NOAA Technical Report OTES- 9

Performance Characteristics of the Bathymetric Swath Survey System

Rockville, Md.
May 1982

U. S. DEPARTMENT OF COMMERCE
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U. S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

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PERFORMANCE CHARACTERISTICS OF THE
BATHYMETRIC SWATH SURVEY SYSTEM

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ABSTRACT: The Bathymetric Swath Survey System (BS^3) is a multi-beam hydrographic system for use in intermediate water depths. The first system of this kind is in operation aboard the NOAA ship DAVIDSON. The multi-beam concept offers the potential for more complete coverage of bottom bathymetry in less time than required for a conventional survey. Realization of this potential depends on the performance characteristics of the system. This report describes the results of a series of tests conducted in April of 1981 to characterize two fundamental aspects of performance - accuracy and reconnaissance capability.

Accuracy was determined by examining the statistics of repeated soundings over the same spot. Accuracy in shallow water over a hard bottom met the international standard for all the beams but tests at another site over a soft bottom showed unacceptable variability. Tests in deep water showed that the central 14 beams met the accuracy requirement. Tests over a steep slope showed results that were not inconsistent with the accuracy standards but system variability could not be completely separated from effects of positioning inaccuracies and bottom variations.

Reconnaissance tests showed that the system could not reliably detect an object as small as a 60 centimeter triplane but it did produce reliable indications of the wreckage of a tanker. Least depths indicated for the wreckage were accurate within ±1.5 percent of the depth if the soundings were from central 14 beams. Natural shoals were clearly indicated by the real-time outputs of the system and these were quantitatively accurate enough to guide ship operations. Post-processing software was able to extract least depth over natural features which also were accurate within ±1.5 percent of depth.

1.0 INTRODUCTION

The Bathymetric Swath Survey System (BS^3) is a multi-beam sonar system designed to gather hydrographic data in water depths from 25 to 2000 feet. The multi-beam concept makes it possible to have complete coverage of bottom bathymetry in swaths of width roughly 2.5 times the water depth. The concept is similar to the SASS and BOTASS systems used by the U.S. Navy and to the Sea Beam System which is now in use by NOAA as well as several universities and foreign governments. The BS^3 differs from these systems in that it is designed to provide the higher accuracy and broader angular coverage required in shallower water depths. The system used by NOAA is the first and, at present, the only one of its kind.

The basic components of the BS^3 were designed by General Instruments Government Systems Division and were delivered to NOAA in September of 1977. Software development and system tests were conducted from 1977 until 1979. Several major problems remained in the system at that time. In October of 1979 the Engineering Development Office of NOAA was requested to undertake a program to define and correct these deficiencies and to conduct tests to characterize the performance of the system. Modifications to the system were made during 1980 and were completed in February of 1981. Tests in March of 1981 showed that these modifications were successful in rectifying the problems that were addressed. A systematic series of tests were designed and conducted in April of 1981 to characterize the system performance. This report is an analysis of the results of those tests.

2.0 SYSTEM DESCRIPTION

The BS^3 gathers inputs from six subsystems - the sonar, a heave-roll-pitch sensor, a positioning system, a tide measurement system, the gyroscope and a sound velocity measurement device. The following equipment forms these subsystems.

SUBSYTEM	MODEL	MANUFACTURER
sonar	BOSUN	General Instruments
heave-roll-pitch	HIPPY 120	Datawell
positioning	MINIRANGER or	Motorola
	Raydist	Teledyne Hastings-Raydist
tide	TMS	NOAA/EDO
gyroscope	MK 14	Sperry
sound velocity	Model 9090 XSTD or	Grundy
	Model TDC or	Martek
	Nansen casts	

These subsystems are integrated through a CAMAC interface to a Digital Equipment Corporation PDP 11/34 minicomputer. Outputs are displayed in the form of depth contours on a Gould electrostatic plotter and in the form of a position plot on a Houston Instruments DP-3 plotter. Data are logged on a magnetic tape (DEC TS-03) and flexible disks (DEC RX-02) for post-processing. Operator interaction is through a video terminal (DEC VT-52). Operation of the system is under the control of a program entitled SURVEY. The BS^3 is presently installed aboard the NOAA ship DAVIDSON. Further descriptions of the BS^3 have been published by Hopkins and Mobley (1978), Farr (1980) and McCaffrey (1981).

Modifications made to the system prior to these tests included changes to the sonar transducer installation, replacement of the prototype heave-roll-pitch sensor with a production version, improvements to the cabling and interconnection of subsystems as well as a number of software changes. Sonar modifications consisted of mounting a baffle and a more acoustically transparent window in the original transducer assembly which was enclosed in a dome. A second independent set of transducers was installed in fairings. To accommodate the different alignment of thse two sets of transducers, two versions of SURVEY were used entitled SUDOME and SUFAIR. The transducers in the fairings were considered the primary set. This was based on post-drydock tests which showed that although the two sets performed similarly, the transmitter in the fairings seemed to show slight improvement in the number of missed soundings in moderate sea conditions.

Two additional features were incorporated for these tests. Data from the Ross depth sounder were logged on the BS^3 magnetic tape by connecting its output through one of the unused navigation ports. This permitted direct comparison between the data from NOS' standard system and the BS^3. For use in water depths beyond the capability of the Ross system, the ship's 12 KHz sounder was outfitted with a Raytheon PDD-200 digitzer and its outputs were connected to the BS^3 logging in a similar fashion as the Ross system. The second feature added was an additional tape recorder connected to record all terminal dialog. This helped to insure that a complete record of the tests was preserved.

3.0 TEST DESCRIPTION

The objective of these tests was to characterize two fundamental aspects of the BS^3 performance - its accuracy and its reconnaissance ability. The questions to be answered were: 1) what subset of the data will meet hydrographic standards and 2) will the system enable hydrographers to reduce or eliminate the need for special ship operations to develop features. There are several other aspects of the system which are important for its operational use. These include its ability to provide a means of verifying data, its ability to process data into boat sheet form, the ability of personnel to plan and conduct surveys using the system as well as the reliability and maintainability of the system. Only to a very limited extent were the tests planned to shed light on these aspects. Appendix E is a summary of the difficulties encountered with subsystems during these tests.

The approach was to structure the tests in such a way as to permit comparison of results with a model of the performance characteristics. The model is based on analysis of subsystems to see how errors and limitations arise and a study of how they propagate through the system to limit its accuracy and reconnaissance capability. Expected dominant error sources and the prime features limiting detectability were identified. The tests were then designed to vary the parameters which control the influence of these errors and limitations. If the model can be made quantitative and verified, the test results could be extended to a wide range of operating conditions.

Project instructions were developed in a cooperative effort between the Engineering Development Office and the Office of Marine Surveys and Maps of NOS. The requirements for these tests from the point of view of NOS are described in Appendix A. Final project instructions are included in Appendix B. The detailed test plan forms Appendix C.

3.1 Depth Measurement Accuracy

Depth measurement accuracy standards are prescribed by NOS, the International Hydrographic Bureau and the National Map Accuracy Standards. These are reviewed in Appendix A. Figure 1 is a plot of the international

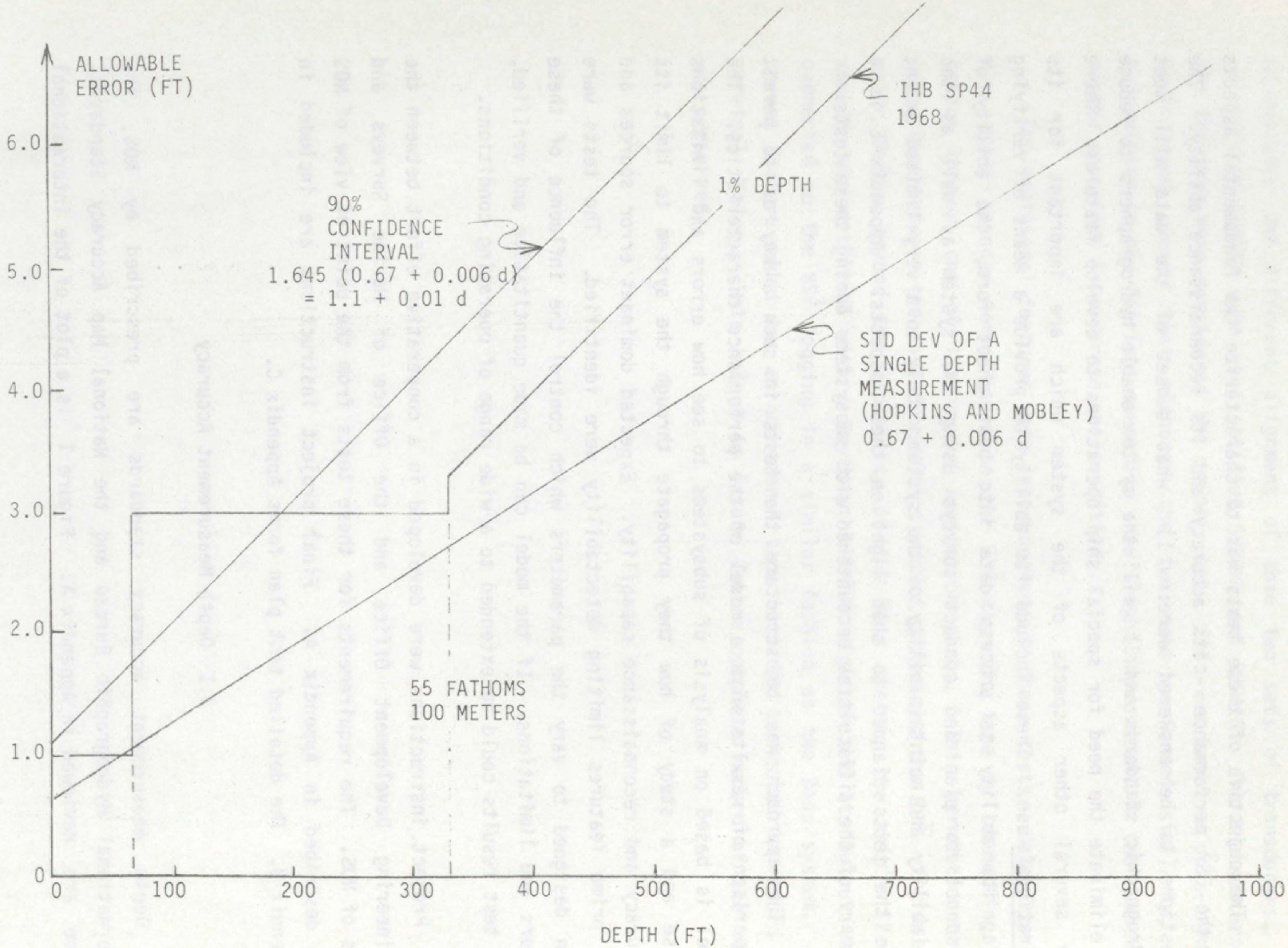


Figure 1. Accuracy Requirements

standards together with a statistical interpretation proposed by Hopkins and Mobley (1978). These authors proposed the following error budget to support their interpretation of the international standards. All errors are stated in terms of standard deviations.

error source	feet	meters
depth measurement (timed)	(.30 + .003 d)	(.10 + .003 d)
heave error	.30	.12
pointing error (roll and pitch)	.003 d	.003 d
tidal zone (variation)	(.12 + .003 d)	(.06 + .003 d)
(rounding)	.06	.06
velocity measurement	.002 d	.002 d
(zone measurement)	.002 d	.002 d
(rounding)	.06	.06
draft measurement	.12	.06
(time variation)	.30	.12
settlement and squat measurement	.12	.06
(variation)	.30	.12
TRA rounding	.06	.06
tidal datum	.18	.06

Assuming all the above errors are independent, the standard deviation of a single depth measurement would be:

	feet	meters
	±(.67 + .006 d)	±(.28 + .006 d)

Of these only the timed depth measurement error, heave, roll, and pitch errors, and sound velocity errors have unusual aspects in the BS^3 system. Since the other errors are common to all hydrographic systems these tests did not address their characteristics. Other error analysis of the BS^3 were performed by Angelari (1978) and Neal (1981). These studies showed general agreement on the primary error sources for the system.

Timed depth or slant range measurement error is an error in the data produced by the BOSUN sonar. Sources of this error could include internal clock variations and unaccounted delays in processing circuitry. The more basic error source is involved with estimating the return time of the echo. The transmitted pulse is greatly distorted by reflection from the bottom before it is returned to the sonar. This takes the form of stretching due to beam angle, beam width and depth as well as random corruption due to reflection from a rough bottom. Within the sonar the return is modified by circuitry controlled by the gates and the side lobe inhibit detector. This chops out sections of the return signal. It is then fed to "matched" filters and an estimate is made of the time to the centroid within five dB of the peak. Parameters which would affect this error are beam angle and depth, bottom composition and roughness, gate height, and the relative level and timing of side lobe signals. Water depth and slope of the bottom would be expected to control the last two variables.

Heave, roll, and pitch errors are primarily errors in the data provided by the Datawell Hippy 120 motion sensor. This device has been extensively tested and the results are described by Pryor (1981). Heave errors are due to disturbances of the pendulum suspension from vertical, and frequency response characteristics of the double integration filters. Disturbances of the pendulum are caused by large course or speed changes. Processing or frequency reponse errors are a function of the period of the motion. Periods longer than 30 seconds will not be adequately measured. For motions with shorter periods the accuracy should be limited only by the three percent ripple in the passband of the integrator. Roll and pitch errors could be caused by disturbances of the pendulum suspension from vertical, imbalance of the platform at the bob of the pendulum, and inaccuracies of the alignment of the HIPPY and transducers. Errors of more than 0.1 degree will exceed the budget proposed by Hopkins and Mobley. Laboratory checks were made on the HIPPY and careful alignment of the HIPPY and transducers while the DAVIDSON was in drydock. All alignment data have been included in the programs to correct the BS^3 soundings. Thus the parameters which should affect heave, roll, and pitch measurement errors are sea state, heading and speed relative to the waves, and speed and course changes. The effect of roll and pitch errors on depth accuracy is dependent on beam angle and depth.

Sound velocity errors include measurement errors, unmeasured temporal and spatial variation, and inaccuracies in calculation of corrections for sound velocity effects. Sound velocity data is used to make three types of corrections - travel time, launch angle, and refraction. Travel time correction is very similar to corrections applied to conventional hydrographic systems. Data supplied by the sonar assumes a sound velocity of 1463.04 meters per second (4800 feet per second) in order to be interpreted as range. It must be corrected for the actual average sound velocity. Launch angle correction is required because the acoustic beams are formed at five degree increments in angle only if the wavelength of the sound at the transducer is exactly as the designer assumed. This corresponds to a sound velocity of 1496.42 meters per second. Differences in sound velocity at the transducer from that which is reported to the processor of five meters per second will cause launch angle errors that will consume the entire budget for either velocity measurement or zone variation in the outer beams. The third correction is for refraction or ray bending. This correction is based on the deviation of sound velocity from isovelocity. Algorithms for correction of these effects have been examined and found to sufficiently accurate if provided sound velocity measurements correct within plus or minus two meters per second. The bulk of the sound velocity data for these tests was obtained from the Grundy Model 9090 XSTD System. Tests reported by Callahan (1976) indicated that the system is capable of this accuracy but the depth accuracy was limited and a number of operational problems were reported. Supplemental data were obtained from Nansen casts and from a Martek TDC Metering System.

Determination of positioning accuracy was not a primary objective of these tests but it is important because positioning accuracy will affect the apparent depth accuracy. The accuracy of positioning center beam soundings is dependent on the positioning system in the same way as a conventional hydrographic system. Positioning of outer beam soundings must be projected using the measured depth, heading, roll, pitch, and sound velocity. These soundings will be positioned less accurately than soundings from a conventional system. The BS^3 is presently configured to interface to a Raydist system for medium range (a few hundred meters to 250 kilometers) or a

Miniranger system for short range (a few meters to 80 kilometers). Miniranger accuracy is reported to be plus or minus three meters. Raydist accuracy is reported to be comparable but only under ideal conditions. In normal operations its accuracy is expected to be less. The accuracy of projected positions is given by:

$$\sigma(xy)^2 = [\sigma(d) \tan \theta]^2 + [\sigma(\phi) d \tan \theta]^2 + [\sigma(R) d \sec^2 \theta]^2 + [\sigma(P) d]^2 + [K \sigma(c) d]^2$$

where $\sigma(xy)$ = standard deviation of projected position
$\sigma(d)$ = standard deviation of depth error
$\sigma(\phi)$ = standard deviation of heading error
$\sigma(R)$ = standard deviation of roll error
$\sigma(P)$ = standard deviation of pitch error
$\sigma(c)$ = standard deviation of sound velocity error
θ = beam angle
d = depth
k = constant

Heading information is taken from a Sperry MK14 gyrocompass. The overall accuracy of this device is expected to be of the order of one degree. If one assumes 0.1 degree roll and pitch errors, one degree heading error, depth error equal to (.28 + .006 d) meters and neglects for the present sound velocity errors then the accuracy of the projected positions for the outer beams is about .33 + .02 d meters or 2.33 meters in 100 meter depths. The heading error is the largest contributor.

Thus, the dominant error sources for depth accuracy and the parameters on which they depend are:

error source	parameter
range measurement error	beam angle
	depth
	bottom composition and roughness
	slope

error source (cont)	parameter (cont)
heave, roll, and pitch errors	beam angle
	depth
	sea state
	heading and speed relative to waves
	speed and course changes
	platform and installation biases
sound velocity errors	beam angle
	depth
	mean sound velocity
	sound velocity at transducer
	sound velocity gradient and structure

The tests were designed to vary the parameters of depth, sea state, and bottom slope. The test conditions are shown in the following matrix.

test	depth	sea state	bottom	location
1	shallow (~ 100 ft)	calm	flat	Bellingham Harbor
2	deep (~ 2000 ft)	rough	flat	offshore of Astoria
3	shallow (~ 100 ft)	rough	flat	Cape Disappointment
4	intermediate	calm	sloped	San Juan Island

Since data was gathered from all beams during each of these tests the variation with beam angle did not require different test conditions. Bottom composition and roughness varied at different test sites but it was not possible to systematically control this parameter. Nearly isovelocity conditions existed at each of the sites. Efforts were made to minimize positioning errors rather than to characterize these errors.

Three different techniques were devised to analyze the system accuracy. The simplest of these was time series analysis. The sequence of data points logged from each beam was analyzed during portions of the test that were thought to be over a flat bottom. The corrected soundings were plotted, histograms formed, and statistics calculated. Though this permitted a quick look at the data the estimates of accuracy were corrupted with true depth variations.

The second technique was intercomparison with the data from a conventional sounding system. Data from both the Ross and Raytheon sounders were logged on magnetic tape through the BS^3. The same corrections were applied to both the BS^3 soundings and those from the conventional system. There were some inaccuracies in this technique due to the physical offsets of the transducers and to the lack of synchronization between the soundings. Also this technique could not provide any information on the performance of the outer beams of the BS^3. Nevertheless, it provided very valuable information on the performance of the center beams with respect to the standard system in use by NOS. (Note that the center beam is the beam which would be vertical if the ship were on an even keel. There are actually two of these in swath - one formed by the port transducers and one by the starboard transducers).

The third technique was dubbed the "patch test". This involved running the ship in a figure eight or modified figure eight pattern over the selected test site. The center beam soundings formed a line of depths on the first leg and this line was swath sounded by the system when the ship passed again on a heading ±90 degrees from that line. Figure 2 shows the course of a patch run. The juncture of the two headings is referred to as the origin. The origin was sounded by the central beam on every pass regardless of heading. At the origin the performance of the central beam was determined by comparison to ground truth measurements. The central beam was then used as a transfer standard to evaluate the performance of the outer beams. The goal was to be able to estimate:

1) the standard deviation of depths for all beams such that at the 90 percent confidence level this estimate is in error by no greater than 25 percent from the true standard deviation.

2) the mean difference from true depth for all beams within three inches of the actual bias at the 90 percent confidence level.

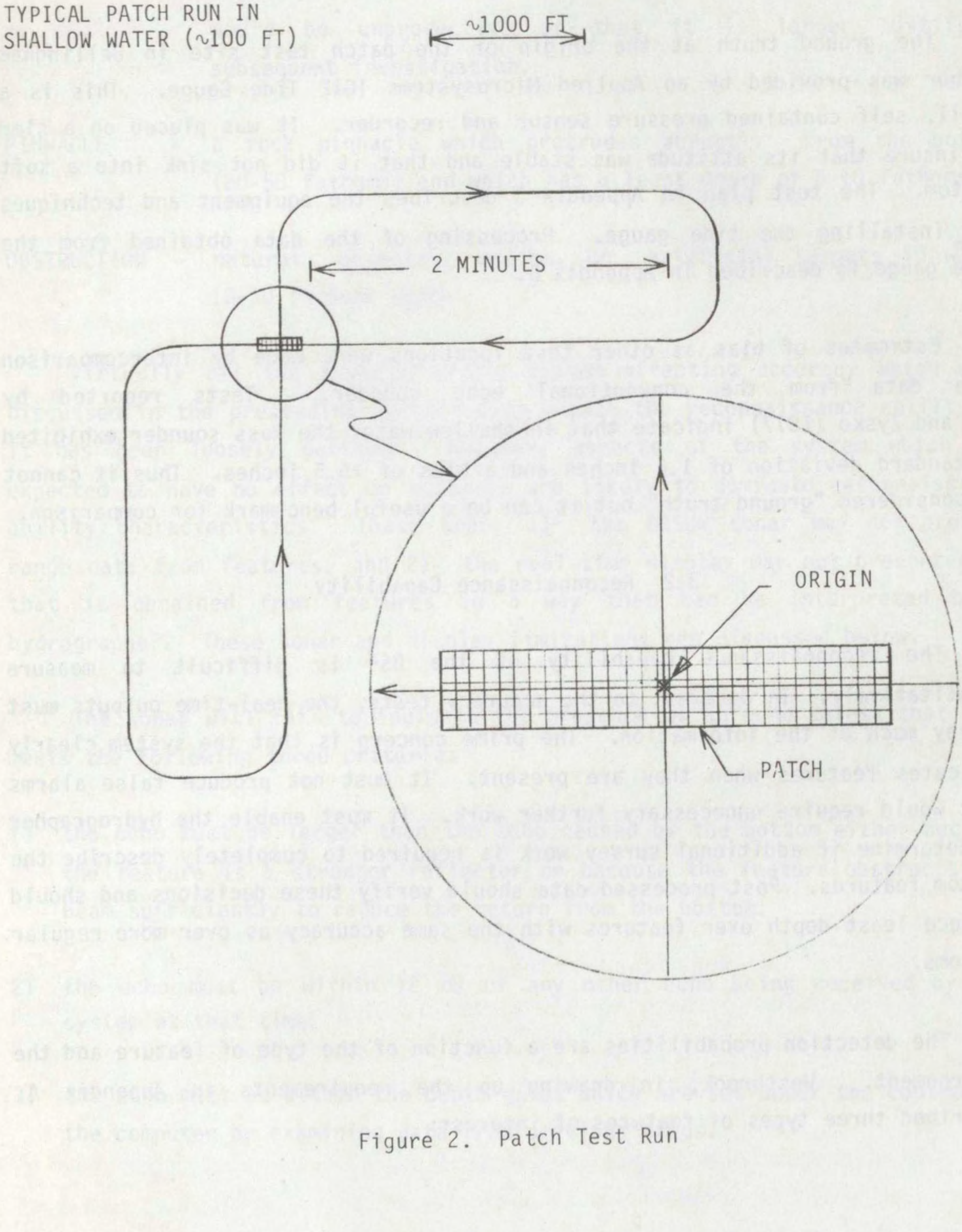


Figure 2. Patch Test Run

Assuming the statistics are normally distributed, the standard deviation goal requires at least 31 samples. Each run provides one sample.

The ground truth at the origin of the patch test site in Bellingham Harbor was provided by an Applied Microsystems TG12 Tide Gauge. This is a small, self contained pressure sensor and recorder. It was placed on a sled to insure that its attitude was stable and that it did not sink into a soft bottom. The test plan in Appendix C describes the equipment and techniques for installing the tide gauge. Processing of the data obtained from the tide gauge is described in Appendix D.

Estimates of bias at other test locations were made by intercomparison with data from the conventional echo sounder. Tests reported by New and Zysko (1977) indicate that in shallow water the Ross sounder exhibited a standard deviation of 1.6 inches and a bias of +5.5 inches. Thus it cannot be considered "ground truth" but it can be a useful benchmark for comparison.

3.2 Reconnaissance Capability

The reconnaissance capability of the BS^3 is difficult to measure quantitatively. In contrast to the accuracy tests, the real-time outputs must convey much of the information. The prime concern is that the system clearly indicates features when they are present. It must not produce false alarms that would require unnecessary further work. It must enable the hydrographer to determine if additional survey work is required to completely describe the bottom features. Post processed data should verify these decisions and should produce least depth over features with the same accuracy as over more regular bottoms.

The detection probabilities are a function of the type of feature and the environment. Westbrook, in drawing up the requirements in Appendix A, described three types of features of interest:

SHOAL - feature which extends approximately ten percent of the depth above a flat or gently sloping bottom. The system should accurately indicate whether the shoal extends less than this amount above the bottom indicating that further investigation would be unproductive or that it is larger justifying subsequent investigation.

PINNACLE - a rock pinnacle which protrudes abruptly from the bottom (20-50 fathoms) and which has a least depth of 6-10 fathoms.

OBSTRUCTION - natural objects, wrecks, or artificial targets in water 10-30 fathoms deep.

Virtually all the aspects of the system affecting accuracy which were discussed in the preceeding section also impact the reconnaissance ability as it has been loosely defined. However, aspects of the system which are expected to have no effect on accuracy are likely to dominate reconnaissance ability characteristics. These are: 1) the BOSUN sonar may not provide range data from features, and 2) the real-time display may not present data that is obtained from features in a way that can be interpreted by a hydrographer. These sonar and display limitations are discussed below.

The sonar will fail to indicate the presence of an echo unless that echo meets the following three criteria:

1) the echo must be larger than the echo caused by the bottom either because the feature is a stronger reflector or because the feature obstructs the beam sufficiently to reduce the return from the bottom.

2) the echo must be within 12 dB of any other echo being received by the system at that time.

3) the echo must be within the depth gates which are set under the control of the computer by examining data from previous pings.

Echo strength in several cases has been plotted in Figure 3. The ordinate represents the relative strength of the return after it has been processed through the time variable gain circuitry. The relative level will not be changed between this point and where the range estimates are made. It is assumed that the time variable gain corrects for 20 log r + 2 α r propagation loss which would be expected for bottom reverberation. Measurements indicate that the actual gain may fall short of this at the end of the depth range. This would cause all of the signal levels to decrease by the same amount. Echoes from artificial targets plotted in this figure decrease in amplitude with range. This is because the propagation loss for a target is 40 log r + 2 α r. It is clear from this that many "point" features might be missed by the system. It is likely that a feature must have physical size of the order of a beam width to be detected. Its probability of being detected decreases with range.

Side lobe rejection circuitry will remove any echo which is more than 12 dB below any other signal received at the same time. This may create "blind spots" at ranges near the range to the bottom in the vertical beam. A specular echo, that is, an echo from a surface normal to the beam, is the only type of return likely to avoid rejection at this range. Suppression is less strong at ranges greater than that in the vertical but a weak echo that occurs simultaneously with another echo in the system may be rejected regardless of its range.

Depth gates are controlled by the computer unless the system is in manual mode. The height of the gates is set by the maximum deviation in a swath of returns from a straight line in depth when this straight line is formed by averaging the two next-to-outermost returns on each side of the swath. To this is added an increment based on beam width, pulse length, and ping-to-ping jitter. The result is that the gate height is usually between one-third and one-half of the depth. The gates may reject legitimate returns if they differ in range from previous pings by more than the gate height.

Thus the sonar limitations on reconnaissance capability likely to be encountered are: low probability of detection of point targets especially at the end of a particular depth scale, difficulty in detecting targets which

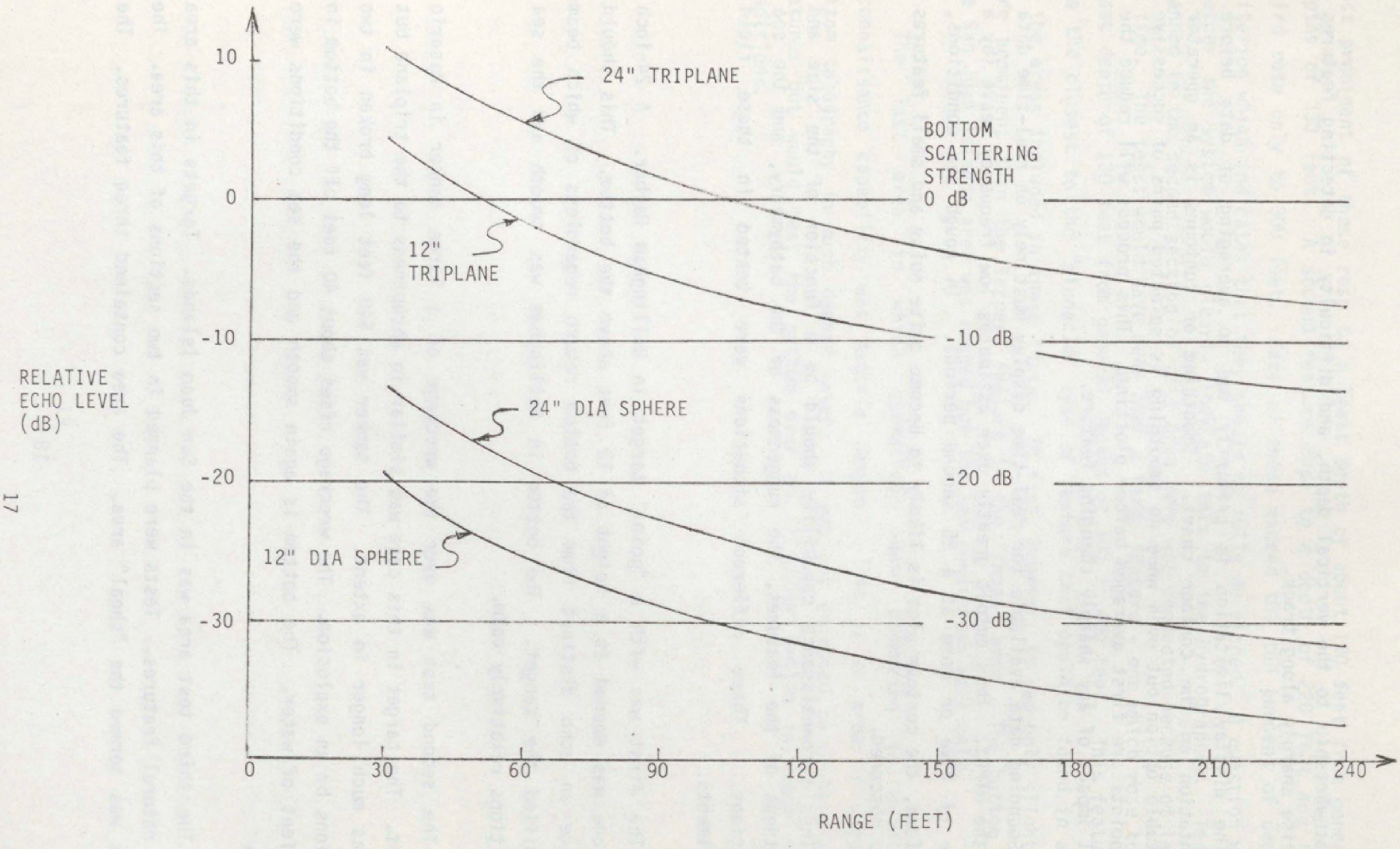


Figure 3. Echo Strengths

rise athwartship to the vertical depth, and difficulty in detecting features that rise sharply along track.

