Introduction to Tidal Theory
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CONTENTS

1. INTRODUCTION

There is a requirement for reliable information regarding the horizontal movement of the water mass. HQAIs-GSI F specifies the requirements and conditions under which the observations must take place. This handout describes and explains the origin of this movement as well as the techniques and equipment used to measure it.

Because of the different terms used to identify water movement Chapter 3 contains definitions of those terms and explains why they are important to the hydrographic surveyor. Chapter 4 describes the origin and nature of water movements such as tidal streams and oceanic currents.

The various techniques and instruments used in the RN as well as other instruments and methods to measure water movement are described in Chapter 5. This includes the latest methods using Remote Sensing.

Chapter 6 gives an outline how measurement results are rendered and consecutively are used for different products published by the UKHO and other agencies.

2. INFLUENCE OF WATER MOVEMENT ON MARITIME OPERATIONS

Maritime operations are influenced by the water movement over the whole column from surface to seabed. For many years the only requirement was for data covering the surface layer (10 m) to assist the navigation of surface vessels but today data is required for other maritime operations as well. The most important ones are described in the following paragraphs.

2.1. DEEP-DRAUGHT VESSEL NAVIGATION

Water movement perpendicular to the course of a ship will influence the course to steer. In itself this is no cause for concern but when a ship is restricted to a narrow channel cross current will result in a narrower effective width of the channel. In relatively shallow areas, 20 - 40 metres water depth, where water movement will be largest, friction with the sea floor will cause variations in speed and direction with increasing depth. The deflection off course will be influenced by the water movement in all layers.

2.2. SUBMARINE NAVIGATION

The surface layer is of (very) little importance but, as with deep-draught vessels, these vessels are subject to the deeper water layer movement. During naval exercises surface and sub-surface vessels are subject to different movements and the same courses to steer result in different courses over the ground.

2.3. EFFECTS ON SEABED SEDIMENT TRANSPORT

Tidal streams transport sediments on the seabed. In the Southern North Sea huge sand ripples exist that are moving under the influence of the water movement and can create a hazard to shipping. When tidal streams change in direction and strength as a result of man-made structures they may move vast amounts of sediment which previously were not affected e.g. Weston Mill Lake Jetty, Plymouth UK.

2.4. EFFECTS ON FIXED STRUCTURES

Rigs, jetties, beacons etc. are affected by water movements. Either through erosion or by washing away supporting sediment, the strength of structures is affected.

2.5. EFFECTS ON GROUND MINES

The effect on ground mines is twofold:

a. The tidal stream creates a scour behind the mine, into which the mine will eventually fall.

b. The sediment moved by the tidal stream covers the mine. This happens especially on a sandy seabed (Southern North Sea).

2.6. RESEARCH INTO OCEANIC CURRENTS AND OTHER PHENOMENA

That research includes internal waves. The movement of the oceanic current can only be explained by looking at the water movement of the whole water layer. Different densities will stratify the water column and all those layers are moving in different directions. Effects like El Niño can only be explained by the movement of warm water from Asia to the America's and therefore numerous observing stations exist in the Pacific.

3. DEFINITIONS

3.1. TIDAL STREAM

The motion of the water particles is ***caused by the tide-generating forces only***. The velocity and direction of each particle will vary with time, and each particle will return to its starting point (approximately-since the tide raising forces also show long-period changes) after one stream cycle (12 hours if streams are semi-diurnal, 25 hours if diurnal).

This motion will be modified by meteorological changes, and the effects of any current present. The direction and rate of the stream at any instant may well vary with depth below the surface, so it is important to know the depth at which observations are taken. (When using a pole logship, the mean motion over the part of the column equal to the depth of the logship is obtained).

Predictions always refer to the pure tidal stream, unless there is a note to the contrary.

3.2. TIDAL FLOW

The actual movement experienced, this is including the effects of weather, currents and random errors of measurement. By convention flow and stream are expressed as a rate towards a certain direction, e.g. 1.4 knots, (towards) 137°.

3.3. RESIDUAL MOTION

The component of the tidal flow comprising the true current and short-period meteorological effects.

3.4. CURRENT

Currents are mainly meteorological in origin, and often involve density changes. They are approximately constant in rate and direction from day to day, but may change from month to month in an annual cycle. The true current cannot be obtained in the field with less than 29 days continuous tidal stream observations.

