UNSW SYDNEY

Collection analysis and presentation of estuarine current data

Author:
Atkinson, William

Publication Date:
1980

DOI:
https://doi.org/10.26190/unsworks/4927

License:
https://creativecommons.org/licenses/by-nc-nd/3.0/au/
Link to license to see what you are allowed to do with this resource.

Downloaded from http://hdl.handle.net/1959.4/56317 in https://unsworks.unsw.edu.au on 2024-05-03

The quality of this digital copy is an accurate reproduction of the original print copy

Collection, Analysis and Presentation
of Estuarine Current Data

by

William Atkinson

Project

SCHOOL OF CIVIL ENGINEERING

MASTER OF ENGINEERING SCIENCE

8·909G PROJECT REPORT

THE UNIVERSITY OF NEW SOUTH WALES

WATER RESEARCH LABORATORY
THE UNIVERSITY OF NEW SOUTH WALES
KING STREET, MANLY VALE, NSW, 2093

Collection, Analysis and Presentation of Estuarine Current Data

by

William Atkinson

Project

Master of Engineering Science

UNIVERSITY OF NEW SOUTH WALES
WATER REFERENCE
LIBRARY
WATER RESEARCH FOUNDATION WATER RESEARCH

December, 1980.

ANNEXURE B
to Procedures
8.3.1.

1. STUDENTS DECLARATION

A) This is to certify that I ...William Atkinson......................
being a candidate for the degree of Master of Engineering Science am fully aware of the policy of the University relating to the retention and use of higher degree projects namely that the University retains the copies of any thesis submitted for examination, "and is free to allow the thesis to be consulted or borrowed. Subject to the provisions of the copyright Act (1968) the University may issue the thesis in whole or in part, in photostat or microfilm or other copying medium."

I also authorize the publication by University Microfilms of a 600 word abstract in Dissertation Abstracts International (D.A.I.)

B) I hereby declare that none of the work in this project has been submitted to any other institution for the award of a higher degree.

Signature ....

2. SUPERVISORS CERTIFICATION

I certify that this project has been completed under my supervision and is in my opinion in a form suitable for examination as part of the requirements for admission to the degree of Master of Engineering Science.

Signature ....
(D.N. FOSTER)

UNIVERSITY OF NEW SOUTH WALES
WATER REFERENCE LIBRARY
WATER RESEARCH FOUNDATION RESEARCH

Contents

List of Tables

1. INTRODUCTION.

Collection of tidal current data in an estuary is usually one aspect of the investigation stage for relatively major projects such as harbour and port development.

The use of current data depends on the requirements of the particular project. The project in which the writer is involved is the harbour and port development of Botany Bay, New South Wales. The current data collected in Botany Bay over the past four years has been used for many purposes directly and indirectly related to the Port Botany development. These uses include prototype verification of physical and mathematical hydrodynamic models (Reference 2), sediment transport studies and measurement of entrance channel conditions imposed on V.L.C.Cs (Very Large Crude Carriers).

Due to the relatively shallow conditions found in Botany Bay with an average water depth before dredging of 5 metres, problems encountered in collecting current data in this and other similar estuaries, are different to those encountered in deep ocean current data collection.

In some ways, current data collection in shallow estuaries is easier than that in deep oceans since the deployment/retrieval operation does not encounter problems associated with great depths where the use of expensive ocean going vessels and devices such as acoustic releases is required. In shallow estuaries small boats and manual deployment is preferred. However the fact that the current meter is being placed in only 5 metres of water creates both practical and theoretical problems unique to this situation.

A reasonable amount of attention in the literature has been given to the problems of deep ocean current data collection, however relatively little has been aimed at shallow water current data collection, analysis and presentation. For those involved in long term projects where specialist consultants are not used, the collection of current data can be filled with many mistakes which could have been avoided had the experience of others involved in such 'one-off' projects been recorded.

The current data collection system used at Botany Bay involved usually three Aanderaa RCM-4 meters. On occasions up to twelve of these meters were deployed at various locations about the estuary at one time.

This report draws on the experience gained by the writer in collecting current meter data in Botany Bay and points out the problems and limitations of such an undertaking.

The problem of what to do with the data, once collected, is one of the major considerations in the whole exercise. Various methods of data analysis and presentation are discussed and the use to which the data may be applied is considered.

The relationship between current regime and tidal regime is investigated and it is found that the strength of this relationship depends on the location within the estuary. In locations where there is not a strong quantitative relationship between current regime and tidal regime, other forms of reducing current data to a useful format are put forward.

2. PRACTICAL CONSIDERATIONS.

2.1 Choice of Current Meter

The choice of current meter is probably the most difficult and yet most important stage of current data aquisition. It tends also to be the most rushed stage and decisions made at this time can render the whole operation either a success or of little benefit.

It is recommended that a total current data acuisition system design approach be adopted. The current meter is one important part in the system which includes deployment equipment, mooring system, recorded data translation, analysis and presentation of current speed, direction and any other relevent data such as temperature and salinity.

The type of current meter used depends on cost, size of operation, field team and equipment (including boat) available, wave conditions, site conditions which determine how often the meter can be attended to, the type of analysis to be carried out on the raw data, whether manual or by computer, delivery time, technical support, whether or not there are other people with experience with a particular current meter and a number of other considerations particular to the given project.

Many equipment-associated problems in the collection of current data in Australia are simply due to the fact that most of the suitable current meters are manufactured in either the United States of America or Europe and the only people in Australia with sufficient knowledge of various current meters are those who use them regularly and have learnt from experience and their own trial and error.

There are advances being made in current meters continuously and keeping abreast of the advances is difficult without actually travelling to the United States of America or Europe. Purchasing a highly advanced (and expensive) current meter without being able to draw upon other people's experience often leads to months of trial and error after purchase before the system can be said to be producing reliable results. It may be better to forego a little technical advancement and purchase a well proven current meter if early, reliable results are required.

Although direct read current meters are available, only self contained meters are considered here. No matter how regularly a field team takes current measurements, it is very unlikely that the results will give a true representation of the overall current regime. Continuously recording, self contained current meters give just that - a continuous recording of currents. It is only from this record that reliable conclusions can be drawn and design current values estimated.

A full resume of the workings and advantages and disadvantages of all the available current meters would entail volumes. However, four of the oft-considered current meters for use in Australia are listed below and their attributes discussed. A comprehensive survey of 21 current meters has been carried out by G.F. Appell and D.R. Crump of the National Ocean Survey's Test and Evaluation Laboratory, Washington, D.C., U.S.A. (Reference 1).

The following draws on information contained in that survey and was current at July, 1977. Table 1 (page 5) presents a brief comparison of four current meters. The costs of the current meters is given for comparison purposes only as present costs for some of the meters are now at least twice those indicated.

One of the first considerations necessary is to realise if current recordings are to be taken in the presence and within the effect of waves. Water particle velocity under a wave can be very significant with respect to the net 'tidal' current and hence alter the water current regime the meter is measuring. Table 2 (page 6) gives an indication of the significance of water particle horizontal speeds under a wave for various wave periods, and heights at various depths below still water level.

Table 1 Current Meter Comparison Table.

	Manufacturer/Model			
	Aanderaa RCM-4	E.G.& G. CT-3	Marsh McBirney 585	Neil Brown ACM-1
Approx. cost at July,1977	$4334	$5300	$9500	$9500
Date first manufactured	1967	Dec. 1974	1977	1977
Speed Measurement	Savoneous Rotor	Electro Magnetic sensors	Electro Magnetic sensors	Acoustic phase shift
Direction measurement	Vane	Large fin	2-axis EM sensor related to "Digicourse" magnetic compass	2-axis acoustic sensor related to magnetometer
Threshold (cm/s)	1.5	1.7	0.15	0.15
Range (cm/s)	2.5-250	3-300	0-300	0-300
Allowable tilt	± 27°	± 30°	± 45°	± 30°
Recorder Type	½" reel to reel mag. tape	Digital cassette tape	Digital cassette tape	Digital cassette tape
Weight	24.5 kg.	23 kg.	43 kg.	34 kg.

Table 2 Average Horizontal Water Particle Speed (cm/s) in 6 m Water Depth

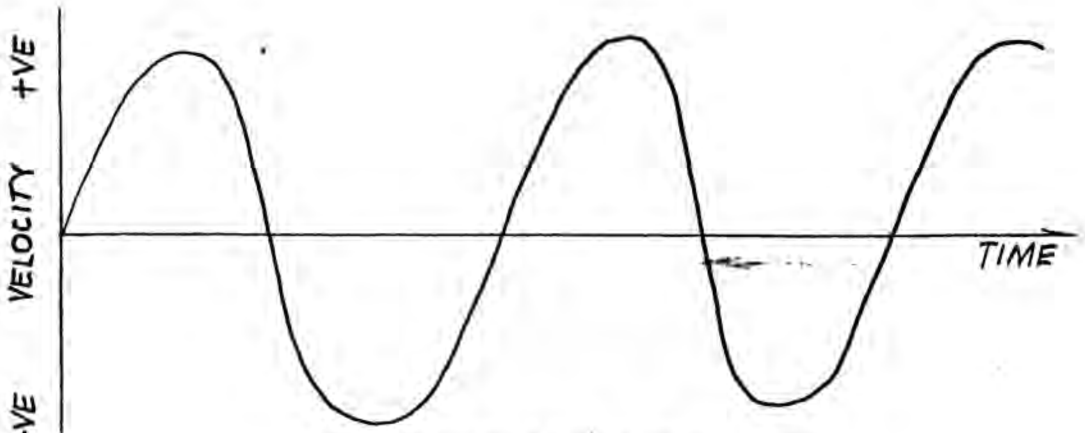
Wave Period	10 secs		14 secs	
Wave Height	0.5 m	1.0 m	0.5 m	1.0 m
Depth Below SWL				
1 m	20.4	40.8	20.4	40.8
3 m	19.3	38.6	19.9	39.7
6 m	18.7	37.4	19.5	39.0

The speeds shown in the above table are calculated as the total water particle excursion over the wave period according to linear theory and is the speed by which a Savoneous rotor type current meter would over-read the net tidal current. This aspect is discussed further in the following section.

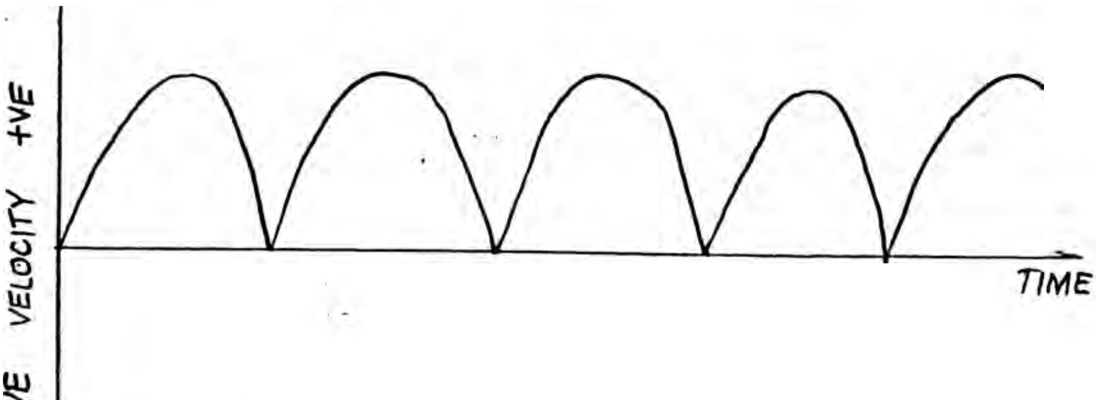
Under such conditions where wave induced water particle velocities are significant, Savoneous rotor type current meters are not suitable.

2.1.1 Current Meter Description.

The Savoneous rotor is non directional, i.e., it reads current velocity as positive even when the current is negative with respect to the meter. This error can be demonstrated graphically as shown in the sketch below.



ACTUAL VELOCITY FIELD



VELOCITY FIELD AS RECORDED BY SAVONEOUS ROTOR

Thus when short period flow reversals occur, the Savoneous rotor overestimates average current speed over the sampling interval.

When net current speed is greater than the wave particle speed and flow reversal does not occur, the savoneous rotor would not over read; rather it would simply slow down and speed up as the wave passed. Hence, if a long enough recording interval was selected (say 10 minutes in the presence of 10 second waves) the average recorded speed would indicate the actual average net speed.

This assumes that the net tidal current is flowing in the same direction as the wave orthogonals and that the wave is linear. The fact that a wave is non-linear and may not be travelling parallel to the net current, further complicates the situation.

Electromagnetic sensors overcome the problem of current measurements in the presence of waves as they detect negative velocities, i.e., electromagnetic sensors integrate current velocity.

The EG & G electromagnetic current meter has a fin which aligns it for direction measurement. The measurement of current direction with vane/fin type current meters is also a problem in the presence of waves. If the natural period of response of the current meter is much greater than the wave period, and a speed integrating sensor is used, then there is no problem. However if these periods are at all similar, then direction reading is a problem to the extent that fin type current meters have been known to align themselves 90° to the direction of the waves (and net current).

Bi-axis, tri-axis electromagnetic or acoustic sensors used for both speed and direction recording are suitable for current recording in the presence of waves.

Electromagnetic (EM) current meters operate on the principle of charged water particles (ions in salt sea water) breaking an electromagnetic field and producing a potential difference between the two poles. This potential difference (voltage) is dependent upon the speed of the charged particles through the field. Thus, current speed is calibrated to voltage. The 2-axis EM sensor current meters measure X and Y components of the water current and relate the axis to direction with the use of a compass. Current readings are measured almost instantaneously every 1 second say and the resulting record is a digital representation of the passing current.

Acoustic current meters operate by measuring a phase shift of transmitted sound waves. Sound waves of a known frequency and phase are transmitted through the passing water current. Depending on the relative velocity of the water current and sound waves, the received sound wave phase will be either lagging or ahead of that transmitted. The difference in transmitted and received phases is measured, being calibrated to water current velocity. A 2-axis digital representation of water current, similar to the EM current meters is recorded. The wave-induced currents can be 'removed' by a vector averaging process or spectral analysis of raw 1 second interval data.

2.1.2 Deployment Time

Deployment time is an important consideration in choosing a current meter. The time a self contained current meter can record is limited either by battery life, magnetic tape length or amount of marine growth fouling. In relatively shallow estuaries where light is not reduced by depth, fouling is generally the limiting factor, particularly in summer months. Aanderaa savoneous rotor current meters were limited to about 2 weeks recording in Botany Bay in summer months due to marine fouling.

Non mechanical speed sensors such as the EM or acoustic type are not as susceptible to marine fouling as they continue to detect current even if fouled with marine growth. However, marine fouling on the sensor or around the sensor on protection bars and such, disturbs the normal current flow past the meter and must thus effect current records of such current meters.

Magnetic tape length limits deployment period particularly on EM or acoustic type current meters which generally use digital cassettes. Due to their nature of digital measurement of water currents in 2 axes at very short intervals, a relatively large amount of data is required to be recorded for a continuous record. This is overcome by setting the current meter to sample over short bursts at certain intervals, but results in the necessity to arrive at a compromise between reasonable deployment period and sufficient sampling time. The fact that a continuous record cannot be achieved is a drawback of this type of current meter.

The Aanderaa current meters used by the writer were generally set to record every ten minutes. These Savoneous rotor type meters measure average current speed over the past ten minutes and instantaneous direction at the time of record. Thus only 2 data items for 10 minutes are required to continuously record water current velocity and hence magnetic tape length (reel to reel on Aanderaas) is generally not a limiting factor in deployment time of Aanderaa current meters.

Unlike deep ocean current recording where several months deployment using short sampling bursts at long intervals is employed, battery life is generally not a limiting factor in deployment period for shallow estuary projects. One advantage of the acoustic type current meter over the electromagnetic type current meter is its lower power demand and hence longer battery life. This difference is generally not of significance in shallow estuary deployment however, as battery life is not a limiting factor.

2.1.3 Other Considerations.

The weight of the current meter is an important consideration in the choice of a current meter as the weight determines the type and capacity of the mooring system and whether or not a winch or crane is necessary to deploy and recover the instrument. This latter consideration in turn determines the size of boat necessary.

Anything heavier than about 25 to 30 kilograms cannot be manually lifted up over the gunwalls of a small (4m) runabout and a much larger vessel is required.

Most of the Aanderaa current meter deployment and retrieval carried out in Botany Bay by the writer was done with a 4m outboard boat with either 2 or 3 people. The multi current meter moorings required the use of a sea-going fishing boat with a crane.

No matter how secure a mooring system may seem, Murphy's Law applies and it is likely that at least one current meter will be 'lost' during the life of a project.

The Aanderaa current meters have transducers which send out sound waves every record interval. The intended use of the transducer is to transmit the recorded data by sound waves to a hydrophone for remote data recording. This system of data recording is designed for deep ocean use and could not be employed in Botany Bay due to the shallow water and 'noise' from the many boats. However, directionaly sensitive hydrophones were used to find lost Aanderaas. Thus a system for locating a lost instrument is a consideration when purchasing a current meter.

Most self-contained current meters require computer data analysis due to the large amount of data recovered. The more recent current meters have micro-processors aboard which do vector-averaging of the 'raw' data before it is recorded onto magnetic tape. The Aanderaa current meters simply record, for example, the number of rotor turns during the record interval. When choosing a current meter, the type of analysis required must be fully recognised and the analysis system understood.

2.2 Mooring System

The mooring system for a current meter in shallow, populated waters such as Botany Bay is a very important aspect towards the success or otherwise of current data collection.

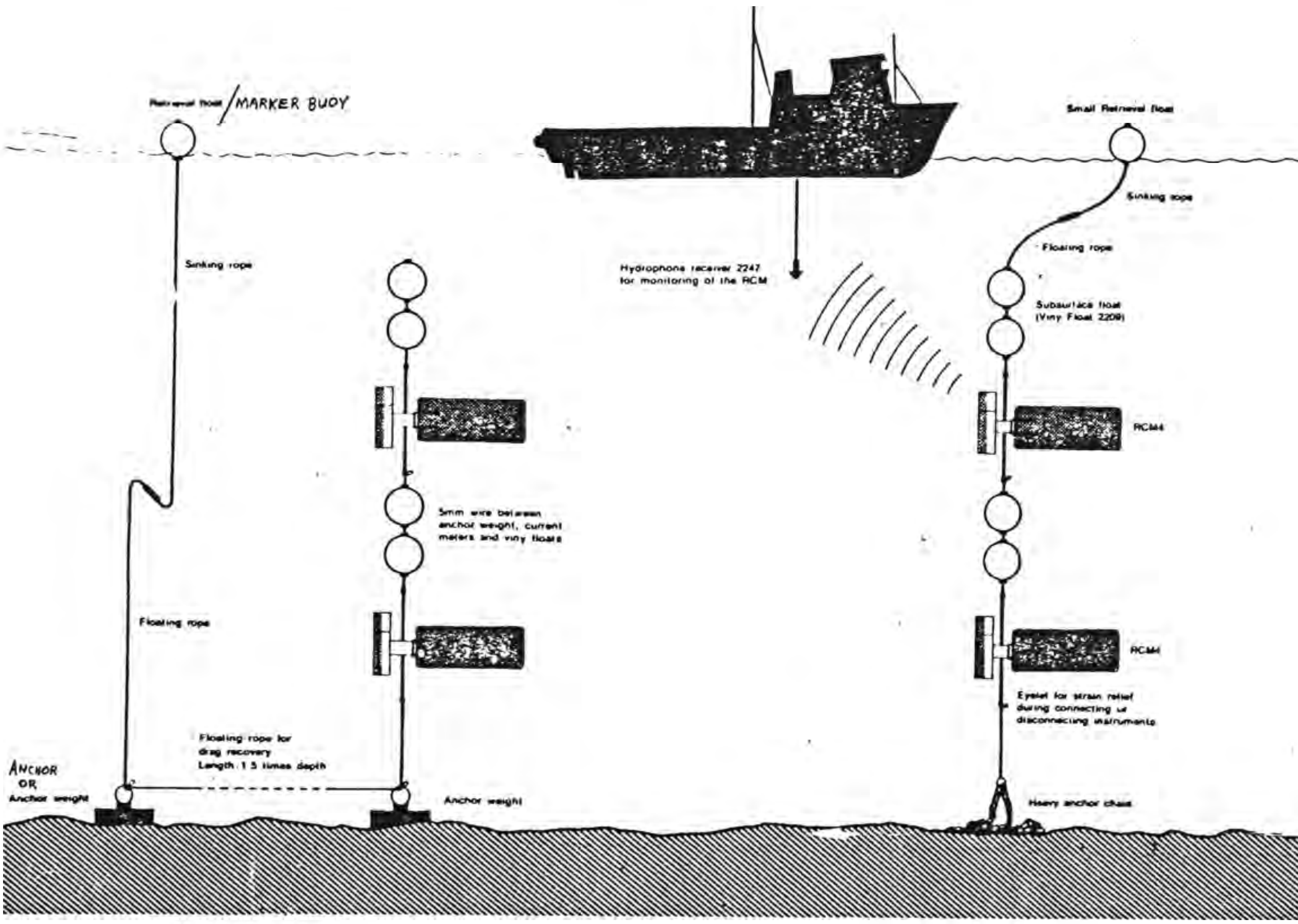
The main aims of a mooring system are ;

- to maintain the current meter in a fixed position relative to the bed.
- to allow the current meter unhindered movement necessary to measure direction, if a fin or vane type meter is used.
- to not interfere with that water flow the current meter is measuring.
- to enable easy deployment and recovery of the instrument.
- to be durable and maintain its effectiveness in the marine environment against corrosion and marine growth.
- to be vandal proof.
- to enable quick and easy location of the instrument.
- to ensure the instrument is not run over by vessels – both during the day and night.
- to be as inexpensive as possible.

Many of the above aims of a mooring system conflict, and an effective system depends on the particular project requirements and local conditions.

Most current meter manufacturers recommend particular mooring systems to be used.

The system the writer used for single current meter deployment is similar to the "U-anchoring" as illustrated on the following page.



U-anchoring **I-anchoring**

MOORING SYSTEM FOR AANDERAA CURRENT METERS

"U" ANCHORING WAS USED FOR SINGLE CURRENT METER DEPLOYMENT

The marker buoy is the most vulnerable element of the system and as such is knocked, used as a mooring by week-end fishermen and is affected by waves, tidal stage and wind. For these reasons, it is best if the instrument is not supported off the marker buoy, but from an independent, submerged flotation buoy.

Supporting the current meter from a submerged flotation buoy also results in constant tension of the line supporting the meter. The flotation buoy as well as the current meter is affected by wave and current action which moves the flotation buoy and tilts the current meter away from the vertical. The current meter only measures that component of current perpendicular to its vertical axis. Thus as the tilt of the current meter varies, the component of velocity actually being measured varies. Therefore, it is important to keep the motion of the flotation buoy to a minimum. This is achieved by maximum tension in the line between the concrete weight and flotation buoy. The larger the weight and bigger the flotation buoy, the greater is the tension achieved. However, as the size of the flotation buoy increases, so does the current drag increase.

Most current meter manufacturers supply drag coefficients and submerged weights for their meters. The amount of tilt resulting from a certain current can be calculated and thus the tilt error estimated. Alternatively, the required flotation and size of concrete weight necessary for a certain tilt limit in a particular current can be calculated. These calculations are derived in Appendix 1.

The Aanderaa current meters partly overcame the problem of slight inclination by being supported on a gymble which allowed the meter to retain its balanced vertical position up to 27° inclination of the supporting rod.

The marker buoy used in the middle of Botany Bay, position WRB 3, was a shell of a Waverider buoy including flashing light at night with the words "Danger, High Voltage" written on it. This seemed to be the only reasonably effective way of keeping inquisitive people away. However, this was not 100% effective as one Aanderaa including flotation buoy and sand anchor was stolen with only the marker buoy, tied to the concrete weight, and short length of cut stainless steel wire remaining. Hence, one aim, not always achievable, of the mooring system, is to be vandal proof.

There are various other types of mooring systems available, limited only by the inventiveness of the user. The main aim of maintaining a current meter in a fixed location is best achieved by attaching the meter to a fixed structure such as a pile. This system, however, often conflicts with the other main aim of not hindering that flow which is being measured.

The effectiveness of a mooring system can best be achieved by adopting the system to the local conditions. When it was decided to place a current meter at the Georges River entrance, the piers of Captain Cook Bridge were utilised. A 5mm diameter steel wire was tied between piers 2 and 3 (numbered from the northern bank) at a depth being 0.4 of the mean depth from the bottom.

The Aanderaa was swung from the wire rope using a stainless steel wire and shackle and a weight swung below the Aanderaa to minimise tilt. This proved to be an excellent system as far as correctly measuring currents, however provided a few practical problems.

A diver was required to deploy and recover the Aanderaa and this could only be carried out during slack tide due to the swift current at other times.

The other problem was that of navigation of deep draft vessels. Although the wire rope was considered to be deeper than the keel of the larger vessels likely to use the Georges River, large warning signs were placed on the adjacent bridge piers and a notice to mariners lodged with the Navy as well as local papers.

It can be realised, then, that the current meter mooring system, as well as being critical to the success of the project, can create many difficulties. If possible, it is better to foresee these difficulties and design the mooring system accordingly.

3. DATA ANALYSIS, PRESENTATION AND INTERPRETATION.

This section deals with the analysis and presentation of current data collected using Aanderaa RCM 4 current meters. During the three year period of this study of currents in Botany Bay, Aanderaa current meters were placed at a number of locations as shown in figure 1. The type of data analysis and presentation best suited to each location depends on the current regime particular to that location.

3.1 Data Reduction

Once removed from the current meter, the $\frac{1}{4}$" reel-to-reel magnetic tape is translated by an Aanderaa 2103 tape reader and the records read onto punched paper tape by a Facit 4070 paper tape punch.

Each 10 minute record consists of six 10 bit binary 'words'. The 'words' represent

- meter reference number
- temperature
- conductivity
- depth
- direction
- number of rotor turns.

The use of paper tape rather than magnetic tape for transfer of raw data into a computer for analysis has the advantage of the user being able to directly read the raw data manually. In this manner, many problems related to the operation of the current meter have been resolved. The majority of raw data problems occur at the beginning of the tape due to such things as the magnetic tape not having correct tension and dirty record heads. When this results in faults being read or missing sync holes, the paper tape can be 'doctored' to allow proper computer reduction. By manually reading the paper tape raw data, a problem can be more readily pinpointed to either the current meter, tape reader or computer program. This manual checking of raw data cannot be as readily achieved using magnetic tapes.

Once the raw data is read into a binary file in the computer, a program appropriately called AANDANAL, written by officers of the Maritime Services Board of N.S.W., reads the raw data and other relevant data such as location, time interval and start time and reduces the data to an easily read list of date, time, temperature, salinity, depth, direction and speed.

A copy of the first page of such an output is shown in figure 2.

In order to reduce the number of words read onto the Aanderaa magnetic tape and thus maximize deployment time, time, as such, is not recorded by the meter. The operator notes the exact time he starts the current meter and the meter will record exactly on every 10 minute interval (or whatever interval is chosen) after that.

This system of correctly 'finding' oneself on the data file with respect to time was not infallible due to the occurence of faults and unreliable records for the first two or three records on the tape. Therefore the exact number of records from the beginning was not confidently known. This problem was overcome by the writer by firstly starting the current meter on an even 10 minutes and taping the rotor to prevent it spinning.

After a few records (30 minutes say) and generally just prior to deploying the instrument, the rotor was freed and, at an off-even-ten-minute time, spun a large number of times. The time that the rotor is spun is noted, together with times in and out of the water and the time the meter is switched off.

This procedure resulted in a sequence of zero speed values followed by a high speed value at the beginning of the data tape.

The AANDANAL program was revised to recognize this event and relate it to time. As an extra check, the times in and out of the water could be checked against other recognisable events such as changes in salinity or temperature.

Any recognisable event could have been used to relate time to current records, however, change in speed was the most reliable and easily controlled.

AANDANAL reads the instrument reference number and checks this against the instrument serial number. If the two do not match it is an indication of a fault in the data.

Temperature, depth, direction and speed are calculated directly from calibration equations supplied by the manufacturer. Salinity is calculated from temperature and conductivity.

The absolute value of depth is not reliable as the depth sensor is designed for depths much greater than those encountered in Botany Bay.

