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A Handbook on the use of Moored Current Meters in Coastal Waters

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A HANDBOOK OF THE USE OF MOORED CURRENT METERS IN COASTAL WATERS

by R.G. Bell; J.W. Oldman; T.M. Hume

Water Quality Centre
Ministry of Works and Development
Hamilton

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A Handbook on the Use of
Moored Current Meters in Coastal Waters

R.G. BELL, J.W. OLDMAN, T.M. HUME
Water Quality Centre, Ministry of Works and Development, Hamilton, New Zealand

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This handbook provides information for the successful use of moored current meters in coastal waters. It describes the oceanographic conditions peculiar to this environment and the way they influence site investigations, mooring design, instrument selection, deployment, maintenance, retrieval and record analysis. The handbook is intended as a reference text for scientists, engineers and technicians involved in collecting and using coastal current data.

Front Cover: A diver checking an Aanderaa RCM4 current meter moored in shallow coastal waters off the New Zealand Coast. (Photo supplied by the Taranaki Catchment Commission.)

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CHAPTER 1

INTRODUCTION

A moored current meter system comprises an instrument with various sensors and a data logging capability, mounted on a mooring at a remote location in the sea. It is used to measure and record a long term time series of oceanographic parameters, in particular current speed and direction.

Current meters have traditionally used rotors to measure currents and recorded the data on a chart or magnetic tape. Recently developed instruments have no external moving parts, sample currents by electromagnetic or acoustic sensors and record data in a solid state memory. To increase versatility, current meters will often have additional sensors to measure water conductivity, temperature, pressure and water quality parameters (pH, dissolved oxygen etc).

A mooring system is generally anchored in position by heavy weights, with the current meters being supported at selected levels in the water column by either sub-surface buoys or a rigid cage structure. The mooring may also be marked by a surface buoy with a flashing identification light and radar reflector.

The technique of measuring currents at a fixed location can be described as a flow or Eulerian method. The other class of current measurement techniques is the path or Lagrangian method, where a device is placed in the water and is free to move with the current. The latter method is not covered in this handbook. The major advantage of using a moored current meter is that a long term record (e.g. several months) can be obtained from an unattended station. The major disadvantage, apart from cost, is that each meter can measure the velocity at only one point in the water column. To overcome this, a mooring system can be designed to support several current meters on a 'string' throughout the water column.

In New Zealand there is an increasing use of moored current meter systems to obtain tidal current and circulation data in the coastal waters of estuaries and the inner continental shelf. The measured data are being used in a variety of research programmes and engineering survey investigations, and by a wide range of organisations. There are problems, however, in the use of moored current meter systems in shallow waters, and careful planning is essential. Current meter deployments are expensive and the data record, which may form an important part of a larger survey, irreplaceable.

The value of a set of comprehensive guidelines in the use of such instruments in coastal waters was noted at a Tides and Waves Measurement Workshop in Christchurch, New Zealand in 1984. This handbook has been produced in response to this need. It combines technical information with field experience and describes the special problems associated with oceanographic investigations in shallow coastal waters and the way they influence site investigations, mooring design, notifications, instrument selection, maintenance, retrieval techniques and record analysis. It will be of benefit to scientists, engineers and technicians involved in collecting and using coastal current data.

CHAPTER 2

COASTAL OCEANOGRAPHY AND IMPLICATIONS FOR MOORED SYSTEMS

The waters of estuaries and the inner continental shelf (to 40 metres depth) present unique oceanographic conditions which can have significant effects on the performance of moored current meters.

2.1 Strong Currents

Meters deployed within regions of strong tidal currents (e.g. tidal inlets, narrow straits) require greater buoyancy or unique mooring designs to reduce the effects of axial tilt. In addition, the gimbal arrangements for meters like the Aanderaa RCM4 are only balanced at low velocities and therefore for higher velocities (e.g. 1-1.5 m/s) the dynamic pressure differential over the instrument case can also produce tilting. Tilting may produce errors in the measurement of the horizontal speed and cause variations in the depth of the instrument. Although such variations are normally minor, they can be a significant proportion of the depth in shallow estuarine waters. Axial tilt can also cause compass jamming resulting in direction errors.

2.2 Marine Fouling

Biological fouling during a typical deployment period is not a problem in deep water because low light levels and cooler temperatures result in low productivity. However in shallow temperate coastal waters the attachment of marine fouling organisms can be a significant problem. Fouling organisms include 'slimes', 'hard fouling' (e.g. barnacles, molluscs), 'soft-fouling' (e.g. sponges, anenomes) and 'floaters' (e.g. hydroids, seaweeds) (Foster, 1982). The type of fouling which occurs is dependent on the location, seasonal factors, the variety of species involved, light, nutrient levels, turbidity, current speed, salinity variations and temperature. Bio-fouling can be extreme (Figure 1), particularly in the vicinity of ocean outfalls and estuaries where high biological productivity occurs. Bio-fouling increases the drag on the mooring system and therefore leads to increased axial tilt and also to a net

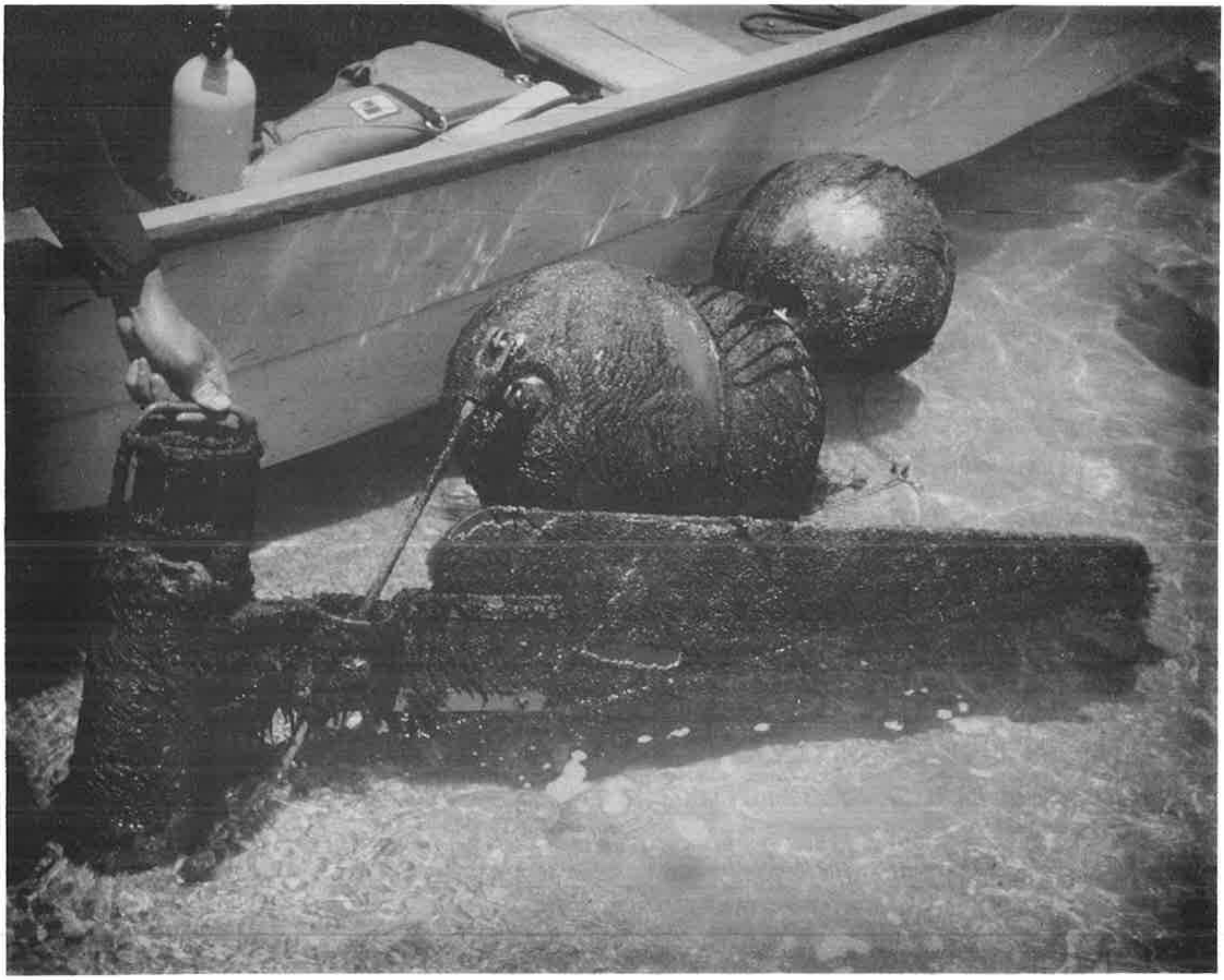

Figure 1. Bio-fouling on an Aanderaa RCM4 after a 2 month deployment in a tidal inlet.

reduction in the buoyancy of sub-surface buoys. Bio-fouling in the region of a rotor sensor, particularly from the 'floaters', can exert drag on the rotor and its spindle, eventually causing it to stall. Errors associated with bio-fouling can also be pronounced for other sensors, particularly the conductivity sensor. Examples of these effects are illustrated later in Chapters 7 and 8.

2.3 Waves

In coastal waters the currents are generally weaker than in estuaries and therefore tilt is not a problem but the increased exposure to wave action can lead to large speed errors for nonvector-averaging current meters with rotors (see Chapter 3). These errors are caused by the response of the rotor to mooring line oscillations and sub-surface orbital motions generated by waves. The intensity of these orbital motions are related to wave period, wave height, still water depth and the level of the instrument above the seabed.

By way of example, a correlation between wave heights measured by a Waverider Buoy off Tatapouri Point (Gisborne), and speeds recorded by an Aanderaa RCM4 moored at the entrance to Poverty Bay, was carried out for a 15 day period in September 1984. For the mid-depth deployment 17 metres below the surface, wave heights above 1 metre significantly affected the performance of the rotor, causing increased speed values. Later in the deployment speed errors of up to 30 cm/s occurred during a severe storm when estimated wave heights were up to 5 metres. Because the influence of wave motions decreases exponentially with depth, it is desirable to deploy this type of meter and the sub-surface buoys as low as possible in the water column, depending on the type and scope of the oceanographic survey. Experiments by Halpern and Pillsbury (1976) and Pearson et al. (1981) using Aanderaa RCM4 current meters with sub-surface buoys at various depths indicated the critical importance of this factor. If an accurate record of current velocities is required a vector-averaging current meter is a better choice (see Chapter 3).

2.4 Floods and Storms

One particular problem encountered in estuaries is caused by debris washed down during floods. This can foul or snag external moving sensors or, even worse, result in the loss of parts of the mooring system. The increased current speed associated with floods should be considered when designing the mooring system.

High bedload transport generated by storm waves or floods can bury ground lines and anchors, which may lead to problems when retrieving mooring systems. Wave action during storms also creates severe strain on mooring lines and linkages. Precautions such as adequate anchorage, use of swivels, secure connections, regular maintenance and accurate position fixing should all minimise these risks.

2.5 Stratification and tide levels

Small errors in computed depth values using accurate pressure sensors can occur because of density changes within the water column. Absolute pressure measurements must first be converted to gauge pressures, using the local atmospheric pressure, and then converted to a depth using a computed sea water density. The density can be calculated from measurements made by the conductivity and temperature sensors, if they are fitted. Vertical density variations in the water column above the meter can be significant, particularly in estuaries. In extreme cases, errors of up to 7 cm could occur for every 5 metres of water depth above a meter which is located near the bed in oceanic-type water ($S = 35.0 \times 10^{-3}$) with near freshwater conditions ($S = 0.0 \times 10^{-3}$) at the surface.

The tidal range in an estuary is normally a significant proportion of the water depth remaining at Low Water (LW). Therefore careful consideration is required when designing a mooring system, such as ensuring sufficient draught is available in navigation channels at LW, to prevent damage to instruments. The level at which velocities are measured, as a proportion of the instantaneous water depth, also changes throughout a tidal cycle and should be taken into account when analysing and presenting the data for estuarine sites.

CHAPTER 3

TYPES OF RECORDING CURRENT METERS

Recording current meters (referred to as RCM), employ various types of sensors and recording techniques. The measured data is stored either in a solid-state memory or on a physical recording medium such as magnetic tape, or in the past, strip chart. The sensors may be static, with no external moving parts, or dynamic, with an impellor or rotor. Velocity is a vector quantity defined by a magnitude (the speed) and a direction, and therefore must be measured by two independent sensors. The real challenge to designers has been to sample and record sufficient output from these two sensors to describe adequately the velocity field, particularly within the wave zone.

The nonvector-averaging meter usually record an average speed taken over an averaging interval but record direction only at the end of the interval. This can lead to uncertainties in determining the true magnitude of the velocity vector components. This type of instrument is intended primarily for use in situations where no frequent reversals of the current occur during the sampling interval. These conditions are normally present only outside the wave zone, in deep water (>100 metres depth) and in sheltered estuaries.

The vector-averaging current meter (VACM) is designed to measure the velocity (magnitude and direction) frequently, resolve it into rectangular components and finally record average velocity components at the end of a preset sampling interval. The VACMs have a wider range of applications, most being suitable for deployment within the wave zone.

At present the majority of recording current meters used in New Zealand are the nonvector-averaging type, principally the Aanderaa RCM4. For this reason the Aanderaa RCM4 is used more often as an example in this handbook. The reasons for its popularity are the relatively low cost compared with VACM's (only 1/3 to 1/6 of the latter), a proven record of reliability and durability and ready access to data decoding facilities. However a significant number of deployments of the Aanderaa instrument (and others of a similar type) are made in shallow coastal waters (less than 40 metres depth) where use of this type of meter has severe limitations.

This section describes examples of the major types of RCM used in the Eulerian determination of current velocities. Further detailed information on types of instruments is available in, for example, Grace (1978), Morris (1983) and Pickard and Emery (1982).

3.1 Rotor-Vane Current Meters

The most widely used and understood method of measuring current speeds utilises a rotating sensor. This may be either a propellor mounted on a horizontal shaft or, more frequently, the Savonius rotor which is less susceptible to the effects of vertical movement. The Savonius rotor consists of half-hollow cylindrical blades mounted on a vertical axis with flat end-plates. Since the necessity for direction measurements usually requires the inclusion of a vane of some sort, these meters are commonly referred to as "rotor-vane" current meters.

The Savonius rotor is usually made of plastic so that it is neutrally buoyant in sea water and bearing friction is reduced. It is more sensitive, therefore, to low threshold currents (1.5-2 cm/s) than most other speed sensors. It also has the advantage of being relatively cheap, robust, omni-directional and of having a consistent long-term linear calibration in steady flow. These features have made the Savonius rotor, in its present form, an attractive sensor. However it does have limitations which can significantly affect its performance, particularly in shallow water applications:

(i) Savonius rotors, in common with other external moving parts, suffer from bio-fouling problems in shallow coastal waters.

(ii) In the wave zone, the Savonius rotor translates wave-induced mooring motion and orbital water movements into net rotations which are recorded as a contribution to the speed (Karweit, 1974). Speed magnitudes recorded during periods of wave activity are thus overestimated.

(iii) The Savonius rotor must remain perpendicular to the current direction and therefore any vertical tilting of the meter (e.g. during strong tidal flows) will cause a reduction in the speed magnitude. Bio-fouling increases the drag and will thus also increase the likely occurrence of this problem.

The two 'rotor-vane' instruments which have dominated the field are the Aanderaa RCM4 (A in Figure 2) and the AMF Sea-Link VACM (B). The Aanderaa meter uses a Savonius sensor and a relatively large vane keeps the entire package orientated into the flow via a gimbal arrangement, so that only a compass is needed to measure direction, relative to magnetic north.