The display limitation is primarily due to averaging of data before presentation on the contour chart. Smoothing of contours is an operator selectable option but even when no smoothing is selected pairs of successive data points are first averaged before plotting. This process will reduce the visual impact of any sharply changing feature.

Sounding data available for real-time display must rely on real-time data from the HIPPY. This output greatly over estimates low frequency heave (by a factor of five or more at a 25 second period). In rough sea conditions, therefore, the contour plot is likely to become quite noisy and small features may be obscured.

Thus reconnaissance capability should be a function of the size and abruptness of the features, the ruggedness of the bathymetry, and the sea conditions. Three different situations were tested in these field experiments.

The first was with a "point" target in Bellingham Harbor. A 24-inch triplane was moored at a height of 12 feet above the bottom. This should produce an echo distinct from the bottom return regardless of which beam insonified the target. The bottom in Bellingham was smooth and the sea conditions relatively calm.

The second test was over the wreckage of a large tanker in Rosario Strait. The target in this case was similar in abruptness to the triplane but it was much longer in extent. The tanker was 540 feet long broken in two sections by an explosion. The wreckage rises about 40 feet off the bottom in 270 feet of water. The bottom is again smooth and the sea conditions were calm.

The third test area was in the San Juan Islands. Targets in this area were natural features. Tests were planned in two sections of this area. The first was termed the "shoal" area. The area contained three features. The most prominent of these rose to a least depth of about 190 feet from general depths of 350 feet. A second feature rose to a depth of 220 feet and the third rose only to 300 feet. Each of these exceed the ten percent of depth criterion which indicates that they should be fully developed. A question was whether the system would clearly indicate this to the hydrographer. Tests planned in the second section of this area were not conducted because of lack of time. The tests would have been over a large feature - one which rose to a least depth of 130 feet from general depths of 300 to 400 feet. This feature was the closest to the "pinnacle" type of feature that could be found in any of the areas included in these tests. In fact, however, it was only slightly more prominent than the largest feature in the "shoal" area. The bottom in the San Juan Islands area was rugged but the sea conditions were calm.

The last area in which operations were conducted to examine reconnaissance capability was Astoria Canyon. This is an area of rugged bottom topography in much deeper water. It was not expected to contain any features but would test the system over an irregular bottom in rough sea conditions.

4.0 DATA PROCESSING

Codes for analysis of data from these tests were derived from the Combined Offline Program (COP). This program has two major functions. The first is to assemble the data, combine it, and produce corrected soundings. The second is to pick a subset of the data which is meaningful for presentation on a nautical chart. To improve processing speed the sequence of operations is to make approximate corrections, select soundings and then make accurate corrections to the selected soundings. Since the techniques devised for analysis of data from these tests required access to the complete set of corrected soundings the program was modified to eliminate the selection process. Consequently these results reflect the adequacy of the correction algorithm but in operational use additional effects from the selection process are expected. At this stage of the analysis these effects have not been examined.

A flow diagram for the data analysis is shown in Figure 4. The revised Combined Offline Program, dubbed COPEDO, is near the middle of this flow. Preparation of the data for use by this program is similar to steps which would be required in operational use of the system. Details of the preparatory steps differ from the expected treatment of operational data partly because these tests were unique in some respects and partly because some of the software had not been brought up to date with the current status of the BS^3. A second variant of the Combined Offline Program, entitled COPEGG, was developed to handle data from the conventional sounder as well as the BS^3 for intercomparison. Programs which operate on the outputs of COPEDO/COPEGG were specifically designed for the analysis of data from these tests.

Preparation of raw data tapes for COPEDO/COPEGG consisted of removing end of files marks and splicing together data segments which had for one reason or another been originally recorded on more than one tape. This was carried out in the same fashion as it would be in operational use. Preparation of the survey summary file diskettes consisted of copying and editing. Copying was done to preserve the integrity of the original data set. Editing was required to insert tide data as well as final sound velocity data and alignment

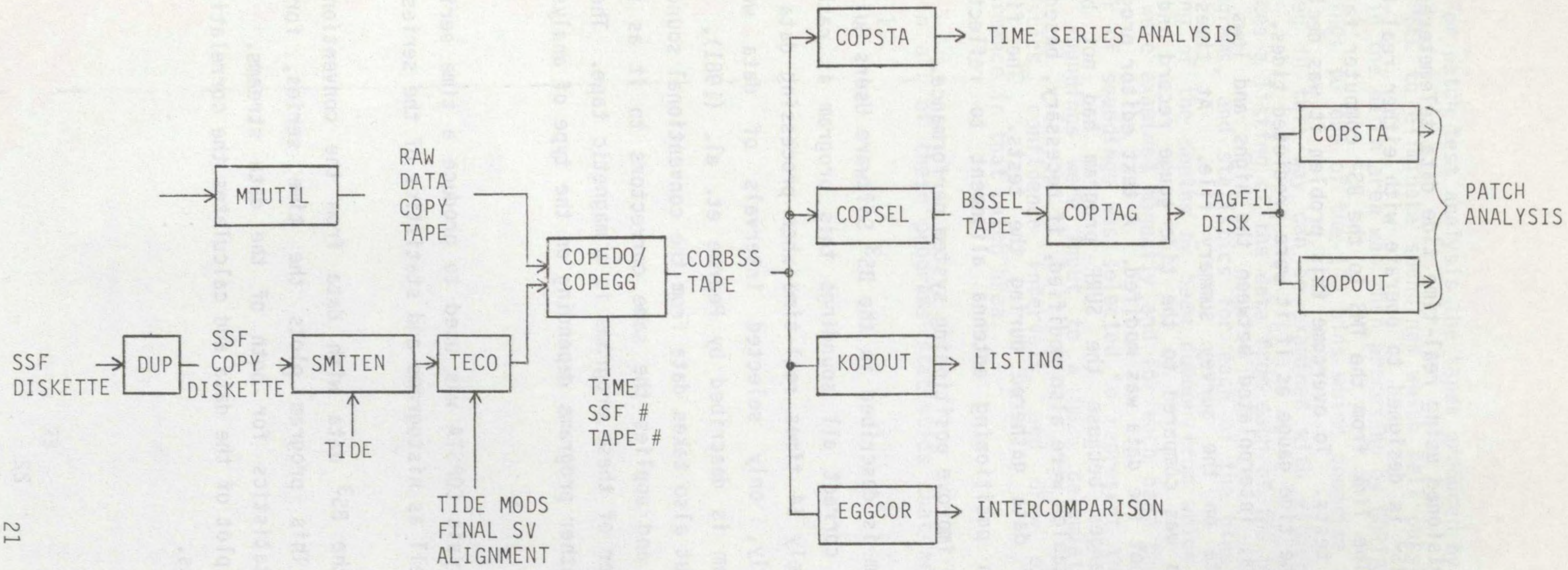


Figure 4. Data Analysis Flow Diagram

information. These tests envisioned using real-time tide data telemetered to the ship by the TMS. (The BS^3 is designed to operate with either real-time tides or predicted tides.) The link from the TMS to the BS^3 computer failed during large portions of the tests. To overcome this problem it was decided to enter data recorded from the tide gauge as if it were predicted tides. The SMITEN program took this data, interpolated between the highs and lows and entered the interpolated data on the survey summary file. At times of particular interest this data was compared to the tide gauge record and if different by more than 0.1 foot the data was modifed. A text editor program was used to make these changes because the SURF program had not been updated. The sound velocity tables were also modified, if necessary, based on a review of the ensemble of data gathered during the tests. The final modification was to data on positioning antenna alignment to reflect a temporary installation made to improve positioning system performance.

Use of the COPEDO program is described in the BS^3 Software Users Guide. Because of the necessity to correct all soundings this program is rather slow. It runs at approximately 14 times real-time when processing data in shallow water. Consequently, only selected intervals of data were processed. The COPEGG program is described by Pearce et. al. (1981). It operates similarly to COPEDO but also takes data from the conventional sounder through the navigation ports and applies the same correctors to it as the BS^3 data. The output of either of these programs is a magnetic tape. These tapes were then processed by other programs depending on the type of analysis required.

For the time series analysis COPSTA was used to produce a time series plot of the selected data as well as histograms and statistics of the series.

For intercomparison of the BS^3 data with data from the conventional sounder EGGCOR was used. This program plots the time series, forms histograms, and calculates statistics for both of the data streams. In addition it produces a scatter plot of the data and calculates the correlation coefficient of the two data sets.

For patch test analysis the tapes produced by COPEDO were first processed by COPSEL to eliminate soundings which fell outside of the patch area. The data in the patch area was then processed by COPTAG which assigned each of the soundings to one of the 145 bins which comprise the patch area. The TAGFIL created in this way can be examined with either KOPOUT or COPSTA. KOPOUT produces a listing of the data from each of the bins. COPSTA produces plots, histograms, and statistics for each of the bins and in addition produces a listing of the depths by beam number from which they were acquired. These data were examined manually and for each beam the bin containing the largest number of soundings was selected to represent the performance of that beam. These soundings were input to a 9825 calculator programmed to calculate statistics, confidence intervals, and draw plots representing the BS^3 performance in that patch area.

In all of these programs statistics that are calculated are defined in Table 1.

TABLE 1

STATISTICAL DEFINITIONS

- MEAN: $\overline{X} = \frac{\sum^{N} X_i}{N}$

- STANDARD DEVIATION: $S_D = \sqrt{\frac{\sum (X_i - \overline{X})^2}{N-1}}$

NOTE: EGGCOR uses N in the denominator. This results in a biased estimate of the standard deviation but for large N the difference is negligible.

- CORRELATION COEFFICIENT:

$$\rho = \frac{\frac{\sum^{N} X_i Y_i}{N} - \overline{X}\,\overline{Y}}{\left(\frac{\sum^{N} X_i^{\,2}}{N} - \overline{X}^2\right)\left(\frac{\sum^{N} Y_i^{\,2}}{N} - \overline{Y}^2\right)}$$

- CONFIDENCE INTERVAL ABOUT MEAN:

$$\left(\overline{X} - \frac{S_D\ t_{N-1;\alpha/2}}{\sqrt{N}}\right) \leq \mu_D \leq \left(\overline{X} + \frac{S_D\ t_{N-1;\alpha/2}}{\sqrt{N}}\right)$$

where μ_D is the true mean of the population and $t_{N-1;\alpha/2}$ is a parameter from the student T distribution for N-1 degrees of freedom at a confidence level of $(1-\alpha)$ 100%.

- CONFIDENCE INTERVAL ABOUT STANDARD DEVIATION:

$$\frac{(N-1)S_D^{\,2}}{\chi^2_{N-1;\alpha/2}} \leq \sigma_D^{\,2} \leq \frac{(N-1)S_D^{\,2}}{\chi^2_{N-1;1-\alpha/2}}$$

where σ_D is the true standard deviation of the population and $\chi^2_{N-1;\alpha/2}$ is a parameter from the chi-square distribution.

- CONFIDENCE INTERVAL ABOUT BIAS ESTIMATE WITH RESPECT TO BEAM 0:

$$\left(\overline{X}-\overline{X}_0 - t_{v;\alpha/2}\sqrt{\frac{S_D^2}{N} + \frac{S_{D0}^2}{N_0}}\right) \le \overline{\mu}_D - \overline{\mu}_{D0} \le \left(\overline{X}-\overline{X}_0 + t_{v;\alpha/2}\sqrt{\frac{S_D^2}{N} + \frac{S_{D0}^2}{N}}\right)$$

where

$$t_v = \frac{\left(\frac{S_D^2}{N} + \frac{S_{D0}^2}{N_0}\right)^2}{\frac{\left(\frac{S_D^2}{N}\right)^2}{N-1} + \frac{\left(\frac{S_{D0}}{N}\right)^2}{N_0-1}}$$

and S_{D0} is the sample standard deviation of beam 0 soundings and N_0 is the number of beam 0 soundings.

5.0 TEST RESULTS

Tests were performed to characterize the performance of the BS^3 from the point of veiw of accuracy and reconnaissance capability. Table 2 lists the test areas, objectives, and analysis techniques employed.

5.1 Accuracy Tests

Bellingham Harbor

Tests in Bellingham Harbor were intended to be the benchmark for accuracy estimates. Runs over the patch site occupied five days. Water depth was approximately 90 feet at MLLW. The harbor is protected and sea conditions were never rough. Weather varied over the period with winds ranging from calm to 35 knots and waves from 0.5 feet to four feet. The bottom in the area was described as mud. Sound velocity in the water column was very nearly constant at 1480 meters per second.

A total of 40 runs were conducted over the patch site each consisting of two passes over the origin. Figure 5 shows the patch area divided into bins. Each bin was three meters square chosen to be roughly equal to the size of the footprint of the BS^3 beams on the bottom. The figure shows that the number of soundings in each bin ranged from 32 to 167. Figure 6 shows the distribution of soundings by beam number in each bin of row three of the patch area. East-west passes over the patch tend to sound all the bins with the nominal vertical beam 0. North-South passes tend to sound the center bin with beam 0 and the other bins with the outer beams. The maximum number of soundings in any one bin for each beam is circled. The statistics of these soundings are plotted in Figures 7 and 8.

The standard deviation of the soundings representing the performance of the various beams ranged from 0.87 to 2.28 feet. In nearly all beams the standard deviation was unacceptable by comparison to the goal for this water depth of 1.25 feet. There was no evidence that the variation in the outer beams was much greater than in the center beams. The vertical bars represent the 90 percent confidence interval of these standard deviation estimates. The

		BEL'HAM	SAN JUAN ISLANDS		ROSARIO	OFF ASTORIA		CAPE
			SHOAL	SLOPE	STRAIT	CANYON	DEEP WATER	DIS.
ACCURACY	PATCH	X		X			X	X
	INTERCOMPARISON	X	X	X		X	X	X
	TIME SERIES	X					X	X
	OUTLIERS	X				X	X	X
RECON	TARGET	X						
	SHOAL		X					
	WRECK				X			

Table 2. Characterization Tests

ENTRY = NO. OF SOUNDINGS

BINS = 3 METERS SQUARE

Bin No.

Row	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	52	56	66	80	66	100	94	96	99	118	123	117	132	132	144	128	113	118	114	107	90	95	101	80	104	66	75	77	96
2	57	71	85	87	93	102	101	97	105	121	123	112	129	144	139	134	129	139	131	112	124	123	123	108	95	130	116	67	53
3	69	73	88	102	113	108	107	141	118	130	128	142	145	141	140	166	109	139	126	104	115	101	100	91	97	84	58	107	36
4	114	139	121	121	95	126	114	129	125	134	128	139	140	144	164	138	131	148	142	131	132	123	113	107	100	88	79	81	67
5	57	74	84	104	114	111	110	116	124	133	134	137	136	146	167	137	131	136	120	116	112	126	107	117	98	91	82	80	82

Figure 5. Bellingham Patch

ROW 3
ENTRIES ≥ 7

BIN NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
10				(13)																									
9					9	(9)	7							8							8								
8					8	9	(11)	10	8						8					7		7							
7							7	(12)	11												10								
6								9	(16)		7									9									
5										(13)									8										
4										9	(13)	9	7					11	10										
3	7							9	8	8	14	(15)	15	13	10	12	10	7						7		10			
2					7			8	8		9	16	(13)	12	7	15	8		10		10	10		11	15	7	7		
1	12		12		7	9		11	7	9	10	11	(15)	12	12	8	7	8	9	8	16	8	9	8	14			7	
0	8	10	9	11	8	9	9	11	9	11	11	13	17	(21)	18	13	7	9	14			10	9	8		9	7	9	
- 0	7	9	12	10	10	9	9	11	9	8	14	14	20	18	(20)	14	7	9	9		7	7	9		7	8	7	9	
- 1	8		10	9	20	8	9	12			11	11	12	18	14	(16)	7	11	9	7		8			7				7
- 2												9	9	9	(15)	11	9						7		8	8		7	
- 3												8	7			(9)							7						
- 4								7		7							(8)		8										
- 5											9				8		9	(15)	8	8									
- 6										8		9				8		8	(11)										
- 7																				(9)									
- 8					7																9	(10)							
- 9						7																9	(8)						
-10																								(8)	7				

Figure 6. Distribution of Soundings
Bellingham Patch

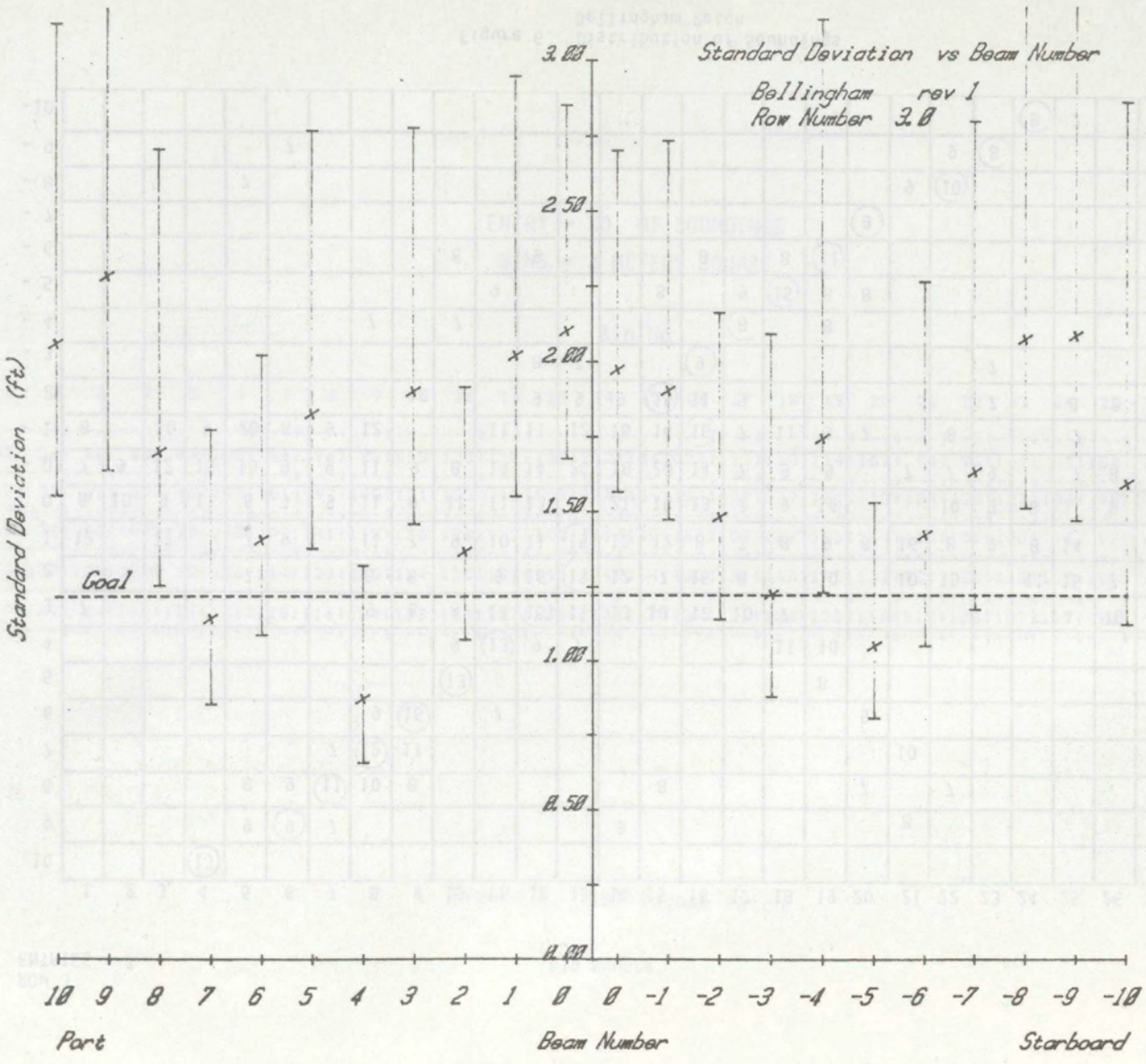


Figure 7. Standard Deviations -
Bellingham Patch

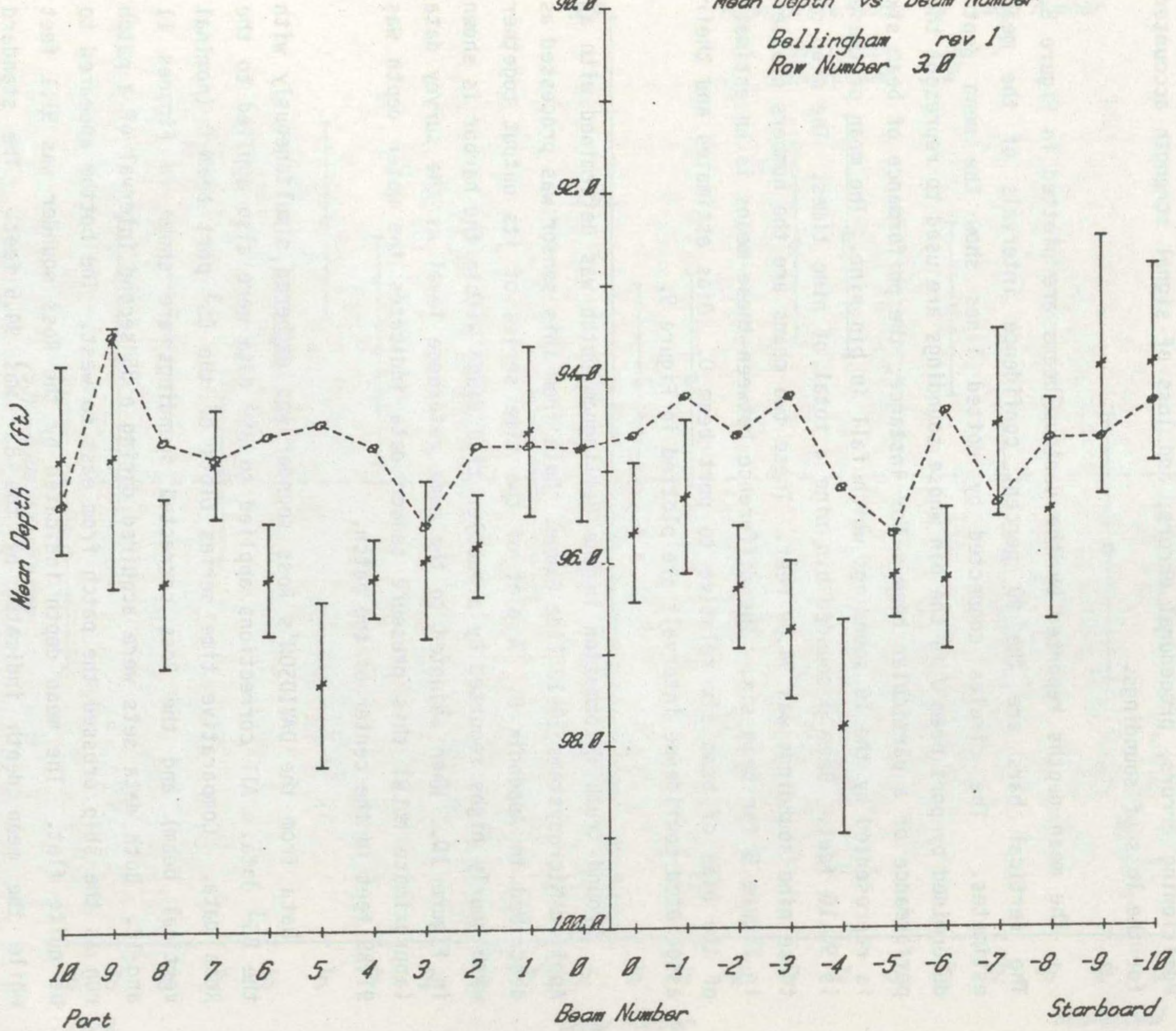


Figure 8. Mean Depths - Bellingham Patch

relatively large size of these confidence intervals is due to the fact that eight to 21 soundings were used to represent the performance of each beam. The test was designed to produce approximately 30 soundings for each beam. Positioning errors, procedural errors, and loss of signal strength accounted for the loss of soundings.

The mean depths reported by the various beams are plotted in Figure 8. The vertical bars are the 90 percent confidence intervals of the mean estimates. The circles connected by dotted lines show the mean depth determined by port beam 0 in the bin whose soundings are used to represent the performance of a particular beam. For instance, the performance of beam six is represented by the 16 soundings which fall in bin nine. The mean of these is 96.16 feet. Beam 0 sounded bin nine a total of nine times. The mean of these nine soundings was 94.59 feet. These two means are the numbers plotted in Figure 8 for beam six. The difference between these means is an estimate of the bias of beam six relative to port beam 0. Bias estimates and their associated confidence intervals are plotted in Figure 9.

Ground truth information in the Bellingham patch was determined with an Applied Microsystems TG-12 Tide Gauge. Data from this sensor was processed as described in Appendix D. A plot of the time series of its output together with hourly highs reported by a bubbler tide gauge within the harbor is shown in Figure 10. When adjusted to the same reference level as the survey data (approximate MLLW) this pressure sensor data indicates the water depth was 91.39 feet in the center of the patch.