The output from AANDANAL thus consisted of a header showing details of the instrument and its location, date and time the instrument was started, deployed, recovered and switched off, followed by columns of data (figure 2).

Presentation of data in this form is of little benefit apart from gaining an idea of the order of magnitude of the current velocities. At 58 records per page, each record at 10 minute intervals, results in 9 hours 40 minutes worth of current data per page or 907 pages for a year of continuous records. During the three years of current data collection, approximately 1,700 pages of computer printout of raw data has resulted - a total of nearly 100,000 10 minute records.

Clearly, in order to gain any meaningful results, or any 'design' current values a means of efficiently presenting this data is necessary. In this manner, an appreciation of the current regimes in a particular area can be gained.

UNIVERSITY OF NEW SOUTH WALES
WATER REFERENCE
LIBRARY
WATER RESEARCH FOUNDATION

3.2 Literature Search.

There is very little published on the analysis and presentation of current meter data. Generally, this aspect is mentioned in passing as a part of an overall investigation study including wind, waves and tides, with wave data attracting most attention.

Durham and Reid (Reference 3) collected 3 days of continuous current measurements in 300 feet of water over the north eastern shelf of the Gulf of Mexico. Spectral and harmonic analyses was carried out to determine the dominant tidal components present in the northward and eastward components of the current measurements. This method of analysis enabled them to confirm that tidal currents were associated primarily with the external tides of the area under study.

Tarbell and Webster (Reference 4) and Tarbell and Spencer (Reference 5) present moored current meter data collected by the Woods Hole Oceanographic Institution Buoy Group. These two reports as part of a series of sixteen, present current and associated data collected from 1966 to 1975. The chief method of presentation is by the use of various computer display plots.

For each current meter there are a number of data displays. The type of mooring system is sketched together with the location and depth of the instrument, depth of water and quality of the data.

Statistics on the current data are presented. Standard statistical parameters are calculated for data over a given time period. For a sample of speed/direction records

n = number of records

i = record number

S_i = speed

θ_i = direction from north

$E_i = S_i \sin \theta_i$

$N_i = S_i \cos \theta_i$

'A' representing either E (easterly component), N (northerly component) or S (velocity magnitude) the following is calculated.

mean $\bar{A} = \frac{1}{n}\sum_{i=1}^{n} A_i$

variance $\sigma_A^2 = \frac{1}{n}\sum_{i=1}^{n} A_i^2 - \bar{A}_i$

standard error of the mean $= \frac{\sigma_A}{\sqrt{n}}$

standard deviation $= \sigma_A$

skewness $= \frac{1}{\sigma_A^2}\left[\frac{1}{n}\sum_{i=1}^{n} A_i^3 - \frac{3\bar{A}}{n}\sum_{i=1}^{n} A_i^2 + 2\bar{A}^3\right]$

kurtosis $= \frac{1}{\sigma_A^4}\left[\frac{1}{n}\sum_{i=1}^{n} A_i^4 - \frac{4\bar{A}}{n}\sum_{i=1}^{n} A_i^3 + \frac{6\bar{A}^2}{n}\sum_{i=1}^{n} A_i^2 - 3\bar{A}^4\right]$

North and East statistics are also calculated;

covariance, $M = \frac{1}{n}\sum_{i=1}^{n} E_i N_i - \bar{E}\bar{N}$

standard deviation of covariance, $\sigma_m = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (E_i N_i)^2 - \overline{EN}^2}$

standard error of covariance $= \frac{\sigma_m}{\sqrt{n}}$

correlation coefficient, $M' = \frac{M}{\sigma_E \sigma_M}$

as well as parameters related to vector quantities;

scaler amplitude of the vector mean $V_m = \sqrt{\bar{E}^2 + \bar{N}^2}$

vector variance $V_v = \frac{1}{2}\left(\sigma_E^2 + \sigma_N^2\right)$

standard deviation $= \sqrt{V_v}$

The uses to which all of the above statistical parameters may be put depends on the reasons for collecting the data.

Progressive vector displacements are plotted. The net vector for one day is apparently calculated and plotted. This plot accentuates very low frequency events and does not detect high frequency oscillations.

Currents versus time are plotted with time-averaged currents calculated over one hour and plotted. This emphasises higher frequency oscillations such as tides.

Spectra are also plotted as well as Gausian Filtered Plots.

Gausian Filtered Plots are plots of points being the average current over a 24 hour period taken from midnight to midnight.

Vector 'sticks' are plotted along a time scale and this is a good method of showing trends in low frequency changes. A sample of vector stick plots is shown in Figure 3. The inclination of the 'stick' represents current direction and the length represents current velocity magnitude.

The analysis and presentation of data carried out by Tarbell et-al is appropriate for deep ocean moored current meter data over long durations. She presents the data in many forms. Then, depending on the use to which the data is to be put, others may use various aspects of the presentation.

The analysis and presentation of current data in a shallow estuary is different to that of deep ocean currents in that one is usually interested in a time scale of the order of a tidal cycle, i.e. hours, and not days and months as is the case in deep ocean current data collection.

Knox and Sessions (Reference 7) discuss the practical difficulties of obtaining reliable long term series of ocean current data at a remote site without the facility of a research vessel. The authors discuss the mooring methods used and discuss types of acoustic and time release systems. Their presentation of data (a 3 month period in 1977) consists of simple plots of speed, direction, east/west component, north/south component and a vector stick plot against time. Power spectral densities of the data is also presented.

As mentioned previously, the analysis and presentation of current data in shallow tidal estuaries is necessarily different to that in deep ocean studies. Deep ocean current studies are carried out and determination of tidal regimes and long term seasonal influences is of importance.

In the writer's case of shallow tidal estuaries where tidal regimes are well known, such analysis is of no real benefit other than to confirm that the currents are influenced mainly by tides. A major aim is to gain a useable relationship between tidal regime and current regime. Thence, tidal predictions can be extended to tidal current predictions.

Reference 6, under its chapter 'Parameters affecting port and ship operations', says "In the case of tidal currents, regular patterns occur and the relation between tidal movements and current velocity and direction can best be presented in a tidal flow vector diagram. In some locations, currents are more closely related to atmospheric cond itions and as such are far less predictable, so that a forecast has to be made in probabilistic terms."

The International Commission for the Reception of Large Ships (I.C.R.L.S.) of the Permanent International Association of Navigation Congress suggests that special attention be given to the interaction of currents and waves which can generate peak forces. In the report's appendix, the interaction of wave forces and currents is expounded. In summary, the relationship between wave steepness and changing current velocity is as follows and is appropriate to the case of a ship in deep water approaching a tidal harbour of shallow water depths.

In the case of increasing current speed in the direction of wave propagation, wave height and steepness decrease relative to that offshore in deep water. The case of decreasing current speed in the direction of wave propogation and indeed currents in the opposite direction to wave propogation results in an increase in wave height and steepness and possible wave breaking.

A practical example is mentioned of waves nearing a coast and entering an extended harbour basin, a tidal estuary or a tidal river flowing into the sea. The wave length, height and steepness will be influenced to a high degree by the tidal currents in the entrance channel. During rising tide (flood tide) the waves will be relatively long, low and flat while during falling tide (ebb tide) the waves will be relatively short, high and steep. The report comments that the manoeuvre of entering a port will be more difficult during falling (ebb) tide.

Thus, when a decision is made by the Harbour Master of a harbour authority as to whether or not it is safe to bring a ship into harbour, consideration needs not only to be taken of the offshore wave height and period, but also of the tidal current regime.

In fact, the above report states that "currents forecasting and prediction methods must be available for estimating the effect that this parameter has on port availability".

3.3 Analysis and Presentation - Overview.

As mentioned previously, three years of current data collection in Botany Bay has resulted in some 1,700 pages of computer printout.

This data was used for various studies from sediment transport studies around the Georges River entrance to studying current regimes encountered by large ships along the entrance channel to Port Botany.

During these studies, as in most scientific 'experiments', a 'control' was necessary. A current meter was placed in the middle of Botany Bay at position WRB 3 (Figure 1). By comparing the tidal currents at a point of interest with the 'control' tidal currents, it could be determined whether a change in currents at the point of interest was a local effect or part of an overall change in the currents field within the whole of the estuary.

The position in the middle of the bay was chosen as a control as it was thought that this location would be clear of boundary influences and would give a true representation of the overall bay currents regime. That is, it would not demonstrate any local effects peculiar to its location.

That may be true, however it was later realised that the middle of the bay was also a location plagued by large scale eddies of almost random occurence and magnitude. Thus, although a representative current velocity at this location could be used as a basis for comparing data at a site of interest at a particular time, there appears to be little relationship between currents and tides at this location. Thus for purposes of current predictions from tides, position WRB 3 is not very suitable.

In order to develop a method of relating tidal regime to current regime it was necessary to acquire fairly long term data without the added variable of large scale eddies.

A great number of variables influence the resulting current speed and direction. A few of the more obvious variables which influence current velocity within a shallow tidal estuary are tidal range, whether flood or ebb tide and net tidal flow or river inflow. Other variables which may effect current velocity are tidal stage, the immediate past tidal ranges, wind and other atmospheric conditions and changing underwater topography due to moving sediments.

The fortnightly tide of two springs and two neap tides per month affect tidal currents by 'pumping' the estuary/river up. This aspect is particularly important in pollution transport studies or salinity intrusion studies.

Many of these variables are difficult to reliably measure in a form that may be quantitatively analysed along with the current data. Thus, in order to develop a basic method by which currents can be predicted, it is desirable to elliminate the effect of as many variables as possible.

The influence of wind on water currents was investigated by applying a constant 15 knot N.E. wind over a hydrodynamic mathematical model of Botany Bay, developed by officers of the Maritime Services Board. The model was run without tides for 10 hours prototype and resulted in depth average currents of 1.0 cm/s. Hence, the effect of wind on tidal currents whose magnitude is of the order of 20 cm/s is very minimal and has been discounted in this study.

A location where large scale eddies would be negligible was at the entrance to Georges River. The location between piers 2 and 3 (numbering from the northern bank) of the Captain Book Bridge was chosen for its topographical advantages of a stable bed, fairly constant depth in the direction of flow and the practical mooring benefits gained.

A galvanised wire was strung between the piers and the current meter and weight strung from this. Flotation buoys were placed along the horizontal wire and these, together with the weight slung below the current meter ensured sufficient tautness in the vertical mooring line, to keep tilt of the current meter to a minimum. The current meter was changed by a diver. This operation had to be carried out on slack tides due to the tidal currents at other times making underwater manoeuvring very difficult.

This mooring system and the relatively protected location (protected from swell waves and long fetch wind waves) enabled regular changing of the current meter and hence continuous quite reliable records.

One obvious variable, apart from tidal influence, is the Georges River fresh water flow. Data in the form of daily flows read at Liverpool weir (the tidal limit of the Georges River) are available through the Sydney Water Board. Assuming a fairly high monthly flow of 2000 megalitres, results in an average velocity at Captain Cook Bridge of the order of 0.1 cm/s. Thus even allowing for flow many times greater than that assumed, by the time it reaches Captain Cook Bridge, the velocity due to fresh water outflow on an average is at least one order of magnitude less than the velocity due to tidal influence. For this reason, together with the fact that accurate measurements of fresh water flow at the site of interest are not available and that multivariate analysis presents a number of complexities, the variable of fresh water flow has not been included in this study.

Multivariate analysis and its applicability to tidal current analysis is discussed later.

Along with the requirement to develop a relationship between tides and resulting currents, is the necessity to reduce the amount of data to a more manageable and meaningful form. As noted earlier, it is difficult to arrive at a 'design' current velocity for a particular location by merely perusing thousands of records of current speed and direction values. Thus, the following analysis technique, as well as arriving at a quantitative relationship between tides and currents, greatly reduces the amount of data to a useful format.

3.4 Method of Data Analysis

In order to investigate any relationship between tides and currents, the tide as well as current parameters with which currents are to be represented need to be defined.

Firstly tides: The tides in shallow estuaries take significant time for their effect to be felt upstream of the estuary mouth. There is, for example, approximately 90 minutes lag between Fort Denison tide times and tide times at Captain Cook Bridge. This tidal lag is not accurately known and varies slightly depending on average tidal stage over a tidal half cycle and tidal range as well as river outflow.

Therefore, where the influence of tide on currents is being examined, it is most correct to determine tidal times by the resultant current regime, i.e., in simplistic terms, as far as the currents are concerned, high tide is when the currents change direction from upstream to downstream and low tide is when current direction changes from downstream to upstream.

The absolute value of the tidal high and low stage can still be measured at a recognised tidal station such as Fort Denison, but the relevant times of high and low tides must be determined from the current regime. In this manner, a relevant and correct period of time over which current parameters are to be calculated can be determined.

Other authors (References 4 and 5), in determining current parameters such as average speed, do so over a selected period of time. Being deep ocean studies, the period of time is generally selected as the period over which data has been reliably collected for the particular instrument at the particular location.

In the case where current parameters are being related to tidal parameters, the period over which current parameters are calculated must match the period for which the tidal parameters are calculated.

Viewing time scale plots of current speed and direction for Captain Cook Bridge, (CCB)(figure 4) it is obvious at what exact time the high and low tides occur. The direction plot is very square with abrupt changes in direction of 180 degrees and very obvious minimum values of speed at the same time as change in direction.

The plotted times of high and low tides are approximately one and a half hours prior to the obvious slack tides. The plotted tide times and heights are those read from the Sydney tidal prediction charts which are estimated from records at the Fort Denison tide gauge. The time lag between tide change and current velocity change is due to the distance upstream of deepwater of the site of interest. It is also noted that the actual time lag is not a constant value from one tide to the next and in fact varies from a lag of one hour to a lag of two hours.

Thus, it would be very difficult, if not impossible to estimate the local tide times from which to determine tidal periods to calculate current parameters. This is especially the case in the general situation where any location within a shallow estuary may be under study.

At position WRB3 in the middle of Botany Bay, the time plots of current speed and direction (figure 5) do not show the abrupt changes in direction and minimum speed values that are apparent at position CCB. Hence, the local change of tide times are not as obviously picked out from the current record plot as they are at CCB where the flow regime is more ordered.

To cover all cases of tidal flow regimes, the writer has developed a computer program which mathematically determines the time of local tide change. This program, called TIDCUR (TIDe and CURrent analysis) estimates the times at which slack tides actually occur at the site and hence the tidal half cycle period. Once this period has been determined, current parameters for that tidal half cycle are calculated. The current parameters together with tidal parameters are then presented in a useable format (figure 6). A more detailed commentary on TIDCUR is presented in the Computer Programs section.

Any current parameters could be calculated over the tidal half cycle period. The writer has calculated the mean, maximum, minimum and standard deviation of speed, direction and salinity. The parameters calculated for a particular study would depend on the use to which the data is to be put.

Tidal parameters presented are whether it is an ebb or flood half tide, the tide heights, tidal range and average tidal stage over the tidal half cycle. The tide times and heights are those of the Sydney tide charts while the local calculated tidal times are printed above the current parameters in days and minutes.

The calculated local tide times are the current meter record times. The beginning time of a tidal half cycle is the time at which the first 10 minute record of the tide half cycle was recorded. i.e. the actual theoretical beginning of a tidal half cycle is 10 minutes prior to that indicated. The end of the tide half cycle is in fact the time indicated.

Thus, once the correct tidal half cycle times have been established for the vicinity under study, meaningful relationships between tidal parameters and current parameters can be established.

3.5 Tide - Current Relationship.

This section discusses the relationship between various tidal parameters and current parameters at different locations throughout Botany Bay. The surrounding conditions at a particular location greatly effect the conciseness of the relationship between parameters. Where conditions lead to a fairly clear relationship, then the confidence intervals are relatively narrow and current parameter predictions from tidal prediction charts become quite feasible and reliable. Where conditions are such that there is little if any relationship between tidal and current parameters and confidence intervals are wide then current parameter prediction from tidal predictions is of little use.

3.5.1 Captain Cook Bridge.

At locations where tidal current flow is ordered, such as at the entrance to Georges River at Captain Cook Bridge (Figure 1) the relationships between tidal parameters and current parameters is apparent.

3.5.1.1 Absolute Tidal Range.

A plot of absolute tidal range (i.e. ebb and flood tides) against average speed over 19 days from day 80, 1979 (figure 7) shows a clear relationship of the form;

$$SA = 5.0 + 13.7 \times TR \quad - \quad \text{where } TR = \text{tidal range (m)}$$
$$SA = \text{average speed (cm/s)}$$

with a coefficient of determination of 0.71. The derivation of the curve equation was carried out using a linear regression analysis computer program written by the writer.

A brief discussion of this program (LREGPM) and linear regression analysis is presented in the 'Computer Programs' section.

Plotting all of the available data at location CCB which consists of data collected between day 259, 1978 and day 99, 1979 (205 days not continuously) the absolute tidal range versus average speed equation (figure 8) is -

$$SA = 6.7 + 14.2\ TR$$

with a coefficient of determination of 0.55. This equation covers a greater range of tidal ranges from 0.5m to 1.9m and is derived from data collected over a greater time span. Thus this set of data would include longer term seasonal variations in current flow due to dry periods and low river flow and wet periods and high river flow. This explains the significantly lower coefficient of determination. The tidal range/average speed equation for the 19 days of data is covered within the 95 percent confidence intervals of the same equation over 205 days.

Maximum speed within a tidal half cycle is plotted against absolute tidal range in figure 9 for all data collected at Captain Cook Bridge. This plot demonstrates a reasonably good relationship with a coefficient of determination equal to 0.61. The equation is

$$SM = 10.4 + 22.4 \times TR \qquad \text{where } SM = \text{maximum speed}$$

It is noted that neither the tidal range versus average speed or tidal range versus maximum speed equations pass through the origin. That is, if these equations were extrapolated back to zero tidal range, the current speed would not be zero as would be expected.

The non-zero ordinate may be due to the fact that the equation chosen to fit the data may not be exactly suitable. If it were possible to extrapolate back to zero tidal range, the curve of data may be steeper near the origin and flatten out near the range of tides being measured in this study. The curve equation is thus the curve of best fit for the tidal ranges under consideration. A discussion of various curve types is presented in the "Curve Types" section (3.5.1.3).

A plot of absolute tidal range versus standard deviation of speed is shown in figure 10 for 19 days of data from day 80, 1979. The quite low scatter of points (apart from two 'strays') and increase in standard deviation with increase in tidal range is simply due to the following. For practically all tidal ranges at Captain Cook Bridge the minimum current speed is close to zero, occuring at the change of tide. As tidal range increases, so does the maximum speed and average speed, as demonstrated above. Hence as tidal range increases, so the range of current speed values increases as does the standard deviation of speed.

Average current speed is plotted against tidal stage in figure 11 using 19 days of data from day 80, 1979. Tidal stage in this sense is defined as the average tidal stage over a tidal half cycle. There appears to be no relationship at all between tidal stage and average current speed at this location.

This is due to the fact that at Captain Cook Bridge, water depth is large compared to differences in average tidal stages. At a location where the cross section was wide and shallow it would be expected that tidal stage would have an effect on current speed.

3.5.1.2 Effect of Ebb and Flood Tides.

One variable which is readily accounted for using program TIDCUR is that of whether the tide half cycle is an ebb (outgoing) or flood (incoming) tide.

Plots of average current speed over the half tide cycle versus tidal range for ebb tides is shown in figure 12 and for flood tides in figure 13. These plots use the same data base as that for the absolute tidal range plots. The tidal range/average speed relationships are summarised in the following table.

Tidal Range	Relationship	Coefficient of Determination
Absolute	SA = 6.7 + 14.2 x TR	0.55
Ebb	SA = 4.5 + 14.8 x TR	0.70
Flood	SA = 9.2 + 13.5 x TR	0.48

Where SA = average speed in cm/s and TR = tidal range in metres.

It is apparent from these relationships and the respective coefficients of determination that the current speed during ebb tides is more dependent on tidal range than that during flood tides. The average speed value increases at a greater proportion with ebb tidal range than it does with flood tidal range.

Plots of average direction versus tidal range are shown for ebb tides in figure 14 and flood tides in figure 15.

Although there is no significant relationship between current direction and either ebb or flood tidal range, there appears to be less scatter of current direction with flood tides than that for ebb tides.

Thus, ebb tides result in fairly predictable current speed values while current direction values appear to be randomly distributed about 110°. This distribution is fairly wide, ranging from about 60° to 150°.

Flood tides result in less predictable current speed values while current direction values are distributed about 280°, demonstrating less scatter and ranging from about 250° to 290°.

Thus there appears to be an inconsistency. Average current speed varies more with flood tides while average current direction varies more with ebb tides.

Clearly, current velocity is influenced by other variables as well as tidal range. However, at the entrance to the Georges River where it would be expected that current regime be ordered, tidal range has a major influence on current regime. Meaningful relationships are able to be derived, albeit with wide confidence intervals, between tidal range and current velocity.

3.5.1.3 Curve Types

In all relationships between tidal parameters and current parameters discussed, a linear relationship of the form;

$$Y = A + BX$$

has been assumed.

This equation, or curve type has been assumed in the regression analysis as there is no reason to suggest that any other form of relationship should exist.

To confirm that this simple assumption was valid, regression analysis was carried out using four other curve types. The analysis was carried out on the same data as that plotted in figure 12; ebb tidal range versus average speed for all data at position CCB.

The following table presents the coefficients of determination for the various curve types.

Curve Equation	Coefficient of Determination
$Y = 4.5 + 14.8X$	0.705
$Y = \frac{X}{0.05 - 0.0004X}$	0.613
$Y = 35.5 - \frac{14.7}{X}$	0.678
$Y = 19.0\left(X^{0.86}\right)$	0.699
$Y = 8.5^{0.77X}$	0.640

X ≡ Ebb Tidal Range (m)

Y ≡ Average Speed (cm/s)

Thus the simple linear equation results in the highest coefficient of determination and the assumption of a linear relationship holds.

3.5.2 Middle of Botany Bay.

At location WRB3 in the middle of Botany Bay (figure 1), tidal current flow is apparently not ordered and certainly is affected by other variables as well as tidal parameters such as tidal range.

Physical model studies (Reference 2) show that position WRB3 is affected by large scale eddies. The eddy pattern is quite complex and in part is due to the airport runway and port development reclamation segmenting the bay. Reference 2 in discussing these large scale eddies observed in the physical model, comments that "slack water is not well defined; parts of the bay can be flooding while other parts are ebbing. The change from an ebb tide to a flood - and vice versa - is not a simple matter of the flow halting and reversing, but involves the action of an eddy which grows on one side of the bay and moves across to the other side".

Thus a clear relationship between tidal parameters and current parameters would not be expected at a location such as WRB3.

Plots of absolute, ebb and flood tidal range versus average speed are shown in figures 16, 17 and 18 respectively. There is no clear relationship between tidal range and current speed other than a general trend of increasing current speed with increasing tidal range. The curve of closest fit has no significance other than to highlight the general trend and is included only for completeness. The large scatter of data about the lines is demonstrated by the very low coefficients of determination. With coefficients of determination around 0.1, no significance can be attributed to differences in the values between ebb tide and flood tide curves.

Similar comments can be aimed at the plots of ebb and flood tidal range versus average direction as shown in figures 19 and 20 respectively. There is no relationship between tidal range and average direction other than that the average direction with ebb tides is randomly scattered about 100° and the average direction with flood tides is randomly scattered about 270°. The curves of closest fit are included only for completeness and no significance can be placed in them with coefficients of determination below 0.05.

Plots of other tide and current parameters were carried out but are not included here as there was no meaningful relationship determined.

Clearly then, as the confidence limits of any relationships between tidal parameters and current parameters are so wide, any current predictions based on tide charts would need to be qualified with regard to probability of occurence.

3.6 Other Forms of Current Regime Representation

At a location such as the middle of Botany Bay where current speed and direction appear to be almost random, a probabilistic approach to current prediction needs to be adopted.

One method of describing the current regime at a location such as WRB3, is that which is used to represent wind data; i.e., a rose diagram. This shows, for all directions, the probability that speed will exceed a particular value.

Probability contours on a direction/speed grid is another method of representing the current regime at a particular location.

Twenty nine days of continuous good quality data from 1020 hours on day 306, 1977 to 1010 hours on day 336, 1977 at WRB3 has been used as a sample in the following.

Probability contours have been plotted in figure 21. Each element in the array is the probability that current will flow in a particular direction at a particular speed at that location.

Each column represents a range of directions. In this case each range of directions is centred about one of 16 compass points. Each row represents a range of speeds. Hence, for example, at any one instant there is a 12.8% probability that current flow will be in an easterly direction (actually within 11.25° either side of east) at a speed of between 15 to 20 cm/s.

By interpolating between element points, probability contours may be draw. The grid chosen in this case is quite coarse and only the 1% and 2% probability contours have been plotted. A finer grid would yield more detailed information. However it is apparent from this plot that during an ebb tide it is most likely that current flow will be towards the east (90°) at 15 to 20 cm/s. During a flood tide it is most likely that current flow will be towards the west at 15 to 20 cm/s. These conclusions are borne out by perusal of the tidal range versus speed and direction plots in figures 16 to 20.

Depending on the particular aspect of the current regime which was of interest, probability plots of speed for a given direction or direction for a given speed can be derived from the speed/direction probability contour plot.

If the point of interest is for absolute speed only (i.e. direction is of no consequence) such as for the calculation of current forces on a pile, a probability of exceedence plot as shown in figure 22 can be derived. The shape of this curve indicates that current speed at WRB3 is normally distributed. Thus extrapolation to determine low probability events is possible.

Spectral analysis of this 29 days of data was carried out on both the northern and easterly current components. For each record the northern and easterly component of the current vector was calculated and the spectral analysis carried out on the resultant data.

Energy spectrum plots for the northern and easterly components are shown in figures 23 and 24 respectively. In viewing these plots it must be noted that the energy ordinate scale is an order of magnitude greater for the northern component than that for the easterly component.

These plots confirm the dominant tidal periods present at Botany Bay and also that the majority of the current energy at WRB3 is in the east-west direction.

It can be seen then, that the "best" way of representing current data at locations where there is little relationship with tidal parameters depends on the use to which the data is to be put and one good general format is that of speed/direction probability contour plots.

It is also apparent that factors other than tidal parameters affect current regime. This is discussed further in section 3.7.

3.7 Other Factors Affecting Current Regime.

There are other factors apart from tides which affect the resultant current regime.

At locations such as the mouth of the Georges River, other factors have little effect and the major influence on currents is tides as demonstrated earlier.

At locations such as WRB 3 in the middle of Botany Bay, tidal parameters do not have a unique and exclusive influence on currents as can be seen by the wide scatter of points on plots such as tidal range versus average current speed (figure 14). Clearly, then, there are other variables which combine to give the resultant current velocity. These variables include immediate tidal parameters, past tidal parameters, river fresh water flow, wind conditions, atmospheric conditions, swell wave setup and offshore longshore currents. Some of these variables have significant effect and others have little if no effect on the currents at a particular location. The effect of the large scale eddies mentioned earlier is of major consideration for locations such as WRB 3 but is very difficult to quantify.

In fact, the most direct effect on currents at location WRB 3 may be the currents at other locations throughout the bay.

The current regime at position 'R' (figure 1) may be directly related in phase and scale to that at WRB 3. On the other hand, the current regime at location 'I' may have no bearing whatsoever on that at WRB 3.

The interrelationship of current regimes at various locations throughout an estuary is of great importance in understanding the workings of the estuary.

Such interrelationships between various locations and indeed the variables mentioned above may be able to be determined by multivariate analysis such as factor analysis.

Factor analysis, used by psychologists and more recently by geologists in the analysis of grain orientation data, is analogous to linear regresssion analysis in that it determines the strength of interrelationship between variables.

Factor analysis is a very complex analysis technique about which many books and papers have been written (references 9 to 12) and has not been used in this study. However, if current data were to be obtained in a number of locations throughout an estuary over a common period of time, together with relevent data such as tidal parameters, wind parameters and river flow then the inter-dependence of all measured data could be determined by factor analysis.

Results of this type of analysis for Botany Bay would show for instance that there is a strong dependence of current velocity at Captain Cook Bridge on tidal range and a weak dependence of current speed at WRB 3 on tidal range. The inter-dependence of various locations throughout Botany Bay would also be demonstrated.

The vast amount of data obtained from current measurements is well suited to multivariate analysis such as factor analysis and there is clearly room for further work in this area.