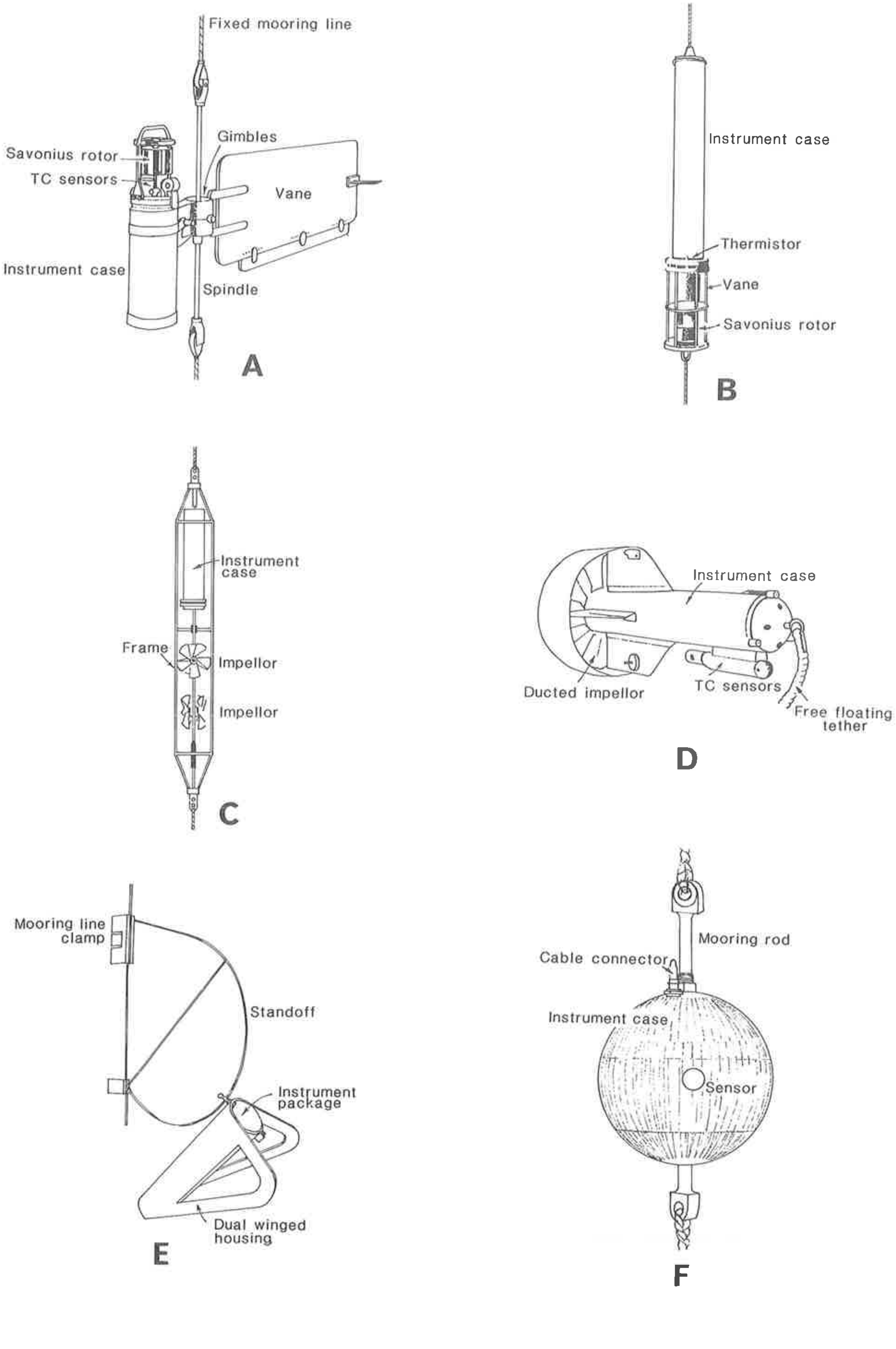

Figure 2. Examples of various types of recording current meters

The basic Savonius rotor current meter was improved in the development of the AMF Sea-Link VACM. This instrument samples current speed and direction every 1/8 turn of its rotor and continuous digital processing converts the signals to Cartesian coordinate vector components. Northerly and easterly current components are averaged over a pre-set period and the averages are recorded on a magnetic cassette tape.

A comparison of the AMF Sea-Link and Aanderaa RCM4 was carried out in the wave zone by Saunders (1976). This study showed that the Aanderaa RCM4 recorded higher currents than the AMF Sea-Link. The difference was partly attributed to the higher rotational inertia of the larger Aanderaa vane system in response to rapid wave-induced reversals in current speeds and the lower sampling frequency.

A further development which does not require a vane is the vector measuring current meter (VMCM), also known as the Davis-Weller meter (C in Figure 2). This uses two orthogonal propellors to mesure the rectangular vector components directly and records average velocity components at pre-set sampling intervals. It has proved to be effective in shallow water where other meters are susceptible to wave effects (Heinmiller, 1983).

3.2 Ducted Impellor Meters

The Endeco Type 174 tethered current meter (D in Figure 2) features a neutrally buoyant flow reversible impellor which turns inside a cylindrical duct. The entire instrument is neutrally buoyant in a horizontal orientation which allows the current meter to be tethered by a slack line to a taut mooring cable. The tether isolates the instrument from mooring oscillations, mooring tilt and wave-induced orbital motions, and this, coupled with a vector-averaging capability, make this type of meter suitable for deployment within the wave zone. However the susceptibility to bio-fouling inside the duct is a major disadvantage.

3.3 Tilting Current Meters

The concept of a current meter as a device suspended by a thin wire, which deviates from the vertical in proportion to the current velocity, has been around for many years. Problems have arisen, however, in the techniques to measure the tilt and the subsequent transformation of the data to current speeds. The General Oceanics Model 6011 Niskin Winged current meter (E in Figure 2) has been developed over the past 10 years using this tilting concept.

A cylindrical aluminium housing, containing the electronics and sensors, is attached by a swivel to a curved wire standoff and hangs vertically in the absence of a current. The angle of tilt from the vertical varies with the speed of the current and is measured by a tilt inclinometer. Advantages are that mooring tilt does not affect the instrument recorded speed and the absence of external moving parts eliminates the problems associated with rotor sensors. A burst sampling mode enables wave effects to be filtered from the record and ensures that the meter is also suitable for use in shallow water.

3.4 Electromagnetic Current Meters

Several attempts have been made to produce a reliable electromagnetic current meter. Water velocity is determined by measuring voltage response when a moving conductor (sea water in this case) cuts an artificially generated magnetic field created by the instrument. The voltage response is directly proportional to the current speed. Time averaging of velocity is simplified because two orthogonal pairs of electrodes are used to measure the velocity directly in Cartesian coordinates. A sensor is also required to measure the orientation of the instrument in order to resolve the velocity components relative to north and east reference axes. Examples of this type of current meter are the Inter-Ocean S4 (F in Figure 2) and the Marsh-McBirney 711. Because these meters have no external moving parts and incorporate a true vector-averaging capability they are suitable for shallow water applications in the wave zone. Furthermore bio-fouling is less of a problem compared with other meters.

3.5 Acoustic Current Meters

There are two acoustic types of current meter, one of which detects the change in travel time of a sound pulse between two probes, and the other of which detects the Doppler shift in frequency of a sound pulse reflected from particles in the moving water column.

In general, while both Doppler and travel time instruments may be obtained from several manufacturers, they are not yet in wide use in oceanographic work. It seems likely that this will change in the near future, due to advantages such instruments have over other types of moored current meters (no moving parts, fast response and flexibility of sampling). There are now also acoustic current profilers which can measure continuous vertical current profiles up to 500 m.

CHAPTER 4

PLANNING A DEPLOYMENT

Thorough preliminary investigations, good mooring design, careful deployment logistics and regular field checks are all essential to minimise any risk of instrument loss or damage and to reduce time spent in the field. Current meter data records are irreplaceable and usually an integral part of a larger regional study, therefore it is important to minimise any contamination of the data due to the effects of bio-fouling, snagging, wave action or abnormal tilting.

4.1 Preliminary investigations

Local environmental conditions should be investigated before any deployment. Existing data on depth, tidal streams, freshwater input and wave climate are all relevant. Localised bathymetric features (e.g. submerged reefs) and bottom sediment type must also be considered when choosing a site. Both the Royal New Zealand Navy (RNZN) and Harbour Board hydrographic charts should be consulted where applicable, and an approach to local experts (Harbourmaster, fishermen, divers) can often be useful.

For long deployments it may be necessary to collect some basic field data in order to select the best site, define current direction and speed within the water column (e.g. by a direct-reading current meter), and determine spatial variations in salinity and temperature. Measurements within estuaries should be carried out at various times before and after high and low tide to check that no atypical tidal currents occur at the mooring site (e.g. interactions with localised bathymetric features), and to determine the likely maximum spring tidal current. It is important to check that sufficient depth is available at low spring tides to support the mooring and that an estimate is made of high current velocities which might occur during a flood.

To assess the wave climate, local data may be available from harbour boards, NZ Meteorological Service, NZ Oceanographic Institute, the newly formed NZ Wave Society, oil companies, universities, local catchment authorities, or engineering consultants. Most well-populated areas have a local surf life-saving club which can be of help. If no local data is available an estimate could be made from general published data with an allowance for local variations.

Information on boating and fishing activity within the location can be obtained from residents, catchment authorities, fishing and yachting clubs, harbour boards and local Ministry of Agriculture and Fisheries staff. Busy areas such as trawling lanes, fishing grounds and navigation channels should be noted and the necessary precautions taken to ensure the safety of meters and boats. If mooring sites are located near harbour approaches, the harbourmaster should be consulted to determine the exact location of navigation channels and paths and likely draught of vessels. Deployment in coastal areas involves a a high risk but the risk can be minimised with good public relations. It is also possible to insure oceanographic equipment against loss.

4.2 Notification and Marking

The Ministry of Transport (MOT) requires that any oceanographic station be adequately marked and an application should be made for consent to install, alter or remove a navigation aid. The MOT recommends that the surface buoys of Ocean Data Acquisition Systems (ODAS) be marked in the following manner:

1 The standard colour should be yellow.

2 Flashing identification lights should be clearly distinct from those used in navigational buoys and other aids to navigation.

Colour - yellow, visible all round the horizon with a group flash 5 every 20 seconds.

3 Radar reflectors should be fitted unless the buoy is of such size and shape as to be a good radar target.

Buoys should also be marked with identity code numbers and a contact address. There is a description of an ODAS for mariners in the System of Buoyage and Beaconage for NZ (Appendix I). The MOT promulgates the position of ODAS buoys in Notices to Mariners which are available from government shipping offices and certain RNZN chart agents. The Ministry needs at least 3 weeks advance notice to arrange for publications at specified dates.

It is worthwhile to notify the relevant harbour board, trawler bases, the Ministry of Agriculture and Fisheries and interested local residents. We have also found it useful to make a local contact and arrange for someone to check periodically for the surface buoys and their lights and to report back any problems.

CHAPTER 5

EQUIPMENT CHOICE, CALIBRATION AND SAMPLING STRATEGIES

5.1 Choice of Instrument

The type of instrument selected for use in a moored current meter system depends on a number of factors, including the type of mooring used, the water depth, exposure to wave effects and the quality of data required. The latter will be dictated by the purpose and scope of the oceanographic investigation and the degree of funding available. The harsh environment within the wave zone imposes additional constraints for scientists and engineers designing sub-surface mooring systems that will operate in shallow water. When planning an investigation and choosing the type of instrument to use, it is also prudent to think ahead to the methods that will be used to process and analyse the data.

The various types of current meters in common use and their suitability for use in shallow water were discussed in Chapter 3. A few specific points relevant to the choice of instrument are further discussed below.

The Savonius rotor is susceptible to the effects of waves, particularly if coupled with an infrequent sampling frequency for speed and direction in comparison to the time scale of wave-induced motions. The nonvector-averaging Aanderaa RCM4 falls into this category and therefore the results from a shallow-water mooring of this meter during periods of significant wave activity will need to be treated with suspicion. A depth of 18 metres for the upper sub-surface buoy of a moored Aanderaa system was found by Pearson et al. (1981) to give satisfactory results for long-term low frequency and semi-diurnal tidal currents. However, for some oceanographic surveys deployments do need to be made in shallower waters. In many of these cases data measured during calm or slight sea states may suffice. For other types of investigation (e.g. ocean outfall investigations), reasonable results have been obtained by deploying Aanderaa RCM4 meters in depths greater than 10 metres and using empirical speed factors to correct for wave effects (Taranaki Catchment Commission, 1985). The correction factor was calculated from the statistical properties of the cumulative frequency curve of speed magnitudes (Figure 15 is an example) and the results of calibration tests using drogues set at the same depth as the meter. Corrections for VACM's due to mooring line motions and dynamic wave effects are discussed by Chhabra (1985).

Aanderaa instruments have recently produced a further refinement of the Savonius rotor designed specifically for use within the wave zone. The 'paddle' rotor has flat blades without end caps (to reduce the inertia of entrapped water) and is shielded around half of its circumference by a metal shroud. Flow tests conducted under steady flow conditions in a rating tank by the Water and Soil Instrument Service Centre, (Ministry of Works and Development) indicated satisfactory results for speeds under 1 m/s when compared with the manufacturer's calibration, (Figure 3). However, the large discrepancies between recorded and actual speeds for various tilt angles indicate that the shrouded rotor is more prone to tilt errors than the standard rotor.

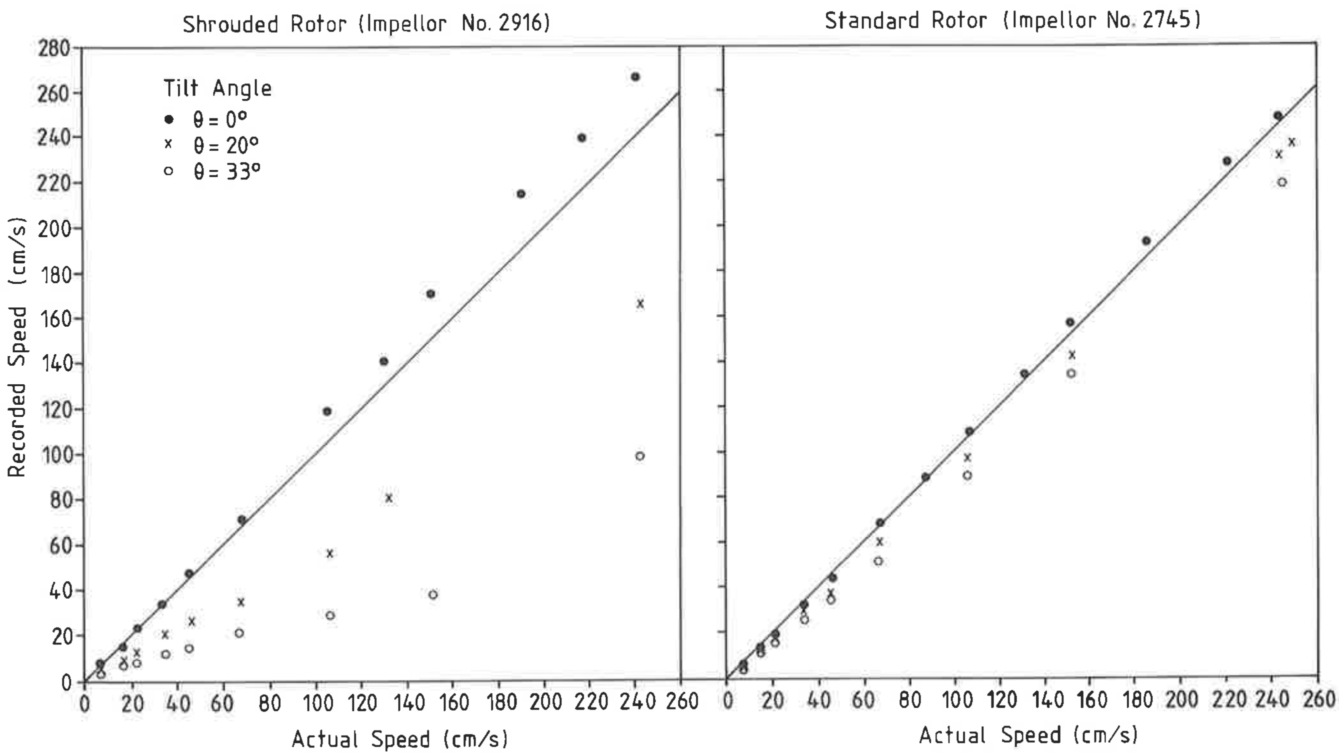

Figure 3. Results of calibration tests in tow tank for an Aanderaa RCM4 equipped alternately with standard and shrouded wave rotors.

The more suitable alternative, if an accurate record of current velocities is required throughout the deployment and sufficient funding is available, is to use a vector-averaging current meter. One VACM may be used in conjunction with several RCM4's with the data from the VACM being used to 'calibrate' the RCM4s. Using the VACM also reduces the frequency and hence the cost of maintenance checks, as the effects of bio-fouling on external sensors are not as critical for tilting or electromagnetic types.

5.2 Calibration of Instruments

It is not normally necessary to hydrodynamically calibrate individual current meters of a given design before every deployment, provided quality control is exercised during manufacture (Kalvaitis, 1972). A non-hydrodynamic calibration, such as a spin-down technique (in air) for instruments with rotors, or a zero-flow offset test for electromagnetic current meters, may be sufficient to check for any inconsistencies prior to deployment.

It is recommended, however, that a periodic hydrodynamic calibration (every 1-2 years) be conducted at a suitable tow tank facility to verify the manufacturer's calibration. When calibrating a current meter under steady flow conditions in a tow tank, care should be exercised to minimise calibration errors particularly for the more sophisticated electromagnetic current meters (see Trageser and Roy, 1986).

The calibration results from a tow tank test at the Water and Soil Instrument Service Centre are shown in Figure 3 for both the standard and shrouded shallow-water rotors on the same Aanderaa RCM4 at tilt angles of 0°, 20° and 33° from the vertical. The results for the normal vertical position show reasonable agreement with actual speeds for the standard rotor but a diverging slope for the shrouded shallow-water rotor, indicating the need for periodic hydrodynamic calibration. The influence of tilt on the performance of the Aanderaa rotors, particularly for the shrouded rotor, is displayed in Figure 4. The cosine curve is also included as a comparison as many oceanographic instrument manufacturers state that their Savonius rotors follow the cosine error curve (Serkin and Kronengold, 1974).

