph scaling device in the field has long been warrented, this gauge has been fitted with a scaling indicator and time correction scale, and can be used for scaling graphs of any of the recorders in present use. This a very useful aid when tabulating the hourly heights on Form T W L-501, as both time and height errors can be eliminated prior to scaling operations. When used in a scaling role the timing gears on the left of the gauge must be removed to facilitate paper movement.

Time errors on the graph are eliminated by use of the plastic correction scale (1) on the left of the gauge. The time error is set on the plastic scale with reference to the graph paper, the indicator pointer (2) is set on this time correction and the paper then adjusted so that either the zero or sixty minute division rests exactly over the hour divisions on the graph paper according as to whether the correction is minus or plus respectively. The pointer, when placed over the graph, has thus been adjusted for the gauge time error. Errors of up to plus or minus one hour can be eliminated in this manner.

Height errors on the graph can be eliminated by rotating the indicator pointer, (2), to the left for a plus correction or to the right for a minus correction. The tip of the pointer as it follows the gauge graph will thus compensate for a height discrepancy of up to 1 foot on the 0-10 foot range, or up to 2 feet on the 0-20 foot range.

Both time and height errors are now removed, and the gauge graph can be scaled directly by placing the pointer over the graph and reading the corrected heights on the upper scale. The scale can be changed according to the range of the graph concerned.

When using this instrument in conjunction with cotidal charts, the time zone correction can be incorporated in the time correction scale by the method described above.

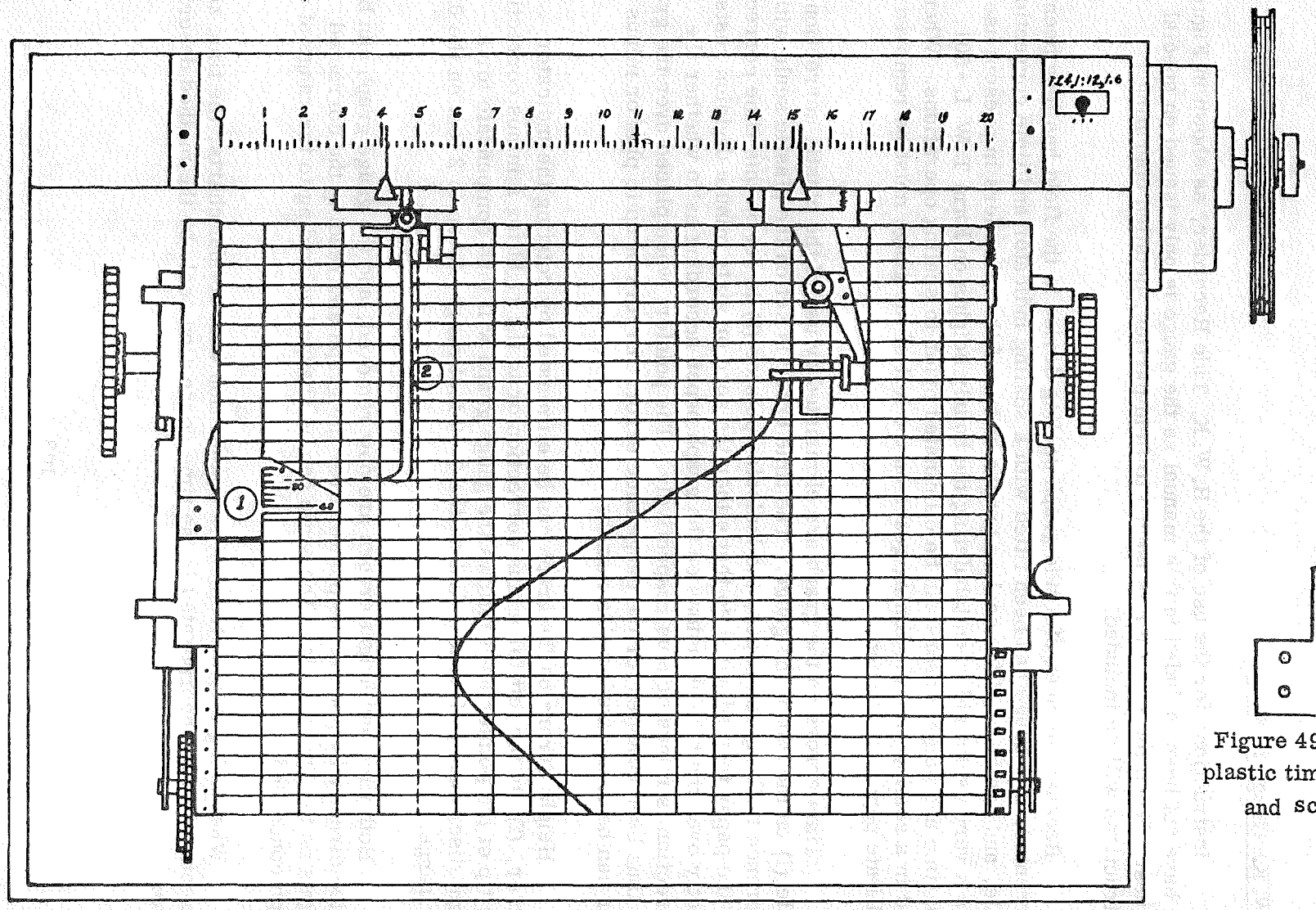


Figure 49. H. W. K. Gauge in two applications; on the left in a scaling role, and on the right as a tide or water level recorder.

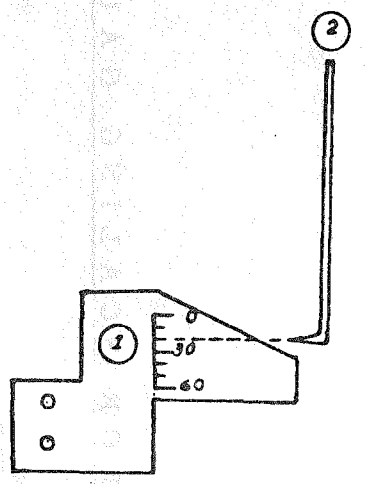


Figure 49a. Enlarged view of plastic time correction scale (1) and scaling indicator (2).

HARMONIC METHOD OF TIDAL PREDICTIONS

The tide at any given point can be considered as a combination of a number of tidal constituents with a constant amplitude (A) and a constant phase lag (g). By harmonic analyses these constituents have been computed for many ports and coastal localities. Their characteristics are valid without major changes for several years, and tidal predictions may be carried out for any day or time of the year. The formula for the prediction of the tide level is:

$$h(t) = Z_o + A_i f_i \cos (V_i + u_i - g_i + a_i t)$$

where Z_o is the mean water level; A and g the amplitude and phase lag; f, V + u the astronomical arguments; and a, the angular speed of a particular constituent.

Up to 60 constituents are sometimes used for the High and Low water predictions in the Tide Tables. To carry out the necessary computations by hand would be very time consuming, therefore analog or digital computers are employed. For the reduction of soundings or other navigational purposes however, it may become necessary to know the hourly water levels for a day or several days. These predictions may be carried out by hand, with the aid of the following tidal constituents:

Z_o, M_2, S_2, K_2, N_2, u_2, K_1, O_1, P_1, M_4 and MS_4

and the tables:

1. Astronomical argument 360 - V + u.
2. Daily corrections for the astronomical argument;
3. Time of High Water;
4. Water level at half-hourly intervals for given amplitudes;
5. Astronomical factor (f) for January 1 of each year.

Definitions of Constituents

M_2 - Principal lunar semi-diurnal constituent.

M_4 - Shallow water constituent.

S_2 - Principal solar semi-diurnal constituent.

MS_4 - Shallow water constituent.

N_2 - Larger lunar elliptic semi-diurnal constituent.

u_2 - Smaller lunar elliptic constituent.

P_1 - Principal solar declinational diurnal constituent.

O_1 - Principal lunar declinational diurnal constituent.

K_1 - Combination of lunar and solar declinational diurnal constituents.

K_2 - Combination of lunar and solar declinational semi-diurnal constituent.

Z_o - Elevation of mean sea level above chart datum.

g - The lag of the phase of the tidal constituent behind the phase of the corresponding equilibrium constituent at Greenwhich.

w - An angle varying within a cycle of 18.61 years.

A - Amplitude of a constituent.

f - A factor varying within a cycle of 18.61 years.

Example of Harmonic Prediction (Figures 50, 51.)

Predict the tide at hourly intervals for August 10, 1964 (E.S.T.) at Father Point, Que.

Given the following constituents:

	Z_o	M_2	S_2	K_2	N_2	u_2	K_1	O_1	P_1	M_4	MS_4
A ft	7.5	4.2	1.4	0.4	0.9	0.2	0.8	0.7	0.3	-	0.1
g° (0500 Hours)	-	053	090	087	029	001	202	182	198	-	038

LOCALITY FATHER POINT (E.S.T.) MONTH AUGUST 10 YEAR 1964

	M_2	S_2	N_2	K_2	u_2	K_1	O_1	P_1	M_4	S_4			Z_0	Use table
MARK	033	000	090	178	065	359	030	010		033				1
DAY	013	000	033	282	025	141	232	219		013				2
°	053	090	029	087	001	202	182	198		038				
	099	090	152	547	091	702	444	427		084				
-360				360		360	360	360						
	099	090	152	187	091	342	084	067		084				
Table 1	3.5	3.0	5.5	6.0	3.5	23.0	6.0	4.5		1.5				3
A	4.2	1.4	0.9	0.4	0.2	0.8	0.7	0.3		0.1				
f	1.001	1.000	1.001	1.008	1.001	1.011	1.018	1.000		1.001				2
Cor.	4.2	1.4	0.9	0.4	0.2	0.8	0.7	0.3		0.1			7.5	
0	-0.8	0.0	-0.8	-0.4	0.0	0.8	0.1	0.1		0.0			6.5	4
1	1.3	0.7	-0.6	-0.3	0.1	0.7	0.3	0.1		0.1			9.9	↓
2	3.0	1.2	-0.2	-0.2	0.1	0.6	0.4	0.2		0.1			12.7	↓
3	4.1	1.4	0.3	0.0	0.2	0.4	0.6	0.3		0.0			14.8	
4	4.1	1.2	0.6	0.2	0.2	0.2	0.7	0.3		-0.1			14.9	
5	3.0	0.7	0.9	0.3	0.1	0.0	0.8	0.3		-0.1			13.5	
6	1.3	0.0	0.9	0.4	0.1	-0.2	0.8	0.3		0.0			11.1	
7	-0.8	-0.7	0.6	0.3	0.0	-0.4	0.8	0.2		0.1			7.6	
8	-2.7	-1.2	0.3	0.2	-0.1	-0.6	0.7	0.1		0.1			4.3	
9	-3.9	-1.4	-0.2	0.0	-0.2	-0.7	0.6	0.1		0.0			1.8	
10	-4.2	-1.2	-0.6	-0.2	-0.2	-0.8	0.4	0.0		-0.1			0.6	
11	-3.3	-0.7	-0.8	-0.3	-0.2	-0.8	0.3	-0.1		-0.1			1.5	
12	-1.7	0.0	-0.9	-0.4	-0.1	-0.8	0.1	-0.2		0.0			3.5	
13	0.4	0.7	-0.8	-0.3	0.0	-0.7	-0.1	-0.2		0.1			6.6	
14	2.4	1.2	-0.5	-0.2	0.1	-0.6	-0.3	-0.3		0.1			9.4	
15	3.8	1.4	0.0	0.0	0.2	-0.4	-0.6	-0.3		0.0			11.7	
16	4.2	1.2	0.4	0.2	0.2	-0.2	-0.6	-0.3		0.0			12.6	
17	3.6	0.7	0.7	0.3	0.2	0.0	-0.7	-0.3		-0.1			11.9	
18	2.1	0.0	0.9	0.4	0.1	0.2	-0.8	-0.3		0.1			10.0	
19	0.1	-0.7	0.8	0.3	0.1	0.4	-0.8	-0.3		0.0			7.4	
20	-2.0	-1.2	0.5	0.2	0.0	0.6	-0.8	-0.2		0.1			4.7	
21	-3.5	-1.4	0.1	0.0	-0.1	0.7	-0.7	-0.2		0.0			2.4	
22	-4.2	-1.2	-0.3	-0.2	-0.2	0.8	-0.6	-0.1		-0.1			1.4	
23	-3.8	-0.7	-0.7	-0.3	-0.2	0.8	-0.4	0.0		-0.1			2.1	
24	-2.5	0.0	-0.9	-0.4	-0.2	0.8	-0.3	0.1		-0.1			4.0	

Figure 50. Example of form used for computing Harmonic Tidal Predictions.

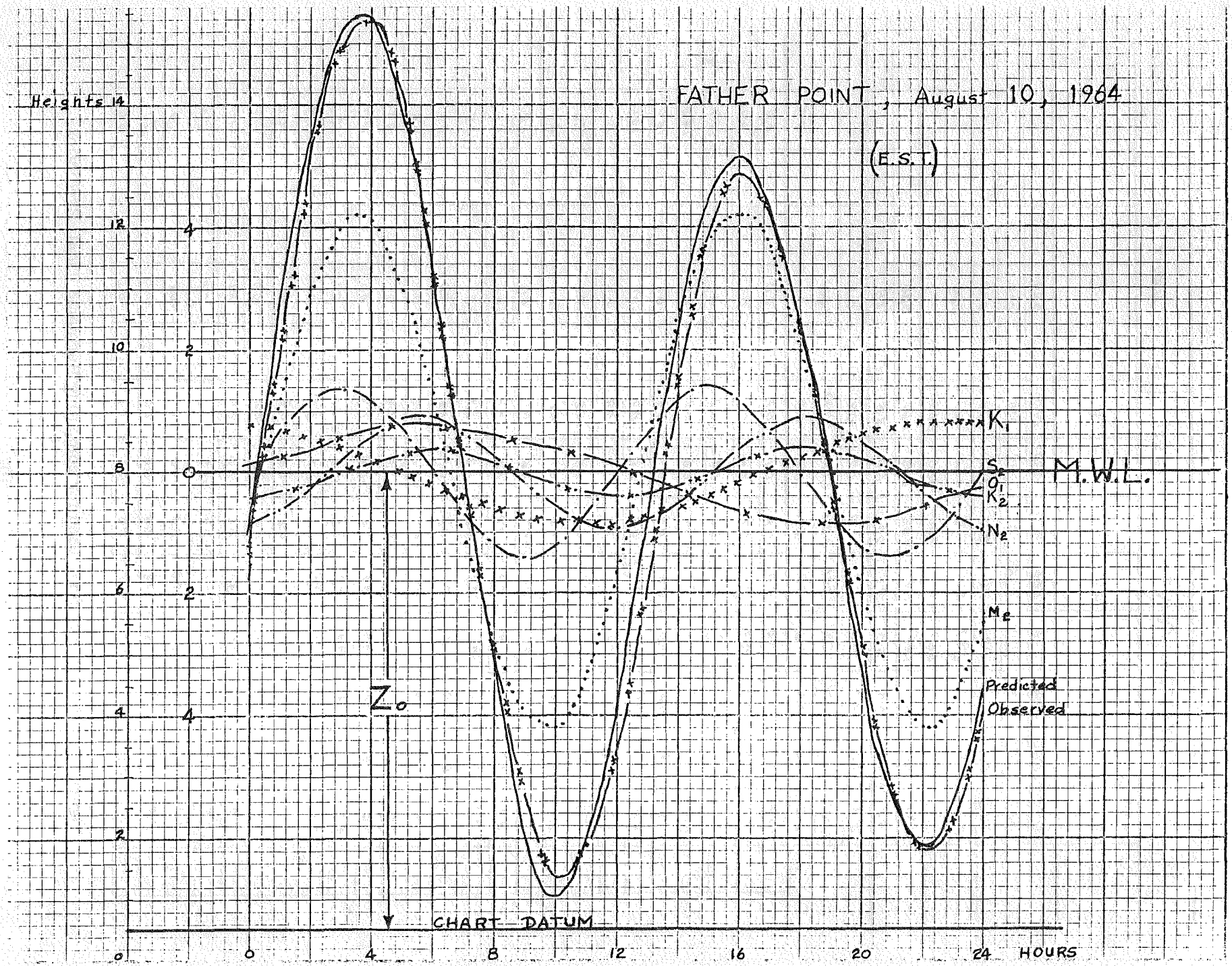


Figure 51. Predicted and observed tidal curves.

CURRENT MEASUREMENT FOR HYDROGRAPHY

HORIZONTAL MOVEMENTS OF THE SEA

The horizontal movements of the sea are due to; (a) the periodical tide-generating forces of the Moon and Sun, and (b) non-periodical changes, mainly brought about by changes in meteorological conditions.

Tidal Streams

The periodical horizontal movements of the sea, in response to the tide-generating forces, are termed tidal streams. Solely under the influence of tidal streams a particle of water will not change its mean position over the surface of the Earth, but will oscillate to and fro, over, or about, that mean position.

The tidal streams respond to the changes in the tide-generating forces, brought about by the changing relative positions of the Moon, Sun and Earth, in a manner similar to that of the tides. In consequence, the distances over which a particle oscillates from its mean position during a tidal cycle varies with these changes. As the duration of the cycle is practically constant, it follows that the rates, at which the particle travels, vary with these changes in astronomical conditions.

Rectilinear Tidal Streams (Figure 58): In narrow channels the tidal streams flow in two opposing directions. During each cycle a particle of water travels to and fro in the direction of the channel.

Rotary Tidal Streams (Figure 59): Owing to the gyroscopic effects of the Earth's rotation about its axis, there is always a tendency for a moving body to be deflected towards the right in the northern hemisphere and to the left in the southern hemisphere. In open waters, therefore, a particle of water, solely under the influence of tidal streams, tends to travel in an ellipse about its mean position over the surface of the Earth.

In the great majority of cases, the tidal streams fall between the two extremes and a particle of water travels in a fairly narrow ellipse around its mean position.

Semidiurnal Tidal Streams: If the complete oscillation, which carries a particle of water to and fro over, or in an ellipse around its mean position, takes place in an average period of half a lunar day, the tidal stream has a semi-diurnal cycle.

Diurnal Tidal Streams: If the complete oscillation, which carries a particle of water to and fro over, or in an ellipse around its mean position, takes place in an average period of a lunar day, the tidal stream has a diurnal cycle.

Currents

The non-periodical horizontal movements of the sea come under the general heading of currents. Solely under the influence of currents, a particle of water will change its position over the Earth's surface either progressively or seasonally or with non-periodical fluctuations. In practice, the term "current" is usually applied only to the progressive or seasonal movements which can be forecast and therefore taken into consideration in navigation. If the horizontal water movements are observed over an even number of exact tidal cycles, the difference between the position of a particle over the surface of the Earth at the beginning and end of the observations is termed the residual movement. If a long series of observations has been obtained at one place, the rate of the residual movement can be accepted as the average current. This is also the case if a short series of observations have been obtained at a large number of places in the same locality and the residual movements from these observations are consistent. If a short series of observations is available at only one place, then the residual movement must be assumed to be associated only with the meteorological conditions prevailing during the period of the observations.

Flow

The term has the same meaning as horizontal water movement, as it is the combination, at any instant, of the tidal stream and current.

Methods of observing Horizontal Water Movements

In the open sea or in a wide channel, where the flow has everywhere the same general directions, it is necessary to determine as accurately as possible the directions and rates at representative positions in the area. From these observations the flow over the area as a whole may be deduced. Extensive observations for this purpose are obtained from a surveying ship anchored in a number of selected sites distributed over the area.

For ordinary navigational purposes it is necessary to know the tidal streams experienced by a ship of average draught, and that will depend to a considerable extent on the depths of water in the channels. In the channels used by deep draught ships the streams observed are those experienced by a ship drawing 30 feet.

Near-Surface Observations of a Free Drift Pole - In winding channels, abruptly constricted passages, or in an estuary encumbered with sandbanks, the rates and directions of flow are liable to change considerably over relatively short distances. These streams will be of particular importance at points where there is a considerable increase in their rate, or where they set onto or towards dangers to navigation. For these conditions a drift pole (obtainable from B. I. O. Current Section) is allowed to travel freely downstream over these points at various states of the tide.

Drift poles, of a length such that they will not ground at low water in the navigable parts of the estuary, are used. One or more drift poles are released in a line across the channel, upstream of the point where the tidal streams seriously affect navigation, at regular intervals throughout the tidal cycle. The drift poles are allowed to travel downstream and their positions are fixed at frequent intervals, either from boats following them up or from shore stations. The fixes are plotted and the rates are calculated from the distance and time interval between successive fixes.

In narrow but important channels, much frequented by shipping, where continuous observations over a period of 15 days or longer are required, observations from a boat at anchor are combined with observations of a free drift pole. It is impractical to anchor the boat in mid-channel, consequently the observations at anchor are obtained near the edge of the fairway in a position where it has been ascertained that eddies do not occur. At the times of maximum stream in either direction, rates are observed with a free drift pole through the most restricted part of the channel, which are compared with the rates observed simultaneously from the boat in order to determine the factor to be applied to the latter.

When observations of a free drift pole are taken it is important that weather conditions are observed and recorded in the field note book.

Near-Surface Observations with Overside Current Meters - The standard current meter at present being supplied to Hydrographic Survey Parties is the OTT Arkansas Mk. V. This current meter will normally suffice where observations are being taken in shallow water inside a harbour or river. If however, the direction of flow is not easily measured with a drogue over the stern, the Kelvin Hughes Direct Reading Current Meter is to be used. Generally this latter meter will be required when observing in the approaches to a harbour, in areas where eddies are found, and generally in open waters.

Periods for which Observations should be Obtained

In order to predict the tides accurately a continuous period of observation for a year is regarded as essential. A similar period of observation would be essential to attain the same standard of accuracy in predicting tidal streams. With

tides it is relatively easy to obtain such observations with the aid of automatic recorders, but at the present time this is not practical for recording tidal streams. In some areas it can be assumed that the characteristics of the tide and tidal streams are very similar; the range of the tide varies with changes in astronomical conditions, and the rates of the tidal streams vary in much the same proportion as the range of the tide in the same locality. At each interval from high water the directions of the tidal stream are usually unaffected by changes in the range of the tide and remain nearly constant. It is this close relationship between the tide and tidal streams in these waters which enables reasonably accurate predictions of the tidal streams to be based on only very short periods of observation. This close relationship exists only when the tides and tidal streams are predominantly semi-diurnal.