4. COMPUTER PROGRAMS

This section describes the various computer programs used in analysing and presenting the current meter data. The programs have been written so all are compatible with each other and Aanderra current meters.

Of major importance in any data collection project is the computing cost of analysing the results. Based on present commercial computer bureau charges, the computing discussed in this section would cost approximately 5 cents per current data record.

All of the computing has been carried out on a Prime 400 mini-computer and listings of the important programs written by the writer are in Appendix 3.

4.1 AANDANAL

(Not written but modified by the writer.)

AANDANAL reads the raw data as recorded by the Aanderaa meter. Using calibration equations supplied by the manufacturer it calculates values of speed, direction, depth, conductivity and temperature. Salinity is calculated from temperature and conductivity.

The time the instrument is started is read, together with other relevant times, and current data records are related to correct time by recognising an event in the current speed values. This event is at least two zero values followed by a value greater than 10.

Printout consists of a header showing instrument location and other details and a table of relevant times, followed by columns of record times and measured data (figure 2).

4.2 AAPLOT

(Not written by the writer)

AAPLOT reads instrument and time details and record times and date from AANDANAL output. Tide times and heights are also read.

Current speed and direction is plotted separately against time and tide heights are shown at the relevent times (figures 4 and 5).

4.3 TIDCUR

TIDCUR reads data from AANDANAL output. The aim is to determine the tidal half cycles directly from current data records. If tide data from tide records or charts is available, then the derived tide half cycle current data is related to these. If no tide data is available, the analysis is still carried out but without relating the current data parameters to tidal parameters.

Determination of tidal half cycles is based on current direction. As a starting point a tidal half cycle is assumed to be 6.2 hours (37 ten minute records).

The 6.2 hour period over which the variance of direction is a minimum is taken as the basic half tide cycle. The search for the next half tide cycle is then started 3 hours worth of records hence.

As the current data record is not ideal and the basic half tide cycles do not start immediately after the previous one ended (i.e. there are gaps and overlaps in derived tide half cycles) the end and start times of consecutive tide half cycles are averaged. This average time is then taken to be the actual 'slack tide' time.

Once the start and end times of all half tide cycles have been determined, various statistical parameters are calculated over the tidal half cycle.

The average, minimum, maximum and standard deviation of direction, speed and salinity are calculated.

When available, the measured or chart tidal values are related to the derived tidal half cycles. Tidal parameters of flood or ebb, tidal range and average tidal stage are calculated. These, together with tide heights and times are presented in the printout (figure 6).

4.4 LREGPM

LREGPM (Linear REGression, Prediction and Maximisation of coefficient of determination) uses linear regression analysis to derive a curve of closest fit. The user chooses one of six of the following curves:

$$Y = A + BX$$
$$Y = Ae^{BX}$$
$$Y = AX^{B}$$
$$Y = A + \frac{B}{X}$$
$$Y = \frac{1}{(A+BX)}$$
$$Y = \frac{X}{(A+BX)}$$

By linearising the data in accordance with the chosen equation, the line of best fit is determined using the least squares method. The data is then 'delinearised' and extrapolation is carried out if desired.

The coefficient of determination is maximised by transposing the X axis for curves such as hyperbola where this is effective.

The coefficient of determination being a value between 0.0 and 1.0 is a measure of the closeness of fit of data to the curve.

Output, not shown here, consists of the curve equation, coefficient of determination, 95 percent confidence intervals of the curve equation, observed X and Y values (raw data), predicted

Y values (according to the derived curve) and 95 percent confidence limits for individual Y values.

4.5 APLT.CV

APLT.CV plots any set of data as well as the curve of best fit. The data set and curve of best fit is read from LREGPM output. Figure 7 is a typical plot.

5. CONCLUSION

In the collection of current data in an estuary, the importance of the appropriate type of current meter has been discussed. Practical considerations such as the mooring system have also been outlined.

The type of analysis and presentation to be used in any current data collection program is a major consideration.

In this report, detailed analysis of current data collected at two locations has been carried out. These locations; WRB3 (middle of Botany Bay) and CCB (entrance to Georges River) represent the two extremes of the type of current regimes likely to be encounted in estuarine waters.

Many variables affect the resulting current regime. The significance of each of these variables depends on the location, within the estuary, under consideration. At position CCB, the most significant of these variables is the tide.

At CCB there exists a strong relationship between tidal parameters and resultant current parameters. The most important tidal parameter as far as currents are concerned is the tidal range, while tidal stage has very little significance at all. There is quite a strong relationship between tidal range and both average current speed and maximum current speed. Current direction, although varying from one tide to the next, does not demonstrate a strong dependence on tidal range.

At position WRB3, variables other than tidal parameters appear to be more significant. Although the cyclic trend associated with tides is obvious in the temporal plot of current speed and direction at WRB3, the strong relationships between tidal parameters and current parameters found at CCB, do not exist at WRB3. Due to the large scale eddie action in the middle of Botany Bay, the other variables with strongest influence on the resultant current velocity at WRB3 are probably the current velocities at other locations within the estuary.

It is suggested that a form of multivariate analysis would yield the interdependence of currents at one location, as well as variables such as tidal parameters and river flow, to currents at another location.

At locations where there is a significant relationship between tidal parameters and current parameters, current predictions can be made on the basis of tidal predictions by utilising the methods outlined in this report.

UNIVERSITY OF NEW SOUTH WALES
WATER REFERENCE LIBRARY
WATER RESEARCH FOUNDATION

ACKNOWLEDGEMENTS

Many thanks are extended to the following people, without whose assistance and enthusiasm this report would not have come to fruition:

Brian Jenkins for his supervision of the project and, together with Doug Foster, Neil Lawson and Doug Treloar, for their technical advice and enlightening discussions.

Paul Kitchen, Bruce Hudson, Denis Whittard and Percy Bow for their assistance in the collection of field data.

My mother, Margaret Atkinson, for her patience in typing the manuscript and my wife, Jennifer, for her understanding and encouragement.

Reference List

1. "Current Measurement Subsystem Technology Survey" compiled by Gerald F. Appell and David R. Crump of the National Ocean Survey's Test and Evaluation Laboratory, Washington, D.C., July, 1977.

2. "Tidal Hydraulics of Botany Bay" by K. Higgs, P.D. Treloar, D.N. Foster, B.S. Jenkins and N.V. Lawson, Report No. 155, Water Research Laboratory, University of New South Wales, March, 1980.

3. "Analysis of Tidal Current Observations over the Northeastern Shelf of the Gulf of Mexico" D.L. Durham and R.O. Reid, Department of Oceanography, Texas, A. & M. University, College Station, Texas, U.S.A., April, 1967. (Unpublished report)

4. "A Compilation of Moored Current Meter and Wind Observations" S. Tarbell and F. Webster, Woods Hole Oceanographic Institution, Reference 71-50, July, 1971. (Unpublished Manuscript)

5. "A Compilation of Moored Current Data and Associated Observations" S. Tarbell and A. Spencer, Woods Hole Oceanographic Institution, Reference 78-5, March, 1978. (Unpublished Manuscript)

6. "Methods for analysing wind, wave and swell data to estimate on an annual basis the number of days, and the maximum duration of periods during which port and ship operations will be impeded by the elements. (Availability of ports and terminals)" Annex to Bulletin No.32 (Vol. 1979) of the Permanent International Association of Navigation Congress.

Referen e List (continued)

7. "Compact current meter moorings: design and preliminary results" by R.A. Knox and U.H. Sessions, Deep Sea Research, Vol. 26A, pp 109 to 119, Pergamon Press, Britain, 1979.

8. "Basic Statistical Methods for Engineers and Scientists" by A.M. Neville and J.B. Kennedy, Intertext, London, 1964.

9. "A Primer of Multivariate Statistics" by Richard J. Harris

10. "The Factor Analysis of Data Matrices" by Paul Horst (out of print)

11. "Delineation and Analysis of Clusters in Orientation Data" Shanley, R.J., Mahtab, M.A., Mathematical Geology, Vol. 8, No. 1, 1976.

12. "Mathematical Analysis of Grain Orientations", by Jizlin, Z.V., in 'Procedures in Sedimentary Petrology' by R.E. Carver, Wiley-Interscience, Chapter 13, p 313-333, 1971.

Appendix One

Size Determination of Flotation Buoy and Anchor Weight

APPENDIX ONE

SIZE DETERMINATION OF FLOTATION BUOY AND ANCHOR WEIGHT.

The tilt of a current meter must be limited if an accurate measurement of tidal current is to be achieved. In the case of Aanderaa current meters with which the writer is familiar, the current meter is suspended via a nylon gymble on a stainless steel rod. Connected to the rod is the anchor weight below and flotation buoy above. The gymble allows 27 degrees of rotation from the vertical axis with the current meter remaining vertical. Thus the angle from the vertical of the stainless steel support rod exceeds this value the tilt of the current meter occurs resulting in inaccuracies due to the savoneous rotor measuring only that component of velocity perpendicular to the major axis of the rotor/current meter.

The following derives a relationship between buoy size, anchor weight and angle of tilt for a typical single current meter mooring.

It is assumed that the mooring lines are straight, weightless and offer no drag.

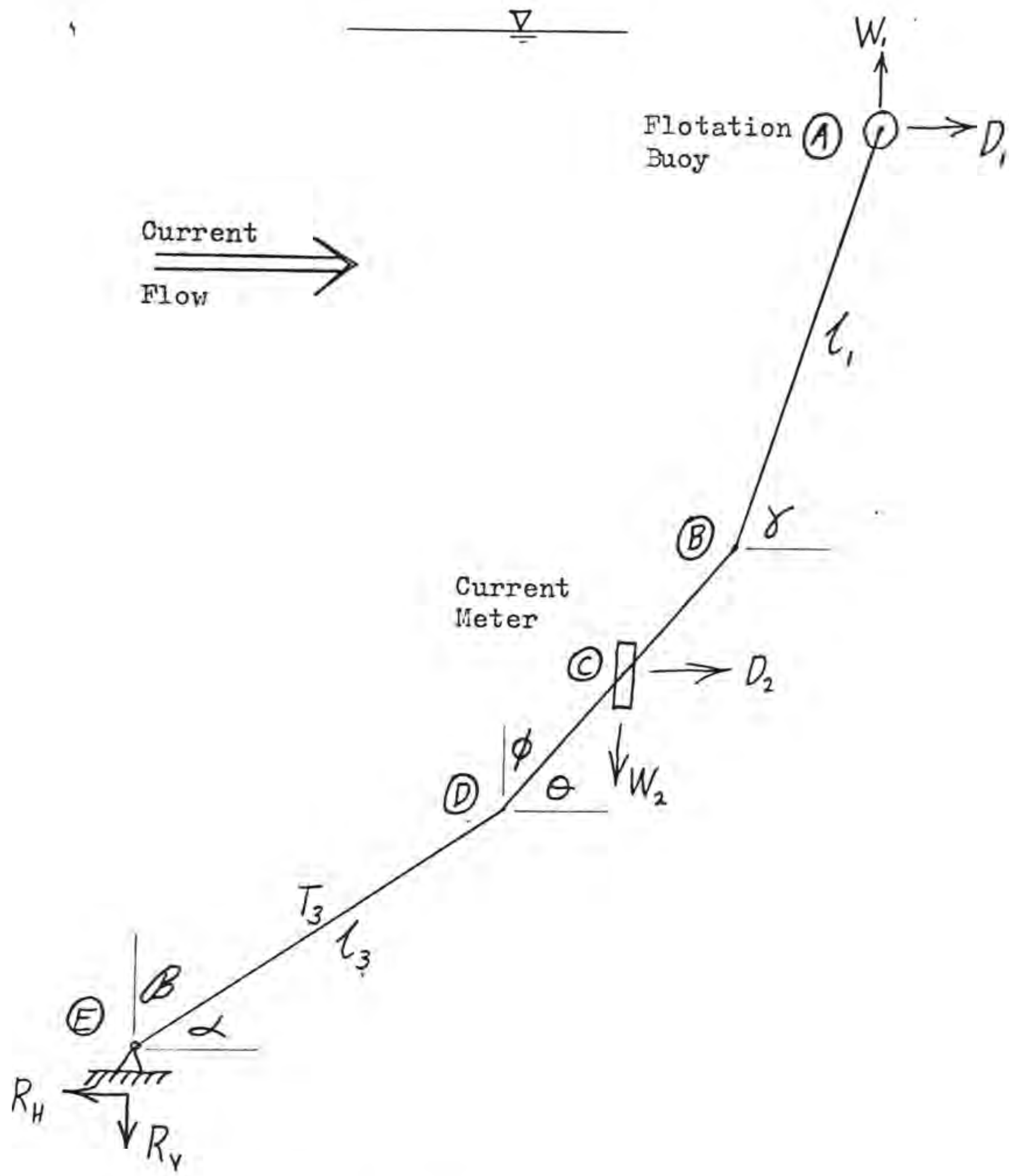
A definition sketch is presented in figure A1, page A1.2.

Summing forces and moments;

$$\Sigma F_{\uparrow} = 0 = W_1 - W_2 - R_V \qquad (1)$$

$$\Sigma F_{\rightarrow} = 0 = D_1 + D_2 - R_H \qquad (2)$$

$$\circlearrowleft \Sigma M_0 = 0 = -W_2 \tfrac{1}{2} l_2 \cos\theta - D_2 \tfrac{1}{2} l_2 \sin\theta + W_1 (l_2 \cos\theta + l_1 \cos\gamma) - D_1 (l_2 \sin\theta + l_1 \sin\gamma)$$



W_1 ≡ Net flotation of buoy

W_2 ≡ Net weight of current meter

R_V ≡ Vertical reaction; ie. minimum required anchor weight

D_1 ≡ Drag on buoy

D_2 ≡ Drag on current meter

R_H ≡ Horizontal reaction

T_i ≡ Line tension

l_i ≡ Line lengths

γ, θ, α ≡ Line angles from horizontal

ϕ ≡ Angle of tilt from vertical

β ≡ Angle from vertical of lower line

Figure A1 - Definition Sketch

$$\therefore \Sigma M_D = \tfrac{1}{2} l_2 \left(-W_2 \cos\theta - D_2 \sin\theta\right) + l_2 \left(W_1 \cos\theta - D_1 \sin\theta\right) + l_1 \left(W_1 \cos\gamma - D_1 \sin\gamma\right) \qquad (3)$$

$$\Sigma M_B = 0 = W_1 l_1 \cos\gamma - D_1 l_1 \sin\gamma = l_1 \left(W_1 \cos\gamma - D_1 \sin\gamma\right) \qquad (4)$$

Substitute (4) into (3) and divide by l_2;

$$\tfrac{1}{2}\left(W_2 \cos\theta + D_2 \sin\theta\right) = W_1 \cos\theta - D_1 \sin\theta \qquad (5)$$

Divide (5) by $\cos\theta$;

$$\tfrac{1}{2} W_2 + \tfrac{1}{2} D_2 \tan\theta = W_1 - D_1 \tan\theta$$

$$\therefore \tan\theta \left(\tfrac{1}{2} D_2 + D_1\right) = W_1 - \tfrac{1}{2} W_2 \qquad (6)$$

$$\tan\theta = \frac{W_1 - \frac{1}{2} W_2}{D_1 + \frac{1}{2} D_2} \qquad (7)$$

The angle of the lower line is also important.

$$\tan\alpha = \frac{R_V}{R_H}$$

Thus, from (1) and (2);

$$\tan\alpha = \frac{W_1 - W_2}{D_1 + D_2} \qquad (8)$$

$$\therefore \tan\beta = \frac{D_1 + D_2}{W_1 - W_2} \qquad (9)$$

The weight in water and drag of the current meter in certain velocity fields is generally given by the manufacturer and these figures are listed in reference 1. The flotation and drag of the buoy can either be obtained from the manufacture or calculated assuming a drag coefficient.

Thus once D_2 and W_2 are known the tilt angle for various available buoy sizes (W_1 and D_1 values) can be calculated to determine the buoy size resulting in less than or equal to the allowable tilt angle.

The angle of the line and the line tension between the anchor weight and the current meter is also important and is often the governing criterion. If this angle is too great, the change in vertical location of the current meter will be significant. Line tension needs to be sufficient to inhibit tangling of the line.

Once the buoy size is determined, the size of the anchor weight can be calculated using an appropriate factor of safety: the bigger the better, however the weight also needs to be able to be handled.

A typical buoy size calculation follows.

Typical Buoy Size Calculation

Aanderaa RCM4

Allowable mooring tilt angle = 27°

Current velocity: 105 cm/s

$$\therefore D_2 = 27 \ N \qquad \text{(Given by manufacturer)}$$

$$W_2 = 17.7 \ kg \qquad \text{(Buoyant force)}$$

$$= 174 \ N$$

$$D_1 = C_D \frac{\pi d^2}{4} \frac{\rho v^2}{2} \qquad (C_D = 0.5)$$

$$= 0.5 \frac{\pi d^2}{4} \times 500 v^2$$

$$\therefore D_1 = 216 d^2 \ N \qquad (d \text{ in metres})$$

Assuming the buoy material is weightless;

$$W_1 = \frac{4}{3}\pi \frac{d^3}{8} \rho_w g \qquad \rho_w = \text{water density}$$
$$= 1000 \ kgm^{-3} \text{ say}$$

$$= \frac{4}{3} \frac{\pi \times 10^3 \times 9.8}{8} d^3$$

$$= 5137 \ d^3 \ N \qquad (d \text{ in metres})$$

From equation (7);

$$\tan 27^\circ = \frac{216 d^2 + 0.5 \times 27}{5137 d^3 - 0.5 \times 174}$$

$$\therefore 2617 d^3 - 44.33 = 216 d^2 + 13.5$$
$$2617 d^3 - 216 d^2 = 57.83$$

$$\therefore d = 0.31 \ m$$

Check;

$$\therefore D_1 = 20.8 \ N$$
$$W_1 = 153 \ N$$

$$\therefore \phi = \tan^{-1}\left(\frac{20.8 + \frac{27}{2}}{153 - \frac{174}{2}}\right)$$
$$= 27.5^\circ \qquad \text{OK.}$$

Thus a buoy of 310mm diameter will limit the angle ϕ to 27°. However it is noted that for this size buoy, W_1 (buoyancy) is less than W_2 (current meter weight) and thus the angle of the lower line (equation ⑨) governs.

Allowable $\beta = 30°$ say

$$\therefore \tan 30° = \frac{216d^2 + 27}{5137d^3 - 174}$$

$$2966d^3 - 100.5 = 216d^2 + 27$$

$$\therefore 2966d^3 - 216d^2 = 127.5$$

$$\therefore d = .375$$

<u>Check</u>;

$$D_1 = 30.4 \ N$$

$$W_1 = 270.9 \ N$$

$$\therefore \beta = \tan^{-1}\left(\frac{30.4 + 27}{270.9 - 174}\right)$$

$$\doteq 30.6° \qquad \text{OK.}$$

Therefore, use a 375mm diameter buoy.

Anchor weight : $R_v = (W_1 - W_2)x$

$$= (271 - 174)5$$

$$= 485 \ N \qquad (49 \text{ kg})$$

When a particular size buoy is unavailable, a number of smaller buoys may be used with appropriate alterations to the above equations.

Large flotation buoys are often required in deep sea applications and high current fields. In these cases (generally not in shallow estuaries) line tension also needs to be checked.

Appendix Two

Figures

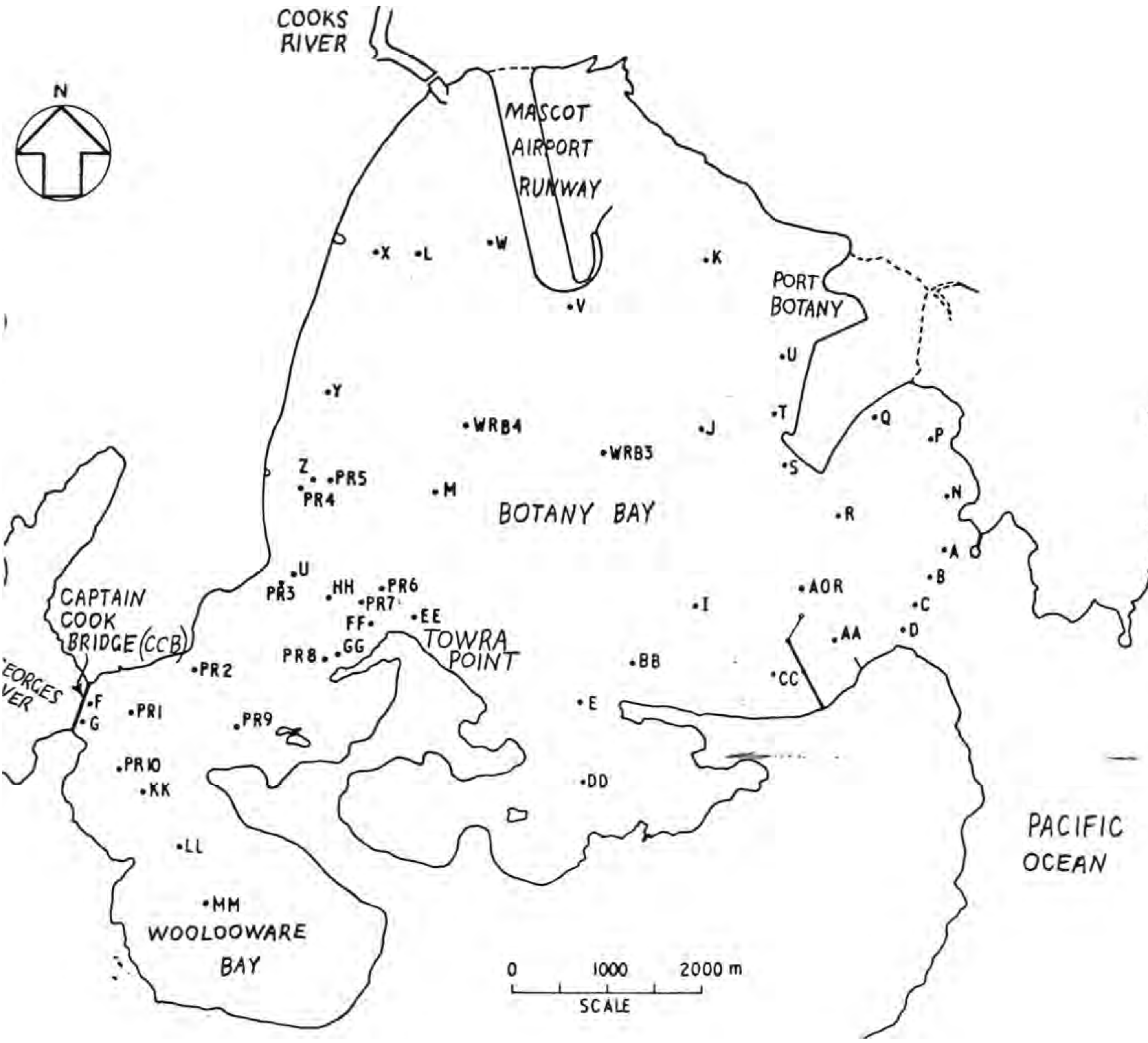


Figure 1: Botany Bay Showing Aanderra Current Meter Locations (from Reference 2)

STATION : BOTANY BAY / GEORGES RIVER
LOCATION : CAPTAIN COOK BRIDGE - BETWEEN PIERS 2 & 3
INSTRUMENT SERIAL NO: 2298
SAMPLING INTERVAL : 10
WATER DEPTH ISLW : 10.9 M
INSTRUMENT DEPTH
FROM THE BOTTOM : 4.7 M

		YEAR	DAY	TIME
TIME STARTED	:	1979	80	1040
TIME ROTOR SPUN	:	1979	80	1202
TIME IN WATER	:	1979	80	1212
TIME OUT OF WATER	:	1979	101	1550
TIME STOPPED	:	1979	101	1620

YEAR	DAY	TIME E.STD	TEMP @C	SALINITY PPT	DEPTH M.	CURRENT DIR @MAG	CURRENT VEL CM/SEC
0	0	0	22.07	0.00	-1.42	219	0.00
0	0	0	22.09	0.00	-1.42	219	0.00
0	0	0	22.09	0.00	-1.42	219	0.00
0	0	0	22.30	0.00	-1.42	359	0.00
0	0	0	24.33	0.00	-1.42	359	0.00
0	0	0	25.27	0.00	-0.98	74	0.00
0	0	0	25.48	0.00	-0.98	359	0.00
1979	80	1210	25.87	0.00	-0.53	34	47.98
1979	80	1220	23.06	33.67	4.53	273	20.54
1979	80	1230	23.06	33.67	4.38	272	23.06
1979	80	1240	23.09	33.87	4.23	272	23.62
1979	80	1250	23.06	33.83	4.08	269	23.62
1979	80	1300	23.06	33.89	4.08	269	21.94
1979	80	1310	23.06	33.89	4.08	271	19.98
1979	80	1320	23.13	34.06	4.08	268	19.42
1979	80	1330	23.11	33.91	4.08	270	17.46
1979	80	1340	23.13	33.95	4.08	270	16.06
1979	80	1350	23.25	34.02	4.08	270	14.66
1979	80	1400	23.18	34.08	4.08	270	11.58
1979	80	1410	23.18	34.08	4.23	271	9.62
1979	80	1420	23.20	34.06	4.23	270	8.78
1979	80	1430	23.18	34.08	4.38	270	7.94
1979	80	1440	23.16	34.09	4.53	270	6.54
1979	80	1450	23.16	34.04	4.67	270	3.18
1979	80	1500	23.13	34.00	4.67	266	1.78
1979	80	1510	23.11	33.96	4.67	226	5.70
1979	80	1520	23.11	33.96	4.82	220	7.94
1979	80	1530	23.11	33.96	4.82	216	9.62
1979	80	1540	23.11	33.96	4.82	160	11.02
1979	80	1550	23.16	33.82	4.82	152	12.42
1979	80	1600	23.16	33.93	4.82	146	11.86
1979	80	1610	23.16	33.98	4.82	124	14.10
1979	80	1620	23.13	34.00	4.82	122	12.14
1979	80	1630	23.18	33.97	4.82	122	15.22
1979	80	1640	23.18	33.91	4.97	121	15.78
1979	80	1650	23.18	33.91	4.97	119	15.50
1979	80	1700	23.16	33.93	4.97	119	14.10
1979	80	1710	23.13	33.84	4.97	119	15.78