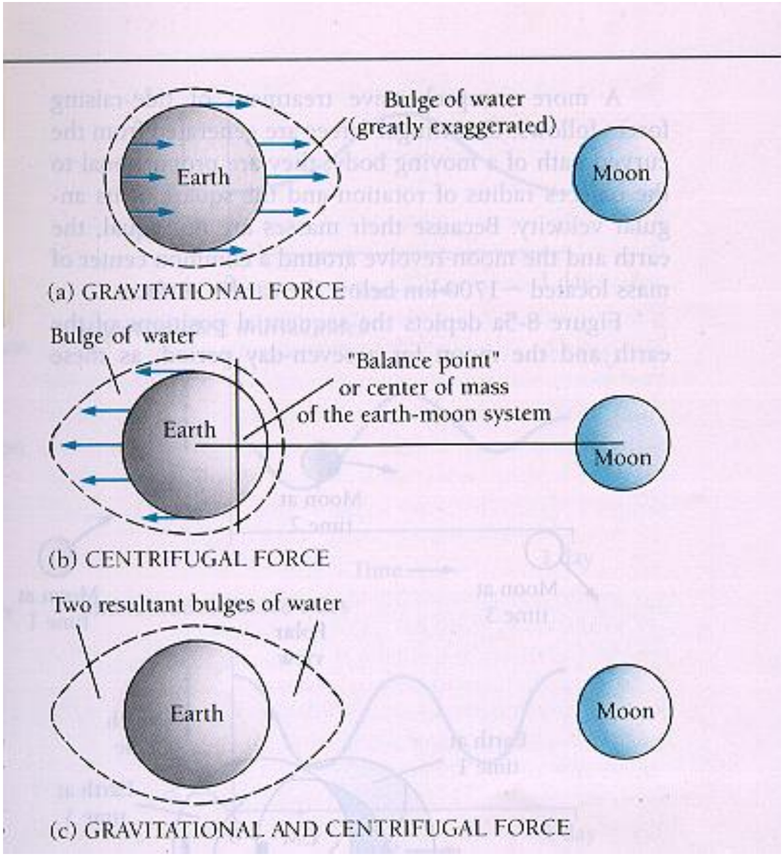
The hydrographic surveyor conducting tidal stream observations would like to measure tidal stream without having the measurements ‘contaminated’ by weather or current effects. Under ideal circumstances this might happen but in reality all measurements include some form of non-tidal components. When accepting tidal stream measurements as Tidal Stream includes the assumption that other effects are negligible.

4. ORIGIN AND NATURE OF TIDAL STREAMS AND OCEANIC CURRENTS

4.1. ORIGIN OF TIDAL STREAMS: PROGRESSIVE AND STANDING WAVES

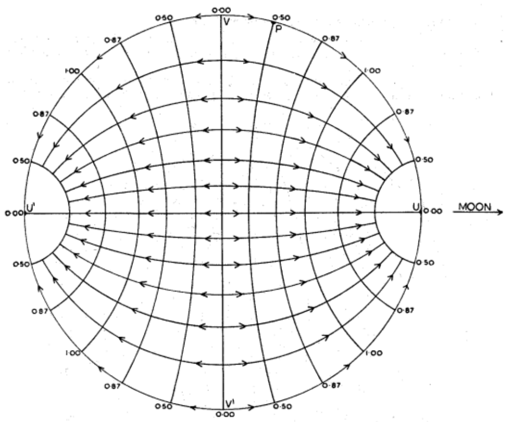
The Equilibrium Tide developed from Newton's theory of gravitation consists of two symmetrical tidal bulges, directly under and directly opposite the moon or sun.

Figure 1: Water movement as result of tide raising forces



The attractive forces of sun and moon cause horizontal movement of the water masses over the surface of the earth. These water masses will initially move as continuous progressive waves and may create a system of standing waves.

Figure 2: Tractive Forces



Movements of water on the surface of the earth must obey the physical laws, which means they must propagate as progressive waves. Natural phenomena change the progressive wave with the standing wave as the ultimate result.

Waves will behave as waves with properties from either the progressive wave or the standing wave and therefore both forms will be discussed below.

Progressive waves

The progressive tidal wave in this paragraph has certain characteristics:

- Wave amplitudes are small compared with the depth, and the depth is small compared with the wavelength.

As the progressive wave moves past some fixed point, a succession of high and low sea levels will be observed. At local High Water there is a maximum current in the direction of wave propagation, but at Low Water there is a current in the opposite direction.

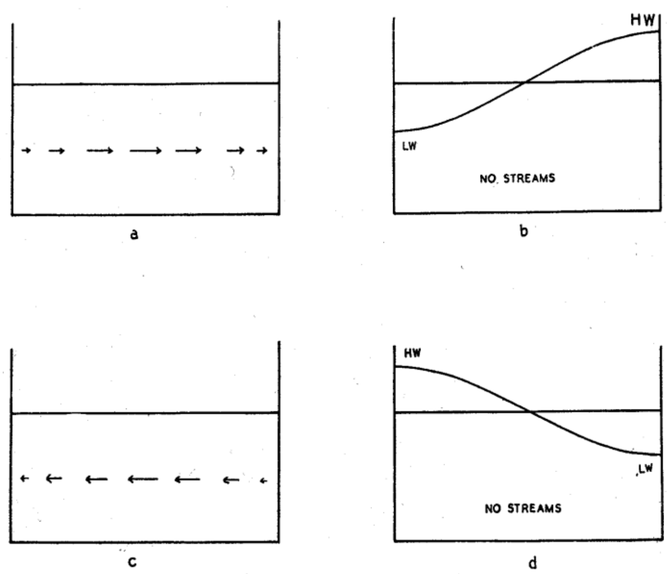
Remember that this is valid for a Progressive Wave.

Standing waves: Reflection and Resonance

Any propagation of a wave from east to west around the earth would be impeded by the north-south continental boundaries. The only latitudes for unimpeded circumpolar movement are around the Antarctic continent and in the Arctic basin.

For a progressive wave the currents, which are a maximum in the direction of wave propagation at local high water, are rectilinear but this only happens near to steep coasts or in narrow channels. In the real oceans, tides cannot propagate endlessly as progressive waves. They undergo reflection at sudden changes of depth, and at the coastal boundaries. The reflected and incident waves combine together to give the observed total wave.