In such areas, observations for only one but preferably more successive periods of 25 hours near spring tides will provide useful information for navigation. The directions at each interval from high water at a Standard Port in the vicinity, as determined by these observations, are assumed to remain constant under any astronomical conditions and the rates at each of these intervals are assumed to vary proportionately with changes in the range of the tide at that port.

Observing Procedures

It is essential that adequate observations should be obtained and a great deal of the responsibility falls on the observer in the field; he must scrutinize his observations and assess their value.

WHEN - Current observations should be obtained when the tides are large. It is easier to justify the reduction of observed rates to the average than to take observations when the tides are below average. The minimum length of continuous observations is 25 hours but this should be extended whenever possible.

To permit the plotting of a curve of observed values, observations must be taken at regular intervals of not more than 30 minutes apart. The recommended interval is 10 minutes during normal operations.

The usual length of time the current meter is operated for one observation is 2 minutes, and the result divided by this number to reduce the readings to revolutions per minute. This length of time may not suit all conditions so it remains with the observer on the spot to adjust this to the prevailing conditions. A general rule is the weaker the rate the longer the time necessary to obtain a good reading. A sample of the current observation notes is shown in Figure 52.

TIME		COUNT	RATE	DIRECTIONS	COM-PASS °	VAR. ±	TRUE °	METER *	DEPTH M	REMARKS
START	END									
0815	17	83	0.7				350	63	5	
30	32	155	1.3				340	"	"	
45	47	262	2.2				330	"	"	
0900	02	323	2.7				325	"	"	
15	17	335	2.8				320	"	"	
30	32	347	2.9				320	"	"	

Figure 52. Current observation notes.

WHERE - Observations should be taken where it is expected to encounter maximum velocities and where the information can be of the greatest benefit to navigation. In general this will cover the principle shipping routes.

The depth at which the observations are obtained should be equivalent to the draft of ships using the channels.

A great deal of information regarding the streams and their importance to navigation can be gleaned during the day to day movements of the ship or the launches during the course of the survey. This will assist in the selection of suitable sites at which to take observations. If there is ice in the area, the same general ideas can be obtained by noting its movements. Very useful and reliable information on predominate sets and treacherous currents can be obtained from conversation with local fishermen and coastal vessel captains.

THE OTT ARKANSAS MK. V CURRENT METER

The Ott Arkansas Mk. V current meter is a precise and compact instrument, which will provide reliable readings under a large variety of conditions. The instrument is supplied with an instruction booklet which outlines in detail many aspects of its construction and operation versatility. The operator should be familiar with this instruction booklet before dismantling or adjusting any parts of the meter.

The meter consists of two distinct components: the propeller unit, and the meter body.

The Propeller Unit - comprises of the propeller, the shaft, the rotating sleeves and the ball-bearings. When operating the current meter in water heavy with silt or other debris, the propeller unit should be dismantled (Figure 53) and cleaned every 3 or 4 days. At the termination of any period of recording the same procedure should be followed and the instrument stored in a clean condition. Before reassembling, the propeller hub should be half filled with oil (supplied in the instrument case). It is rare for trouble to develop in this part of the meter if kept properly clean.

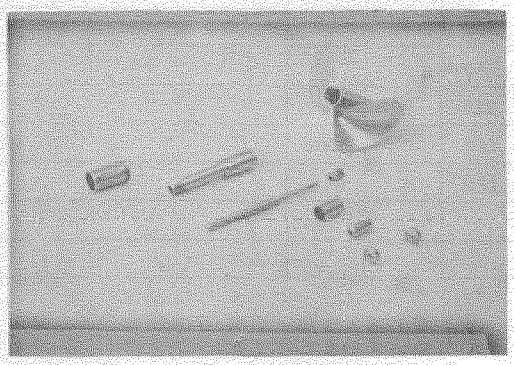


Figure 53. Dismantled propeller.

The meter body - contains the electrical impulse generating unit, and the cable connection socket and terminal. When operating the meter in very silty water the sliding cover over the gear chamber should be removed, so that the chamber can be continuously flushed clean (Figure 54).

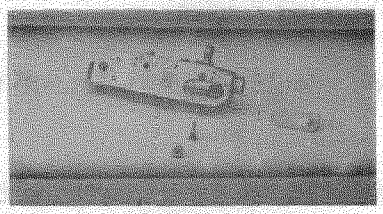


Figure 54. The meter body.

Figure 55 shows the assembled current meter with electrical plug and shackle. Before inserting the electrical plug into the socket, slip a piece of rubber tubing (provided in meter box) over the pin of the connector for about half of its length and fill the socket with the waterproof grease which is provided.

Fault finding procedure

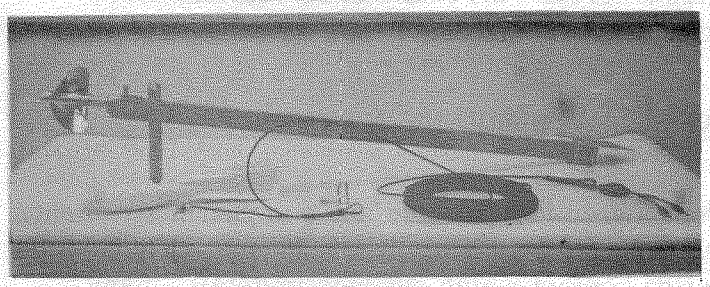


Figure 55. Assembled meter.

Fault - No signal from counting mechanism.

1. Check batteries in counter box, replace if necessary and try meter. If trouble persists -

2. Remove electrical plug and clean socket, test without grease when all parts are dry. If meter is running, regrease connection and test again. However, if trouble persists -

3. Remove electrical contact chamber cover and inspect for water or dirt. Clean, replace oil, and test meter. If trouble still persists -

4. Inspect the cable for break or abrasion. If no abnormality is found -

5. Follow through and check the fitting of each electrical connection.

Other faults: Other faults generally result from improper assembly. If faults develop, check through assembly section to ensure proper fitting. It should be remembered that the current meter is a precise instrument, and if treated with due respect, will provide many trouble-free hours of operation.

DROGUE

Shown in Figures 56 and 57 are typical drogues used by the Current Survey Section. However, any object may be used which presents little or no surface above the water to be affected by wind, and which provides an area larger than the surface float to the sub-surface currents. The drogue is released over the stern of the ship or launch and allowed to drift at a distance of at least 300 feet off. If for some reason a compass bearing cannot be accurately taken close to the position where the drogue is made fast, then a pelorous or circular protractor should be mounted there and the angle the drogue assumes relative to the fore and aft line of the ship recorded. In this case each time a reading is taken the ships head must also be recorded to determine the current direction. During slack water caution should be exercised so that the drogue does not become fouled in the ships anchor cable. During this period the drogue may have to be hauled on board and released on the other side of the ship.

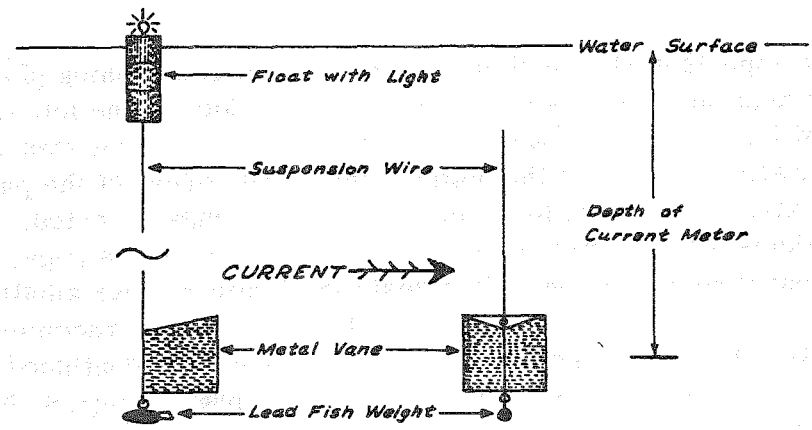


Figure 56. Metal drogue.

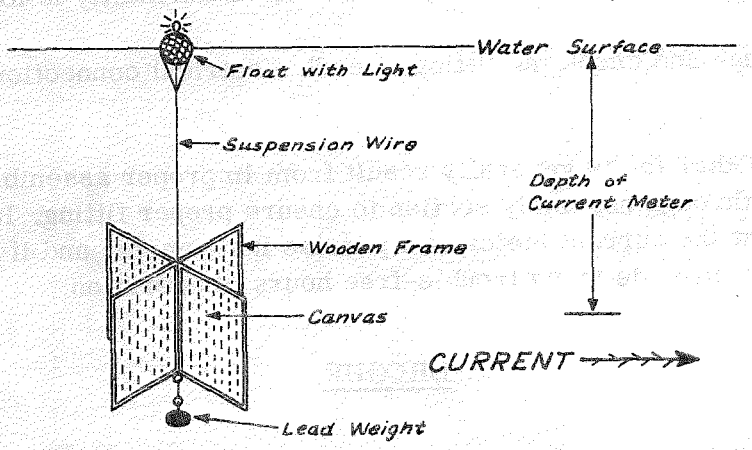


Figure 57. Wooden drogue.

DATA PRESENTATION

Those parties intending to observe currents should request a supply of Forms 1009, and Current Observation Note Books from the B. I. O. Inshore Tides and Current Group. The note books are simple to follow, as the column headings are self explanatory.

To facilitate the operation of converting the count from revolutions per minute to rate in knots, a graph or table should be drawn up using the calibration formula for the particular meter.

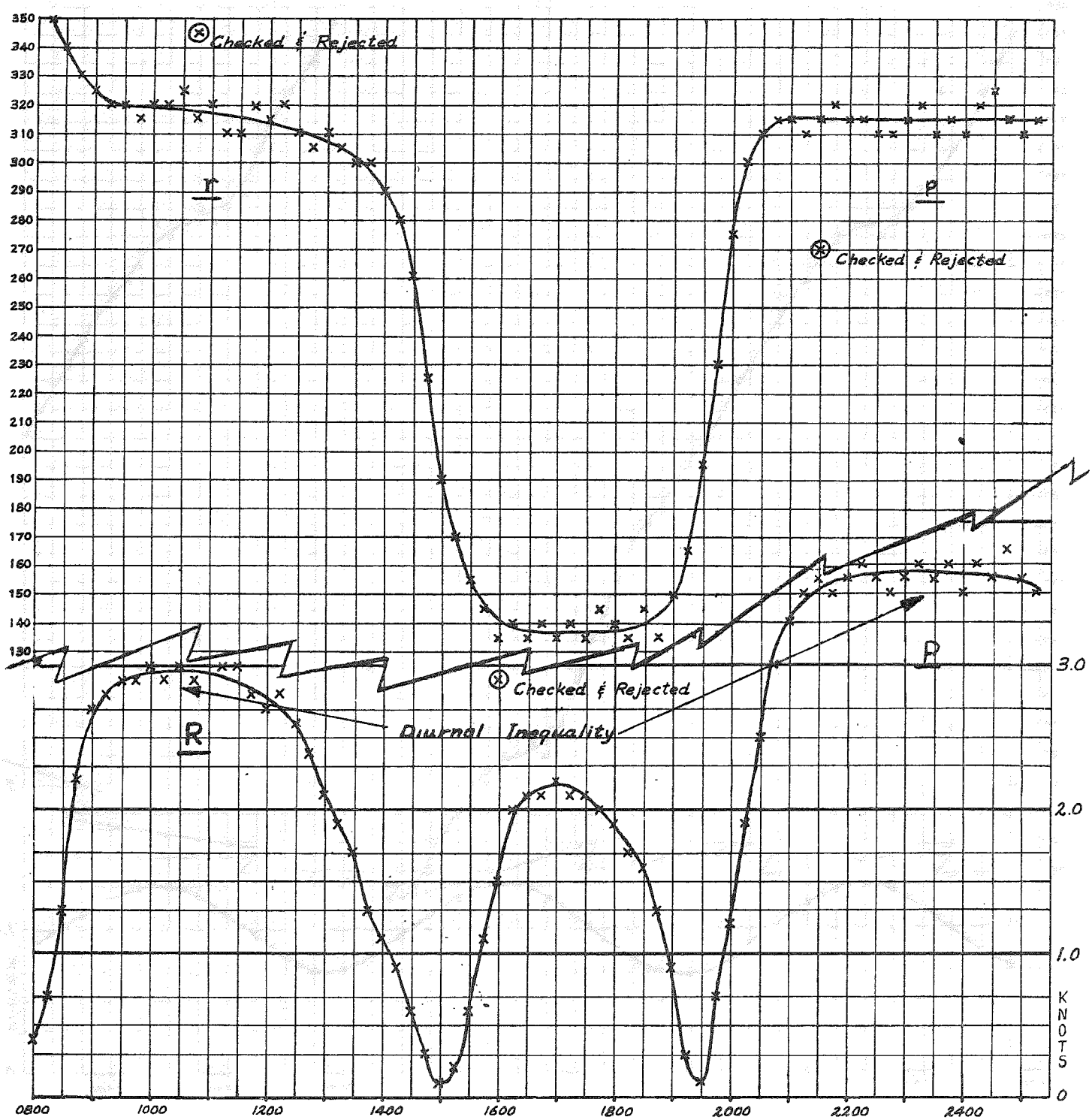
It is very important when making observations that a running plot of recorded values be kept on the cross sectional pages provided. The left side of the page is graduated for direction, but the observer should select his own vertical scale for rate. Zero should be at the bottom right hand corner of the page and the scale should be extended upwards to cover the velocity range expected. The observer also selects a horizontal scale across the bottom of this page, from left to right, to represent time. A convenient scale is 10 minutes per small square, which corresponds to the interval at which the observations are recommended to be taken. To cover the 25-hour period the plot will have to be continued on successive pages. It is necessary when starting a new page to repeat the last hour from one page to another. Keeping a running plot in this manner enables the observer to keep a check on the validity of his recordings. The following figures and explanations will assist with this scrutiny.

Figure 58 depicts a typical river, harbour entrance, or strait with a rectilinear flow. Note the imbalance between the rates in the opposing directions. The duration and rate of flow in the easterly direction are less than those of the

Station No. 605 Date 6 Aug, 1965 Lat. 45° 50'

Time Zone A.S.T. Long. 76° 10'

Meter Type OTT Arkansas MK V Position lowered



Position fix.

Left object C.H.S. Δ RAM Center Object WATER TR. Right Object R.C. CHURCH

Subtended Angles 68° 11' 71° 30'

Figure 58. Rate and direction of Rectilinear Flow.

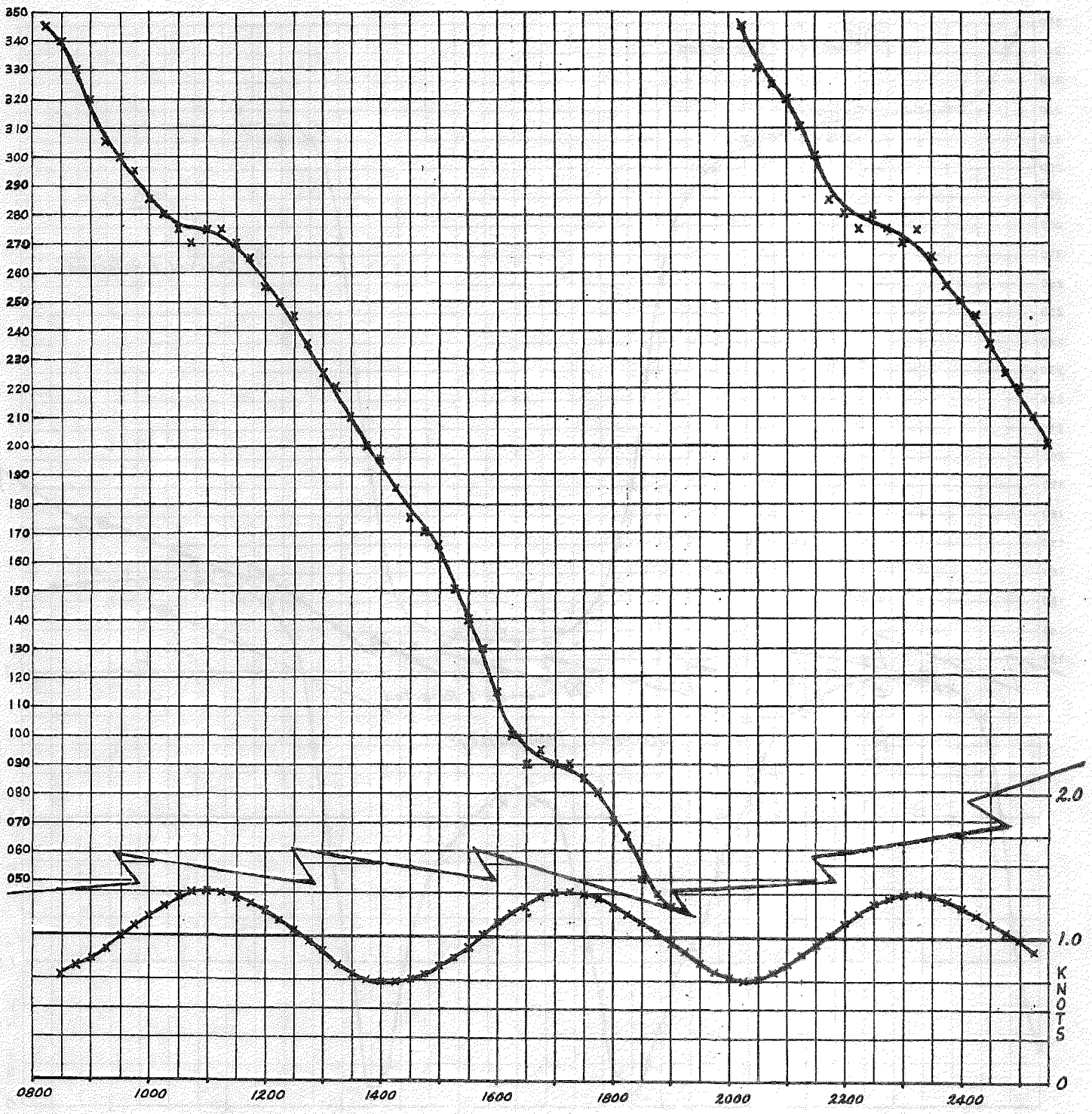


Figure 59. Rate and direction of Rotary Flow.

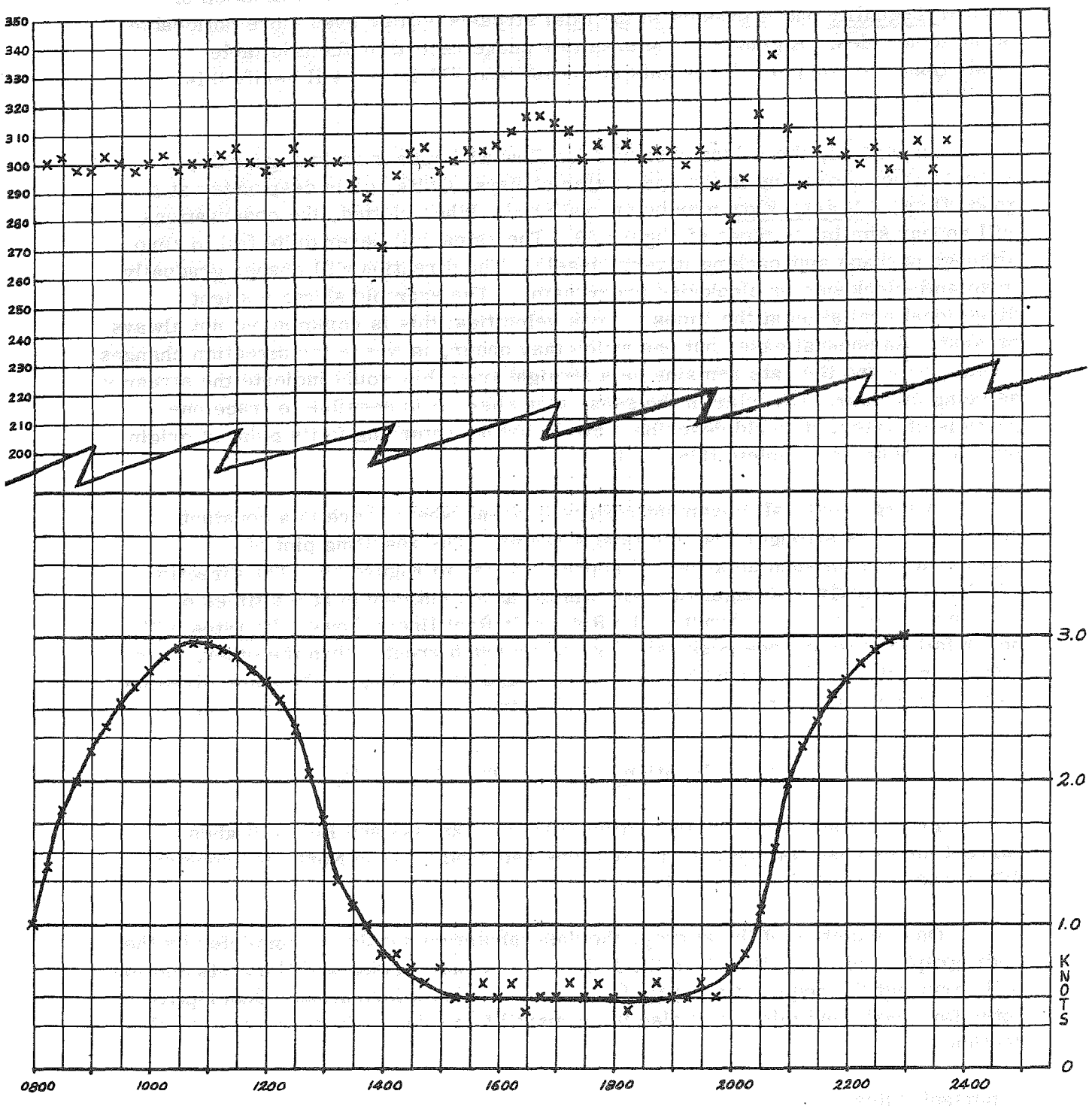


Figure 60. Rate and direction of Constant Current.

west going. This indicates the presence of a residual current. In a river the residual current will set seaward, westerly in this case. An imbalance between successive flows in the same direction, curves Rr and Pp, is an indication of diurnal inequality and if present in the tidal streams will be even more noticeable in the local tides. A glance at the area tide gauge record or the tide table predictions, to compare the heights of the AM and PM tides, will verify this condition.