Data from the DAVIDSON's Ross sounder was gathered simultaneously with the BS^3 data. All corrections applied to BS^3 data were also applied to the Ross data. Comparative time series plots of the BS^3 port beam 0 (nominal vertical beam) and the Ross corrected soundings are shown in Figures 11 and 12. Both data sets were acquired during a 35 second interval of a patch run as the ship crossed the patch from east to west. The bottom appeared to be quite flat. The mean depth indicated by the Ross sounder was 91.1 feet while the mean depth indicated by the BS^3 was 94.5 feet. The standard deviation of the Ross soundings was 0.26 feet as compared a standard deviation of 1.72 feet for the BS^3 soundings. Similar intercomparisons were computed

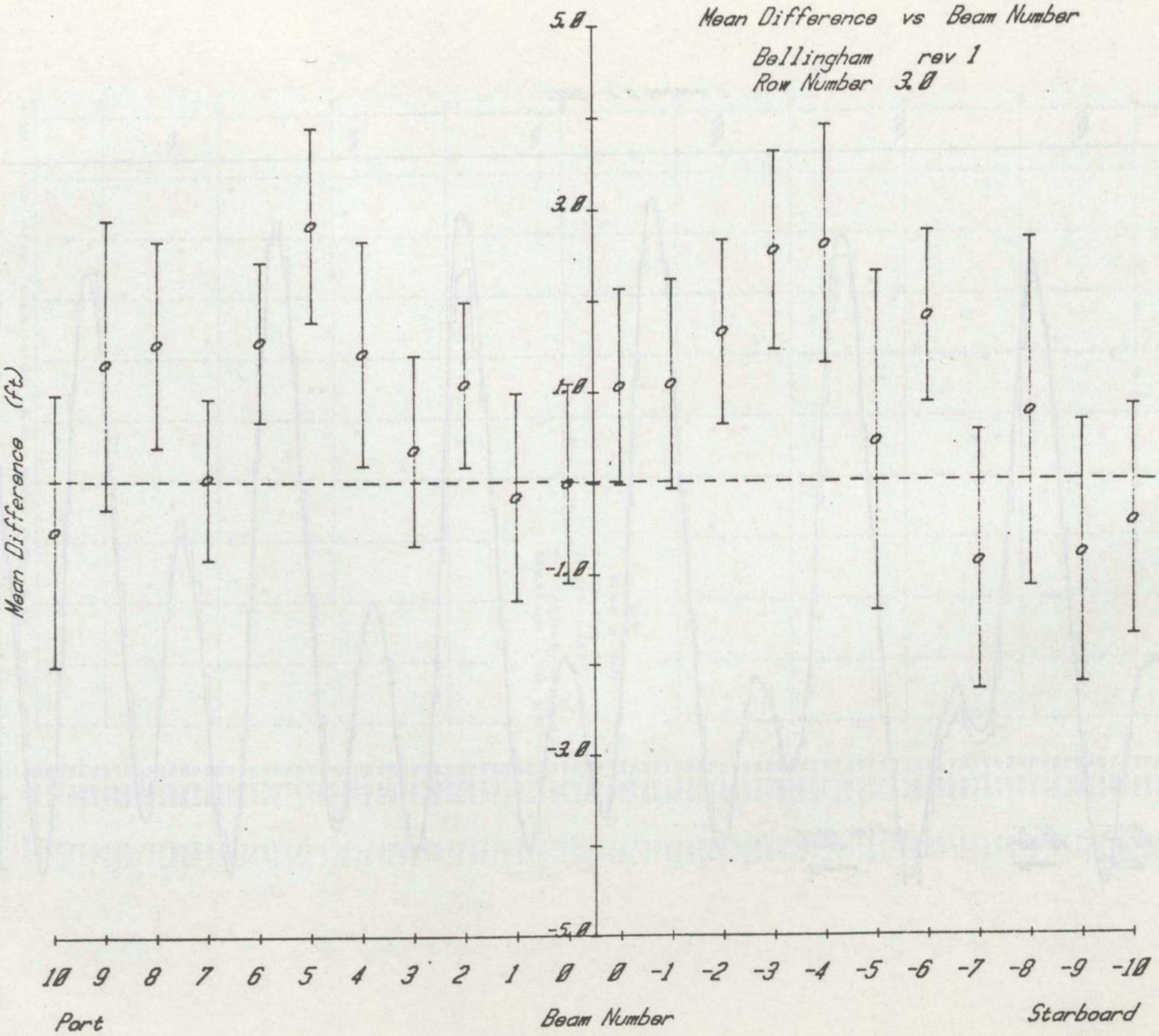


Figure 9. Biases - Bellinham Patch

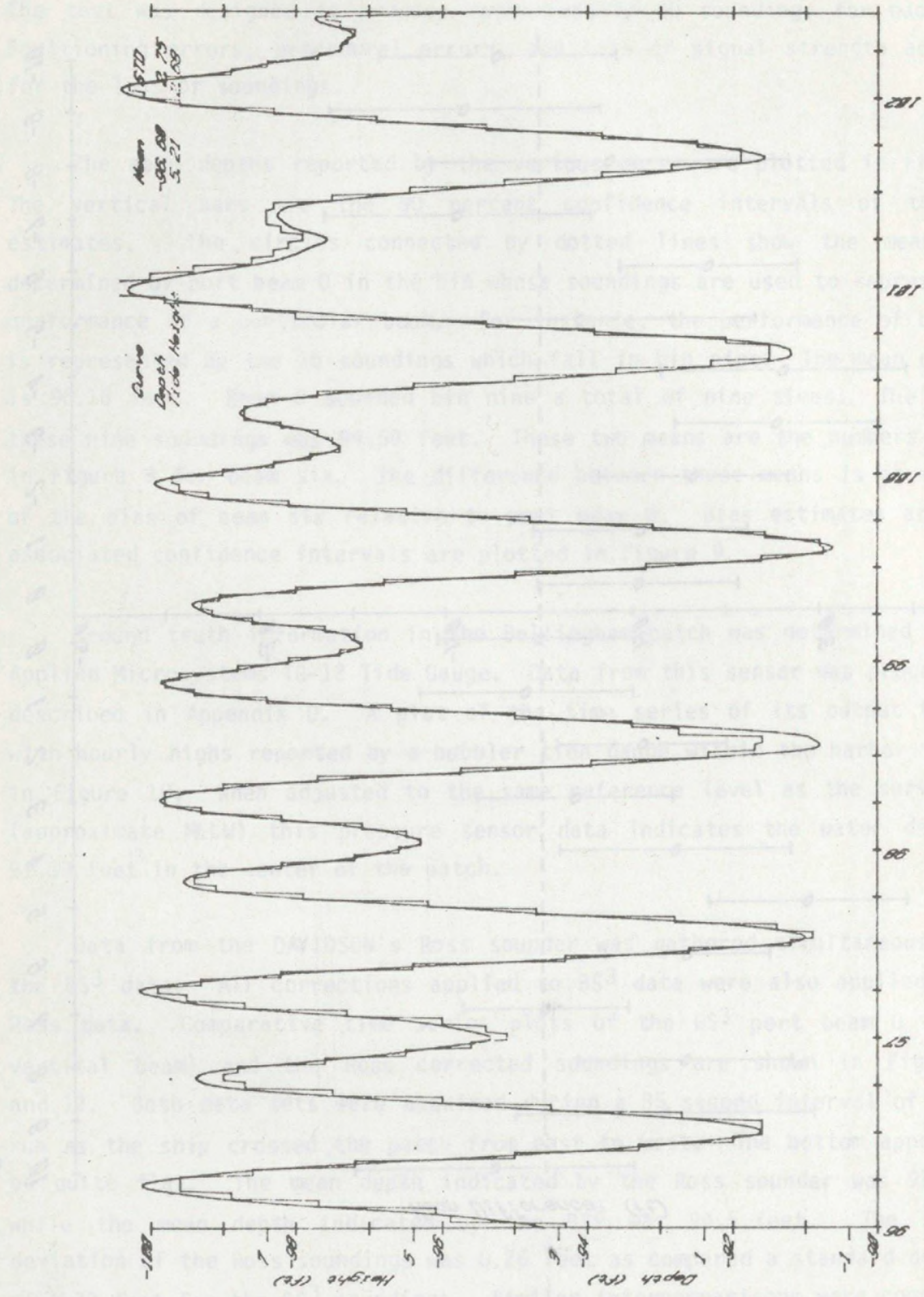


Figure 10. Pressure Sensor and Tide Gage Records

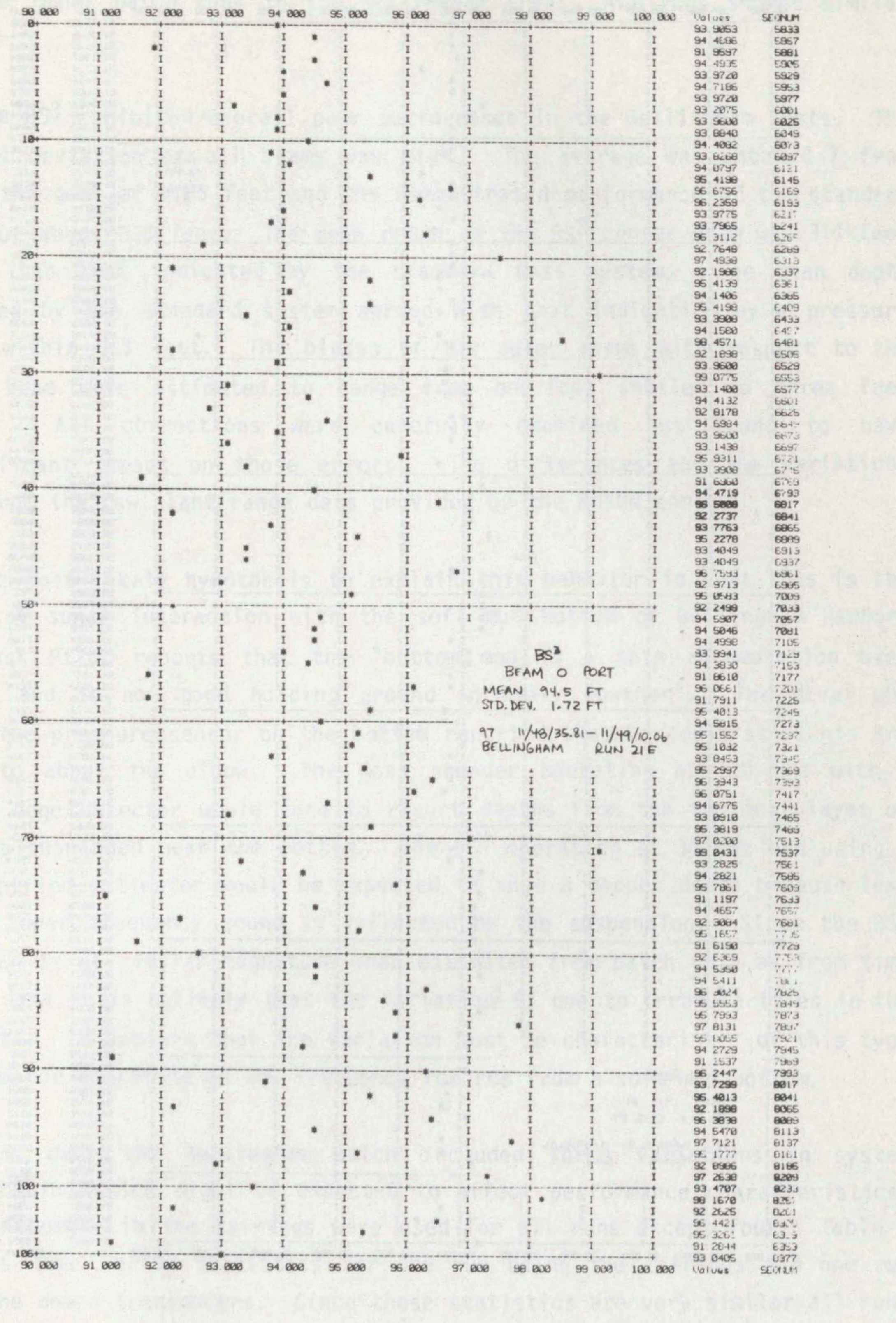


Figure 11. BS^3 Time Series-Bellingham

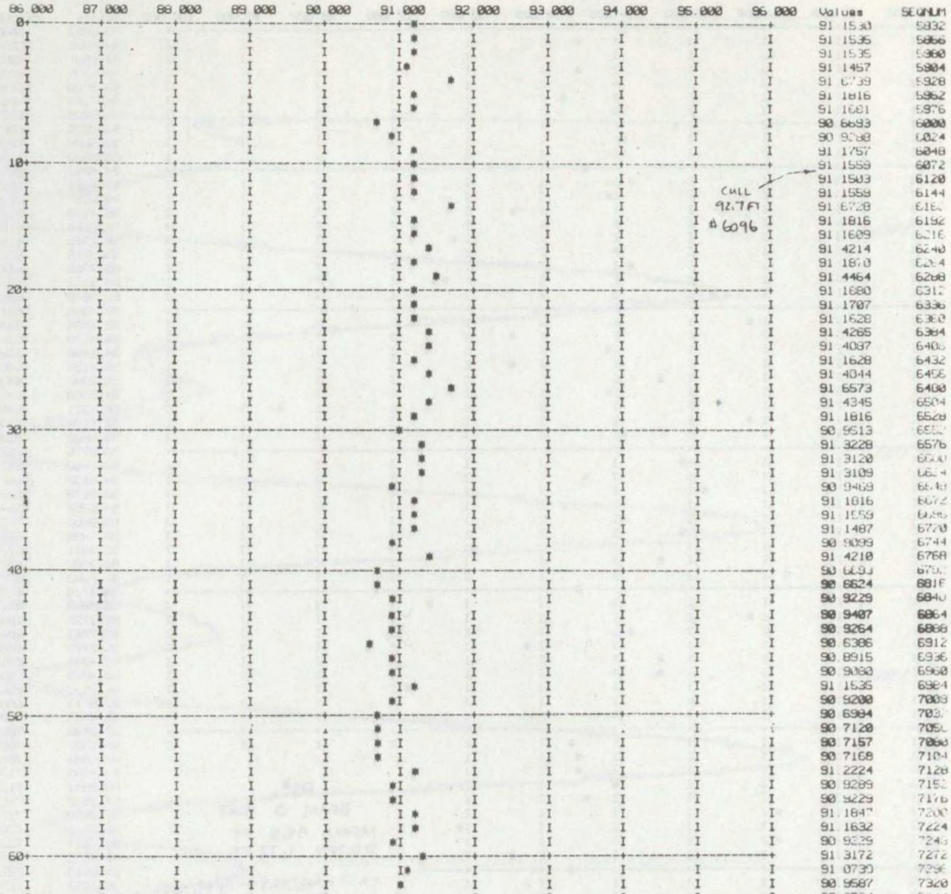


Figure 12. Ross Time Series-Bellingham

for four other patch runs in the Bellingham area. All runs showed similar behavior.

The BS^3 exhibited overall poor performance in the Bellingham tests. The standard deviation of all beams was high. The average was about 1.7 feet versus the goal of 1.25 feet and the demonstrated performance of the standard system of about 0.3 feet. The mean depth of the BS^3 center beam was 3.4 feet deeper than that indicated by the standard Ross system. The mean depth indicated by the standard system agreed with that indication by a pressure sensor within 0.3 feet. The biases of the outer beams with respect to the center beam were estimated to range from one foot shoaler to three feet deeper. All corrections were carefully examined but found to have insignificant impact on those errors. The differences and the variations arise from the raw slant range data provided by the BOSUN sonar.

The most likely hypothesis to explain this behavior is that this is the result of sonar interaction with the soft mud bottom of Bellingham Harbor. The Coast Pilot reports that the "bottom mud is a thin accumulation over hardpan and is not good holding ground in heavy weather". The diver who placed the pressure sensor on the bottom reported that he could stick his arm in up to about the elbow. The Ross sounder operating at 100 KHz with a leading edge detector would tend to report depths from the top most layer of sediment suspended near the bottom. The BS^3 operating at 36 KHz and using a peak/centriod estimator would be expected to show a deeper depth because less of the lower frequency sound is reflected by the suspension. Since the BS^3 variation is of similar magnitude when estimated from patch data as from time series data it is unlikely that the variation is due to irregularities in the substrate. It appears that the variation must be characteristic of this type of estimator operating on low frequency returns from a soft mud bottom.

Runs over the Bellingham patch included three variations in system configuration which might be expected to effect performance characteristics. The transducers in the fairings were used for all runs except four. Table 3 compares time series statistics for one run using the fairings and one run using the domed transducers. Since these statistics are very similar all runs were processed as a homogeneous set. The second variation was in attenuation

RUN 4 E DAY 96			RUN 23 S DAY 98		
BEAM	$\overline{X}$	S_D	BEAM	$\overline{X}$	S_D
10 (Port)	100.1	1.6	10 (Port)	98.6	1.6
9	99.7	1.7	9	97.8	1.6
8	100.4	1.6	8	99.0	1.7
7	100.6	1.7	7	99.2	1.6
6	101.0	1.5	6	99.7	1.5
5	101.4	1.6	5	100.0	1.7
4	101.3	1.7	4	100.3	1.6
3	100.9	1.6	3	100.2	1.6
2	100.8	1.7	2	99.8	1.7
1	100.0	1.8	1	99.3	1.7
0	99.4	1.7	0	99.2	1.8
- 0	99.4	1.8	- 0	99.3	1.7
- 1	100.4	1.5	- 1	100.3	1.7
- 2	101.2	1.8	- 2	101.0	1.7
- 3	101.1	1.8	- 3	100.8	1.6
- 4	101.3	1.5	- 4	101.1	1.8
- 5	101.0	1.6	- 5	101.0	1.7
- 6	101.0	1.5	- 6	100.9	1.5
- 7	100.3	1.6	- 7	100.2	1.8
- 8	100.4	1.6	- 8	100.3	1.5
- 9	99.5	1.7	- 9	99.4	1.7
-10 (STBD)	99.5	1.5	-10 (STBD)	99.3	1.6
FAIRINGS			DOME		

Table 3: Time Series Statistics

Dome vs. Fairings

of the transmit signal. Most runs were conducted with no transmit attenuation. Several runs were conducted with six and 12 dB attenuation. The attenuation appeared to contribute to problems of signal loss but where sufficient signal strength for digitization was present the corrected sounding data appeared to have the same statistical performance. The transmit beamwidth was also changed during these runs. Most runs were conducted with the normal five degrees beamwidth. Some were conducted with a 20 degree beamwidth. Again there appeared to be no difference in the statistical performance between these two conditions.

Cape Disappointment

The tests at Cape Disappointment are most directly comparable to the Bellingham Harbor tests. The water depth was nearly the same - approximately 90 feet at MLLW. The most important differences were increased vessel motion and different bottom composition. In contrast to the Bellingham site, Cape Disappointment is open coast. The sea state was approximately one with two to three foot swells from the west. The peak vessel motions recorded were 7.5 degrees in roll, 2.3 degrees in pitch, and 4.2 feet in heave. The bottom was sand as opposed to the mud of Bellingham. The sound velocity was nearly constant at 1488 meters per second except in the upper ten meters where it fell to 1475 meters per second at the transducer. The patch test runs occupied only nine hours versus the five days required at Bellingham. This was partly because the procedure had become routine but mostly because the system operated more smoothly (positioning was less erratic and fewer system malfunctions were encountered).

A total of 32 runs were conducted over the patch site each consisting of two passes over the origin. Figure 13 shows the patch area and the number of soundings in each bin. Figure 14 shows the distribution of soundings by beam number in row two of the patch. Row 2 was chosen because the density of beam 0 soundings across the patch was higher than in any other row. As before the maximum number of soundings in a bin for each beam is circled. The statistics of these soundings are plotted in Figures 15 and 16.

The standard deviations are distinctly improved over those measured in Bellingham. Values ranged from 0.45 to 1.28 feet. The performance of all the beams with one marginal exception is within the acceptable bound set as a goal. The confidence intervals are still somewhat wide since the estimates are based on from 12 to 21 soundings per beam. There appears to be no distinct pattern of variation across the array although the standard deviations of the two nominally vertical beams are lower than any of the other beams.

The mean depths reported by the various beams are plotted in Figure 16. Port beam 0 data shows the area to be quite flat at a depth of 92 feet with a

ENTRY = NO. OF SOUNDINGS
BINS = 3 METERS SQUARE

Bin No.

Row	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	81	68	92	93	80	114	106	121	121	118	127	125	143	150	153	130	141	142	141	125	107	108	96	99	66	90	70	83	53
2	76	66	81	87	99	105	110	115	107	111	139	113	140	131	140	110	111	125	114	94	109	97	82	69	66	71	67	69	59
3	77	71	74	78	101	109	95	119	113	127	135	109	145	136	133	121	116	132	109	107	101	99	95	90	79	69	79	78	54
4	62	56	75	67	85	96	90	105	100	104	109	97	133	112	119	113	106	113	97	102	105	97	89	83	74	76	65	65	51
5	63	60	71	77	89	95	94	94	99	110	118	97	144	136	125	108	113	109	108	95	92	87	86	73	70	62	69	65	51

Figure 13. Cape Disappointment Patch

ROW 2
ENTRIES ≥ 7

BIN NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
10			(13)	9	8																								
9					(14)	12																							
8						13	(15)																						
7							12	(15)	8																				
6								12	(15)	7																			
5							8	7	(12)	11	9																		
4										(17)	11	7																	
3	9							7			(18)	7			7			9			9	11	8				10	7	
2	8	11	7					7	13		15	(19)	11	7		11	8	13	10	7	8	9	8	8		9	10	8	8
1	12		9	9		11		11	12	13	12	17	(17)	17	10	11	11	17	11				8			9			
0	8	6	3	12	5	8	12	9	6	11	15	9	(21)	18	22	9	13	6	9	5	8	6	8	3	3	10	8	7	4
-0	6	5	4	9	6	8	10	8	6	7	16	10	22	(21)	21	10	12	6	8	6	9	7	7	3	3	7	8	6	3
-1												9		(16)	10	12													
-2				7	11	8	7	8						11	(19)				8										
-3										8		8	13	8	(16)	10	11	10			10				7			8	8
-4																(15)	12	11								7			
-5			12						7		7				9		(16)	11	9										
-6																7		(18)	9										
-7																			(15)	8									
-8																				(14)	10								
-9																					(13)		7						
-10																						8		(12)					

Figure 14. Distribution of Soundings
Cape Disappointment Patch

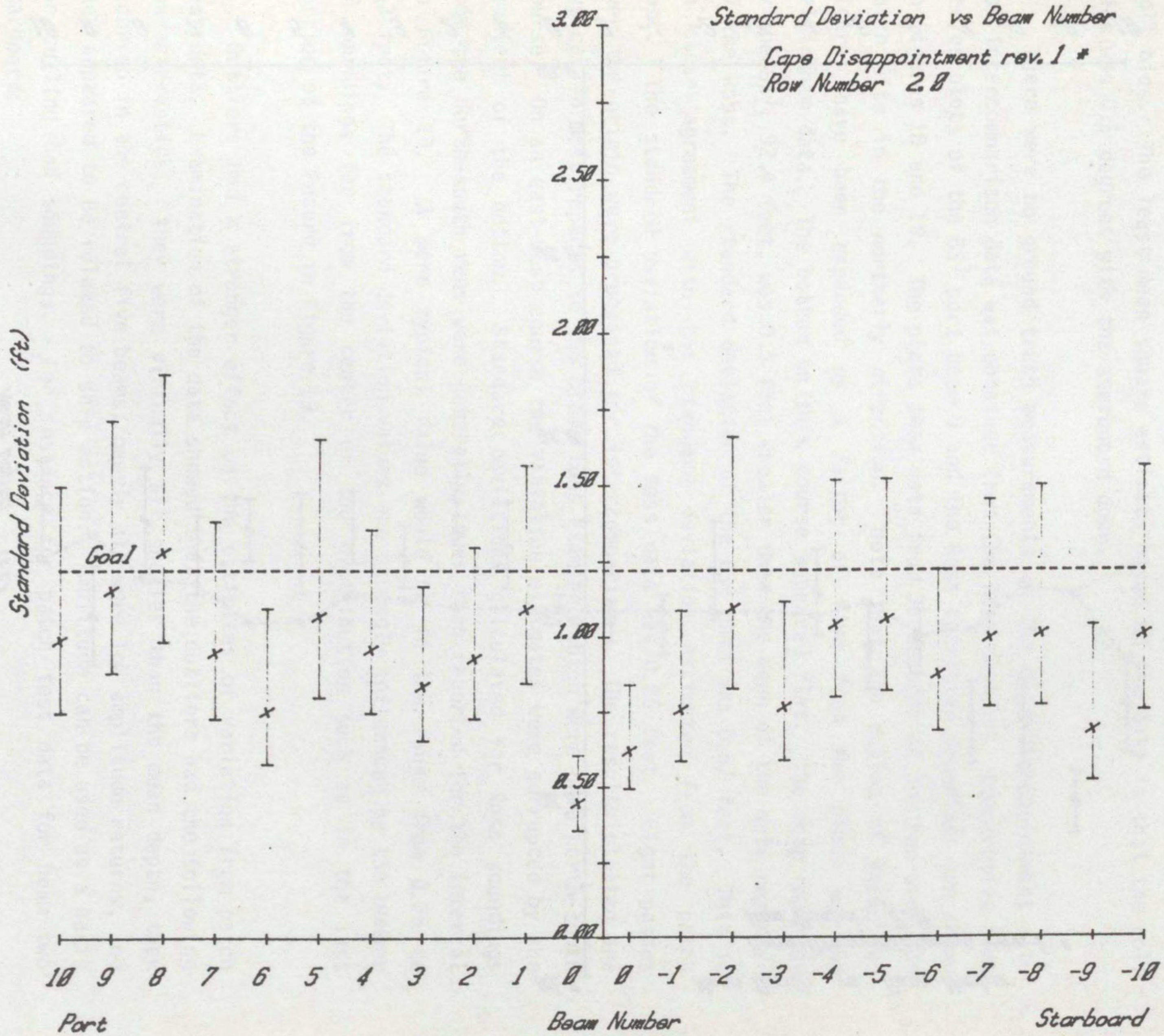


Figure 15. Standard Deviations - Cape Disappointment

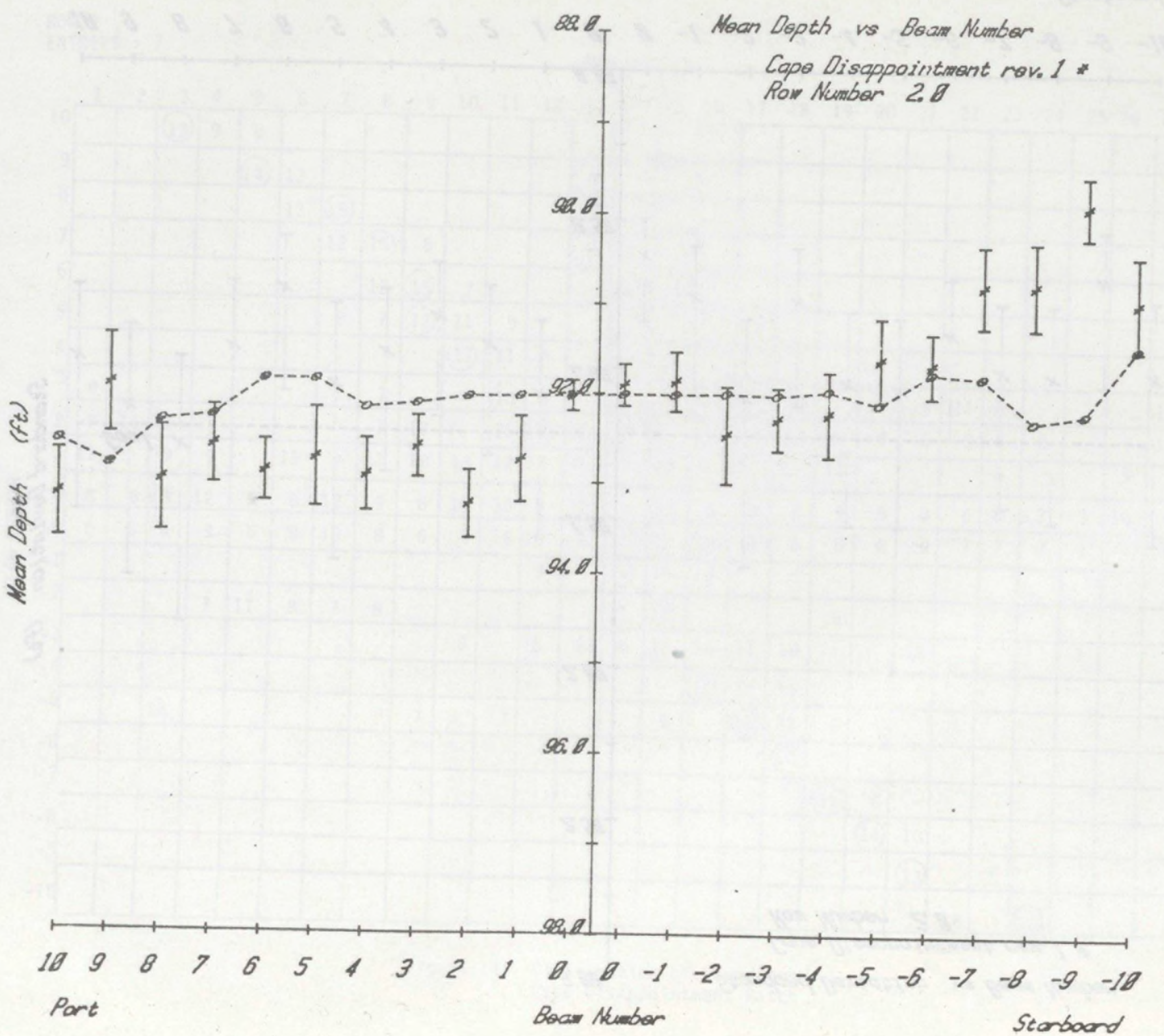


Figure 16. Mean Depths -
Cape Disappointment

slight slope toward the beach. Estimates of the bias with respect to port beam 0 are plotted in Figure 17 together with confidence intervals. The estimated biases were generally less than one foot. The exceptions were beams seven, eight, and nine to starboard. The estimates suggest that there was a roll bias. The least mean square estimate based on the data is that the roll bias was 0.5 degrees with the starboard down.

There were no ground truth measurements at the Cape Disappointment site but intercomparison data was obtained from the Ross sounder. Comparative time series plots of the BS^3 port beam 0 and the Ross corrected soundings are shown in Figures 18 and 19. The plots show data from 33 seconds of one run over the patch site in the northerly direction. Note that the scales of these two figures have been expanded by a factor of five from the plots of the Bellingham data. The bottom on this course appeared flat. The mean reported by the BS^3, 92.4 feet, was 0.5 feet shoaler than the mean of the data reported by the Ross. The standard deviation of the BS^3 data was 0.57 feet. This is in close agreement with the standard deviation estimated from the patch test. The standard deviation of the Ross data was 0.26 feet. Eight passes over the origin were processed for intercomparison. The results plotted are typical in most repects to the other runs examined which were on a north-south course. On an east-west course the variation estimates were corrupted by the gradient of the bottom. Standard deviations calculated for Ross soundings from the north-south runs were generally lower than reported for the interval in Figure 19. A more typical value would be in the range from 0.25 to 0.3 feet. The standard deviation values are strongly influenced by the number of soundings far from the center of the distribution such as in the last portion of the record in Figure 19.

Outliers had a stronger effect on the estimates of variation from patch test data. Examination of the data showed that the outliers had the following characteristics: they were virtually all shoaler than the mean depth, they occurred in the central five beams, nearly all were low amplitude returns, and they appeared to be related to ship motion. Amplitude can be used as a basis for culling bad soundings. For instance for patch test data for beam two starboard:

cull amp ≤	N	$\bar{x}$	S_D
0	19	90.92	3.92
3	16	92.36	1.82
4	13	92.46	1.10

A criterion in the COP program is that the amplitude be greater than or equal to three in order to be considered a valid sounding. These results suggest that amplitude of less than or equal to four be culled. Data on which the statistics in Figures 15, 16, and 17 are based have been using this criterion. The outliers noted in the time series also tend to be low amplitude returns.

Examination of the correctors applied to the Cape Disappointment data showed that tide correction was not entirely adequate. Tide data was obtained from a tide gauge installed in the mouth of the Columbia River near Point Adams. The record from this gauge is consistent with predicted tides based on the Tide Tables for this location. The project instructions, however, indicate that the tide at the test site should read highs and lows approximately 35 minutes before highs and lows at Point Adams. To determine whether this time difference affected the patch test data the soundings from port beam 0 were examined. Figure 20 shows a plot of the difference of each sounding from the mean versus the difference in tide at the time of the sounding if there was a 35 minute delay. There is a clear correlation. This shows that the tide data contributed an inordinate amount to the variability of soundings. If data were obtained from a tide gauge closer to the test site the variability of soundings over the patch site would have been decreased. The intercomparison data suggest that the variability in beam 0 would have decreased to about 0.3 feet.