Figure 3: Oscillations of water in a closed rectangular box



The interference between the two waves produces a fixed pattern of *standing waves* which have alternate **nodes**, positions where the amplitude is zero, and **antinodes**, positions where the amplitude is a maximum. They are separated by a distance $\lambda/4$ where λ is the wavelength of the original progressive wave. At the nodes there is no net change of water level, but the currents have their maximum amplitude whereas at the antinodes, the *maximum* change of water level occurs but there are no currents. This is illustrated in *figure 3.*

Standing waves may also occur in a box that is closed at one end but driven by oscillations of in-and-out currents at the other open end. The irregular shapes of real lakes and oceans result in several natural periods of oscillation including lateral as well as longitudinal modes whereby the oscillations will bear strong resemblance to the diurnal and semi-diurnal cycle of the tide raising forces.

Systems which are forced by oscillations close to their natural period have large amplitude responses, a phenomenon which is called **resonant behaviour**. In nature the forced resonant oscillations cannot grow indefinitely because energy losses due to friction increase more rapidly than the amplitudes of the oscillations themselves. Also, reflected waves are smaller than the ingoing waves due to a not perfect reflection off a coast.

Table 1: Natural Oscillations in different basins

Examples of the natural period of oscillation of water bodies			
	Length	Depth	Period
Bath	1.5 m	0.2 m	2.1s
Swimming Pool	10 m	2.0 m	4.5s
Loch Ness, Scotland	38 km	130 km	35 min

The oscillation and resonance theory shows how considerable vertical and horizontal water movements are created by the tide raising forces in the real world. Whereas the vertical motion is linear and easy to measure, tidal streams are neither, since they involve direction and velocity, both of which may be changing with time, and depth below the surface. Streams may display semi-diurnal or diurnal characteristics, or a mixture of both (diurnal inequality), in which case they will vary with declination of the sun and moon.

Summary

Depending on whether tidal stream is part of a Standing Wave or a Progressive Wave it shows a certain relationship with High and Low Water.

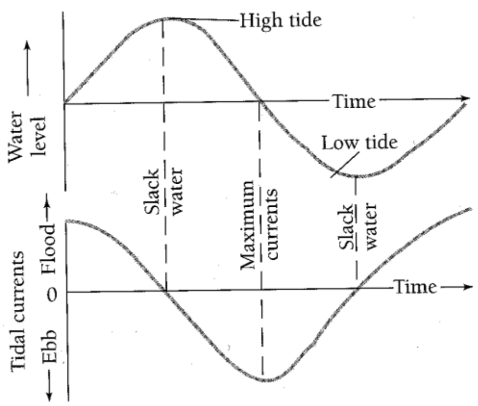
- Standing Wave: At the nodes there is no net change of water level, but the currents have their maximum amplitude whereas at the antinodes, the *maximum* change of water level occurs but there are no currents.

- Progressive Wave: At local High Water there is a maximum current in the direction of wave propagation, but at Low Water there is a current in the opposite direction

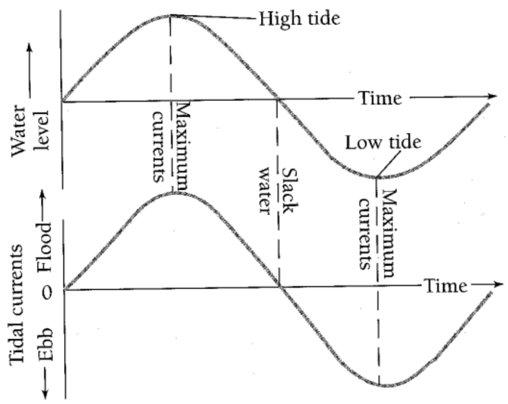
Figure 4 shows theoretical relationships between Tidal Height and Tidal Stream in case of Standing and Progressive Waves. The reality is that neither Progressive nor Standing Waves occur on their own. Figures 21 & 22 on pages 91 & 92 of Tidal Handbook No. 1 show true relationships between tidal height and tidal stream.

Figure 4: Tidal Stream - Tidal Height relationship

Standing Wave



Progressive Wave



4.2. NATURE OF TIDAL STREAMS

A theoretical progressive tidal wave has rectilinear streams. However, it is known from observations that tidal streams in most cases do not simply flow to and fro in one direction, but they change direction and *rotate* in the tidal period. Tidal streams in the open are, by their very nature, rotary. They only tend to flow back and forth in opposite directions (rectilinear) when constrained by land masses or shoals.

The sense of rotation, clockwise or anticlockwise, is controlled by many factors and there are no simple rules to decide which effects will be most important. In some cases the rotation sense may be different at the top and bottom of the water column. In this paragraph the following effects will be briefly discussed:

a. Tide raising forces.
b. Coriolis accelerations.
c. Shelving coast.
d. Combinations of oscillations and progressive waves.
e. Bathymetry.

Tide raising forces

If the sun and moon remain on the plane of the earth's equator at fixed distances, the result of the earth's rotation will be tidal streams which flow due east and west on the equator, and elsewhere they will rotate, clockwise in the northern hemisphere, anti-clockwise in the southern. The path of a particle of water will be elliptical, ranging from a circle at the pole to a straight line at the equator. This results from the tractive forces having easterly and northerly components which relate to latitude, longitude and declination.