In general, the values observed for flow will appear as in Figure 58, however when observing in the open water of Bays, Gulfs, or in deep water at a good offing, a Rotary Flow may be encountered. When plotted, the observations will appear similar to those of Figure 59. The rates will never quite fall to zero although perhaps approaching it very closely. The direction will change gradually in an anti-clockwise or clockwise progression. The example shows a slight directional hesitation at the times of peak velocities; this is common but not always present. An unusual case, but one which may occur, is where the direction changes continuously and the rate remains as a straight line; this would indicate the streams as being circular. Circular in the sense that where it is possible to trace one particle of water, it would describe a circle before returning to its point of origin over a 25-hour or complete tidal cycle.

A large residual movement results in areas where there is a constant current which is stronger than the tidal streams. The resulting plot of observations from such an area will appear similar to Figure 60. The direction will be very nearly a straight line with disturbances noticeable at the times of minimum velocity. In contrast to the Rotary or Rectilinear flows, the rates will never fall to zero and one peak velocity will be much greater than the other. The maximum rates will occur when the tidal streams are setting in the same direction as the current, and minimum rates when the stream is opposing the current.

Data Tabulation - Form C1009 (Figure 61)

Form C1009 is for the tabulation of OTT Arkansas and Kelvin Highes current meter observations, with directions referred to True North and counter differences converted to rate in Knots.

On completion of the survey, the data tabulation should be completed by the Hydrographer while he is still in the field. The Inshore Tides and Currents Section will carry out the required analysis from the recorded information. Descriptive notes for charts and pilots will also be prepared from the analysed records by this Section.

Important Rules

1. Start a new sheet for each new series of observations filling in only line one of the header card, with time, date, meter number,

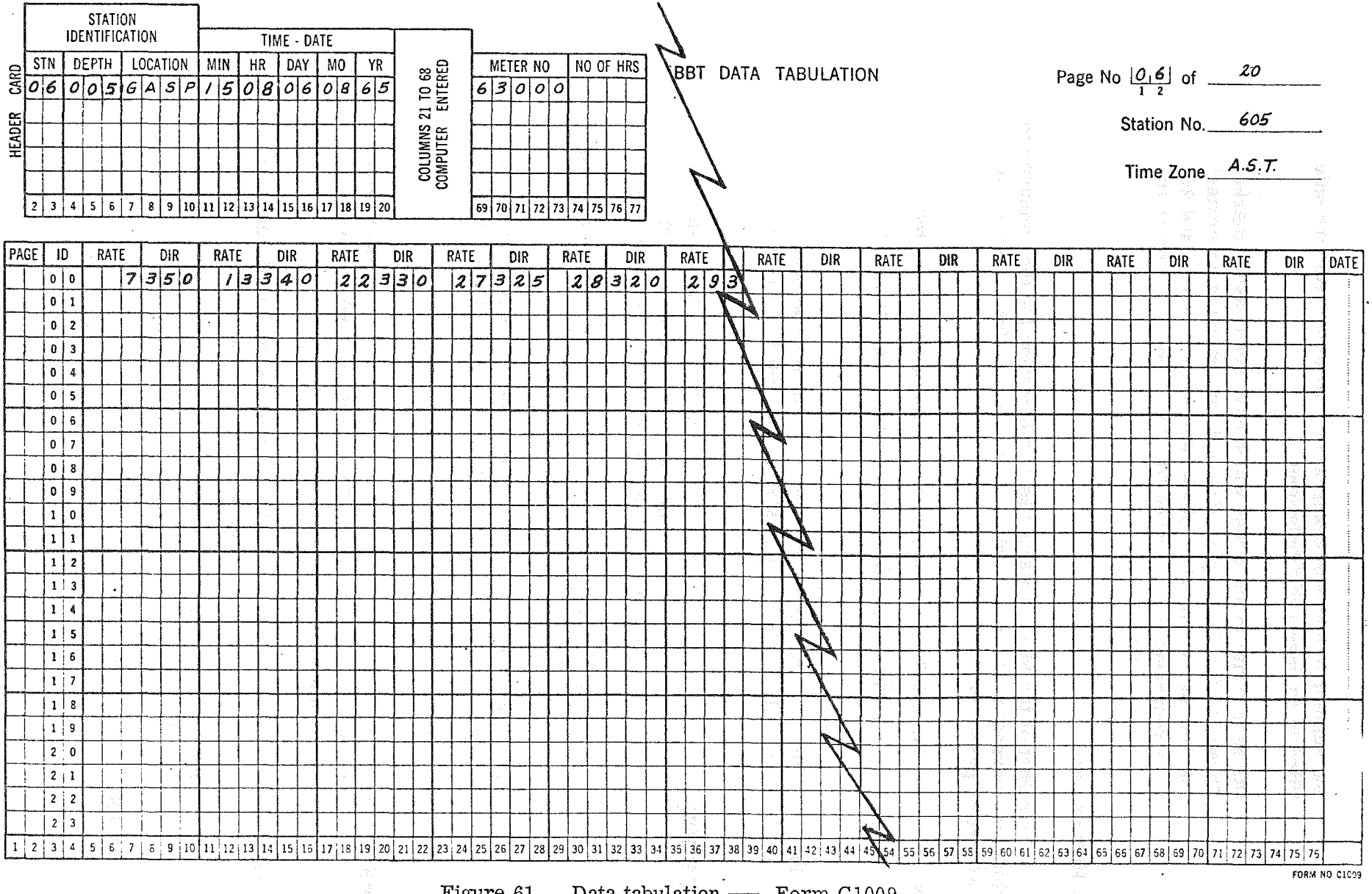


Figure 61. Data tabulation — Form C1009.

and number of hours of observation. Header cards are only filled in on page 1 of tabulations.

2. DO NOT write in any areas which have been hashed marked. These are for the programmer and data analysis supervisor. One line in the tabulation block represents 2 hours, and 24 lines represent 2 days, when filled with observations at 10 minute intervals.

The Header Card

This part of the form contains basic information for the computer to perform the correct program of analysis, and also for future punch card identification purposes.

STN: Cols. 2 & 3. The number of the station to be inserted here -

NO LETTERS TO BE USED - Eg. 0 6 (2 3) Station #6

DEPTH: Cols. 4 to 6. Enter depth at which meter had been suspended. Eg. 0 0 5 (4 5 6) Meter suspended at 5 meters.

LOCATION: Cols. 7 to 10, enter an abbreviated form of the strait, bay or river name, or any other positive identification of the survey location which cannot be confused with another area.

Eg. G A S P (7 8 9 10) survey of '62 carried out in GASPE Passage.

If a survey was carried on in the same area in another year, this would be indicated by a different arrangement of the letters such as S P A G (7 8 9 10) for a survey in 1965.

TIME-DATE: Cols. 11 to 20. MIN - HR - DAY - MO - YR is the Minute, Hour, Day, Month, Year of the first rate and direction in the tabulation block.

METER NO: Cols. 69 to 73. Enter the number assigned to the current meter, followed with zeros to fill in the alloted space.

Eg. 6 3 0 0 0 (69 70 71 72 73) BBT No. 63

NO. HOURS: Cols. 74 to 77. Leave blank

Page Identification

PAGE NO: Cols. 1 & 2. Enter each consecutive page number in the top right-hand corner of the page where indicated. DO NOT write anything in columns 1 & 2 in the body of the tabulation block; this will be done automatically by the key punch operator.

Eg. $\frac{0\ 6}{1\ 2}$ of 20, (Page 6) of 20 pages.

STATION NO: In this position the easy reference station identification number for these sheets is entered. This number is a combination of station number and depth from the header card. Eg. 113, Station #1 at 13 meters; 285, Station #2 at 85 meters, etc.

TIME ZONE: The time zone of the data entered in the tabulation block.

Tabulation Block

PAGE: Leave blank

ID: These numbers are for line identification only.
However, note that line,
00 Will contain the first two hours, 00 Hrs - 02 Hrs of a day.
12 Will contain the first two hours of the succeeding day of continuous observations.

DIRECTION & RATE: Enter simulatneous readings at 10 minute intervals.

RATE: Enter rate in knots to one decimal point. It is not necessary to enter zeros (e.g. 0.7), therefore leave the zero space open.

DIRECTION: Compass direction, use three digit (000° - 359°) notation entering compass reading corrected for compass errors.

TABLE 1 Astronomical argument 360 - V + u

M_2 MS_4	K_1	O_1	N_2	K_2	M_4	μ_2	Year
334	355	337	125	169	309	308	1961
234	357	233	114	174	109	107	62
134	359	131	102	177	268	266	63
33	359	30	90	178	67	65	64
317	358	316	115	176	274	272	65
216	356	217	103	173	72	70	66
114	354	118	91	169	229	228	67
13	352	20	78	165	26	26	68
296	349	307	103	158	232	232	69
195	347	209	90	153	29	30	70
93	344	111	77	148	186	188	71
352	343	12	65	145	344	346	72
275	341	298	90	142	191	193	73
175	341	198	78	142	350	352	74
74	342	96	66	144	148	150	75
334	344	354	55	148	308	309	76
258	346	274	81	152	156	157	77
158	350	169	69	159	316	316	78
58	353	63	58	166	116	116	79
318	356	318	47	172	276	275	80
242	358	241	73	174	124	122	81
142	358	139	61	177	283	281	82
41	358	39	49	177	82	80	83
300	358	299	37	176	240	238	84
223	355	226	62	171	86	85	85
122	353	127	49	166	244	243	86
20	351	29	36	162	41	41	87
279	348	291	24	157	198	198	88
202	345	218	48	150	44	45	89
101	343	120	36	146	201	203	90
359	342	21	23	143	359	1	91
259	341	281	11	142	157	160	92
182	341	206	37	142	5	7	93
82	342	104	25	145	164	166	94
342	344	0	14	150	324	325	95
242	348	255	2	156	123	124	96
166	350	175	28	161	332	332	97
66	354	70	277	167	132	131	98
326	357	325	6	173	292	290	99

S_2 always 000 P_1 always 010

TABLE 2 Daily corrections for the astronomical argument

January

Date	M_2 MS_4	S_2	N_2	K_2	K_1	O_1	P_1	M_4 μ_2
1	0°		0°	0°	0°	0°	0°	0°
2	24		37	358	359	25	1	49
3	49		75	356	358	51	2	98
4	73		112	354	357	76	3	146
5	98		150	352	356	101	4	195
6	122		187	350	355	127	5	244
7	146		225	348	354	152	6	293
8	171		262	346	353	178	7	341
9	195		300	344	352	203	8	30
10	219		337	342	351	228	9	79
11	244		14	340	350	254	10	128
12	268		52	338	349	279	11	176
13	293		89	336	348	304	12	225
14	317	0°	127	334	347	330	13	274
15	341		164	332	346	355	14	323
16	6		202	330	345	21	15	11
17	30		239	328	344	46	16	60
18	54		277	326	343	71	17	109
19	79		314	325	342	97	18	158
20	103		351	323	341	122	19	206
21	128		29	321	340	147	20	255
22	152		66	319	339	173	21	304
23	176		104	317	338	198	22	353
24	201		141	315	337	223	23	42
25	225		179	313	336	249	24	90
26	250		216	311	335	274	25	139
27	274		254	309	334	300	26	188
28	298		291	307	333	325	27	237
29	323		329	305	332	350	28	285
30	347		6	303	331	16	29	334
31	11		43	301	330	41	30	23

February

Leap year: 29, February look up 1, March

Date	M_2 MS_4	S_2	N_2	K_2	K_1	O_1	P_1	M_4 μ_2
1	36°		81°	299°	329°	66°	31°	72°
2	60		118	297	328	92	32	120
3	85		156	295	327	117	33	169
4	109		193	293	326	142	34	218
5	133		231	291	326	168	34	267
6	158		268	289	325	193	35	315
7	182		306	287	324	219	36	4
8	206		343	285	323	244	37	53
9	231		20	283	322	269	38	102
10	255		58	281	321	295	39	151
11	280		95	279	320	320	40	199
12	304		133	277	319	345	41	248
13	328		170	275	318	11	42	297
14	353	0°	208	273	317	36	43	346
15	17		245	271	316	62	44	34
16	42		283	269	315	87	45	83
17	66		320	267	314	112	46	132
18	90		357	265	313	138	47	181
19	115		35	263	312	163	48	229
20	139		72	261	311	188	49	278
21	163		110	259	310	214	50	327
22	188		147	257	309	239	51	16
23	212		185	256	308	264	52	64
24	237		222	254	307	290	53	113
25	261		260	252	306	315	54	162
26	285		297	250	305	341	55	211
27	310		334	248	304	6	56	259
28	334		12	246	303	31	57	308

March

For leap years look up one day later

Date	M_2 MS_4	S_2	N_2	K_2	K_1	O_1	P_1	M_4 μ_2
1	359°		49°	244°	302°	57°	58°	357°
2	23		87	242	301	82	59	46
3	47		124	240	300	107	60	95
4	72		162	238	299	133	61	143
5	96		199	236	298	158	62	192
6	120		237	234	297	183	63	241
7	145		274	232	296	209	64	290
8	169		311	230	295	234	65	338
9	194		349	228	294	260	66	27
10	218		26	226	293	285	67	76
11	242		64	224	292	310	68	125
12	267		101	222	291	336	69	173
13	291		139	220	290	1	70	222
14	315	0°	176	218	289	26	71	271
15	340		214	216	288	52	72	320
16	4		251	214	287	77	73	8
17	29		288	212	286	103	74	57
18	53		326	210	285	128	75	106
19	77		3	208	284	153	76	155
20	102		41	206	283	179	77	204
21	126		78	204	282	204	78	252
22	151		116	202	281	229	79	301
23	175		153	200	280	255	80	350
24	199		191	198	279	280	81	39
25	224		228	196	278	305	82	87
26	248		266	194	277	331	83	136
27	272		303	192	276	356	84	185
28	297		340	190	275	22	85	234
29	321		18	188	274	47	86	282
30	346		55	187	273	72	87	331
31	10		93	185	272	98	88	20

April

Date	M_2 MS_4	S_2	N_2	K_2	K_1	O_1	P_1	M_4 μ_2
1	34°		130°	183°	271°	123°	89°	69°
2	59		168	181	270	148	90	117
3	83		205	179	269	174	91	166
4	107		243	177	268	199	92	215
5	132		280	175	267	225	93	264
6	156		317	173	266	250	94	312
7	181		355	171	265	275	95	1
8	205		32	169	264	301	96	50
9	229		70	167	263	326	97	99
10	254		107	165	262	351	98	148
11	278		145	163	261	17	99	196
12	303		182	161	260	42	100	245
13	327		220	159	259	67	101	294
14	351	0°	257	157	258	93	102	343
15	16		294	155	257	118	103	31
16	40		332	153	257	144	103	80
17	64		9	151	256	169	104	129
18	89		47	149	255	194	105	178
19	113		84	147	254	220	106	226
20	138		122	145	253	245	107	275
21	162		159	143	252	270	108	324
22	186		197	141	251	296	109	13
23	211		234	139	250	321	110	61
24	235		271	137	249	346	111	110
25	259		309	135	248	12	112	159
26	284		346	133	247	37	113	208
27	308		24	131	246	63	114	257
28	333		61	129	245	88	115	305
29	357		99	127	244	113	116	354
30	21		136	125	243	139	117	43

TABLE 2 Daily corrections for the astronomical argument

May

For leap years look up one day later

Date	M_2 MS_4	S_2	N_2	K_2	K_1	O_1	P_1	M_4 μ_2
	°		°	°	°	°	°	°
1	46		174	123	242	164	118	92
2	70		211	121	241	189	119	140
3	95		248	120	240	215	120	189
4	119		286	118	239	240	121	238
5	143		323	116	238	266	122	287
6	168		1	114	237	291	123	335
7	192		38	112	236	316	124	24
8	216		76	110	235	342	125	73
9	241		113	108	234	7	126	122
10	265		151	106	233	32	127	170
11	290		188	104	232	58	128	219
12	314		225	102	231	83	129	268
13	338		263	100	230	108	130	317
14	3	0°	300	98	229	134	131	5
15	27		338	96	228	159	132	54
16	52		15	94	227	185	133	103
17	76		53	92	226	210	134	152
18	100		90	90	225	235	135	201
19	125		128	88	224	261	136	249
20	149		165	86	223	286	137	298
21	173		203	84	222	311	138	347
22	198		240	82	221	337	139	36
23	222		277	80	220	2	140	84
24	247		315	78	219	28	141	133
25	271		352	76	218	53	142	182
26	295		30	74	217	78	143	231
27	320		67	72	216	104	144	279
28	344		105	70	215	129	145	328
29	8		142	68	214	154	146	17
30	33		180	66	213	180	147	66
31	57		217	64	212	205	148	114

June

Date	M_2 MS_4	S_2	N_2	K_2	K_1	O_1	P_1	M_4 μ_2
	°		°	°	°	°	°	°
1	82		254	62	211	230	149	163
2	106		292	60	210	256	150	212
3	130		329	58	209	281	151	261
4	155		7	56	208	307	152	310
5	179		44	54	207	332	153	358
6	204		82	52	206	357	154	47
7	228		119	51	205	23	155	96
8	252		157	49	204	48	156	145
9	277		194	47	203	73	157	193
10	301		231	45	202	99	158	242
11	325		269	43	201	124	159	291
12	350		306	41	200	149	160	340
13	14		344	39	199	175	161	28
14	39	0°	21	37	198	200	162	77
15	63		59	35	197	226	163	126
16	87		96	33	196	251	164	175
17	112		134	31	195	276	165	223
18	136		171	29	194	302	166	272
19	160		208	27	193	327	167	321
20	185		246	25	192	352	168	10
21	209		283	23	191	18	169	58
22	234		321	21	190	43	170	107
23	258		358	19	189	69	171	156
24	282		36	17	188	94	172	205
25	307		73	15	188	119	172	254
26	331		111	13	187	145	173	302
27	356		148	11	186	170	174	351
28	20		185	9	185	195	175	40
29	44		223	7	184	221	176	89
30	69		260	5	183	246	177	137

July

For leap years look up one day later

Date	M_2 MS_4	S_2	N_2	K_2	K_1	O_1	P_1	M_4 μ_2
	°		°	°	°	°	°	°
1	93		298	3	182	271	178	186
2	117		335	1	181	297	179	235
3	142		13	359	180	322	180	284
4	166		50	357	179	348	181	332
5	191		88	355	178	13	182	21
6	215		125	353	177	38	183	70
7	239		162	351	176	64	184	119
8	264		200	349	175	89	185	167
9	288		237	347	174	114	186	216
10	312		275	345	173	140	187	265
11	337		312	343	172	165	188	314
12	1		350	342	171	190	189	2
13	26		27	340	170	216	190	51
14	50	0°	65	338	169	241	191	100
15	74		102	336	168	267	192	149
16	99		140	334	167	292	193	198
17	123		177	332	166	317	194	246
18	148		214	330	165	343	195	295
19	172		252	328	164	8	196	344
20	196		289	326	163	33	197	33
21	221		327	324	162	59	198	81
22	245		4	322	161	84	199	130
23	269		42	320	160	110	200	179
24	294		79	318	159	135	201	228
25	318		117	316	158	160	202	276
26	343		154	314	157	186	203	325
27	7		191	312	156	211	204	14
28	31		229	310	155	236	205	63
29	56		266	308	154	262	206	111
30	80		304	306	153	287	207	160
31	104		341	304	152	312	208	209

August

For leap years look up one day later

Date	M_2 MS_4	S_2	N_2	K_2	K_1	O_1	P_1	M_4 μ_2
	°		°	°	°	°	°	°
1	129		19	302	151	338	209	258
2	153		56	300	150	3	210	307
3	178		94	298	149	29	211	355
4	202		131	296	148	54	212	44
5	226		168	294	147	79	213	93
6	251		206	292	146	105	214	142
7	275		243	290	145	130	215	190
8	299		281	288	144	155	216	239
9	324		318	286	143	181	217	288
10	348		356	284	142	206	218	337
11	13		33	282	141	232	219	25
12	37		71	280	140	257	220	74
13	61		108	278	139	282	221	123
14	86	0°	145	276	138	308	222	172
15	110		183	274	137	333	223	220
16	135		220	273	136	358	224	269
17	159		258	271	135	24	225	318
18	183		295	269	134	49	226	7
19	208		333	267	133	74	227	55
20	232		10	265	132	100	228	104
21	257		48	263	131	125	229	153
22	281		85	261	130	151	230	202
23	305		122	259	129	176	231	251
24	330		160	257	128	201	232	299
25	354		197	255	127	227	233	348
26	18		235	253	126	252	234	37
27	43		272	251	125	277	235	86
28	67		310	249	124	303	236	134
29	92		347	247	123	328	237	183
30	116		25	245	122	353	238	232
31	140		62	243	121	19	239	281