The BS^3 showed acceptable accuracy performance in the Cape Disappointment tests. The patch tests indicated standard deviations of about one foot for all the beams versus the goal of 1.3 feet. The nominal vertical beams showed standard deviations of about 0.5 feet. It was necesary to cull outliers on the basis of the amplitude of the returns in order to achieve this accuracy. If more accurate tide correctors were available the performance of all the

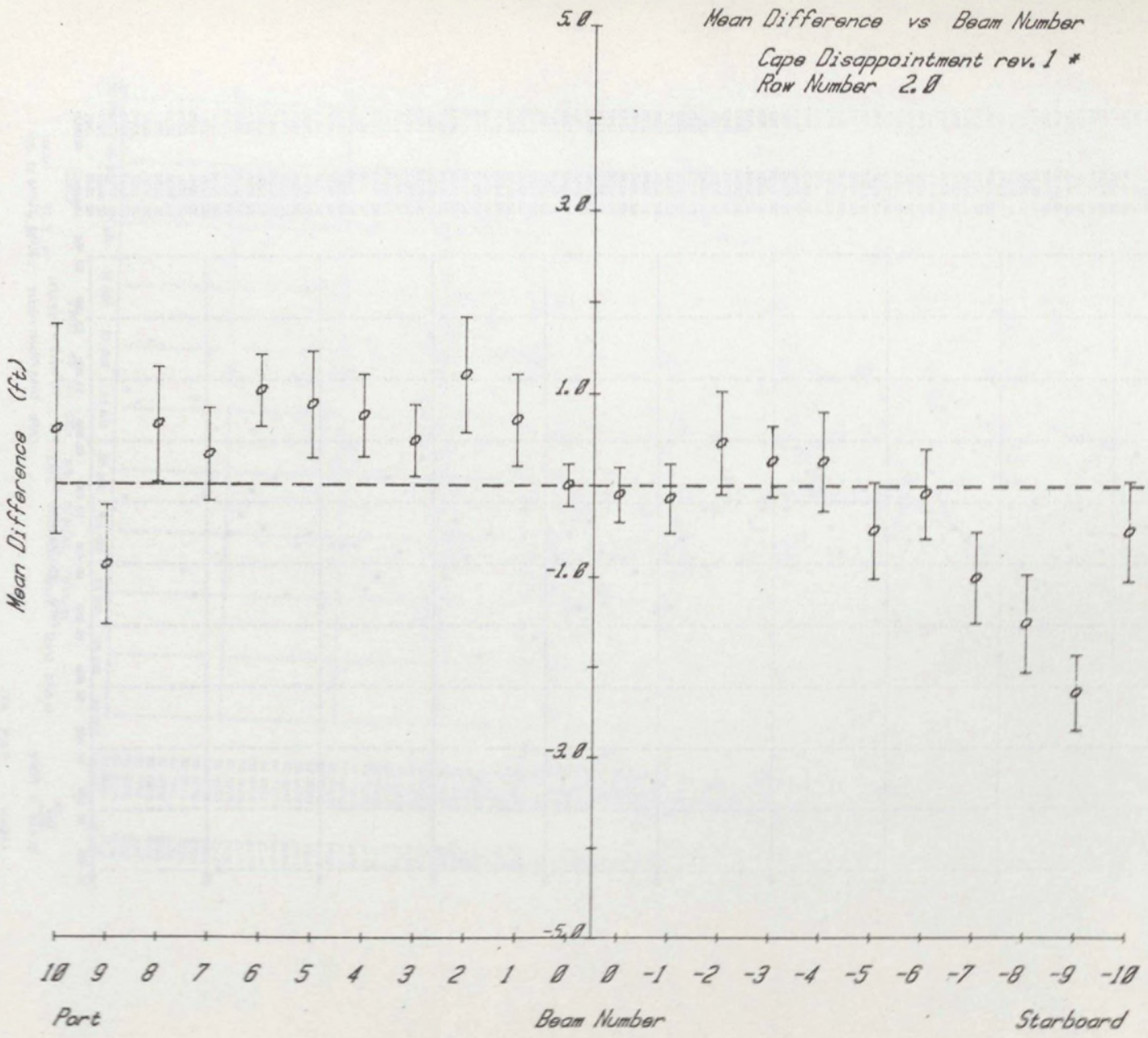


Figure 17. Biases - Cape Disappointment

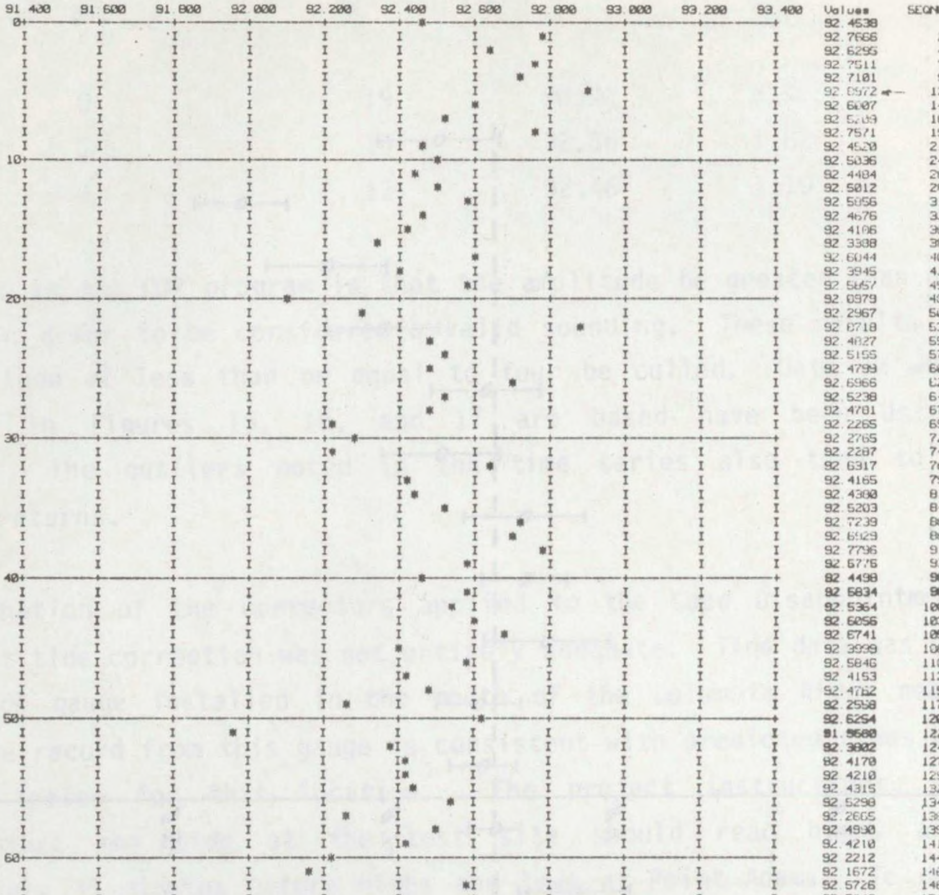


Figure 18. BS^3 Time Series — Cape Disappointment

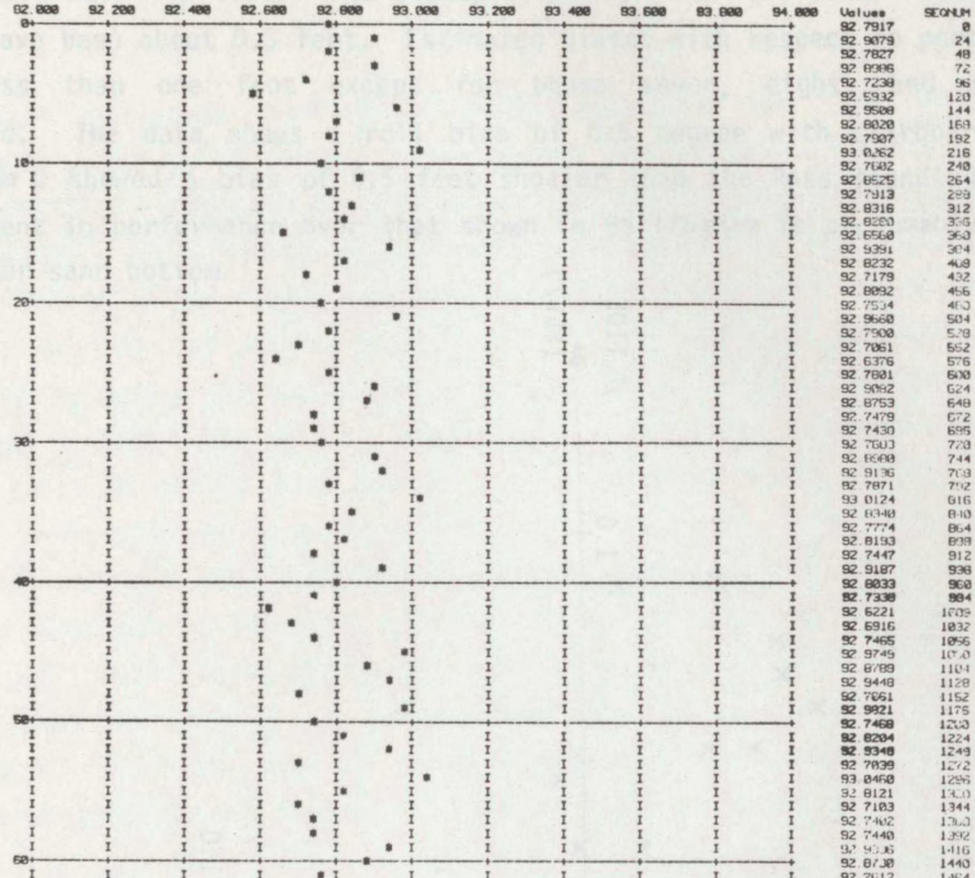


Figure 19. Ross Time Series –
Cape Disappointment

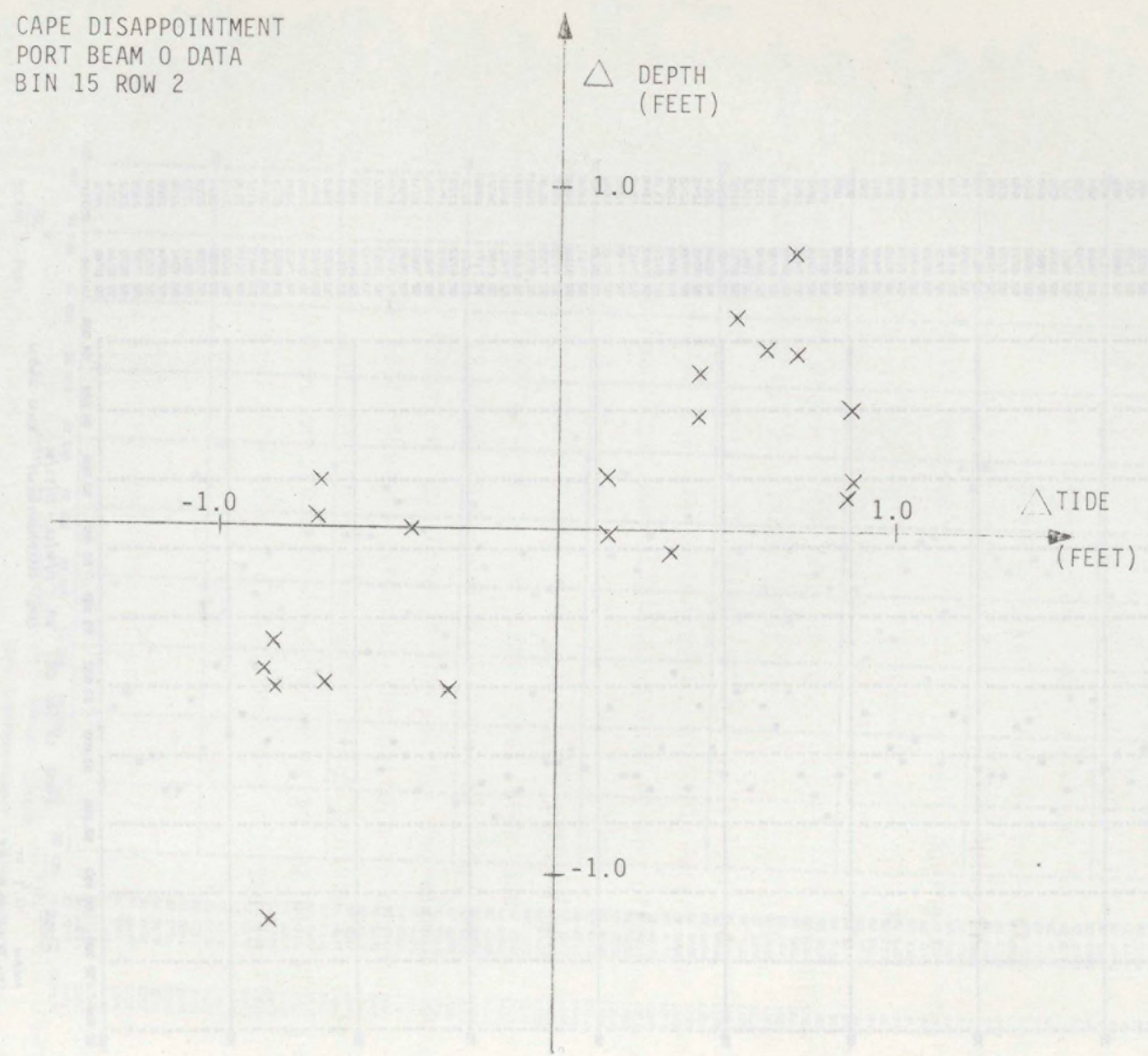


Figure 20. Sounding Error vs. Tide Shift

beams would have improved. The standard deviation of the center beams would likely have been about 0.3 feet. Estimated biases with respect to port beam 0 were less than one foot except for beams seven, eight, and nine to starboard. The data shows a roll bias of 0.5 degree with starboard down. Port beam 0 showed a bias of 0.5 feet shoaler than the Ross soundings. The improvement in performance over that shown in Bellingham is presumably due to the harder sand bottom.

Deep Water

A patch test was conducted near the maximum operating depth for the BS^3. The site selected was off Astoria, Oregon, in an area where the distance between the 300 and 400 fathom contours was greatest. This increased the likelihood that the patch test site would be nearly flat. The average depth was about 2200 feet. The operating depth limit specified by General Instruments is 2000 feet. NOS' specification for the system was 2500 feet. No difficulties were encountered operating the system at the test depth. The tests were conducted during a storm. Winds built from 12 knots to 30 knots. Swells built from three feet to six feet during the test which occupied eight hours. The peak motions recorded were 14 degrees in roll, 4 degrees in pitch, and 5 feet in heave. Patch test bins were increased to 60 meters square to be equal to the size of the footprint of the beams on the bottom. No information was available about the bottom composition. The sound velocity was again nearly constant with a slight decrease from 1489 meters per second at the transducer depth to 1481 meters per second at the bottom. No tide correctors were applied because of the offshore location.

Sixteen runs were conducted over the patch site each of which consisted of two passes over the origin. The patch test area and the number of soundings in each bin is shown in Figure 21. Figure 22 shows the distribution of soundings by beam number in row three of the patch. The maxmimum number of soundings in a bin for each beam is circled. The pattern of soundings is much more tightly grouped than in the shallow water sites because the effects of positioning and navigation errors were less relative to the bin size in deep water. The statistics of the selected soundings are plotted in Figures 23, 24, and 25.

The goal for the standard deviation of soundings in this water depth was 14.0 feet. Figure 23 shows that the center 14 beams were within this bound. The outer four beams on each side show larger than acceptable standard deviations. Confidence intervals on these estimates are reasonably tight since the number of sounding representing each beam ranged from 16 to 46. The pattern of increased variation in the outer beams is an expected characteristic of a swath system.

ENTRY = NO. OF SOUNDINGS
BINS = 60 METERS SQUARE

Bin No.

Row	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	35	42	54	65	71	74	74	80	82	91	89	101	100	95	112
2	33	42	59	73	72	84	73	84	98	91	86	100	110	108	117
3	41	67	80	92	102	106	103	106	112	126	120	112	108	115	138
4	30	42	57	56	68	76	71	74	78	80	79	87	93	98	121
5	18	42	48	59	49	61	61	57	55	63	67	65	64	77	118

Row	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	95	85	84	92	73	65	65	70	67	64	57	70	55	60
2	107	86	92	82	72	78	63	70	67	65	60	64	55	51
3	115	116	97	114	106	90	94	86	71	74	80	79	67	67
4	99	112	96	92	104	86	79	89	78	65	86	66	72	62
5	98	99	96	85	101	86	75	87	79	75	84	69	66	62

Figure 21. Deep Water Patch

ROW 3
ENTRIES ≥ 7

BIN NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
10	8	25	23	16	16	11	15	12	14	14	19	15	9	15	7														
9				12	21																								
8						23	9																						
7							14	18																					
6								10	25																				
5										25																			
4											25																		
3												24	7																
2													24																
1	7		7			9						8	7	29	18		9		8			7	7	9				7	
0	10	16	20	29	27	28	33	24	28	28	22	23	23	27	46	31	22	21	22	29	26	23	20	22	26	16	18	9	9
-0	12	13	24	22	25	29	26	30	26	26	23	26	20	23	46	28	28	22	24	26	21	26	24	22	17	16	14	13	10
-1																28	11	7											
-2																	21	7											
-3																		20	8										
-4																			18	8									
-5																				14	12								
-6																					11	21		11	11	17	14	23	12
-7																			20	20	8	11	23	9					
-8														9	12	12	10							10	18				
-9													9												7	12	16		
-10																												11	18

Figure 22. Distribution of Soundings
Deep Water Patch

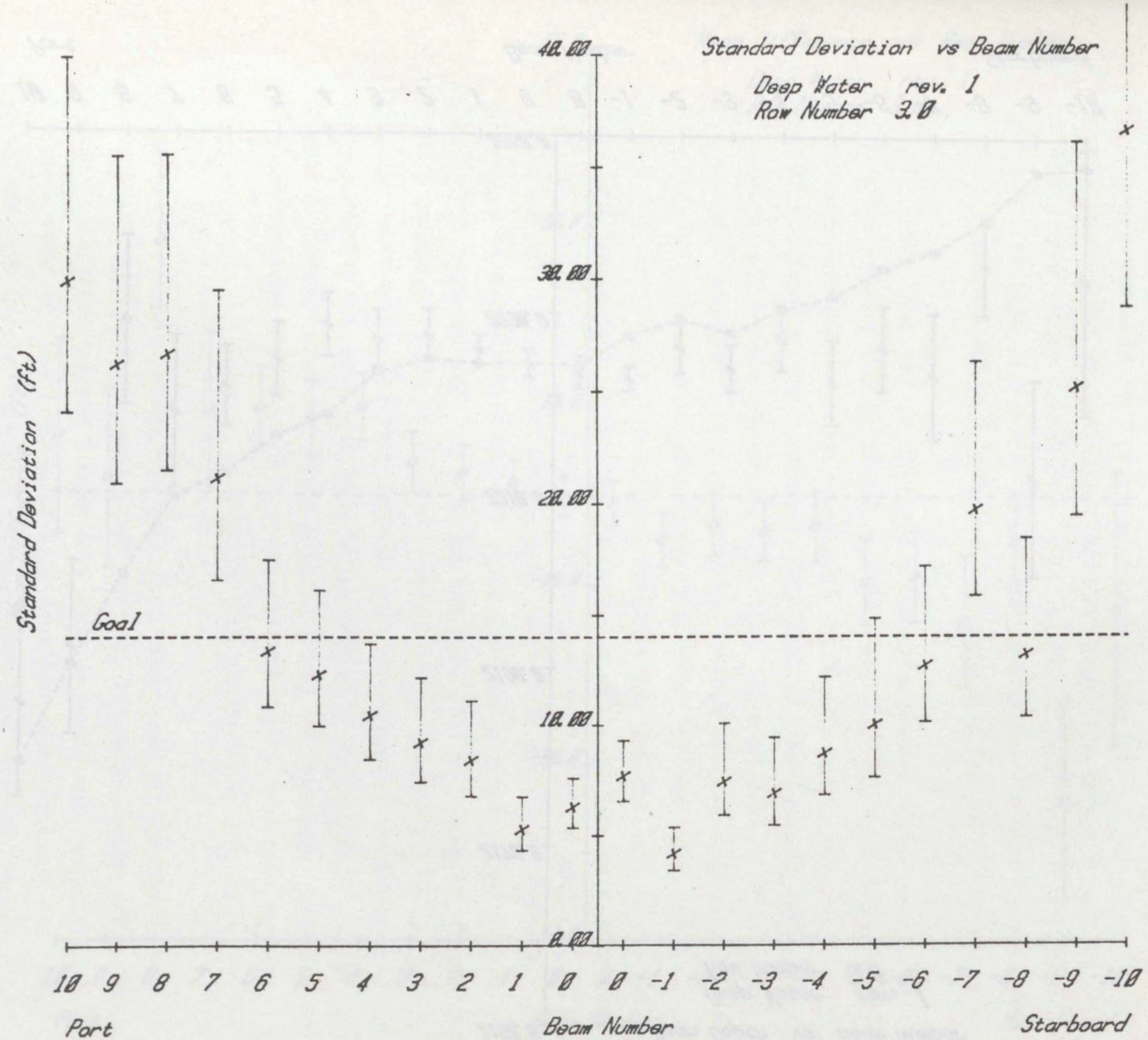


Figure 23. Standard Deviations - Deep Water

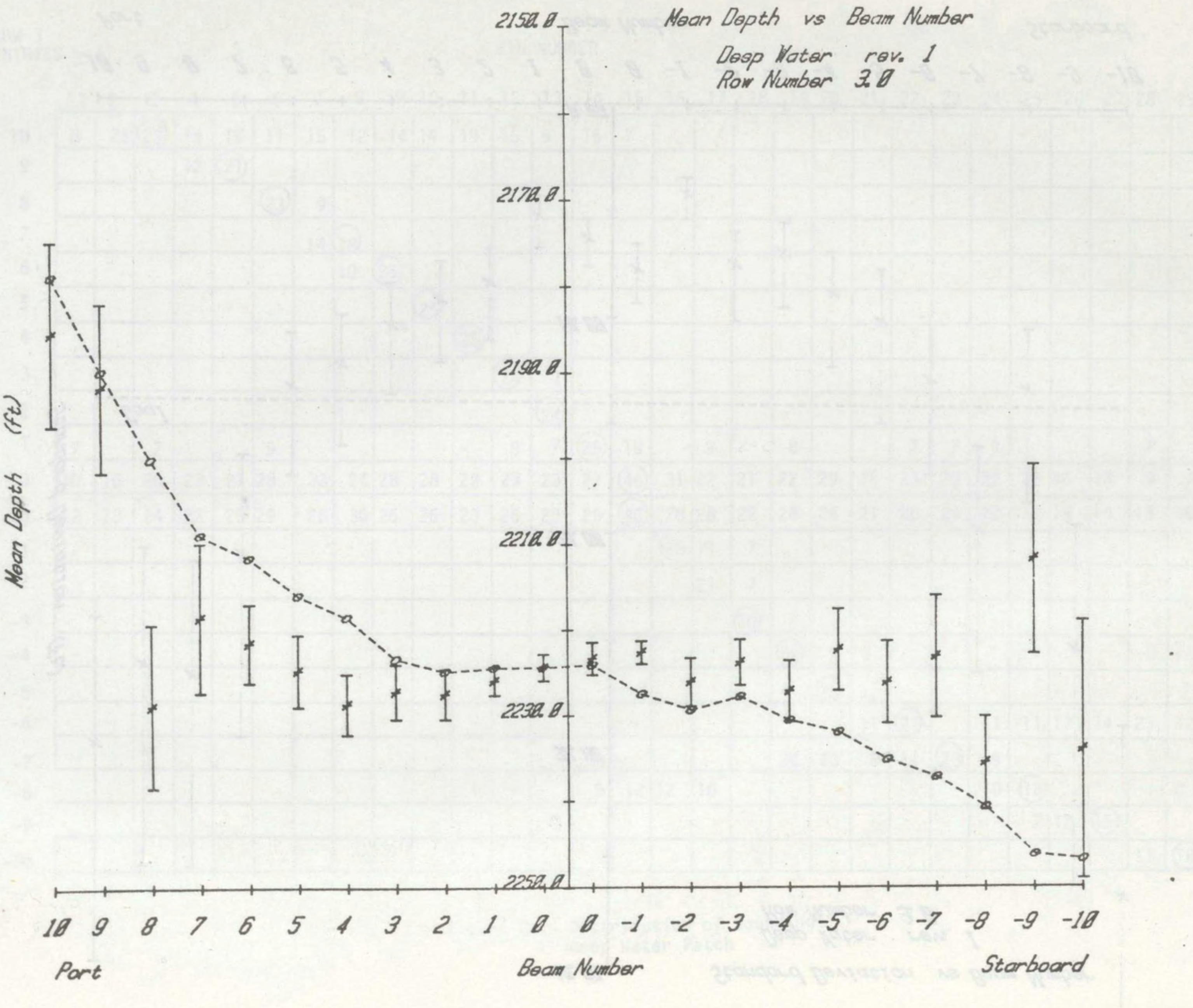


Figure 24. Mean Depths - Deep Water

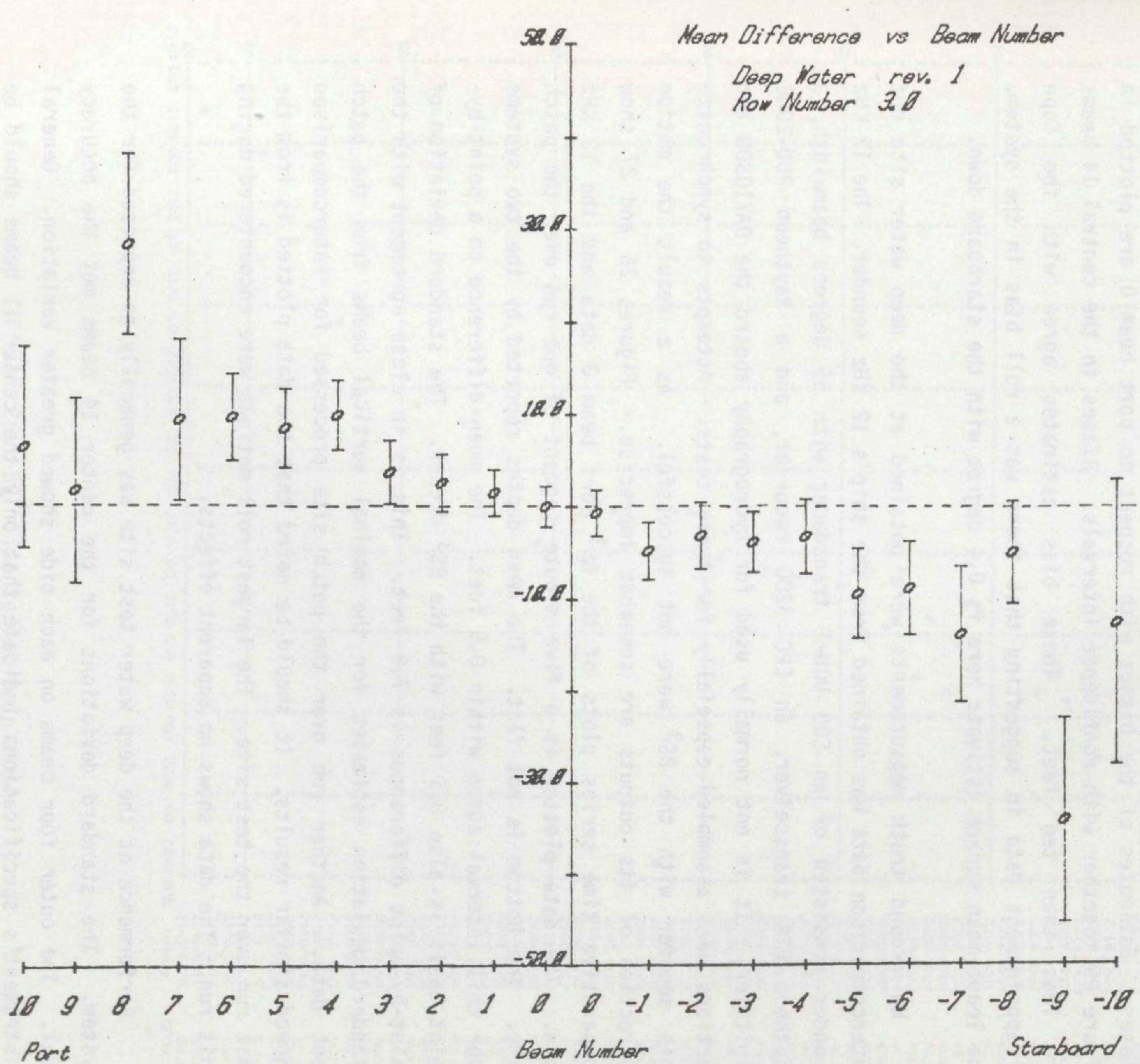


Figure 25. Biases - Deep Water

The mean depths for each of the beams are plotted in Figure 24. Port beam 0 data shows a slope of about 1.4 percent from north to south. This slope is less clear from the swath data because it is obscurred by apparent biases. Estimates of the biases with respect to port beam 0 are plotted in Figure 25 together with confidence intervals. Biases in the central 14 beams are less than ten feet. These bias estimates agree with the Cape Disappointment data in suggesting that there was a roll bias in the system. The least mean square estimate here is 0.4 degree with the starboard down.

No ground truth measurements were obtained at the deep water site but intercomparison data was obtained from the ship's 12 KHz sounder. The 12 KHz sounder consisted of an EDO UQN-1 transducer with 35 degrees beamwidth, a Raytheon PTR transceiver, an EPC 3200 recorder, and a Raytheon PDD-200C digitizer. It is not normally used for hydrography aboard the DAVIDSON and portions were assembled especially for these tests. Attempts to synchronize this sounder with the BS^3 were not successful. As a result the motion correction of its outputs are somewhat imprecise. Figures 26 and 27 show comparative time series plots of the BS^3 port beam 0 data and the 12 KHz data. The data plotted is a five minute segment of one run over the patch site. The bottom is not flat. The mean depths reported by the two systems over this interval agree within 0.5 feet. The mean difference on a point-by-point basis is also 0.5 feet with the BS^3 deeper. The standard deviation of point-by-point differences is 7.9 feet. This is in close agreement with the standard deviation estimates for the nominal vertical beams from the patch test data. Another run over the patch site processed for intercomparison showed similar results. It should be noted that the data plotted is from the last run over the test site. The largest roll motions were encountered during this run. The data shows no apparent effects.