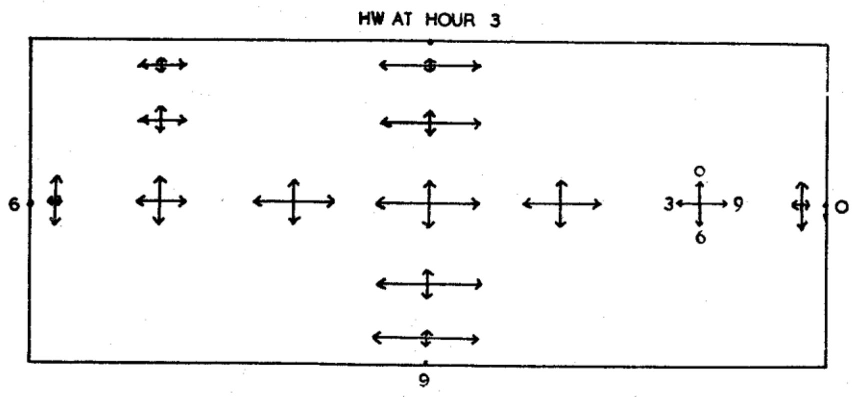
As soon as the sun and moon move out of the plane of the equator and the other effects such as changing distance are considered (i.e. all the 400+ tide-raising constituents), the stream will become rotary, even on the equator, and the actual path traced out by a particle will become very complex.

Coriolis Accelerations

Considering a tidal stream in the Northern Hemisphere moving east/westwards with a period of 12 hours. When it starts moving east at +0 hours the coriolis force will impart a southerly component to the stream that will reach a maximum at +6 hours at which time the stream turns and the easterly components become 0. As it starts to move west coriolis will induce a northerly component which will reach a maximum at +12 hours at which time the easterly component having been negative, again becomes 0. The resultant of these components is a clockwise rotation in the Northern Hemisphere.

Coastal Streams

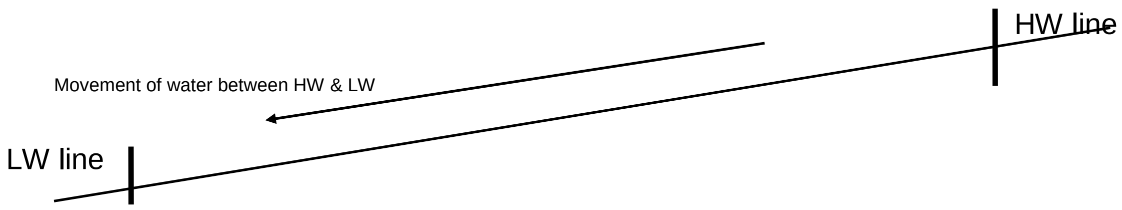
Figure 5: Semi-diurnal tides and rotary tidal streams in a rectangular basin.



Semidiurnal tides and tidal streams in revolving rectangular basin.

At high and low water (hour 3 and 9) there is no necessity for *transverse* streams to be flowing as there is no increase of elevation. At half-tide (hour 0 and 6) however, transverse streams have their maximum rate in case of a shelving coast where the waterline of HW and LW will be in significantly different positions, e.g. a beach. These streams occur in addition to the maximum rates of the tidal streams *along* the coast at high and low water. This is illustrated in *figure 5 & 6.* (Further explanation in NP120 p.184.)

Figure 6: Rotary Streams at Shelving Coasts



Combination of Oscillations and Progressive Waves.

A combination of two standing oscillations in different directions and of different periods will form a rotary stream.

A combination of a progressive wave and a standing oscillation will form a rotary stream whose shape and directions will vary between the periods of oscillation.

A full description of the development of standing waves and oscillations can be found in the AMHS Vol.II, Chapter 2.

Bathymetry.

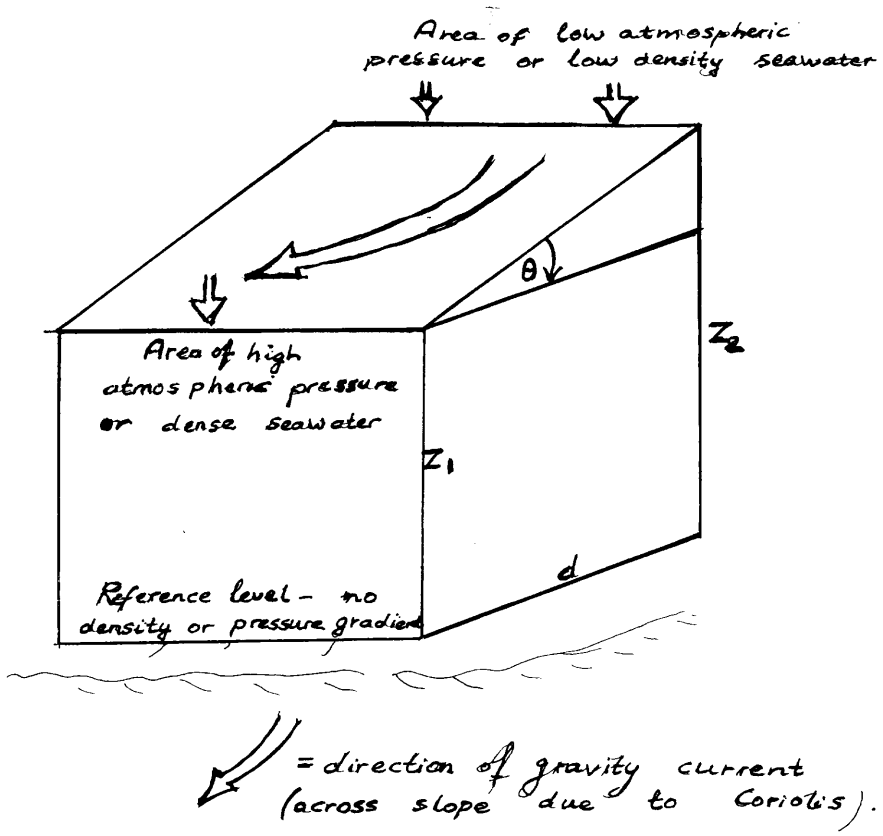
On the continental shelf the sense of rotation is usually controlled by the bathymetry and by coastal wave reflections in a similar way as with a shelving coast.