TABLE 2 Daily corrections for the astronomical argument

September

For leap years look up one day later

Date	M_2 MS_4	S_2	N_2	K_2	K_1	O_1	P_1	M_4 μ_2
1	165°		99°	241°	120°	44°	240°	329°
2	189		137	239	120	70	240	18
3	213		174	237	119	95	241	67
4	238		212	235	118	120	242	116
5	262		249	233	117	146	243	164
6	287		287	231	116	171	244	213
7	311		324	229	115	196	245	262
8	335		2	227	114	222	246	311
9	0		39	225	113	247	247	0
10	24		77	223	112	273	248	48
11	49		114	221	111	298	249	97
12	73		151	219	110	323	250	146
13	97		189	217	109	349	251	195
14	122	0°	226	215	108	14	252	243
15	146		264	213	107	39	253	292
16	170		301	211	106	65	254	341
17	195		339	209	105	90	255	30
18	219		16	207	104	115	256	78
19	244		54	205	103	141	257	127
20	268		91	204	102	166	258	176
21	292		128	202	101	192	259	225
22	317		166	200	100	217	260	273
23	341		203	198	99	242	261	322
24	5		241	196	98	268	262	11
25	30		278	194	97	293	263	60
26	54		316	192	96	318	264	108
27	79		353	190	95	344	265	157
28	103		31	188	94	9	266	206
29	127		68	186	93	34	267	255
30	152		105	184	92	60	268	304

October

Date	M_2 MS_4	S_2	N_2	K_2	K_1	O_1	P_1	M_4 μ_2
1	176°		143°	182°	91°	85°	269°	352°
2	201		180	180	90	111	270	41
3	225		218	178	89	136	271	90
4	249		255	176	88	161	272	139
5	274		293	174	87	187	273	187
6	298		330	172	86	212	274	236
7	322		8	170	85	237	275	285
8	347		45	168	84	263	276	334
9	11		82	166	83	288	277	22
10	36		120	164	82	314	278	71
11	60		157	162	81	339	279	120
12	84		195	160	80	4	280	169
13	109		232	158	79	30	281	217
14	133	0°	270	156	78	55	282	266
15	157		307	154	77	80	283	315
16	182		345	152	76	106	284	4
17	206		22	150	75	131	285	53
18	231		59	148	74	156	286	101
19	255		97	146	73	182	287	150
20	279		134	144	72	207	288	199
21	304		172	142	71	233	289	248
22	328		209	140	70	258	290	296
23	353		247	138	69	283	291	345
24	17		284	136	68	309	292	34
25	41		322	135	67	334	293	83
26	66		359	133	66	359	294	131
27	90		37	131	65	25	295	180
28	114		74	129	64	50	296	229
29	139		111	127	63	76	297	278
30	163		149	125	62	101	298	326
31	188		186	123	61	126	299	15

November

For leap years look up one day later

Date	M_2 MS_4	S_2	N_2	K_2	K_1	O_1	P_1	M_4 μ_2
1	212°		224°	121°	60°	152°	300°	64°
2	236		261	119	59	177	301	113
3	261		299	117	58	202	302	161
4	285		336	115	57	228	303	210
5	310		14	113	56	253	304	259
6	334		51	111	55	278	305	308
7	358		88	109	54	304	306	357
8	23		126	107	53	329	307	45
9	47		163	105	52	355	308	94
10	71		201	103	51	20	309	143
11	96		238	101	51	45	309	192
12	120		276	99	50	71	310	240
13	145	0°	313	97	49	96	311	289
14	169		351	95	48	121	312	338
15	193		28	93	47	147	313	27
16	218		65	91	46	172	314	75
17	242		103	89	45	197	315	124
18	266		140	87	44	223	316	173
19	291		178	85	43	248	317	222
20	315		215	83	42	274	318	270
21	340		253	81	41	299	319	319
22	4		290	79	40	324	320	8
23	28		328	77	39	350	321	57
24	53		5	75	38	15	322	106
25	77		42	73	37	40	323	154
26	102		80	71	36	66	324	203
27	126		117	69	35	91	325	252
28	150		155	68	34	117	326	301
29	175		192	66	33	142	327	349
30	199		230	64	32	167	328	38

December

Date	M_2 MS_4	S_2	N_2	K_2	K_1	O_1	P_1	M_4 μ_2
1	223°		267°	62°	31°	193°	329°	87
2	248		305	60	30	218	330	136
3	272		342	58	29	243	331	184
4	297		19	56	28	269	332	233
5	321		57	54	27	294	333	282
6	345		94	52	26	319	334	331
7	10		132	50	25	345	335	19
8	34		169	48	24	10	336	68
9	58		207	46	23	36	337	117
10	83		244	44	22	61	338	166
11	107		282	42	21	86	339	214
12	132		319	40	20	112	340	263
13	156		356	38	19	137	341	312
14	180	0°	34	36	18	162	342	1
15	205		71	34	17	188	343	50
16	229		109	32	16	213	344	98
17	254		146	30	15	239	345	147
18	278		184	28	14	264	346	196
19	302		221	26	13	289	347	245
20	327		259	24	12	315	348	293
21	351		296	22	11	340	349	342
22	15		334	20	10	5	350	31
23	40		11	18	9	31	351	80
24	64		48	16	8	56	352	128
25	89		86	14	7	81	353	177
26	113		123	12	6	107	354	226
27	137		161	10	5	132	355	275
28	162		198	8	4	158	356	323
29	186		236	6	3	183	357	12
30	210		273	4	2	208	358	61
31	235		311	2	1	234	359	110
	259		348	0	0	259	360	158

TABLE 3 Time of high water

Time of Highwater	S_2	M_2	K_1	O_1	P_1	N_2	K_2	M_4	MS_4	μ_2
u.	°	°	°	°	°	°	°	°	°	°
0	0	0	0	0	0	0	0	0	0	0
0,5	15	14	8	7	7	14	15	29	29	14
1	30	29	15	14	15	28	30	58	59	28
1,5	45	43	23	21	22	43	45	87	88	42
2	60	58	30	28	30	57	60	116	118	56
2,5	75	72	38	35	37	71	75	145	147	70
3	90	87	45	42	45	85	90	174	177	84
3,5	105	101	53	49	52	100	105	203	206	98
4	120	116	60	56	60	114	120	232	236	112
4,5	135	130	68	63	67	128	135	261	265	126
5	150	145	75	70	75	142	150	290	295	140
5,5	165	159	83	77	82	156	165	319	324	154
6	180	174	90	84	90	171	180	348	354	168
6,5	195	188	98	91	97	185	196	—	383	182
7	210	203	105	98	105	199	211	—	—	196
7,5	225	217	113	105	112	213	226	—	—	210
8	240	232	120	112	120	228	241	—	—	224
8,5	255	246	128	119	127	242	256	—	—	238
9	270	261	135	125	135	256	271	—	—	252
9,5	285	275	143	132	142	270	286	—	—	266
10	300	290	150	139	150	284	301	—	—	280
10,5	315	304	158	146	157	299	316	—	—	294
11	330	319	165	153	165	313	331	—	—	308
11,5	345	333	173	160	172	327	346	—	—	322
12	360	348	180	167	180	341	361	—	—	336
12,5	—	362	188	174	187	355	—	—	—	350
13	—	—	196	181	194	370	—	—	—	364
13,5	—	—	203	188	202	—	—	—	—	—
14	—	—	211	195	209	—	—	—	—	—
14,5	—	—	218	202	217	—	—	—	—	—
15	—	—	226	209	224	—	—	—	—	—
15,5	—	—	233	216	232	—	—	—	—	—
16	—	—	241	223	239	—	—	—	—	—
16,5	—	—	248	230	247	—	—	—	—	—
17	—	—	256	237	254	—	—	—	—	—
17,5	—	—	263	244	262	—	—	—	—	—
18	—	—	271	251	269	—	—	—	—	—
18,5	—	—	278	258	277	—	—	—	—	—
19	—	—	286	265	284	—	—	—	—	—
19,5	—	—	293	272	292	—	—	—	—	—
20	—	—	301	279	299	—	—	—	—	—
20,5	—	—	308	286	307	—	—	—	—	—
21	—	—	316	293	314	—	—	—	—	—
21,5	—	—	323	300	322	—	—	—	—	—
22	—	—	331	307	329	—	—	—	—	—
22,5	—	—	338	314	337	—	—	—	—	—
23	—	—	346	321	344	—	—	—	—	—
23,5	—	—	353	328	352	—	—	—	—	—
24	—	—	361	335	359	—	—	—	—	—
24,5	—	—	—	342	366	—	—	—	—	—
25	—	—	—	349	—	—	—	—	—	—
25,5	—	—	—	356	—	—	—	—	—	—
26	—	—	—	363	—	—	—	—	—	—

TABLE 4 Water level at half hour intervals for given amplitudes

S_2	K_2		M_2																					
Hours before or after H.W.	AMPLITUDE.		Hours before or after H.W.	AMPLITUDE.																				Hours before or after H.W.
	98	100		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	
u			u																					u
0	98	100	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	0
0,5	95	97	0,5	2	4	6	8	10	12	14	15	17	19	21	23	25	27	29	31	33	35	37	39	41	0,5
1	85	87	1	2	3	5	7	9	10	12	14	16	17	19	21	23	24	26	28	30	31	33	35	37	1
1,5	69	71	1,5	1	3	4	6	7	9	10	12	13	15	16	17	19	20	22	23	25	26	28	29	30	1,5
2	49	50	2	1	2	3	4	5	6	7	8	10	11	12	13	14	15	16	17	18	19	20	21	22	2
2,5	25	26	2,5	1	1	2	2	3	4	4	5	5	6	7	7	8	8	9	10	10	11	11	12	13	2,5
3	0	0	3	0	0	0	0	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3
3,5	-25	-26	3,5	0	-1	-1	-2	-2	-2	-3	-3	-4	-4	-4	-5	-5	-6	-6	-6	-7	-7	-8	-8	-8	3,5
4	-49	-50	4	-1	-2	-3	-3	-4	-5	-6	-7	-8	-9	-10	-10	-11	-12	-13	-14	-15	-16	-17	-17	-18	4
4,5	-69	-71	4,5	-1	-3	-4	-5	-6	-8	-9	-10	-12	-13	-14	-16	-17	-18	-19	-21	-22	-23	-25	-26	-27	4,5
5	-85	-87	5	-2	-3	-5	-7	-8	-10	-11	-13	-15	-16	-18	-20	-21	-23	-25	-26	-28	-29	-31	-33	-34	5
5,5	-95	-97	5,5	-2	-4	-6	-7	-9	-11	-13	-15	-17	-19	-21	-22	-24	-26	-28	-30	-32	-34	-36	-37	-39	5,5
6	-98	-100	6	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20	-22	-24	-26	-28	-30	-32	-34	-36	-38	-40	-42	6
6,5	-95	-97	6,5	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20	-22	-24	-26	-28	-30	-32	-34	-36	-38	-40	-42	6,5
7	-85	-87	7	-2	-4	-6	-7	-9	-11	-13	-15	-17	-18	-20	-22	-24	-26	-28	-29	-31	-33	-35	-37	-39	7
7,5	-69	-71	7,5	-2	-3	-5	-6	-8	-10	-11	-13	-14	-16	-17	-19	-21	-22	-24	-25	-27	-29	-30	-32	-33	7,5
8	-49	-50	8	-1	-2	-4	-5	-6	-7	-9	-10	-11	-12	-14	-15	-16	-17	-19	-20	-21	-22	-23	-25	-26	8
8,5	-25	-26	8,5	-1	-2	-2	-3	-4	-5	-6	-6	-7	-8	-9	-10	-10	-11	-12	-13	-14	-14	-15	-16	-17	8,5
9	0	0	9	0	-1	-1	-1	-2	-2	-2	-3	-3	-3	-3	-4	-4	-4	-5	-5	-5	-6	-6	-6	-7	9
9,5	25	26	9,5	0	0	1	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4	9,5
10	49	50	10	1	1	2	3	3	4	5	5	6	7	7	8	9	10	10	11	12	12	13	14	14	10
10,5	69	71	10,5	1	2	3	5	6	7	8	9	10	11	12	14	15	16	17	18	19	20	21	23	24	10,5
11	85	87	11	2	3	5	6	8	9	11	12	14	15	17	18	20	21	23	24	26	27	29	30	32	11
11,5	95	97	11,5	2	4	5	7	9	11	13	14	16	18	20	21	23	25	27	29	30	32	34	36	38	11,5
12	98	100	12	2	4	6	8	10	12	14	16	18	20	22	23	25	27	29	31	33	35	37	39	41	12
12,5	95	97	12,5	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	12,5
13	85	87	13	2	4	6	8	10	11	13	15	17	19	21	23	25	27	29	31	33	34	36	38	40	13
13,5	69	71	13,5	2	3	5	7	9	10	12	14	15	17	19	21	22	24	26	27	29	31	32	34	36	13,5
14	49	50	14	1	3	4	6	7	8	10	11	13	14	15	17	18	20	21	22	24	25	27	28	29	14
14,5	25	26	14,5	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	14,5
15	0	0	15	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	11	11	15
15,5	-25	-26	15,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	15,5
16	-49	-50	16	0	-1	-1	-2	-2	-3	-3	-4	-4	-5	-5	-6	-6	-7	-7	-8	-8	-9	-9	-10	-10	16
16,5	-69	-71	16,5	-1	-2	-3	-4	-5	-6	-7	-8	-9	-9	-10	-11	-12	-13	-14	-15	-16	-17	-18	-19	-20	16,5
17	-85	-87	17	-1	-3	-4	-5	-7	-8	-9	-11	-12	-14	-15	-16	-18	-19	-20	-22	-23	-24	-26	-27	-28	17
17,5	-95	-97	17,5	-2	-3	-5	-7	-8	-10	-12	-13	-15	-17	-18	-20	-22	-24	-25	-27	-29	-30	-32	-34	-35	17,5
18	-98	-100	18	-2	-4	-6	-8	-9	-11	-13	-15	-17	-19	-21	-23	-25	-27	-28	-30	-32	-34	-36	-38	-40	18
18,5	-95	-97	18,5	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20	-22	-24	-26	-28	-30	-32	-34	-36	-38	-40	-42	18,5
19	-85	-87	19	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20	-22	-24	-26	-28	-29	-31	-33	-35	-37	-39	-41	19
19,5	-69	-71	19,5	-2	-4	-5	-7	-9	-11	-13	-14	-16	-18	-20	-22	-24	-25	-27	-29	-31	-33	-34	-36	-38	19,5
20	-49	-50	20	-2	-3	-5	-6	-8	-9	-11	-12	-14	-15	-17	-18	-20	-22	-23	-25	-26	-28	-29	-31	-32	20
20,5	-25	-26	20,5	-1	-2	-4	-5	-6	-7	-8	-9	-11	-12	-13	-14	-15	-16	-18	-19	-20	-21	-22	-23	-25	20,5
21	0	0	21	-1	-1	-2	-3	-4	-4	-5	-6	-7	-7	-8	-9	-9	-10	-11	-12	-12	-13	-14	-15	-15	21
21,5	25	26	21,5	0	0	-1	-1	-1	-1	-2	-2	-2	-2	-3	-3	-3	-3	-4	-4	-4	-4	-5	-5	-5	21,5
22	49	50	22	0	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	5	5	5	5	6	22
22,5	69	71	22,5	1	2	2	3	4	5	5	6	7	8	8	9	10	11	11	12	13	14	14	15	16	22,5
23	85	87	23	1	2	4	5	6	7	8	10	11	12	13	14	16	17	18	19	20	21	23	24	25	23
23,5	95	97	23,5	2	3	5	6	8	9	11	12	14	16	17	19	20	22	23	25	26	28	30	31	33	23,5
24	98	100	24	2	4	5	7	9	11	13	15	16	18	20	22	24	26	27	29	31	33	35	36	38	24
			24,5	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	33	35	37	39	41	24,5
			25	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	25
u			u																					u
	98	100		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	
	AMPLITUDE.			AMPLITUDE.																					

TABLE 4 Water level at half hour intervals for given amplitudes

M_2

Hours before or after H.W.	AMPLITUDE.																							Hours before or after H.W.
	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	
h																									h
0	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	0
0,5	43	45	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	77	79	81	83	85	87	0,5
1	38	40	42	44	45	47	49	51	52	54	56	58	59	61	63	65	66	68	70	72	73	75	77	79	1
1,5	32	33	35	36	38	39	41	42	44	45	46	48	49	51	52	54	55	57	58	60	61	62	64	65	1,5
2	23	24	25	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	45	46	47	48	2
2,5	13	14	14	15	16	16	17	17	18	19	19	20	20	21	22	22	23	24	24	25	25	26	27	27	2,5
3	2	2	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	5	5	5	3
3,5	−9	−9	−10	−10	−10	−11	−11	−12	−12	−12	−13	−13	−13	−14	−14	−15	−15	−15	−16	−16	−17	−17	−17	−18	3,5
4	−19	−20	−21	−22	−23	−24	−24	−25	−26	−27	−28	−29	−30	−31	−31	−32	−33	−34	−35	−36	−37	−38	−38	−39	4
4,5	−29	−30	−31	−32	−34	−35	−36	−38	−39	−40	−42	−43	−44	−45	−47	−48	−49	−51	−52	−53	−54	−56	−57	−58	4,5
5	−36	−38	−39	−41	−43	−44	−46	−47	−49	−51	−52	−54	−56	−57	−59	−61	−62	−64	−65	−67	−69	−70	−72	−74	5
5,5	−41	−43	−45	−47	−49	−51	−52	−54	−56	−58	−60	−62	−64	−66	−67	−69	−71	−73	−75	−77	−79	−81	−82	−84	5,5
6	−44	−46	−48	−50	−52	−54	−56	−58	−60	−62	−64	−66	−68	−70	−72	−74	−76	−78	−80	−82	−84	86	88	89	6
6,5	−44	−46	−47	−49	−51	−53	−55	−57	−59	−61	−63	−65	−67	−69	−71	−73	−75	−77	−79	−81	−83	85	87	89	6,5
7	−41	−42	−44	−46	−48	−50	−52	−53	−55	−57	−59	−61	−63	−64	66	−68	−70	−72	−74	−76	−77	−79	81	−83	7
7,5	−35	−37	−38	−40	−41	−43	−44	−46	−48	−49	−51	−52	−54	56	57	59	−60	−62	−64	65	−67	−68	70	72	7,5
8	−27	−28	−30	−31	−32	−33	−35	−36	−37	−38	−40	41	−42	43	44	46	−47	48	−49	−51	−52	−53	54	56	8
8,5	−18	−18	−19	−20	−21	−22	−22	−23	−24	−25	−26	−26	−27	−28	−29	−30	−30	−31	−32	−33	−34	34	35	−36	8,5
9	−7	−7	−8	−8	−8	−9	−9	−9	10	−10	−10	−10	−11	−11	−11	−12	−12	−12	−13	−13	−13	14	−14	−14	9
9,5	4	4	4	5	5	5	5	5	6	6	6	6	6	7	7	7	7	7	7	8	8	8	8	8	9,5
10	15	16	16	17	18	18	19	20	20	21	22	22	23	24	24	25	26	26	27	28	29	29	30	31	10
10,5	25	26	27	28	29	30	32	33	34	35	36	37	38	39	41	42	43	44	45	46	47	49	50	51	10,5
11	33	35	36	38	39	41	42	44	45	47	48	50	51	53	54	56	57	59	60	62	63	65	66	68	11
11,5	39	41	43	45	46	48	50	52	54	55	57	59	61	63	64	66	68	70	71	73	75	77	79	80	11,5
12	43	45	47	49	51	53	55	57	59	61	63	65	66	68	70	72	74	76	78	80	82	84	86	88	12
12,5	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	12,5
13	42	44	46	48	50	52	54	56	57	59	61	63	65	67	69	71	73	75	77	79	80	82	84	86	13
13,5	38	39	41	43	44	46	48	50	51	53	55	56	58	60	62	63	65	67	68	70	72	73	75	77	13,5
14	31	32	33	35	36	38	39	40	42	43	45	46	47	49	50	52	53	54	56	57	59	60	61	63	14
14,5	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	14,5
15	12	12	13	13	14	14	15	15	16	16	17	17	18	18	19	19	20	21	21	22	22	23	23	24	15
15,5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15,5
16	−10	−11	−11	−12	−12	−13	−13	−14	−14	15	−15	16	−16	−17	17	−18	−18	−19	−19	−19	−20	−20	−21	−21	16
16,5	−21	−22	−23	−24	−25	−26	−26	−27	−28	−29	−30	31	−32	−33	−34	−35	16	−37	−38	−39	−40	−41	−42	−43	16,5
17	−30	−31	−33	−34	−35	−37	−38	−39	−41	−42	−43	−45	−46	−47	−49	50	−52	−53	−54	−56	−57	−58	−60	−61	17
17,5	−37	−39	−40	−42	−44	−45	−47	−49	−50	−52	−54	−55	−57	−59	−61	−62	−64	−66	−67	−69	−71	−72	−74	−76	17,5
18	−42	−44	−46	−47	−49	−51	−53	−55	−57	−59	−61	−63	−65	66	−68	−70	−72	74	76	−78	−80	82	−84	−85	18
18,5	44	−46	48	−50	−52	−54	56	−58	−60	−62	−64	−66	−68	−70	−72	−74	−76	−78	80	−82	−84	−86	−88	−90	18,5
19	−43	−45	−47	−49	−51	−53	−55	−57	−59	−61	−63	−65	−67	−69	−71	−73	−75	−77	−79	−81	−83	−85	−86	−88	19
19,5	−40	−42	−43	−45	−47	−49	−51	−52	−54	−56	−58	−60	−62	−63	65	67	69	−71	−72	−74	−76	−78	−80	−81	19,5
20	−34	35	−37	−38	−40	−42	−43	45	−46	−48	−49	51	−52	54	55	−57	−58	−60	62	63	−65	−66	−68	−69	20
20,5	−26	−27	−28	−29	−30	−32	33	−34	−35	−36	−37	−39	40	41	−42	−43	−44	46	47	−48	−49	−50	−52	−53	20,5
21	−16	−17	−17	−18	−19	−20	−20	−21	−22	−23	−23	−24	−25	−25	−26	−27	−28	−28	−29	−30	−31	−31	−32	−33	21
21,5	− 5	− 5	− 6	− 6	− 6	− 6	− 7	− 7	− 7	− 7	− 8	− 8	− 8	− 8	− 9	− 9	−9	−9	−10	−10	−10	−10	−10	−11	21,5
22	6	6	6	7	7	7	7	8	8	8	9	9	9	9	10	10	10	10	11	11	11	11	12	12	22
22,5	17	17	18	19	20	20	21	22	23	23	24	25	26	26	27	28	29	29	30	31	32	32	33	34	22,5
23	26	27	29	30	31	32	33	35	36	37	38	39	41	42	43	44	45	47	48	49	50	51	53	54	23
23,5	34	36	37	39	40	42	44	45	47	48	50	51	53	54	56	58	59	61	62	64	65	67	69	70	23,5
24	40	42	44	46	47	49	51	53	55	56	58	60	62	64	66	67	69	71	73	75	77	78	80	82	24
24,5	43	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81	83	85	87	89	24,5
25	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	25
h																									h
	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	
	AMPLITUDE.																								