FIGURE 2: AANDERAA CURRENT METER DATA - AANDANAL OUTPUT

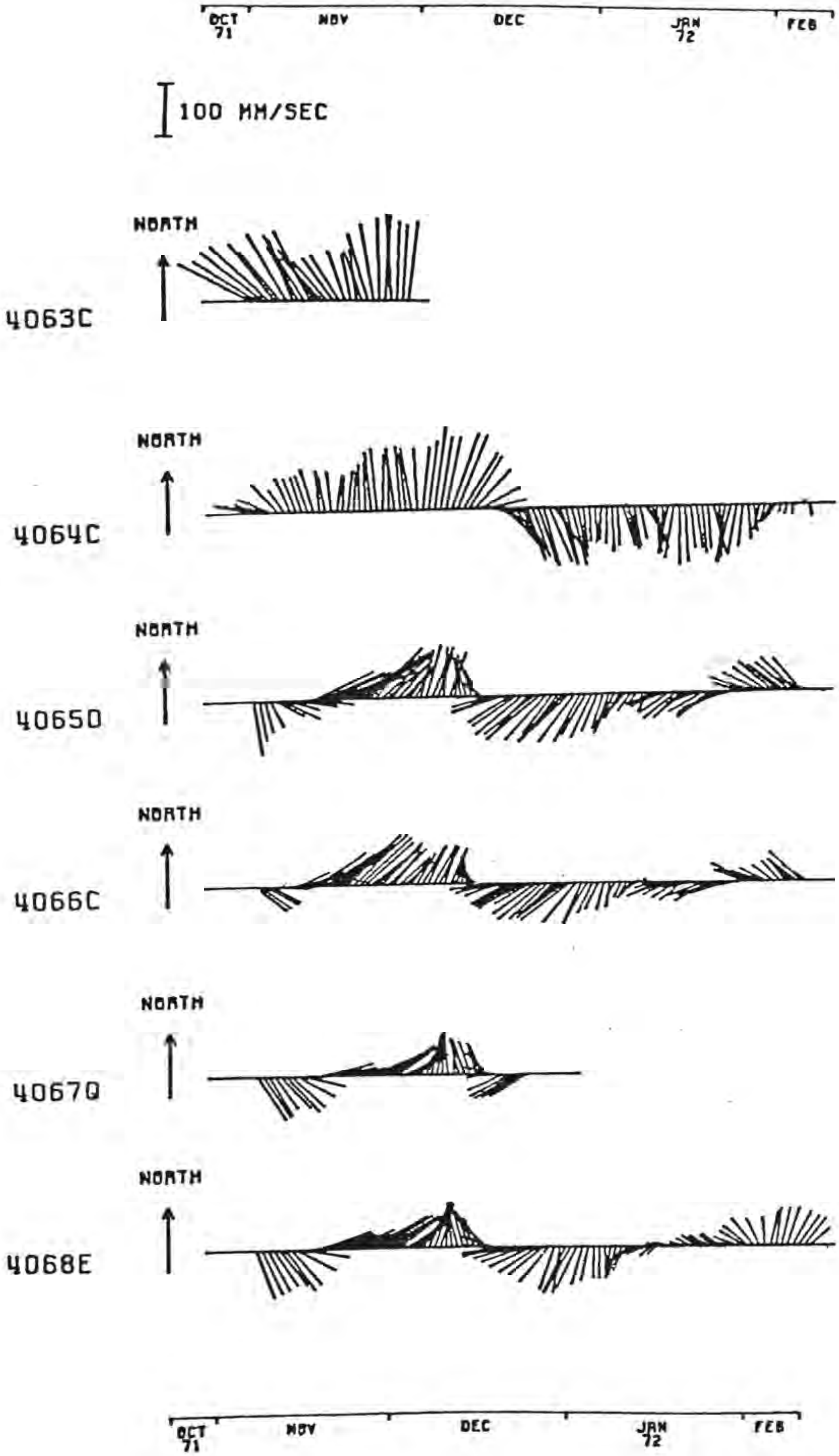


FIGURE 3: VECTOR STICK PLOT (FROM REFERENCE 5)

FIGURE 6: TYPICAL TIDCUR OUTPUT

DATE: 1979/ 80 AANDERAA NO.: 2298 LOCATION: CAPTAIN COOK BRIDGE - BETWEEN PIERS 2 & 3

FROM 80 1500 TO 80 2100 (37 RECORDS)

	AVE.	STD. DEV.	MAX.	MIN.
DIRECTION	156.86	58.423	269.00	108.00
SPEED(cm/s)	10.82	3.985	15.78	1.78
SALINITY	33.71	0.213	34.00	33.20

EBB TIDE: FROM 80 1351 (1.20 m) TO 80 1937 (0.60 m)
AVE. TIDAL STAGE: 0.90 m
TIDAL RANGE : -0.60 m

FROM 80 2110 TO 81 340 (40 RECORDS)

	AVE.	STD. DEV.	MAX.	MIN.
DIRECTION	267.82	17.669	359.00	222.00
SPEED(cm/s)	20.13	8.127	32.30	-1.00
SALINITY	33.90	0.261	34.22	33.33

FLOOD TIDE: FROM 80 1937 (0.60 m) TO 81 216 (1.50 m)
AVE. TIDAL STAGE: 1.05 m
TIDAL RANGE : 0.90 m

FROM 81 350 TO 81 1020 (40 RECORDS)

	AVE.	STD. DEV.	MAX.	MIN.
DIRECTION	127.82	18.566	216.00	96.00
SPEED(cm/s)	16.92	6.154	26.98	2.62
SALINITY	33.60	0.385	34.20	33.05

EBB TIDE: FROM 81 216 (1.50 m) TO 81 905 (0.50 m)
AVE. TIDAL STAGE: 1.00 m
TIDAL RANGE : -1.00 m

FROM 81 1030 TO 81 1630 (37 RECORDS)

	AVE.	STD. DEV.	MAX.	MIN.
DIRECTION	271.24	2.306	274.00	266.00
SPEED(cm/s)	15.89	6.620	23.34	0.00
SALINITY	33.73	0.230	34.08	33.29

FLOOD TIDE: FROM 81 905 (0.50 m) TO 81 1510 (1.20 m)
AVE. TIDAL STAGE: 0.85 m
TIDAL RANGE : 0.70 m

FROM 81 1640 TO 81 2230 (36 RECORDS)

	AVE.	STD. DEV.	MAX.	MIN.
DIRECTION	151.61	59.086	272.00	96.00
SPEED(cm/s)	11.96	4.831	18.58	-1.00
SALINITY	32.72	5.535	34.02	0.00

EBB TIDE: FROM 81 1510 (1.20 m) TO 81 2054 (0.60 m)
AVE. TIDAL STAGE: 0.90 m
TIDAL RANGE : -0.60 m

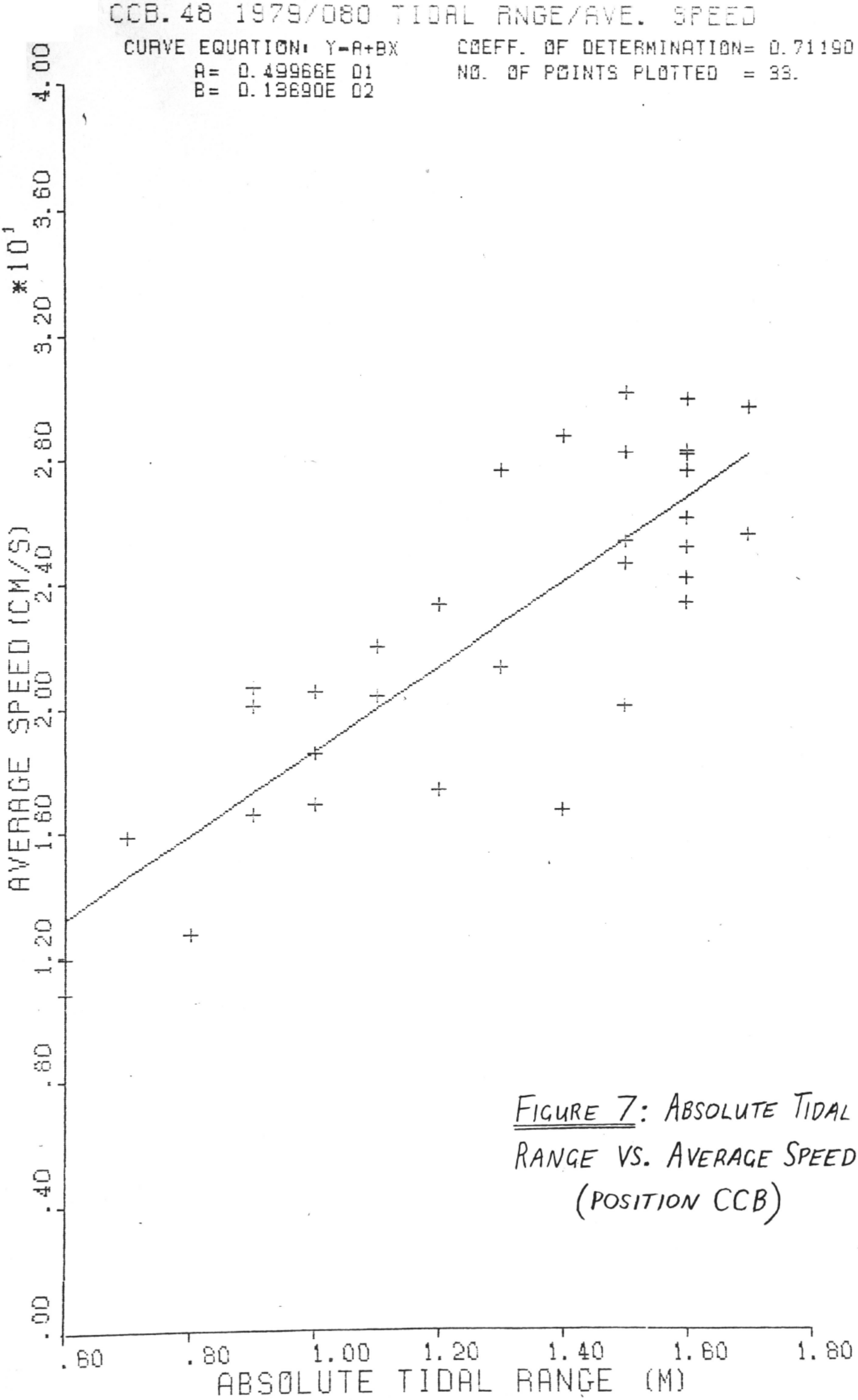


FIGURE 7: ABSOLUTE TIDAL RANGE VS. AVERAGE SPEED (POSITION CCB)

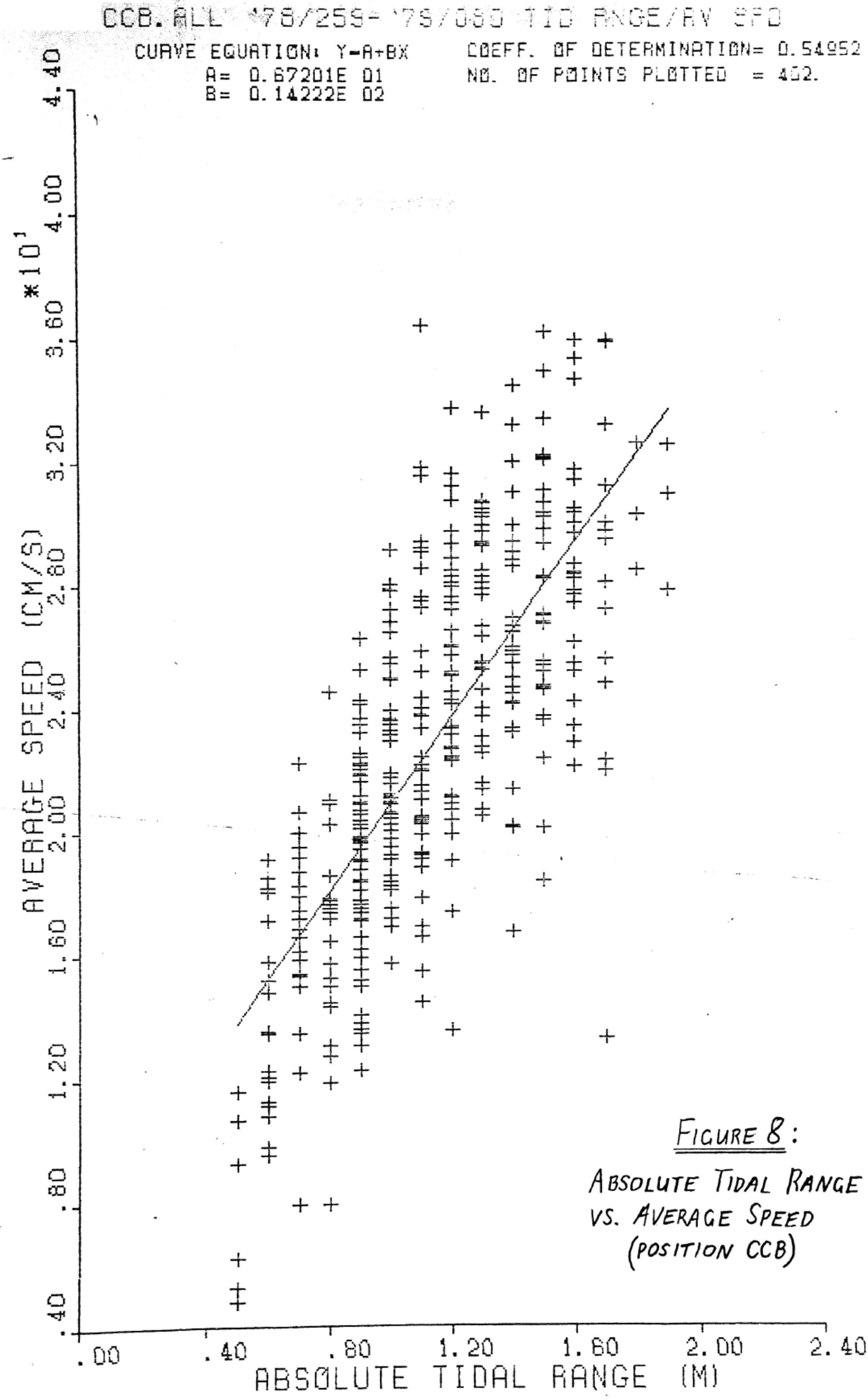


FIGURE 8: ABSOLUTE TIDAL RANGE VS. AVERAGE SPEED (POSITION CCB)

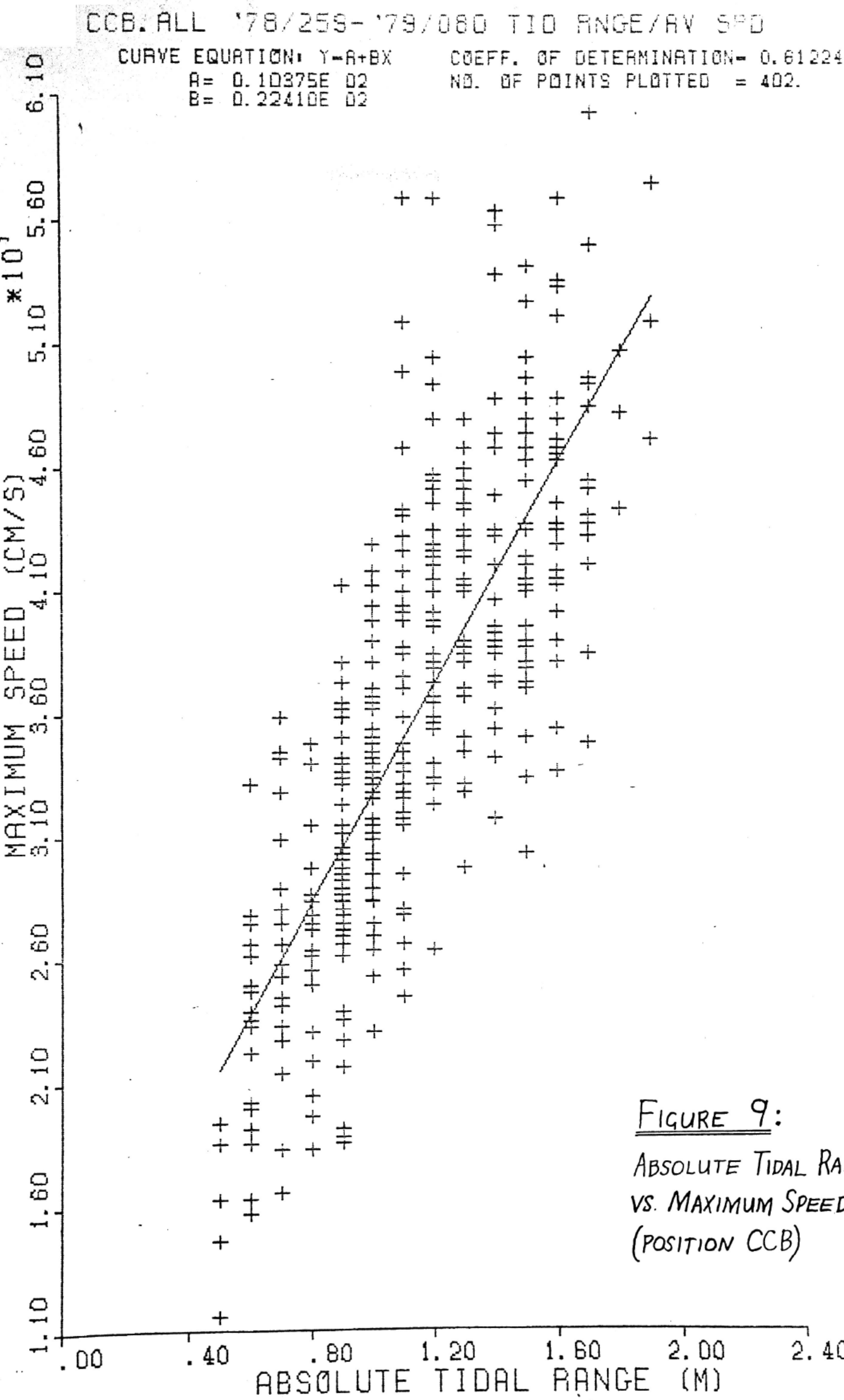


FIGURE 9:
ABSOLUTE TIDAL RANGE VS. MAXIMUM SPEED (POSITION CCB)

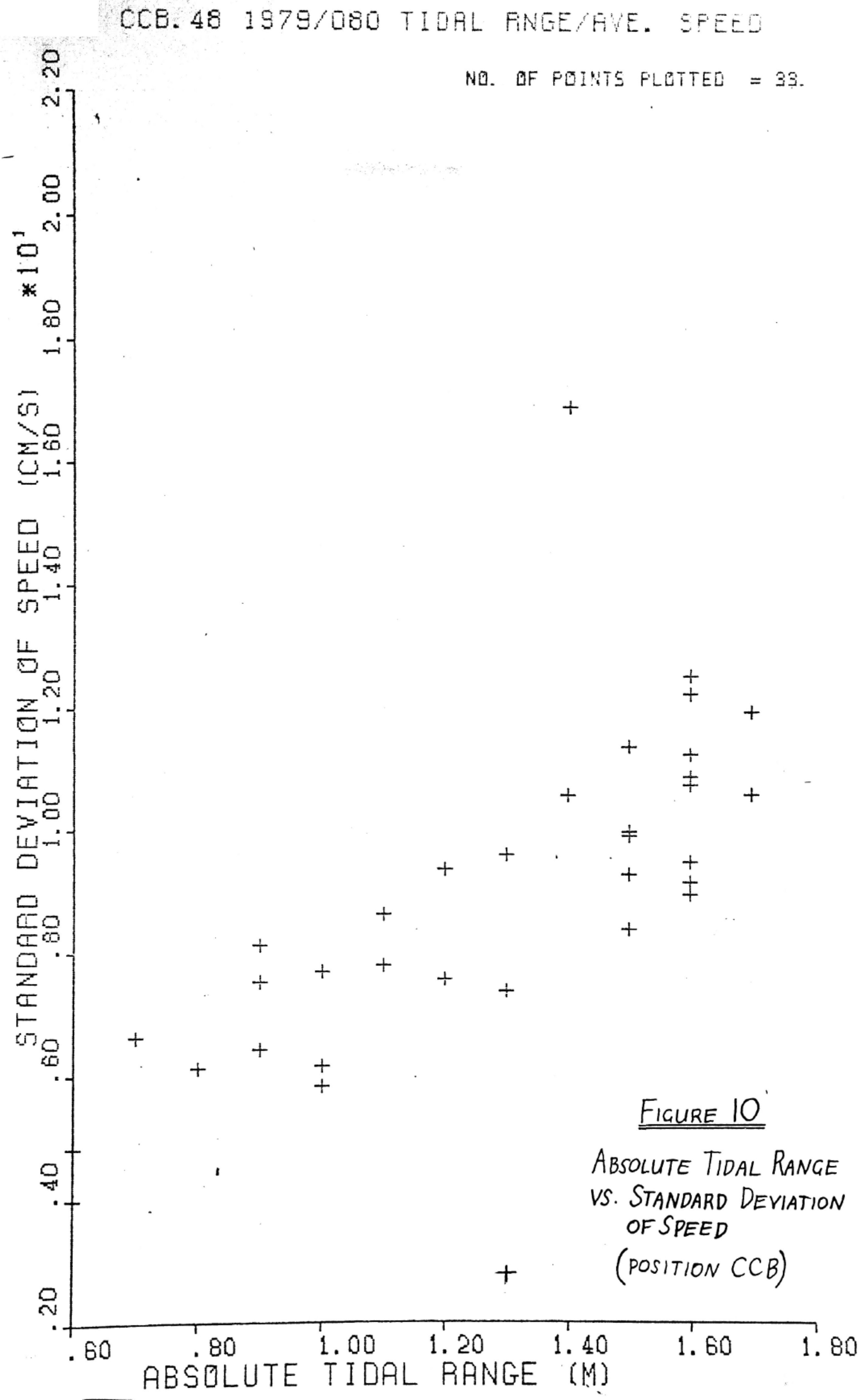


FIGURE 10

ABSOLUTE TIDAL RANGE VS. STANDARD DEVIATION OF SPEED (POSITION CCB)

CCB. 48 1979/080 TIDAL RNGE/AVE. SPEED

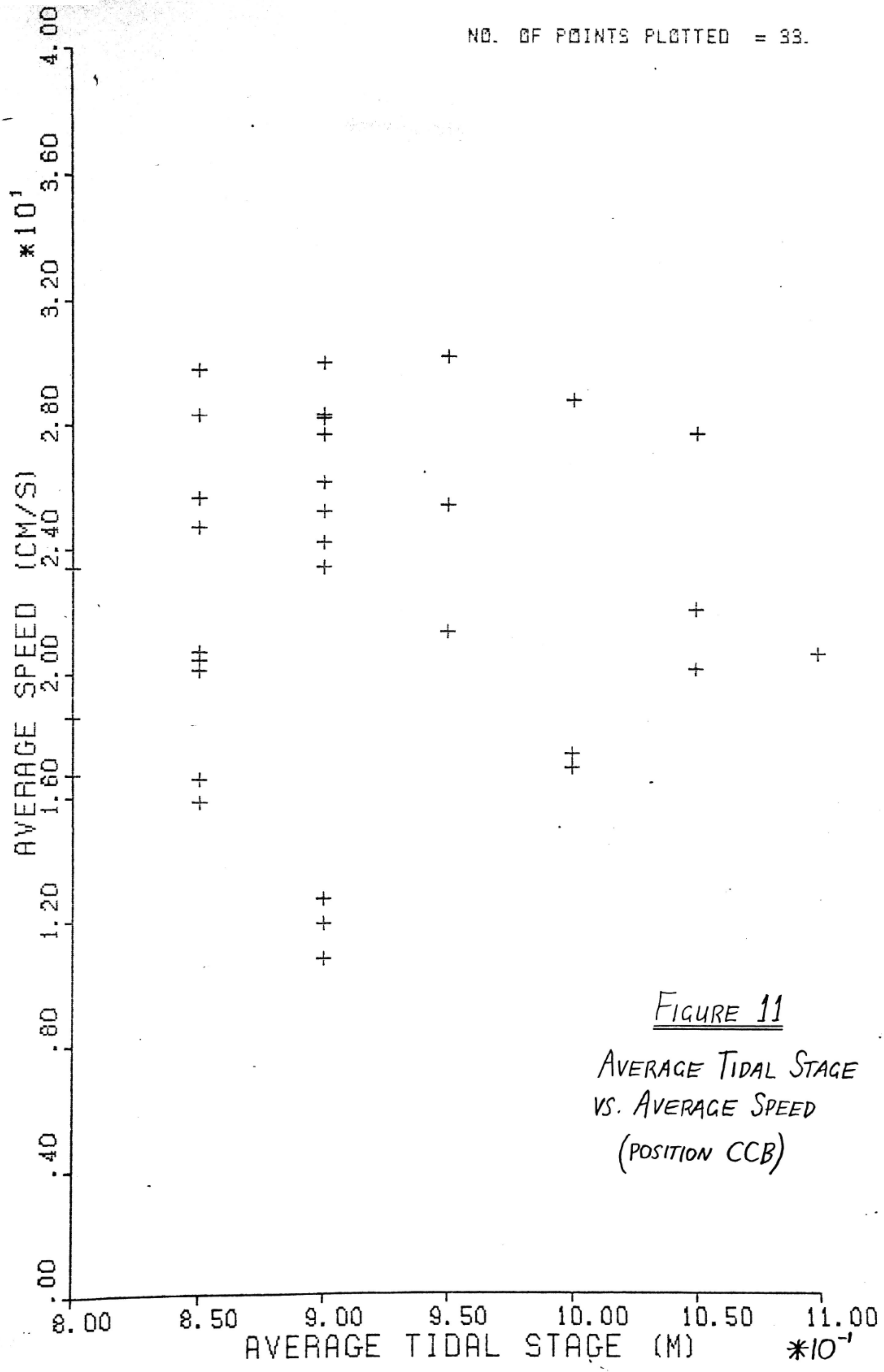


FIGURE 11

AVERAGE TIDAL STAGE VS. AVERAGE SPEED (POSITION CCB)

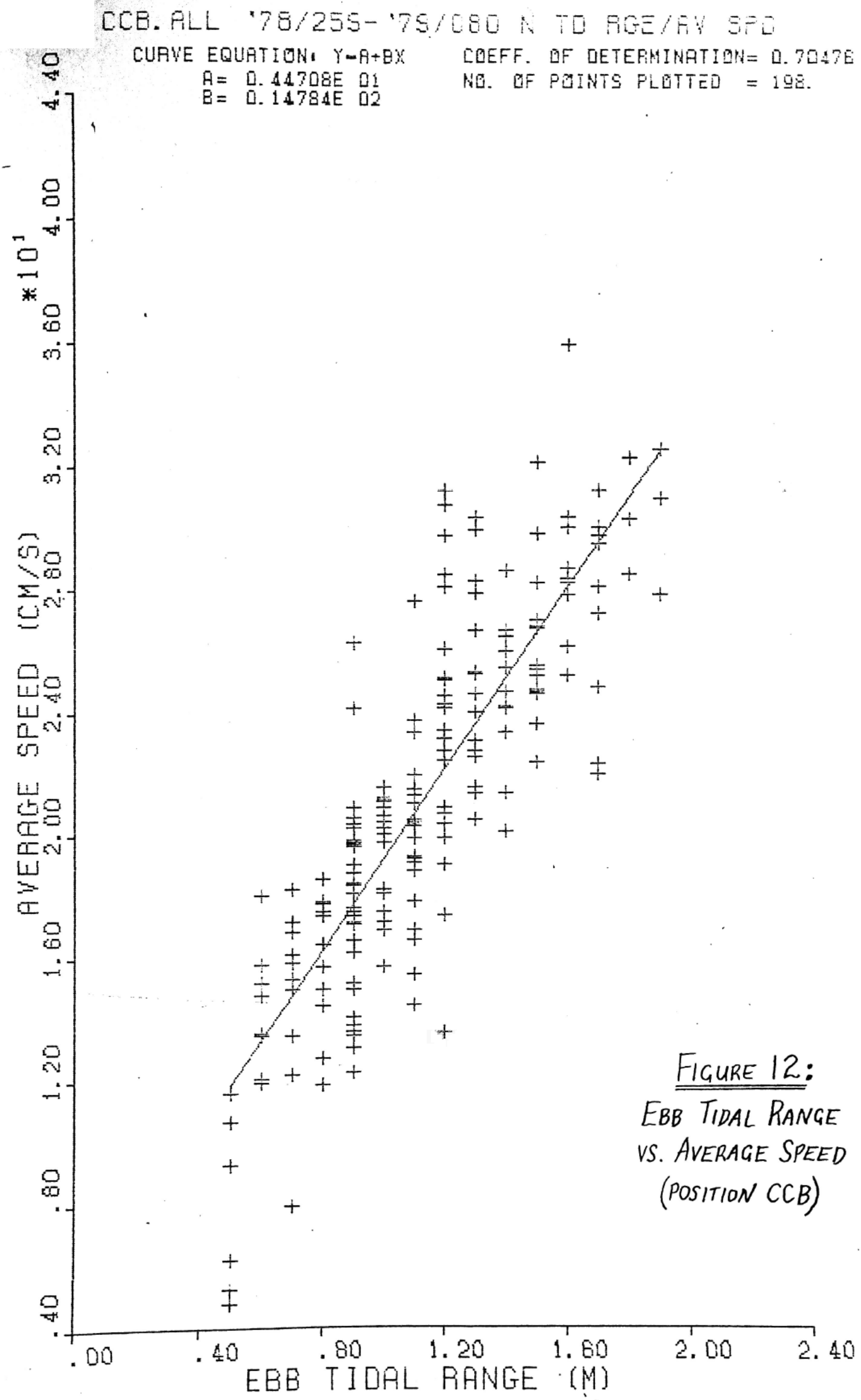


FIGURE 12: EBB TIDAL RANGE VS. AVERAGE SPEED (POSITION CCB)