4.3. NATURE OF OCEANIC CURRENTS

Currents in the deep oceans are set up by a number of mechanisms:

a. Astronomical tide-generating forces.
b. Coriolis.
c. Prevailing winds (wind generated gravity waves).
d. Gravity currents caused by atmospheric pressure gradients.
e. Gravity currents set up by density gradients. Density varies with salinity, temperature and pressure (depth).

Figure 7: Ocean Currents



The oceanic regime is thus extremely complex. The effects often extend to shallow water and cause additional complications. One result of such complexity is that streams may not reverse exactly at HW or LW, and the presence of horizontal motion at these times is often indicative of a current.

5. OBSERVATIONS - EQUIPMENT AND PROCEDURES

5.1. MEASUREMENT OF TIDAL STREAM

This is not a simple task, and tidal stream or current observations require careful planning and application if the results are to be reliable. Traditionally, the complete resources of a survey vessel would be required for a day or more, to the exclusion of most other activities since the vessel will be stopped. This was a very uneconomic way of acquiring what is essentially only spot data. Further more, even if the greatest care had been applied to the measurements, the resulting tidal stream predictions could never be as accurate as vertical movement tidal predictions. This was because the random errors of measurement were usually large compared with the quantities measured, and little time was available to reduce the errors by repetition (compare with tidal observations, where data covering 30 days is relatively easy to obtain).

The trend in equipment had therefore to be towards instruments, which permit continuous acquisition of data with the ship underway. The buoy-moored current-meter is the most obvious result of this trend.

Ideally, observations should be made at hourly or half-hourly intervals, for a lunar month (29 days). In practice, unless a buoy-moored, remote-recording current meter is available, a much shorter period of time will be allocated to stream observations. Thus:

a. Obtain a minimum of 25 hours readings at hourly or half-hourly intervals, and 50 hours if possible (with diurnal tides, 50 hours observations should be obtained during periods of large tidal range).

b. Observations should be made when the weather is good.

c. Observations should be made at springs, when streams are strongest and errors will be minimised.

d. If possible, repeat at a time other than springs.

Measurement techniques

They fall into two general categories:-

a. Lagrangian Techniques - Labelling and tracking a volume of water (e.g. pole logship).

b. Eulerian Techniques - monitoring flow past a point (e.g. current meter).

Pole Logships

a. Either free-floating or tethered, they give the average flow rate and direction over the pole depth. Pole lengths should be chosen to equate to the expected draught of vessels using the area.

Disadvantages:

Immobilises ship or boat and personnel for long periods.
Handling problems.
High accuracy fixing required.
Inaccurate results.

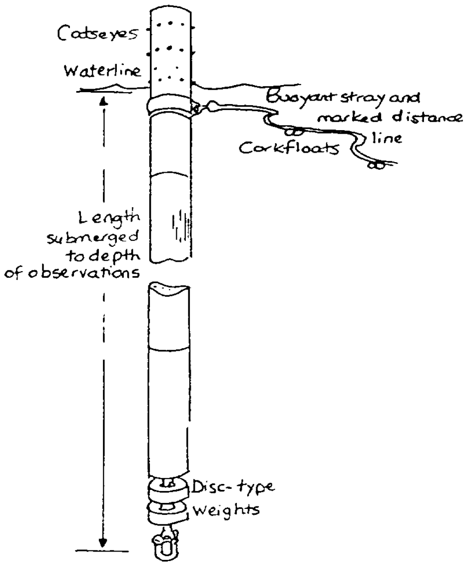
Procedure

a. Give the logships a good soaking for about 24 hours so that it is waterlogged, then add weights as required to leave about 18 inches above the surface of the water.

b. Preparation in the boat or ship:- Anchor or secure to a buoy in the position you are to take the observation and prepare the following gear.

c. Mooring and manoeuvring board, Stopwatch, H183, Tidal stream and current log (ROUGH), Dividers, Deadbeat compass or Gyro repeat, Parallel ruler, Aldis lamp, Pencils as required, Logships (pre-soaked and weighted), Current line.