TABLE 4 Water level at half hour intervals for given amplitudes

M_2

Hours before or after H.W.	AMPLITUDE.																							Hours before or after H.W.
	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120	122	124	126	128	130	132	134	136	138	
u																									u
0	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120	122	124	126	128	130	132	134	136	138	0
0,5	89	91	93	95	97	99	101	103	105	107	108	110	112	114	116	118	120	122	124	126	128	130	132	134	0,5
1	80	82	84	86	87	89	91	93	94	96	98	100	101	103	105	107	108	110	112	114	115	117	119	121	1
1,5	67	68	70	71	73	74	75	77	78	80	81	83	84	86	87	89	90	91	93	94	96	97	99	100	1,5
2	49	50	51	52	53	54	55	56	57	58	59	60	62	63	64	65	66	67	68	69	70	71	72	73	2
2,5	28	28	29	30	30	31	31	32	33	33	34	34	35	36	36	37	37	38	39	39	40	40	41	42	2,5
3	5	5	5	5	5	5	6	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7	3
3,5	−18	−19	−19	−19	−20	−20	−21	−21	−21	−22	−22	−23	−23	−23	−24	−24	−25	−25	−25	−26	−26	−27	−27	−27	3,5
4	−40	−41	−42	−43	−44	−45	−45	−46	−47	−48	−49	−50	−51	−52	−52	−53	−54	−55	−56	−57	−58	−59	−59	−60	4
4,5	−60	−61	−62	−64	−65	−66	−67	−69	−70	−71	−73	−74	−75	−77	−78	−79	−80	−82	−83	−84	−86	−87	−88	−89	4,5
5	−75	−77	−79	−80	−82	−83	−85	−87	−88	−90	−92	−93	−95	−97	−98	−100	−101	−103	−105	−106	−108	−110	−111	−113	5
5,5	−86	−88	−90	−92	−94	−95	−97	−99	−101	−103	−105	−107	−109	−110	−112	−114	−116	−118	−120	−122	−124	−125	−127	−129	5,5
6	−91	−93	−95	−97	−99	−101	−103	−105	−107	−109	−111	−113	−115	−117	−119	−121	−123	−125	−127	−129	−131	−133	−135	−137	6
6,5	−91	−93	−95	−97	−99	−101	−103	−105	−107	−109	−111	−113	−115	−117	−119	−121	−123	−125	−127	−129	−131	−133	−135	−137	6,5
7	−85	−87	−88	−90	−92	−94	−96	−98	−99	−101	−103	−105	−107	−109	−111	−112	−114	−116	−118	−120	−122	−123	−125	−127	7
7,5	−73	−75	−76	−78	−79	−81	−83	−84	−86	−87	−89	−91	−92	−94	−95	−97	−99	−100	−102	−103	−105	−106	−108	−110	7,5
8	−57	−58	−59	−61	−62	−63	−64	−65	−67	−68	−69	−70	−72	−73	−74	−75	−77	−78	−79	−80	−81	−83	−84	−85	8
8,5	−37	−38	−38	−39	−40	−41	−42	−42	−43	−44	−45	−46	−47	−47	−48	−49	−50	−51	−51	−52	−53	−54	−55	−55	8,5
9	−15	−15	−15	−16	−16	−16	−17	−17	−17	−17	−18	−18	−18	−19	−19	−19	−20	−20	−20	−21	−21	−21	−22	−22	9
9,5	9	9	9	9	9	10	10	10	10	10	10	11	11	11	11	11	12	12	12	12	12	12	13	13	9,5
10	31	32	33	33	34	35	35	36	37	37	38	39	39	40	41	41	42	43	43	44	45	45	46	47	10
10,5	52	53	54	55	56	58	59	60	61	62	63	64	65	67	68	69	70	71	72	73	74	76	77	78	10,5
11	69	71	72	74	75	77	78	80	81	83	84	86	87	89	90	92	93	95	96	98	99	101	102	104	11
11,5	82	84	86	88	89	91	93	95	96	98	100	102	104	105	107	109	111	113	114	116	118	120	122	123	11,5
12	90	92	94	96	98	100	102	104	106	108	109	111	113	115	117	119	121	123	125	127	129	131	133	135	12
12,5	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120	122	124	126	128	130	132	134	136	138	12,5
13	88	90	92	94	96	98	100	101	103	105	107	109	111	113	115	117	119	121	123	124	126	128	130	132	13
13,5	79	80	82	84	85	87	89	91	92	94	96	97	99	101	103	104	106	108	109	111	113	115	116	118	13,5
14	64	66	67	68	70	71	73	74	75	77	78	80	81	82	84	85	86	88	89	91	92	93	95	96	14
14,5	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	61	62	63	64	65	66	67	68	14,5
15	24	25	25	26	26	27	27	28	28	29	29	30	30	31	32	32	33	33	34	34	35	35	36	36	15
15,5	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	15,5
16	−22	−22	−23	−23	−24	−24	−25	−25	−26	−26	−27	−27	−28	−28	−29	−29	−29	−30	−30	−31	−31	−32	−32	−33	16
16,5	−44	−44	−45	−46	−47	−48	−49	−50	−51	−52	−53	−54	−55	−56	−57	−58	−59	−60	−61	−62	−62	−63	−64	−65	16,5
17	−62	−64	−65	−66	−68	−69	−71	−72	−73	−75	−76	−77	−79	−80	−81	−83	−84	−85	−87	−88	−90	−91	−92	−94	17
17,5	−77	−79	−81	−82	−84	−86	−87	−89	−91	−92	−94	−96	−98	−99	−101	−103	−104	−106	−108	−109	−111	−113	−114	−116	17,5
18	−87	−89	−91	−93	−95	−97	−99	−101	−103	−104	−106	−108	−110	−112	−114	−116	−118	−120	−122	−123	−125	−127	−129	−131	18
18,5	−92	−94	−96	−98	−100	−102	−104	−106	−108	−110	−112	−114	−116	−118	−120	−122	−124	−126	−128	−130	−132	−134	−136	−138	18,5
19	−90	−92	−94	−96	−98	−100	−102	−104	−106	−108	−110	−112	−114	−116	−118	−120	−122	−124	−126	−128	−130	−132	−134	−136	19
19,5	−83	−85	−87	−89	−90	−92	−94	−96	−98	−100	−101	−103	−105	−107	−109	−110	−112	−114	−116	−118	−119	−121	−123	−125	19,5
20	−71	−72	−74	−75	−77	−78	−80	−82	−83	−85	−86	−88	−89	−91	−92	−94	−95	−97	−99	−100	−102	−103	−105	−106	20
20,5	−54	−55	−56	−57	−59	−60	−61	−62	−63	−64	−66	−67	−68	−69	−70	−71	−73	−74	−75	−76	−77	−78	−80	−81	20,5
21	−33	−34	−35	−36	−36	−37	−38	−39	−39	−40	−41	−41	−42	−43	−44	−44	−45	−46	−47	−47	−48	−49	−49	−50	21
21,5	−11	−11	−11	−12	−12	−12	−12	−13	−13	−13	−13	−14	−14	−14	−14	−15	−15	−15	−15	−15	−16	−16	−16	−16	21,5
22	12	13	13	13	13	14	14	14	14	15	15	15	15	16	16	16	17	17	17	17	18	18	18	18	22
22,5	35	35	36	37	38	38	39	40	41	41	42	43	44	44	45	46	47	47	48	49	50	51	51	52	22,5
23	55	56	57	58	60	61	62	63	64	66	67	68	69	70	72	73	74	75	76	78	79	80	81	82	23
23,5	72	73	75	76	78	79	81	83	84	86	87	89	90	92	93	95	97	98	100	101	103	104	106	107	23,5
24	84	86	87	89	91	93	95	97	98	100	102	104	106	107	109	111	113	115	117	118	120	122	124	126	24
24,5	91	93	95	97	99	100	102	104	106	108	110	112	114	116	118	120	122	124	126	128	130	132	134	136	24,5
25	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120	122	124	126	128	130	132	134	136	138	25
u																									u
	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120	122	124	126	128	130	132	134	136	138	
	AMPLITUDE.																								

TABLE 4 Water level at half hour intervals for given amplitudes

M_2

Hours before or after H.W.	AMPLITUDE.																								Hours before or after H.W.
	140	142	144	146	148	150	152	154	156	158	160	162	164	166	168	170	172	174	176	178	180	182	184	186	
u																									u
0	140	142	144	146	148	150	152	154	156	158	160	162	164	166	168	170	172	174	176	178	180	182	184	186	0
0,5	136	137	139	141	143	145	147	149	151	153	155	157	159	161	163	165	167	168	170	172	174	176	178	180	0,5
1	122	124	126	128	129	131	133	135	136	138	140	142	143	145	147	149	150	152	154	156	157	159	161	163	1
1,5	102	103	104	106	107	109	110	112	113	115	116	118	119	120	122	123	125	126	128	129	131	132	134	135	1,5
2	74	75	76	77	78	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	97	98	99	2
2,5	42	43	43	44	45	45	46	46	47	48	48	49	49	50	51	51	52	52	53	54	54	55	55	56	2,5
3	7	8	8	8	8	8	8	8	8	8	9	9	9	9	9	9	9	9	9	9	10	10	10	10	3
3,5	-28	-28	-29	-29	-29	-30	-30	-31	-31	-31	-32	-32	-33	-33	-33	-34	-34	-35	-35	-35	-36	-36	-37	-37	3,5
4	-61	-62	-63	-64	-65	-66	-66	-67	-68	-69	-70	-71	-72	-73	-73	-74	-75	-76	-77	-78	-79	-80	-80	-81	4
4,5	-91	-92	-93	-95	-96	-97	-99	-100	-101	-102	-104	-105	-106	-108	-109	-110	-112	-113	-114	-115	-117	-118	-119	-121	4,5
5	-115	-116	-118	-119	-121	-123	-124	-126	-128	-129	-131	-133	-134	-136	-137	-139	-141	-142	-144	-146	-147	-149	-151	-152	5
5,5	-131	-133	-135	-137	-139	-140	-142	-144	-146	-148	-150	-152	-154	-155	-157	-159	-161	-163	-165	-167	-169	-170	-172	-174	5,5
6	-139	-141	-143	-145	-147	-149	-151	-153	-155	-157	-159	-161	-163	-165	-167	-169	-171	-173	-175	-177	-179	-181	-183	-185	6
6,5	-138	-140	-142	-144	-146	-148	-150	-152	-154	-156	-158	-160	-162	-164	-166	-168	-170	-172	-174	-176	-178	-180	-182	-184	6,5
7	-129	-131	-133	-135	-136	-138	-140	-142	-144	-146	-147	-149	-151	-153	-155	-157	-158	-160	-162	-164	-166	-168	-170	-171	7
7,5	-111	-113	-114	-116	-118	-119	-121	-122	-124	-126	-127	-129	-130	-132	-133	-135	-137	-138	-140	-141	-143	-145	-146	-148	7,5
8	-86	-88	-89	-90	-91	-93	-94	-95	-96	-98	-99	-100	-101	-102	-104	-105	-106	-107	-109	-110	-111	-112	-114	-115	8
8,5	-56	-57	-58	-59	-59	-60	-61	-62	-63	-63	-64	-65	-66	-67	-67	-68	-69	-70	-71	-71	-72	-73	-74	-75	8,5
9	-22	-23	-23	-23	-24	-24	-24	-24	-25	-25	-25	-26	-26	-26	-27	-27	-27	-28	-28	-28	-29	-29	-29	-30	9
9,5	13	13	13	14	14	14	14	14	15	15	15	15	15	15	16	16	16	16	16	17	17	17	17	17	9,5
10	48	48	49	50	50	51	52	52	53	54	54	55	56	56	57	58	58	59	60	60	61	62	62	63	10
10,5	79	80	81	82	83	85	86	87	88	89	90	91	92	94	95	96	97	98	99	100	102	103	104	105	10,5
11	105	107	108	110	111	113	114	116	117	119	120	122	123	125	126	128	129	131	132	134	135	137	138	140	11
11,5	125	127	129	130	132	134	136	138	139	141	143	145	147	148	150	152	154	155	157	159	161	163	164	166	11,5
12	137	139	141	143	145	147	149	151	152	154	156	158	160	162	164	166	168	170	172	174	176	178	180	182	12
12,5	140	142	144	146	148	150	152	154	156	158	160	162	164	166	168	170	172	174	176	178	180	182	184	186	12,5
13	134	136	138	140	142	144	146	147	149	151	153	155	157	159	161	163	165	167	168	170	172	174	176	178	13
13,5	120	121	123	125	126	128	130	132	133	135	137	138	140	142	144	145	147	149	150	152	154	156	157	159	13,5
14	98	99	100	102	103	105	106	107	109	110	112	113	114	116	117	119	120	121	123	124	126	127	128	130	14
14,5	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	14,5
15	37	37	38	38	39	39	40	40	41	42	42	43	43	44	44	45	45	46	46	47	47	48	48	49	15
15,5	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	15,5
16	-33	-34	-34	-35	-35	-36	-36	-37	-37	-38	-38	-38	-39	-39	-40	-40	-41	-41	-42	-42	-43	-43	-44	-44	16
16,5	-66	-67	-68	-69	-70	-71	-72	-73	-74	-75	-76	-77	-78	-79	-79	-80	-81	-82	-83	-84	-85	-86	-87	-88	16,5
17	-95	-96	-98	-99	-100	-102	-103	-104	-106	-107	-109	-110	-111	-113	-114	-115	-117	-118	-119	-121	-122	-123	-125	-126	17
17,5	-118	-119	-121	-123	-124	-126	-128	-129	-131	-133	-135	-136	-138	-140	-141	-143	-145	-146	-148	-150	-151	-153	-155	-156	17,5
18	-133	-135	-137	-139	-141	-142	-144	-146	-148	-150	-152	-154	-156	-158	-160	-161	-163	-165	-167	-169	-171	-173	-175	-177	18
18,5	-140	-142	-144	-146	-148	-150	-152	-154	-156	-158	-160	-162	-164	-166	-168	-170	-172	-174	-176	-178	-180	-182	-184	-186	18,5
19	-138	-140	-141	-143	-145	-147	-149	-151	-153	-155	-157	-159	-161	-163	-165	-167	-169	-171	-173	-175	-177	-179	-181	-183	19
19,5	-127	-128	-130	-132	-134	-136	-138	-139	-141	-143	-145	-147	-148	-150	-152	-154	-156	-157	-159	-161	-163	-165	-167	-168	19,5
20	-108	-109	-111	-112	-114	-115	-117	-119	-120	-122	-123	-125	-126	-128	-129	-131	-132	-134	-135	-137	-139	-140	-142	-143	20
20,5	-82	-83	-84	-85	-87	-88	-89	-90	-91	-92	-94	-95	-96	-97	-98	-100	-101	-102	-103	-104	-105	-107	-108	-109	20,5
21	-51	-52	-52	-53	-54	-55	-55	-56	-57	-57	-58	-59	-60	-60	-61	-62	-63	-63	-64	-65	-65	-66	-67	-68	21
21,5	-17	-17	-17	-17	-18	-18	-18	-18	-19	-19	-19	-19	-20	-20	-20	-20	-20	-21	-21	-21	-21	-22	-22	-22	21,5
22	19	19	19	19	20	20	20	21	21	21	21	22	22	22	22	23	23	23	23	24	24	24	24	25	22
22,5	53	54	54	55	56	57	57	58	59	60	60	61	62	63	63	64	65	66	66	67	68	69	69	70	22,5
23	84	85	86	87	88	90	91	92	93	94	95	97	98	99	100	101	103	104	105	106	107	109	110	111	23
23,5	109	111	112	114	115	117	118	120	121	123	125	126	128	129	131	132	134	135	137	139	140	142	143	145	23,5
24	128	129	131	133	135	137	138	140	142	144	146	148	149	151	153	155	157	158	160	162	164	166	168	169	24
24,5	138	140	142	144	146	148	150	152	154	156	158	160	162	164	166	167	169	171	173	175	177	179	181	183	24,5
25	140	142	144	146	148	150	152	154	155	157	159	161	163	165	167	169	171	173	175	177	179	181	183	185	25
u																									u
	140	142	144	146	148	150	152	154	156	158	160	162	164	166	168	170	172	174	176	178	180	182	184	186	
	AMPLITUDE.																								

TABLE 4 Water level at half hour intervals for given amplitudes

M_2

Hours before or after H.W.	AMPLITUDE.						
	188	190	192	194	196	198	200
h							
0	188	190	192	194	196	198	200
0,5	182	184	186	188	190	192	194
1	164	166	168	170	171	173	175
1,5	136	138	139	141	142	144	145
2	100	101	102	103	104	105	106
2,5	57	57	58	58	59	60	60
3	10	10	10	10	10	11	11
3,5	- 37	- 38	- 38	- 38	- 39	- 39	- 40
4	- 82	- 83	- 84	- 85	- 86	- 87	- 87
4,5	-122	-123	-125	-126	-127	-128	-130
5	-154	-155	-157	-159	-160	-162	-164
5,5	-176	-178	-180	-182	-183	-185	-187
6	-187	-189	-191	-193	-195	-197	-199
6,5	-186	-188	-190	-192	-194	-196	-198
7	-173	-175	-177	-179	-181	-182	-184
7,5	-149	-151	-153	-154	-156	-157	-159
8	-116	-117	-119	-120	-121	-122	-123
8,5	- 75	- 76	- 77	- 78	- 79	- 79	- 80
9	- 30	- 30	- 31	- 31	- 31	- 31	- 32
9,5	18	18	18	18	18	18	19
10	64	64	65	66	67	67	68
10,5	106	107	108	109	111	112	113
11	142	143	145	146	148	149	151
11,5	168	170	172	173	175	177	179
12	184	186	188	190	192	194	195
12,5	188	190	192	194	196	198	200
13	180	182	184	186	188	190	191
13,5	161	162	164	166	167	169	171
14	131	133	134	135	137	138	139
14,5	93	94	95	96	97	98	99
15	49	50	50	51	52	52	53
15,5	2	2	3	3	3	3	3
16	- 45	- 45	- 46	- 46	- 47	- 47	- 48
16,5	- 89	- 90	- 91	- 92	- 93	- 94	- 95
17	-128	-129	-130	-132	-133	-134	-136
17,5	-158	-160	-161	-163	-165	-166	-168
18	-179	-180	-182	-184	-186	-188	-190
18,5	-188	-190	-192	-194	-196	-198	-200
19	-185	-187	-189	-191	-193	-195	-197
19,5	-170	-172	-174	-176	-177	-179	-181
20	-145	-146	-148	-149	-151	-152	-154
20,5	-110	-111	-112	-114	-115	-116	-117
21	- 68	- 69	- 70	- 71	- 71	- 72	- 73
21,5	- 22	- 23	- 23	- 23	- 23	- 24	- 24
22	25	25	26	26	26	26	27
22,5	71	72	72	73	74	75	75
23	112	113	115	116	117	118	119
23,5	146	148	149	151	153	154	156
24	171	173	175	177	179	180	182
24,5	185	187	189	191	193	195	197
25	187	189	191	193	195	197	199
h							
	188	190	192	194	196	198	200
	AMPLITUDE.						