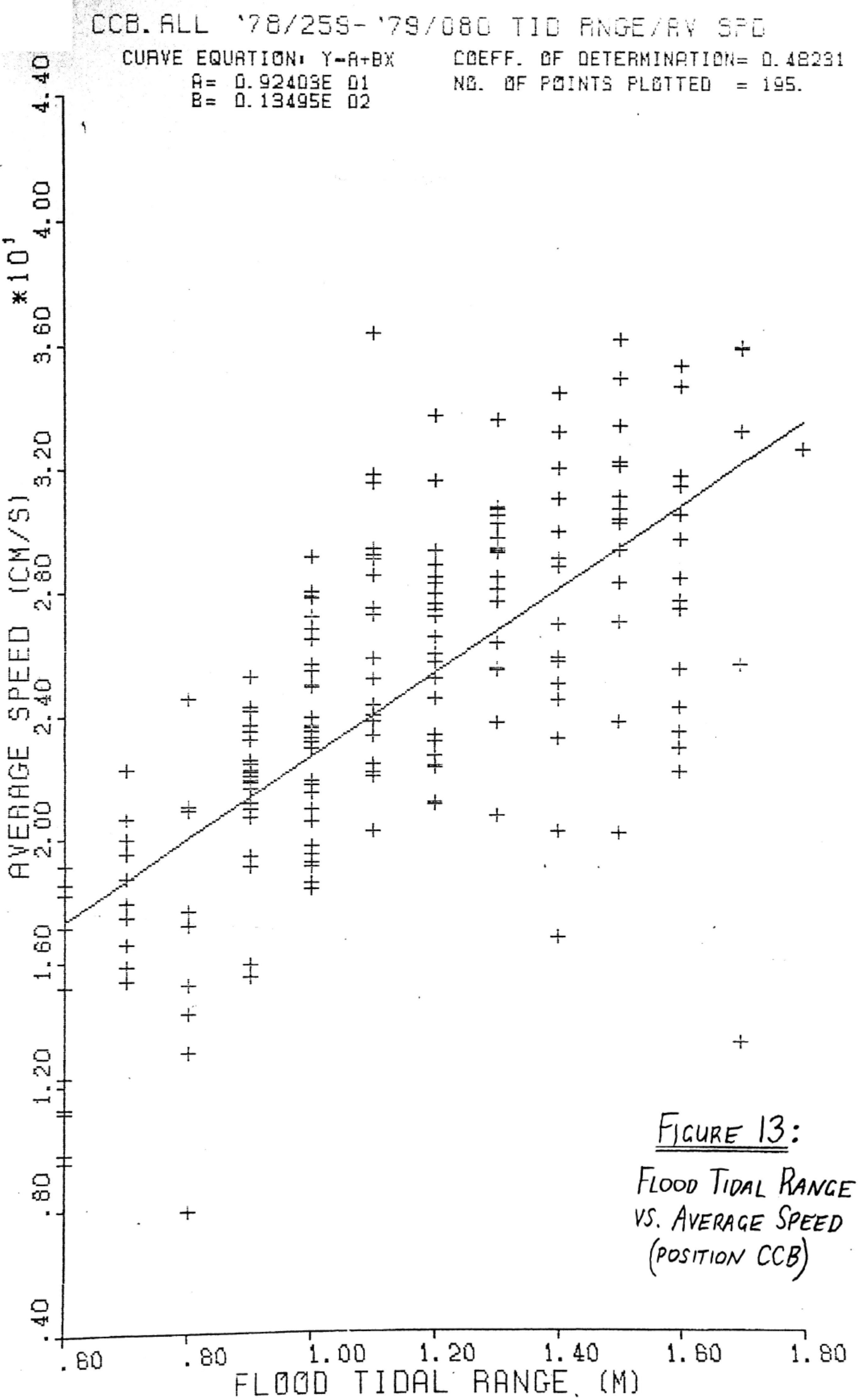


FIGURE 13:

FLOOD TIDAL RANGE VS. AVERAGE SPEED (POSITION CCB)

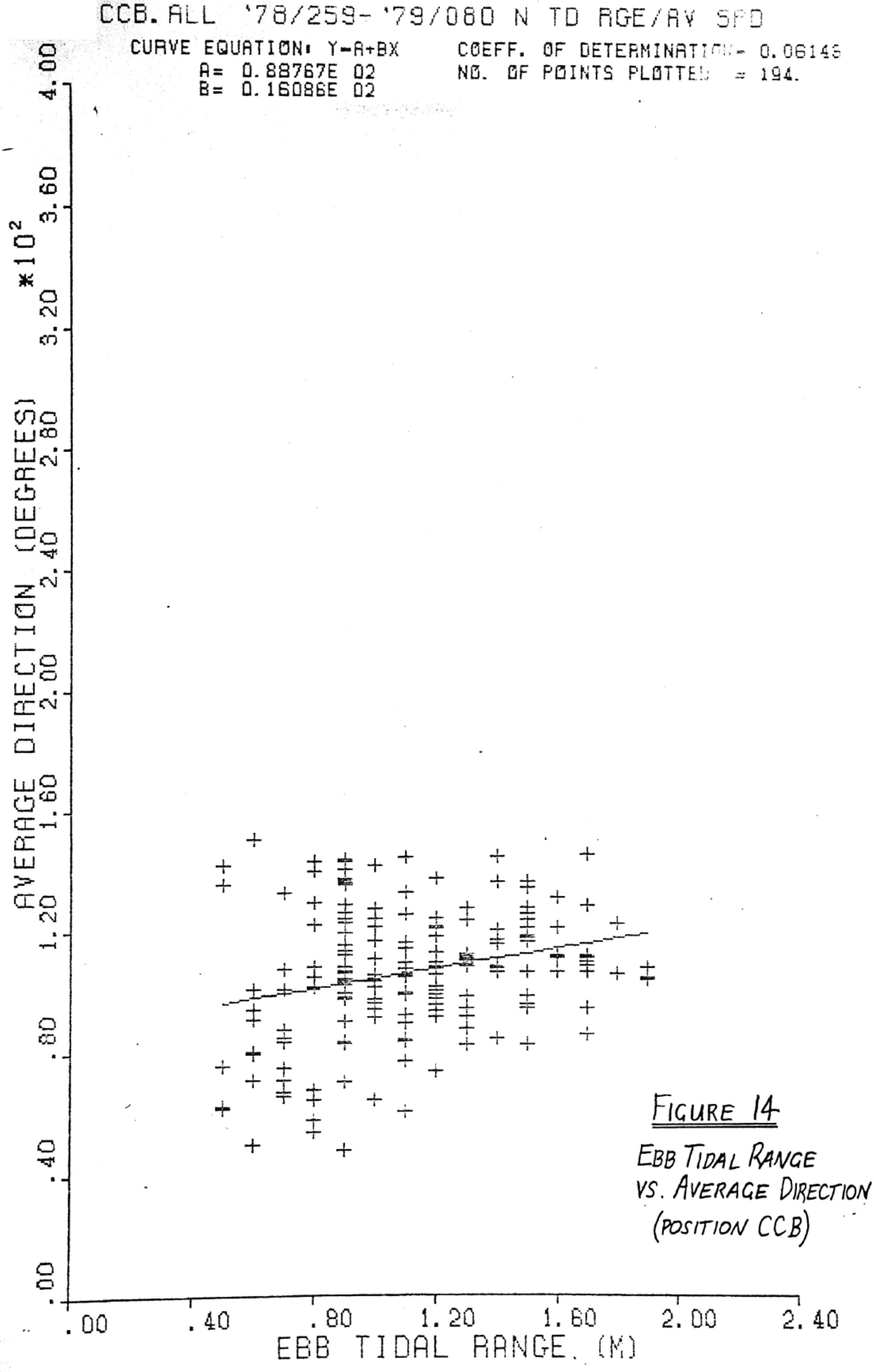


FIGURE 14

EBB TIDAL RANGE VS. AVERAGE DIRECTION (POSITION CCB)

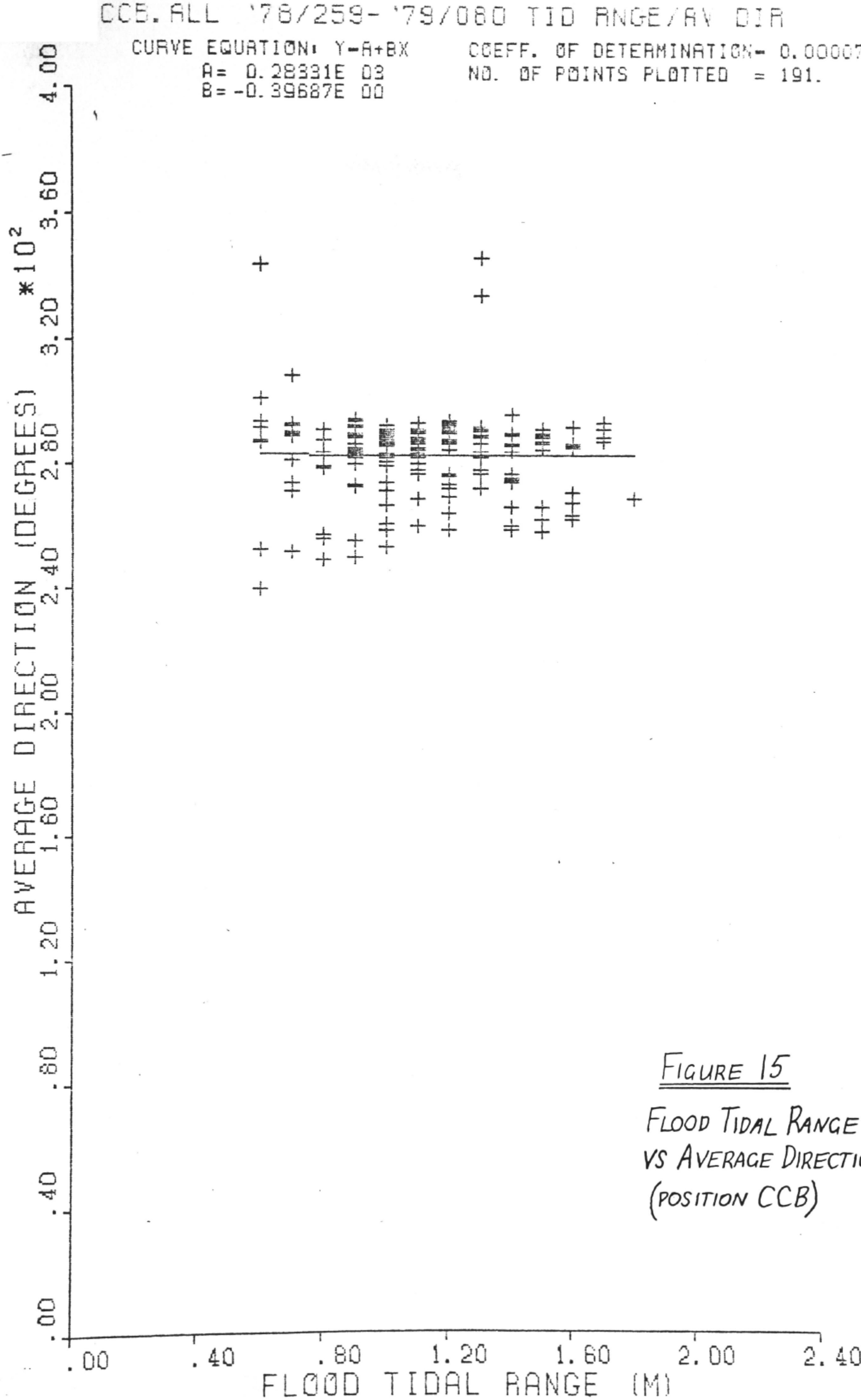


FIGURE 15

FLOOD TIDAL RANGE VS AVERAGE DIRECTION (POSITION CCB)

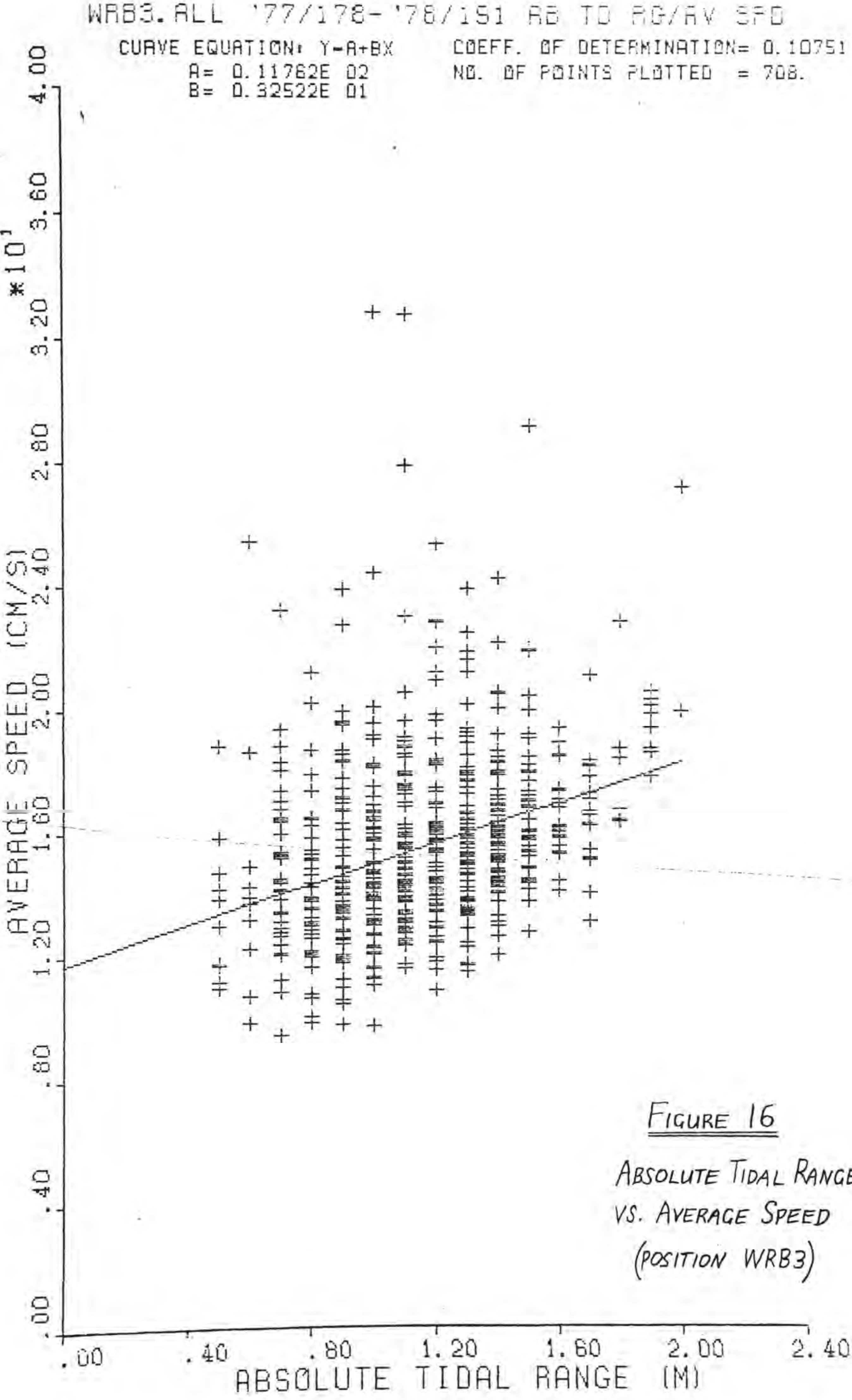


FIGURE 16

ABSOLUTE TIDAL RANGE VS. AVERAGE SPEED (POSITION WRB3)

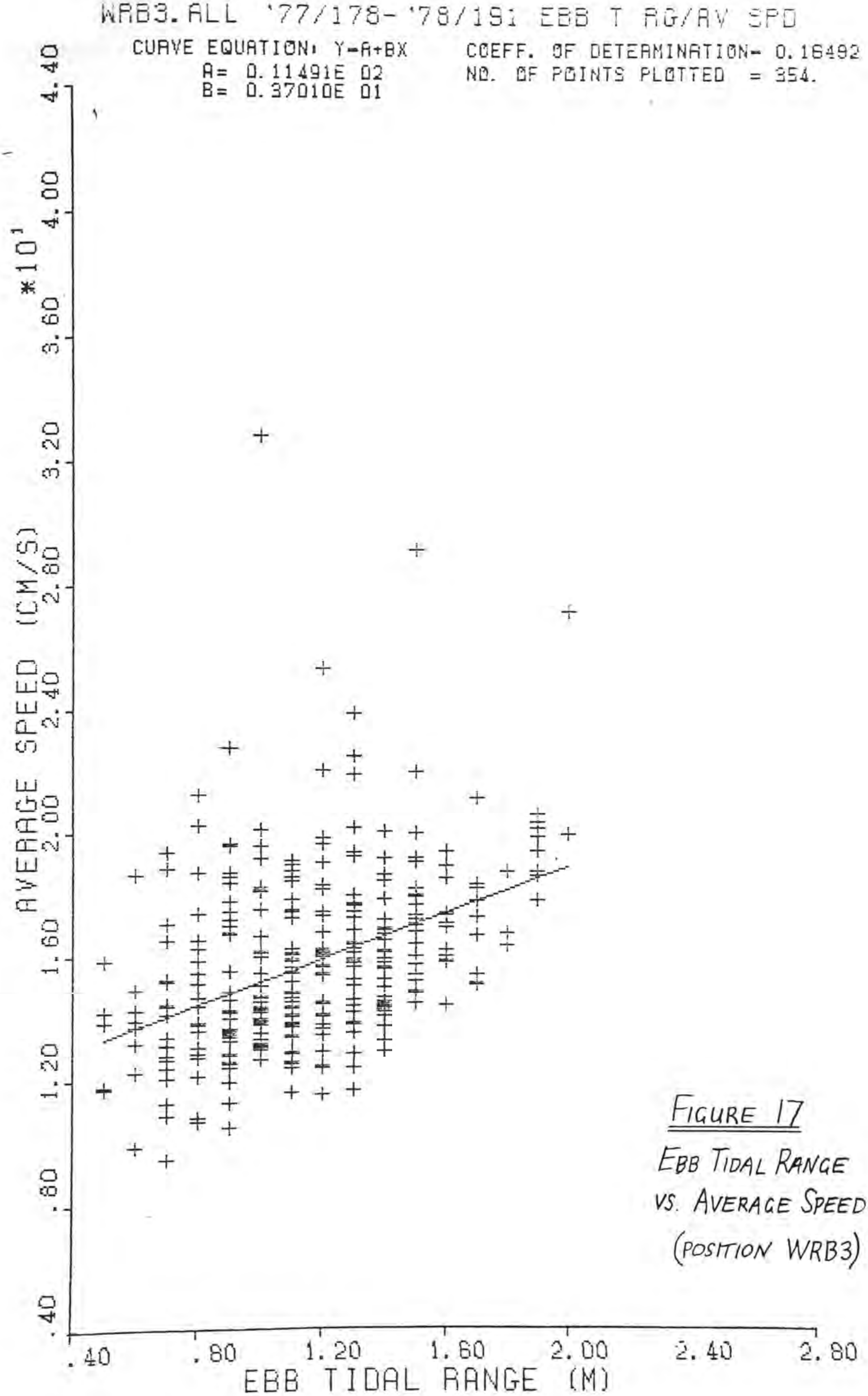


FIGURE 17
EBB TIDAL RANGE vs. AVERAGE SPEED (POSITION WRB3)

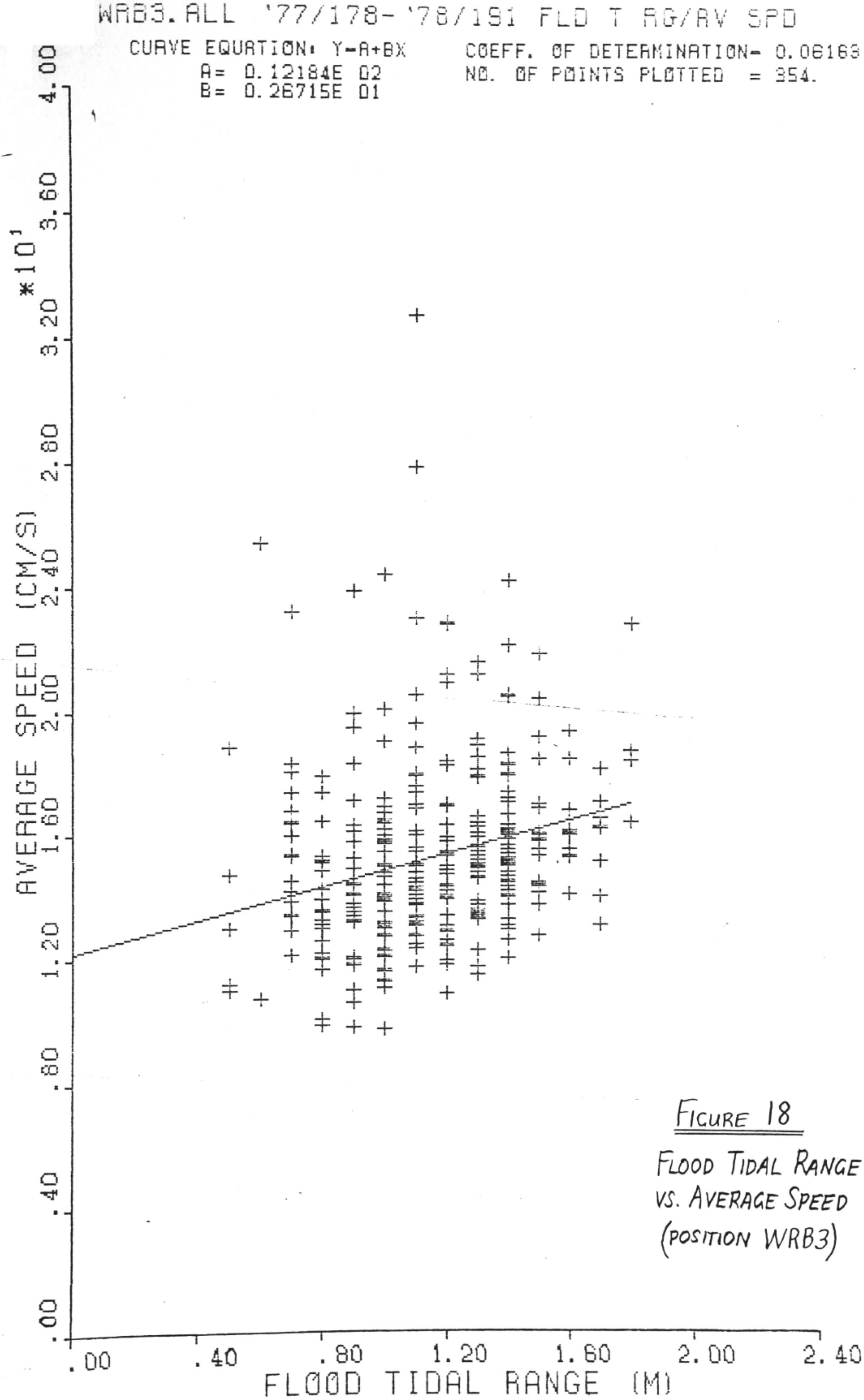


FIGURE 18

FLOOD TIDAL RANGE VS. AVERAGE SPEED (POSITION WRB3)

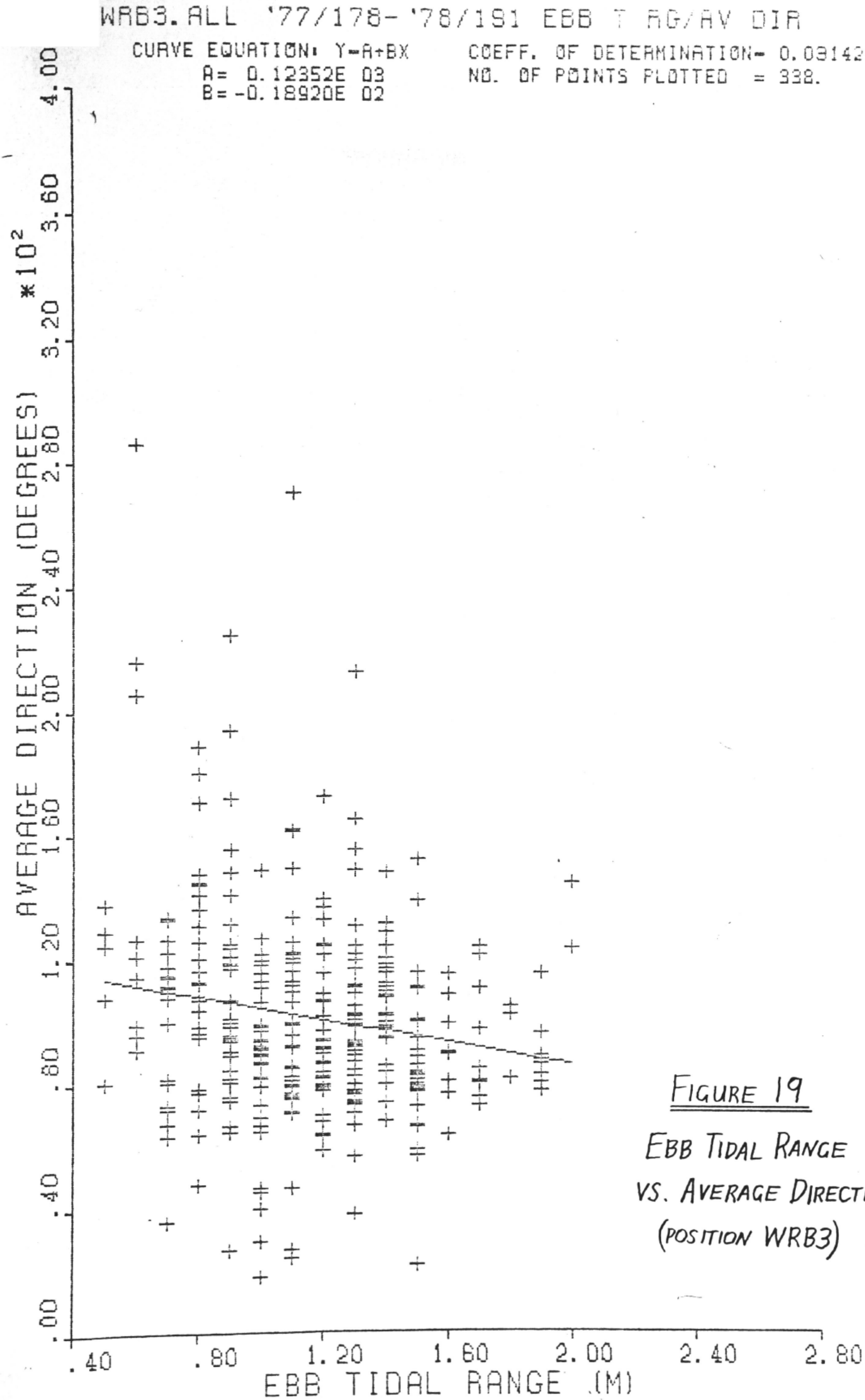


FIGURE 19

EBB TIDAL RANGE VS. AVERAGE DIRECTION (POSITION WRB3)