Figure 8: The Pole Logship



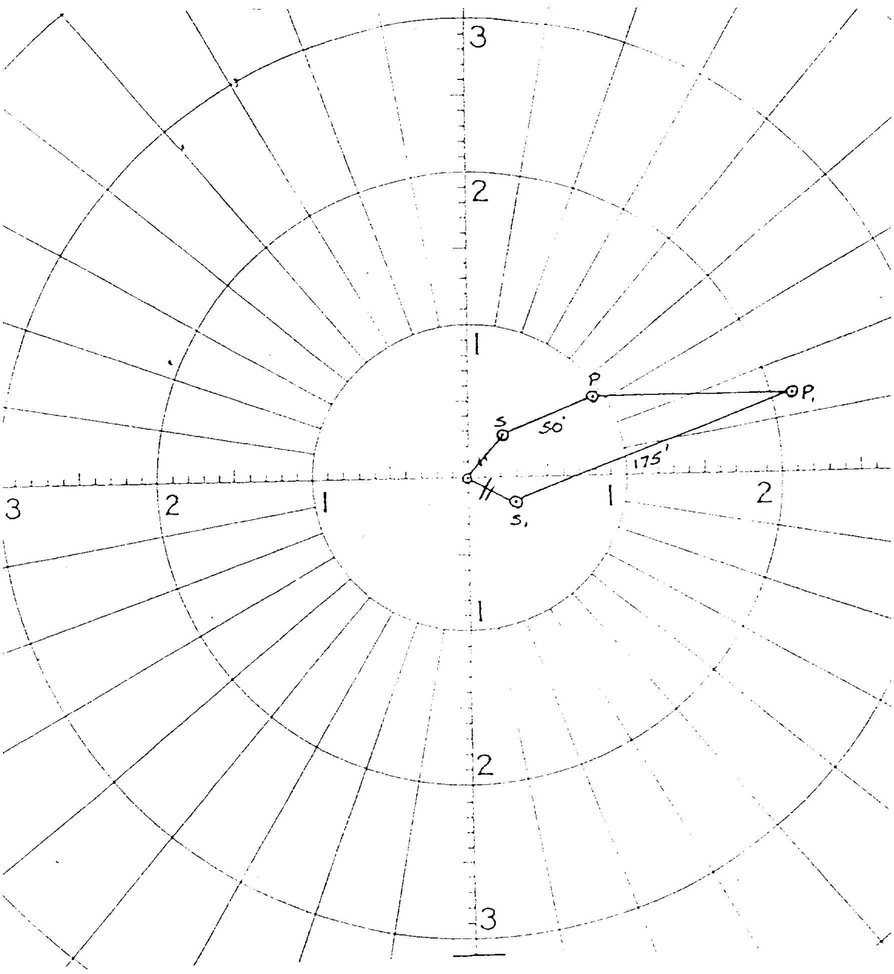
The logship is usually 15 or 30 feet (4.5 or 9m) long, of uniform cross-section, weighted so that it floats upright with only a few inches above the surface reducing windage to a minimum but providing sufficient for tracking. The top of the pole is fitted with a small battery-powered light, and studded with cats eyes for tracking at night.

Procedure - Tethered Logship

a. Pole is attached to vessel by a buoyant line-the first 15-30 metres is unmarked strayline, the remainder marked as for a lead-line.
b. A precise method of measuring the observer’s movements is required, e.g. DGPS. It is a fallacy to assume that the vessel pivots about her anchor, with the cable pulled out taut.
c. Allow logship to drift away freely on stray line, away from vessel’s influence.
d. At zero of logline, start stop-watch, fix vessel, note ship’s head and bearing of logship (gyro compass at stern).
e. After 1 or 2 minutes, depending on stream, stop the watch, fix the vessel, note bearing of logship, ship’s head and amount of line out (draw taut) (1kt = 100ft/min, or 31m/min).
f. Obtain 3 sets of observations in quick succession if possible-results can then be referred to the mean time of observation. Note prevailing meteorological conditions; use form H183.
g. Plot all 3 runs and combine to obtain mean rate and direction of flow. The Plot should allow for the motion of the vessel during a run.

Plotting Tethered Logship Observations

Figure 9: Logship Plot



As the stern of an anchored vessel will not remain stationary over a 1 or 2 minute run a large-scale mooring / manoeuvring board, central on the vessels anchor position, should be drawn up.

The raw data should be recorded in a deck / sounding book for ease of checking. Plot the position of the stern of the vessel at the first fix i.e. Zero of the marked logline = position S. Plot position of the pole (P) by bearing and distance from S. Plot position of the stern of the vessel at end of run (S1). Plot position of the stern of the pole (p1) by bearing and distance. (Remember dist + 50'). Joining P to P1 gives direction and the tidal stream. The distance between P and P1 in feet divided by a 100'/min gives total stream rate. The means of each set of OBS should be recorded in the H138.

Procedure - Free-floating Logship.

a. The same pole can be used, without the distance line. The position of observation should be marked by a small buoy
b. The logship is released from a boat upstream from the buoy. As soon as it is drifting freely, its position is fixed, but it is important that the coxswain of the boat does not approach the logship too closely, to avoid disturbing it.
c. After suitable intervals, the pole is re-fixed two or three more times, taking the fix times to the nearest second
d. The logship is recovered, and the sequence repeated once or twice in quick succession. Note prevailing meteorological conditions.
e. Plot the fixed positions of the logship, compute the rate and direction for each run, mean these, and refer them to the mean time of observation.

(A free-floating logship can also be tracked by high-definition radar, as long as the radar reflector on the pole does not offer significant windage. Allowances for ship motion must, of course, be made).

Flow meters.

A current meter is the most versatile method of measuring rate and direction of low at any depth, including the ocean deeps. They may be ship-tethered or buoy moored. The equipment itself is expensive when compared with a logship, but the savings in ship time and manpower often make use of such meters far more cost-effective, particularly if they are self-recording devices which can be left unattended. There are numerous models of meter on the market, many designed specifically for work at great depths. The readout is either direct to a control unit situated in the surface vessel, or remotely recorded on magnetic tape within the body of the meter. Some can telemeter information to a surface buoy for recording or direct transmission to a ship.