Performance at the deep water test site was generally as expected for the system. The standard deviations for the center 14 beams met the accuracy goal. The outer four beams on each side showed greater variation. General Instrument's specifications indicate that only the center 11 beams should be used in depths greater than 800 feet. Estimated biases for the center 14 beams with respect to port beam 0 were less than ten feet. The data indicates that there is a roll bias of about 0.4 degree with the starboard

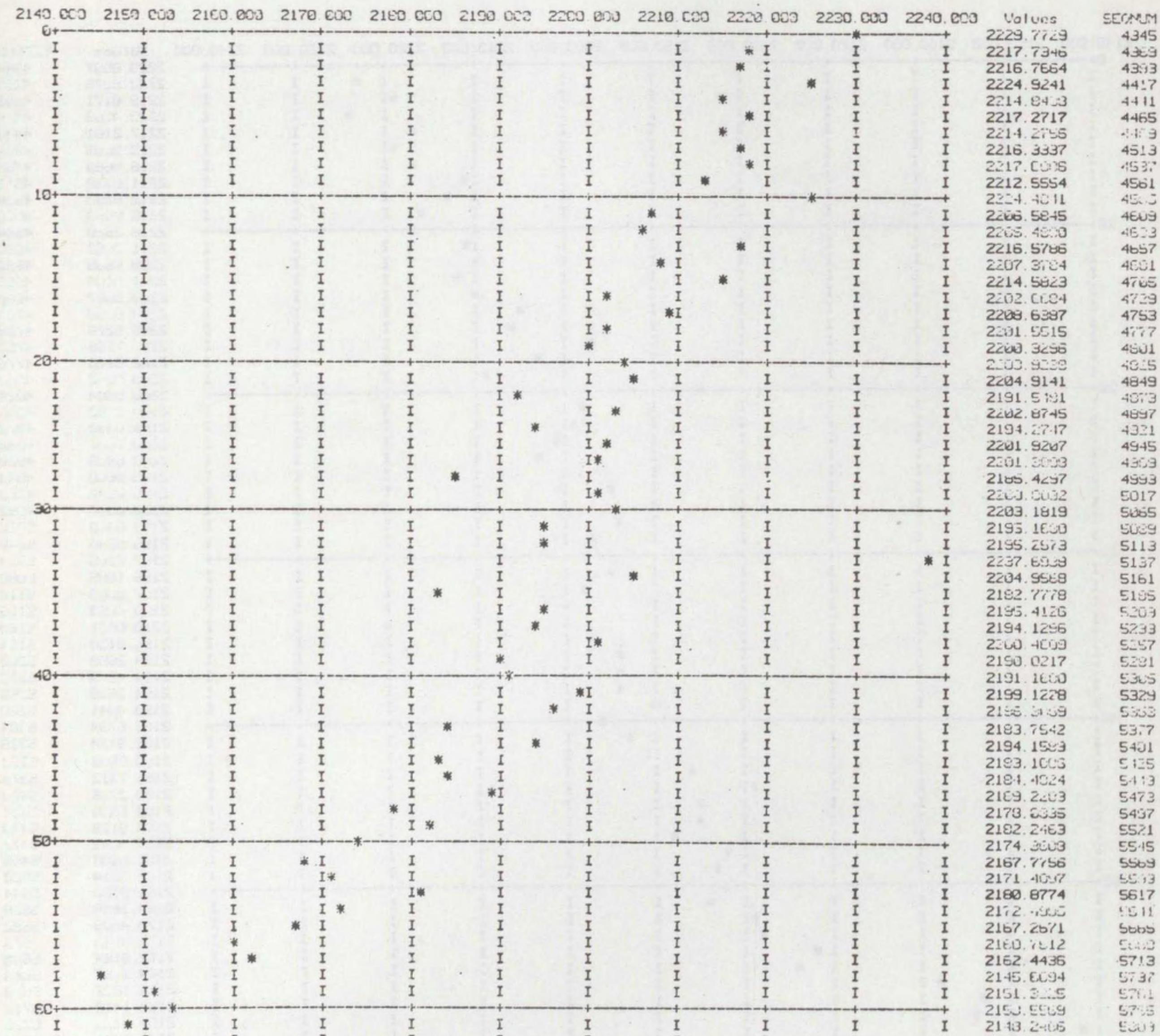


Figure 26. BS^3 Time Series-Deep Water

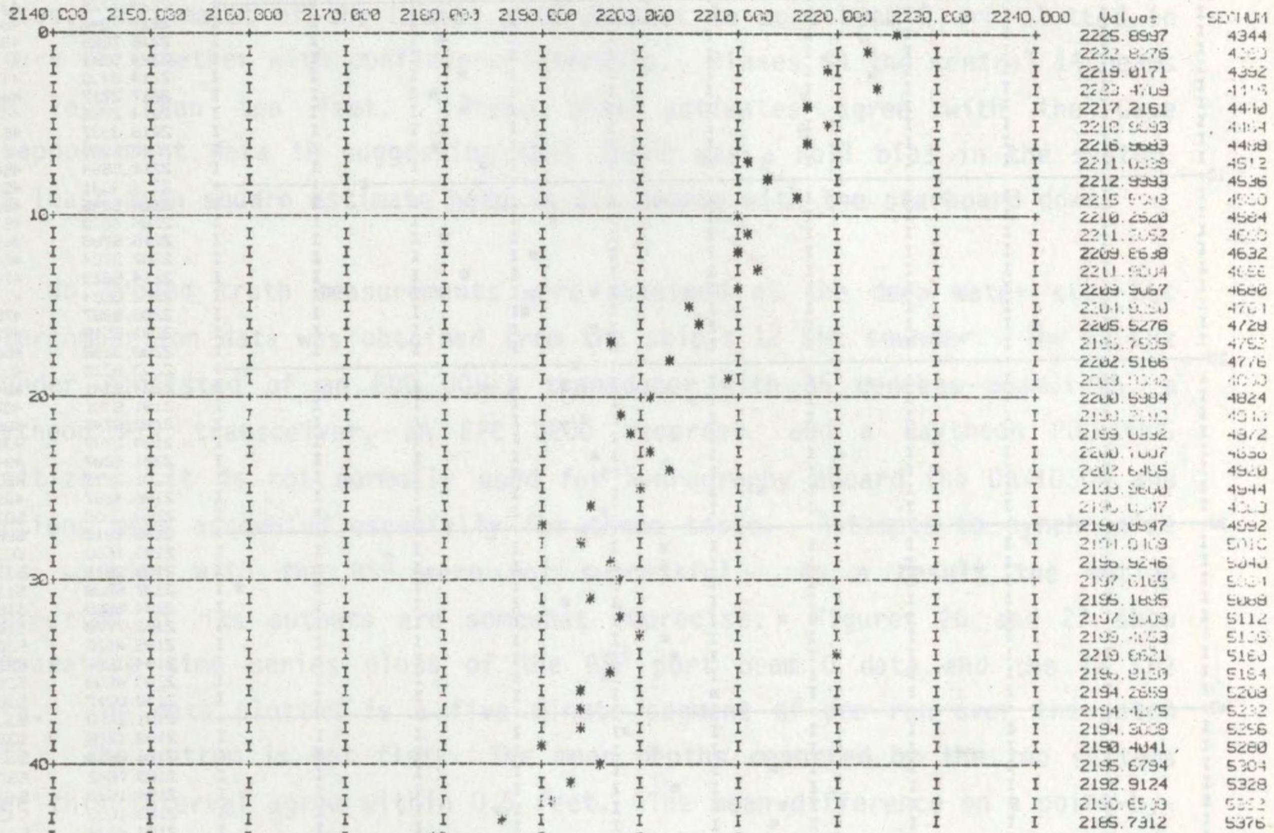


Figure 27. 12 KHz Sounder Time Series - Deep Water

down. The nominal vertical beams produced the same depth as the 12 KHz system within 0.5 feet. This was achieved despite sea conditions which were uncomfortable for routine hydrography.

San Juan Islands Slope

A fourth patch test was conducted over a steeply sloped bottom in the San Juan Islands. The patch was oriented perpendicular to the slope and water depths in the patch ranged from 160 to 260 feet. The bin size was chosen to be six meters square. The slope was 45 degrees or more at points within the patch. Patch runs occupied two days. The weather was overcast with winds from six to 12 knots. Surface conditions were smooth with waves never exceeding one foot in height. A grab sample near the bottom of the slope showed gravel, broken scallop and whelk shells, and grey mud. The steeper portions of the slope are likely to be very hard. The sound velocity was again nearly constant with a slight increase from 1484 meters per second at the transducer depth to 1486 meters per second at the bottom. Tide correctors were obtained from a tide gauge close to the test site which showed a range of eight feet.

Thirty-eight runs were conducted over the patch site each of which consisted of two passes over the origin. The patch test area with the number of soundings in each bin is shown in Figure 28. Figure 29 shows the distribution of soundings by beam number in row three of the patch. The maximum number of soundings in a bin for each beam is circled. These soundings were selected to represent the performance of the various beams. The statistics of the selected soundings are plotted in Figures 30, 31, and 32. Note that there was insufficient data to estimate the performance of port beam 0.

The complete data set for this patch includes a large number of soundings which were determined not to represent the basic accuracy of the BS^3. These data were removed before the statistics plotted were calculated. These soundings were identified either as second bottom returns or low amplitude returns.

Second bottom returns were clearly evident in histograms of the data for each bin. Two clusters of soundings were apparent - one at the true depth and a second at twice this depth. The clustering existed even though the soundings had not been sorted by beam number. Further examination showed that

ENTRY = NO. OF SOUNDINGS
BINS = 6 METERS SQUARE

Bin No.

Row	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	19	29	33	45	43	31	41	56	56	56	57	56	48	59	114	69	66	67	67	81	70	77	67	78	61	49	36	50	62
2	19	23	36	41	30	31	47	52	49	57	60	61	62	58	102	69	63	55	65	74	86	60	71	79	73	53	44	39	56
3	24	30	43	54	35	34	50	51	55	54	58	65	66	68	110	67	65	56	71	68	71	62	77	68	90	58	56	65	70
4	31	41	38	46	43	42	51	52	71	59	67	59	61	91	92	74	71	70	69	101	96	88	88	93	91	66	72	71	74
5	27	24	45	48	40	38	47	51	61	60	55	48	56	56	110	76	72	73	67	85	106	69	106	75	76	62	55	91	86

Figure 28. San Juan Islands Slope Patch

ROW 3
ENTRIES ≥ 5

BIN NUMBER

BEAM NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
10																									6				
9			8																										
8				10	7	6																	5						
7							7		5																6				
6								7		5																		5	6
5										9	5																		5
4											9								6								5	7	14
3								5			6	15	6												7	9	15	9	15
2							6	5	6		9	5	15	7			6	5		6	9	6	7	10	9	6	6		
1	5	7				6			10		9	12	10	20	9	9	10	6	11	6	8								
0	6		7	9			8		6		8	6	8	11	19	16	8	7	9		6	5	5	6					5
- 0	6	5	7	5	5	5	6	10		7	5	9	10	11	18	16	7	6	5		5		7	5	6	5		6	
- 1															11	7	14			5			5	8	8	9	6	17	8
- 2												5		8	5	6	11	7	6									6	5
- 3																	6	8	8										
- 4																			11	7									
- 5										5										10		6	5						
- 6																				7	8		5						
- 7								5													6	7			7				
- 8				5																			10		8				
- 9																							7	6	7	6			
-10																									14		6	5	

Figure 29. Distribution of Soundings
Slope Patch

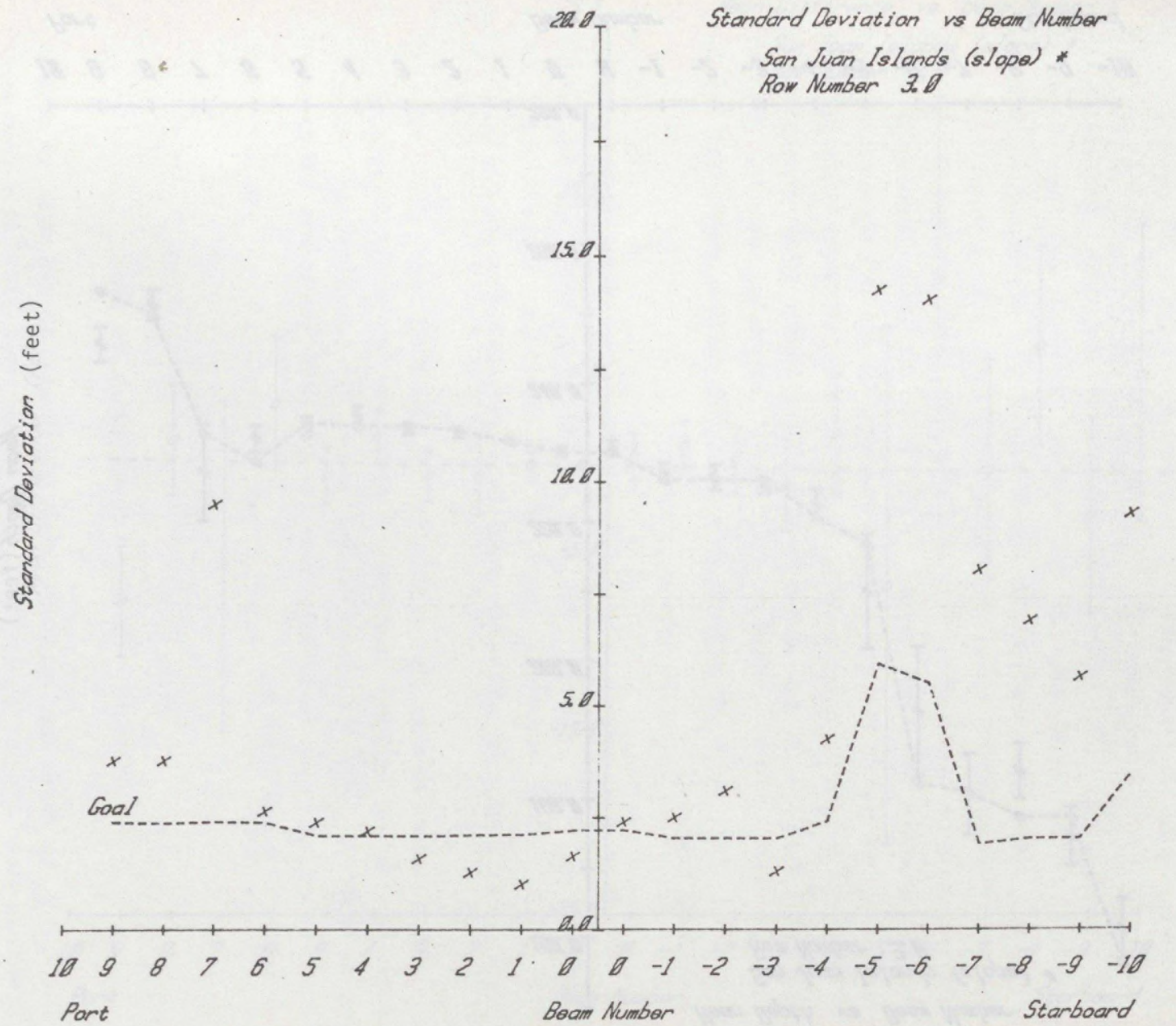


Figure 30. Standard Deviations - Slope Patch

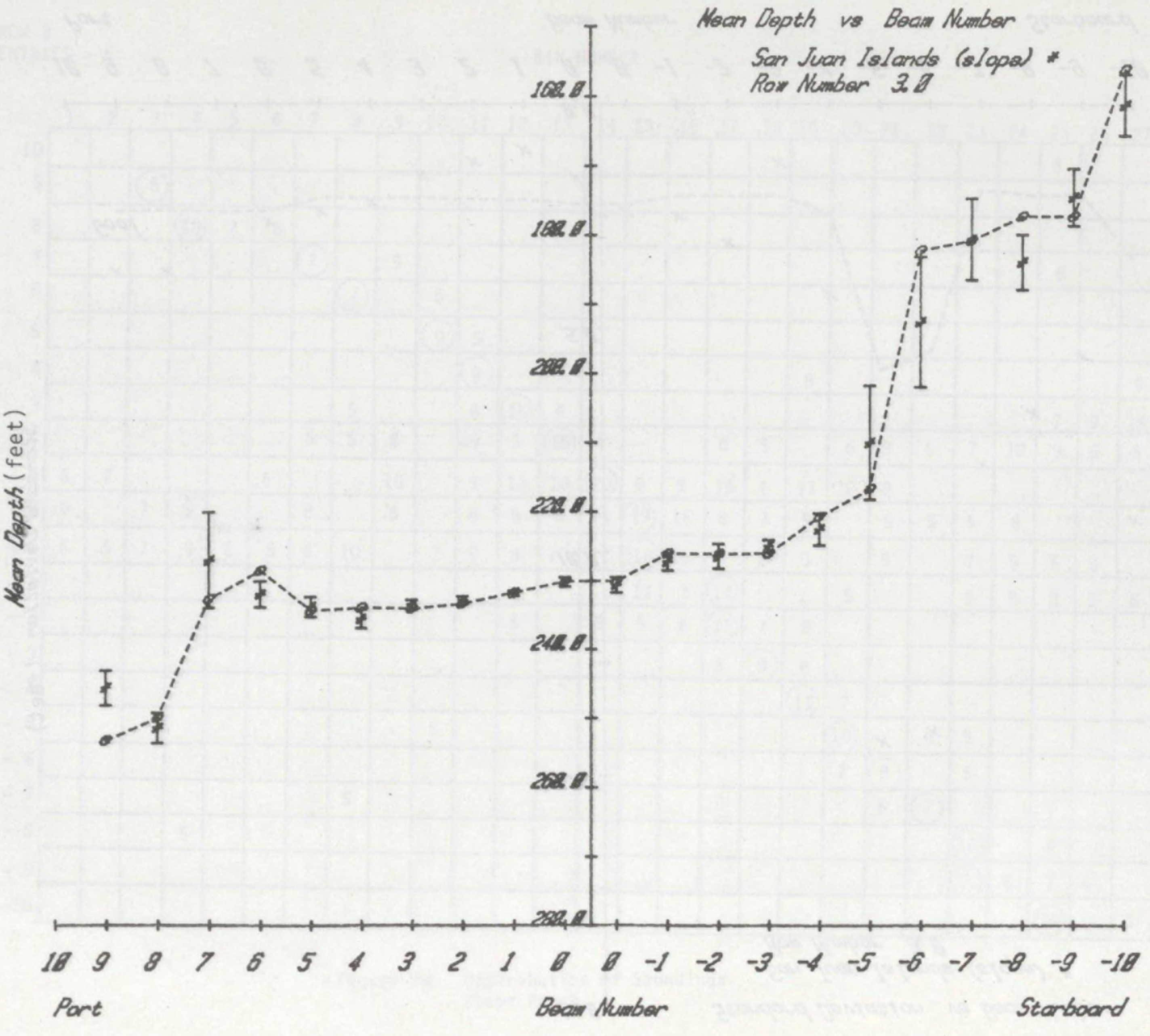


Figure 31. Mean Depths - Slope Patch

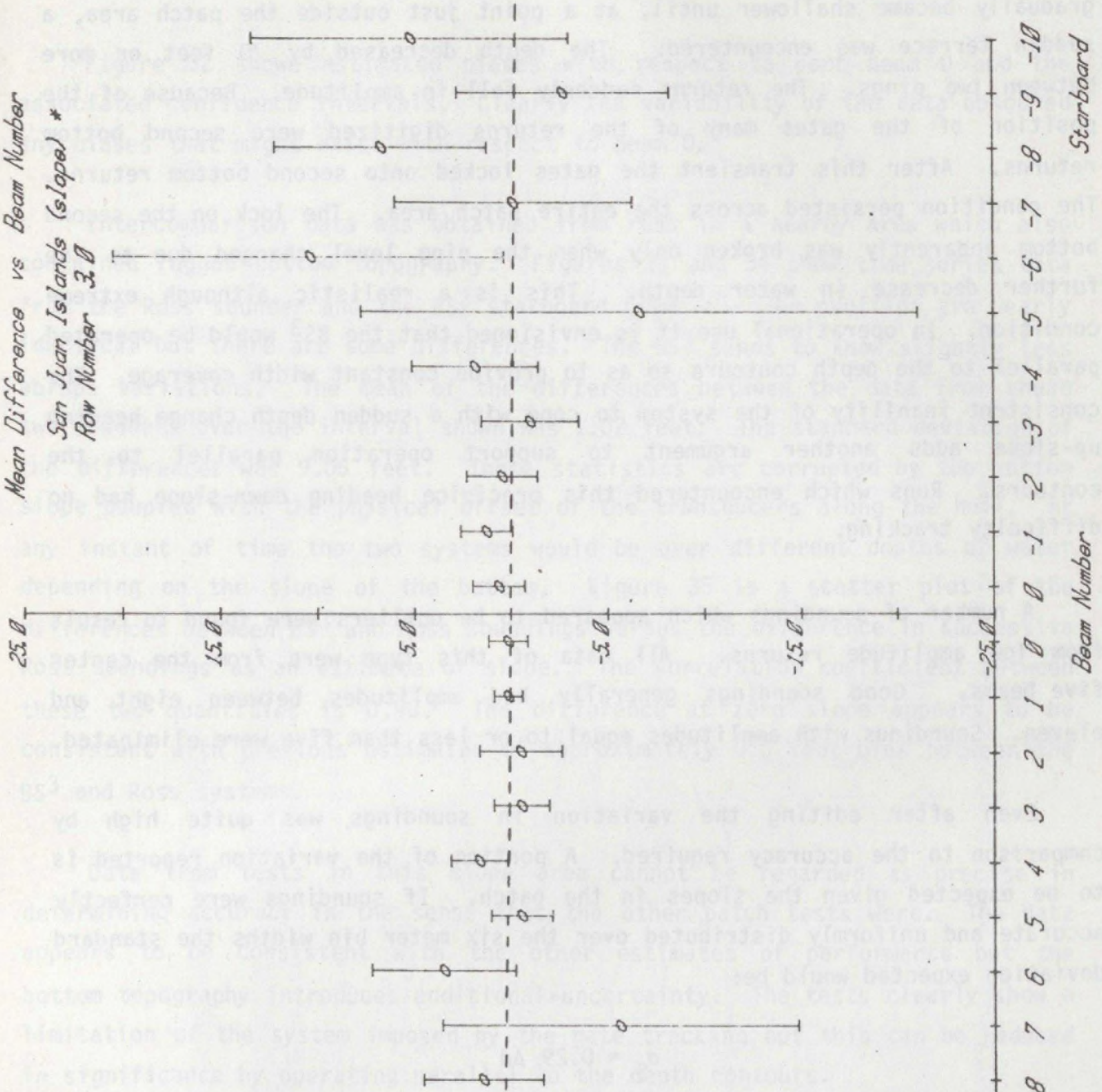


Figure 32. Biases - Slope Patch

the second bottom returns invariably came from up-slope runs. With two exceptions every up-slope run produced second bottom returns. These runs started with data showing the correct depth of more than 400 feet. Depths gradually became shallower until, at a point just outside the patch area, a sudden terrace was encountered. The depth decreased by 70 feet or more between two pings. The returns suddenly fell in amplitude. Because of the position of the gates many of the returns digitized were second bottom returns. After this transient the gates locked onto second bottom returns. The condition persisted across the entire patch area. The lock on the second bottom apparently was broken only when the ping level changed due to the further decrease in water depth. This is a realistic although extreme condition. In operational use it is envisioned that the BS^3 would be operated parallel to the depth contours so as to provide constant width coverage. The consistent inability of the system to cope with a sudden depth change heading up-slope adds another argument to support operation parallel to the contours. Runs which encountered this precipice heading down-slope had no difficulty tracking.

A number of soundings which appeared to be outliers were found to result from low amplitude returns. All data of this type were from the center five beams. Good soundings generally had amplitudes between eight and eleven. Soundings with amplitudes equal to or less than five were eliminated.

Even after editing the variation in soundings was quite high by comparison to the accuracy required. A portion of the variation reported is to be expected given the slopes in the patch. If soundings were perfectly accurate and uniformly distributed over the six meter bin widths the standard deviation expected would be:

$$\sigma_S = 0.29\ \Delta d$$

where Δd = change in depth across the bin

The change in depth was estimated from the change in the mean of beam 0 soundings from adjacent bins. This quantity was then added in a root-mean-square fashion to the accuracy goal required at the bin depth to produce the dashed line in Figure 31. For most beams the variation still exceeds this value. It cannot be confidently determined whether the excess represents true inaccuracy on sloped bottoms or merely statistical variations coupled with some positional inaccuracy appearing as depth variations.

Figure 32 shows estimated biases with respect to port beam 0 and the associated confidence intervals. Clearly the variability of the data obscured any biases that might exist with respect to beam 0.

Intercomparison data was obtained from runs in a nearby area which also contained rugged bottom topography. Figures 33 and 34 show time series data from the Ross sounder and the BS^3 starboard beam -0. The profiles are nearly identical but there are some differences. The BS^3 tends to show slightly less abrupt variations. The mean of the differences between the data from these two sounders over the interval shown was 1.02 feet. The standard deviation of the differences was 9.06 feet. These statistics are corrupted by the bottom slope coupled with the physical offset of the transducers along the hull. At any instant of time the two systems would be over different depths of water depending on the slope of the bottom. Figure 35 is a scatter plot of the differences between BS^3 and Ross soundings versus the difference in successive Ross soundings as an estimate of slope. The correlation coefficient between these two quantities is 0.90. The difference at zero slope appears to be consistent with previous estimates of approximately 0.5 foot bias between the BS^3 and Ross systems.

Data from tests in this slope area cannot be regarded as precise in determining accuracy in the sense that the other patch tests were. The data appears to be consistent with the other estimates of performance but the bottom topography introduces additional uncertainty. The tests clearly show a limitation of the system imposed by the gate tracking but this can be reduced in significance by operating parallel to the depth contours.

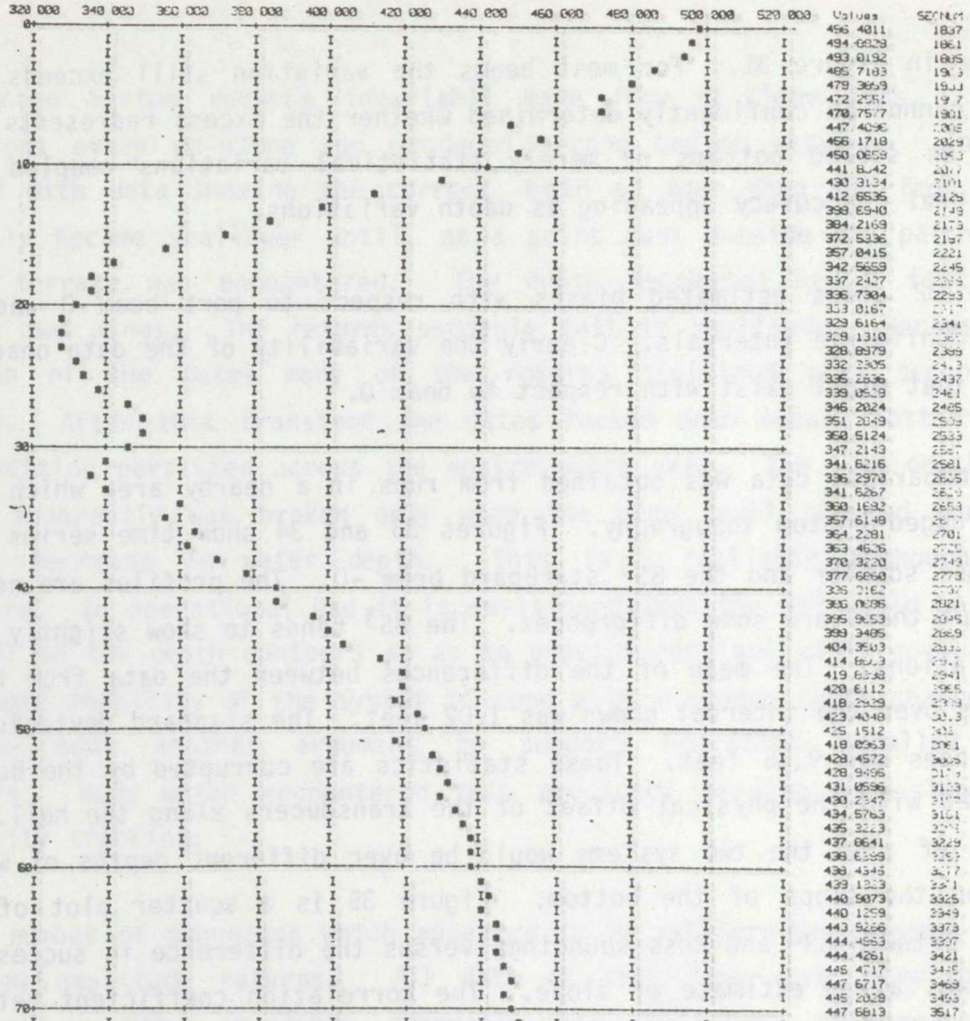


Figure 33. BS^3 Time Series – San Juan Islands

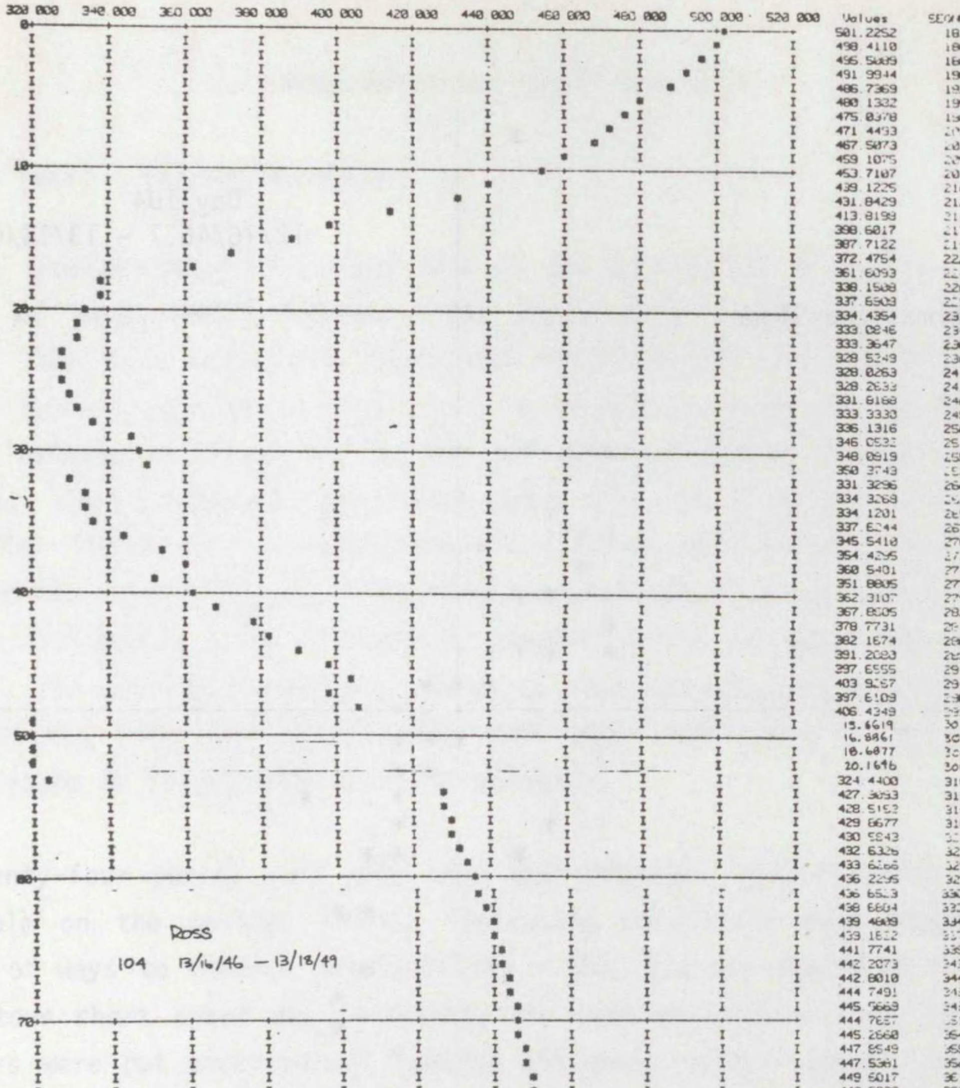
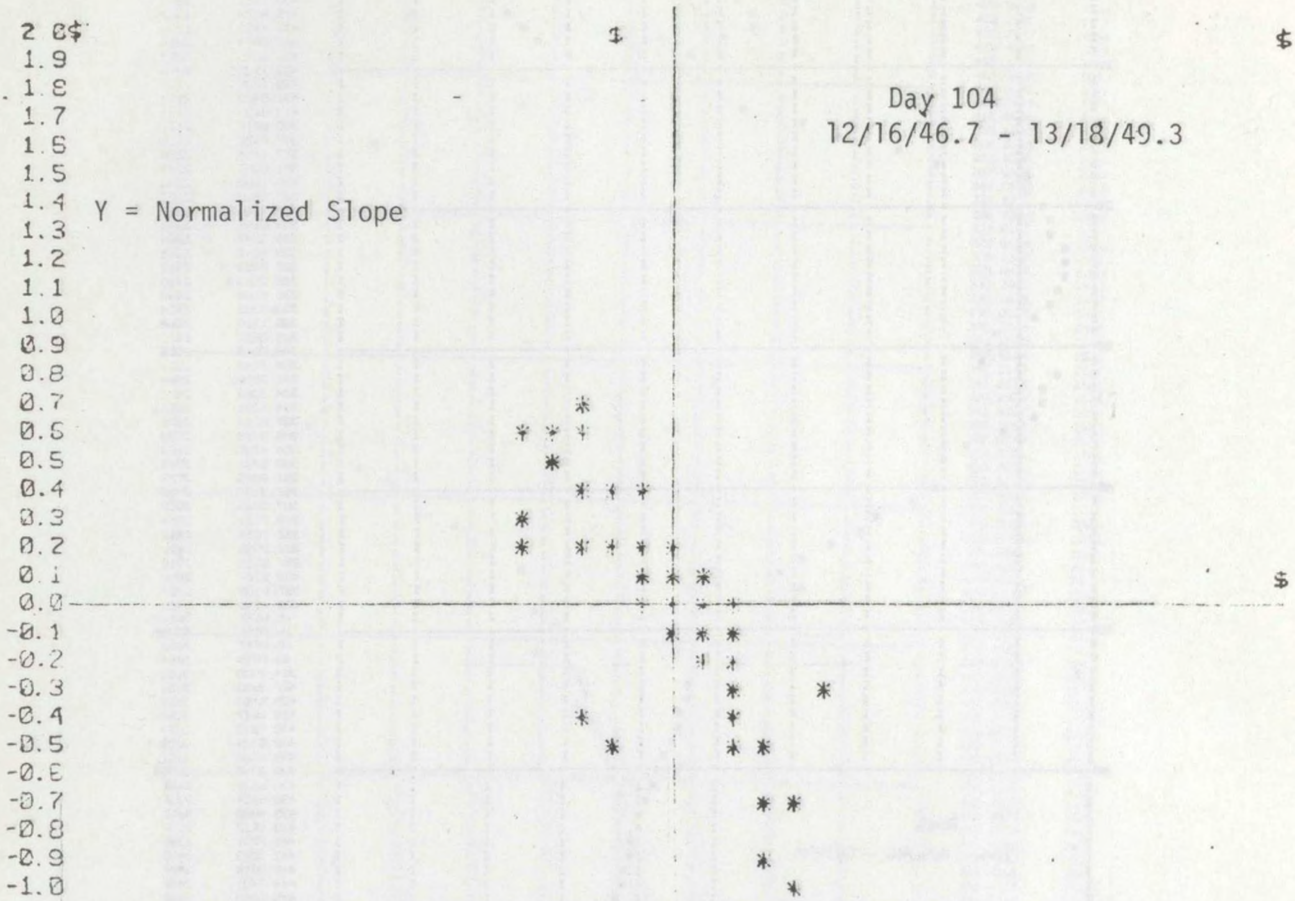