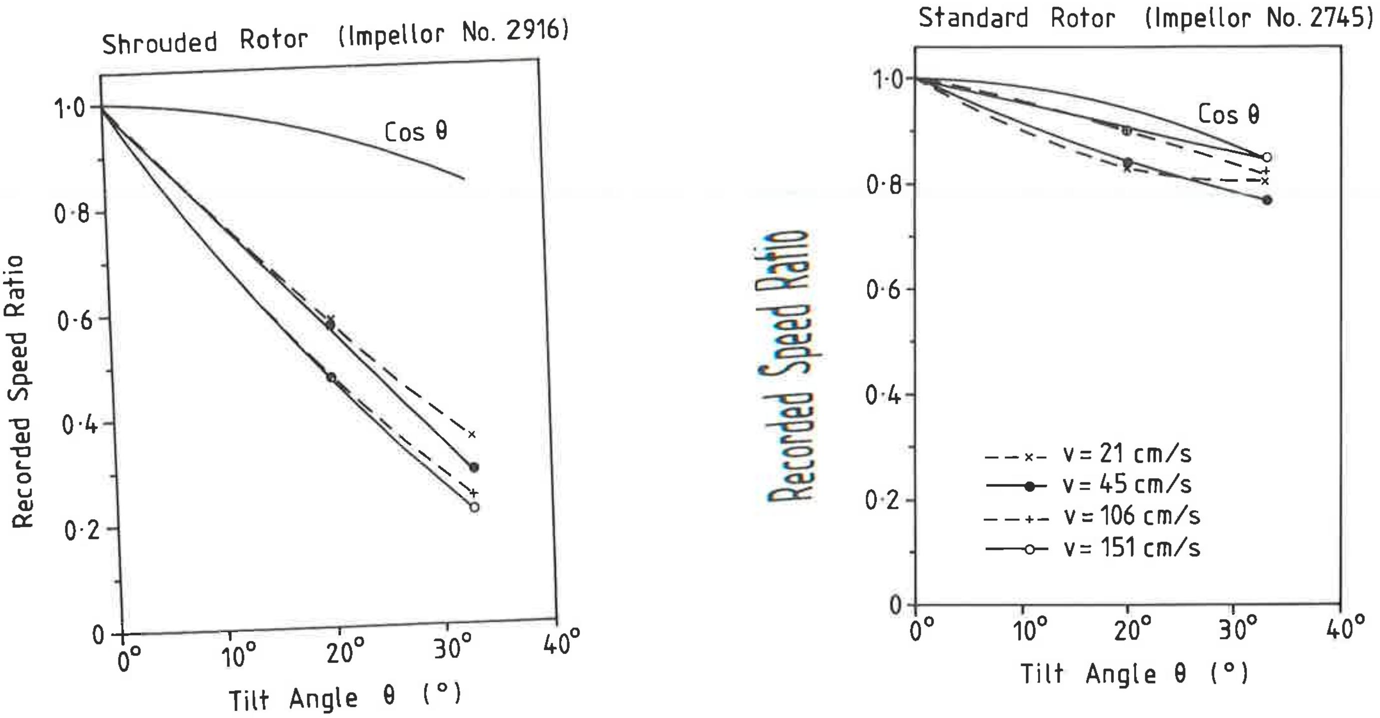

Figure 4. The influence of current meter tilt on speed record for Aanderaa meters fitted with standard or shrouded wave rotors.

5.3 Sampling Strategies for Current Data

Once a current measuring system has been adopted, serious thought must be given to the frequency and duration of sampling necessary if reasonable confidence is to be placed in the deductions made from the data.

The recording frequency should adequately represent the time periodicity of the highest frequency current generating mechanism. Normally this will mean representing adequately the quarter diurnal tide cycle with a period of about 6 hours. The recording frequency must be slow enough to conserve data storage capacity (and thus prolong the deployment period) and also to allow the instrument's data averaging logic to filter out some of the high frequency noise such as wave effects. Recording frequencies of once every 10 or 15 minutes are commonly used in oceanographic surveys.

A decision about the duration of a current measuring programme is not usually possible unless prior information exists or some preliminary measurements have been made. Where there are serious complicating conditions such as coastal discontinuities, river discharges or predominance of wind-generated currents, protracted sampling maybe required until repeatable circulation patterns are identified. If no clear patterns emerge then sampling should continue until any addition of data has no appreciable effect on the frequency distributions of the current rose. In practice about 60 to 100 days of measurements usually suffice. For New Zealand waters this would cover some 200 tidal cycles and the passage of about 20 mid-latitude depressions and five Tasman depressions. It is usual, for example when small-capacity outfalls are being planned, to reduce the current measuring programme because of the cost and the time taken.

A decision must also be made on the level to place the instrument within the water column. The level is largely dependent on the type of oceanographic survey. For the two most common investigations in shallow water - mean velocity/circulation and sediment transport studies - the level of the meter is usually set at 0.4 times the depth and 1 metre respectively above the seabed. For outfall studies, the former depth represents something of a trade-off between proximity to the surface and the poor performance of a non-vector averaging current meter in the wave zone.

CHAPTER 6

MOORING DESIGN

The quality of the measurements is dependent not only on the instrument but also the mooring type. The depth at which measurements are made will determine the type of mooring used.

6.1 Mooring Type

Moorings suitable for most coastal oceanographic applications (Fig. 5) include the U-, I-, top-mounted and cage moorings. It is possible to string several current meters at different depths along the same mooring line.

The U-mooring (Fig. 5) is the most widely used in shallow water applications. It is anchored on the seabed and the instrument stabilised by the sub-surface buoys. A surface buoy marks the sub-surface mooring system for later recovery and provides a measure of protection against damage by trawlers and other vessels. The surface marking buoy is connected to a separate "crown" anchor so that wave action on the buoy does not influence the meter readings.

The ground line connecting the anchors should be at least twice the water depth and consist of floating rope. If the surface buoy disappears, the floating rope will assist recovery of the current meter. This can be done by dragging a grapnel hook or using SCUBA divers to search the area. A ground line of this type is also useful for the guidance of divers on maintenance checks when underwater visiblity is poor, and the long length of rope greatly assists in the eventual retrieval of the mooring system. The Water Quality Centre has made extensive use of the U-mooring and has found the ground line invaluable, as surface buoys are prone to being 'lost at sea'. As an extra precaution acoustic beacons can be attached to the meters, to enable divers with a directional receiver to locate them. Further protection for the instrument can be obtained by using an acoustic release, particularly for the more expensive current meters.

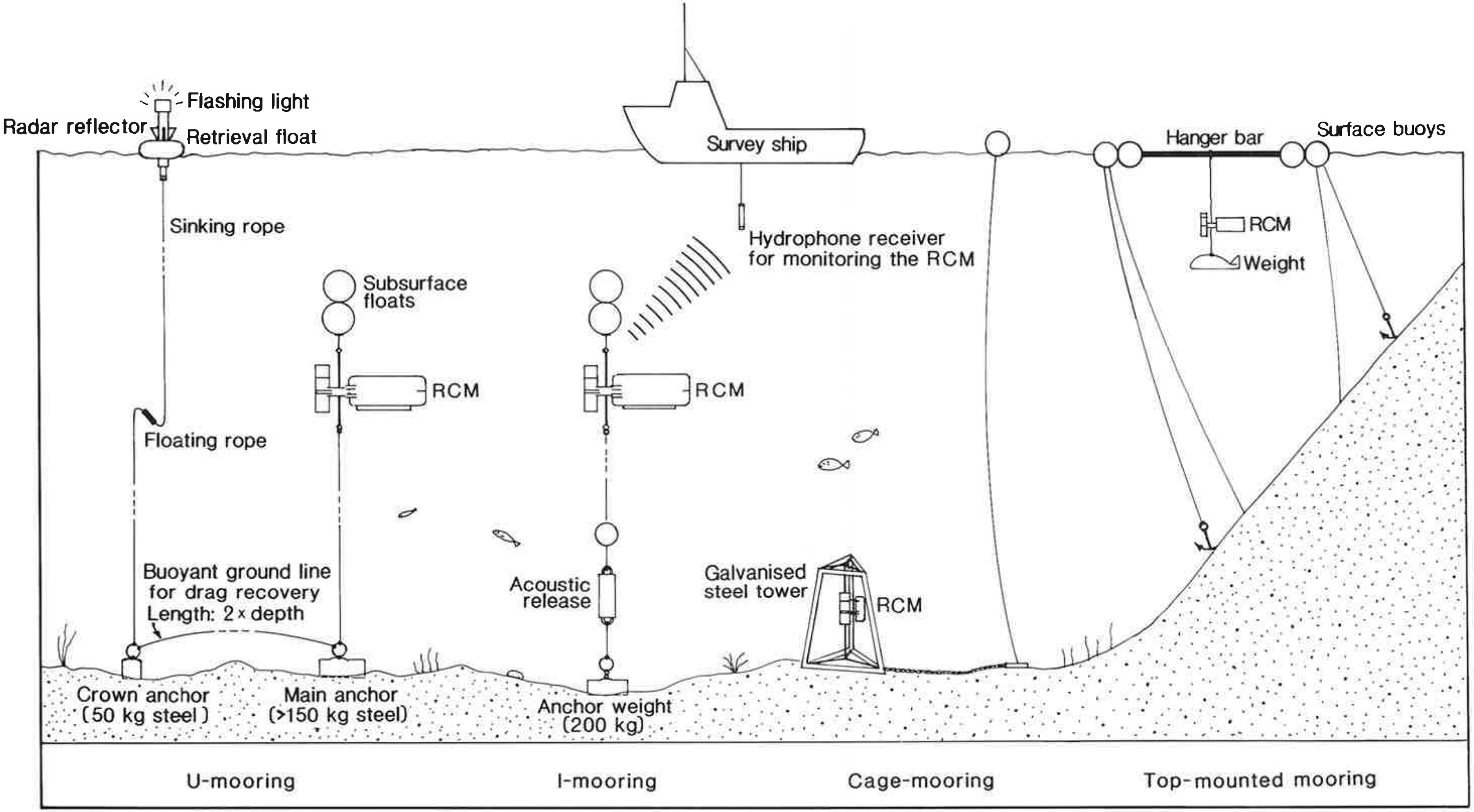

Figure 5. Methods of mooring current meters in shallow coastal waters.

For deep water deployments the I-mooring (Fig. 5) is most commonly used. The instrument can be recovered either by sending a signal from a ship-borne transmitter to trigger an acoustic release coupling, or by using a time release triggered after a predetermined time. The instrument is then carried to the surface by the buoyant force of the sub-surface buoys. These types of releases remove the need for precise positioning, but the success of a timed release does depend on good sea conditions in the recovery area. Malfunctions of both types of release components have been known to occur.

A rigid cage-mooring (Fig. 5) is a means of fixing a current meter close to the seabed where it will remain relatively undisturbed by wave-action or strong currents. The cage can also provide a support for other instruments such as wave or tide pressure sensors and cameras. The cage frame should be heavy enough to prevent tipping or sliding from the combined hydrodynamic drag of the current meter and the frame itself. No ferrous metals should be used in the frame if the current meter contains any form of magnetic compass or is of the electromagnetic type. Careful attention also needs to be given to potential corrosion problems from the use of dissimilar metals.

Top-mounted moorings (Fig. 5) are designed for use in strong tidal currents (e.g. estuaries) to overcome drag forces which can cause excessive axial tilt and result in incorrect speed readings. The meter is suspended from the surface by buoys moored in such a manner as to stabilise them in reversing tidal currents. It is held in a vertical position by a weight. Because the meter is suspended from the surface, this type of mooring is not suitable for use in the wave zone.

6.2 Sub-surface Buoyancy

The buoyancy required from the sub-surface buoys to stabilise current meters under strong tidal flows or oscillating wave motions can be determined from the horizontal drag forces on the mooring components and the net vertical buoyancy. The optimum buoy shape is determined by two requirements: maximum net positive buoyancy and a streamlined shape with low hydrodynamic drag. The sub-surface buoy must also have a collapse pressure which is significantly greater than the hydrostatic pressure exerted at the immersion depth. When a number of recording current meters are mounted on the same mooring line, several distributed sub-surface buoys should be used, preferably with one above each instrument.

The three important parameters which determine the sub-surface buoyancy required are the drag coefficients and projected frontal areas for each component of the mooring system, and the maximum current or wave-induced orbital velocity. A mooring system comprising one Aanderaa RCM4 with a standard Aanderaa spherical Viny float set (Fig. 5) is used as an example for computing the sub-surface buoyancy. A list of maximum drag coefficients (C_D) and projected frontal areas (A) of various shapes of components used in such a mooring system is given in Table 1. The drag coefficient is a function of the shape and the Reynolds Number (which in turn is a function of flow velocity and a length scale). Table 1 gives **maximum** values of C_D in the normal range of Reynolds Numbers expected in the field. This will result in a more conservative mooring design.

TABLE 1: Drag coefficients and projected frontal areas for components of a mooring system

Item	Drag Coefficient C_D	Projected Frontal Area (m^2)
RCM4	0.8	0.065
Viny buoy set**	0.5	0.192
Cylindrical shape	1.2	d x l
Spherical shape	0.5	$\pi d^2/4$
Rope/Wire	1.2	d x l

Key: d = Diameter, l = Length.
**Consists of two spherical buoys of 345 mm diameter joined together on a tie rod.

The other oceanographic parameter of importance when designing the net buoyancy required for a sub-surface mooring is the maximum likely current velocity. The maximum velocity for estuaries and tidal inlets can be obtained from existing data (e.g. hydrographic charts), or by measuring peak spring tide flows using a direct-reading current meter.

The maximum horizontal orbital velocity under a wave, U_z, at any level above the seabed can be calculated using the Airy linear wave equation:

$$U_z = \frac{\pi H \operatorname{Cosh}(kz)}{T \operatorname{Sinh}(kd)} \quad (1)$$

where

H = wave height (m)

T = wave period (sec)

d = total still water depth (m)

z = height of instrument above the seabed (m)

($z = 0$ at seabed and $z = d$ at surface)

$k = 2\pi/L$

L = wavelength (m)

At the seabed where $z = 0$, the term Cosh (kz) reduces to a value of 1.0.

To simplify the computation, three categories based on a dimensionless depth are normally specified when calculating the wave length L:

a Deep water where $d/L > 0.25$

$$L = L_o = T^2 \ (g/2\pi) = 1.56 \ T^2 \qquad (2)$$

b Transition depths where $0.04 < d/L < 0.25$

An approximation can be used (within 5%)

$$L = L_o[\tanh \ (2\pi d/L_o)]^{1/2} \qquad (3)$$

c Shallow water where $d/L < 0.04$

$$L = T(gd)^{1/2} \qquad (4)$$

In the shallow water case, the Airy linear theory rapidly breaks down because of non-linear effects. Most deployments, however, are normally in the first two categories.

The calculation of maximum wave orbital velocities for typical applications in coastal waters has been carried out using a computer program adapted from Pickrill and Currie (1983) and is listed in Appendix II. The cases covered are wave periods of 6, 8 and 10 seconds for two common deployment levels:

(i) where the current meter is at 1 m above the seabed, and

(ii) where the current meter is deployed at 0.4 times the still water depth above the seabed.

The range of depths and wave heights considered were 2-50 metres and 0.5-6 metres respectively. CERC (1984), Komar (1976) and Pickrill and Currie (1983) provide further details on computing orbital velocities for any situation not covered in Appendix II.

Preliminary site information (expected maximum current velocities and sea water densities) and the data in Table 1 can be used in Equation 5 to calculate the total horizontal drag force on the mooring system (Table 2) when applied separately to each component.

$$F_D = C_D(\rho U^2/2g)A \qquad (5)$$

where F_D = drag force (in kg)
C_D = coefficient of drag
ρ = density of water (kg/m³)
A = projected area normal to flow (m²)
U = current velocity (m/s)
(Note for drag force in Newtons, F_D is multiplied by g = 9.81 m/s^2).

The buoyancy of each component of a mooring system is determined by the Archimedes Principle, which states that any body, floating or immersed in a liquid, is acted upon by a buoyant force equal to the weight of the liquid displaced. Therefore the net buoyancy force (F_B) is

$$F_B = \rho.V - W_{air} \qquad (6)$$

where V = enclosed volume (m^3), W_{air} = weight of object in air (kg) and F_B is in kg.

TABLE 2: Drag forces (kg) for various components of an Aanderaa mooring at selected current velocities

	Velocity			
Component	0.5 m/s	1.0 m/s	2.0 m/s	2.5 m/s
RCM4 + 1 Viny buoy set	1.9	7.7	30.9	48.3
RCM4 + 1½ Viny buoy sets	2.6	10.2	40.9	64.0
RCM4 + 2 Viny buoy sets	3.2	12.7	51.0	79.7
12 mm rope/m	0.2	0.8	3.0	4.7
5 mm wire/m	0.0	0.3	1.3	2.0

Note: ρ = 1025 kg/m³

Velocities of around 1 m/s often occur with tidal flows in estuaries or when wave heights exceed 2.5 m in shallow coastal waters (less than 10 metres deep). For a mooring system consisting of 5 m of 12 mm rope, one Viny buoy set and one Aanderaa RCM4 in a velocity field of 1 m/s, the total horizontal drag force (F_D) is (Table 2):

F_D = 7.7 kg on the RCM4 meter and buoys + 5x0.8 kg on rope = 12 kg

Summation of the net buoyancy forces for each component of the mooring system: Viny buoy set (+41 kg buoyancy): Aanderaa RCM4 (-17.3 kg weight in water); and mooring rope (approximately -0.2 kg in water), results in a net positive buoyancy (F_B) of 23.5 kg. Combining the total horizontal drag force and the net vertical buoyancy leads to a resultant force as shown in Figure 6.