Meters in use today employ one of three methods of measuring rate and direction:

i. Impeller or rotor.

ii. Electromagnetic Current Meters.

iii. Acoustic Doppler Current Profilers (ADCPs).

Impeller or rotor.

The impeller rotates in the current, at a speed proportional to the current rate, and a vane arrangement on the body keeps the whole instrument facing the current flow. A magnetic coupling drives a hexagonal cam inside the sealed, oil filled body, making six electrical contacts per revolution of the impeller. A succession of pulses is sent via umbilical cable to

the control unit, where the current rate is displayed direct in kts or metres/sec as a voltage dependent on the pulse repetition frequency.
Direction is usually sensed by an aircraft-type magnetic compass inside the body of the underwater unit, and is often compensated for residual deviation. Gyro compasses are rare in such devices since they are expensive.

The types in RN service is:

DNC-3N current meter. The DNC-3N current meter was introduced into RN service to replace some of its ageing and now obsolescent meters, although it too is tending to be superseded by more modern current meters. The instrument consists of two parts; the underwater unit and the surface unit, connected by a standard oceanographic cable mounted on a reel. The system as purchased is able to measure *velocity* and *direction*

- ***DNC-3N: System description***

The underwater unit consists of three main parts; the nose cone, the rear tube and the fin/impeller guard assembly. The nose cone portion contains the input socket for the data cable while the sensors and electronic components are contained in the rear tube. Hung under the main part of the unit is a ballast weight, which ensures that the unit is horizontal when current measurements are being taken.

The surface unit consists of a portable splash proof box, which contains the equipment electronics. The front of the unit consists of the ON/OFF switch, a liquid crystal display with an intensity control and an atmospheric compensation control. A gland plate containing the terminal connections to external power supplies and peripherals is situated at one end of the surface unit. It is recommended that the plastic cover is kept on the set as much as possible during operation as the front panel itself is not splash proof.

The interconnecting cable between the two units is of an oceanographic type that combines the functions of strain cable and data transfer.

- ***DNC-3N: Individual parameters***

Direction: The direction of the current is determined by a precision double mounted compass which is sampled 3 times a second. The resulting digital signal is converted to an analogue one and transmitted to the surface.

Velocity. The impeller is magnetically coupled to an optical sensing mechanism which converts the rotation to an electrical signal.

- ***DNC-3N: Operation of the current meter***

To use the equipment the following sequence of operations should be followed:

a. Connect the underwater unit to the cable, ensuring that the load bearing loop is properly secured to the fish.

b. Connect the interconnecting cable from the cable reel to the surface unit.

c. Connect any external power cables that are required to the surface unit (either mains or 24V DC).

d. On switching on the unit a flashing green indicator should show on the front panel while a “sign on” message should appear on the display. Following this original message summary of the modules fitted will appear. The instrument should now go through a series of self-checks; if a fault is detected then an error message will be displayed whereas if all operations are correct then the instrument will work normally.

e. For greater accuracy atmospheric pressure compensations should be applied. This is done by pressing the atmospheric compensation button while the unit is being switched on. This will enable the depth to be determined independently of the ambient atmospheric pressure. This pressure compensation will only be valid, however, for short periods. when the correction has been actioned the display will show “PRESSURE COMPENSATION INITIATED”. Continued operation of the compensation will be indicated by a colon in place of the decimal point in the depth figure. If the unit is switched off then pressure compensation will have to be re-initialised on switch-on.

f. The unit should then be lowered to the required depths and measurements taken as required.

g. On return to the surface and before the underwater unit is stowed it should be washed off with fresh water and then dried.

Electromagnetic Current Meters.

No moving parts, therefore no risk of interference by floating debris. These meters use Faraday’s law of electromagnetic induction by measuring water-flow-induced voltage on two orthogonally placed pairs of electrodes within a locally-generated magnetic field. By resolving the two orthogonal measurements, a polar co-ordinate vector may be obtained which represents the flow rate and direction. In the HSS the S4 current meter is in use. Refer to the handbook for technical details.

Acoustic Doppler Current Profilers (ADCPs).

Again, there are no moving parts. They employ a configuration of transducers to examine the Doppler frequency shifts caused by acoustic transmissions in the presence of water flow. Typically, very short pulses are transmitted between pairs of transceivers, the geometry being designed to yield precise measurements independent of the local acoustic propagation velocity. Orthogonal measurements are again resolved to obtain the flow rate and direction. The theory of the Doppler measurements is explained in the next paragraph.

5.2. DOPPLER THEORY AND ADCP OPERATION

The Doppler effect is a change in the observed sound pitch that results from relative motion. An example of the Doppler effect is the sound made by a train as it passes. The whistle has a higher pitch as the train approaches and a lower pitch as it does moves away from you. This change in pitch is directly proportional to how fast the train is moving. Therefore, if you measure the pitch and how much it changes you can calculate the speed of the train.

Imagine you are next to some water, watching waves pass by you. While standing still, you see eight waves pass in front of you in a given interval. Now, if you start walking toward the waves, more than eight waves will pass by in the same interval. Thus, the wave frequency appears to be higher. If you walk in the other direction, fewer than 8 waves pass by in this time interval, and the frequency appears lower. This is the Doppler effect. The Doppler shift is the difference between the frequency you hear when you are standing still and what you hear when you move.