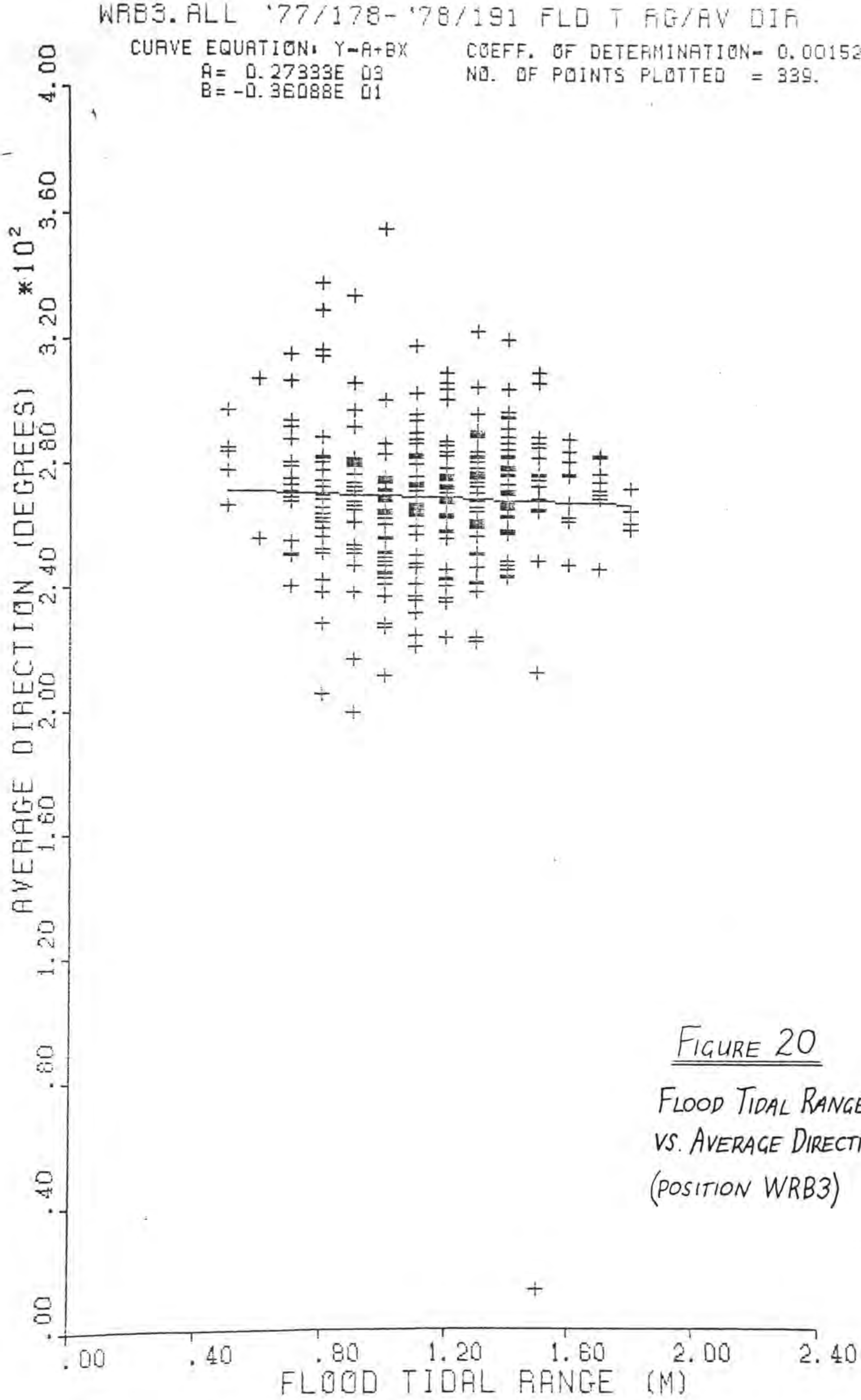
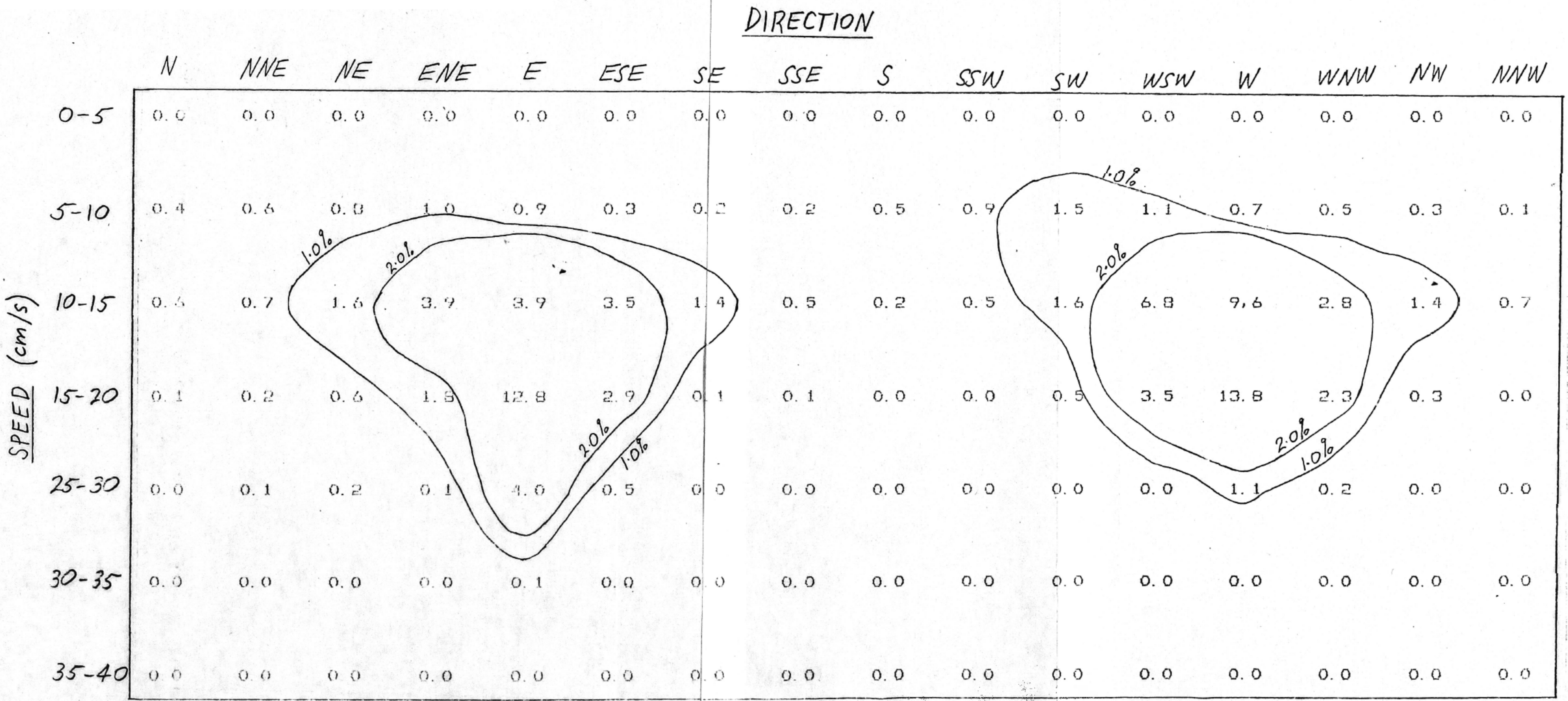


FIGURE 20

FLOOD TIDAL RANGE VS. AVERAGE DIRECTION (POSITION WRB3)



SPEED/DIRECTION PROBABILITY
CONTOUR PLOT
(POSITION WRB3)

FIGURE 21

CURRENT SPEED VS. PROBABILITY OF EXCEEDENCE AT WRB3

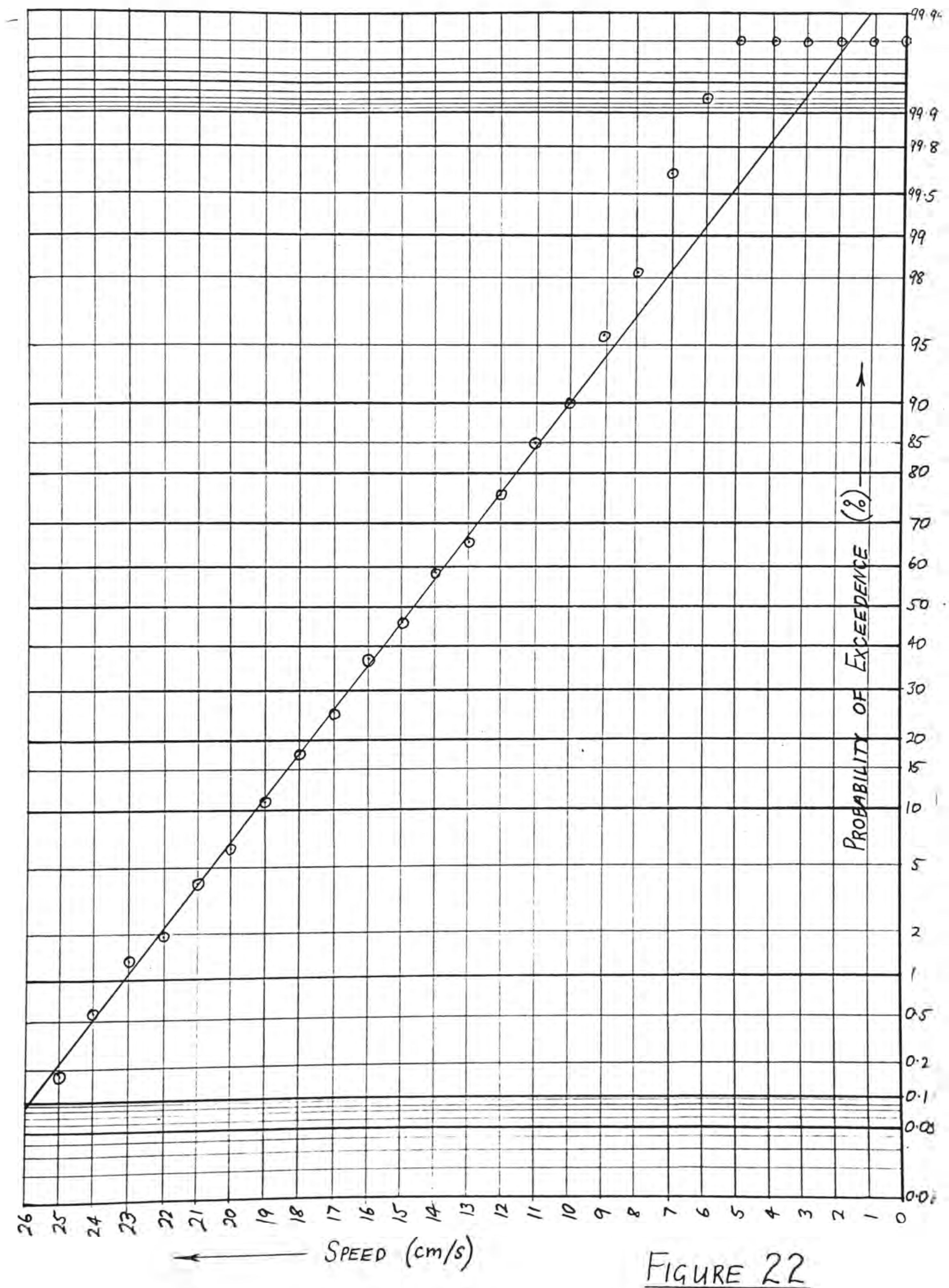


FIGURE 22

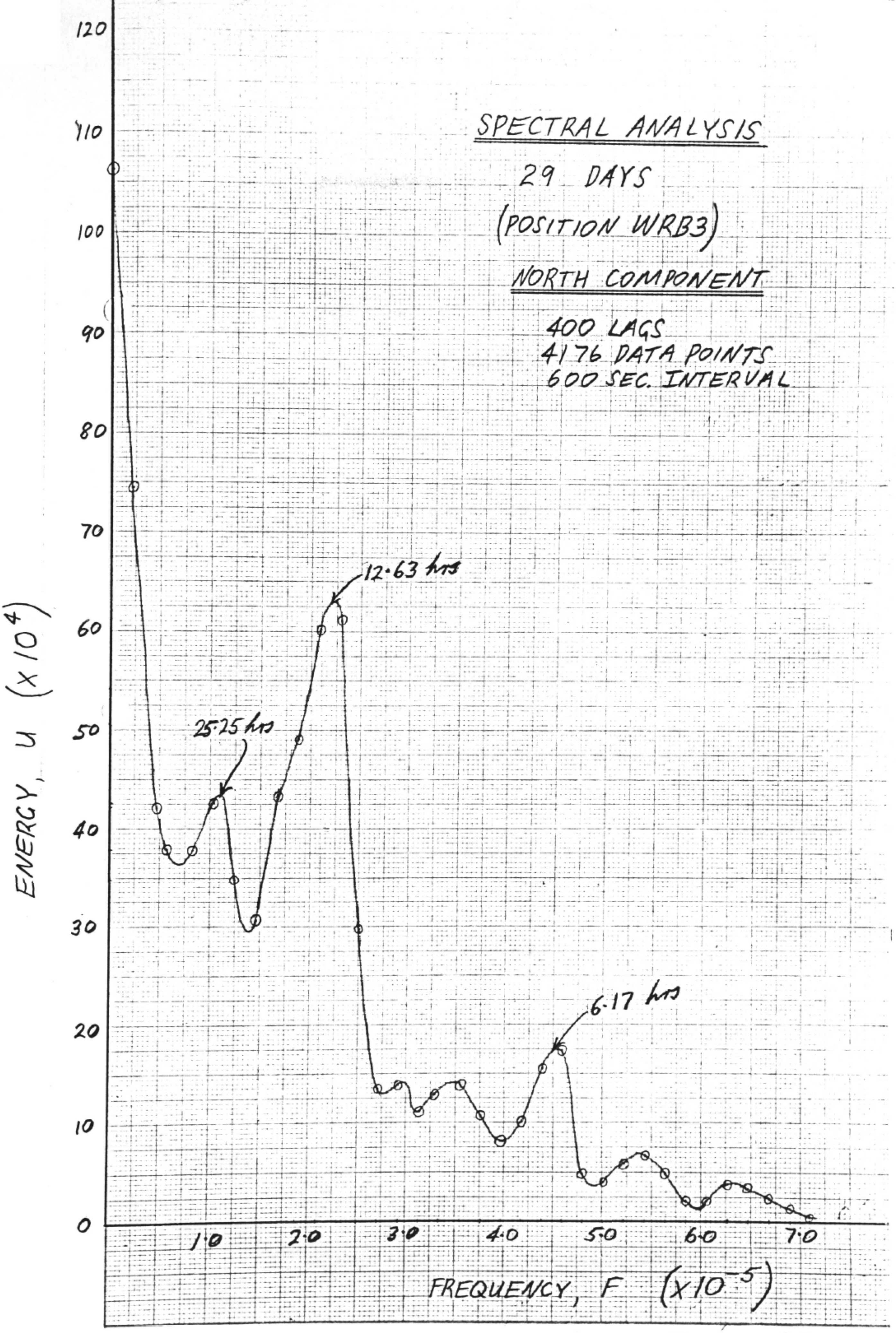

SPECTRAL ANALYSIS
29 DAYS
(POSITION WRB3)
NORTH COMPONENT
400 LAGS
4176 DATA POINTS
600 SEC. INTERVAL
12·63 hrs
25·25 hrs
6·17 hrs
ENERGY, U ($\times 10^4$)
FREQUENCY, F ($\times 10^{-5}$)
0
10
20
30
40
50
60
70
80
90
100
110
120
1·0
2·0
3·0
4·0
5·0
6·0
7·0

FIGURE 23

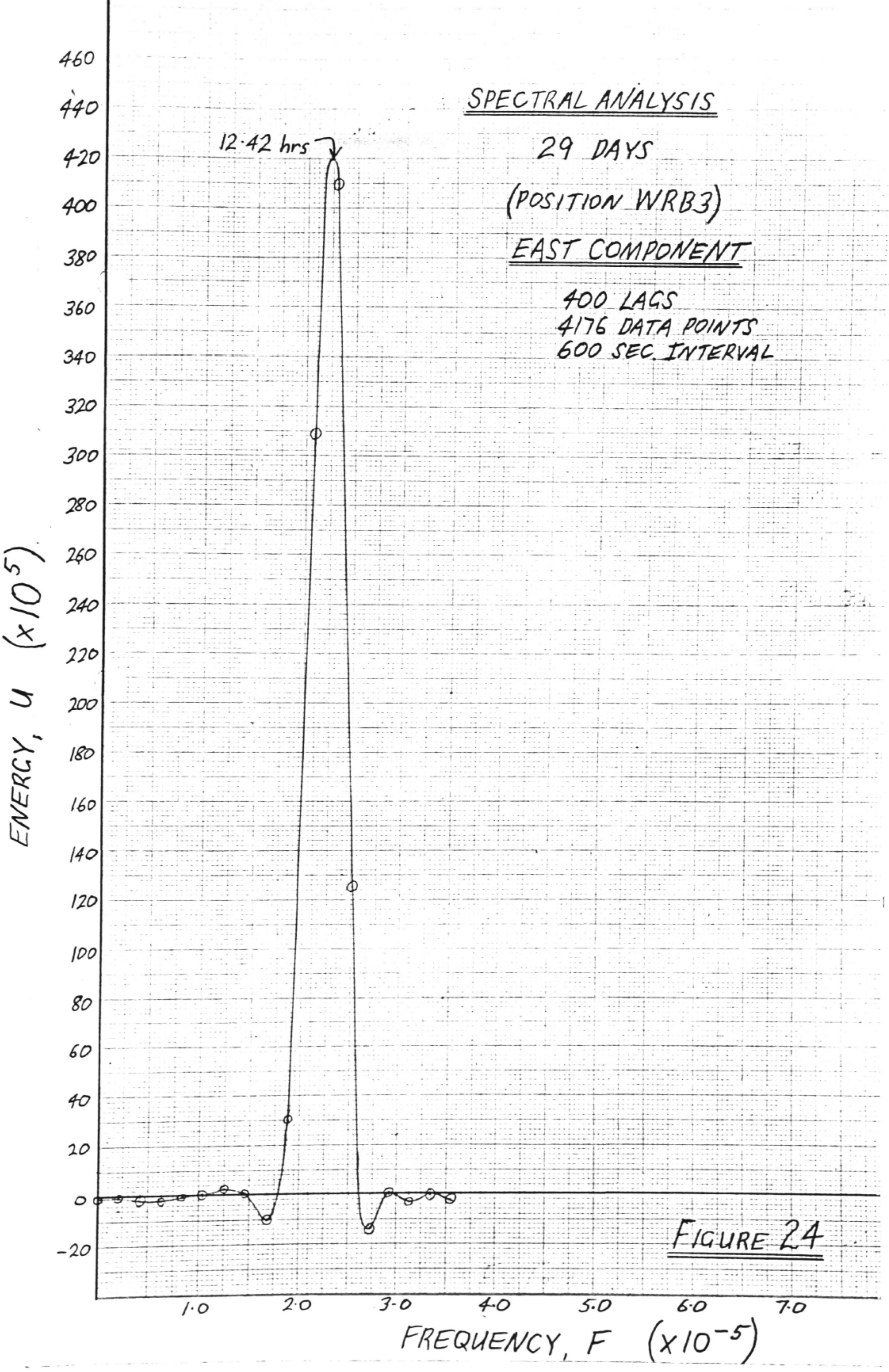

SPECTRAL ANALYSIS
29 DAYS
(POSITION WRB3)
EAST COMPONENT
400 LAGS
4176 DATA POINTS
600 SEC INTERVAL
12·42 hrs
ENERGY, U (x10^5)
FREQUENCY, F (x10^-5)
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
1·0
2·0
3·0
4·0
5·0
6·0
7·0