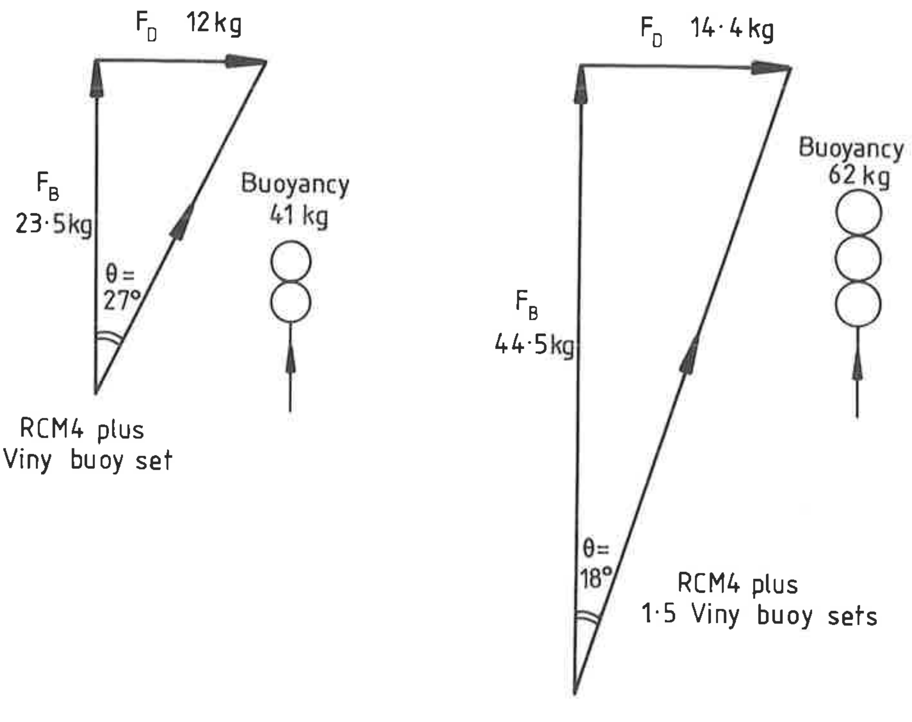

Figure 6. Resultant mooring force diagrams for a velocity of 1 m/s.

The approximate deviation angle θ of the mooring line from the vertical is obtained from

$$\tan \theta = F_D/F_B \qquad (6)$$

and for the above example is 27°. (In reality, the mooring line will adopt a catenary profile which will vary with the vertical velocity profile). Our worked example shows that even at low velocities (1 m/s) the gimbal housing of the Aanderaa RCM4, which can handle up to 27° deviation of the mooring line before the instrument tilts, is at its limit.

Adding a further single spherical Viny buoy with a net buoyancy of 21 kg increases the buoyancy to the equivalent of 1½ Viny sets. If a similar calculation is carried out using the extra buoyancy, the mooring line tilt would be 18°, well inside the maximum allowable 27° of axial tilt (see Figure 6). It is clear from this example that even at commonly encountered velocities in tidal inlets there is always the potential for significant axial tilt errors to occur, particularly with instruments without gimbal arrangements. Locating meters lower in the water column or increasing the net buoyancy to drag force ratio can overcome this problem, although with the latter approach, the law of diminishing returns applies as the price of more sub-surface buoyancy is an ever increasing drag force.

6.3 Anchor Weights

A clump anchor with adequate <u>submerged</u> weight is required to offset the buoyancy of the sub-surface buoys. A ratio of at least 3:1 should be maintained between anchor weight in water to net sub-surface buoyancy F_B. To achieve efficiency in handling, a high density material should be used to minimise the effect of the displaced water. To calculate the submerged weight of an object:

$$\text{Submerged weight} = \text{weight in air} \times [1 - (\rho/\rho_m)] \qquad (7)$$

where ρ_m = the density of the material is in kg/m^3 and ρ = seawater density (typically 1025 kg/m^3). Using densities for concrete (2400 kg/m^3) and iron (7900 kg/m^3), a 100 kg concrete anchor weighs only 57 kg in water compared with 87 kg for a 100 kg iron anchor.

In the presence of strong bottom currents or wave motions, smaller and denser anchors are more likely to bury themselves in the seabed, making the mooring more secure. We have found railway iron ideal as it is easy to handle, a good shape to stow in small boats and it tends to bury itself in highly mobile sediments. Large anchor weights can be assembled by bolting several lengths together. For coastal deployments, small boats are often used and therefore it is desirable to keep the anchor weight below 200 kg.

In high velocity tidal inlets, the security of a clump anchor can be enhanced by attaching Danforth anchor(s).

Crown anchors for a U-mooring, which only hold a slack-line to a surface buoy, normally have a much lower submerged weight than the main clump anchor. As a guide, minimum submerged weights of 130 kg and 50 kg for the main and crown anchors respectively have been found to be adequate in heavy seas for a single instrument deployment with an equivalent buoyancy of 1½ Viny buoy sets (net buoyancy of 45 kg).

6.4 Surface Buoys

Any surface buoy should be a yellow colour marked with a regulation light at night and have a radar reflector (Appendix I). Daylight identification of the buoy is helped considerably when it is marked with a Danbuoy with a flag on a 2-3 m high pole, similar to those fishermen use to mark longlines. This can be moored alongside the buoy if necessary. They are readily visible at some distance because the flag is silhouetted against the sky, above the surrounding wave peaks.

6.5 Mooring lines and connectors

For coastal deployments, 12 mm to 16 mm diameter polypropylene rope is recommended for lines to the meter from both the main clump anchor and sub-surface buoy. It will secure the mooring and minimise the transfer motion of the sub-surface buoys. Polypropylene rope manufactured specifically for set lines and nets is recommended as it is easy to handle and is reasonably abrasion resistant. For wire lines, ensure that high grade galvanised steel is used, otherwise rapid corrosion will occur. A nylon impregnated galvanised wire is also now available. Wire diameters of 5 to 7 mm are normally used for shallow water deployments.

Careful attention to connections is particularly important as they create weak links in any mooring system. If shackles are used the pins must be wired up with seizing wire made of a non-corroding metal or cotter pins used for bolt shackles. Bowlines should be used in rope connections and the end tied off with two half hitches. Where excessive mooring motion is expected an anchor bend knot (fisherman's bend) can be used to minimise chaffing. Eye thimbles should be used where possible as these reduce chaffing to rope. All loose ends of rope should be taped down with insulation tape to prevent fraying. Splicing can be used but requires some skill and from our own experience it is not necessary. Beware of mixing ropes of different types and diameters as this usually leads to ropes becoming untwined or knots untied. Ropes to the surface buoy should be long enough to allow for tide and wave lift and have swivels attached to lessen the risk of rope strands unravelling. Surface buoys are frequently pilfered, so for greater security a suitable length of chain could be used over the top few metres of the crown anchor line. Avoid contact between dissimilar metals when using connectors as electrolysis can cause severe corrosion problems with pins and shackles. Further details and practical procedures on mooring line connectors are given in Grace (1978) and Morris (1983).

CHAPTER 7

DEPLOYMENT AND RETRIEVAL

7.1 Pre-deployment checks

It is necessary to carry out a bench check of all meters before deployment in the field. This consists of a series of visual and mechanical checks to determine if all sensors, circuits etc. are working and to ensure that sufficient magnetic tape or memory is available to cover the deployment period at the specified sampling rate. It may be that the same current meter is to be moored more than once during an oceanographic study. Even though the data storage capacity of the meter may be large enough to accommodate the combined records from several moorings, the memory should be downloaded or the tape removed and replaced by a fresh de-magnetized magnetic tape before each new mooring. This reduces the possibility of confusion but even more importantly it protects each record from loss or damage. It is a false economy to conserve magnetic tape when considerable time, effort and expense are invested in a successful mooring. A new battery should also be installed for the same reason and the sacrificial anodes checked. The technical manual for given current meter usually covers requirements for bench checks.

7.2 Deployment

It is essential to use an equipment checklist. An example is given in Appendix III.

Each meter must be switched on, preferably well before the deployment and synchronised to the standard local time. For ease of data processing, the meter should be synchronised so that a reading always occurs on the hour, (e.g. for a 10 minute sampling interval, data is recorded at 1200, 1210, 1220 hrs).

The gimbal/vane arrangement for rotor-vane meters can be fully assembled before boarding the vessel but the meter should be kept in its transit container until required. The O rings which seal removable sections of any current meter should be checked, cleaned with a small amount of methylated spirits and lightly coated with silicone grease before the parts are screwed tight (but not overtight). A rubber band is placed around Savonius rotors to prevent them spinning in the wind and causing excessive wear on bearings. In areas where bio-fouling is severe, meters can be smeared with silicone grease to retard marine growth. However no grease should cover external sensors including the rotor. Antifouling paint can be applied where necessary, but again, not near the sensors.

On board all lines should be laid out with anchors and buoys. Typically a davit on board can be used to set out the components for a U-mooring system, (Figure 7).

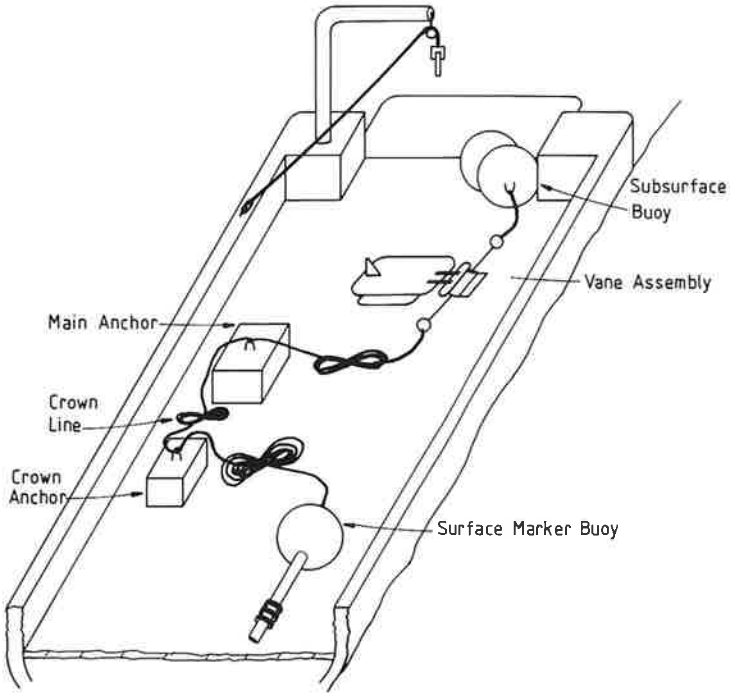

Figure 7. A current meter U-mooring system assembled on deck prior to deployment.

The U-mooring system is normally deployed over the stern in the following manner:

- Vessel held in desired position to shoot position fixes and determine water depth from echo sounder. Deploy:
  - Sub-surface buoys and current meter.
  - Main clump anchor
- Drift downstream or motor into the current playing out:
  - Ground line.

- Crown anchor and crown line
- Surface buoy.

A skilled helmsman is required to hold the vessel on position while the mooring system is layed out over the stern. Some instruments can be easily installed by divers once the mooring system has been laid out. This will help to prevent damage to the instrument.

Experience has proved it necessary to have divers check the mooring system after deployment. The divers as a matter of course should lay the system out on the seabed in an orderly fashion. This ensures that the mooring lines do not entangle the instrument or vane assembly and minimises potential abrasion areas around the anchors. Times for each event (meter in water, anchor on bottom) and other relevant information such as current and wind direction, wave height, position fixes and actual water depth should be recorded in the deployment log.

7.3 Positioning

Accurate positioning of meters is necessary to:

(i) establish the mooring site,
(ii) enable future deployments to be made at the same site,
(iii) comply with the Ministry of Transport notification and
(iv) aid recovery of current meter.

The latter is particularly important if surface buoys are lost and the mooring is to be relocated in low visibility waters by SCUBA divers.

The methods of position fixing are compared below.

Method	Comment
Compass	Unreliable, take several bearings to check closure
Range finder	Useful over short distances, take several fixes to check
Visual or photographic record of land marks	Can be quite accurate if land marks are well chosen. Excellent back-up method
Sextant	Versatile instrument, choose shore marker stations carefully, accuracy ± 10 m/km range

Theodolite bi/trisection	Good close to shore, choose shore marker positions carefully, accuracy < 1 m/km range
Electronic distance meter (EDM)	Useful up to about 5 km range depends on type, accuracy a few cm/km range
Trisponder systems	Good for greater distances offshore, accuracy a few cm/km range

Regardless of the method used, it is wise to take more position fixes than the minimum and have a back-up method available.

Before deployment of the mooring system the desired position can be pre-marked with a temporary buoyed line.

7.4 Maintenance During the Deployment

Regular field trips are necessary to clean and check the performance of the meters and the integrity of the mooring system. From our experience, a two week period should be the maximum interval between site visits in New Zealand's northern temperate waters because bio-fouling can cause a deterioration in sensor performance, particularly instruments with external sensors (Figure 8).

As each site will be slightly different, initial checks could be carried out at even shorter intervals and the interval adjusted as necessary depending on a number of factors including the current meter type, current velocities, salinity, season and the initial growth rate of bio-fouling.

During these field trips salinity, temperature, and current speed/direction can be measured using direct-reading field meters. Divers should note in the deployment log the condition of the meter, the extent of bio-fouling and anything unusual, as this information is later useful to check the recorded data during the processing. A note of the sea state should be made as this may also influence direct-reading current measurements.

Cleaning consists of de-fouling the meter, vane and sub-surface buoys to minimise drag. A small bottle brush is useful for cleaning sensors, especially rotors and conductivity cells which are vulnerable to fouling. Any tangling of mooring lines and anchors should be straightened out as much as possible to aid

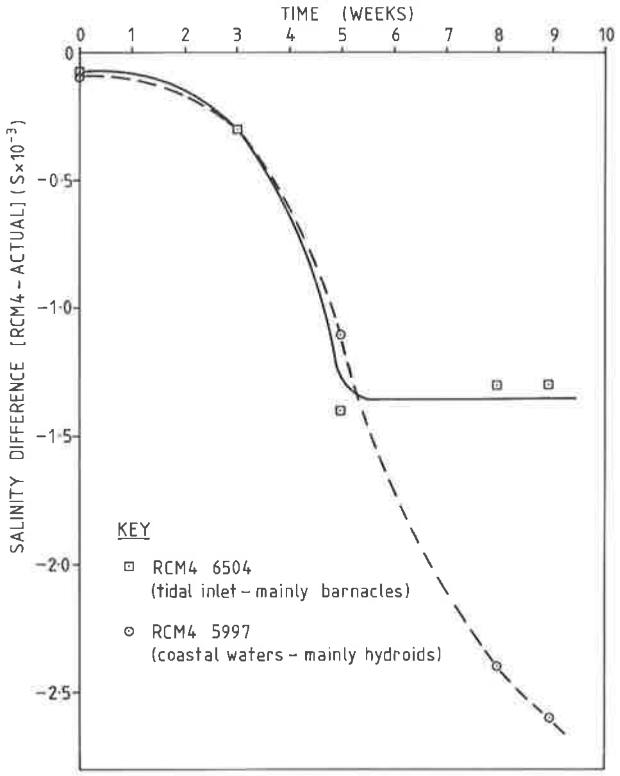

Figure 8. The effect of bio-fouling on the performance of the conductivity sensor on an Aanderaa RCM4 during October-November on NE coast of North Island.

later recovery. For some current meters (e.g. Aanderaa) a hydrophone/printer can also be used to determine if the meter is working by recording the output as it is transmitted by the meter.

Positioning of meters should be checked and any drift of the mooring system noted. For nonvector-averaging meters deployed in the wave zone it is essential that regular wave height measurements or observations are made throughout the deployment period. The NZ Meteorological Service has several wave observation sites around the country. Predicted wave heights are also given in coastal marine weather forecasts. This wave information will greatly assist the interpretation of the velocity data.

7.5 Recovery

When the mooring system has been located (either by the surface buoy, position fixing or dragging), the current meter is normally recovered first. For U or I mooring systems, the mooring line between the meter and the main clump anchor is severed, allowing the meter (and vane assembly if present) to rise to the surface under the buoyancy of the sub-surface buoys. Detachable instruments, such as the Aanderaa RCM4 meter, should previously have been disconnected from the gimbal/vane assembly by divers to prevent any damage to the meter. If necessary the rest of the mooring (including anchors) can also be lifted separately to the surface using lift bags. If a larger boat with a derrick is available, the complete mooring system can be recovered in the reverse order used during the initial deployment. Where acoustic or timed releases are used, recovery from the surface is all that is required once meters have been released. Care is needed to avoid positioning the retrieving vessel immediately above the mooring as this is liable to damage the meters. For a cage mooring, a larger boat with a derrick is required for the recovery operation.

The instrument and moorings should be cleaned as soon as possible after retrieval as bio-fouling is easiest to remove at this stage. Water blasting is an excellent way to carry out this messy task except near sensors. Scrubbing brush and plastic scraper are also useful. The instrument housing should finally be soaked in fresh water.

Any unusual aspects of the meter (e.g. corrosion, fouled rotor, battery condition, tape run out, time fault) should be noted to aid subsequent data processing and instrument servicing.

7.6 Lost and Found

Mooring current meters in the coastal zone is a risky business because, compared to the deep ocean deployments, the mooring is normally marked by a surface buoy and located in an area used extensively by commercial and recreational boats. Moorings can be lost through theft, vandalism, damage to the surface buoy, trawler sweeps or severe storms that may break mooring lines or move the mooring system <u>en masse</u>. The chance of loss can be minimised by employing some of the features described earlier in this report and summarised here.