- **How ADCPs use Backscattered sound to measure velocity**

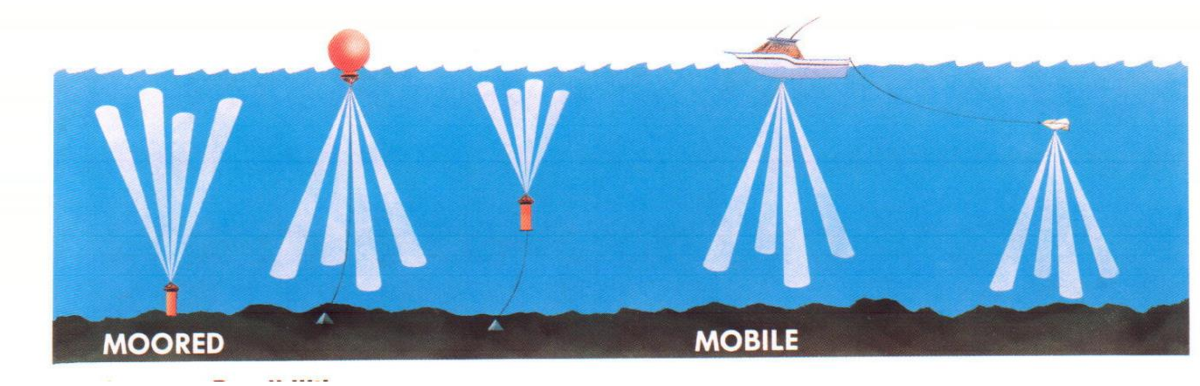
  ADCPs use the Doppler effect by transmitting sound at a fixed frequency and listening to echoes returning from sound scatterers in the water. These sound scatterers are small particles or plankton that reflect the sound back to the ADCP. Scatterers are everywhere in the ocean. They float in the water and on average they move at the same horizontal velocity as the water (**note that this is a key assumption**!). Some examples of typical scatterers in the ocean are: Pteropod, Copepod and Euphasud.

  Sound scatters in all directions from scatterers. Most of the sound goes forward, unaffected by the scatterers. The small amount that reflects back is Doppler shifted.

- **Multiple Beams**

  When an ADCP uses multiple beams pointed in different directions, it senses different velocity components. For example, if the ADCP points one beam east and another north, it will measure east and north current components. If the ADCP beams point in other directions, trigonometric relations can convert current speed into north and east components. A key point is that one beam is required for each current component. Therefore, to measure three velocity components (e.g. east, north, and up), there must be at least three acoustic beams. Four are often used in the "Janus configuration", as illustrated in Figure 10.

Figure 10: Deployment Possibilities of an ADCP



Deployment Possibilities of an ADCP are:

- Fixed on stationary platforms.
- Suspended on a mooring.
- Housed in bottom frames.
- Attached to surface buoys.

- Towed behind or mounted on vessels (surface or submerged).

Accuracy: Some important accuracies are stated below:

- Heading: +/- 2 º
- Velocity: +/- 2 % +/- 0.02 cm/s

5.3. REMOTE SENSING

Radar Backscatter.

Commercial VHF and HF radar backscatter systems and experimental systems using military radars have shown the benefits of long range horizontal coverage that are possible. The technology has matured with a variety of systems available. Interpretation is not as simple and inter-comparisons between radar and drifter measurements are important. Clearly the radar systems yield excellent information often, however, only the surface movement is detected, so wind-driven surface currents may well obscure the tidal flow.

Satellite observations of ocean currents and wind have long been sought. The leap from laboratory developments of radar backscatter models to satellite measurements needs more observations at the intermediate scale where the commercial radar backscatter systems are providing data, to have some means of ground-truthing RS data.

6. RENDERING AND ANALYSIS OF DATA

6.1. RENDERING OF TIDAL STREAM DATA

HQAIs-GSIs F.5.1 to F.5.3 indicates the tidal stream records to be rendered. In case of S4 (or other current meter with observations stored on disk) observations, a hard copy and the raw digital data must be part of Annex J to the report of Survey. If an analysis has been carried out it is recommended to use the lay-out of tables and graphs as mentioned in the AMHS.

6.2. ANALYSIS OF TIDAL STREAM DATA

Procedures for the analysis of tidal stream observations are laid down in the AMHS Vol II, Chapter 2 (see also HQAIs-GSI F.4.1). This 1967 publication describes two methods for analysis of tidal stream data:

- **Harmonic Analysis**, in a way similar to that used for the vertical movement of tides. When just 25 or 50 hourly observations have been obtained only the four main tidal constituents can be determined.

- **Semi-graphic methods** to obtain an empirical relationship between the tidal stream at a place and the tide at a suitable standard port. This method cannot handle diurnal inequalities in the tidal stream and assumes that the tidal streams are completely semi-diurnal.

With the introduction of the S4 current meter and therefore Digital Data, the UKHO prefers to receive the raw data and carry out the analysis themselves. In case of logship observations however, the surveyor is required to carry out the analysis on board and at page 109 AMHS Vol II, Chapter 2 the records to be rendered are listed under *f*.

As the use of the logship will slowly phase out it is foreseen that analysis will become more and more carried out by Hydrographic Offices, especially with the developments in the area of Remote Sensing.

7. REFERENCES

Admiralty Manual of Tides, NP120

Admiralty Tidal Handbook, No 1

Tides, Surges and Mean Sea Level - DT Pugh

Oceanography - Paul R Pinet

Admiralty Manual of Hydrographic Surveying, Vol 2, Chapter 2 - Tides & Tidal Streams

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