Figure 34. Ross Time Series – San Juan Islands



BEAM 12 TYPE 1 VS BEAM 11 TYPE 1

CORRELATION BETWEEN BEAM 12 TYPE 1 AND BEAM 11 TYPE 1 IS -0.90350187

$Y = \frac{s - \bar{s}}{\sigma_s}$ $\quad X = \frac{\Delta - \bar{\Delta}}{\sigma_\Delta}$ $\quad$ at $s = 0$

$\bar{s} = 4.41$ feet $\quad \bar{\Delta} = 0.09$ feet $\quad Y_0 = -\frac{\bar{s}}{\sigma_s}$ $\quad X_0 = \frac{-\hat{B} - \bar{\Delta}}{\sigma_\Delta}$

$\sigma_s = 47.66$ feet $\quad \sigma_\Delta = 15.94$ feet

$\Rightarrow \hat{B} = -0.61$ feet

Figure 35. Bias vs. Slope

5.2 Reconnaissance Capability Tests

Triplane Tests - Bellingham Harbor

The triplane tests provided data on the ability of the BS^3 to detect a feature of very small extent. The tests were performed in Bellingham Harbor. The test conditions have been described in the discussion of the accuracy tests conducted at this site. A 24-inch triplane was moored 12 feet off the bottom, suspended by two 12-inch diameter floats 20 feet above the triplane. This equipment was placed about 200 feet from the center of the patch site. Water depth, bottom conditions, and sound velocity structure were unchanged over this distance. The triplane provides a strong, omnidirectional acoustic reflector. The floatation spheres should be much less prominent targets. The mooring height was chosen so that the triplane would produce an echo distinct from the bottom echo even when insonified by the outermost beam. Figure 36 illustrates the test geometry.

Twenty-four passes were made over the triplane. Its presence was never detectable on the contour chart. Operating conditions were adjusted in a variety of ways to enhance detectability - the ship was slowed to five knots, the contour chart speed was increased, the contour interval was changed, and the gates were put under manual control and opened wide. Target returns were reportedly observed in the BOSUN display CRT. Figure 37 is a copy of the contour chart from one pass over the triplane. It shows an amount of clutter which may have obscured possible target indications. The results from the accuracy tests showed that the variability of soundings in Bellingham was relatively high compared to performance over a harder bottom. The amount of clutter on the contour chart would be reduced if the variability of soundings was reduced. This may improve the detectability of point targets. In a soft bottom area the tests showed that the real-time outputs could not detect a target of such small extent.

Data from thse runs were post processed and manually scanned for indications of target returns. Of the 24 runs data were recorded for only 21. Four others did not sound the target location. This left 17 good runs. Target returns were found for at least one beam on one ping of eight of these runs. Data from these target returns are listed in Table 4.

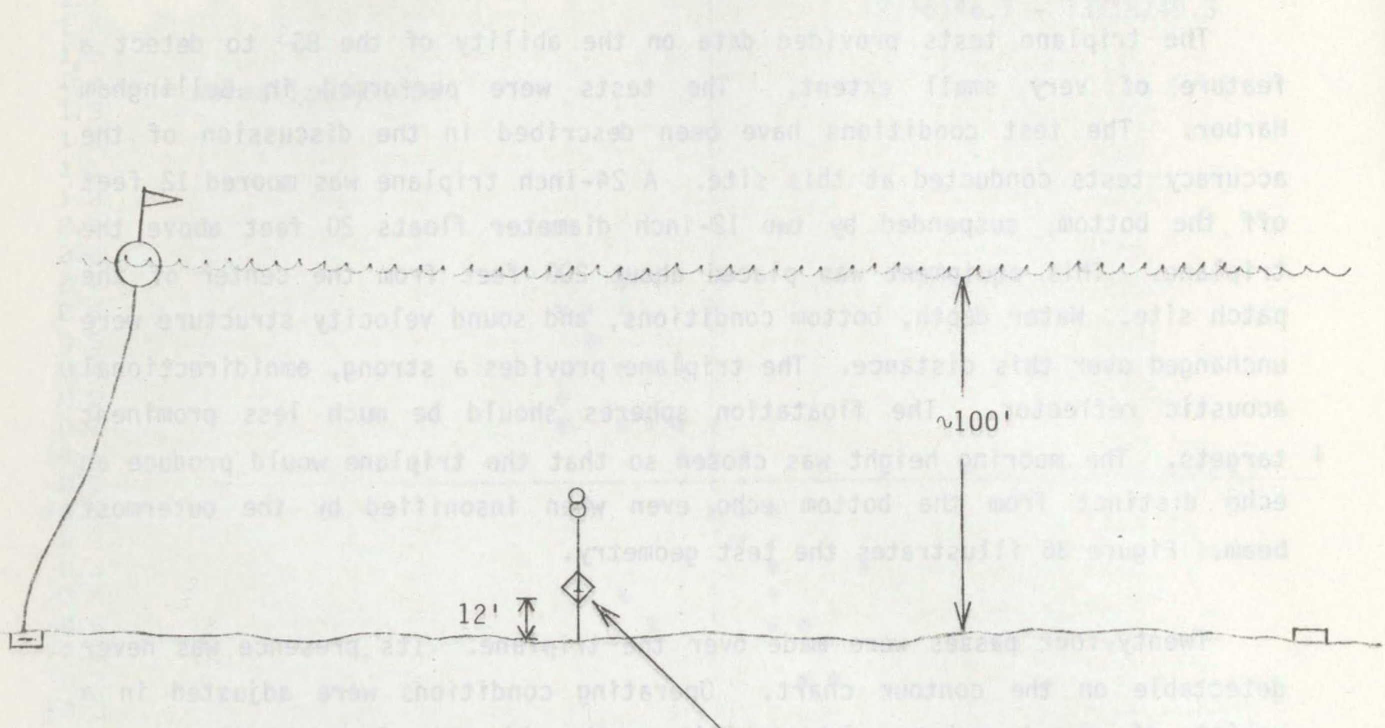


Figure 36. Triplane Tests

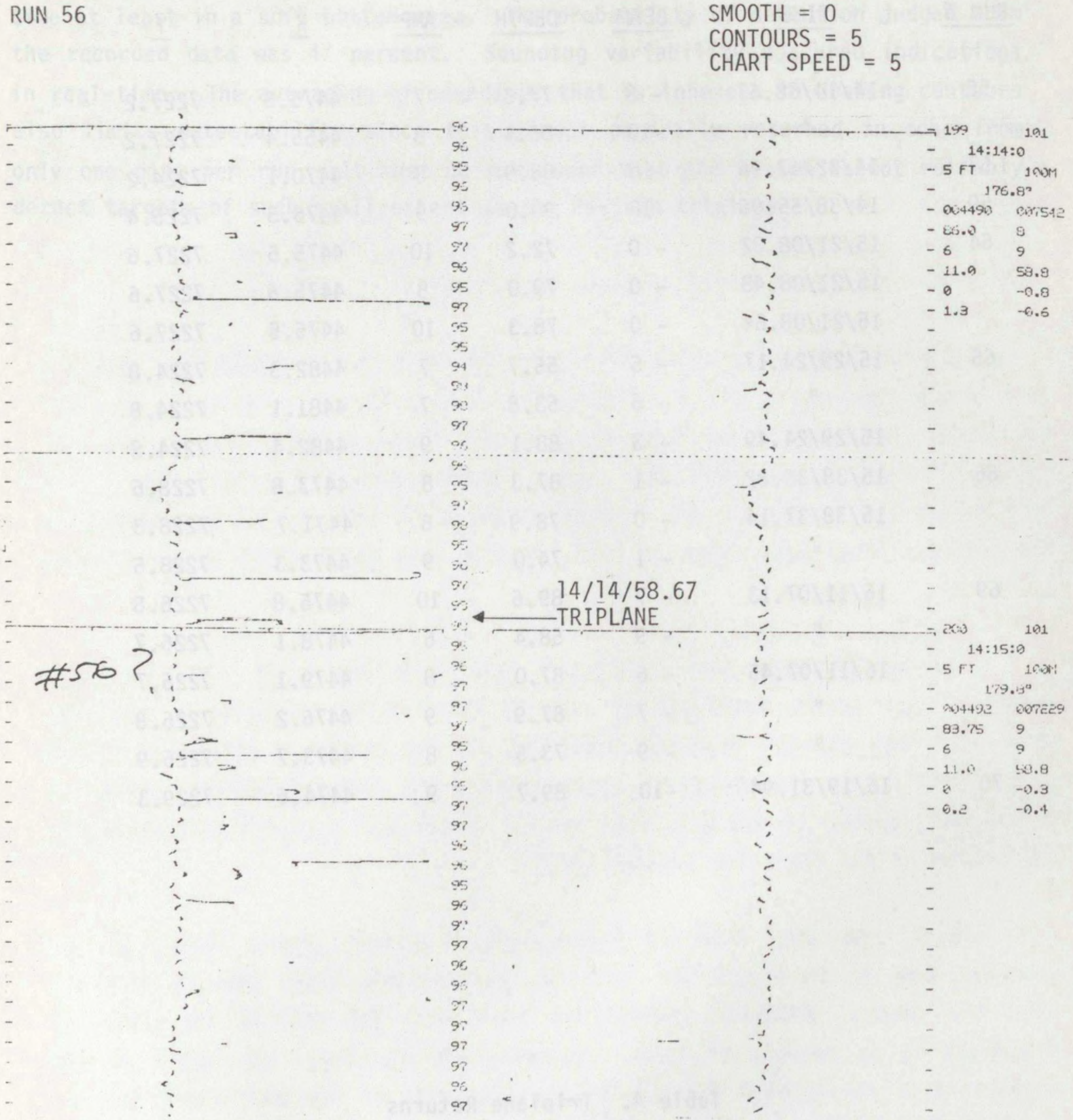


Figure 37. Contour Chart - Triplane Test

RUN #	TIME	BEAM	DEPTH	AMP	X	Y
56	14/14/58.67	- 8	77.3	7	4475.5	7227.2
	"	-10	86.4	8	4465.4	7227.2
57	14/22/47.96	-10	88.9	8	4470.1	7224.2
59	14/38/55.98	-10	90.0	9	4476.3	7225.4
64	15/21/08.32	- 0	72.2	10	4475.5	7227.6
	15/21/08.48	- 0	79.0	8	4475.6	7227.6
	15/21/08.64	- 0	78.3	10	4475.5	7227.6
65	15/29/24.17	- 5	55.7	7	4482.3	7224.8
	"	- 6	53.8	7	4481.1	7224.8
	15/29/24.49	- 3	88.1	9	4482.4	7224.8
66	15/38/36.82	- 1	87.3	8	4473.8	7228.6
	15/38/37.14	- 0	78.9	8	4471.7	7228.3
	"	- 1	74.0	9	4473.3	7228.5
69	16/11/07.13	- 7	89.6	10	4475.8	7226.8
	"	- 9	58.4	6	4478.1	7226.7
	16/11/07.45	- 6	87.0	8	4479.1	7226.7
	"	- 7	87.9	9	4476.2	7226.8
	"	- 9	73.5	8	4473.7	7226.9
70	16/19/31.94	-10	89.7	9	4474.6	7229.3

Table 4. Triplane Returns

The triplane tests showed that a point target was not detectable in real-time at least in a soft bottom area. The probability of detection judged from the recorded data was 47 percent. Sounding variability obscured indications in real-time. The averaging of soundings that is inherent in drawing contours also limits detectability since this target generally returned an echo from only one ping per run. It must be concluded that the system cannot reliably detect targets of such small extent as the 24-inch triplane.

Wreck Tests - Rosario Strait

Wreck tests were designed to determine the reconnaissance capability with a relatively large obstruction. Operations were conducted in Rosario Strait over the site of the wreckage of the tanker Bunker Hill. This ship was a T-2 tanker 504 feet long displacing 10,590 tons. It went down in March of 1964 after being ripped apart by an explosion in an empty cargo tank. The wreckage lies in two pieces separated by about one mile.

The water depth was about 270 feet. The bottom was relatively flat. A grab sample returned grey mud, pebbles, and broken shells. The tests occupied two days. The weather was calm and overcast. Wave heights were two feet or less. The sound velocity was nearly constant increasing from 1483 meters per second at the transducer depth to 1484 meters per second at the bottom. Tides were obtained from a nearby tide gauge which showed a range of 7 feet.

A series of runs were completed over both the north and the south wrecks. Each series consisted of runs at three different pairs of headings with different closest approach distances to the wrecks. Distances ranged from directly over the wrecks to approximately 250 feet athwartship where the wreck would appear in the outermost beams. Every run produced indications of the wrecks on the real-time contour chart.

Some of the runs produced indications that were nearly images of the wreckage such as in Figure 38. Others, particularly those running directly over the wrecks, produced indications that were not readily identifiable. Figure 39 is an example of this. Geometry was one important factor in the appearance of the contour chart. The physical size of the obstruction and the speed of the ship were also very important. The first of these examples was of the southern portion. It was produced at a ship speed of five knots. The second example was produced by the north wreckage at a ship speed of ten knots. Contour smoothing had a clear effect, as expected, on the appearance of the contours. About half of the runs were with no contour smoothing and half with smoothing set for two. Smoothing had little effect on the prominence of the wreck indications. Beamwidth and attenuation were also

SOUTH WRECK
5 KTS

5° BEAMWIDTH
ATTENUATION = 0 dB
SMOOTH = 2

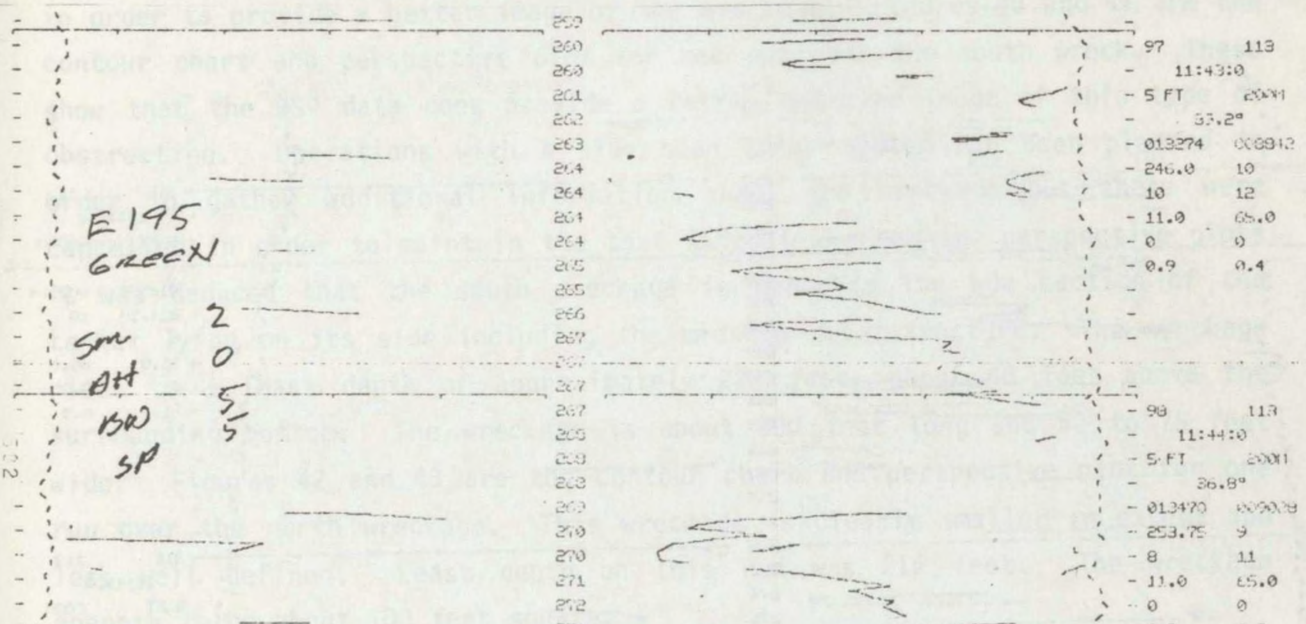


Figure 38. Contour Chart -
Wreck Run 195

NORTH WRECK
10 KTS

20° BEAMWIDTH
ATTENUATION = 0 dB
SMOOTH = 0

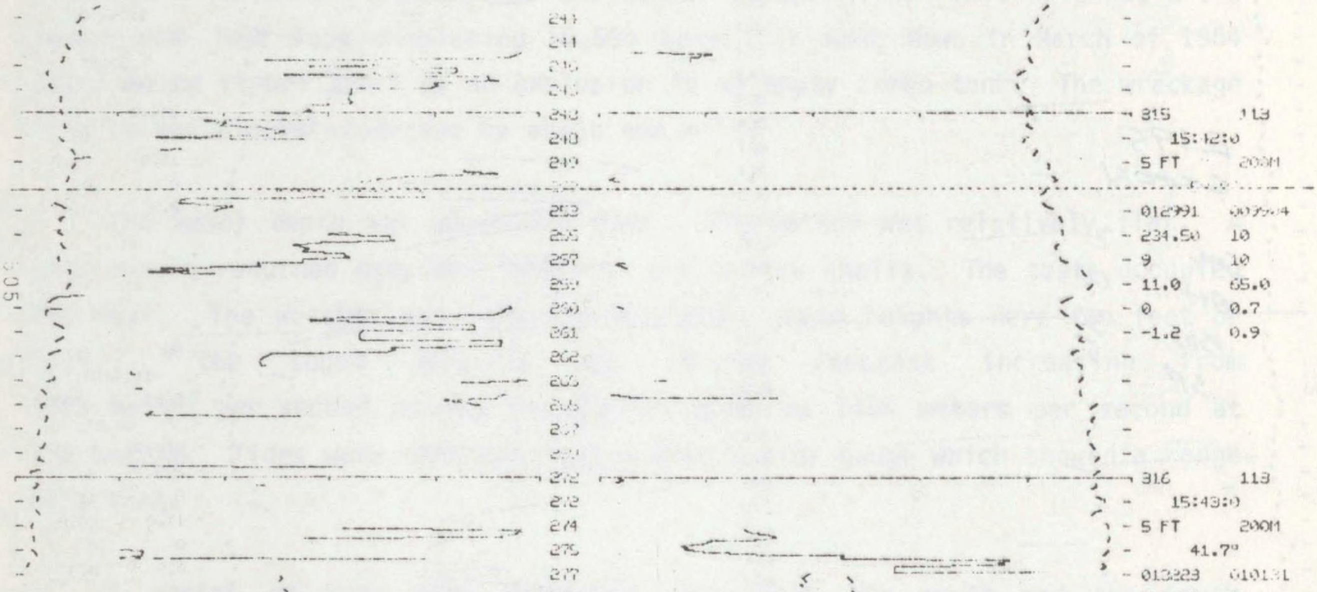


Figure 39. Contour Chart -
Wreck Run 220

varied during the tests but these parameters had no apparent effects on the contours.

Perspective plots were constructed from data from some of the wreck runs in order to provide a better image of the wreckage. Figures 40 and 41 are the contour chart and perspective plot for one run over the south wreck. These show that the BS^3 data does provide a fairly detailed image of this type of obstruction. Operations with a side scan sonar system had been planned in order to gather additional information about the wreckage but these were cancelled in order to maintain the test schedule. From the perspective plots it was deduced that the south wreckage is probably the bow section of the tanker lying on its side including the midship superstructure. The wreckage rises to a least depth of approximately 222 feet, about 48 feet above the surrounding bottom. The wreckage is about 300 feet long and 50 to 75 feet wide. Figures 42 and 43 are the contour chart and perspective plot for one run over the north wreckage. This wreckage is clearly smaller in extent and less well defined. Least depth on this run was 214 feet. The wreckage appears to be about 100 feet square.

Least depths recorded for runs over the south wreck are shown in Table 5. The least depths are consistent within plus or minus three feet except for the outer beams (7-10) which did not report as shoal depths. This may be due in part to instances in which the least depth was not included within the swath.

The wreck runs showed that the BS^3 is consistently able to indicate the presence of such an obstruction. The prominence of indications on the real-time contour chart depended upon the geometry of the encounter with the outer beams producing the most easily recognized indication. The larger the extent and the slower the ship speed the more prominent was the indication. Least depths were consistent within about one percent if the obstruction was sounded with the central 14 beams.