(i) Follow the MOT "Notification" procedures;

(ii) Have contingency plans available for mooring recovery in the event of a loss. Favourable weather conditions in the area may not hold for long;

(iii) Design moorings thoroughly and check them regularly;

(iv) Position the mooring accurately, attach an acoustic locator beacon and note orientation of ground line to aid diver or drag recovery;

(v) Mark the surface and sub-surface parts of the mooring with a contact name, address and phone number. If possible state the mooring's function to lessen the chance of buoys being cut loose from valuable instrument packages (or what to a fisherman may look like an undetonated military device!);

(vi) When available, use an acoustic release;

(vii) Insure the instrument.

If the mooring does go missing and the search area is large trawlers have been used successfully to cut the instruments free from the anchors or net the entire mooring system. If the meter is not found, try advertising in the local area. Instruments have been known to turn up anonymously on a wharf somewhere.

CHAPTER 8

DATA PROCESSING

8.1 Decoding Stored Data

8.1.1 Magnetic Tape

The recording and translation format for most current meters using magnetic tape storage is similar to that for Aanderaa instruments. Magnetic or cassette tapes ready for processing can be labelled with the instrument and deployment number in the form 5997/6 (where this would be the sixth deployment of meter number 5997). The tape is then sent to the nearest tape translation agency accompanied by a tape reading order with deployment details and relevant information on the tape dataset. Magnetic tape should be shipped on the lower tape spool as wound up by the instrument.

8.1.2 Solid state memory

Recent developments in solid-state data storage (e.g. the Inter-Ocean S4 current meter) require a RS 232-C standard interface which enables the raw data to be streamed directly through to a PC or micro-computer for processing and conversion to engineering units, using software supplied by the manufacturer. It goes without saying that the correct baud rate is needed for the data transfer.

8.1.3 Processing information

The information required to process the current meter data is given below:

- Meter serial no./deployment no;
- Instrument type (e.g. RCM4 or RCM4S for shrouded wave rotor);
- Sampling and recording intervals (minutes);
- Rotor counter setting or averaging sequence;
- Start time and date (NZST);
- Time and date for first measurement in water (NZST);
- Time and date taken out of water (NZST);
- End time and date (NZST);
- Local magnetic variation;
- Location;
- Water depth (Chart datum);

- Height above seabed;
- Additional sensors used;
- Calibration coefficients for sensors;
- Remarks (e.g. tape or memory run out before retrieval, rotor damage or premature battery failure and wave activity.)

Note that the compasses in most current meters record in oceanographic convention which is the direction toward which the current is flowing (the opposite of wind records). During the processing stage, the local magnetic variation angle must be added to convert directions to true north.

Raw data from an instrument is normally processed and converted into engineering or physical units. To do this, the calibration equations for each sensor are required as these relate the raw readings to the corresponding physical quantity. A set of calibration coefficients is supplied with each individual meter.

8.2 Record Editing

No matter how sophisticated the analysis methods are, the results will be only as good as the input data. Regardless of how the data were obtained and entered into a computer file, it is essential that a thorough check for errors be made before any analysis begins. This error-checking procedure may involve manual observation of computer listings, calculation of summary statistics (e.g. minimum, maximum, standard deviation) and computer plotting.

(i) Beginning and end of data record

Accurate time keeping is of paramount importance for current velocity data, particularly where tidal currents are significant and it may be necessary to compute phases for tidal constituents. Information from the deployment and recovery logs (e.g. when the meter entered and left the water) should provide supplementary time checks on the records, and can frequently resolve uncertainties caused by an error in either the initial or final time check. Particular care is required during the period of NZ Daylight Time when records should preferably be made according to NZ Standard Time.

The times from the logs can be used to exclude launching and recovery transients at the start and finish of the record, when the meter was not on station at its specified mooring depth. The salinity data processed from the conductivity sensor is also a useful check for determining when the meter was submerged as it will have settled down to give consistent and sensible salinity values.

(ii) Obvious errors

Obvious errors in the processed data need to be corrected. In most cases plotting the data as a time series will reveal these errors (Figure 9) e.g. uncharacteristic spikes or speeds constantly registering the threshold speed value. The latter usually indicates a stalled rotor due to a blockage or severe bio-fouling. An uncharacteristic fall-off in speed or step changes in salinity may also indicate problems with the encoder or sensor.

If only a few values are involved these errors can be subsequently corrected or a portion of the record erased and the edited time series replotted. Generally spikes or glitches in the processed data from current meters are limited to isolated values which can be replaced by linearly interpolated results using the adjacent data. Bio-fouling and encoder problems generally manifest themselves near the end of a deployment and in these cases the dataset should be truncated to include only the reliable data.

Identification of periods when significant wave activity affected the performance of nonvector-averaging meters should be carried out by considering the set of wave height observations or estimates compiled throughout the deployment period. The effects of wave activity are indicated in the time series plot of speed by high peaks (or plateaus for longer storm periods) and higher slack tide speeds (where the tidal signal is dominant) relative to the adjacent seemingly normal values (Figure 9). A cross-check with the wave observations should be made to confirm this, as significant wind-driven currents may also have been present. High frequency small amplitude oscillations are often superimposed on the peaks or plateaus by random wave motions.

Velocity data severely affected by wave motions during large storms is virtually useless apart from indicating possible "current" drift directions during the storm. Velocity data recorded during moderate storms can be corrected for engineering applications by subtracting a wave correction factor (Taranaki Catchment Commission, 1985).

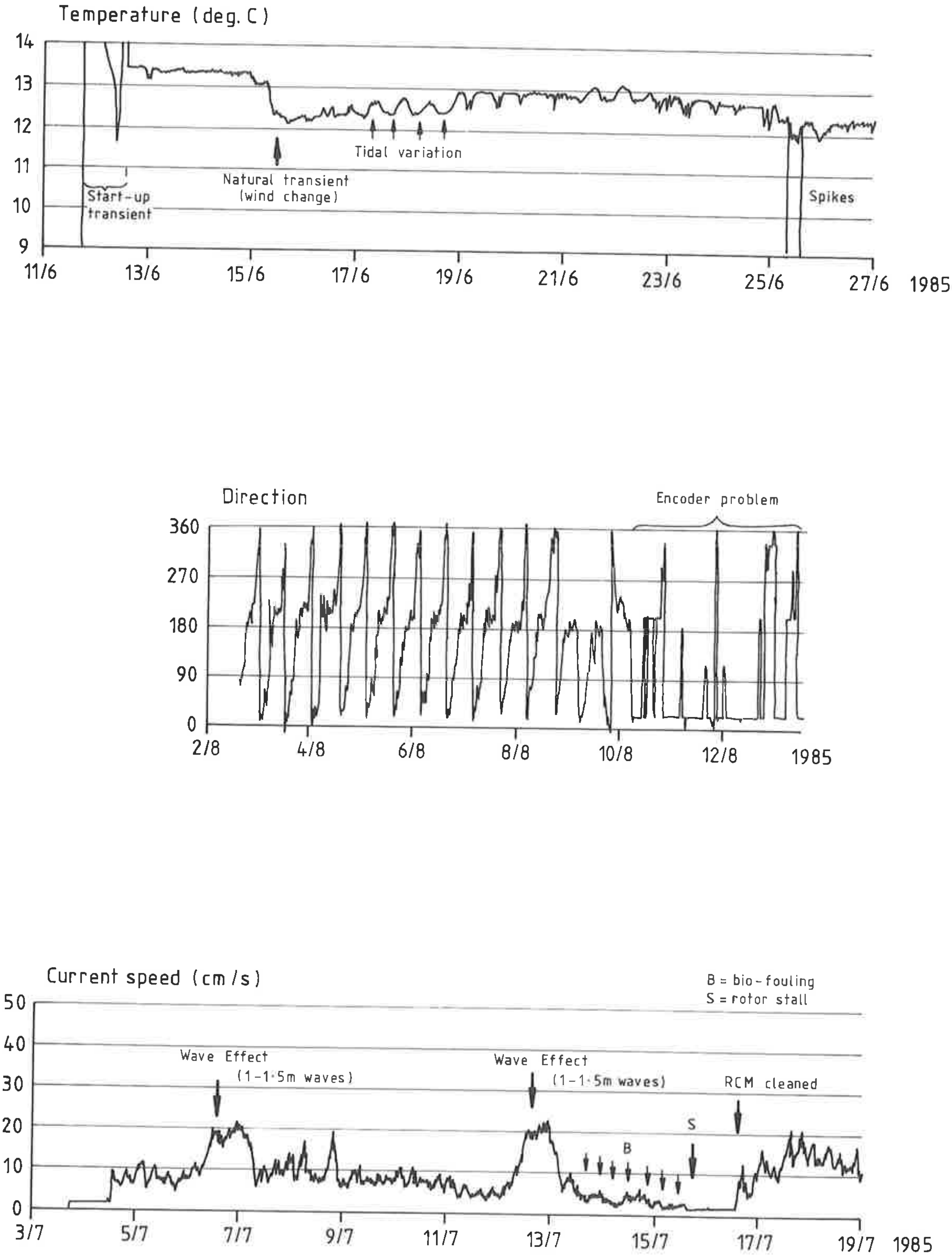

Figure 9. Examples of various features of a data record from an Aanderaa RCM4 which are relevant to the record editing phase.

8.3 Presentation and Analysis of Data

Any investigator using field instrumentation capable of measuring and recording thousands of sample values is faced with the problem of how to present and analyse the raw data so that it can be easily understood by others. With the advent of computer plotting systems, graphics equipment are an integral part of the oceanographer's instrumentation.

The choice of data to be plotted and the format in which it is presented will depend largely on the purpose of the investigation. The oceanography texts in the References (e.g. Beer (1983), Pickard and Emery (1982) and Grace (1978)) should be consulted for additional details.

Current velocity, being a vector quantity, is more difficult to present because it must be described by two quantities (i.e. speed and direction), in contrast with scalar quantities such as temperature, water level and salinity. There are several formats in which the data time series can be displayed in two-dimensional plots:

(i) Time series plots of current speed and direction (e.g. Fig. 9) are a useful start but can be difficult to interpret in some situations. Alternatively, time series can be plotted as two rectangular velocity components either for east-west and north-south or alongshore and cross-shore directions (Figure 10). Alternatively the components can be resolved along major and minor principal axes, where the former is the orientation along which the standard deviation of the resolved speed time series is maximised. Generally the major principal axis is aligned approximately parallel to the shoreline or localised bathymetric contours except in the region of tidal entrances.

(ii) Current vector 'stick' plots depict the average hourly current vector as a line originating from the time axis whose magnitude and direction mimic that of the observation (Figure 11). A time series is then represented by a series of 'sticks' drawn in succession from the time axis at their time of observation. Unacceptable speed values should appear as blanks.

(iii) Current roses depict the proportion of observations for various sectors of the compass rose (Figure 12). Various forms of current roses are given in Williams (1985). In some forms, each sector can also be subdivided into segments indicating the frequency of occurrence for various speed ranges. Current roses are lumped statistics which display the correlation between velocity and direction. They can be extended to show the correlation between direction and cumulative current run (velocity x duration) (Kibblewhite, 1982).

(iv) Progressive vector diagrams are suitably scaled current vectors (usually hourly average values) plotted so that the tail of each vector rests on the head of the preceding vector (Figure 13). Plotted positions correspond to the virtual horizontal displacement of the water that would occur <u>if</u> the motion in the entire neighbouring area around the current meter was the same as at the meter site. Unacceptable speed data (e.g. elevated values during active wave periods) can be arbitrarily replaced by the scalar average speed to produce a realistic vector plot (see Kibblewhite, 1982).

(v) Scatter diagrams show the distribution of current vectors on a north/east horizontal plane. The points are plotted from the north/south and east/west velocity components. The patterns which emerge in scatter diagrams (Figure 14) often indicate the relative importance of the semi-diurnal tidal current (elliptical shape) or a longshore current (large lobe on one side). This format however masks the time variation. If a significant 'hole' appears in the centre of a scatter plot it usually implies that the record has been affected by elevated speeds caused by wave activity.

(vi) Cumulative current speed distribution plots are particularly useful for ocean outfall investigations (Figure 15). The plots display the frequency of occurrence of speeds <u>below</u> a given current speed along the abscissa. This information could also be plotted as a log-normal distribution. The median speed can be readily obtained from the 50% frequency ordinate. Unacceptably high speeds during periods of wave activity should be left out of the frequency analysis or corrected using an empirical wave correction factor.

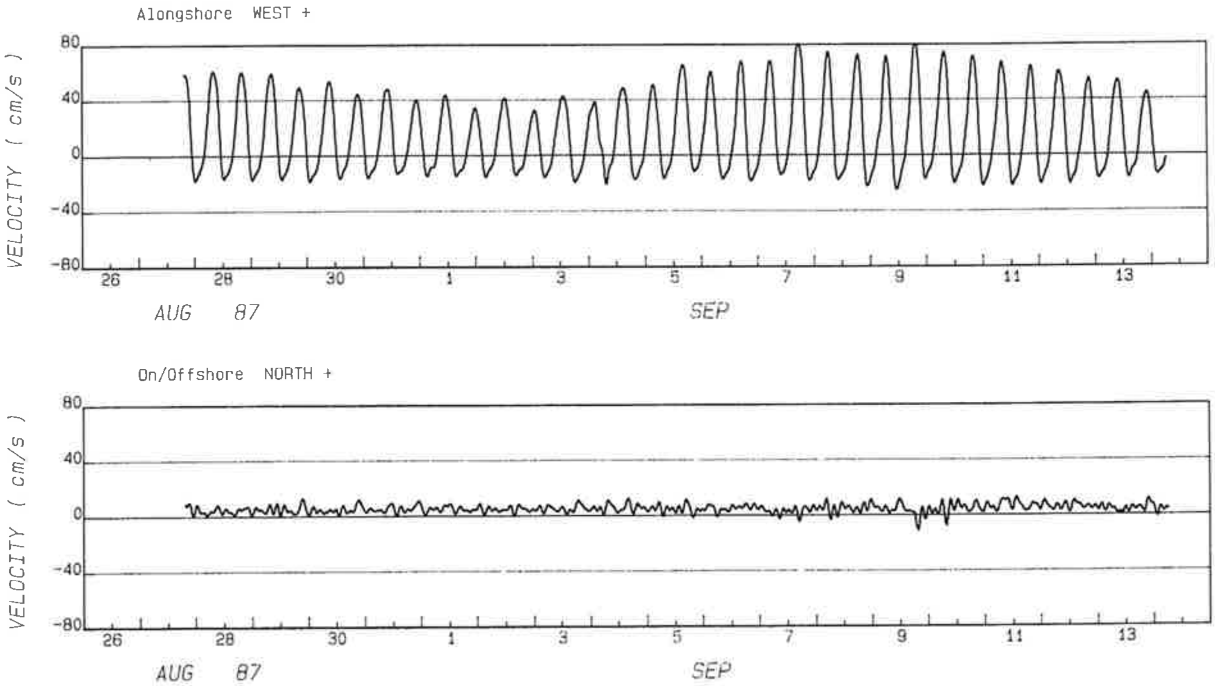

Figure 10. Time series plots of current components.

(a) Longshore component
(b) On/Offshore component

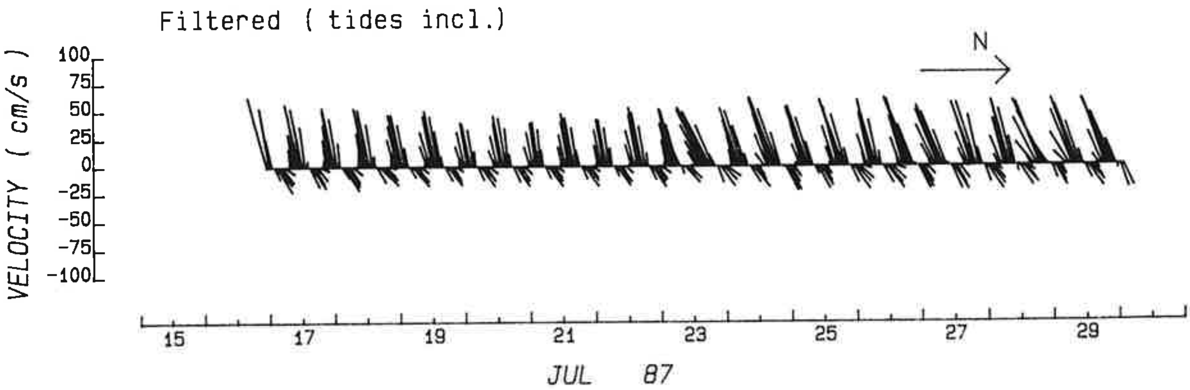

Figure 11. Current vector stick plot.

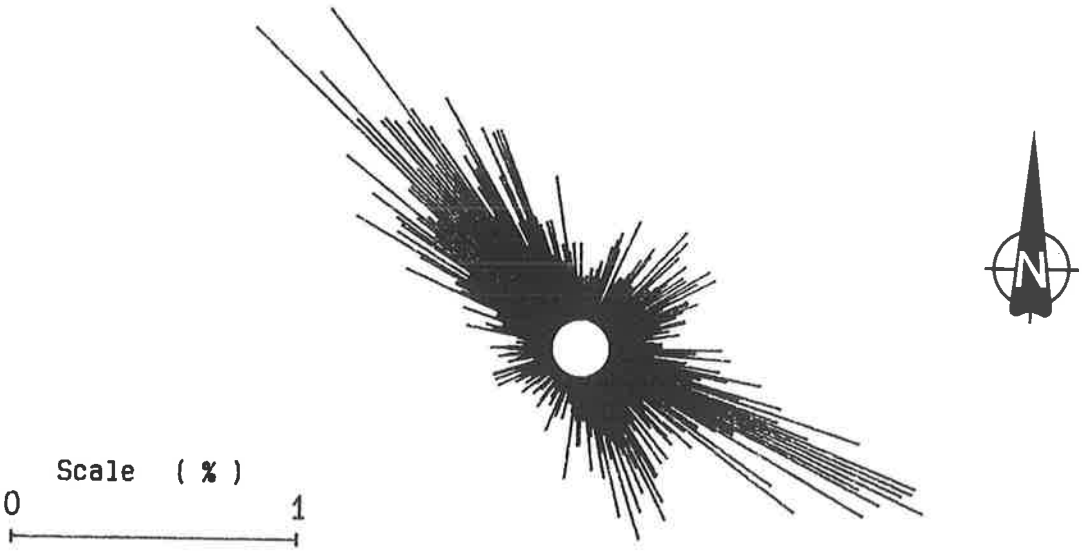

Figure 12. Current rose at 1° intervals with directions in oceanographic convection.