FIGURE 24

Appendix Three

TIDCUR Listing

C DETERMINATION OF TIDAL CYCLES FROM CURRENT DATA 'TIDCUR'

```
C           DETERMINATION OF TIDAL CYCLES FROM CURRENT DATA    'TIDCUR'
C
C      THIS VERSION READS CUURENT DATA FROM AANDANAL OUTPUT
C      ...SAME AS PJC'S AAPLOT
C
C      THIS UPDATED (4/8/80) VERSION READS FROM EITHER OLDER TYPE AANDANA
C      OUTPUT OR NEWER TYPE: THAT WITH A DATE/TIME HEADER TABLE
C
C************************   MAIN   ********************************
C
$INSERT SYSCOM>A$KEYS
$INSERT SYSCOM>KEYS.F
$INSERT SYSCOM>ERRD.F
      PARAMETER IHT=37     /*  No. records per half tide cycle
      PARAMETER JUMP=18     /*No. records per 1/4 tide cycle.
      DOUBLE PRECISION TC
      LOGICAL TYN
      INTEGER DATEY,DATED,DATET           /* DATE: YEAR, DAY, TIME.
      INTEGER THISD,THIST,PREVD,PREVT
      INTEGER*4 ITT,IT1,IT2,IAVET,IT
C     REAL NEW
      DIMENSION CDATA(40),OUT(40)
      DIMENSION TDATA(40)
      DIMENSION IDIR(5000),IT(5000),ID(5000)
      DIMENSION LS(1000),LE(1000)
      DIMENSION S(5000),V(5000)
      DIMENSION XD(100),XV(100),XS(100)
      DIMENSION X(100),Y(100)
      DIMENSION IDT(1000),ITT(1000),TIDE(1000),IAVET(1000),IAVED(1000)
      DIMENSION ATIDE(1000),TR(1000),TC(1000)
      DIMENSION LOCAT(26),INSTO(2)
      DIMENSION NEW(2)
      CALL ATTDEV(7,7,7,0)      /*TIDE DATA
      CALL ATTDEV(10,7,10,0)      /*CURRENT DATA
      CALL ATTDEV(9,7,9,0)      /*OUTPUT
      CALL TONL
      CALL OPNP$A('NAME OF CURRENT DATA FILE  ',27,A$READ+A$SAMF,CDATA,8
     10,10)
      CALL TONL
      TYN=YSNO$A('HAVE YOU ANY TIDE DATA',22,A$DYES)
      IF(TYN) GO TO 1
      GO TO 3
    1 CALL OPNP$A('WHERE IS IT THEN - ',19,A$READ,TDATA,80,7)
    3 CALL TONL
      CALL OPNP$A('WHERE DO YOU WANT YOUR OUTPUT - ',32,A$WRIT,OUT,80,9)
      CALL TONL
      I=0
      PRINT 1021
 1021 FORMAT('READING FROM YOUR CURRENT DATA FILE NOW.')
C
C      DETERMINE IF CURRENT DATA FILE IS OF THE OLDER OR
C      NEWER TYPE; ie has a DATE/TIME header table or not.
C
C      NEW='TIME'  :  New type.
C      NEW=' DAY'  :  Old type.
C
      READ(10,3000)NEW
 3000 FORMAT(9(/),5X,2A2)
```

```
      CALL CLOS$A(10)
      CALL OPEN$A(A$READ+A$SAMF,CDATA,80,10)
C     PRINT 3020,NEW(1),NEW(2)
C3020 FORMAT('    NEW=',2A2)
      IF(NEW(1).EQ.'TI'.AND.NEW(2).EQ.'ME') GO TO 8
C
C     Current file is older type:
C
      PRINT 3040
 3040 FORMAT('    OLDER TYPE CURRENT FILE')
      READ(10,912)LOCAT,INSTO
  912 FORMAT(/26X,26A2/27X,2A2,10(/))
C
C     Determine year and date:
C
   12 READ(10,913)DATEY,DATED,DATET
  913 FORMAT(I5,I4,I5)
      IF(DATEY.EQ.0.OR.DATED.EQ.0) GO TO 12
      WRITE(9,911)DATEY,DATED,INSTO,LOCAT
      GO TO 11
C
C     Current file is newer type:
C
C        DETERMINE THE LOCATION AND INSTRUMENT NUMBER
C     AND WRITE THEM TO OUTPUT FILE.
C
    8 PRINT 3030
 3030 FORMAT('    NEWER TYPE CURRENT FILE')
      READ (10,910) LOCAT,INSTO,DATEY,DATED,DATET
  910 FORMAT (/26X,26A2/27X,2A2,7(/),27X,I4,I5,I6,11(/))
      WRITE(9,911)DATEY,DATED,INSTO,LOCAT
  911 FORMAT('    DATE:',I4,'/',I3,'    AANDERAA NO.: ',2A2,3X,'LOCATION:
     1 ',26A2)
C
C        READ SUBSEQUENT PAPER TAPE DATA RECORDS UNTIL SALINITY IS
C        NON-ZERO,DEPTH AND DIRECTION ARE POSITIVE AND SPEED IS IN RANGI
C
   11 READ (10,930) JYR,SALNTY,DEPTH,IDIRR,SPEED
  930 FORMAT (3X,I2,15X,2F6.2,1X,I3,F6.2)
      IF (JYR.EQ.0) GO TO 11
      IF (DEPTH.LE.0.01) GO TO 11
      IF (IDIRR.LE.0) GO TO 11
      IF (SPEED.LE.0.01.OR.SPEED.GT.60.0) GO TO 11
C
C        SKIP ONE MORE RECORD TO ENSURE STABILITY OF RECORDING
C
      READ (10,935) IYR,IDAY,ITIME
  935 FORMAT (3X,I2,1X,I3,1X,I4)
   10 I=I+1
C     PRINT 2000,I
C2000 FORMAT('I=',I4)
      READ(10,1020,END=20,ERR=13)ID(I),IT(I),S(I),IDIR(I),V(I)
 1020 FORMAT(5X,I4,I5,6X,F6.2,6X,I4,F6.2)
      IF(ID(I).EQ.0.AND.IT(I).EQ.0.AND.S(I).EQ.0.AND.IDIR(I).EQ.0.AND.V
     1I).EQ.0) GO TO 20
      GO TO 10
   20 NSIZE=I-1
      PRINT 2011,NSIZE
```

```
 2011 FORMAT('THAT WAS',I6,' GOOD RECORDS LONG')
C
C      Read in tide data, if any.
C
       IF(TYN) GO TO 60
       GO TO 50
   60  I=0
       CALL TONL
       PRINT 1022
 1022  FORMAT('READING TIDE DATA NOW')
   40  I=I+1
C
C      P. J. C. 's TIDE DATA FILES ARE SUCH THAT THE FIRST TIDE RECORD
C      IS ON THE SAME DAY AS THE FIRST DAY OF THE CORRESPONDING
C      CURRENT DATA RECORD.
C
C
       READ(7,1070,END=30,ERR=15)ITT(I),TIDE(I)
 1070  FORMAT(I6,F5.1)
       ITT(I)=IABS(ITT(I))
C      PRINT 1071 I,ITT(I),TIDE(I)
C1071  FORMAT(' I=',I3,'   ITT(I)=',I6,'   TIDE(I)=',F5.1)
C
C      HIS TIDE RECORDS DO NOT INCLUDE THE DAY, JUST THE TIME. 'TIDCUR'
C      REQUIRES THE DAY. THEREFORE, GENERATE DAY DATA:
C
       IF(I-1) 300,300,310
  300  IDT(1)=DATED
       GO TO 320
  310  IDT(I)=DATED
       CALL GT24(IDT(I),ITT(I))
  320  CONTINUE
C      PRINT 1071,I,IDT(I),ITT(I),TIDE(I)
C1071  FORMAT('  I=',I3,2I6,F6.1)
       GO TO 40
   30  NSIZET=I-1
       PRINT 2011,NSIZET
C
C      Get tide information from tides 'O' to 'NSIZET'.
C
       CALL TID(NSIZET,IDT,ITT,TIDE,IAVED,IAVET,ATIDE,TR,TC)
C      PRINT 9000,(TC(I),I=1,NSIZET)
C9000  FORMAT(10('TC=',A7))
   50  CONTINUE
C
C       'N' & 'M' are positions in array IDIR(I)
C
       MIN=0
       N=0
       M=IHT
       NS=NSIZE/(IHT)
C
C      Get times (locations in array) of slack tides.
C
       DO 120 J=1,NS
C      PRINT 2009,J
 2009  FORMAT('J=',I5)
       N=N+1
```

```
      M=N+IHT-1
      DO 100 K=1,IHT
C
C     NINS &MINS are also pointers: (N(INSIDE LOOP))
C
      NINS=N+K-1
      MINS=M+K-1
C     PRINT 1000(IDIR(I),I=N,M)
C
C     Put these into array 'X'
C
      MN=MINS-NINS+1
      DO 110 I=1,MN
      NI=NINS+I-1
      X(I)=IDIR(NI)
  110 CONTINUE
C
C     Get rid of '360>0' problem.
C
      CALL PR360(X,MN)
C
C     Get sum of squares of deviations from mean.
C
      CALL MEAN(MN,X,SUMD,DUMMY1,DUMMY2)
C     PRINT 2008,K
 2008 FORMAT(10('K=',I7))
C     PRINT 2007,SUMD
 2007 FORMAT('SUMD=',F8.3)
C
C     Put 'SUMD's into array 'Y'
C
      Y(K)=SUMD
  100 CONTINUE
C
C     Find minimum (sum of squares of deviations)
C
      CALL LOW(MIN,MN,Y,DUMMY)
C
C     'MIN' is the position in array 'Y' of the minimum sum of
C     squares of deviations
C
C     'ISTART' is start of half tide cycle
C     'IEND' is end of half tide cycle.
C
      ISTART=N+MIN-1
      IEND=ISTART+IHT-1
C
C     Put ISTART & IEND into arrays LS & LE.
C
      LS(J)=ISTART
      LE(J)=IEND
C
C     Jump from MIN to 1/4 tide cycle past MIN
C
      N=ISTART+JUMP-1
C     PRINT 2010,N,M
  120 CONTINUE
      CALL TONL
```

```
      PRINT 1105
 1105 FORMAT('NOW FOR THE JUICY BITS!')
C
C     Now, do calculations on tide half cycles.
C     JS is start of half tide cycle.
C     JE is end of half tide cycle.
C
      DO 140 J=1,NS
C     PRINT 9002,J
 9002 FORMAT('J=',I4)
      IF(J.EQ.1) GO TO 160
      IF(J.EQ.NS) GO TO 150
      JS=(LS(J)+LE(J-1))/2+1
      JE=(LE(J)+LS(J+1))/2
      GO TO 151
  150 JE=LE(NS)
      JS=(LS(J)+LE(J-1))/2+1
      GO TO 151
  160 JS=LS(1)
      JE=(LE(1)+LS(2))/2
  151 CONTINUE
C     PRINT 9003,JS,JE
 9003 FORMAT('JS=',I4,'  JE=',I4)
C
C     If tide data available, get appropriate tide data for
C     this tide cycle
C
      IF(TYN) GO TO 70
      GO TO 80
   70 DO 170 I=1,NSIZET
C
C     'I' is the tide cycle no. in the tide records array
C
C     Get relevent tide for this cycle.
C
C     PRINT 9004,IAVED(I),IAVET(I),ID(JS),IT(JS),ID(JE),IT(JE)
C9004 FORMAT('IAVED=',F5.1,' IAVET=',F6.1,' ID(JS)=',F5.1,' IT(JS)=',F6
C    1l,' ID(JE)=',F5.1,' IT(JS)=',F6.1)
      IF(IAVED(I).GE.ID(JS).AND.IAVED(I).LE.ID(JE)) GO TO 180
      GO TO 170
  180 IF(IAVED(I).EQ.ID(JS)) GO TO 190
      GO TO 220
  190 IF(IAVET(I).GT.IT(JS)) GO TO 200
      GO TO 170
  200 IF(IAVED(I).EQ.ID(JE)) GO TO 252
      GO TO 242
  252 IF(IAVET(I).LT.IT(JE)) GO TO 210
      GO TO 170
  220 IF(IAVED(I).EQ.ID(JE)) GO TO 232
      GO TO 170
  232 IF(IAVET(I).LT.IT(JE)) GO TO 210
      GO TO 170
  242 IF(IAVED(I).LT.ID(JE)) GO TO 210
      GO TO 170
  170 CONTINUE
      NTS=0               /* Relevent tide not found.
      GO TO 80
  210 NTS=I               /* Relevent tide cycle in tide record array.
```

```
      NTE=I+1
C
C     Put direction, speed & salinity over half tide cycle
C     into arrays XD, XV, XS.
C
C     NUM is number of records in half tide cycle.
C
   80 NUM=JE-JS+1
C     PRINT 9001,NTS
C9001 FORMAT('NTS=',I5)
      DO 130 I=1,NUM
      IST=JS+I-1
      XD(I)=IDIR(IST)
      XV(I)=V(IST)
      XS(I)=S(IST)
  130 CONTINUE
C
C     Get means of direction, speed & salinity over tide 1/2 cycle
C     Also standard deviation, maximum & minimum.
C
      CALL PR360(XD,NUM)
      CALL MEAN(NUM,XD,DUMMY,AVED,STDD)
      CALL GT360(AVED)
      CALL LOW(MIN,NUM,XD,AMIND)
      CALL GT360(AMIND)
      CALL HIGH(MAX,NUM,XD,AMAXD)
      CALL GT360(AMAXD)
      CALL MEAN(NUM,XV,DUMMY,AVEV,STDV)
      CALL LOW(MIN,NUM,XV,AMINV)
      CALL HIGH(MAX,NUM,XV,AMAXV)
      CALL MEAN(NUM,XS,DUMMY,AVES,STDS)
      CALL LOW(MIN,NUM,XS,AMINS)
      CALL HIGH(MAX,NUM,XS,AMAXS)
      IF(TYN) GO TO 240
      GO TO 250
  240 IF(NTS.EQ.0) GO TO 230
      WRITE(9,1075)ID(JS),IT(JS),ID(JE),IT(JE),NUM,TC(NTS),IDT(NTS),ITT
     1NTS),IDT(NTE),ITT(NTE),TIDE(NTS),TIDE(NTE)
 1075 FORMAT(//,3X,'FROM',2I5,3X,'TO',2I5,3X,'(',I3,' RECORDS)',13X,A6,
     1TIDE:  FROM',2I5,3X,'TO',2I5,/,16X,'AVE.   STD. DEV.    MAX.     MIN.
     2,31X,'(',F4.2,' m)',8X,'(',F4.2,' m)')
      WRITE(9,1040)AVED,STDD,AMAXD,AMIND,ATIDE(NTS)
      WRITE(9,1050)AVEV,STDV,AMAXV,AMINV,TR(NTS)
      WRITE(9,1060)AVES,STDS,AMAXS,AMINS
 1040 FORMAT(' DIRECTION   ',F8.2,F10.3,2F8.2,27X,'AVE.  TIDAL STAGE:',F5.
     12,' m')
 1050 FORMAT(' SPEED(cm/s)',F8.2,F10.3,2F8.2,27X,'TIDAL RANGE      :',F5.
     12,' m')
 1060 FORMAT(' SALINITY    ',F8.2,F10.3,2F8.2)
      GO TO 140
  230 WRITE(9,1120)ID(JS),IT(JS),ID(JE),IT(JE),NUM
 1120 FORMAT(//,3X,'FROM',2I5,3X,'TO',2I5,3X,'(',I3,' RECORDS)',13X,'REL
     1EVENT TIDE NOT FOUND',/,16X,'AVE.   STD. DEV.    MAX.     MIN.')
      WRITE(9,1130)AVED,STDD,AMAXD,AMIND
      WRITE(9,1140)AVEV,STDV,AMAXV,AMINV
      WRITE(9,1150)AVES,STDS,AMAXS,AMINS
 1130 FORMAT(' DIRECTION   ',F8.2,F10.3,2F8.2)
 1140 FORMAT(' SPEED(cm/s)',F8.2,F10.3,2F8.2)
```

```
 1150 FORMAT(' SALINITY     ',F8.2,F10.3,2F8.2)
      GO TO 140
  250 WRITE(9,1080)ID(JS),IT(JS),ID(JE),IT(JE),NUM
 1080 FORMAT(//,3X,'FROM',2I5,3X,'TO',2I5,3X,'(',I3,' RECORDS)',/,16X,'A
     1VE.   STD. DEV.     MAX.       MIN.')
      WRITE(9,1090)AVED,STDD,AMAXD,AMIND
      WRITE(9,1100)AVEV,STDV,AMAXV,AMINV
      WRITE(9,1110)AVES,STDS,AMAXS,AMINS
 1090 FORMAT(' DIRECTION    ',F8.2,F10.3,2F8.2)
 1100 FORMAT(' SPEED(cm/s)',F8.2,F10.3,2F8.2)
 1110 FORMAT(' SALINITY     ',F8.2,F10.3,2F8.2)
  140 CONTINUE
      GO TO 14
   13 WRITE(1,9998)I
 9998 FORMAT('  CURRENT DATA READ ERROR ON RECORD ',I4,'. STOP.')
      GO TO 14
   15 WRITE(1,9999)I
 9999 FORMAT('  TIDE DATA READ ERROR ON RECORD ',I4,'. STOP.')
   14 CALL CLOS$A(7)
      CALL CLOS$A(9)
      CALL CLOS$A(10)
      CALL EXIT
      END
C
C********************    MEAN    ***************************
C
      SUBROUTINE MEAN(MN,X,SUMD,AVE,STD)
C
C     Calculates mean & sum of squares of deveations from
C     mean of array 'X'
C
      DIMENSION X(100)
      SUM=0.0
      SUMD=0.0
C
C     Mean
C
      DO 100 I=1,MN
  100 SUM=SUM+X(I)
      AVE=SUM/MN
C
C     Sum of squares of deviations from mean
C
      DO 110 I=1,MN
      DEV2=(X(I)-AVE)**2
C
C     Sum of squares
C
      SUMD=SUMD+DEV2
  110 CONTINUE
C
C     Standard deviation.
C
      IF(SUMD)120,130,120
  130 STD=0.0
      GO TO 140
  120 STD=SQRT(SUMD/MN)
  140 CONTINUE
```

```
 2004 FORMAT(10F8.3)
      RETURN
      END
C
C*****************   LOW   **********************************
C
      SUBROUTINE LOW (MIN,MN,Y,AMIN)
C
C     Calculates minimum value in array 'Y'
C
C     Array: Y
C     Element where minimum occurs: MIN
C     Size of array: MN
C     Minimum value: AMIN
C
      DIMENSION Y(100)
      AMIN=Y(1)
      MIN=1
      DO 100 J=1,MN
      IF(Y(J).GE.AMIN) GO TO 100
      AMIN=Y(J)
      MIN=J
  100 CONTINUE
      RETURN
      END
C
C*********************   PR360   **************************
C
      SUBROUTINE PR360(X,MN)
C
C     Get rid of '360>0' problem.
C     Take X(1) as reference point from which X(I) values
C     are referred.
C
      DIMENSION X(100)
      IFIRST=0
      REF=X(1)
    5 DO 10 I=1,MN
      XD=REF-X(I)
      DIF=ABS(XD-0.0)
      IF(DIF.LE.0.0001) GO TO 10
C     Absolute value of XD:
C     AXD=(XD**2)**0.5
      AXD=ABS(XD)
      IF(AXD.GT.180.0) GO TO 20
      GO TO 10
   20 IF(X(I).GT.180.0) GO TO 30
      X(I)=X(I)+360.0
      GO TO 10
   30 X(I)=X(I)-360.0
   10 CONTINUE
C
C     Now, take 'AVE' as reference from which X(I) values are
C     refered. Do this twice.
C
      IF(IFIRST.EQ.2) GO TO 50
      CALL MEAN(MN,X,DUMMY,AVE,DUMMY2)
      CALL GT360(AVE)
```

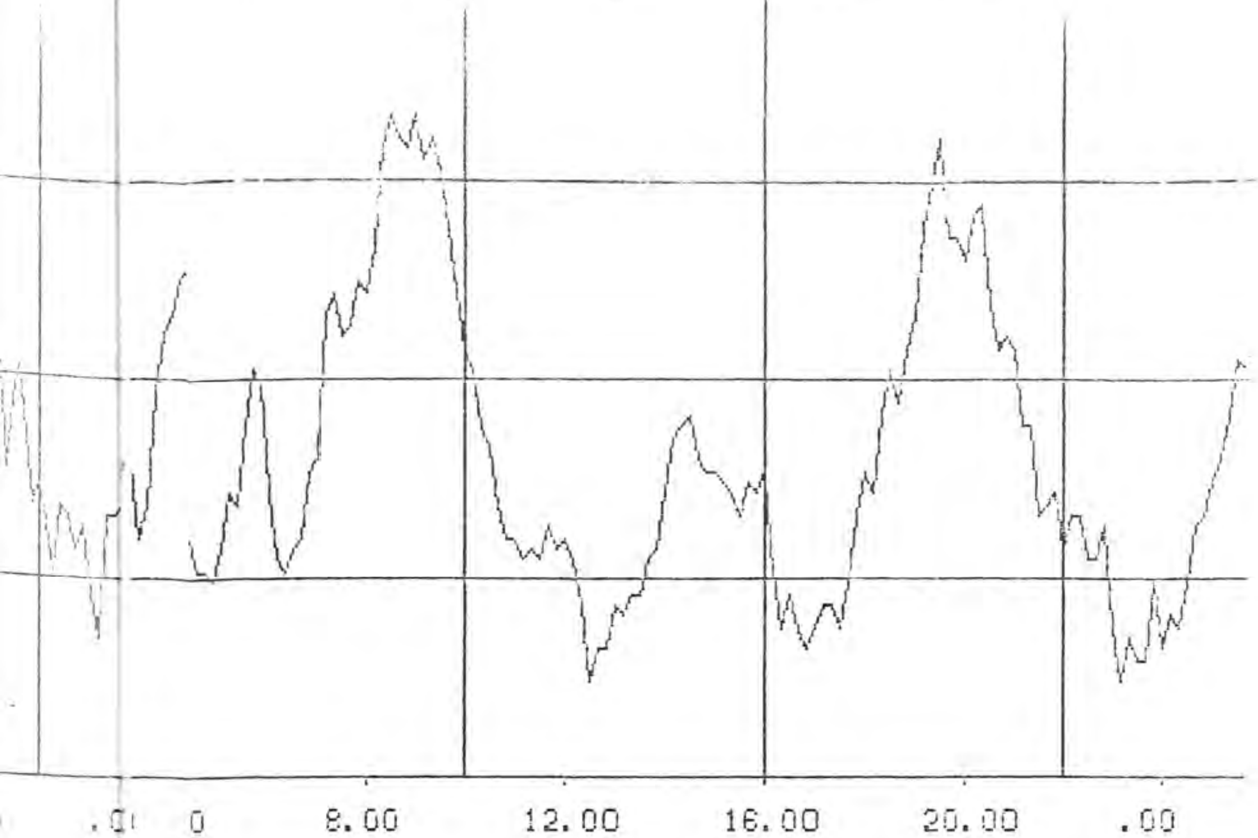
```
      IFIRST=IFIRST+1
      REF=AVE
      GO TO 5
   50 RETURN
      END
C
C********************   GT360   ********************************
C
      SUBROUTINE GT360(U)
C
C     Corrects 'U' to be: 0<U<360 degrees instead
C     of being negative or greater than 360.
C
   80 IF(U-360.0) 60,70,70
   70 U=U-360.0
      GO TO 80
   60 IF(U-0.0) 65,75,75
   65 U=U+360.0
      GO TO 60
   75 CONTINUE
      RETURN
      END
C
C********************   HIGH   ***************************
C
      SUBROUTINE HIGH(N,K,Y,AMAX)
C
C     Gets maximum value (AMAX) in array Y, size K.
C     N is position of AMAX in array.
C
      DIMENSION Y(900)
      AMAX=0.0
      N=1
      DO 10 J=1,K
      IF (Y(J).LE.AMAX) GOTO 10
      AMAX=Y(J)
      N=J
   10 CONTINUE
      RETURN
      END
C
C*****************   TID   ******************************
C
      SUBROUTINE TID(NS,IDT,ITT,TIDE,IAVED,IAVET,ATIDE,TR,TC)
C
C     Get times of mid tides, average tidal stage (ATIDE), tidal range
C     (TR) and whether FLOOD or EBB (ie. cycle) (TC).
C
      DOUBLE PRECISION TC
      INTEGER*4 ITT,IT1,IT2,IAVET,IT
      DIMENSION IDT(1000),ITT(1000),TIDE(1000),IAVET(1000),IAVED(1000)
      DIMENSION ATIDE(1000),TR(1000),TC(1000)
      DO 100 I=1,NS
      IF(ITT(I+1).LT.ITT(I)) GO TO 10
      GO TO 20
   10 IT2=ITT(I+1)+2400
      IT1=ITT(I)
      GO TO 30
```

```
   20 IT1=ITT(I)
      IT2=ITT(I+1)
   30 CONTINUE
C
C     Time of mid tide.
C
      IAVET(I)=(IT1+IT2)/2
      IAVED(I)=IDT(I)
      CALL GT24(IAVED(I),IAVET(I))
C
C     Average tidal stage.
C
      ATIDE(I)=(TIDE(I)+TIDE(I+1))/2.0
C
C     Tidal range
C
      TR(I)=TIDE(I+1)-TIDE(I)
      IF(TR(I)-0.0) 40,60,50
C
C     Tidal cycle
C
   40 TC(I)='EBB'
      GO TO 70
   50 TC(I)='FLOOD'
      GO TO 70
   60 TC(I)='ZERO'
   70 CONTINUE
  100 CONTINUE
      RETURN
      END
C
C*****************   GT24   ******************************
C
      SUBROUTINE GT24(ID,IT)
C
C     Corrects IT to be: 0<IT<2400 hours instead of being
C     negative or greater than 2400 hours.
C
      INTEGER*4 IT
C
   80 IF(IT-2400) 60,70,70
   70 IT=IT-2400
      ID=ID+1
      GO TO 80
   60 IF(IT-0) 65,75,75
   65 IT=IT+2400
      GO TO 60
   75 CONTINUE
      RETURN
      END
```

INITIAL DATE : 27.2.79 AANDERAA NO. : 2297 LOCATION : CAPTAIN COOK BRIDGE - BETWEEN PIERS 2 & 3

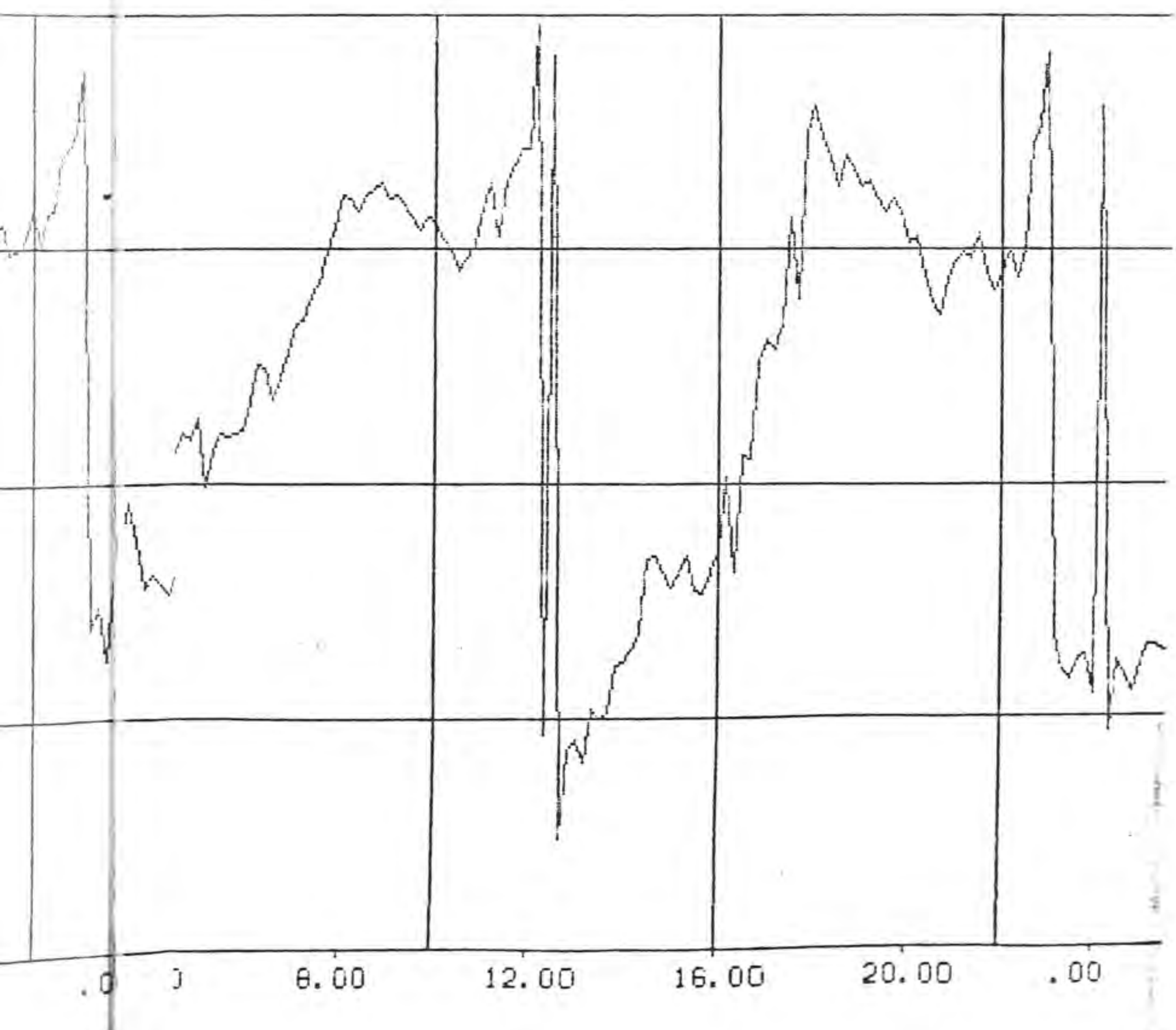
UNIVERSITY OF NEW SOUTH WALES
WATER REFERENCE
LIBRARY
WATER RESEARCH FOUNDATION

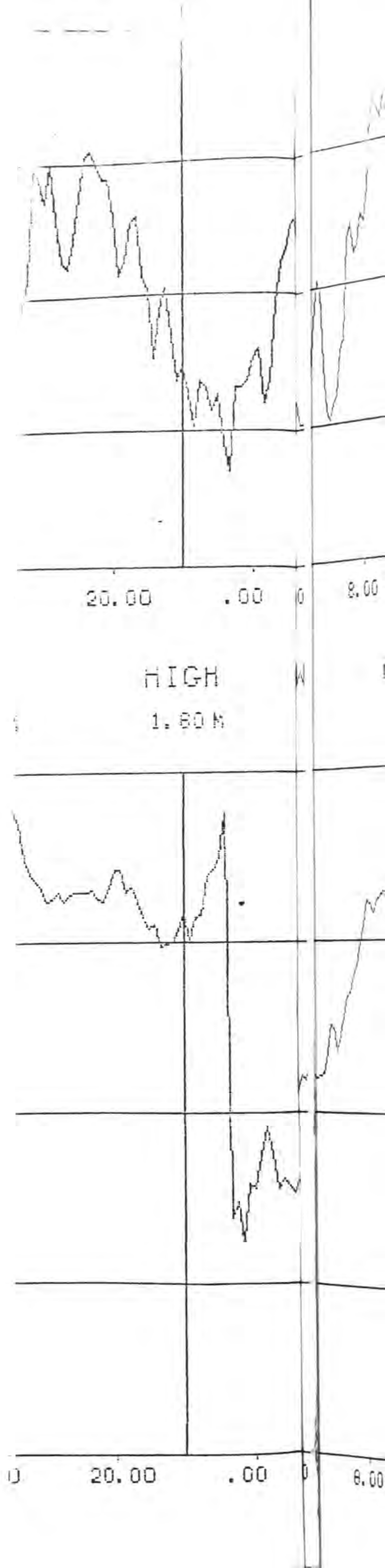
FIGURE 5: PLOT OF CURRENT SPEED AND DIRECTION VS. TIME - MIDDLE OF BOTANY BAY - WRB