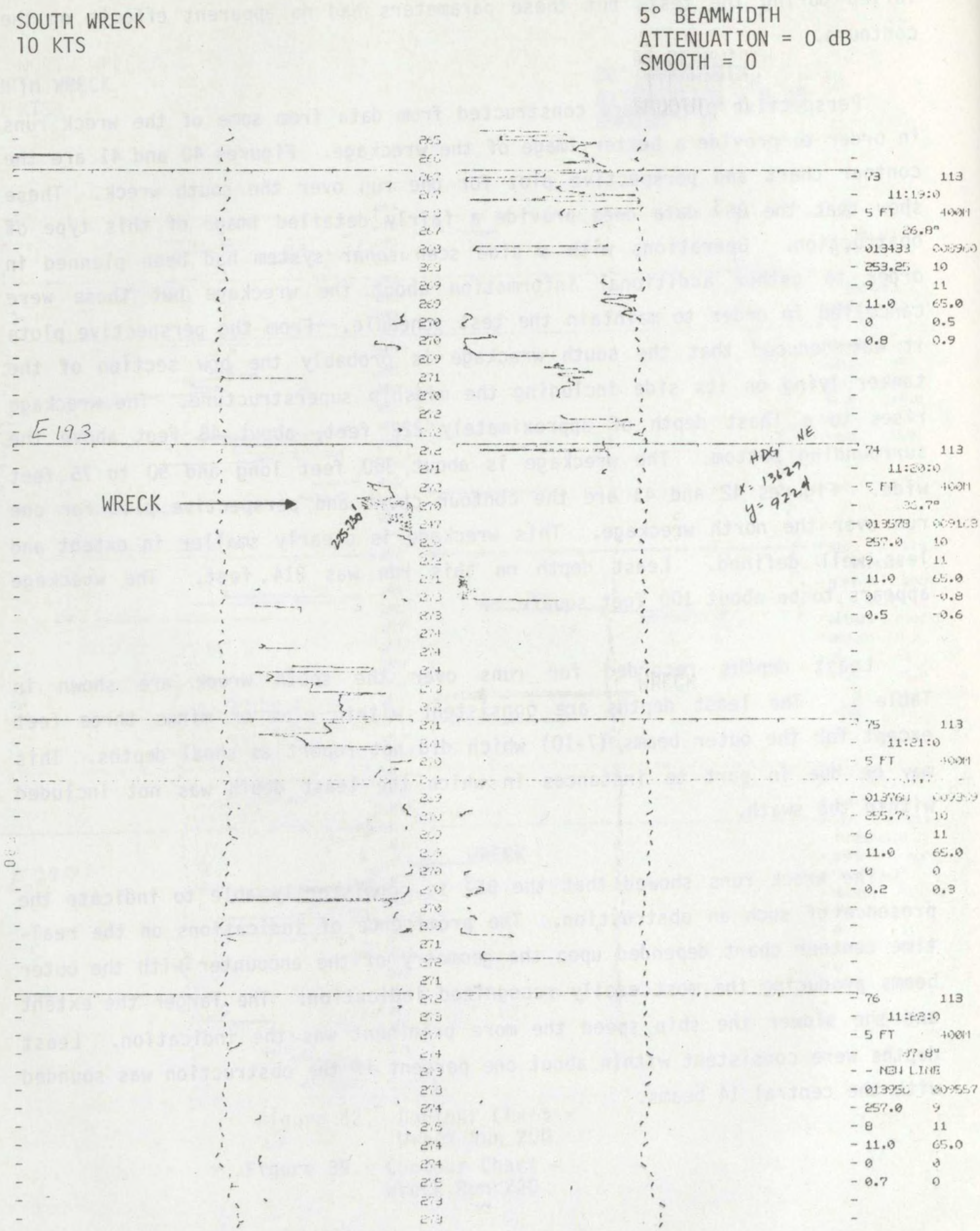


Figure 40. Contour Chart -
Wreck Run 193

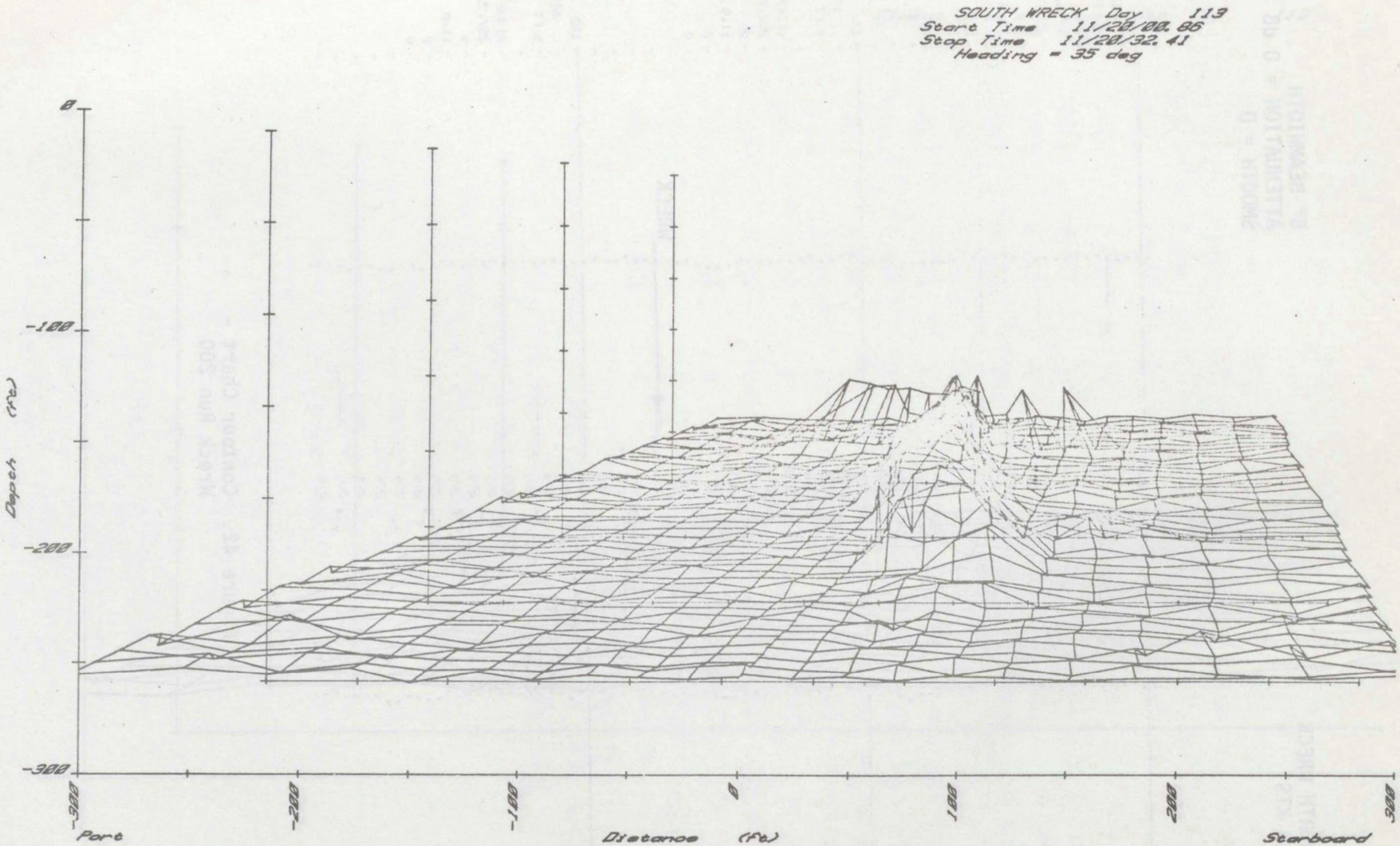


Figure 41. Perspective Plot - Wreck Run 193

NORTH WRECK
10 KTS

5° BEAMWIDTH
ATTENUATION = 0 dB
SMOOTH = 0

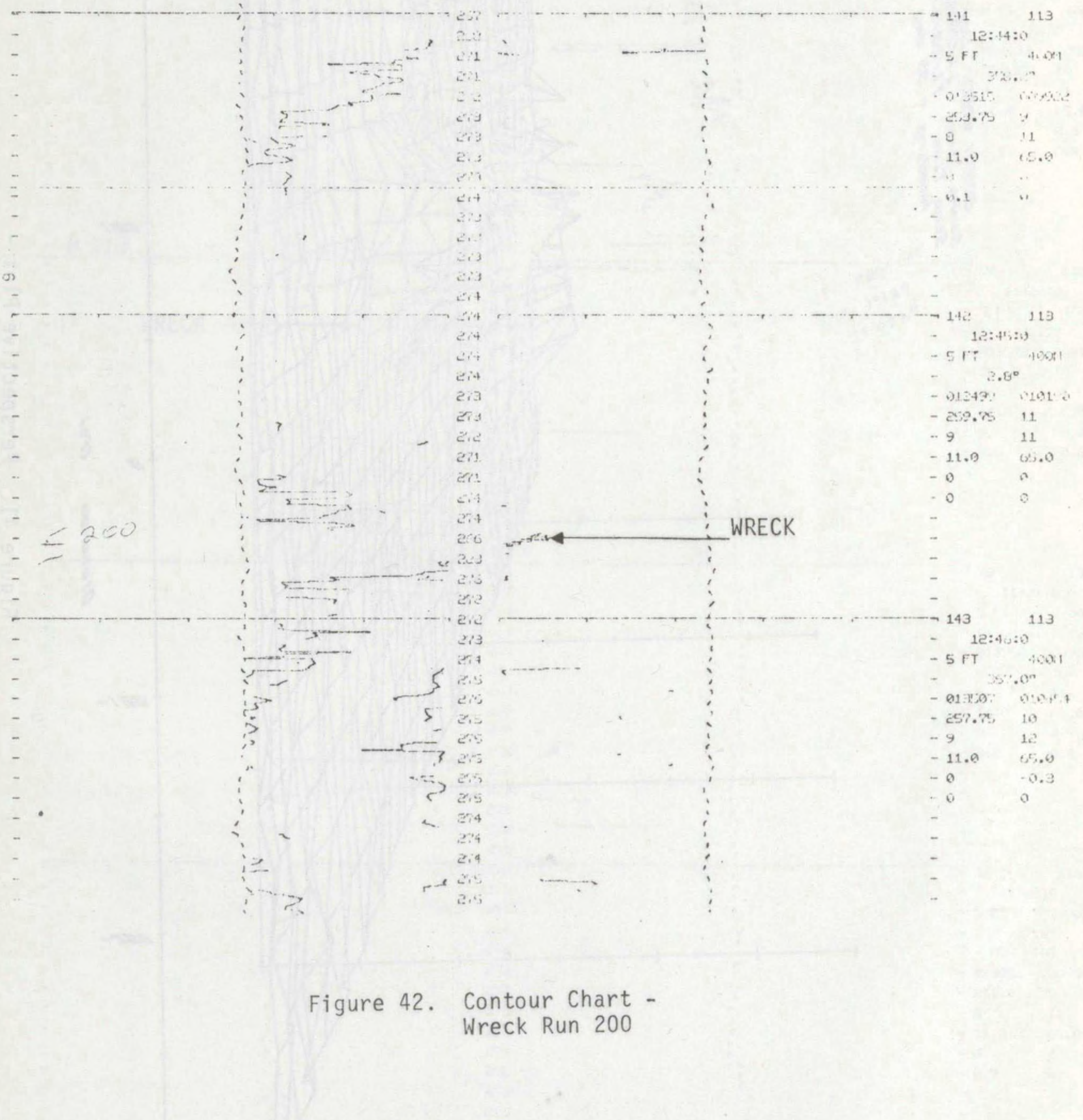


Figure 42. Contour Chart - Wreck Run 200

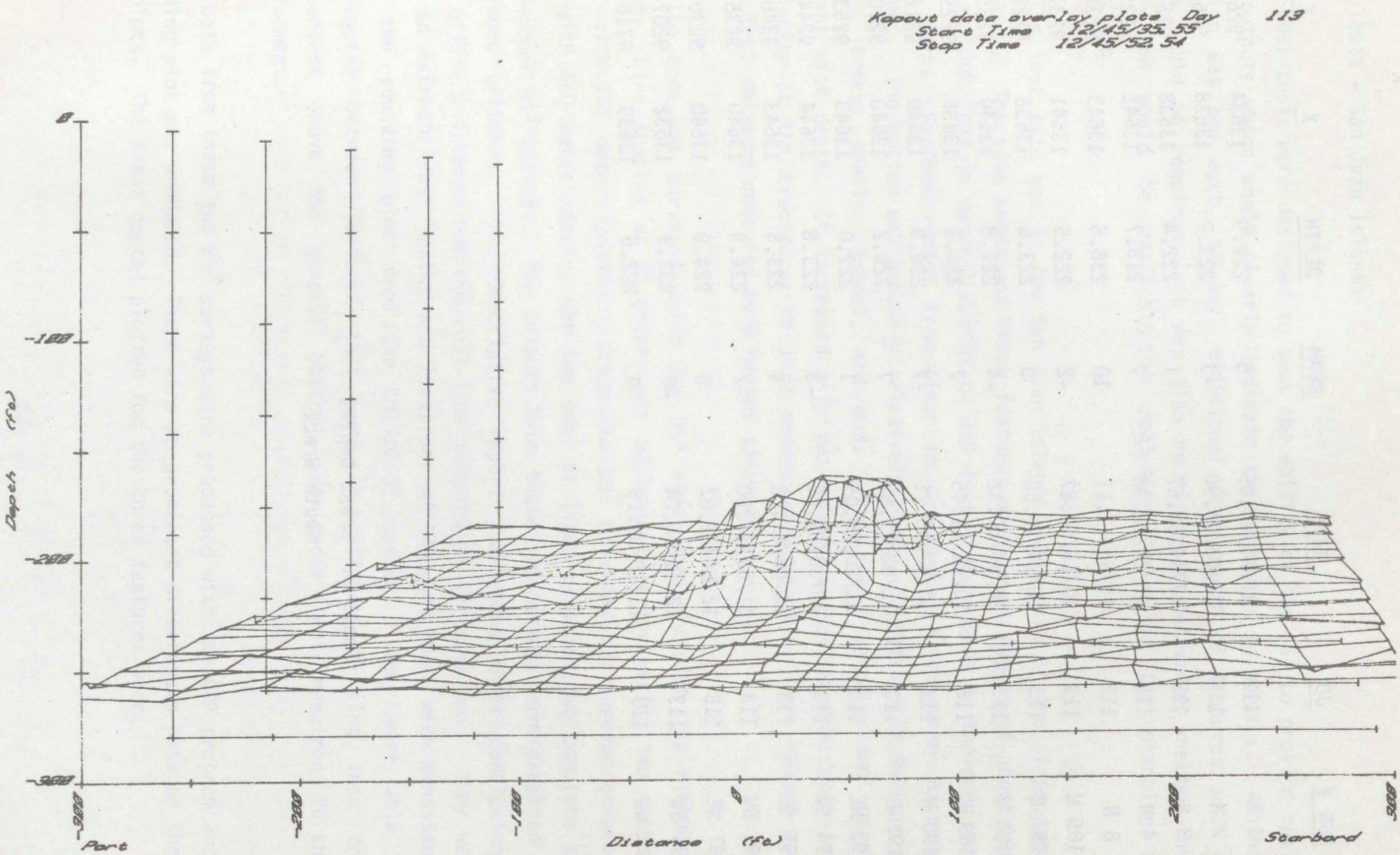


Figure 43. Perspective Plot - Wreck Run 200

RUN #	JD	TIME	BEAM	DEPTH	X	Y
1 S	112	16/46/14.05	5	222.9	13634	9268
2 N	112	17/03/03.90	-3	223.2	13638	9265
3 S	112	17/14/30.57	-1	222.4	13638	9257
4 N	112	17/22/02.98	7	218.7	13641	9229
8 N	112	17/56/11.11	10	236.6	13643	9232
186 W	113	10/16/54.87	-2	222.6	13641	9237
187 E	113	10/25/16.50	0	223.6	13636	9226
188 W	113	10/34/00.32	-4	221.8	13640	9235
189 E	113	10/41/51.45	7	226.3	13636	9229
190 W	113	10/52/35.21	-7	236.9	13640	9218
191 E	113	11/02/23.52	7	226.2	13640	9230
193 NE	113	11/20/23.05	1	222.0	13643	9253
194 SW	113	11/33/29.65	-3	223.8	13644	9244
195 NE	113	11/45/01.12	4	223.5	13643	9248
196 SW	113	11/52/14.80	-7	224.9	13640	9235
197 NE	113	12/04/32.87	6	224.8	13640	9230
198 SW	113	12/11/16.74	-8	233.3	13632	9207
199 NE	113	12/18/06.16	9	222.5	13639	9216

Table 5. Least Depths
South Wreck

Shoal Tests - San Juan Islands

Shoal tests were designed to test the ability of the BS^3 to provide real-time outputs which would clearly indicate the existence of shoals. Another question was how much, if any, additional development of features such as shoals would be required. It was also necessary to determine whether this information would be available in real-time to guide the planning of operations.

The test site was in the San Juan Islands just south of the slope patch test area. The site contained three features with least depths of about 180, 220, and 300 feet in general depths of 350 feet. Operations in the area took three days. Weather ranged from clear to overcast. Waves never exceeded 1.5 feet. The bottom was probably relatively hard. A grab sample brought up shells, broken shells, gravel, and mud. The sound velocity was nearly constant with depth. It increased only two meters per second with depth from a velocity at the transducer of 1482 meters per second. Tides ranged over eight feet and were measured by a nearby tide gauge.

The area was surveyed using the BS^3 simultaneously with the HYDROPLOT system. Line spacing of 80 meters was achieved by interleaving two sets of lines with 160 meter spacing. Since the BS^3 provided 100 percent coverage even with 160 meter spacing the two sets of lines produced two complete and independent BS^3 surveys. The outputs from these two surveys were examined by different officers. The descriptive report summarizes their conclusions. Both officers interpreted the real-time outputs in the same way. They were able to extract least depths and locations of features that were consistent with the sounding plot from the HYDROPLOT system. They were able to distinguish between features that were insignificant (rising less than ten percent above the general bottom) and those that required further development.

Data from these two BS^3 surveys were processed with the COP program and a sounding plot was produced. There were no prominent differences between these two plots. The least depths plotted for the three features were:

SSF #	least depths (feet)		
104100	182	211	286
104115			
104120	187	210	286

They are consistent within five feet.

After the survey a series of north-south lines were run with 20 meter spacing covering the peaks of the features. The objective was to see whether the least depth measurements would be a function of beam number. Least depths for the largest feature from these runs are reported in Table 6. All soundings in an area 40 meters square centered in the coordinates of the least depth reported by COP were examined. The standard deviation of these least depths is 3.75 feet which is reasonable considering the expected accuracy in this depth of 1.77 feet coupled with the effects of an irregular bottom. There is a clear tendency, however, for the outer beams to report a deeper depth than the center beams.

Thus, the tests in the shoal area demonstrated that the real-time outputs were adequate to indicate the existence of shoals and to provide enough quantitative information about such features to guide further operations. Least depths from two independent surveys of this area were consistent within plus or minus 5 feet even after processing through COP's sounding selecting routine. Considering all the soundings in the vicinity of the largest feature from a series of runs over its peak the least depths showed a standard deviation of 3.75 feet. The outer beams indicated a slightly deeper least depth than the center beams. This shows that to obtain the greatest confidence in a least depth a development line should be run over the peak of features such as these.

RUN #	JD	TIME	BEAM	DEPTH	X	Y
85 E	104	17/54/17.52	-10	189.4	7831	7732
86 W	104	17/59/51.61	9	187.8	7832	7721
87 E	104	18/13/04.81	-8	183.8	7828	7728
88 W	104	18/18/36.26	0	181.3	7825	7723
89 E	104	18/31/44.34	-2	181.1	7826	7712
90 W	104	18/36/59.71	0	178.0	7835	7692
91 E	104	18/49/45.80	5	181.5	7819	7710
92 W	104	18/57/17.48	-9	189.6	7823	7699
93 W	104	15/22/37.03	9	185.6	7826	7702
101 S	105	16/54/34.25	-1	181.7	7825	7711
103 S	105	17/09/26.10	0	182.0	7825	7712
104 N	105	17/16/16.03	2	180.5	7818	7705

Table 6. Least Depths
Shoal

Canyon Test - Astoria Canyon

The objective of the canyon test was to obtain information on the operation of the BS^3 over a rough bottom in relatively deep water.

The test site was in the center of Astoria Canyon. Depths ranged from 1500 to 2400 feet. Three lines were run with 400 meter spacing. Operations in the area took about two hours. Weather was clear with eight to 12 knot winds. Swells were three feet in height. The sound velocity varied from 1489 meters per second at the transducer depth to 1481 meters per second at the bottom. No tidal corrections were made.

The data from these runs were processed through the COP program and then through a contouring program. Figure 44 shows the result. The original scale was 1:12,000. It is a very detailed and apparently reasonable representation of the bathymetry.

Three "bullseyes" stand out as clear anomalies. One of them is an artifact of the contouring program. The program extrapolated data to fill a grid point for which no real data was available. Near an edge, as this was, the extrapolation is unreliable. The other two anomalies are based on real data. The entire sequence of data adjacent to these selected soundings were examined. The selected soundings were found to be anomalies both with respect to the crosstrack profile indicated by the swath and with respect to the time series produced by that beam. They were not sufficiently distant from adjacent soundings to be rejected as outliers by COP. They were both produced by beam five which has less frequency selectively due to the beam forming network than the other beams. Thus it is possible that they were caused by acoustic interference. It is equally likely that they may have been caused by a fish or some other acoustic reflector in the water.

This test showed that the BS^3 produces an acceptable bathymetric representation in a very irregular area in deep water. Isolated anomalies were noted. Modifications may be possible in the outlier rejecting algorithm in COP so that it will reject these anomalies without rejecting correct data.

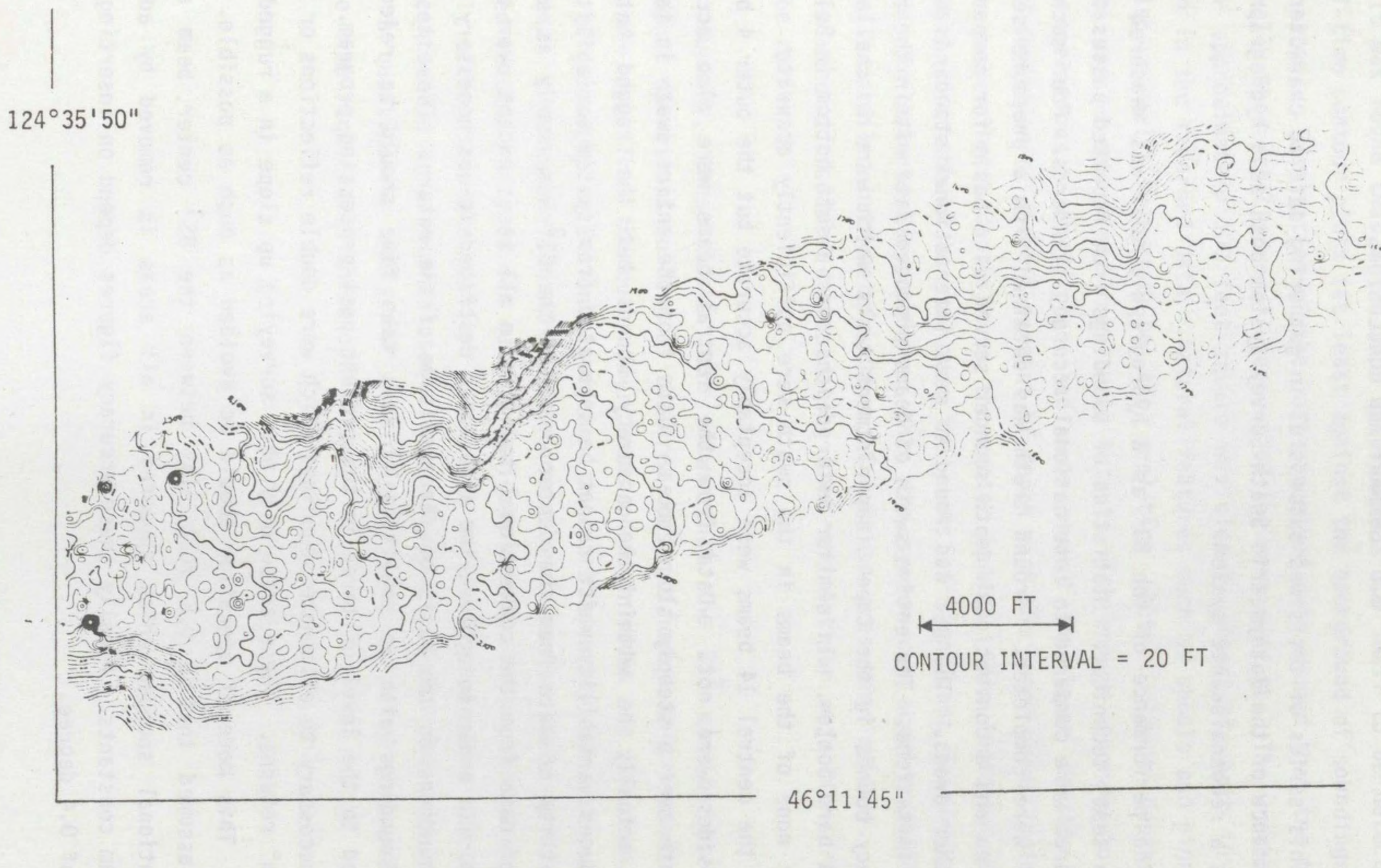


Figure 44. Bathymetric Contours - Astoria Canyon

6.0 SUMMARY AND CONCLUSIONS

This series of tests was successful in gathering data to characterize the performance of the Bathymetric Swath Survey System both as a hydrographic tool and as a reconnaissance system.

The performance of the BS^3 as a hydrographic tool was measured using a "patch test" technique. Statistics of soundings from repeated passes over the same area were compared to international accuracy standards. Four such "patch tests" were completed. Ground truth was obtained from a pressure sensor in one area and a conventional depth sounder served as a basis for comparison in the other areas. The BS^3 was found to meet international standards but with some limitations. The entire swath of beams produced data within the required accuracy bounds in the Cape Disappointment tests which were in shallow water over a hard bottom. In similar water depths over a soft bottom in Bellingham Harbor none of the beams in the swath were sufficiently accurate. In deep water the central 14 beams were acceptably accurate but the outer 4 beams on both sides were not. Data from the central beams were also acceptably accurate over a steeply sloped area. Data from the entire swath in this area might actually be within the accuracy bounds but the rugged bathymetry introduces variability which cannot be separated from system variability. The variability of data from the center beams of the BS^3 was nearly as small as that of data from the conventional sounders in all tests except over the soft bottom. In order to achieve the accuracies described it was necessary to cull the soundings on the basis of the amplitude of the return. These tests show that soundings with an amplitude of less than five should be rejected as opposed to the level of three in the present post-processing program. It was also necessary to eliminate soundings which were double reflections or "second bottom" returns. These arose only when surveying up slope in a rugged bottom area. This mode of operation should be avoided as much as possible. It is also assumed that a 0.5 foot bias between the BS^3 center beam and the conventional sounder which appeared in all areas is removed by adjusting program constants. Finally these accuracy figures depend on inserting a roll bias of 0.4 degree.

The reconnaissance capability of the BS^3 was determined in a variety of ways. It was found that a two foot triplane was too small to be detected in the real-time contour plots (at least against the background of soundings from a soft bottom). Examination of the post-processed data showed that the target had actually been detected on 47 percent of the runs over it. The wreckage of a tanker approximately 100 feet square was clearly detectable both in real-time and in the recorded data. Natural features such as shoals and pinnacles were also clearly indicated on the real-time plots. Least depths and positions can be determined from these outputs with enough accuracy to guide further operations. Post processed data showed the least depths had a standard deviation of about 2 percent of depth with the outer beams indicating slightly deeper least depths than the center beams. This indicates that a development line should be run over the peaks of signficant features. The operations in Astoria Canyon showed that the system can acquire sufficient data for a detailed bathymetric chart of such an area very quickly. A few anomalies were noticeable demonstrating that the outlier rejection criteria should be reviewed.

In summary, these tests have shown that the BS^3 can be used for hydrographic operations so long as the area does not have a soft bottom and so long as the data from the outer four beams on both sides are not used. The effects of sounding selection algorithms on chart accuracy has not yet been addressed. Intercomparison with the conventional sounder data using tools developed in this analysis can quickly indicate whether bottom conditions will seriously affect the data quality. The tests have also shown that the BS^3 has significant value as a reconnaissance and bathymetric tool. The test results provide a quantitative basis for developing strategies using the system to minimize time required in these operations.

ACKNOWLEDGEMENTS

This work is the product of the efforts of many people. Jim Vrancik acted as project engineer. Leon Boulavsky and Armando Alarcon assisted with the field tests. Leon, Armando, and Randy Hinzman developed and ran the post-processing software. Tom Stepka developed the original post-processing codes and performed portions of the processing and analysis reported here. Carol Hurley typed several revisions of the report. The efforts of the officers and crew of the DAVIDSON greatly contributed to the success of these tests. Many others in NOS and OTES provided ideas, support, and guidance which proved to be very helpful.

REFERENCES

Angelari, Richard D., 1978: A Deterministic and Random Error Model for a Multi-beam Hydrographic Sonar System. Proceedings of Oceans '78 Conference, , Institute of Electrical and Electronic Engineers, Inc., New York, N.Y., 48-53.

Callahan, M.R. (Test and Evaluation Laboratory, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Washington, D.C.) 1976: Laboratory and Field Test of the Plessey 9090 XSTD Stystem. 109 pp. (unpublished manuscript).

Farr, Harold K., 1980: Multi-beam Bathymetric Sonar: SEABEAM and HYDROCHART. Marine Geodesy, 4, 77-93.

Hopkins, Robert D. and Mobley, Wayne L., 1978: Recent Developments in Automated Hydrographic and Bathymetric Survey Systems in the National Ocean Survey. Proceedings of the Offshore Technology Conference, 8-11 May 1978, Houston, Texas, Offshore Technology Conference, Dallas, Texas, 1493-1502.

McCaffrey, Edwin K., 1981: Review of the Bathymetric Swath Survey System, International Hydrographic Review, 58, 19-27.

National Oceanic and Atmospheric Administration, 1981: Descriptive Report S-N905-DA-81, BS^3 Characterization Tests (unpublished manuscript).

Neal, Edgar H., (EG&G, Washington Analytical Services Center, Inc., Rockville, MD), 1981: BS^3 Error Analysis, 78 pp. (unpublished manuscript).

New, Ronald and Zysko, Jan, (Systems Analysis Division Office of Marine Technology, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Rockville, MD.), 1977: Test Report on the Analysis of the Launch - Sonar Accuracy Experiment, 30 pp. (unpublished manuscript).

Pearce, William A., Stickles, E. Scott, and Butler, David A., (EG&G, Washington Analytical Services Center, Inc., Wolf Research and Development Group, Riverdale, MD.), 1981: A Comparison of the Bathymetric Swath Sonar System with the Ross and Raytheon Sounders, 27 pp. (unpublished manuscript).

Pryor, Donald, 1981: Characterization Tests of Datawell Hippy 120C Vessel Motion Sensor, NOAA Technical Memorandum OTES ___, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Washington, D.C., 137 pp.

APPENDIX A

TEST REQUIREMENTS

National Ocean Survey
Office of Marine Surveys and Maps
Hydrographic Surveys Division

PROVISIONAL REQUIREMENTS FOR TEST OF THE BATHYMETRIC SWATH SURVEY SYSTEM (BS^3)

Dale E. Westbrook
OA/C35x1
December 10, 1980

CONTENTS

I. INTRODUCTION

The National Ocean Survey (NOS) Bathymetric Swath Survey System (BS^3) was purchased in 1977 from Harris ASW Division of General Instrument Corporation. Since that time, extensive development and testing have been invested in the system. In addition to laboratory tests, the BS^3 has been tested at sea aboard the NOAA launch LAIDLEY and the NOAA Ship DAVIDSON. Software and hardware problems have prevented the running of conclusive tests which would provide enough quality data for a categorical determination of the operational usefulness of this system.

During 1980, several major problems were addressed, and are being rectified in order to allow a definitive test to be made again at sea aboard the Ship DAVIDSON.

The Project Document prepared for the Office of Marine Surveys and Maps (OA/C3) by the Engineering Development Laboratory (OA/C61) of the Office of Marine Technology (OA/C6) in September 1980, states the present objective as follows:

> To perform the development required and to conduct tests to evaluate and characterize the performance of the BS^3 utilizing the center beams for hydrography and the outer beams for reconnaissance.

The technical approach to accomplish this objective was also set forth and is quoted below:

> Complete the development of the BS^3, and eliminate deficiencies only to the point necessary to conduct a meaningful, comprehensive system characterization test. Areas of concentration will include:
>
> 1. Limited hardware improvement to increase reliability.
>
> 2. Survey software development and debugging to eliminate deficiencies.
>
> 3. Sonar installation redesign to eliminate multipath problems.
>
> 4. Test plan development, implementation, and data analysis necessary to characterize performance.

The plan also provides for the reinstallation of the BS^3 aboard the Ship DAVIDSON by March 1981. System tests will be performed during March and April.

This report defines the OA/C3 accuracy requirements, outlines the general requirements for underway test surveys, and discusses, in a preliminary manner, the requirements which must be addressed in order for the system to be "declared operational" in the full sense of the term.

II. ACCURACY REQUIREMENTS

NOS requirements for hydrographic surveys and the attendant accuracy requirements are prescribed in the NOS Hydrographic Manual. The minimum requirements, as agreed to by member states of the International Hydrographic Bureau (IHB) 1967 are reproduced in the back of this report (Appendix A, II). Accuracies attained for all hydrographic surveys conducted by NOS shall equal or exceed these specifications (Hydrographic Manual, Sec. 1.1.2).

Should one regard the above specifications as superficial or not definitive enough for present requirements, detailed accuracy specifications for NOS surveys were proposed by Capt. Wayne L. Mobley, NOAA, in 1978 (Appendix B). Although these specifications have not, to the writer's knowledge, as yet been formally approved, they were specifically designed and formulated for BS^3 purposes. The specifications meet, or exceed both the IHB standards for hydrographic surveys and National Map Accuracy Standards for contour lines (Appendix A, I), and these should be considered as valid goals for NOS hydrographic and bathymetric swath surveys.

III. TEST REQUIREMENTS

A. GROUND TRUTH-HYDROPLOT

In order to adequately calibrate or test a system (or system component) that makes measurements, there must be a device or method external to that system which provides the standard against which the comparison is made. Individual components of the BS^3 system are subject to various laboratory and field tests and this report assumes that the Engineering Development Laboratory will include these in the Test Plan.

The survey tests, on the other hand, will be run under field operating conditions and will include the computer processing of the acquired data in addition to the application of the proper correctors to depth and positioning. For the survey tests, the only acceptable standard (ground truth) presently available against which the BS^3 can be compared is the operational HYDROPLOT system.

All test areas to be surveyed by the BS^3 shall be covered first by a well-developed, carefully conducted and calibrated HYDROPLOT survey. A deep water echo sounder should be available for ground truth in the Deep Water Test. To ensure that any differences found between the two survey systems are not unduly influenced by extraneous factors, no previously surveyed ground truth shall be utilized. A general comparison with prior NOS hydrographic surveys will be made in the common area, however, in accordance with routine procedures.

As a result, in addition to the use of the same survey vessel (DAVIDSON) for both HYDROPLOT and BS^3, several other survey factors, which primarily affect the corrections applied to the data, shall be common to the surveys of both systems, as follows:

- o The same tide gage or gages and datum determination.
- o The same electronic control system, shore station locations, equipment, and calibration points.
- o The same equipment and method for determining sound velocity corrections.
- o The same settlement and squat correction table.

Because the BS^3 is designed to measure and correct for the effect of heave, roll, and pitch, every effort shall be made to perform the HYDROPLOT ground truth surveys during calm weather conditions and to ensure that, to the extent possible, the effects of heave are removed from the raw data.

B. ADDITIONAL OBSERVATIONS

Sea state observations are required once each hour during the tests. The direction the seas are from (0°-360°) and the height of the average seas in feet from peak to trough shall be visually estimated, recorded, and forwarded with the test records.

Any other information which shipboard personnel believe may affect or be pertinent to the evaluation of the test should also be included.

C. GENERAL TEST REQUIREMENTS

The general test requirements are individually described in this section. Although the various tests are discussed separately, subsequent test planning may indicate areas in which some tests may be run concurrently, or at least run in the same locality. The actual details of the tests, line spacing, direction of lines, etc. will be deferred until these proposed requirements have been approved. Survey scales should be 1:10,000, except for the Deep Water Test where a scale of 1:20,000 is proposed. The use of Mini-Ranger would be advantageous, especially where several test areas are required for short periods of operation. Otherwise, Raydist shall be used.