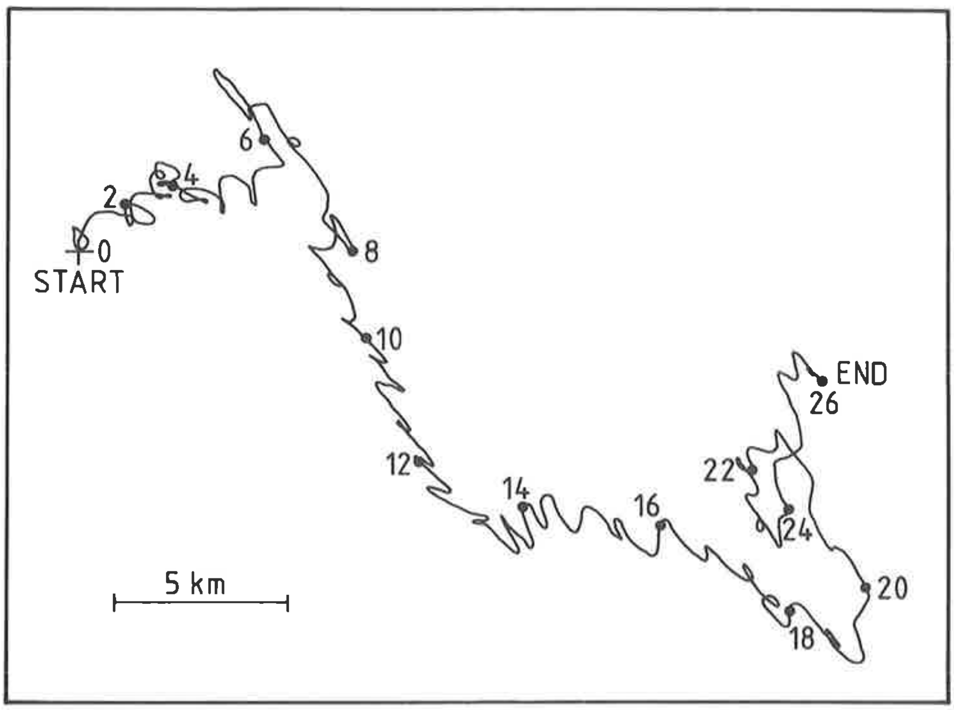

Figure 13. Progressive vector diagram marked at 2 day intervals.

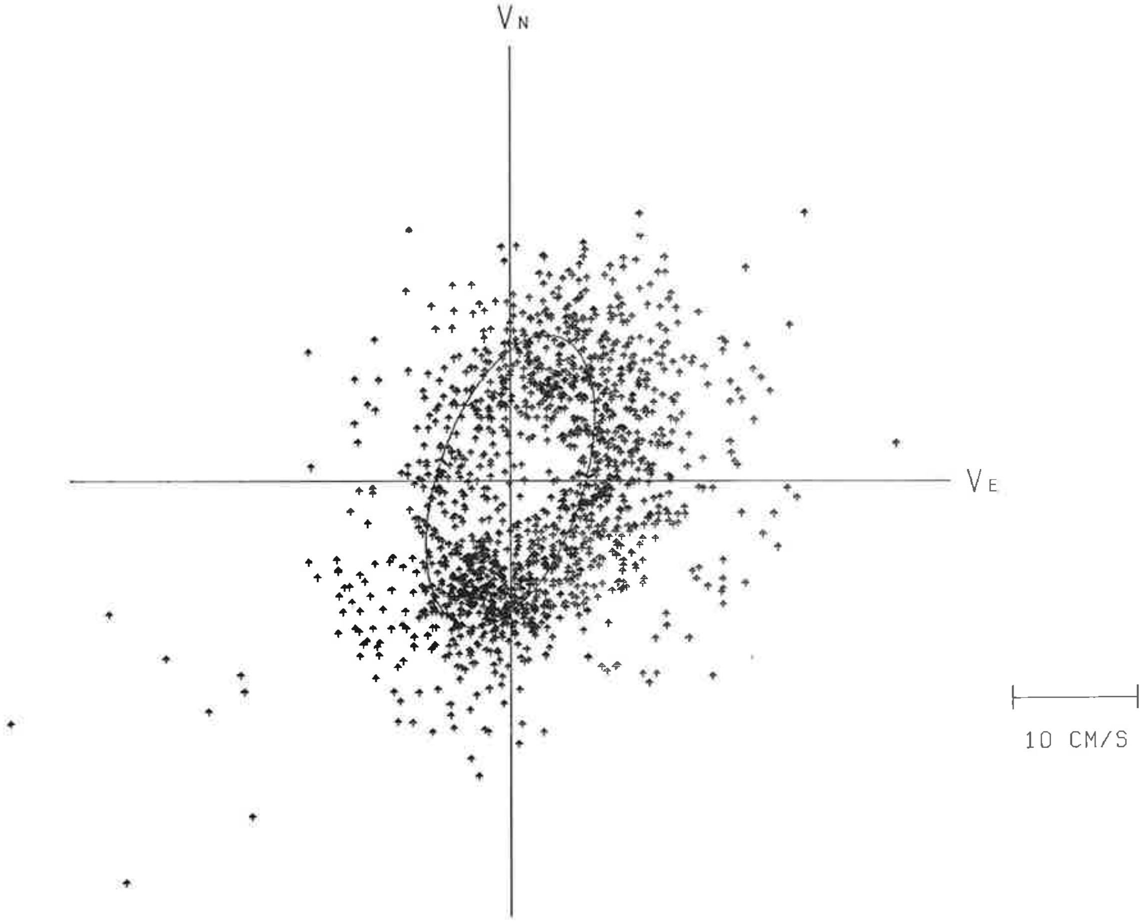

Figure 14. Scatter diagram with the M2 tidal ellipse superimposed on the data.

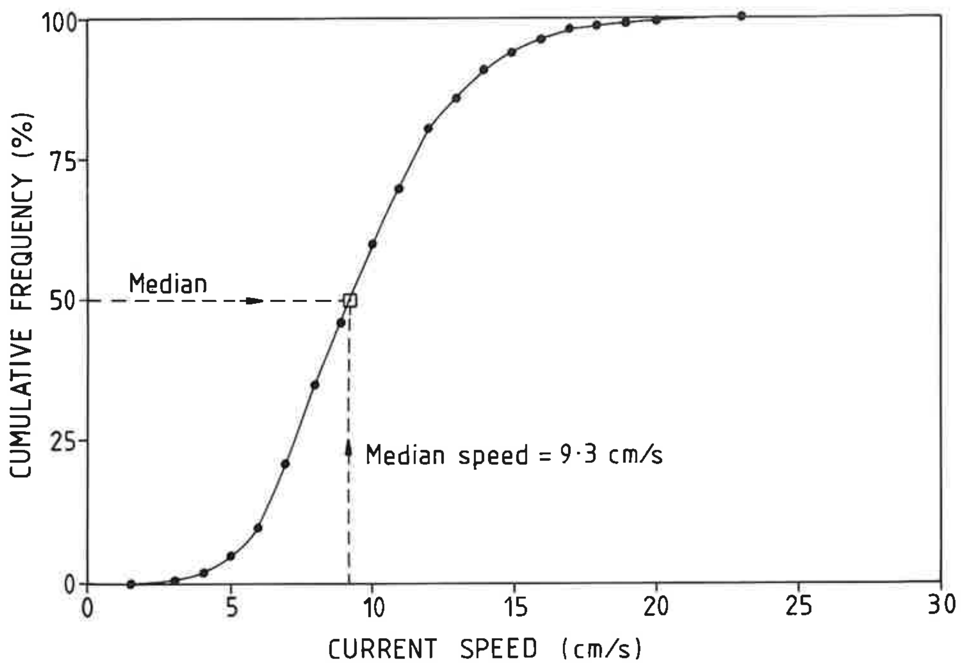

Figure 15. Cumulative speed distribution plot.

After plotting the raw data, the data is usually subject to further processing, which can be broadly described as time series analysis. Time series analysis forms another branch of statistics with its own techniques and vocabulary. The primary objective of any analysis is to find predictable components in the data i.e. determining the 'structure' of the data. The key problem here is to find the most significant components, thereby clarifying the role of tides, inertial oscillations, shelf waves and meteorological forcing on the overall hydrodynamics of the region. The main techniques and analyses that are commonly applied to current meter data are briefly listed below:

(i) Digital filtering. This is a technique to remove the contributions to the time series over a specified band of frequencies. For instance, a low pass filter can be used to remove high frequency noise (e.g. waves). Alternatively all currents in the tidal frequency bands can be screened out to investigate long period residual currents.

(ii) Spectral analysis. This uses the Fast Fourier Transform procedure to fit a series of sine curves of different frequencies (increasing at a constant increment) and phases to reproduce the time series. A strong periodicity in the data (e.g. tidal components), will be represented by a peak in the spectrum. The ordinate (the spectral density) is a measure of the current energy present in each frequency band.

(iii) Harmonic analysis. The Fourier frequencies at constant increments do not often fall exactly on the frequencies of individual tidal constituents in a spectral analysis and therefore a harmonic analysis, which is based on a least squares fit for specified tidal frequencies, can be carried out. The object of a harmonic analysis is to secure the amplitudes, Greenwich phase lags and orientation of the tidal current ellipses for each major tidal constituent.

Further details of various methods of analysis can be found in Godin (1972), Dronkers (1964), Jenkins and Watts (1968) and Hamming (1977).

8.4 Storage of Data

The high cost of obtaining a current meter record means that special attention should be directed at secure storage.

The original magnetic tape records should be stored in containers away from the influence of strong magnetic fields and excessive heat. Where possible, back-up copies of the edited dataset should be stored on a disk or magnetic tape medium in a secure computer system. It is also worthwhile periodically to collate basic details, statistics and plots from recent deployments in a readily referenced format.

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APPENDIX I

MINISTRY OF TRANSPORT SPECIFICATIONS FOR MARKING

(From "System of Buoyage and Beaconage for New Zealand - 1985", Marine Division, Ministry of Transport)

6. MARKING OF OCEANOGRAPHIC STATIONS

6.1. Ocean Data Acquisition Systems (ODAS)

At the present time, considerable expansion is taking place in the science of oceanography which will in the long term confer many benefits on the mariner and other users of the oceans. Two organisations (the World Meteorological Organisation and the Intergovernmental Oceanographic Commission) foresee, in the future, a network of buoy and ship stations throughout the world's oceans collecting and reporting oceanographic data.

6.2. The ODAS (Ocean Data Acquisition Systems) includes a large range of collecting devices from weather ships to plastic envelopes and drift bottles. Those of the greatest concern to the mariner are instrumented buoys systems. These systems may be expected to become more numerous each year.

These buoy systems vary considerably in size and are divided into two categories—moored and free floating. As far as possible the position of the moored buoys will always be widely promulgated and if considered to be of a permanent enough nature, will be charted. The recommendations for the markings of ODAS buoys are as follows:

6.2.1. Standard colour—yellow.

6.2.2. Flashing identification lights clearly distinct from those used in navigational buoys and other aids to navigation.

Colour—yellow, visible all round the horizon with a group flash 5 every 20 seconds (the flash rate not to exceed 30 per minute) and where practicable have a nominal range of at least 5 miles.

6.2.3. A satisfactory radar reflector should be fitted to give a radar response at a distance of at least 2 miles unless the buoy is of such size and shape as to be a good radar target.

6.3. These ODAS buoys may be met with in unexpected areas, often in deep water where navigation buoys would not be found. The mariner's first reaction may be that the buoy is lost and adrift but NO ATTEMPT SHOULD BE MADE AT RECOVERY unless it is clear that the buoy is of the moored type and is adrift or has been reported as adrift.

IMPORTANT—Valuable instruments are often suspended beneath these buoy systems or attached to mooring lines; cases have occurred of the mooring being cut close beneath the buoy by unauthorised salvors, with the loss of the most valuable part of the system.

6.4. Mariners are requested to report the positions of these systems to the Director, Marine Division, Ministry of Transport, Wellington, when encountered, together if possible with their identity code numbers which should be prominently displayed.

APPENDIX II

MAXIMUM WAVE ORBITAL VELOCITIES

[Output from a FORTRAN Program adapted from Pickrill and Currie (1983)]

Parameters

* Reference heights - 1 m and 0.4 times the depth above the seafloor.

* Wave periods - 6, 8, 10 seconds.

For each table the following ranges are used:

Wave heights - 0.5 m to 6.0 m in increments of 0.5 m.

Water depths - 2 m to 50 m in increments of 1 m.

Notes: (i) if all the orbital velocities at a specified depth are <5 cm/s, the table is truncated;

(ii) a value of -0.1 indicates a wave form exists but the theory used is not appropriate.

WAVE GENERATED ORBITAL VELOCITIES (CM/SEC) FOR WAVE PERIOD OF 6.0 SECONDS AT A HEIGHT 1.0 M ABOVE SEABED

WAVE HT M DEPTH M	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
2.00	54.9	192.8	-0.1	-	-	-	-	-	-	-	-	-
3.00	42.7	85.5	185.5	272.8	-	-	-	-	-	-	-	-
4.00	35.6	71.2	130.8	185.1	244.8	309.7	-	-	-	-	-	-
5.00	30.5	61.1	91.6	143.1	185.5	230.4	278.0	-	-	-	-	-
6.00	26.6	53.3	79.9	117.9	150.9	185.3	221.2	258.4	-	-	-	-
7.00	23.5	47.0	70.4	93.9	127.5	155.5	184.2	213.8	244.2	-	-	-
8.00	20.8	41.7	62.5	83.3	110.2	133.7	157.7	182.1	207.1	232.5	-	-
9.00	18.6	37.1	55.7	74.2	92.8	116.7	137.2	157.9	179.0	200.4	222.1	-
10.00	16.6	33.2	49.7	66.3	82.9	102.8	120.6	138.5	156.7	175.0	193.5	212.2
11.00	14.8	29.7	44.5	59.3	74.2	91.1	106.7	122.4	138.2	154.2	170.3	186.4
12.00	13.3	26.6	39.9	53.2	66.4	81.1	94.9	108.7	122.6	136.6	150.7	164.8
13.00	11.9	23.8	35.7	47.7	59.6	71.5	84.6	96.8	109.2	121.5	133.9	146.4
14.00	10.7	21.4	32.1	42.7	53.4	64.1	75.5	86.5	97.4	108.4	119.4	130.4
15.00	9.6	19.2	28.7	38.3	47.9	57.5	67.6	77.3	87.0	96.8	106.6	116.4
16.00	8.6	17.2	25.8	34.4	43.0	51.6	60.5	69.2	77.9	86.6	95.3	104.0
17.00	7.7	15.4	23.1	30.8	38.5	46.2	54.1	61.9	69.7	77.5	85.3	93.1
18.00	6.9	13.8	20.7	27.6	34.5	41.5	48.5	55.4	62.4	69.4	76.3	83.3
19.00	6.2	12.4	18.6	24.8	31.0	37.2	43.4	49.7	55.9	62.1	68.3	74.6
20.00	5.6	11.1	16.7	22.2	27.8	33.3	38.9	44.5	50.0	55.6	61.2	66.8
21.00	5.0	9.9	14.9	19.9	24.9	29.8	34.9	39.8	44.8	49.8	54.8	59.8
22.00	4.5	8.9	13.4	17.8	22.3	26.7	31.2	35.7	40.1	44.6	49.1	53.5
23.00	4.0	8.0	12.0	16.0	20.0	23.9	27.9	31.9	35.9	39.9	43.9	47.9
24.00	3.6	7.1	10.7	14.3	17.9	21.4	25.0	28.6	32.2	35.8	39.3	42.9
25.00	3.2	6.4	9.6	12.8	16.0	19.2	22.4	25.6	28.8	32.0	35.2	38.4
26.00	2.9	5.7	8.6	11.5	14.3	17.2	20.1	22.9	25.8	28.6	31.5	34.4
27.00	2.6	5.1	7.7	10.3	12.8	15.4	17.9	20.5	23.1	25.6	28.2	30.8
28.00	2.3	4.6	6.9	9.2	11.5	13.8	16.1	18.4	20.6	22.9	25.2	27.5
29.00	2.1	4.1	6.2	8.3	10.3	12.4	14.4	16.5	18.6	20.6	22.7	24.8
30.00	1.8	3.7	5.5	7.4	9.2	11.1	12.9	14.8	16.6	18.4	20.3	22.1
31.00	1.6	3.3	4.9	6.6	8.2	9.9	11.5	13.2	14.8	16.5	18.1	19.8
32.00	1.5	2.9	4.4	5.9	7.4	8.8	10.3	11.8	13.3	14.7	16.2	17.7
33.00	1.3	2.6	4.0	5.3	6.6	7.9	9.2	10.5	11.9	13.2	14.5	15.8
34.00	1.2	2.4	3.5	4.7	5.9	7.1	8.2	9.4	10.6	11.8	13.0	14.1
35.00	1.1	2.1	3.2	4.2	5.3	6.3	7.4	8.4	9.5	10.5	11.6	12.6
36.00	0.9	1.9	2.8	3.8	4.7	5.7	6.6	7.5	8.5	9.4	10.4	11.3
37.00	0.8	1.7	2.5	3.4	4.2	5.1	5.9	6.7	7.6	8.4	9.3	10.1
38.00	0.8	1.5	2.3	3.0	3.8	4.5	5.3	6.0	6.8	7.5	8.3	9.0
39.00	0.7	1.3	2.0	2.7	3.4	4.0	4.7	5.4	6.1	6.7	7.4	8.1
40.00	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4	6.0	6.6	7.2
41.00	0.5	1.1	1.6	2.2	2.7	3.2	3.8	4.3	4.8	5.4	5.9	6.5
42.00	0.5	1.0	1.4	1.9	2.4	2.9	3.4	3.9	4.3	4.8	5.3	5.8
43.00	0.4	0.9	1.3	1.7	2.2	2.6	3.0	3.4	3.9	4.3	4.7	5.2
44.00	0.4	0.8	1.2	1.5	1.9	2.3	2.7	3.1	3.5	3.9	4.2	4.6