N_2

Hours before or after H.W.	AMPLITUDE.														
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
h																
0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
0,5	2	4	6	8	10	12	14	16	17	19	21	23	25	27	29	31
1	2	4	5	7	9	11	12	14	16	18	19	21	23	25	26	28
1,5	1	3	4	6	7	9	10	12	13	15	16	18	19	21	22	24
2	1	2	3	4	5	7	8	9	10	11	12	13	14	15	16	17
2,5	1	1	2	3	3	4	5	5	6	6	7	8	8	9	10	10
3	0	0	0	1	1	1	1	1	1	2	2	2	2	2	2	3
3,5	0	- 1	- 1	- 1	- 2	- 2	- 2	- 3	- 3	- 3	- 4	- 4	- 4	- 5	- 5	- 5
4	- 1	- 2	- 2	- 3	- 4	- 5	- 6	- 6	- 7	- 8	- 9	-10	-10	-11	-12	-13
4,5	- 1	- 2	- 4	- 5	- 6	- 7	- 9	-10	-11	-12	-14	-15	-16	-17	-18	-20
5	- 2	- 3	- 5	- 6	- 8	- 9	-11	-13	-14	-16	-17	-19	-21	-22	-24	-25
5,5	- 2	- 4	- 5	- 7	- 9	-11	-13	-15	-16	-18	-20	-22	-24	-26	-27	-29
6	- 2	- 4	- 6	- 8	-10	-12	-14	-16	-18	-20	-22	-24	-26	-28	-30	-32
6,5	- 2	- 4	- 6	- 8	-10	-12	-14	-16	-18	-20	-22	-24	-26	-28	-30	-32
7	- 2	- 4	- 6	- 8	- 9	-11	-13	-15	-17	-19	-21	-23	-25	-26	-28	-30
7,5	- 2	- 3	- 5	- 7	- 8	-10	-12	-13	-15	-17	-18	-20	-22	-23	-25	-27
8	- 1	- 3	- 4	- 5	- 7	- 8	- 9	-11	-12	-14	-15	-16	-18	-19	-20	-22
8,5	- 1	- 2	- 3	- 4	- 5	- 6	- 7	- 8	- 9	- 9	-10	-11	-12	-13	-14	-15
9	0	- 1	- 1	- 2	- 2	- 3	- 3	- 4	- 4	- 5	- 5	- 6	- 6	- 7	- 7	- 8
9,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8
10,5	1	2	3	4	5	6	7	8	9	10	11	11	12	13	14	15
11	1	3	4	5	7	8	10	11	12	14	15	16	18	19	20	22
11,5	2	3	5	7	8	10	12	13	15	17	18	20	22	23	25	27
12	2	4	6	8	9	11	13	15	17	19	21	23	25	27	28	30
12,5	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
13	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
13,5	2	4	5	7	9	11	13	15	16	18	20	22	24	26	27	29
14	2	3	5	6	8	9	11	13	14	16	17	19	20	22	24	25
14,5	1	2	4	5	6	7	9	10	11	12	13	15	16	17	18	20
15	1	2	2	3	4	5	6	6	7	8	9	10	10	11	12	13
15,5	0	1	1	1	2	2	2	3	3	3	4	4	4	4	5	5
16	0	0	- 1	- 1	- 1	- 1	- 1	- 1	- 2	- 2	- 2	- 2	- 2	- 2	- 3	- 3
16,5	- 1	- 1	- 2	- 3	- 3	- 4	- 5	- 5	- 6	- 7	- 7	- 8	- 9	- 9	-10	-11
17	- 1	- 2	- 3	- 4	- 6	- 7	- 8	- 9	-10	-11	-12	-13	-14	-15	-17	-18
17,5	- 1	- 3	- 4	- 6	- 7	- 9	-10	-12	-13	-15	-16	-18	-19	-21	-22	-24
18	- 2	- 4	- 5	- 7	- 9	-11	-12	-14	-16	-18	-19	-21	-23	-25	-26	-28
18,5	- 2	- 4	- 6	- 8	-10	-12	-14	-16	-17	-19	-21	-23	-25	-27	-29	-31
19	- 2	- 4	- 6	- 8	-10	-12	-14	-16	-18	-20	-22	-24	-26	-28	-30	-32
19,5	- 2	- 4	- 6	- 8	-10	-12	-14	-15	-17	-19	-21	-23	-25	-27	-29	-31
20	- 2	- 4	- 5	- 7	- 9	-11	-12	-14	-16	-18	-19	-21	-23	-25	-26	-28
20,5	- 1	- 3	- 4	- 6	- 7	- 9	-10	-12	-13	-15	-16	-18	-19	-20	-22	-23
21	- 1	- 2	- 3	- 4	- 5	- 6	- 8	- 9	-10	-11	-12	-13	-14	-15	-16	-17
21,5	- 1	- 1	- 2	- 3	- 3	- 4	- 4	- 5	- 6	- 6	- 7	- 8	- 8	- 9	-10	-10
22	0	0	0	- 1	- 1	- 1	- 1	- 1	- 1	- 2	- 2	- 2	- 2	- 2	- 2	- 2
22,5	0	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5
23	1	2	2	3	4	5	6	7	7	8	9	10	11	11	12	13
23,5	1	2	4	5	6	7	9	10	11	12	14	15	16	17	19	20
24	2	3	5	6	8	10	11	13	14	16	17	19	21	22	24	25
24,5	2	4	6	7	9	11	13	15	17	18	20	22	24	26	28	29
25	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
25,5	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
h																
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
	AMPLITUDE.															

TABLE 4 Water level at half hour intervals for given amplitudes

Hours before or after H.W.	N_2 AMPLITUDE.															Hours before or after H.W.	K_1 P_1 AMPLITUDE.								Hours before or after H.W.
	34	36	38	40	42	44	46	48	50	52	54	56	58	60	100		2	4	6	8	10	12	14	16	
u																u									u
0	34	36	38	40	42	44	46	48	50	52	54	56	58	60	100	0	2	4	6	8	10	12	14	16	0
0,5	33	35	37	39	41	43	45	47	48	50	52	54	56	58	97	0,5	2	4	6	8	10	12	14	16	0,5
1	30	32	33	35	37	39	40	42	44	46	47	49	51	53	88	1	2	4	6	8	10	12	14	15	1
1,5	25	26	28	29	31	32	34	35	37	38	40	41	43	44	74	1,5	2	4	6	7	9	11	13	15	1,5
2	19	20	21	22	23	24	25	26	27	28	30	31	32	33	55	2	2	3	5	7	9	10	12	14	2
2,5	11	12	12	13	14	14	15	16	16	17	17	18	19	19	32	2,5	2	3	5	6	8	10	11	13	2,5
3	3	3	3	3	3	4	4	4	4	4	4	5	5	5	8	3	1	3	4	6	7	8	10	11	3
3,5	- 6	- 6	- 6	- 7	- 7	- 7	- 8	- 8	- 8	- 9	- 9	- 9	-10	-10	-17	3,5	1	2	4	5	6	7	9	10	3,5
4	-14	-15	-15	-16	-17	-18	-19	-19	-20	-21	-22	-23	-23	-24	-40	4	1	2	3	4	5	6	7	8	4
4,5	-21	-22	-23	-25	-26	-27	-28	-30	-31	-32	-33	-34	-36	-37	-62	4,5	1	2	2	3	4	5	5	6	4,5
5	-27	-28	-30	-32	-33	-35	-36	-38	-40	-41	-43	-44	-46	-47	-79	5	1	1	2	2	3	3	4	4	5
5,5	-31	-33	-35	-37	-38	-40	-42	-44	-46	-48	-49	-51	-53	-55	-92	5,5	0	1	1	1	1	2	2	2	5,5
6	-34	-36	-37	-39	-41	-43	-45	-47	-49	-51	-53	-55	-57	-59	-99	6	0	0	0	0	0	0	0	0	6
6,5	-34	-36	-38	-40	-42	-44	-46	-48	-50	-52	-54	-56	-58	-60	-100	6,5	0	- 1	- 1	- 1	- 1	- 2	- 2	- 2	6,5
7	-32	-34	-36	-38	-40	-42	-43	-45	-47	-49	-51	-53	-55	-57	-95	7	- 1	- 1	- 2	- 2	- 3	- 3	- 4	- 4	7
7,5	-28	-30	-32	-33	-35	-37	-38	-40	-42	-43	-45	-47	-48	-50	-84	7,5	- 1	- 2	- 2	- 3	- 4	- 5	- 5	- 6	7,5
8	-23	-24	-26	-27	-28	-30	-31	-32	-34	-35	-36	-38	-39	-41	- 68	8	- 1	- 2	- 3	- 4	- 5	- 6	- 7	- 8	8
8,5	-16	-17	-18	-19	-20	-21	-22	-23	-24	-25	-26	-27	-27	-28	-47	8,5	- 1	- 2	- 4	- 5	- 6	- 7	- 9	-10	8,5
9	- 8	- 9	- 9	-10	-10	-11	-11	-12	-12	-13	-13	-14	-14	-15	-24	9	- 1	- 3	- 4	- 6	- 7	- 8	-10	-11	9
9,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9,5	- 2	- 3	- 5	- 6	- 8	-10	-11	-13	9,5
10	8	9	9	10	10	11	11	12	12	13	13	14	14	15	25	10	- 2	- 3	- 5	- 7	- 9	-10	-12	-14	10
10,5	16	17	18	19	20	21	22	23	24	25	26	27	28	29	48	10,5	- 2	- 4	- 6	- 7	- 9	-11	-13	-15	10,5
11	23	24	26	27	29	30	31	33	34	35	37	38	39	41	68	11	- 2	- 4	- 6	- 8	-10	-12	-14	-15	11
11,5	29	30	32	34	35	37	39	40	42	44	45	47	49	50	84	11,5	- 2	- 4	- 6	- 8	-10	-12	-14	-16	11,5
12	32	34	36	38	40	42	44	45	47	49	51	53	55	57	95	12	- 2	- 4	- 6	- 8	-10	-12	-14	-16	12
12,5	34	36	38	40	42	44	46	48	50	52	54	56	58	60	100	12,5	- 2	- 4	- 6	- 8	-10	-12	-14	-16	12,5
13	34	35	37	39	41	43	45	47	49	51	53	55	57	59	99	13	- 2	- 4	- 6	- 8	-10	-12	-14	-15	13
13,5	31	33	35	37	38	40	42	44	46	48	49	51	53	55	91	13,5	- 2	- 4	- 6	- 7	- 9	-11	-13	-15	13,5
14	27	28	30	31	33	35	36	38	39	41	42	44	46	47	79	14	- 2	- 3	- 5	- 7	- 9	-10	-12	-14	14
14,5	21	22	23	24	26	27	28	29	31	32	33	34	35	37	61	14,5	- 2	- 3	- 5	- 6	- 8	-10	-11	-13	14,5
15	14	14	15	16	17	17	18	19	20	21	21	22	23	24	40	15	- 1	- 3	- 4	- 6	- 7	- 8	-10	-11	15
15,5	5	6	6	6	7	7	7	8	8	8	9	9	9	10	16	15,5	- 1	- 2	- 4	- 5	- 6	- 7	- 9	-10	15,5
16	- 3	- 3	- 3	- 4	- 4	- 4	- 4	- 4	- 4	- 5	- 5	- 5	- 5	- 5	- 9	16	- 1	- 2	- 3	- 4	- 5	- 6	- 7	- 8	16
16,5	-11	-12	-13	-13	-14	-15	-15	-16	-16	-17	-18	-18	-19	-20	-33	16,5	- 1	- 2	- 2	- 3	- 4	- 5	- 5	- 6	16,5
17	-19	-20	-21	-22	-23	-24	-25	-26	-28	-29	-30	-31	-32	-33	-55	17	- 1	- 1	- 2	- 2	- 3	- 3	- 4	- 4	17
17,5	-25	-27	-28	-30	-31	-33	-34	-35	-37	-38	-40	-41	-43	-44	-74	17,5	0	- 1	- 1	- 1	- 1	- 2	- 2	- 2	17,5
18	-30	-32	-34	-35	-37	-39	-41	-42	-44	-46	-48	-49	-51	-53	-88	18	0	0	0	0	0	0	0	0	18
18,5	-33	-35	-37	-39	-41	-43	-45	-47	-49	-50	-52	-54	-56	-58	-97	18,5	0	1	1	1	1	2	2	2	18,5
19	-34	-36	-38	-40	-42	-44	-46	-48	-50	-52	-54	-56	-58	-60	-100	19	1	1	2	2	3	3	4	4	19
19,5	-33	-35	-37	-39	-41	-43	-45	-46	-48	-50	-52	-54	-56	-58	-97	19,5	1	2	2	3	4	5	5	6	19,5
20	-30	-32	-33	-35	-37	-39	-40	-42	-44	-46	-47	-49	-51	-53	-88	20	1	2	3	4	5	6	7	8	20
20,5	-25	-26	-28	-29	-31	-32	-34	-35	-37	-38	-39	-41	-42	-44	-73	20,5	1	2	4	5	6	7	9	10	20,5
21	-18	-19	-21	-22	-23	-24	-25	-26	-27	-28	-29	-30	-31	-32	-54	21	1	3	4	6	7	8	10	11	21
21,5	-11	-11	-12	-13	-13	-14	-15	-15	-16	-17	-17	-18	-18	-19	-32	21,5	2	3	5	6	8	10	11	13	21,5
22	- 3	- 3	- 3	- 3	- 3	- 3	- 3	- 4	- 4	- 4	- 4	- 4	- 4	- 5	- 8	22	2	3	5	7	9	10	12	14	22
22,5	6	6	7	7	7	8	8	8	9	9	9	10	10	10	17	22,5	2	4	6	7	9	11	13	15	22,5
23	14	15	16	16	17	18	19	20	20	21	22	23	24	25	41	23	2	4	6	8	10	12	14	15	23
23,5	21	22	24	25	26	27	29	30	31	32	33	35	36	37	62	23,5	2	4	6	8	10	12	14	16	23,5
24	27	29	30	32	33	35	37	38	40	41	43	44	46	48	79	24	2	4	6	8	10	12	14	16	24
24,5	31	33	35	37	39	40	42	44	46	48	50	51	53	55	92										
25	34	36	38	40	41	43	45	47	49	51	53	55	57	59	99										
25,5	34	36	38	40	42	44	46	48	50	52	54	56	58	60	100										
u																u									u
	34	36	38	40	42	44	46	48	50	52	54	56	58	60	100		2	4	6	8	10	12	14	16	
	AMPLITUDE.																AMPLITUDE.								

TABLE 4 Water level at half hour intervals for given amplitudes

K_1 P_1

Hours before or after H.W.	AMPLITUDE.																							Hours before or after H.W.
	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	
u																									u
0	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	0
0,5	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	59	61	63	0,5
1	17	19	21	23	25	27	29	31	33	35	37	39	41	43	44	46	48	50	52	54	56	58	60	62	1
1,5	17	18	20	22	24	26	28	30	31	33	35	37	39	41	42	44	46	48	50	52	54	55	57	59	1,5
2	16	17	19	21	23	24	26	28	29	31	33	35	36	38	40	42	43	45	47	48	50	52	54	55	2
2,5	14	16	17	19	21	22	24	25	27	29	30	32	33	35	36	38	40	41	43	44	46	48	49	51	2,5
3	13	14	16	17	18	20	21	23	24	25	27	28	30	31	33	34	35	37	38	40	41	42	44	45	3
3,5	11	12	13	15	16	17	18	19	21	22	23	24	26	27	28	29	30	32	33	34	35	37	38	39	3,5
4	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	4
4,5	7	8	8	9	10	11	11	12	13	14	15	15	16	17	18	18	19	20	21	21	22	23	24	24	4,5
5	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	16	16	17	5
5,5	2	3	3	3	3	4	4	4	4	5	5	5	5	6	6	6	7	7	7	7	8	8	8	8	5,5
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
6,5	−2	−3	−3	−3	−3	−4	−4	−4	−4	−5	−5	−5	−5	−6	−6	−6	−7	−7	−7	−7	−8	−8	−8	−8	6,5
7	−5	−5	−6	−6	−7	−7	−8	−8	−9	−9	−10	−10	−11	−11	−12	−12	−13	−13	−14	−14	−15	−16	−16	−17	7
7,5	−7	−8	−8	−9	−10	−11	−11	−12	−13	−14	−15	−15	−16	−17	−18	−18	−19	−20	−21	−21	−22	−23	−24	−24	7,5
8	−9	−10	−11	−12	−13	−14	−15	−16	−17	−18	−19	−20	−21	−22	−23	−24	−25	−26	−27	−28	−29	−30	−31	−32	8
8,5	−11	−12	−13	−15	−16	−17	−18	−19	−21	−22	−23	−24	−26	−27	−28	−29	−30	−32	−33	−34	−35	−37	−38	−39	8,5
9	−13	−14	−16	−17	−18	−20	−21	−23	−24	−25	−27	−28	−30	−31	−33	−34	−35	−37	−38	−40	−41	−42	−44	−45	9
9,5	−14	−16	−17	−19	−21	−22	−24	−25	−27	−29	−30	−32	−33	−35	−36	−38	−40	−41	−43	−44	−46	−48	−49	−51	9,5
10	−16	−17	−19	−21	−23	−24	−26	−28	−29	−31	−33	−35	−36	−38	−40	−42	−43	−45	−47	−48	−50	−52	−54	−55	10
10,5	−17	−18	−20	−22	−24	−26	−28	−30	−31	−33	−35	−37	−39	−41	−42	−44	−46	−48	−50	−52	−54	−55	−57	−59	10,5
11	−17	−19	−21	−23	−25	−27	−29	−31	−33	−35	−37	−39	−41	−43	−44	−46	−48	−50	−52	−54	−56	−58	−60	−62	11
11,5	−18	−20	−22	−24	−26	−28	−30	−32	−34	−36	−38	−40	−42	−44	−46	−48	−50	−52	−54	−56	−58	−59	−61	−63	11,5
12	−18	−20	−22	−24	−26	−28	−30	−32	−34	−36	−38	−40	−42	−44	−46	−48	−50	−52	−54	−56	−58	−60	−62	−64	12
12,5	−18	−20	−22	−24	−26	−28	−30	−32	−34	−36	−38	−40	−42	−44	−46	−48	−50	−52	−54	−56	−58	−59	−61	−63	12,5
13	−17	−19	−21	−23	−25	−27	−29	−31	−33	−35	−37	−39	−41	−43	−44	−46	−48	−50	−52	−54	−56	−58	−60	−62	13
13,5	−17	−18	−20	−22	−24	−26	−28	−30	−31	−33	−35	−37	−39	−41	−42	−44	−46	−48	−50	−52	−54	−55	−57	−59	13,5
14	−16	−17	−19	−21	−23	−24	−26	−28	−29	−31	−33	−35	−36	−38	−40	−42	−43	−45	−47	−48	−50	−52	−54	−55	14
14,5	−14	−16	−17	−19	−21	−22	−24	−25	−27	−29	−30	−32	−33	−35	−36	−38	−40	−41	−43	−44	−46	−48	−49	−51	14,5
15	−13	−14	−16	−17	−18	−20	−21	−23	−24	−25	−27	−28	−30	−31	−33	−34	−35	−37	−38	−40	−41	−42	−44	−45	15
15,5	−11	−12	−13	−15	−16	−17	−18	−19	−21	−22	−23	−24	−26	−27	−28	−29	−30	−32	−33	−34	−35	−37	−38	−39	15,5
16	−9	−10	−11	−12	−13	−14	−15	−16	−17	−18	−19	−20	−21	−22	−23	−24	−25	−26	−27	−28	−29	−30	−31	−32	16
16,5	−7	−8	−8	−9	−10	−11	−11	−12	−13	−14	−15	−15	−16	−17	−18	−18	−19	−20	−21	−21	−22	−23	−24	−24	16,5
17	−5	−5	−6	−6	−7	−7	−8	−8	−9	−9	−10	−10	−11	−11	−12	−12	−13	−13	−14	−14	−15	−16	−16	−17	17
17,5	−2	−3	−3	−3	−3	−4	−4	−4	−4	−5	−5	−5	−5	−6	−6	−6	−7	−7	−7	−7	−8	−8	−8	−8	17,5
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18
18,5	2	3	3	3	3	4	4	4	4	5	5	5	5	6	6	6	7	7	7	7	8	8	8	8	18,5
19	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13	13	14	14	15	16	16	17	19
19,5	7	8	8	9	10	11	11	12	13	14	15	15	16	17	18	18	19	20	21	21	22	23	24	24	19,5
20	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	20
20,5	11	12	13	15	16	17	18	19	21	22	23	24	26	27	28	29	30	32	33	34	35	37	38	39	20,5
21	13	14	16	17	18	20	21	23	24	25	27	28	30	31	33	34	35	37	38	40	41	42	44	45	21
21,5	14	16	17	19	21	22	24	25	27	29	30	32	33	35	36	38	40	41	43	44	46	48	49	51	21,5
22	16	17	19	21	23	24	26	28	29	31	33	35	36	38	40	42	43	45	47	48	50	52	54	55	22
22,5	17	18	20	22	24	26	28	30	31	33	35	37	39	41	42	44	46	48	50	52	54	55	57	59	22,5
23	17	19	21	23	25	27	29	31	33	35	37	39	41	43	44	46	48	50	52	54	56	58	60	62	23
23,5	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	59	61	63	23,5
24	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	24
u																									u
	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	
	AMPLITUDE.																								