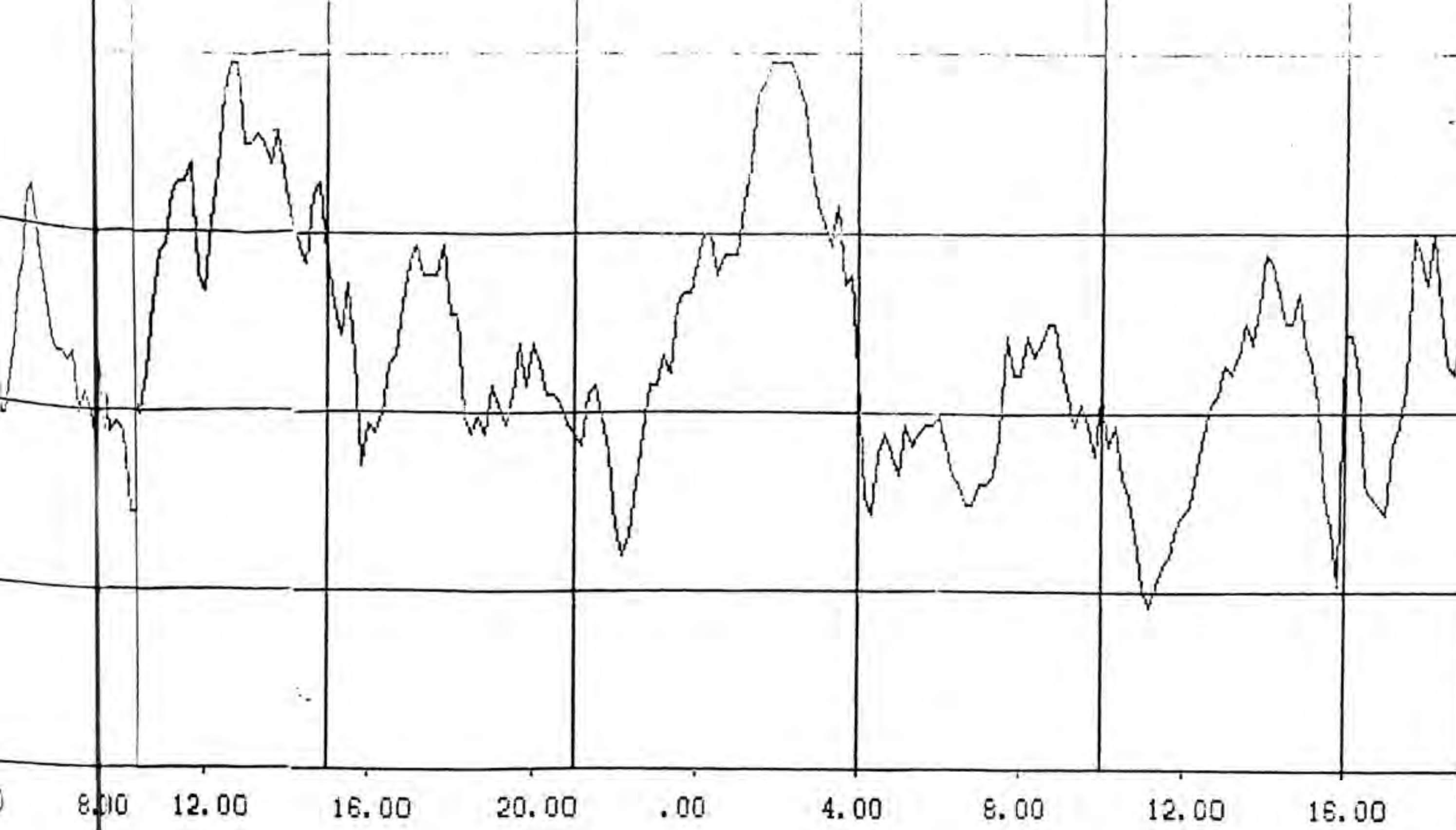


IGH W HIGH LOW HIGH

1.80 M M 1.30 M .40 M 1.60 M

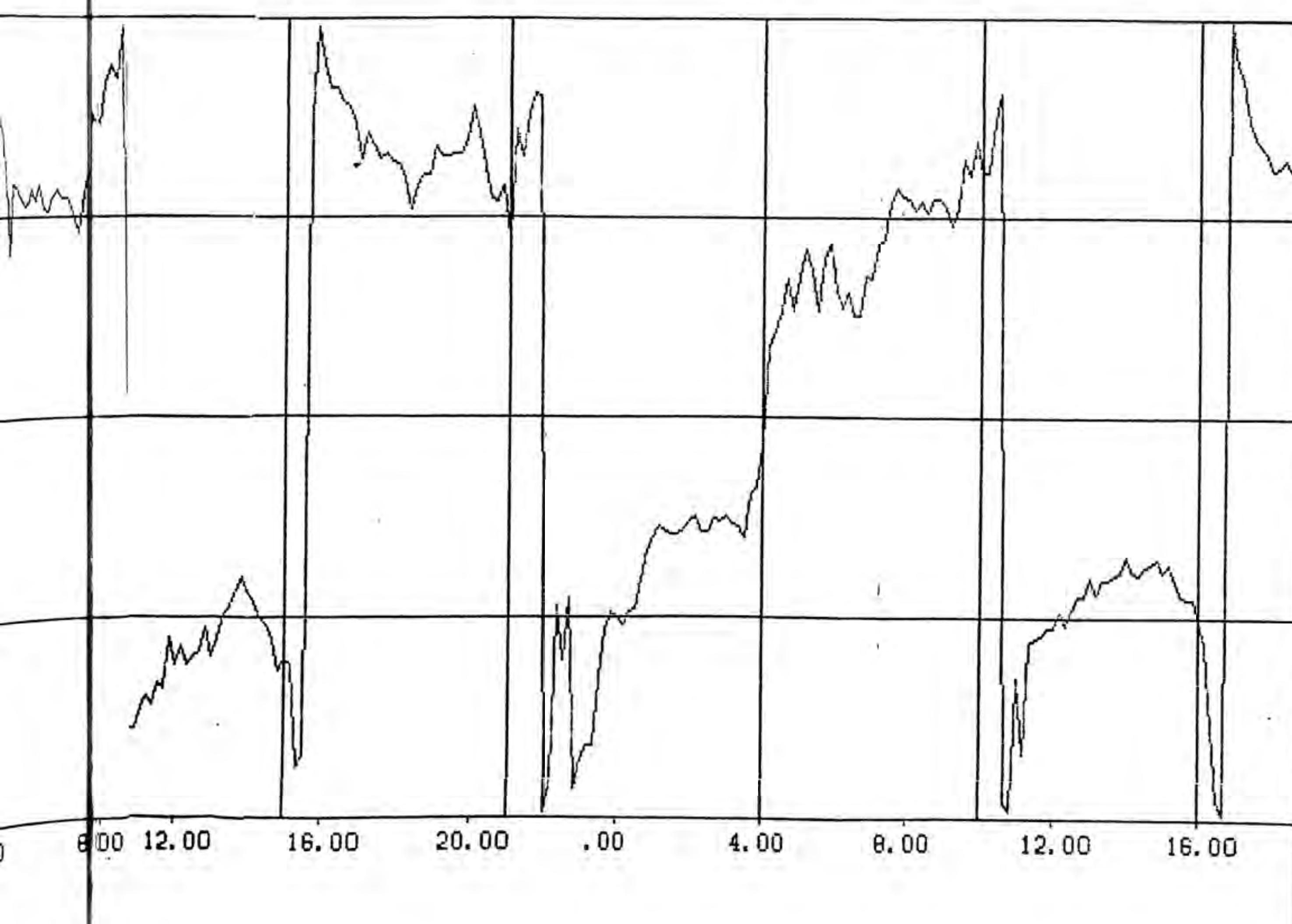


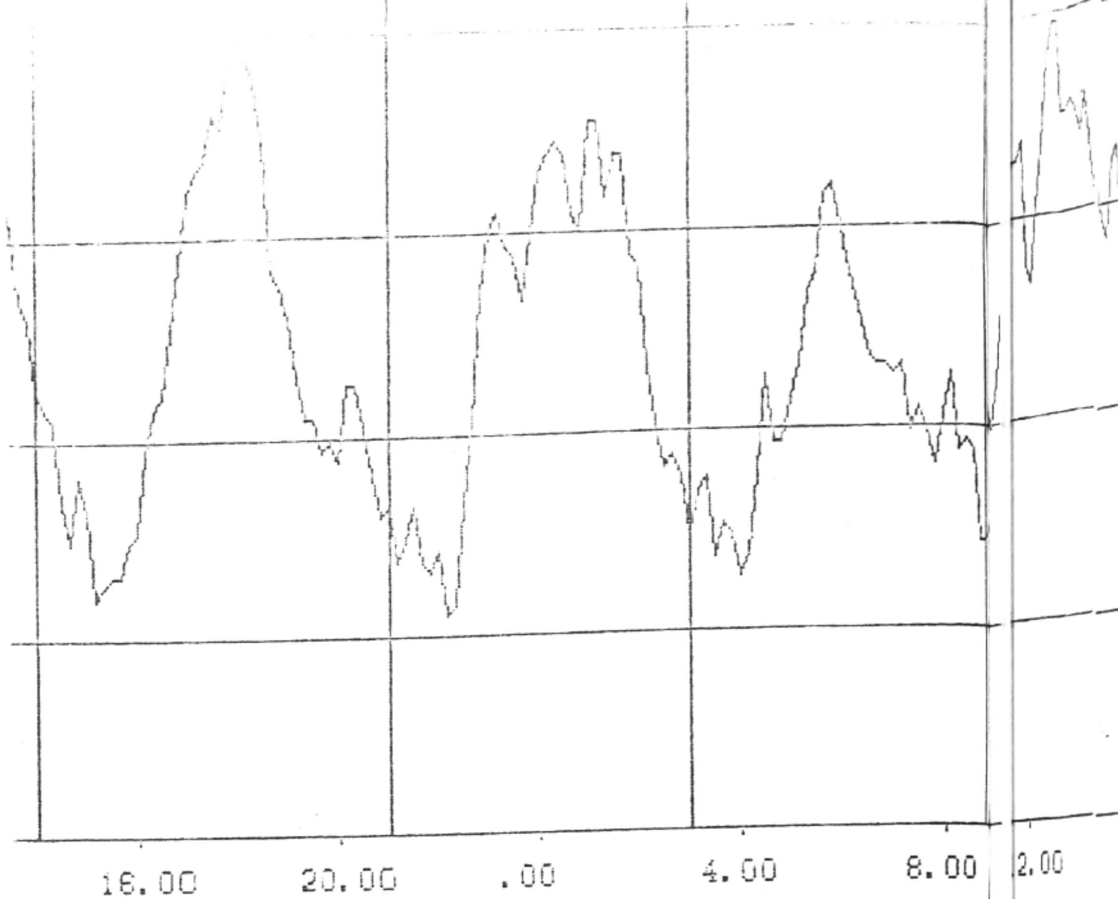

20.00
.00
8.00
HIGH
1.80 M
20.00
.00
8.00



HI LOW HIGH LOW HIGH LOW

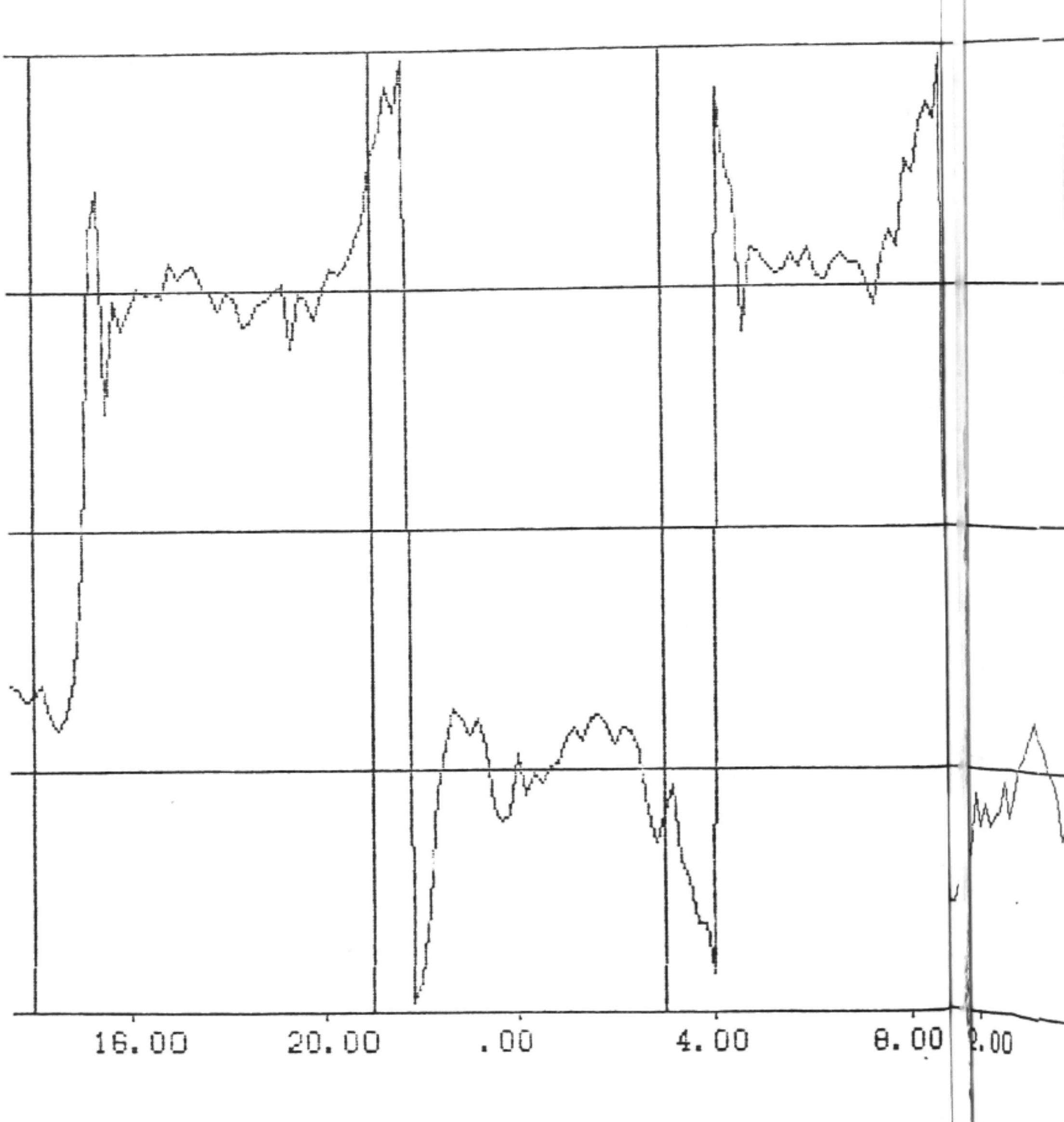
1.! .30 M 1.70 M .30 M 1.40 M .30 M

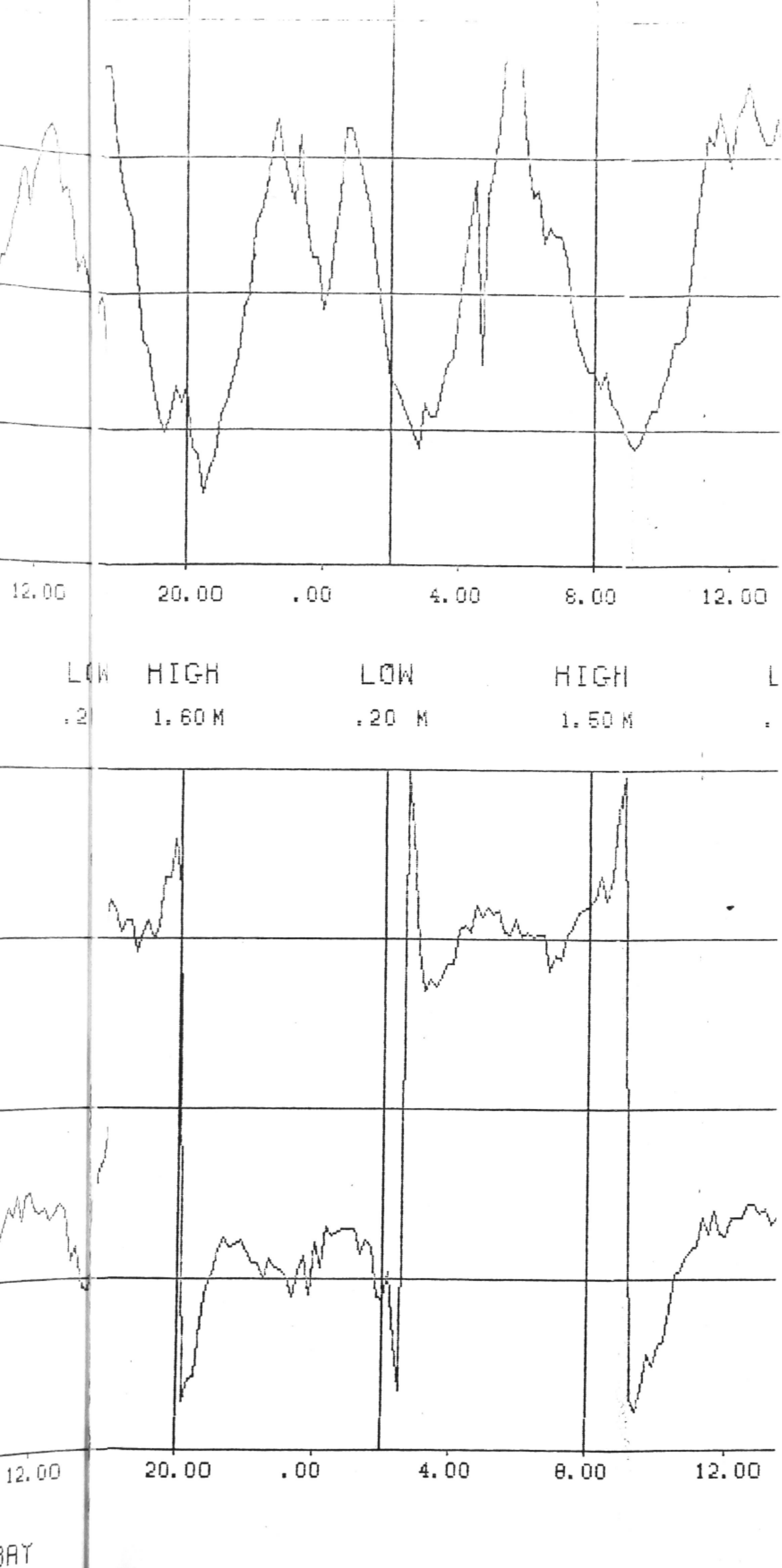




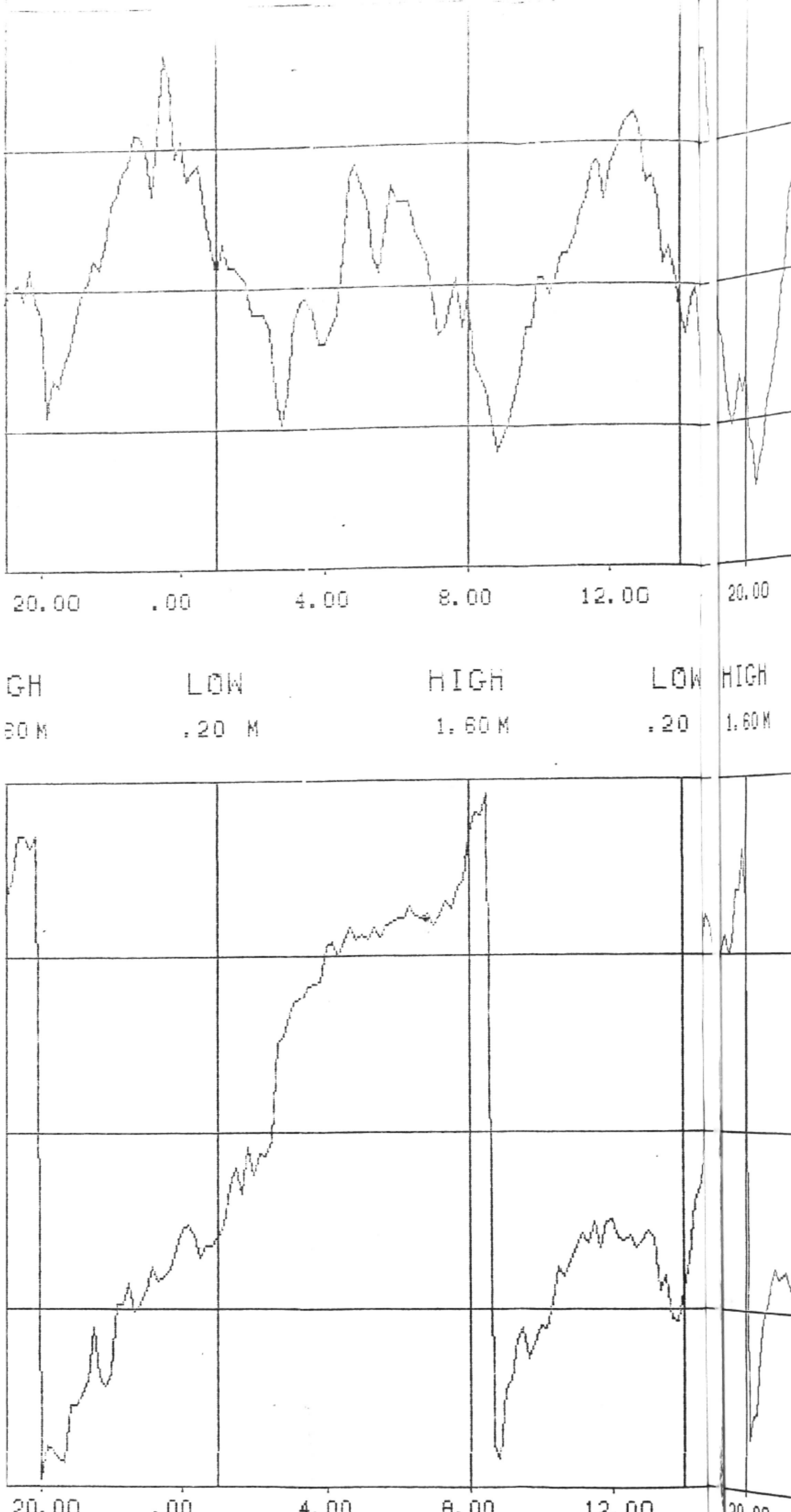
LOW HIGH LOW HI LO

.20 M 1.70 M .20 M 1.

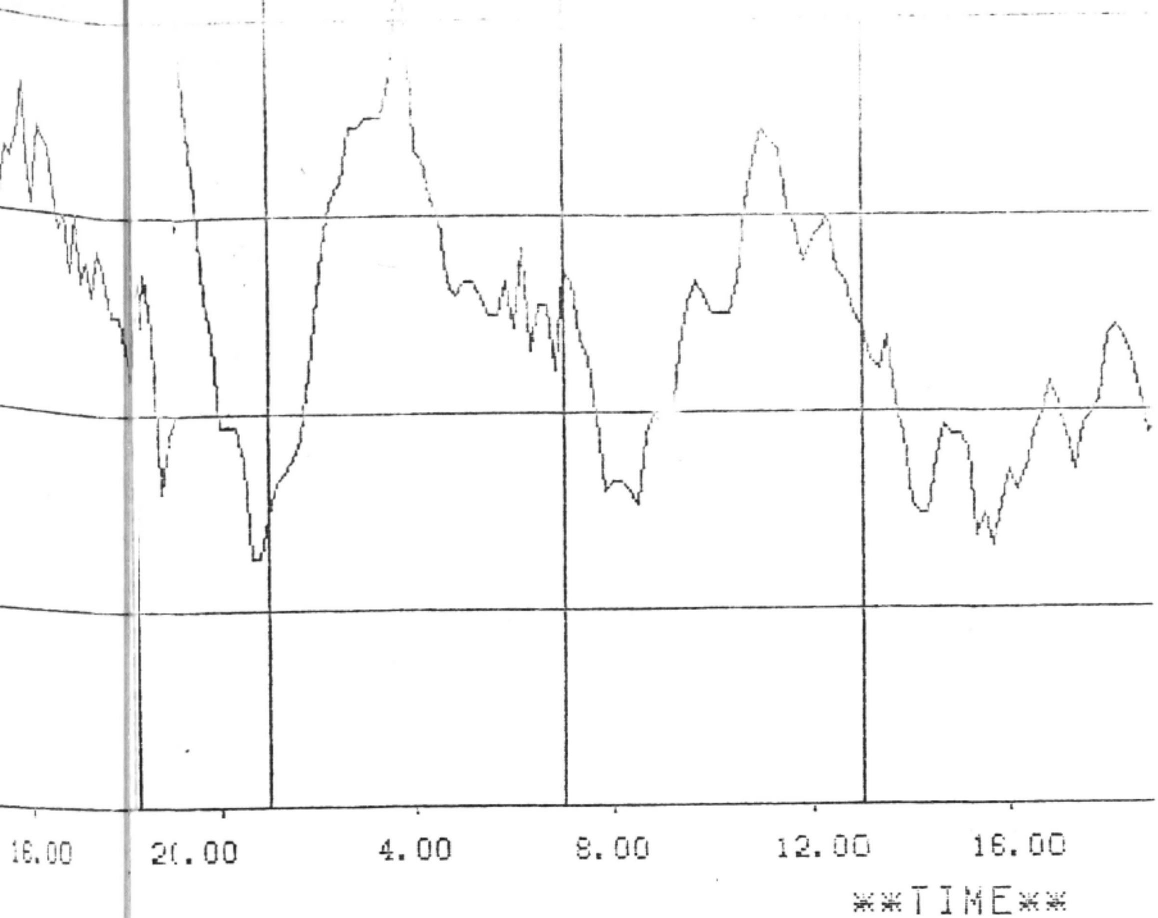




12.00
20.00
.00
4.00
8.00
12.00
HIGH
LOW
HIGH
1.60 M
.20 M
1.50 M
12.00
20.00
.00
4.00
8.00
12.00

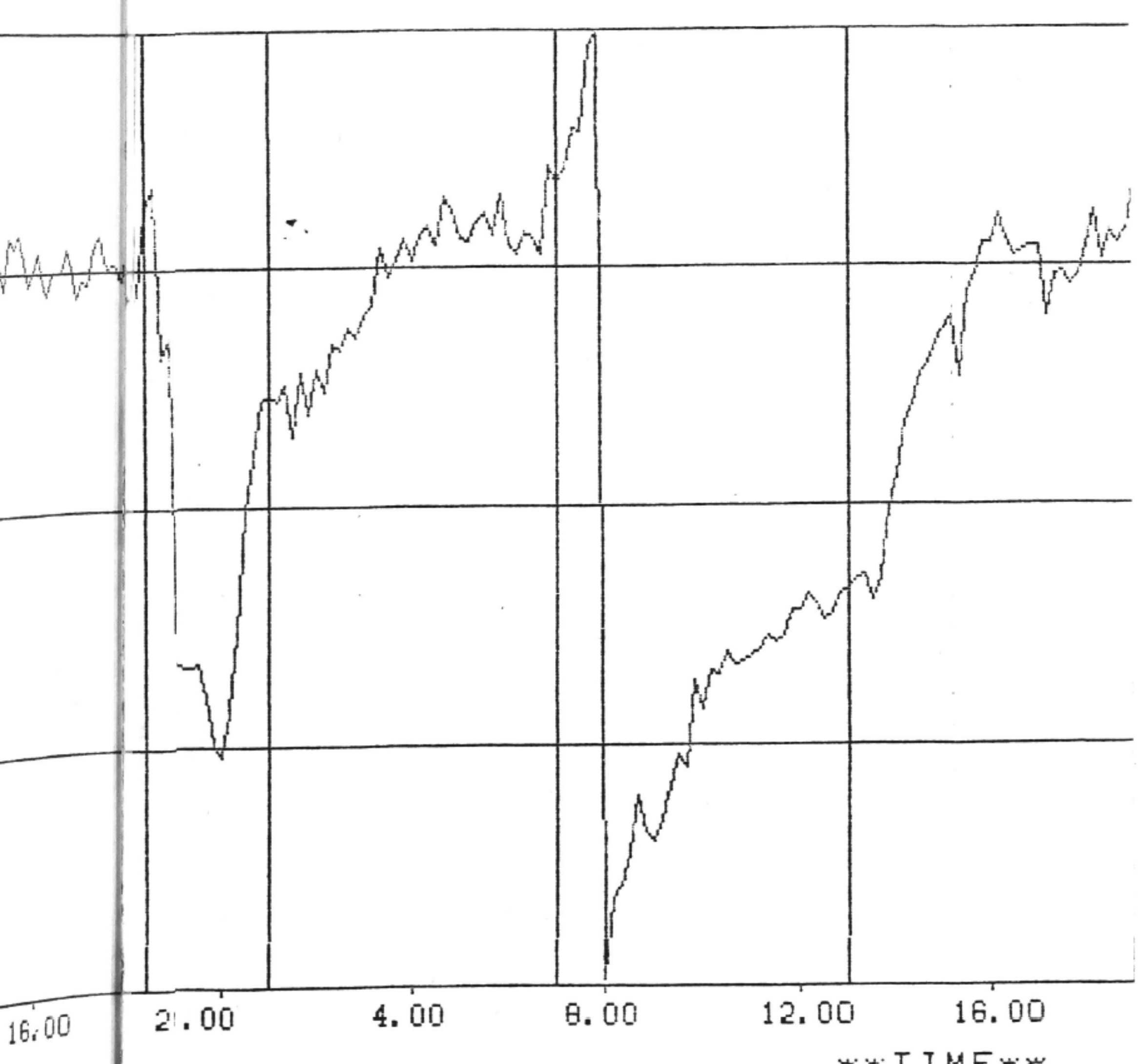


CATION : WRB3: MIDDLE OF BAY

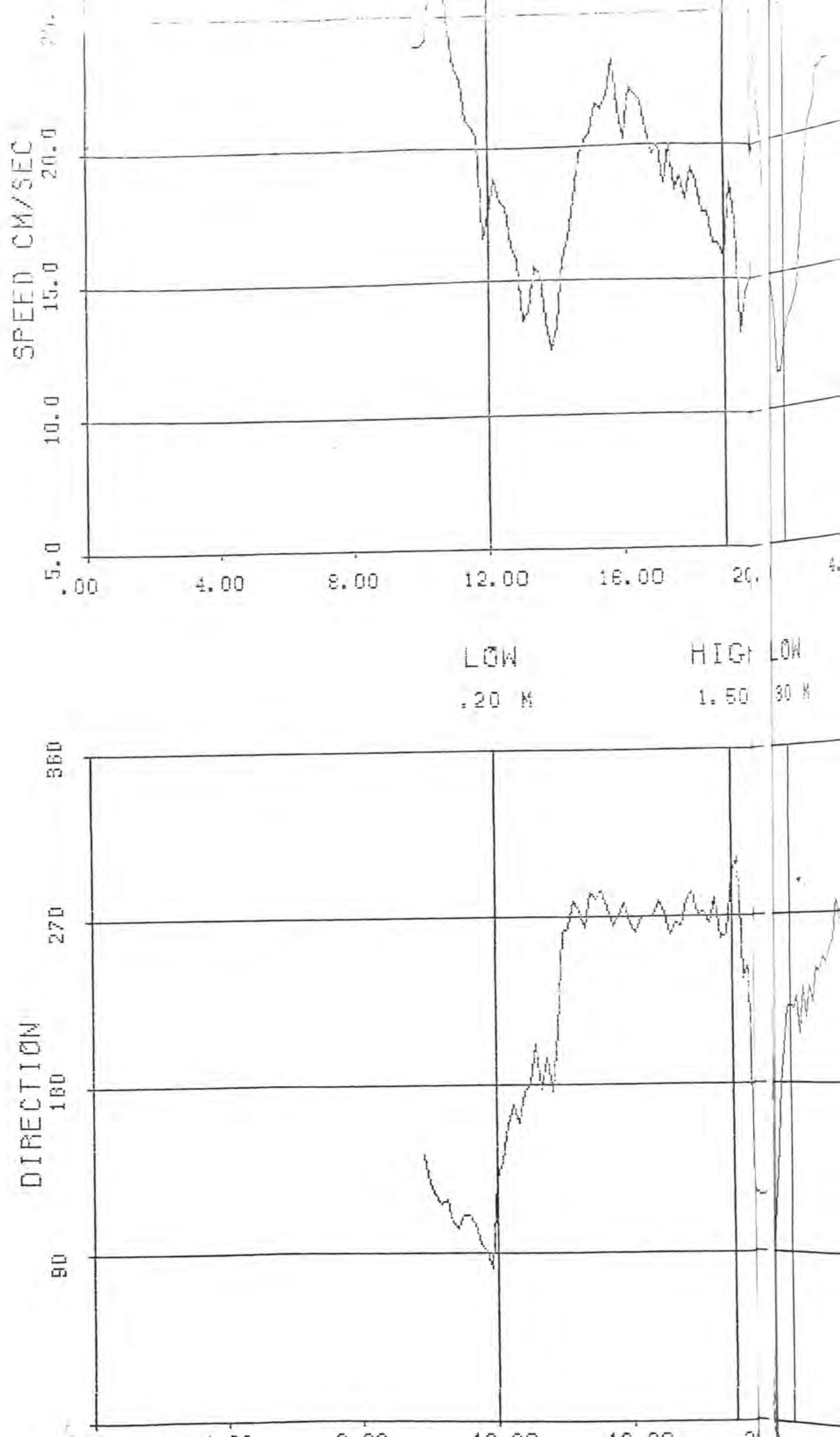


HIGH LOW HIGH LOW HI

1.50 .30 M 1.60 M .20 M 1.



AANDERAA NO. : 2297 LO



INITIAL DATE : 5. 4. 78