WAVE GENERATED ORBITAL VELOCITIES (CM/SEC) FOR WAVE PERIOD OF 8.0 SECONDS AT A HEIGHT 1.0 M ABOVE SEABED

WAVE HT M / DEPTH M	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
2.00	55.1	-0.1	-0.1	-	-	-	-	-	-	-	-	-
3.00	44.3	88.6	249.6	-0.1	-	-	-	-	-	-	-	-
4.00	37.9	75.7	166.6	245.6	336.5	-0.1	-	-	-	-	-	-
5.00	32.9	65.7	98.6	180.7	241.3	308.1	380.9	-	-	-	-	-
6.00	29.4	58.9	88.3	117.7	192.4	241.7	294.6	351.2	411.3	-	-	-
7.00	26.7	53.4	80.1	106.8	161.9	201.1	242.6	286.3	332.4	380.6	-	-
8.00	24.4	48.9	73.3	97.7	122.2	173.6	207.8	243.5	280.7	319.4	359.6	401.3
9.00	22.5	45.0	67.5	90.0	112.6	153.6	182.8	213.0	244.3	276.5	309.8	344.2
10.00	20.8	41.7	62.5	83.4	104.2	125.0	163.6	189.9	216.9	244.6	273.0	302.2
11.00	19.4	38.7	58.1	77.4	96.8	116.2	148.3	171.6	195.4	219.7	244.5	269.9
12.00	18.0	36.1	54.1	72.2	90.2	108.2	126.3	156.5	177.8	199.5	221.5	244.0
13.00	16.8	33.7	50.5	67.4	84.2	101.1	117.9	143.8	163.1	182.6	202.4	222.5
14.00	15.8	31.5	47.3	63.0	78.8	94.6	110.3	126.1	150.4	168.2	186.2	204.4
15.00	14.8	29.5	44.3	59.0	73.8	88.6	103.3	118.1	139.3	155.6	172.1	188.7
16.00	13.8	27.7	41.5	55.4	69.2	83.0	96.9	110.7	129.5	144.5	159.6	174.9
17.00	13.0	26.0	39.0	52.0	64.9	77.9	90.9	103.9	116.9	134.6	148.5	162.6
18.00	12.2	24.4	36.6	48.8	61.0	73.2	85.4	97.6	109.8	125.6	138.5	151.5
19.00	11.5	22.9	34.4	45.8	57.3	68.7	80.2	91.7	103.1	117.4	129.4	141.5
20.00	10.8	21.5	32.3	43.1	53.8	64.6	75.4	86.2	96.9	107.7	121.1	132.3
21.00	10.1	20.2	30.4	40.5	50.6	60.7	70.9	81.0	91.1	101.2	113.4	123.9
22.00	9.5	19.0	28.6	38.1	47.6	57.1	66.6	76.2	85.7	95.2	106.3	116.1
23.00	9.0	17.9	26.9	35.8	44.8	53.7	62.7	71.6	80.6	89.5	99.7	108.9
24.00	8.4	16.8	25.3	33.7	42.1	50.5	58.9	67.4	75.8	84.2	93.6	102.2
25.00	7.9	15.8	23.8	31.7	39.6	47.5	55.4	63.4	71.3	79.2	87.1	95.9
26.00	7.5	14.9	22.4	29.8	37.3	44.7	52.2	59.6	67.1	74.5	82.0	90.1
27.00	7.0	14.0	21.0	28.0	35.0	42.1	49.1	56.1	63.1	70.1	77.1	84.7
28.00	6.6	13.2	19.8	26.4	33.0	39.6	46.2	52.7	59.3	65.9	72.5	79.5
29.00	6.2	12.4	18.6	24.8	31.0	37.2	43.4	49.6	55.8	62.0	68.2	74.8
30.00	5.8	11.7	17.5	23.3	29.2	35.0	40.8	46.7	52.5	58.3	64.2	70.3
31.00	5.5	11.0	16.5	21.9	27.4	32.9	38.4	43.9	49.4	54.9	60.3	66.0
32.00	5.2	10.3	15.5	20.6	25.8	31.0	36.1	41.3	46.4	51.6	56.8	62.1
33.00	4.9	9.7	14.6	19.4	24.3	29.1	34.0	38.8	43.7	48.5	53.4	58.3
34.00	4.6	9.1	13.7	18.2	22.8	27.4	31.9	36.5	41.1	45.6	50.2	54.8
35.00	4.3	8.6	12.9	17.2	21.4	25.7	30.0	34.3	38.6	42.9	47.2	51.5
36.00	4.0	8.1	12.1	16.1	20.2	24.2	28.2	32.3	36.3	40.3	44.4	48.4
37.00	3.8	7.6	11.4	15.2	19.0	22.7	26.5	30.3	34.1	37.9	41.7	45.5
38.00	3.6	7.1	10.7	14.3	17.8	21.4	24.9	28.5	32.1	35.6	39.2	42.8
39.00	3.4	6.7	10.1	13.4	16.8	20.1	23.5	26.8	30.2	33.5	36.9	40.2
40.00	3.1	6.3	9.4	12.6	15.7	18.9	22.0	25.2	28.3	31.5	34.6	37.8
41.00	3.0	5.9	8.9	11.8	14.8	17.8	20.7	23.7	26.6	29.6	32.6	35.5
42.00	2.8	5.6	8.3	11.1	13.9	16.7	19.5	22.3	25.0	27.8	30.6	33.4
43.00	2.6	5.2	7.8	10.5	13.1	15.7	18.3	20.9	23.5	26.1	28.8	31.4
44.00	2.5	4.9	7.4	9.8	12.3	14.7	17.2	19.7	22.1	24.6	27.0	29.5
45.00	2.3	4.6	6.9	9.2	11.5	13.8	16.2	18.5	20.8	23.1	25.4	27.7
46.00	2.2	4.3	6.5	8.7	10.8	13.0	15.2	17.3	19.5	21.7	23.9	26.0
47.00	2.0	4.1	6.1	8.2	10.2	12.2	14.3	16.3	18.3	20.4	22.4	24.5
48.00	1.9	3.8	5.7	7.7	9.6	11.5	13.4	15.3	17.2	19.1	21.1	23.0
49.00	1.8	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	18.0	19.8	21.6
50.00	1.7	3.4	5.1	6.8	8.5	10.2	11.9	13.6	15.3	17.0	18.7	20.4

WAVE GENERATED ORBITAL VELOCITIES (CM/SEC) FOR WAVE PERIOD OF 10.0 SECONDS AT A HEIGHT 1.0 M ABOVE SEABED

WAVE HT M / DEPTH M	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
2.00	-0.1	-0.1	-0.1	-	-	-	-	-	-	-	-	-
3.00	44.6	-0.1	-0.1	-0.1	-	-	-	-	-	-	-	-
4.00	38.3	76.6	204.3	-0.1	-0.1	-0.1	-	-	-	-	-	-
5.00	34.0	68.0	102.0	223.1	306.1	-0.1	-0.1	-	-	-	-	-
6.00	30.8	61.6	92.5	123.3	236.9	304.1	378.0	-0.1	-0.1	-	-	-
7.00	28.3	56.7	85.0	113.3	141.7	247.9	304.3	365.1	430.2	499.7	-	-
8.00	25.8	51.7	77.5	103.3	129.2	207.2	251.9	299.5	350.0	403.3	459.6	518.8
9.00	24.1	48.1	72.2	96.3	120.3	144.4	219.0	258.5	300.1	343.7	389.4	437.2
10.00	22.5	45.1	67.6	90.2	112.7	135.3	194.8	228.7	264.0	300.9	339.3	379.2
11.00	21.2	42.4	63.7	84.9	106.1	127.3	148.5	206.0	236.8	268.8	301.9	336.1
12.00	20.0	40.1	60.1	80.2	100.2	120.3	140.3	160.3	215.4	243.7	272.8	302.8
13.00	19.0	38.0	57.0	75.9	94.9	113.9	132.9	151.9	198.1	223.5	249.5	276.2
14.00	18.0	36.1	54.1	72.1	90.1	108.2	126.2	144.2	162.2	206.7	230.3	254.4
15.00	17.1	34.3	51.4	68.6	85.7	102.9	120.0	137.2	154.3	192.6	214.1	236.1
16.00	16.3	32.7	49.0	65.4	81.7	98.0	114.4	130.7	147.1	163.4	200.3	220.5
17.00	15.6	31.2	46.8	62.4	78.0	93.6	109.2	124.7	140.3	155.9	188.2	206.9
18.00	14.9	29.8	44.7	59.6	74.5	89.4	104.3	119.2	134.1	149.0	163.9	195.0
19.00	14.2	28.5	42.7	57.0	71.2	85.5	99.7	114.0	128.2	142.5	156.7	184.3
20.00	13.6	27.3	40.9	54.5	68.2	81.8	95.5	109.1	122.7	136.4	150.0	163.6
21.00	13.1	26.1	39.2	52.2	65.3	78.4	91.4	104.5	117.6	130.6	143.7	156.7
22.00	12.5	25.0	37.6	50.1	62.6	75.1	87.6	100.2	112.7	125.2	137.7	150.2
23.00	12.0	24.0	36.0	48.0	60.0	72.0	84.0	96.0	108.1	120.1	132.1	144.1
24.00	11.5	23.0	34.6	46.1	57.6	69.1	80.6	92.1	103.7	115.2	126.7	138.2
25.00	11.1	22.1	33.2	44.2	55.3	66.3	77.4	88.4	99.5	110.6	121.6	132.7
26.00	10.6	21.2	31.8	42.5	53.1	63.7	74.3	84.9	95.5	106.1	116.8	127.4
27.00	10.2	20.4	30.6	40.8	51.0	61.2	71.4	81.5	91.7	101.9	112.1	122.3
28.00	9.8	19.6	29.4	39.2	49.0	58.7	68.5	78.3	88.1	97.9	107.7	117.5
29.00	9.4	18.8	28.2	37.6	47.0	56.4	65.9	75.3	84.7	94.1	103.5	112.9
30.00	9.0	18.1	27.1	36.2	45.2	54.2	63.3	72.3	81.4	90.4	99.4	108.5
31.00	8.7	17.4	26.1	34.8	43.4	52.1	60.8	69.5	78.2	86.9	95.6	104.3
32.00	8.4	16.7	25.1	33.4	41.8	50.1	58.5	66.8	75.2	83.5	91.9	100.2
33.00	8.0	16.1	24.1	32.1	40.1	48.2	56.2	64.2	72.3	80.3	88.3	96.3
34.00	7.7	15.4	23.2	30.9	38.6	46.3	54.0	61.8	69.5	77.2	84.9	92.6
35.00	7.4	14.8	22.3	29.7	37.1	44.5	52.0	59.4	66.8	74.2	81.6	89.1
36.00	7.1	14.3	21.4	28.5	35.7	42.8	50.0	57.1	64.2	71.4	78.5	85.6
37.00	6.9	13.7	20.6	27.4	34.3	41.2	48.0	54.9	61.8	68.6	75.5	82.3
38.00	6.6	13.2	19.8	26.4	33.0	39.6	46.2	52.8	59.4	66.0	72.6	79.2
39.00	6.3	12.7	19.0	25.4	31.7	38.1	44.4	50.8	57.1	63.4	69.8	76.1
40.00	6.1	12.2	18.3	24.4	30.5	36.6	42.7	48.8	54.9	61.0	67.1	73.2
41.00	5.9	11.7	17.6	23.5	29.3	35.2	41.1	46.9	52.8	58.7	64.5	70.4
42.00	5.6	11.3	16.9	22.6	28.2	33.8	39.5	45.1	50.8	56.4	62.1	67.7
43.00	5.4	10.8	16.3	21.7	27.1	32.5	38.0	43.4	48.8	54.2	59.7	65.1
44.00	5.2	10.4	15.6	20.9	26.1	31.3	36.5	41.7	46.9	52.2	57.4	62.6
45.00	5.0	10.0	15.0	20.1	25.1	30.1	35.1	40.1	45.1	50.2	55.2	60.2
46.00	4.8	9.6	14.5	19.3	24.1	28.9	33.8	38.6	43.4	48.2	53.1	57.9
47.00	4.6	9.3	13.9	18.6	23.2	27.8	32.5	37.1	41.7	46.4	51.0	55.7
48.00	4.5	8.9	13.4	17.8	22.3	26.8	31.2	35.7	40.1	44.6	49.1	53.5
49.00	4.3	8.6	12.9	17.2	21.4	25.7	30.0	34.3	38.6	42.9	47.2	51.5
50.00	4.1	8.2	12.4	16.5	20.6	24.7	28.9	33.0	37.1	41.2	45.3	49.5

WAVE GENERATED ORBITAL VELOCITIES (CM/SEC) FOR WAVE PERIOD OF 6.0 SECONDS AT A HT. 0.40 X DEPTH ABOVE BED

WAVE HT M / DEPTH M	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
2.00	54.3	188.6	-0.1	-	-	-	-	-	-	-	-	-
3.00	43.1	86.2	188.5	277.6	-	-	-	-	-	-	-	-
4.00	36.4	72.8	135.5	192.3	254.9	323.4	-	-	-	-	-	-
5.00	31.7	63.3	95.0	150.7	195.9	244.1	295.3	-	-	-	-	-
6.00	28.0	56.0	84.0	125.6	161.3	198.7	237.7	278.5	-	-	-	-
7.00	25.0	50.0	75.1	100.1	137.9	168.6	200.3	233.0	266.8	-	-	-
8.00	22.5	45.1	67.6	90.1	120.7	146.8	173.5	200.9	228.9	257.5	-	-
9.00	20.4	40.8	61.2	81.6	102.0	129.9	153.0	176.5	200.4	224.8	249.6	-
10.00	18.5	37.1	55.6	74.1	92.6	116.1	136.5	157.1	177.9	199.1	220.5	242.2
11.00	16.9	33.8	50.7	67.6	84.4	104.7	122.8	141.1	159.5	178.2	197.0	216.0
12.00	15.4	30.9	46.3	61.7	77.2	94.9	111.1	127.5	144.0	160.6	177.4	194.3
13.00	14.1	28.3	42.4	56.5	70.7	84.8	101.0	115.8	130.7	145.6	160.7	175.8
14.00	13.0	25.9	38.9	51.8	64.8	77.8	92.2	105.6	119.1	132.6	146.2	159.8
15.00	11.9	23.8	35.7	47.6	59.5	71.4	84.4	96.6	108.8	121.1	133.5	145.9
16.00	11.0	21.9	32.9	43.8	54.8	65.7	77.4	88.5	99.7	111.0	122.2	133.5
17.00	10.1	20.2	30.3	40.4	50.4	60.5	71.1	81.3	91.6	101.9	112.2	122.5
18.00	9.3	18.6	27.9	37.2	46.5	55.8	65.5	74.9	84.3	93.7	103.2	112.6
19.00	8.6	17.2	25.8	34.3	42.9	51.5	60.3	69.0	77.7	86.3	95.0	103.7
20.00	7.9	15.9	23.8	31.7	39.7	47.6	55.7	63.7	71.7	79.6	87.6	95.7
21.00	7.3	14.7	22.0	29.3	36.7	44.0	51.4	58.8	66.2	73.6	80.9	88.3
22.00	6.8	13.6	20.4	27.1	33.9	40.7	47.6	54.4	61.2	68.0	74.8	81.7
23.00	6.3	12.6	18.9	25.1	31.4	37.7	44.0	50.3	56.6	63.0	69.3	75.6
24.00	5.8	11.6	17.5	23.3	29.1	34.9	40.8	46.6	52.5	58.3	64.2	70.0
25.00	5.4	10.8	16.2	21.6	27.0	32.4	37.8	43.2	48.6	54.1	59.5	64.9
26.00	5.0	10.0	15.0	20.0	25.1	30.1	35.1	40.1	45.1	50.1	55.2	60.2
27.00	4.7	9.3	14.0	18.6	23.3	27.9	32.6	37.2	41.9	46.5	51.2	55.9
28.00	4.3	8.6	13.0	17.3	21.6	25.9	30.3	34.6	38.9	43.2	47.6	51.9
29.00	4.0	8.1	12.1	16.1	20.1	24.2	28.2	32.2	36.3	40.3	44.3	48.4
30.00	3.7	7.5	11.2	15.0	18.7	22.5	26.2	30.0	33.7	37.5	41.2	44.9
31.00	3.5	7.0	10.4	13.9	17.4	20.9	24.4	27.9	31.3	34.8	38.3	41.8
32.00	3.2	6.5	9.7	13.0	16.2	19.4	22.7	25.9	29.1	32.4	35.6	38.9
33.00	3.0	6.0	9.0	12.1	15.1	18.1	21.1	24.1	27.1	30.1	33.2	36.2
34.00	2.8	5.6	8.4	11.2	14.0	16.8	19.6	22.4	25.3	28.1	30.9	33.7
35.00	2.6	5.2	7.8	10.5	13.1	15.7	18.3	20.9	23.5	26.1	28.7	31.4
36.00	2.4	4.9	7.3	9.7	12.2	14.6	17.0	19.5	21.9	24.4	26.8	29.2
37.00	2.3	4.5	6.8	9.1	11.3	13.6	15.9	18.2	20.4	22.7	25.0	27.2
38.00	2.1	4.2	6.3	8.5	10.6	12.7	14.8	16.9	19.0	21.2	23.3	25.4
39.00	2.0	3.9	5.9	7.9	9.9	11.8	13.8	15.8	17.8	19.7	21.7	23.7
40.00	1.8	3.7	5.5	7.4	9.2	11.0	12.9	14.7	16.6	18.4	20.2	22.1
41.00	1.7	3.4	5.1	6.9	8.6	10.3	12.0	13.7	15.5	17.2	18.9	20.6
42.00	1.6	3.2	4.8	6.4	8.0	9.6	11.2	12.8	14.4	16.0	17.6	19.2
43.00	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	14.9	16.4	17.9
44.00	1.4	2.8	4.2	5.6	7.0	8.4	9.8	11.2	12.6	14.0	15.4	16.7
45.00	1.3	2.6	3.9	5.2	6.5	7.8	9.1	10.4	11.7	13.0	14.3	15.6
46.00	1.2	2.4	3.6	4.9	6.1	7.3	8.5	9.7	10.9	12.2	13.4	14.6
47.00	1.1	2.3	3.4	4.5	5.7	6.8	8.0	9.1	10.2	11.4	12.5	13.6
48.00	1.1	2.1	3.2	4.2	5.3	6.4	7.4	8.5	9.5	10.6	11.7	12.7
49.00	1.0	2.0	3.0	4.0	5.0	5.9	6.9	7.9	8.9	9.9	10.9	11.9
50.00	0.9	1.9	2.8	3.7	4.6	5.6	6.5	7.4	8.3	9.3	10.2	11.1