TABLE 4 Water level at half hour intervals for given amplitudes

Hours before or after H.W.	K_1 P_1 AMPLITUDE.																		O_1 AMPLITUDE.					Hours before or after H.W.
	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100		2	4	6	8	10	
u																			u						u
0	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	0	2	4	6	8	10	0
0,5	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99	0,5	2	4	6	8	10	0,5
1	64	66	68	70	71	73	75	77	79	81	83	85	87	89	91	93	95	97	1	2	4	6	8	10	1
1,5	61	63	65	67	68	70	72	74	76	78	79	81	83	85	87	89	91	92	1,5	2	4	6	7	9	1,5
2	57	59	61	62	64	66	68	69	71	73	74	76	78	80	81	83	85	87	2	2	4	5	7	9	2
2,5	52	54	56	57	59	60	62	63	65	67	68	70	71	73	75	76	78	79	2,5	2	3	5	7	8	2,5
3	47	48	49	51	52	54	55	57	58	59	61	62	64	65	66	68	69	71	3	1	3	4	6	7	3
3,5	40	41	43	44	45	46	47	49	50	51	52	54	55	56	57	58	60	61	3,5	1	3	4	5	7	3,5
4	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	4	1	2	3	4	6	4
4,5	25	26	27	28	28	29	30	31	31	32	33	34	34	35	36	37	38	38	4,5	1	2	3	4	5	4,5
5	17	18	18	19	19	20	20	21	21	22	22	23	23	24	24	25	25	26	5	1	1	2	3	3	5
5,5	9	9	9	9	10	10	10	10	11	11	11	11	12	12	12	13	13	13	5,5	0	1	1	2	2	5,5
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	1	1	1	6
6,5	-9	-9	-9	-9	-10	-10	-10	-10	-11	-11	-11	-11	-12	-12	-12	-13	-13	-13	6,5	0	0	0	0	0	6,5
7	-17	-18	-18	-19	-19	-20	-20	-21	-21	-22	-22	-23	-23	-24	-24	-25	-25	-26	7	0	-1	-1	-1	-1	7
7,5	-25	-26	-27	-28	-28	-29	-30	-31	-31	-32	-33	-34	-34	-35	-36	-37	-38	-38	7,5	-1	-1	-2	-2	-3	7,5
8	-33	-34	-35	-36	-37	-38	-39	-40	-41	-42	-43	-44	-45	-46	-47	-48	-49	-50	8	-1	-1	-2	-3	-4	8
8,5	-40	-41	-43	-44	-45	-46	-47	-49	-50	-51	-52	-54	-55	-56	-57	-58	-60	-61	8,5	-1	-2	-3	-4	-5	8,5
9	-47	-48	-49	-51	-52	-54	-55	-57	-58	-59	-61	-62	-64	-65	-66	-68	-69	-71	9	-1	-2	-3	-5	-6	9
9,5	-52	-54	-56	-57	-59	-60	-62	-63	-65	-67	-68	-70	-71	-73	-75	-76	-78	-79	9,5	-1	-3	-4	-5	-7	9,5
10	-57	-59	-61	-62	-64	-66	-68	-69	-71	-73	-74	-76	-78	-80	-81	-83	-85	-87	10	-2	-3	-5	-6	-8	10
10,5	-61	-63	-65	-67	-68	-70	-72	-74	-76	-78	-79	-81	-83	-85	-87	-89	-91	-92	10,5	-2	-3	-5	-7	-8	10,5
11	-64	-66	-68	-70	-71	-73	-75	-77	-79	-81	-83	-85	-87	-89	-91	-93	-95	-97	11	-2	-4	-5	-7	-9	11
11,5	-65	-67	-69	-71	-73	-75	-77	-79	-81	-83	-85	-87	-89	-91	-93	-95	-97	-99	11,5	-2	-4	-6	-8	-9	11,5
12	-66	-68	-70	-72	-74	-76	-78	-80	-82	-84	-86	-88	-90	-92	-94	-96	-98	-100	12	-2	-4	-6	-8	-10	12
12,5	-65	-67	-69	-71	-73	-75	-77	-79	-81	-83	-85	-87	-89	-91	-93	-95	-97	-99	12,5	-2	-4	-6	-8	-10	12,5
13	-64	-66	-68	-70	-71	-73	-75	-77	-79	-81	-83	-85	-87	-89	-91	-93	-95	-97	13	-2	-4	-6	-8	-10	13
13,5	-61	-63	-65	-67	-68	-70	-72	-74	-76	-78	-79	-81	-83	-85	-87	-89	-91	-92	13,5	-2	-4	-6	-8	-10	13,5
14	-57	-59	-61	-62	-64	-66	-68	-69	-71	-73	-74	-76	-78	-80	-81	-83	-85	-87	14	-2	-4	-6	-8	-10	14
14,5	-52	-54	-56	-57	-59	-60	-62	-63	-65	-67	-68	-70	-71	-73	-75	-76	-78	-79	14,5	-2	-4	-6	-7	-9	14,5
15	-47	-48	-49	-51	-52	-54	-55	-57	-58	-59	-61	-62	-64	-65	-66	-68	-69	-71	15	-2	-3	-5	-7	-9	15
15,5	-40	-41	-43	-44	-45	-46	-47	-49	-50	-51	-52	-54	-55	-56	-57	-58	-60	-61	15,5	-2	-3	-5	-6	-8	15,5
16	-33	-34	-35	-36	-37	-38	-39	-40	-41	-42	-43	-44	-45	-46	-47	-48	-49	-50	16	-1	-3	-4	-6	-7	16
16,5	-25	-26	-27	-28	-28	-29	-30	-31	-31	-32	-33	-34	-34	-35	-36	-37	-38	-38	16,5	-1	-3	-4	-5	-6	16,5
17	-17	-18	-18	-19	-19	-20	-20	-21	-21	-22	-22	-23	-23	-24	-24	-25	-25	-26	17	-1	-2	-3	-4	-5	17
17,5	-9	-9	-9	-9	-10	-10	-10	-10	-11	-11	-11	-11	-12	-12	-12	-13	-13	-13	17,5	-1	-2	-3	-4	-4	17,5
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	-1	-1	-2	-3	-3	18
18,5	9	9	9	9	10	10	10	10	11	11	11	11	12	12	12	13	13	13	18,5	0	-1	-1	-2	-2	18,5
19	17	18	18	19	19	20	20	21	21	22	22	23	23	24	24	25	25	26	19	0	0	-1	-1	-1	19
19,5	25	26	27	28	28	29	30	31	31	32	33	34	34	35	36	37	38	38	19,5	0	0	0	0	0	19,5
20	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	20	0	1	1	1	2	20
20,5	40	41	43	44	45	46	47	49	50	51	52	54	55	56	57	58	60	61	20,5	1	1	2	2	3	20,5
21	47	48	49	51	52	54	55	57	58	59	61	62	64	65	66	68	69	71	21	1	2	2	3	4	21
21,5	52	54	56	57	59	60	62	63	65	67	68	70	71	73	75	76	78	79	21,5	1	2	3	4	5	21,5
22	57	59	61	62	64	66	68	69	71	73	74	76	78	80	81	83	85	87	22	1	2	4	5	6	22
22,5	61	63	65	67	68	70	72	74	76	78	79	81	83	85	87	89	91	92	22,5	1	3	4	6	7	22,5
23	64	66	68	70	71	73	75	77	79	81	83	85	87	89	91	93	95	97	23	2	3	5	6	8	23
23,5	65	67	69	71	73	75	77	79	81	83	85	87	89	91	93	95	97	99	23,5	2	3	5	7	8	23,5
24	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	24	2	4	5	7	9	24
																			24,5	2	4	6	8	9	24,5
																			25	2	4	6	8	10	25
																			25,5	2	4	6	8	10	25,5
																			26	2	4	6	8	10	26
u																			u						u
	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100		2	4	6	8	10	
	AMPLITUDE.																			AMPLITUDE.					

TABLE 4 Water level at half hour intervals for given amplitudes

O_1

Hours before or after H.W.	AMPLITUDE.																							Hours before or after H.W.
	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	
u																									u
0	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	0
0,5	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	0,5
1	12	14	16	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	50	52	54	56	1
1,5	11	13	15	17	19	21	22	24	26	28	30	32	34	35	37	39	41	43	45	47	49	50	52	54	1,5
2	11	12	14	16	18	19	21	23	25	27	28	30	32	34	35	37	39	41	42	44	46	48	49	51	2
2,5	10	11	13	15	16	18	20	21	23	25	26	28	30	31	33	34	36	38	39	41	43	44	46	48	2,5
3	9	10	12	13	15	16	18	19	21	22	24	25	27	28	30	31	33	34	36	37	39	40	42	43	3
3.5	8	9	11	12	13	14	16	17	18	20	21	22	24	25	26	28	29	30	32	33	34	36	37	38	3,5
4	7	8	9	10	11	12	13	15	16	17	18	19	20	21	22	24	25	26	27	28	29	30	31	33	4
4,5	5	6	7	8	9	10	11	12	13	14	15	16	16	17	18	19	20	21	22	23	24	25	26	27	4,5
5	4	5	6	6	7	8	8	9	10	10	11	12	12	13	14	15	15	16	17	17	18	19	19	20	5
5.5	3	3	4	4	5	5	6	6	6	7	7	8	8	9	9	10	10	11	11	12	12	12	13	13	5,5
6	1	2	2	2	2	2	3	3	3	3	4	4	4	4	4	5	5	5	5	6	6	6	6	6	6
6,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	− 1	− 1	− 1	− 1	− 1	− 1	− 1	6,5
7	− 2	− 2	− 2	− 2	− 3	− 3	− 3	− 3	− 4	− 4	− 4	− 4	− 5	− 5	− 5	− 6	− 6	− 6	− 6	− 7	− 7	− 7	− 7	− 8	7
7,5	− 3	− 4	− 4	− 5	− 5	− 6	− 6	− 7	− 7	− 8	− 8	− 9	− 9	−10	−10	−11	−11	−12	−12	−13	−13	−14	−14	−15	7,5
8	− 4	− 5	− 6	− 7	− 7	− 8	− 9	−10	−10	−11	−12	−12	−13	−14	−15	−15	−16	−17	−18	−18	−19	−20	−21	−21	8
8,5	− 6	− 7	− 8	− 9	−10	−11	−11	−12	−13	−14	−15	−16	−17	−18	−19	−20	−21	−22	−23	−24	−25	−26	−27	−28	8,5
9	− 7	− 8	− 9	−10	−12	−13	−14	−15	−16	−17	−19	−20	−21	−22	−23	−24	−26	−27	−28	−29	−30	−31	−33	−34	9
9,5	− 8	− 9	−11	−12	−14	−15	−16	−18	−19	−20	−22	−23	−24	−26	−27	−28	−30	−31	−32	−34	−35	−36	−38	−39	9,5
10	− 9	−11	−12	−14	−15	−17	−18	−20	−21	−23	−24	−26	−27	−29	−30	−32	−33	−35	−36	−38	−40	−41	−43	−44	10
10,5	−10	−12	−13	−15	−17	−18	−20	−22	−23	−25	−27	−28	−30	−32	−33	−35	−37	−38	−40	−42	−43	−45	−47	−48	10,5
11	−11	−13	−14	−16	−18	−20	−21	−23	−25	−27	−29	−30	−32	−34	−36	−38	−39	−41	−43	−45	−46	−48	−50	−52	11
11,5	−11	−13	−15	−17	−19	−21	−23	−24	−26	−28	−30	−32	−34	−36	−38	−40	−41	−43	−45	−47	−49	−51	−53	−55	11,5
12	−12	−14	−16	−18	−20	−21	−23	−25	−27	−29	−31	−33	−35	−37	−39	−41	−43	−45	−47	−49	−51	−53	−55	−57	12
12,5	−12	−14	−16	−18	−20	−22	−24	−26	−28	−30	−32	−34	−36	−38	−40	−42	−44	−46	−48	−50	−52	−54	−56	−58	12,5
13	−12	−14	−16	−18	−20	−22	−24	−26	−28	−30	−32	−34	−36	−38	−40	−42	−44	−46	−48	−50	−52	−54	−56	−58	13
13,5	−12	−14	−16	−18	−20	−22	−24	−26	−28	−30	−32	−34	−36	−38	−40	−42	−44	−46	−48	−49	−51	−53	−55	−57	13,5
14	−12	−14	−15	−17	−19	−21	−23	−25	−27	−29	−31	−33	−35	−37	−39	−41	−42	−44	−46	−48	−50	−52	−54	−56	14
14,5	−11	−13	−15	−17	−19	−20	−22	−24	−26	−28	−30	−31	−33	−35	−37	−39	−41	−43	−44	−46	−48	−50	−52	−54	14,5
15	−10	−12	−14	−16	−17	−19	−21	−23	−24	−26	−28	−30	−31	−33	−35	−37	−38	−40	−42	−44	−45	−47	−49	−51	15
15,5	−10	−11	−13	−15	−16	−18	−19	−21	−23	−24	−26	−27	−29	−31	−32	−34	−36	−37	−39	−40	−42	−44	−45	−47	15,5
16	− 9	−10	−12	−13	−15	−16	−18	−19	−20	−22	−23	−25	−26	−28	−29	−31	−32	−34	−35	−37	−38	−39	−41	−42	16
16,5	− 8	− 9	−10	−12	−13	−14	−15	−17	−18	−19	−21	−22	−23	−24	−26	−27	−28	−30	−31	−32	−33	−35	−36	−37	16,5
17	− 7	− 8	− 9	−10	−11	−12	−13	−14	−15	−16	−17	−19	−20	−21	−22	−23	−24	−25	−26	−27	−28	−29	−30	−32	17
17,5	− 5	− 6	− 7	− 8	− 9	−10	−11	−11	−12	−13	−14	−15	−16	−17	−18	−18	−19	−20	−21	−22	−23	−24	−25	− 25	17,5
18	− 4	− 5	− 5	− 6	− 7	− 7	− 8	− 8	− 9	−10	−10	−11	−12	−12	−13	−14	−14	−15	16	−16	−17	−18	−18	−19	18
18,5	− 3	− 3	− 3	− 4	− 4	− 5	− 5	− 5	− 6	− 6	− 7	− 7	− 8	− 8	− 8	− 9	− 9	−10	−10	−10	−11	−11	−12	−12	18,5
19	− 1	− 1	− 1	− 2	− 2	− 2	− 2	− 2	− 2	− 3	− 3	− 3	− 3	− 3	− 4	− 4	− 4	− 4	− 4	− 4	− 5	− 5	− 5	− 5	19
19,5	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	19,5
20	2	2	2	3	3	3	4	4	4	5	5	5	6	6	6	6	7	7	7	8	8	8	9	9	20
20,5	3	4	4	5	5	6	7	7	8	8	9	9	10	10	11	11	12	13	13	14	14	15	15	16	20,5
21	5	5	6	7	8	9	9	10	11	12	12	13	14	15	16	16	17	18	19	19	20	21	22	22	21
21,5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	21,5
22	7	8	10	11	12	13	14	16	17	18	19	20	22	23	24	25	26	28	29	30	31	32	34	35	22
22,5	8	10	11	12	14	15	17	18	19	21	22	23	25	26	28	29	30	32	33	35	36	37	39	40	22,5
23	9	11	12	14	15	17	19	20	22	23	25	26	28	29	31	32	34	36	37	39	40	42	43	45	23
23,5	10	12	14	15	17	19	20	22	24	25	27	29	30	32	34	35	37	39	41	42	44	46	47	49	23,5
24	11	13	14	16	18	20	22	23	25	27	29	31	33	34	36	38	40	42	43	45	47	49	51	52	24
24,5	11	13	15	17	19	21	23	25	27	28	30	32	34	36	38	40	42	44	46	47	49	51	53	55	24,5
25	12	14	16	18	20	22	24	25	27	29	31	33	35	37	39	41	43	45	47	49	51	53	55	57	25
25,5	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	25,5
26	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	26
u																									u
	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	
	AMPLITUDE.																								

TABLE 4 Water level at half hour intervals for given amplitudes

S_2 K_2

Hours before or after H.W.	AMPLITUDE.																								Hours before or after H.W.
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	
u																									u
0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	0
0,5	2	4	6	8	10	12	14	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	44	46	0,5
1	2	3	5	7	9	10	12	14	16	17	19	21	23	24	26	28	29	31	33	35	36	38	40	42	1
1,5	1	3	4	6	7	8	10	11	13	14	16	17	18	20	21	23	24	25	27	28	30	31	33	34	1,5
2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	2
2,5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	2,5
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
3,5	-1	-1	-2	-2	- 3	- 3	- 4	- 4	- 5	- 5	- 6	- 6	- 7	- 7	- 8	- 8	- 9	- 9	-10	-10	-11	-11	-12	-12	3,5
4	-1	-2	-3	-4	- 5	- 6	- 7	- 8	- 9	-10	-11	-12	-13	-14	-15	-16	-17	-18	-19	-20	-21	-22	-23	-24	4
4,5	-1	-3	-4	-6	- 7	- 8	-10	-11	-13	-14	-16	-17	-18	-20	-21	-23	-24	-25	-27	-28	-30	-31	-33	-34	4,5
5	-2	-3	-5	-7	- 9	-10	-12	-14	-16	-17	-19	-21	-23	-24	-26	-28	-29	-31	-33	-35	-36	-38	-40	-42	5
5,5	-2	-4	-6	-8	-10	-12	-14	-15	-17	-19	-21	-23	-25	-27	-29	-31	-33	-35	-37	-39	-41	-43	-44	-46	5,5
6	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20	-22	-24	-26	-28	-30	-32	-34	-36	-38	-40	-42	-44	-46	-48	6
6,5	-2	-4	-6	-8	-10	-12	-14	-15	-17	-19	-21	-23	-25	-27	-29	-31	-33	-35	-37	-39	-41	-43	-44	-46	6,5
7	-2	-3	-5	-7	- 9	-10	-12	-14	-16	-17	-19	-21	-23	-24	-26	-28	-29	-31	-33	-35	-36	-38	-40	-42	7
7,5	-1	-3	-4	-6	- 7	- 8	-10	-11	-13	-14	-16	-17	-18	-20	-21	-23	-24	-25	-27	-28	-30	-31	-33	-34	7,5
8	-1	-2	-3	-4	- 5	- 6	- 7	- 8	- 9	-10	-11	-12	-13	-14	-15	-16	-17	-18	-19	-20	-21	-22	-23	-24	8
8,5	-1	-1	-2	-2	- 3	- 3	- 4	- 4	- 5	- 5	- 6	- 6	- 7	- 7	- 8	- 8	- 9	- 9	-10	-10	-11	-11	-12	-12	8,5
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
9,5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	9,5
10	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	10
10,5	1	3	4	6	7	8	10	11	13	14	16	17	18	20	21	23	24	25	27	28	30	31	33	34	10,5
11	2	3	5	7	9	10	12	14	16	17	19	21	23	24	26	28	29	31	33	35	36	38	40	42	11
11,5	2	4	6	8	10	12	14	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	44	46	11,5
12	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	12
12,5	2	4	6	8	10	12	14	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	44	46	12,5
13	2	3	5	7	9	10	12	14	16	17	19	21	23	24	26	28	29	31	33	35	36	38	40	42	13
13,5	1	3	4	6	7	8	10	11	13	14	16	17	18	20	21	23	24	25	27	28	30	31	33	34	13,5
14	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	14
14,5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	14,5
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
15,5	-1	-1	-2	-2	- 3	- 3	- 4	- 4	- 5	- 5	- 6	- 6	- 7	- 7	- 8	- 8	- 9	- 9	-10	-10	-11	-11	-12	-12	15,5
16	-1	-2	-3	-4	- 5	- 6	- 7	- 8	- 9	-10	-11	-12	-13	-14	-15	-16	-17	-18	-19	-20	-21	-22	-23	-24	16
16,5	-1	-3	-4	-6	- 7	- 8	-10	-11	-13	-14	-16	-17	-18	-20	-21	-23	-24	-25	-27	-28	-30	-31	-33	-34	16,5
17	-2	-3	-5	-7	- 9	-10	-12	-14	-16	-17	-19	-21	-23	-24	-26	-28	-29	-31	-33	-35	-36	-38	-40	-42	17
17,5	-2	-4	-6	-8	-10	-12	-14	-15	-17	-19	-21	-23	-25	-27	-29	-31	-33	-35	-37	-39	-41	-43	-44	-46	17,5
18	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20	-22	-24	-26	-28	-30	-32	-34	-36	-38	-40	-42	-44	-46	-48	18
18,5	-2	-4	-6	-8	-10	-12	-14	-15	-17	-19	-21	-23	-25	-27	-29	-31	-33	-35	-37	-39	-41	-43	-44	-46	18,5
19	-2	-3	-5	-7	- 9	-10	-12	-14	-16	-17	-19	-21	-23	-24	-26	-28	-29	-31	-33	-35	-36	-38	-40	-42	19
19,5	-1	-3	-4	-6	- 7	- 8	-10	-11	-13	-14	-16	-17	-18	-20	-21	-23	-24	-25	-27	-28	-30	-31	-33	-34	19,5
20	-1	-2	-3	-4	- 5	- 6	- 7	- 8	- 9	-10	-11	-12	-13	-14	-15	-16	-17	-18	-19	-20	-21	-22	-23	-24	20
20,5	-1	-1	-2	-2	- 3	- 3	- 4	- 4	- 5	- 5	- 6	- 6	- 7	- 7	- 8	- 8	- 9	- 9	-10	-10	-11	-11	-12	-12	20,5
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21
21,5	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	21,5
22	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	22
22,5	1	3	4	6	7	8	10	11	13	14	16	17	18	20	21	23	24	25	27	28	30	31	33	34	22,5
23	2	3	5	7	9	10	12	14	16	17	19	21	23	24	26	28	29	31	33	35	36	38	40	42	23
23,5	2	4	6	8	10	12	14	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	44	46	23,5
24	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	24
u																									u
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	
	AMPLITUDE.																								