WAVE GENERATED ORBITAL VELOCITIES (CM/SEC) FOR WAVE PERIOD OF 8.0 SECONDS AT A HT. 0.40 X DEPTH ABOVE BED

WAVE HT M / DEPTH M	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
2.00	54.8	-0.1	-0.1	-	-	-	-	-	-	-	-	-
3.00	44.5	89.0	252.3	-0.1	-	-	-	-	-	-	-	-
4.00	38.3	76.6	170.5	252.0	345.9	-0.1	-	-	-	-	-	-
5.00	33.5	67.0	100.5	187.1	250.5	320.5	397.1	-	-	-	-	-
6.00	30.2	60.4	90.6	120.8	200.9	253.1	309.3	369.4	433.6	-	-	-
7.00	27.6	55.1	82.7	110.3	170.0	211.8	256.1	302.9	352.4	404.4	-	-
8.00	25.4	50.8	76.2	101.6	127.0	183.7	220.5	258.9	299.1	341.1	384.7	430.2
9.00	23.6	47.1	70.7	94.2	117.8	163.3	194.8	227.6	261.5	296.7	333.0	370.7
10.00	22.0	43.9	65.9	87.8	109.8	131.7	175.3	203.9	233.3	263.7	294.9	327.0
11.00	20.5	41.1	61.6	82.2	102.7	123.3	159.8	185.2	211.3	238.0	265.4	293.4
12.00	19.3	38.6	57.9	77.1	96.4	115.7	135.0	169.9	193.4	217.3	241.8	266.7
13.00	18.1	36.3	54.4	72.6	90.7	108.9	127.0	157.1	178.4	200.1	222.2	244.7
14.00	17.1	34.2	51.3	68.5	85.6	102.7	119.8	136.9	165.7	185.5	205.7	226.1
15.00	16.2	32.3	48.5	64.7	80.8	97.0	113.2	129.3	154.6	172.9	191.4	210.1
16.00	15.3	30.6	45.9	61.2	76.5	91.8	107.1	122.3	144.8	161.7	178.9	196.2
17.00	14.5	29.0	43.5	57.9	72.4	86.9	101.4	115.9	130.4	151.8	167.8	183.9
18.00	13.7	27.5	41.2	54.9	68.7	82.4	96.1	109.9	123.6	142.9	157.8	172.8
19.00	13.0	26.1	39.1	52.1	65.2	78.2	91.3	104.3	117.3	134.8	148.7	162.8
20.00	12.4	24.8	37.1	49.5	61.9	74.3	86.7	99.1	111.4	123.8	140.5	153.7
21.00	11.8	23.5	35.3	47.1	58.9	70.6	82.4	94.2	105.9	117.7	132.9	145.4
22.00	11.2	22.4	33.6	44.8	56.0	67.2	78.4	89.6	100.8	112.0	125.9	137.7
23.00	10.7	21.3	32.0	42.6	53.3	63.9	74.6	85.3	95.9	106.6	119.5	130.6
24.00	10.1	20.3	30.4	40.6	50.7	60.9	71.0	81.2	91.3	101.5	113.5	124.0
25.00	9.7	19.3	29.0	38.7	48.3	58.0	67.7	77.4	87.0	96.7	106.4	117.8
26.00	9.2	18.4	27.7	36.9	46.1	55.3	64.5	73.7	83.0	92.2	101.4	112.1
27.00	8.8	17.6	26.4	35.2	44.0	52.7	61.5	70.3	79.1	87.9	96.7	106.7
28.00	8.4	16.8	25.2	33.6	41.9	50.3	58.7	67.1	75.5	83.9	92.3	101.6
29.00	8.0	16.0	24.0	32.0	40.0	48.0	56.0	64.0	72.1	80.1	88.1	96.8
30.00	7.6	15.3	22.9	30.6	38.2	45.9	53.5	61.2	68.8	76.4	84.1	92.4
31.00	7.3	14.6	21.9	29.2	36.5	43.8	51.1	58.4	65.7	73.0	80.3	88.1
32.00	7.0	14.0	20.9	27.9	34.9	41.9	48.8	55.8	62.8	69.8	76.7	84.1
33.00	6.7	13.3	20.0	26.7	33.3	40.0	46.7	53.3	60.0	66.7	73.3	80.4
34.00	6.4	12.7	19.1	25.5	31.9	38.2	44.6	51.0	57.4	63.7	70.1	76.8
35.00	6.1	12.2	18.3	24.4	30.5	36.6	42.7	48.8	54.9	61.0	67.1	73.2
36.00	5.8	11.7	17.5	23.3	29.2	35.0	40.8	46.7	52.5	58.3	64.2	70.0
37.00	5.6	11.2	16.7	22.3	27.9	33.5	39.1	44.6	50.2	55.8	61.4	67.0
38.00	5.3	10.7	16.0	21.4	26.7	32.0	37.4	42.7	48.1	53.4	58.8	64.1
39.00	5.1	10.2	15.3	20.5	25.6	30.7	35.8	40.9	46.0	51.1	56.2	61.4
40.00	4.9	9.8	14.7	19.6	24.5	29.4	34.3	39.2	44.1	49.0	53.9	58.8
41.00	4.7	9.4	14.1	18.8	23.5	28.1	32.8	37.5	42.2	46.9	51.6	56.3
42.00	4.5	9.0	13.5	18.0	22.5	27.0	31.5	35.9	40.4	44.9	49.4	53.9
43.00	4.3	8.6	12.9	17.2	21.5	25.8	30.1	34.4	38.8	43.1	47.4	51.7
44.00	4.1	8.3	12.4	16.5	20.6	24.8	28.9	33.0	37.1	41.3	45.4	49.5
45.00	4.0	7.9	11.9	15.8	19.8	23.7	27.7	31.6	35.6	39.6	43.5	47.5
46.00	3.8	7.6	11.4	15.2	19.0	22.8	26.6	30.3	34.1	37.9	41.7	45.5
47.00	3.6	7.3	10.9	14.5	18.2	21.8	25.5	29.1	32.7	36.4	40.0	43.6
48.00	3.5	7.0	10.5	14.0	17.4	20.9	24.4	27.9	31.4	34.9	38.4	41.9
49.00	3.3	6.7	10.0	13.4	16.7	20.1	23.4	26.8	30.1	33.5	36.8	40.2
50.00	3.2	6.4	9.7	12.9	16.1	19.3	22.6	25.8	29.0	32.2	35.5	38.7

WAVE GENERATED ORBITAL VELOCITIES (CM/SEC) FOR WAVE PERIOD OF **10.0 SECONDS** AT A **HT. 0.40 X DEPTH** ABOVE BED

WAVE HT M / DEPTH M	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
2.00	-0.1	-0.1	-0.1	-	-	-	-	-	-	-	-	-
3.00	44.7	-0.1	-0.1	-0.1	-	-	-	-	-	-	-	-
4.00	38.6	77.2	208.0	-0.1	-0.1	-0.1	-	-	-	-	-	-
5.00	34.4	68.8	103.3	229.0	314.7	-0.1	-0.1	-	-	-	-	-
6.00	31.3	62.6	93.9	125.2	244.6	314.7	391.8	-0.1	-0.1	-	-	-
7.00	28.9	57.8	86.7	115.6	144.4	257.4	316.6	380.5	449.1	522.4	-	-
8.00	26.5	52.9	79.4	105.8	132.3	216.0	263.1	313.5	367.0	423.6	483.5	546.5
9.00	24.7	49.5	74.2	99.0	123.7	148.4	229.4	271.3	315.5	362.1	410.9	462.0
10.00	23.3	46.5	69.8	93.1	116.3	139.6	204.6	240.7	278.4	317.8	359.0	401.9
11.00	22.0	44.0	65.9	87.9	109.9	131.9	153.9	217.3	250.3	284.6	320.2	357.1
12.00	20.8	41.7	62.5	83.4	104.2	125.1	145.9	166.8	228.3	258.7	290.1	322.5
13.00	19.8	39.6	59.5	79.3	99.1	118.9	138.8	158.6	210.5	237.9	266.0	295.0
14.00	18.9	37.8	56.7	75.6	94.5	113.4	132.3	151.2	170.1	220.7	246.3	272.5
15.00	18.1	36.1	54.2	72.2	90.3	108.3	126.4	144.4	162.5	206.2	229.7	253.6
16.00	17.3	34.6	51.8	69.1	86.4	103.7	121.0	138.2	155.5	172.8	215.5	237.6
17.00	16.6	33.1	49.7	66.3	82.8	99.4	115.9	132.5	149.1	165.6	203.1	223.7
18.00	15.9	31.8	47.7	63.6	79.5	95.4	111.3	127.2	143.1	159.0	174.9	211.4
19.00	15.3	30.6	45.8	61.1	76.4	91.7	106.9	122.2	137.5	152.8	168.0	200.6
20.00	14.7	29.4	44.1	58.8	73.5	88.2	102.9	117.5	132.2	146.9	161.6	176.3
21.00	14.1	28.3	42.4	56.6	70.7	84.9	99.0	113.2	127.3	141.4	155.6	169.7
22.00	13.6	27.3	40.9	54.5	68.1	81.8	95.4	109.0	122.6	136.3	149.9	163.5
23.00	13.1	26.3	39.4	52.6	65.7	78.8	92.0	105.1	118.2	131.4	144.5	157.7
24.00	12.7	25.3	38.0	50.7	63.4	76.0	88.7	101.4	114.1	126.7	139.4	152.1
25.00	12.2	24.5	36.7	48.9	61.2	73.4	85.6	97.9	110.1	122.3	134.6	146.8
26.00	11.8	23.6	35.4	47.3	59.1	70.9	82.7	94.5	106.3	118.2	130.0	141.8
27.00	11.4	22.8	34.2	45.7	57.1	68.5	79.9	91.3	102.7	114.2	125.6	137.0
28.00	11.0	22.1	33.1	44.1	55.2	66.2	77.2	88.3	99.3	110.3	121.4	132.4
29.00	10.7	21.3	32.0	42.7	53.4	64.0	74.7	85.4	96.0	106.7	117.4	128.0
30.00	10.3	20.6	31.0	41.3	51.6	61.9	72.2	82.6	92.9	103.2	113.5	123.9
31.00	10.0	20.0	30.0	39.9	49.9	59.9	69.9	79.9	89.9	99.9	109.9	119.8
32.00	9.7	19.3	29.0	38.7	48.3	58.0	67.7	77.3	87.0	96.7	106.3	116.0
33.00	9.4	18.7	28.1	37.4	46.8	56.2	65.5	74.9	84.2	93.6	103.0	112.3
34.00	9.1	18.1	27.2	36.3	45.3	54.4	63.5	72.5	81.6	90.6	99.7	108.8
35.00	8.8	17.6	26.3	35.1	43.9	52.7	61.5	70.3	79.0	87.8	96.6	105.4
36.00	8.5	17.0	25.5	34.0	42.5	51.1	59.6	68.1	76.6	85.1	93.6	102.1
37.00	8.2	16.5	24.7	33.0	41.2	49.5	57.7	66.0	74.2	82.5	90.7	99.0
38.00	8.0	16.0	24.0	32.0	40.0	48.0	56.0	64.0	71.9	79.9	87.9	95.9
39.00	7.8	15.5	23.3	31.0	38.8	46.5	54.3	62.0	69.8	77.5	85.3	93.0
40.00	7.5	15.0	22.5	30.1	37.6	45.1	52.6	60.1	67.6	75.2	82.7	90.2
41.00	7.3	14.6	21.9	29.2	36.5	43.7	51.0	58.3	65.6	72.9	80.2	87.5
42.00	7.1	14.1	21.2	28.3	35.4	42.4	49.5	56.6	63.7	70.7	77.8	84.9
43.00	6.9	13.7	20.6	27.5	34.3	41.2	48.0	54.9	61.8	68.6	75.5	82.4
44.00	6.7	13.3	20.0	26.6	33.3	40.0	46.6	53.3	59.9	66.6	73.3	79.9
45.00	6.5	12.9	19.4	25.9	32.3	38.8	45.3	51.7	58.2	64.6	71.1	77.6
46.00	6.3	12.6	18.8	25.1	31.4	37.7	43.9	50.2	56.5	62.8	69.0	75.3
47.00	6.1	12.2	18.3	24.4	30.5	36.6	42.6	48.7	54.8	60.9	67.0	73.1
48.00	5.9	11.8	17.7	23.7	29.6	35.5	41.4	47.3	53.2	59.2	65.1	71.0
49.00	5.7	11.5	17.2	23.0	28.7	34.5	40.2	46.0	51.7	57.5	63.2	68.9
50.00	5.6	11.2	16.7	22.3	27.9	33.5	39.1	44.6	50.2	55.8	61.4	67.0

APPENDIX III

SAMPLE EQUIPMENT CHECKLIST

The following is an example of a checklist of Aanderaa RCM4 equipment required for the deployment of a current meter. Each agency will need to prepare its own list of equipment, some items being unique to a particular model of current meter and deployment site.

1 Current Meter/Mooring System

RCM4 current meters
Vane assembly/balance weight
Gimbal/spindle assembly
Fastening band
Recommended spares and accessories (inc. cotter pins, O-ring, tightening lever, conductivity sensor calibrating resistor)
Magnetic tape
Battery
Silicon grease
Rubber bands (for rotor protection)
Tectyl (to protect scews from corrosion)
Sets of sub-surface buoys
Surface buoys
Danbuoy
Surface light plus batteries
Radar reflector
Chain
Rope or wire cable
Shackles, thimbles and swivels
Siezing wire for shackles (stainless steel)
Insulation tape
Main clump anchor
Crown anchor
Tape measure
Leather gloves

2 Auxiliary Equipment

Boat (and associated equipment e.g. life jackets, flares, boat hook, first aid kit, waterproof clothing, fuel)
Direct reading current meter e.g. Braystoke
Field salinity/temperature meter
Wind anemometer
SCUBA diving gear
Radios - (communication with shore surveyors)
Position fixing instruments (e.g. EDM, theodolites, sextants)
Echo sounder
Camera/film
Watch
Hydrographic chart

3 Toolkit (in a waterproof container e.g. ammunition box with cutting oil in it for divers tools)

Spanners
Crescents
Pliers
Multigrips
Bolt cutters
Insulation tape
Hammer
Screwdrivers
CRC (spray to loosen rusted screws)
Seizing wire
Spare split pins
Trimming blade or knife
Hacksaw
Matches/lighter
Torch
Batteries
Files
Hand cleanser

4 Recording
Field notebooks
Waterproof paper
Pencils/marker pens (waterproof)
Rubber
Meter log sheets
Calculator
Clipboard
Diver notebook (waterproof paper) or slate

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