TABLE 4 Water level at half hour intervals for given amplitudes

S_2 K_2

Hours before or after H.W.	AMPLITUDE.																							Hours before or after H.W.
	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	
u																									u
0	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	0
0,5	48	50	52	54	56	58	60	62	64	66	68	70	71	73	75	77	79	81	83	85	87	89	91	93	0,5
1	43	45	47	48	50	52	54	55	57	59	61	62	64	66	68	69	71	73	74	76	78	80	81	83	1
1,5	35	37	38	40	41	42	44	45	47	48	49	51	52	54	55	57	58	59	61	62	64	65	66	68	1,5
2	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	2
2,5	13	13	14	14	15	16	16	17	17	18	18	19	19	20	20	21	21	22	22	23	23	24	24	25	2,5
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
3.5	-13	-13	-14	-14	-15	-16	-16	-17	-17	-18	-18	-19	-19	-20	-20	-21	-21	-22	-22	-23	-23	-24	-24	-25	3,5
4	-25	-26	-27	-28	-29	-30	-31	-32	-33	-34	-35	-36	-37	-38	-39	-40	-41	-42	-43	-44	-45	-46	-47	-48	4
4,5	-35	-37	-38	-40	-41	-42	-44	-45	-47	-48	-49	-51	-52	-54	-55	-57	-58	-59	-61	-62	-64	-65	-66	-68	4,5
5	-43	-45	-47	-48	-50	-52	-54	-55	-57	-59	-61	-62	-64	-66	-68	-69	-71	-73	-74	-76	-78	-80	-81	-83	5
5,5	-48	-50	-52	-54	-56	-58	-60	-62	-64	-66	-68	-70	-71	-73	-75	-77	-79	-81	-83	-85	-87	-89	-91	-93	5,5
6	-50	-52	-54	-56	-58	-60	-62	-64	-66	-68	-70	-72	-74	-76	-78	-80	-82	-84	-86	-88	-90	-92	-94	-96	6
6,5	-48	-50	-52	-54	-56	-58	-60	-62	-64	-66	-68	-70	-71	-73	-75	-77	-79	-81	-83	-85	-87	-89	-91	-93	6,5
7	-43	-45	-47	-48	-50	-52	-54	-55	-57	-59	-61	-62	-64	-66	-68	-69	-71	-73	-74	-76	-78	-80	-81	-83	7
7,5	-35	-37	-38	-40	-41	-42	-44	-45	-47	-48	-49	-51	-52	-54	-55	-57	-58	-59	-61	-62	-64	-65	-66	-68	7,5
8	-25	-26	-27	-28	-29	-30	-31	-32	-33	-34	-35	-36	-37	-38	-39	-40	-41	-42	-43	-44	-45	-46	-47	-48	8
8,5	-13	-13	-14	-14	-15	-16	-16	-17	-17	-18	-18	-19	-19	-20	-20	-21	-21	-22	-22	-23	-23	-24	-24	-25	8,5
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
9,5	13	13	14	14	15	16	16	17	17	18	18	19	19	20	20	21	21	22	22	23	23	24	24	25	9,5
10	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	10
10,5	35	37	38	40	41	42	44	45	47	48	49	51	52	54	55	57	58	59	61	62	64	65	66	68	10,5
11	43	45	47	48	50	52	54	55	57	59	61	62	64	66	68	69	71	73	74	76	78	80	81	83	11
11,5	48	50	52	54	56	58	60	62	64	66	68	70	71	73	75	77	79	81	83	85	87	89	91	93	11,5
12	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	12
12,5	48	50	52	54	56	58	60	62	64	66	68	70	71	73	75	77	79	81	83	85	87	89	91	93	12,5
13	43	45	47	48	50	52	54	55	57	59	61	62	64	66	68	69	71	73	74	76	78	80	81	83	13
13,5	35	37	38	40	41	42	44	45	47	48	49	51	52	54	55	57	58	59	61	62	64	65	66	68	13,5
14	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	14
14,5	13	13	14	14	15	16	16	17	17	18	18	19	19	20	20	21	21	22	22	23	23	24	24	25	14,5
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
15,5	-13	-13	-14	-14	-15	-16	-16	-17	-17	-18	-18	-19	-19	-20	-20	-21	-21	-22	-22	-23	-23	-24	-24	-25	15,5
16	-25	-26	-27	-28	-29	-30	-31	-32	-33	-34	-35	-36	-37	-38	-39	-40	-41	-42	-43	-44	-45	-46	-47	-48	16
16,5	-35	-37	-38	-40	-41	-42	-44	-45	-47	-48	-49	-51	-52	-54	-55	-57	-58	-59	-61	-62	-64	-65	-66	-68	16,5
17	-43	-45	-47	-48	-50	-52	-54	-55	-57	-59	-61	-62	-64	-66	-68	-69	-71	-73	-74	-76	-78	-80	-81	-83	17
17,5	-48	-50	-52	-54	-56	-58	-60	-62	-64	-66	-68	-70	-71	-73	-75	-77	-79	-81	-83	-85	-87	-89	-91	-93	17,5
18	-50	-52	-54	-56	-58	-60	-62	-64	-66	-68	-70	-72	-74	-76	-78	-80	-82	-84	-86	-88	-90	-92	-94	-96	18
18,5	-48	-50	-52	-54	-56	-58	-60	-62	-64	-66	-68	-70	-71	-73	-75	-77	-79	-81	-83	-85	-87	-89	-91	-93	18,5
19	-43	-45	-47	-48	-50	-52	-54	-55	-57	-59	-61	-62	-64	-66	-68	-69	-71	-73	-74	-76	-78	-80	-81	-83	19
19,5	-35	-37	-38	-40	-41	-42	-44	-45	-47	-48	-49	-51	-52	-54	-55	-57	-58	-59	-61	-62	-64	-65	-66	-68	19,5
20	-25	-26	-27	-28	-29	-30	-31	-32	-33	-34	-35	-36	-37	-38	-39	-40	-41	-42	-43	-44	-45	-46	-47	-48	20
20,5	-13	-13	-14	-14	-15	-16	-16	-17	-17	-18	-18	-19	-19	-20	-20	-21	-21	-22	-22	-23	-23	-24	-24	-25	20,5
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21
21,5	13	13	14	14	15	16	16	17	17	18	18	19	19	20	20	21	21	22	22	23	23	24	24	25	21,5
22	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	22
22,5	35	37	38	40	41	42	44	45	47	48	49	51	52	54	55	57	58	59	61	62	64	65	66	68	22,5
23	43	45	47	48	50	52	54	55	57	59	61	62	64	66	68	69	71	73	74	76	78	80	81	83	23
23,5	48	50	52	54	56	58	60	62	64	66	68	70	71	73	75	77	79	81	83	85	87	89	91	93	23,5
24	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	24
u																									u
	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	
	AMPLITUDE.																								

TABLE 4 Water level at half hour intervals for given amplitudes

O_1

Hours before or after H.W.	AMPLITUDE.											
	60	62	64	66	68	70	72	74	76	78	80	100
u												
0	60	62	64	66	68	70	72	74	76	78	80	100
0,5	60	62	64	66	67	69	71	73	75	77	79	99
1	58	60	62	64	66	68	70	72	74	76	78	97
1,5	56	58	60	62	64	65	67	69	71	73	75	93
2	53	55	57	58	60	62	64	65	67	69	71	88
2,5	49	51	53	54	56	57	59	61	62	64	66	82
3	45	46	48	49	51	52	54	55	57	58	60	75
3,5	40	41	42	43	45	46	47	49	50	51	53	66
4	34	35	36	37	38	39	40	42	43	44	45	56
4,5	27	28	29	30	31	32	33	34	35	36	37	46
5	21	21	22	23	24	24	25	26	26	27	28	35
5,5	14	14	15	15	16	16	17	17	18	18	18	23
6	7	7	7	7	8	8	8	8	8	9	9	11
6,5	- 1	- 1	- 1	- 1	- 1	- 1	- 1	- 1	- 1	- 1	- 1	- 1
7	- 8	- 8	- 8	- 9	- 9	- 9	-10	-10	-10	-10	-11	- 13
7,5	-15	-16	-16	-17	-17	-18	-18	-19	-19	-20	-20	- 25
8	-22	-23	-24	-24	-25	-26	-26	-27	-28	-29	-29	- 37
8,5	-29	-30	-31	-32	-32	-33	-34	-35	-36	-37	-38	- 48
9	-35	-36	-37	-38	-39	-41	-42	-43	-44	-45	-46	- 58
9,5	-41	-42	-43	-45	-46	-47	-49	-50	-51	-53	-54	- 68
10	-46	-47	-49	-50	-52	-53	-55	-56	-58	-59	-61	- 76
10,5	-50	-52	-53	-55	-57	-58	-60	-62	-63	-65	-67	- 83
11	-54	-55	-57	-59	-61	-63	-64	-66	-68	-70	-72	- 89
11,5	-57	-58	-60	-62	-64	-66	-68	-70	-72	-73	-75	- 94
12	-59	-60	-62	-64	-66	-68	-70	-72	-74	-76	-78	- 98
12,5	-60	-62	-64	-66	-68	-70	-72	-74	-76	-78	-80	-100
13	-60	-62	-64	-66	-68	-70	-72	-74	-76	-78	-80	-100
13,5	-59	-61	-63	-65	-67	-69	-71	-73	-75	-77	-79	- 99
14	-58	-60	-62	-64	-66	-68	-69	-71	-73	-75	-77	- 97
14,5	-56	-57	-59	-61	-63	-65	-67	-69	-70	-72	-74	- 93
15	-52	-54	-56	-58	-59	-61	-63	-65	-66	-68	-70	- 87
15,5	-48	-50	-52	-53	-55	-57	-58	-60	-61	-63	-65	- 81
16	-44	-45	-47	-48	-50	-51	-53	-54	-56	-57	-58	- 73
16,5	-39	-40	-41	-42	-44	-45	-46	-48	-49	-50	-51	- 64
17	-33	-34	-35	-36	-37	-38	-39	-40	-41	-42	-44	- 54
17,5	-26	-27	-28	-29	-30	-31	-32	-32	-33	-34	-35	- 44
18	-20	-20	-21	-22	-22	-23	-23	-24	-25	-25	-26	- 33
18,5	-13	-13	-13	-14	-14	-15	-15	-15	-16	-16	-17	- 21
19	- 5	- 5	- 6	- 6	- 6	- 6	- 6	- 7	- 7	- 7	- 7	- 9
19,5	2	2	2	2	2	2	2	2	3	3	3	3
20	9	10	10	10	10	11	11	11	12	12	12	15
20,5	16	17	17	18	19	19	20	20	21	21	22	27
21	23	24	25	26	26	27	28	29	29	30	31	39
21,5	30	31	32	33	34	35	36	37	38	39	40	50
22	36	37	38	39	41	42	43	44	45	47	48	60
22,5	41	43	44	46	47	48	50	51	53	54	55	69
23	46	48	50	51	53	54	56	57	59	60	62	77
23,5	51	52	54	56	57	59	61	63	64	66	68	84
24	54	56	58	60	61	63	65	67	69	70	72	90
24,5	57	59	61	63	65	66	68	70	72	74	76	95
25	59	61	63	65	67	69	71	73	74	76	78	98
25,5	60	62	64	66	68	70	72	74	76	78	80	100
26	60	62	64	66	68	70	72	74	76	78	80	100
u												
	60	62	64	66	68	70	72	74	76	78	80	100
	AMPLITUDE.											

M_4

Hours before or after H.W.	AMPLITUDE.										Hours before or after H.W.
	2	4	6	8	10	12	14	16	18	20	
u											u
0	2	4	6	8	10	12	14	16	18	20	0
0,5	2	3	5	7	9	10	12	14	16	17	0,5
1	1	2	3	4	5	6	7	8	10	11	1
1,5	0	0	0	0	1	1	1	1	1	1	1,5
2	-1	-2	-3	-3	- 4	- 5	- 6	- 7	- 8	- 9	2
2,5	-2	-3	-5	-7	- 8	-10	-11	-13	-15	-16	2,5
3	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20	3
3,5	-2	-4	-6	-7	- 9	-11	-13	-15	-17	-18	3,5
4	-1	-2	-4	-5	- 6	- 7	- 9	-10	-11	-12	4
4,5	0	-1	-1	-1	- 2	- 2	- 2	- 3	- 3	- 3	4,5
5	1	1	2	3	3	4	5	5	6	7	5
5,5	2	3	5	6	8	9	11	12	14	15	5,5
6	2	4	6	8	10	12	14	16	18	20	6
6,5	2	4	6	8	10	11	13	15	17	19	6,5
7	1	3	4	6	7	8	10	11	13	14	7
7,5	1	1	2	2	3	3	4	4	5	5	7,5
8	0	-1	-1	-2	- 2	- 3	- 3	- 4	- 4	- 5	8
8,5	-1	-3	-4	-5	- 7	- 8	- 9	-11	-12	-14	8,5
9	-2	-4	-6	-8	- 9	-11	-13	-15	-17	-19	9
9,5	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20	9,5
10	-2	-3	-5	-6	- 8	- 9	-11	-12	-14	-15	10
10,5	-1	-1	-2	-3	- 4	- 4	- 5	- 6	- 7	- 7	10,5
11	0	1	1	1	1	2	2	2	2	3	11
11,5	1	2	4	5	6	7	8	10	11	12	11,5
12	2	4	5	7	9	11	13	15	16	18	12
12,5	2	4	6	8	10	12	14	16	18	20	12,5
13	2	3	5	7	8	10	12	13	15	17	13
13,5	1	2	3	4	5	6	6	7	8	9	13,5
14	0	0	0	0	0	0	0	0	0	- 1	14
14,5	-1	-2	-3	-4	- 5	- 6	- 7	- 8	- 9	-10	14,5
15	-2	-3	-5	-7	- 9	-10	-12	-14	-16	-17	15
15,5	-2	-4	-6	-8	-10	-12	-14	- 6	-18	-20	15,5
16	-2	-4	-5	-7	- 9	-11	-12	-14	-16	-18	16
16,5	-1	-2	-3	-4	- 6	- 7	- 8	- 9	-10	-11	16,5
17	0	0	0	-1	- 1	- 1	- 1	- 1	- 1	- 2	17
17,5	1	2	2	3	4	5	6	7	7	8	17,5
18	2	3	5	6	8	10	11	13	14	16	18
18,5	2	4	6	8	10	12	14	16	18	20	18,5
19	2	4	6	7	9	11	13	15	17	19	19
19,5	1	3	4	5	6	8	9	10	11	13	19,5
20	0	1	1	1	2	2	3	3	3	4	20
20,5	-1	-1	-2	-3	- 3	- 4	- 4	- 5	- 6	- 6	20,5
21	-1	-3	-4	-6	- 7	- 9	-10	-12	-13	-15	21
21,5	-2	-4	-6	-8	-10	-12	-14	-16	-17	-19	21,5
22	-2	-4	-6	-8	-10	-12	-14	-15	-17	-19	22
22,5	-1	-3	-4	-6	- 7	- 9	-10	-11	-13	-14	22,5
23	-1	-1	-2	-2	- 3	- 3	- 4	- 5	- 5	- 6	23
23,5	0	1	1	2	2	3	3	3	4	4	23,5
24	1	3	4	5	7	8	9	11	12	13	24
24,5	2	4	6	8	9	11	13	15	17	19	24,5
25	2	4	6	8	10	12	14	16	18	20	25
u											u
	2	4	6	8	10	12	14	16	18	20	
	AMPLITUDE.										

TABLE 4 Water level at half hour intervals for given amplitudes

MS_4

Hours before or after H.W.	AMPLITUDE.									
	2	4	6	8	10	12	14	16	18	20
u										
0	2	4	6	8	10	12	14	16	18	20
0,5	2	3	5	7	9	10	12	14	16	17
1	1	2	3	4	5	6	7	8	9	10
1,5	0	0	0	0	0	0	0	0	0	1
2	-1	-2	-3	-4	- 5	- 6	- 7	- 8	- 8	- 9
2,5	-2	-3	-5	-7	- 8	-10	-12	-13	-15	-17
3	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20
3,5	-2	-4	-5	-7	- 9	-11	-13	-14	-16	-18
4	-1	-2	-3	-4	- 6	- 7	- 8	- 9	-10	-11
4,5	0	0	0	-1	- 1	- 1	- 1	- 1	- 1	- 2
5	1	2	3	3	4	5	6	7	8	8
5,5	2	3	5	7	8	10	11	13	15	16
6	2	4	6	8	10	12	14	16	18	20
6,5	2	4	6	7	9	11	13	15	17	18
7	1	2	4	5	6	7	8	10	11	12
7.5	0	1	1	1	1	2	2	2	2	3
8	-1	-1	-2	-3	- 4	- 4	- 5	- 6	- 7	- 7
8,5	-2	-3	-5	-6	- 8	- 9	-11	-12	-14	-16
9	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20
9.5	-2	-4	-6	-8	- 9	-11	-13	-15	-17	-19
10	-1	-3	-4	-5	- 6	- 8	- 9	-10	-12	-13
10,5	0	-1	-1	-1	- 2	- 2	- 3	- 3	- 3	- 4
11	1	1	2	3	3	4	5	5	6	6
11,5	1	3	4	6	7	9	10	12	13	15
12	2	4	6	8	10	12	14	16	18	20
12,5	2	4	6	8	10	11	13	15	17	19
13	1	3	4	5	7	8	10	11	12	14
13.5	0	1	1	2	2	3	3	4	4	5
14	-1	-1	-2	-2	- 3	- 3	- 4	- 4	- 5	- 5
14,5	-1	-3	-4	-6	- 7	- 9	-10	-11	-13	-14
15	-2	-4	-6	-8	-10	-12	-14	-15	-17	-19
15,5	-2	-4	-6	-8	-10	-12	-14	-16	-17	-19
16	-1	-3	-4	-6	- 7	- 9	-10	-12	-13	-14
16,5	-1	-1	-2	-2	- 3	- 3	- 4	- 5	- 5	- 6
17	0	1	1	2	2	3	3	4	4	4
17,5	1	3	4	5	7	8	9	11	12	13
18	2	4	6	8	9	11	13	15	17	19
18,5	2	4	6	8	10	12	14	16	18	20
19	2	3	5	6	8	9	11	12	14	15
19,5	1	1	2	3	3	4	5	5	6	7
20	0	-1	-1	-1	- 2	- 2	- 2	- 3	- 3	- 3
20,5	-1	-3	-4	-5	- 6	- 8	- 9	-10	-11	-13
21	-2	-4	-6	-7	- 9	-11	-13	-15	-17	-19
21,5	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20
22	-2	-3	-5	-6	- 8	-10	-11	-13	-14	-16
22,5	-1	-2	-2	-3	- 4	- 5	- 5	- 6	- 7	- 8
23	0	0	1	1	1	1	2	2	2	2
23.5	1	2	4	5	6	7	8	9	11	12
24	2	4	5	7	9	11	13	15	16	18
24.5	2	4	6	8	10	12	14	16	18	20
u										
	2	4	6	8	10	12	14	16	18	20
	AMPLITUDE.									

μ_2

Hours before or after H.W.	AMPLITUDE.									
	2	4	6	8	10	12	14	16	18	20
u										
0	2	4	6	8	10	12	14	16	18	20
0,5	2	4	6	8	10	12	14	16	17	19
1	2	4	5	7	9	11	12	14	16	18
1,5	1	3	4	6	7	9	10	12	13	15
2	1	2	3	4	6	7	8	9	10	11
2,5	1	1	2	3	3	4	5	5	6	7
3	0	0	1	1	1	1	1	2	2	2
3,5	0	-1	-1	-1	- 1	- 2	- 2	- 2	- 2	- 3
4	-1	-1	-2	-3	- 4	- 4	- 5	- 6	- 7	- 7
4,5	-1	-2	-4	-5	- 6	- 7	- 8	- 9	-11	-12
5	-2	-3	-5	-6	- 8	- 9	-11	-12	-14	-15
5,5	-2	-4	-5	-7	- 9	-11	-13	-14	-16	-18
6	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20
6,5	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20
7	-2	-4	-6	-8	-10	-12	-13	-15	-17	-19
7,5	-2	-3	-5	-7	- 9	-10	-12	-14	-16	-17
8	-1	-3	-4	-6	- 7	- 9	-10	-12	-13	-14
8,5	-1	-2	-3	-4	- 5	- 6	- 7	- 9	-10	-11
9	-1	-1	-2	-3	- 3	- 4	- 4	- 5	- 6	- 6
9,5	0	0	0	-1	- 1	- 1	- 1	- 1	- 1	- 2
10	0	1	1	1	2	2	2	3	3	3
10,5	1	2	2	3	4	5	6	6	7	8
11	1	2	4	5	6	7	9	10	11	12
11,5	2	3	5	6	8	9	11	13	14	16
12	2	4	5	7	9	11	13	15	16	18
12,5	2	4	6	8	10	12	14	16	18	20
13	2	4	6	8	10	12	14	16	18	20
13,5	2	4	6	8	10	11	13	15	17	19
14	2	3	5	7	9	10	12	14	15	17
14,5	1	3	4	6	7	8	10	11	13	14
15	1	2	3	4	5	6	7	8	9	10
15,5	1	1	2	2	3	3	4	5	5	6
16	0	0	0	0	0	1	1	1	1	1
16,5	0	-1	-1	-2	- 2	- 2	- 3	- 3	- 4	- 4
17	-1	-2	-3	-3	- 4	- 5	- 6	- 7	- 8	- 9
17,5	-1	-3	-4	-5	- 6	- 8	- 9	-10	-11	-13
18	-2	-3	-5	-6	- 8	-10	-11	-13	-14	-16
18,5	-2	-4	-6	-7	- 9	-11	-13	-15	-17	-18
19	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20
19,5	-2	-4	-6	-8	-10	-12	-14	-16	-18	-20
20	-2	-4	-6	-8	- 9	-11	-13	-15	-17	-19
20,5	-2	-3	-5	-7	- 8	-10	-12	-13	-15	-17
21	-1	-3	-4	-5	- 7	- 8	- 9	-11	-12	-14
21,5	-1	-2	-3	-4	- 5	- 6	- 7	- 8	- 9	-10
22	-1	-1	-2	-2	- 3	- 3	- 4	- 4	- 5	- 5
22,5	0	0	0	0	0	0	0	0	0	0
23	0	1	1	2	2	3	3	4	4	5
23,5	1	2	3	4	5	5	6	7	8	9
24	1	3	4	5	7	8	9	11	12	13
24,5	2	3	5	7	8	10	11	13	15	16
25	2	4	6	7	9	11	13	15	17	19
25,5	2	4	6	8	10	12	14	16	18	20
u										
	2	4	6	8	10	12	14	16	18	20
	AMPLITUDE.									

TABLE 5 Astronomical factor (f) for January 1 of each year

M_2 μ_2 N_2 MS_4	K_1	O_1	K_2	M_4	Year
1.033	0.903	0.840	0.781	1.066	1961
1.024	0.934	0.891	0.836	1.050	62
1.014	0.972	0.954	0.914	1.027	63
1.001	1.011	1.018	1.008	1.003	64
0.989	1.048	1.076	1.106	0.978	65
0.978	1.077	1.124	1.195	0.956	66
0.969	1.098	1.159	1.265	0.940	67
0.964	1.110	1.178	1.307	0.930	68
0.963	1.113	1.182	1.316	0.928	69
0.966	1.105	1.170	1.289	0.934	70
0.973	1.088	1.143	1.232	0.948	71
0.983	1.063	1.101	1.150	0.967	72
0.995	1.029	1.047	1.055	0.991	73
1.008	0.991	0.984	0.957	1.016	74
1.020	0.951	0.920	0.871	1.039	75
1.029	0.916	0.863	0.804	1.059	76
1.035	0.891	0.822	0.763	1.072	77
1.038	0.882	0.806	0.748	1.077	78
1.036	0.890	0.819	0.760	1.073	79
1.030	0.913	0.858	0.799	1.061	80
1.021	0.948	0.915	0.864	1.042	81
1.009	0.987	0.979	0.949	1.018	82
0.997	1.026	1.041	1.045	0.993	83
0.984	1.060	1.096	1.142	0.969	84
0.974	1.086	1.140	1.226	0.949	85
0.967	1.104	1.168	1.285	0.935	86
0.964	1.112	1.182	1.315	0.928	87
0.964	1.111	1.180	1.310	0.930	88
0.969	1.100	1.161	1.270	0.939	89
0.977	1.079	1.128	1.203	0.955	90
0.988	1.051	1.081	1.115	0.976	91
1.000	1.015	1.024	1.016	1.000	92
1.013	0.976	0.960	0.922	1.025	93
1.024	0.937	0.897	0.842	1.048	94
1.032	0.905	0.844	0.785	1.065	95
1.037	0.886	0.812	0.754	1.075	96
1.038	0.883	0.808	0.750	1.076	97
1.034	0.897	0.832	0.772	1.069	98
1.027	0.926	0.879	0.821	1.054	99

S_2, P_1 always 1.000

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