It should be noted again that all test areas shall have detailed HYDROPLOT survey coverage to provide the basis for evaluation.

1. FLAT AREA TEST

Purpose: To evaluate the accuracy and repeatibility of the BS^3 vertical and side beams, and which, if any, meet NOS accuracy requirements. Also to evaluate heave, roll, and pitch (HRP) corrections made to the data.

Bottom Configuration: A relatively flat or very gently sloping area, perhaps 1/2 to 1 nautical mile on a side, in about 30-40 fms of water.

How run: BS^3 swaths shall be run in several different directions over the same area with 20 percent overlapping coverage.

When: The swaths shall be run twice, once in calm seas, and once in moderate seas.

2. STEEP SLOPE TEST

Purpose: To evaluate the best direction in which to run BS^3 swaths on relatively steep slopes and to determine if the programmed "gating" of the beams reacts satisfactorily in all directions. Also to determine whether the "gating" is a determining factor on optimum swath direction.

Bottom Configuration: A relatively steep slope rising from about 100 fm to 10 fm in 1/2 nautical mile.

How run: Four sets of BS^3 swaths as follows:

- o At 90° to the slope
- o At 45° to the slope
- o Parallel to the slope in both directions

(Overlapping coverage may not be necessary for this test, particularly on the swaths run at an angle to the slope.)

When: During normal sea conditions.

3. PINNACLE TEST

Purpose: To evaluate the capability of the BS^3 to indicate the existence of a pinnacle to the hydrographer and the relative ease by which the hydrographer can locate and determine the least depth on such a pinnacle.

Bottom Configuration: A relatively flat area which contains at least one rock pinnacle which protrudes abruptly from the bottom (20-50 fms), and which has a least depth of from 6-10 fathoms. (Ship must be able to traverse the top of the feature.)

A similar feature should be found, if possible, which is located on a steeply sloping or very irregular bottom.

How run: Three sets of BS^3 swaths at standard line spacing, the pinnacle to be situated one-half way between swath centers, as follows:

- o In any direction over flat bottom.
- o At 45° to the depth curves on sloping or irregular bottom.
- o Parallel to the depth curves over sloping or irregular bottom.

The hydrographer shall note, in each case, whether an indication of the pinnacle was observed on the on-line contour plot at standard line spacing of sufficient magnitude to prompt further investigation. Subsequent overlapping swaths should be run in each case to delineate the feature, one swath running directly over its peak to provide the least depth.

When: During normal sea conditions.

4. SHOAL INDICATION TEST

Purpose: To evaluate the capability of the BS^3 to alert the hydrographer to the existence of a shoal indication, and its capability to subsequently verify or disprove the critical nature of such a shoal indication in comparison with the usual system of split lines required to answer this question with the HYDROPLOT system.

Bottom Configuration: Flat or gently sloping bottom in 20-30 fm depths which contains two shoals which protrude at least 10 percent above the surrounding depths (Hydrographic Manual Sec. 1.4.3).

One shoal will not protrude much more than 10 percent off the bottom, indicating that any subsequent investigation would be unproductive. The other shoal will have a least depth substantially above the surrounding depths, therefore justifying a subsequent investigation.

How run: One BS^3 swath run over each shoal, positioned such that the vertical beam strikes a portion of the shoal which is 10 percent above the general bottom.

The hydrographer should note the results on the on-line plot and try to determine, from that information alone, which shoal indication should be investigated further. Then, one or both shoals should be investigated with the minimum number of overlapping swaths sufficient to adequately develop the bottom configuration and provide the least depths on the features.

When: During normal sea conditions.

5. OBSTRUCTION TEST

Purpose: To evaluate the capability of the BS^3 to detect and provide the least depth on obstructions of small extent, not only by echoes from side beams, but also by traversing the top of such features.

Bottom configuration: Two areas (10-30 fms) deep, as follows:

- o Flat or gently sloping bottom.
- o Highly irregular bottom.

Obstructions will be either natural objects or wrecks already in place or man-made temporary obstructions placed especially for this test.

How run: BS^3 swaths run in both areas, as follows:

- o Obstructions situated in overlap area between two swaths of 20 percent overlap.
- o Obstructions situated mid-way between outer beam and vertical beam.
- o Obstructions situated directly beneath survey vessel (vertical beam) on swath directed to pass over the top of obstructions.

When: During normal sea conditions.

6. DEEP WATER TEST

Purpose: To evaluate the capability of the BS^3 in deep water operations, and to determine the deep water operational limits of the system.

Bottom configuration: A sloping bottom with depths ranging from 50 to 400 fms.

How run: BS^3 swaths run parallel to the slope with approximately 20 percent overlap. (The scale of this survey shall be 1:20,000.)

When: During normal sea conditions.

Note: The specified overlap must take into account the fact that only the center 11 beams are intended to have full capability in the deepest portion of the area (> 130 fm). See Appendix C for examples of overlap computations.

IV. DATA PROCESSING

The Ship DAVIDSON shall process the HYDROPLOT data according to standard practice, and the BS^3 data to the point where combined output (COP) tapes are prepared. COP will be used in a modified form to process all soundings. Details on data transmittal and Marine Center processing requirements will be formulated at a later date.

V. ANALYSIS OF TESTS

Data will be provided by the ship to OA/TE2 (portions of which were formerly OA/C61) in a form required by that office for their analysis.

In addition to OA/TE2's analysis, within 1 month from the receipt of the plots from the Marine Center produced using a duplicate data set, OA/C35 will carefully analyze the results of the survey tests and will prepare a report documenting the results. Provided that the hardware/software system functioned properly, and the tests were adequately performed, OA/C35 will also make recommendations in that report concerning the further operational use of the BS^3 for survey purposes. Additional improvements, if any, suggested for the system will also be addressed.

VI. OPERATIONAL ACCEPTANCE REQUIREMENTS

It is highly unlikely that OA/C35 would consider recommending the future operational use of the BS^3 in any manner unless an analog record of the vertical beam were provided and available for use by the hydrographer and Marine Center processing personnel. Such an analog record is not presently produced by the BS^3, nor will it be available during the tests.

Because of the inherent limitations of digitally acquired depths, an analog record is still believed necessary for an interpretation of apparent anomalies to ensure survey adequacy.

A brochure prepared by the General Instrument Corporation asserts that an analog recorder can be installed, and this claim is supported by Engineering Development Laboratory (OA/C61). Thus, the likelihood that a requirement will be forthcoming for an analog record, in BS^3 operational use, should be borne in mind.

There are several other items that must be addressed should the BS^3 be declared operational. The system will have to be documented for hardware and software including a user's manual; a configuration management system established for changes made to the system; and appropriate provision made for hardware maintenance.

APPENDIX A

Appendix 6

Accuracy Standards

I. United States National Map Accuracy Standards

With a view to the utmost economy and expedition in producing maps which fulfill not only the broad needs for standard or principal maps, but also the reasonable particular needs of individual agencies, standards of accuracy for published maps are defined as follows:

1. *Horizontal accuracy.*—For maps on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 1/30 in [0.846 mm] measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50 in [0.508 mm]. These limits of accuracy shall apply in all cases to positions of well-defined points only. Well-defined points are those that are easily visible or recoverable on the ground, such as the following: monuments or markets, such as bench marks, property boundary monuments; intersections of roads, railroads, etc.; corners of large buildings or structures (or center points of small buildings); etc. In general what is well defined will also be determined by what is plottable on the scale of the map within 1/100 in [0.254 mm]. Thus while the intersection of two road or property lines meeting at right angles would come within a sensible interpretation, identification of the intersection of such lines meeting at an acute angle would obviously not be practicable within 1/100 in [0.254 mm]. Similarly, features not identifiable upon the ground within close limits are not to be considered as test points within the limits quoted, even though their positions may be scaled closely upon the map. In this class would come timber lines, soil boundaries, etc.

2. *Vertical accuracy,* as applied to contour maps on all publication scales, shall be such that not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval. In checking elevations taken from the map, the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale.

3. The accuracy of any map may be tested by comparing the positions of point whose locations or elevations are shown upon it with corresponding positions as determined by surveys of a higher accuracy. Tests shall be made by the producing agency, which shall also determine which of its maps are to be tested, and the extent of such testing.

4. Published maps meeting these accuracy requirements shall note this fact on their legends, as follows: "This map complies with National Map Accuracy Standards."

5. Published maps whose errors exceed those aforestated shall omit from their legends all mention of standard accuracy.

6. When a published map is a considerable enlargement of a map drawing (manuscript) or of a published map, that fact shall be stated in the legend. For example, "This map is an enlargement of a 1:20,000-scale map drawing," or "This map is an enlargement of a 1:24,000-scale published map."

7. To facilitate ready interchange and use of basic information for map construction among all Federal mapmaking agencies, manuscript maps and published maps, where economically feasible and consistent with the uses to which the map is to be put, shall conform to latitude and longitude boundaries, being 15 minutes, of latitude and longitude, or 7.5 minutes, or 3 3/4 minutes in size.

U.S. Bureau of the Budget
Issued June 10, 1941
Revised April 26, 1943
Revised June 17, 1947

II. Accuracy standards recommended for hydrographic surveys

A. General Standards

1. Scale of survey

a. The scale adopted for a survey of a particular area should not be smaller than the scale of the existing or proposed chart of the area and preferably should be at least twice as large as that of the largest scale of the published or proposed chart of the area.

b. Ports, harbors, channels, and pilotage waters should be surveyed on a scale of 1:10,000 or larger.

c. Other waters used by shipping with possible shoals or other dangers to navigation should be sounded on a scale of 1:20,000 or larger.

d. Surveys of coastal and harbor approach areas to a depth of at least 20 m (11 fm) should be conducted on a scale of 1:50,000 or larger.

e. Offshore hydrographic surveys in depths greater than 20 m (11 fm) may be plotted on a scale smaller than 1:50,000 dependent on the importance of the area covered, the depth, and bottom configuration. The scale of the offshore plotting sheet should not be smaller than is necessary to provide a sheet of convenient size that will extend a short distance beyond the offshore limit of the survey and will, where feasible, include the stations necessary for control of the survey.

2. Interval of sounding lines at the scale of the survey

a. Spacing of principal sounding lines

1.0 cm (0.4 in) or less, as may be needed to thoroughly develop the area at the scale of the survey, except where depth and character of the bottom will permit wider spacing.

b. Spacing of cross-check lines:

7.5 cm (3.0 in) or less.

3. Interval of plotted soundings

Frequency along sounding lines:

Spacing should be less than the interval with peak and deep soundings shown, but this interval may be increased in areas of even bottom, and where the soundings are recorded on an echogram.

4. Sampling of bottom characteristics

In general, sufficient sampling should be done to demarcate the limits where one general type of bottom changes to another.

In waters that may be used for anchoring, samples should be taken at regular intervals not to exceed 5 cm (2 in) at the scale of the survey. In other areas, shoaler or deeper, a spacing of 8 cm (3 in) is sufficient depending on the regularity of the bottom. Deep-water bottom samples, over 100 m (55 fm), are classed as oceanographic observations requiring special equipment and samples will be taken as required.

5. Spacing of position fixes

The spacing of position fixes on the survey sheets shall be from 2 to 4 cm (1-1.5 in).

6. Current observations

When velocity is expected to exceed 0.2 kn, both velocity and direction of currents shall be observed at entrances to harbors or channels, at any change in direction of channels, in anchorages, and adjacent to a pier or wharf area. It is also desirable to measure coastal and offshore currents when they are of sufficient strength to affect shipping. (Editor's note: Current observations for a circulating survey by NOS are made under more rigid and exacting specifications).

B. Specific Standards

1. Horizontal control

a. Primary shore stations

The location of primary shore control stations and electronic positioning stations shall be within the limits of accuracy for third-order control when the geodetic survey extends no more than 50 km (31 mi) from the point of origin or from stations of a geodetic net of higher order used as the origin. When the extent of the geodetic survey is in excess of 50 km the use of second-order control methods is desirable, and if the stations of an electronic positioning system are separated by distances in excess of 200 km (124 mi) ties shall be made to basic first-order control whenever possible.

b. Hydrographic signals

The error in location of hydrographic signals used for visual fixing, with relation to the primary shore control should not exceed 1 mm (0.04 in) at the scale of the survey.

c. Position fixes and floating aids

(1) The indicated repeatability of a fix (accuracy of location referred to shore control) in the operating area, whether observed by visual or electronic methods, combined with the plotting error, shall seldom exceed 1.5 mm (0.06 in) at the scale of the survey.

(2) Ocean surveys for nautical charts (shoal searches, investigation of doubtful soundings, etc.): acceptable error when fixing a reference beacon by astronomic or electronic means: 1 km (0.6 mi).

d. Aids to navigation

(1) Fixed aids to navigation shall be located within the same limits of accuracy as primary shore stations stated in paragraph 1.

(2) Floating aids to navigation shall be located within the same limits of accuracy as position fixes stated in paragraph 3.

e. Offshore installations dangerous to navigation. Location of offshore installations, dangerous to navigation should, when feasible, meet the requirements for third-order control.

2. Vertical control

a. Measurements of depth

Allowable errors:

(1) 0-20 m (0-11 fm): 0.3 m (1.0 ft)

(2) 20-100 m (11-55 fm): 1.0 m (0.5 fm)

(3) Deeper than 100 m (55 fm): 1 percent of depth

Normally, a disagreement of cross-check lines with principal sounding lines of three times or more the allowable error stated above indicates error in either position, depth, or both, and should be further investigated.

b. Sweeping over wrecks, obstructions, and shoals

The same accuracy as that specified for the measurement of depths (art. B.2.a.) to a depth of 30 m (16 fm). In depths greater than 30 m (16 fm) the same accuracies as for measurement of depth (art. B.2.a.) where the depth and equipment available permit these accuraries.

c. Reference of sounding to vertical datum

Location and duration of tidal observations to be such that each sounding can be referred to the sounding datum with an error no greater than one-half that specified in art. B.2.a., above. Tidal reductions are not usually applied to oceanic soundings over 200 m (109 fm).

3. Current measurements

The velocity of the current at each station should be determined to the nearest 0.1 kn and the direction of the current to the nearest 10°.

APPENDIX B

During this same period, DAVIDSON will also conduct a carefully-controlled experiment to characterize the accuracy of each of the 21 sonar beams. Highly accurate data are expected from the vertical and near-vertical beams; however, as the beams progress farther away from the vertical, the accuracy of the data becomes more and more sensitive to pulse stretching, as well as small error in the measurement of vessel roll. The LAIDLY sea trails have shown that all outer beam data are useful for the qualitative real-time contour graphics. However, the accuracy of some of these outer beam data may not meet NOS accuracy standards for use in NOS chart compilation. (See Appendix).

CONCLUSION

The development of the Bathymetric Swath Survey System by the National Ocean Survey is intended to move bathymetric and hydrographic surveying firmly into the realm of science.

The very latest state-of-the-art instrumentation and analytic techniques have been brought together in this effort. Tests to date indicate significant improvements in the accuracy of the data obtained and the cost of completion for surveys within the depth ranges for which the system was designed (10-300 fathoms). New survey and processing techniques developed during the trial period on the DAVIDSON are expected to result in significant advances in capability for NOS to carry out its hydrographic survey mission.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the contributions of Donald J. White, Harold Farr, and William J. Capell of Harris A.S.W., General Instrument Corporation; Richard S. Stone and Donald L. Sullivan of Arthur D. Little; and Louis C. Adamo, Louis C. Adamo Corporation, representative of Datawell Corporation, the Netherlands.

APPENDIX

The following standards of precision have been proposed for depths and geographic positioning of area measuring devices and methods, such as the BS^3. These standards meet or exceed the International Hydrographic Bureau Accuracy standards recommended for hydrographic surveys [1] and National Standards of Map Accuracy [2].

Vertical Accuracy Goal. (1σ) d = depth

Error Source	Feet	Meters
Depth Measurement (timed)	±(.30 + .003 d)	±(.10 + .003 d)
Heave Error	± .30	± .12
Pointing Error (roll and pitch)	± .003 d	± .003 d
Tidal Zone (variation)	±(.12 + .003 d)	±(.06 + .003 d)
(rounding)	± .06	± .06
Velocity Measurement	± .002 d	± .002 d
Zone Variation	± .002 d	± .002 d
Rounding	± .06	± .06
Draft Measurement	± .12	± .06
Time Variation	± .30	± .12
Settlement and Squat Measurement	± .12	± .06
Variation	± .30	± .12
TRA Rounding	± .06	± .06
Tidal Datum	± .18	± .06

With the assumption that all the above errors are independent, the law of propagation of variance yields:

	Feet	Meters
Standard Deviation of a Single Depth Measurement	±(.67 + .006 d)	±(.28 + .006 d)

Horizonal Accuracy Goal (1σ)

Typical Operating Range	0-50 KM	50-300 KM	300-500 KM
Typical Survey Scales	1:5K 1:10K 1:20K	1:20K 1:40K 1:80K	1:40K 1:80K
Position Accuracy Goal (1σ)	5 m @ 50 km	20 m @ 300 km	40 m @ 500 km

The ability to meet a required accuracy shall be assumed to be a function of two independent terms, repeatability and predictability; based on the above analysis of error sources for an automated system, the following accuracy standards are proposed as a function of bottom relief.

1. In areas of flat bottom or top-of-shoal features, 90 percent of the differences in depth, which result from a comparison of crosslines with principal sounding lines, shall not exceed:

   ±(1.5 + .014 d) feet or ±(.7 + .014 d) meters

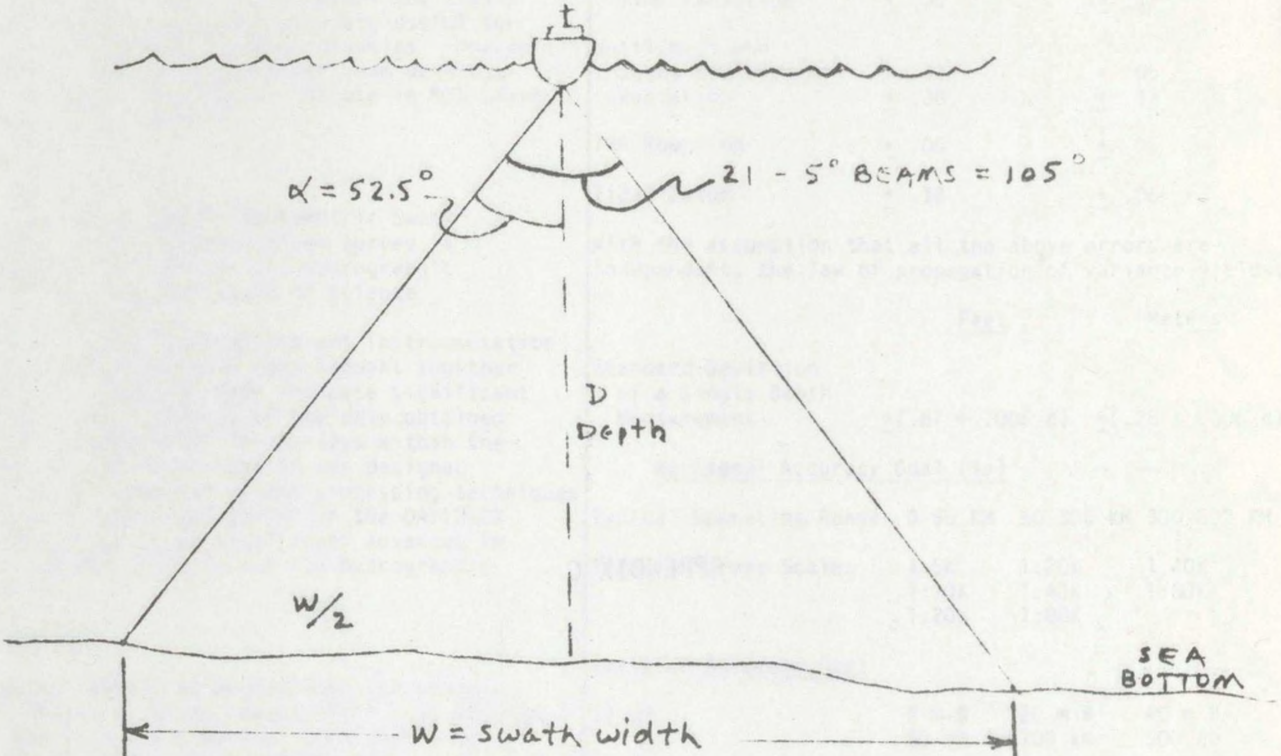
   This is based on the previous analysis of error sources and the propagated error of the difference between two independent determinations of the same quantity. Any single error greater than twice those listed should be investigated for blunder; in areas of flat bottom, this error is presumably due to measurement of depths.

2. In areas of sloping bottom independent checks of depth expressed as equal elevation (contour lines) should not differ by more than one half of the contour interval 10 percent of the time. Horizontal error in the plotted position of the contour will be accounted for when making this comparison.

APPENDIX C

BS^3 SWATH WIDTH

21 BEAMS



$$\tan \alpha = \frac{W/2}{D}$$

$$1.303\ D = W/2$$

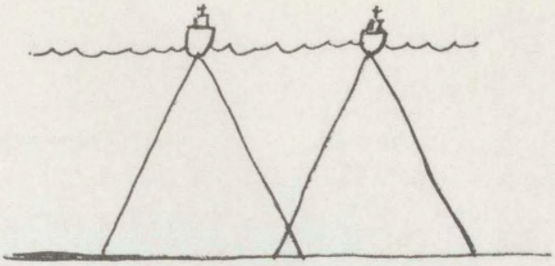
$$W = 2.606\ D$$

For ease of calculation and to allow a small safety factor, assume:

Swath width = 2.5 x Depth

For 21 Beams

C-2



FLAT BOTTOM
Assume swath width =

2.5 x Depth
21 Beams

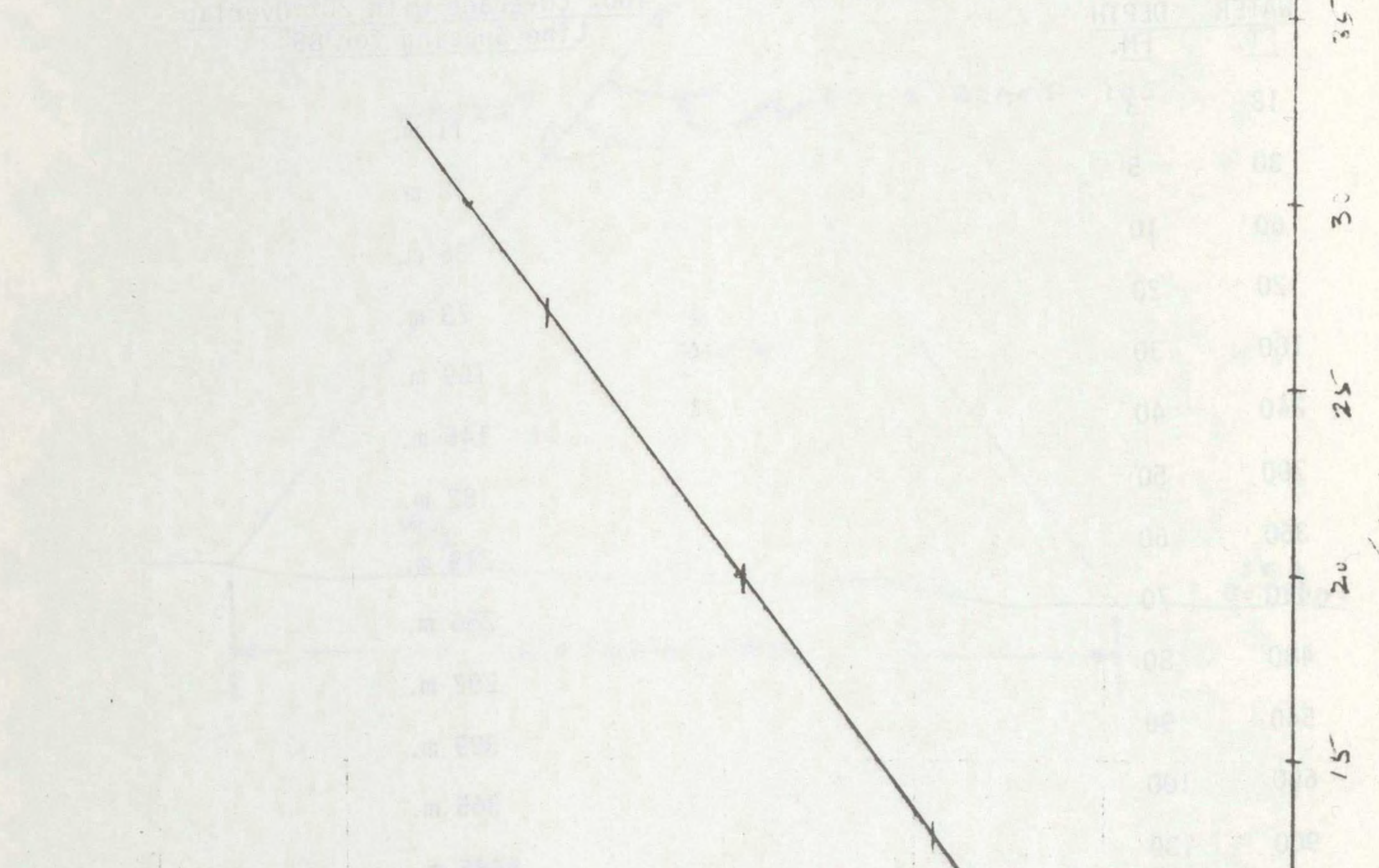
WATER DEPTH FT.	WATER DEPTH FM.	100% Coverage with 20% Overlap Line Spacing for BS^3
18	3	11 m.
30	5	18 m.
60	10	36 m.
120	20	73 m.
180	30	109 m.
240	40	146 m.
300	50	182 m.
360	60	219 m.
420	70	256 m.
480	80	292 m.
540	90	329 m.
600	100	365 m.
900	130	475 m.

FORMULA

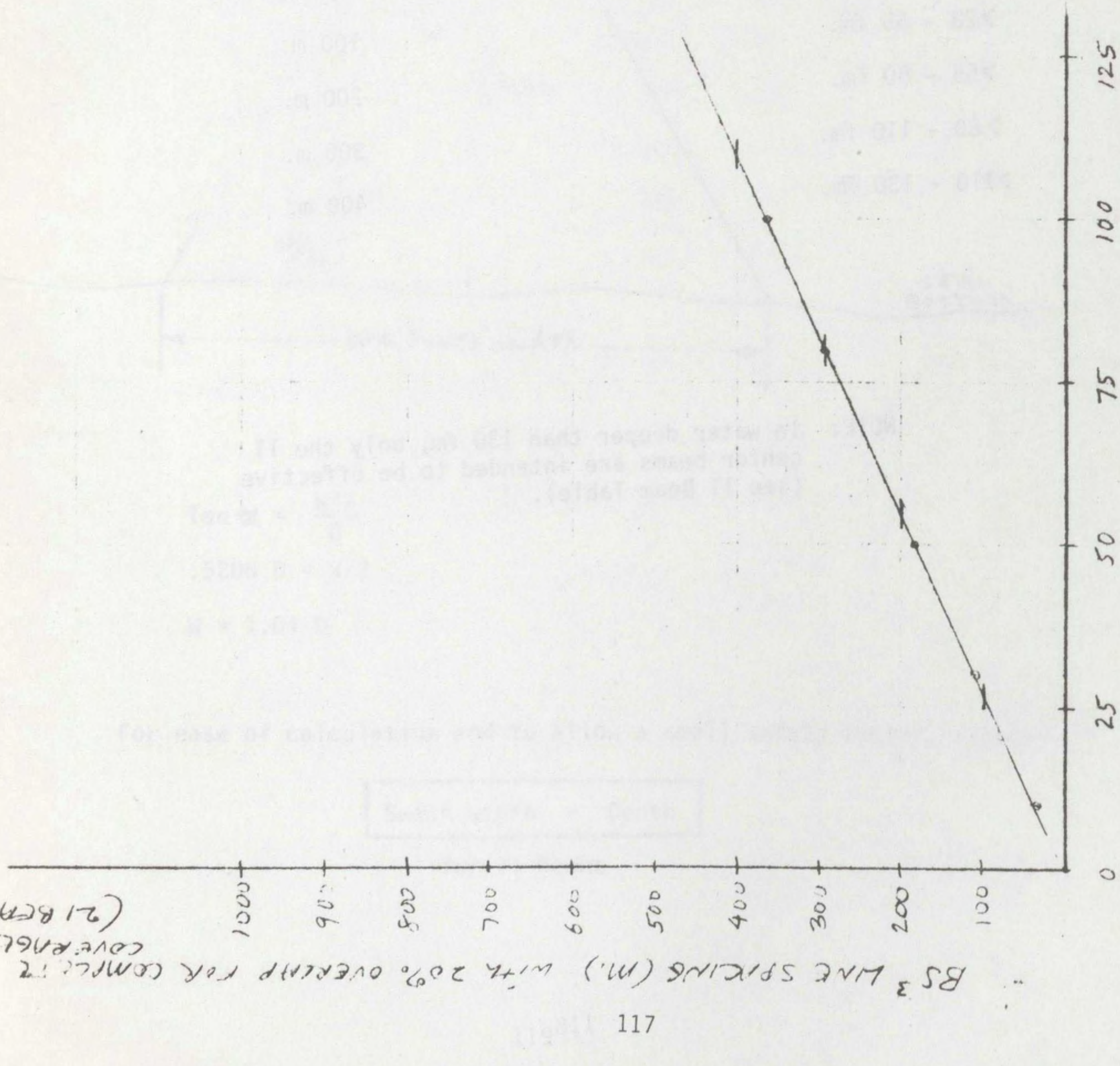
Spacing (m.) = Depth in fm. x 2.5 x 1.8288 x .8

↑ 1.8288: fathoms to meters

↑ .8: 20% overlap



Depth (fm)
0
5
10
15
20
25
30
35
25
50
75
100
125
BS3 LINE SPACING (m) WITH 20% OVERLAP FOR COMPLETE COVERAGE (21 Beams)



Depth (fm.)
0
25
50
75
100
125
100
200
300
400
500
600
700
800
900
1000
BS 3 LINE SPACING (M.) WITH 20% OVERLAP FOR COMPLETE COVERAGE (21 BEAMS)

FLAT BOTTOM

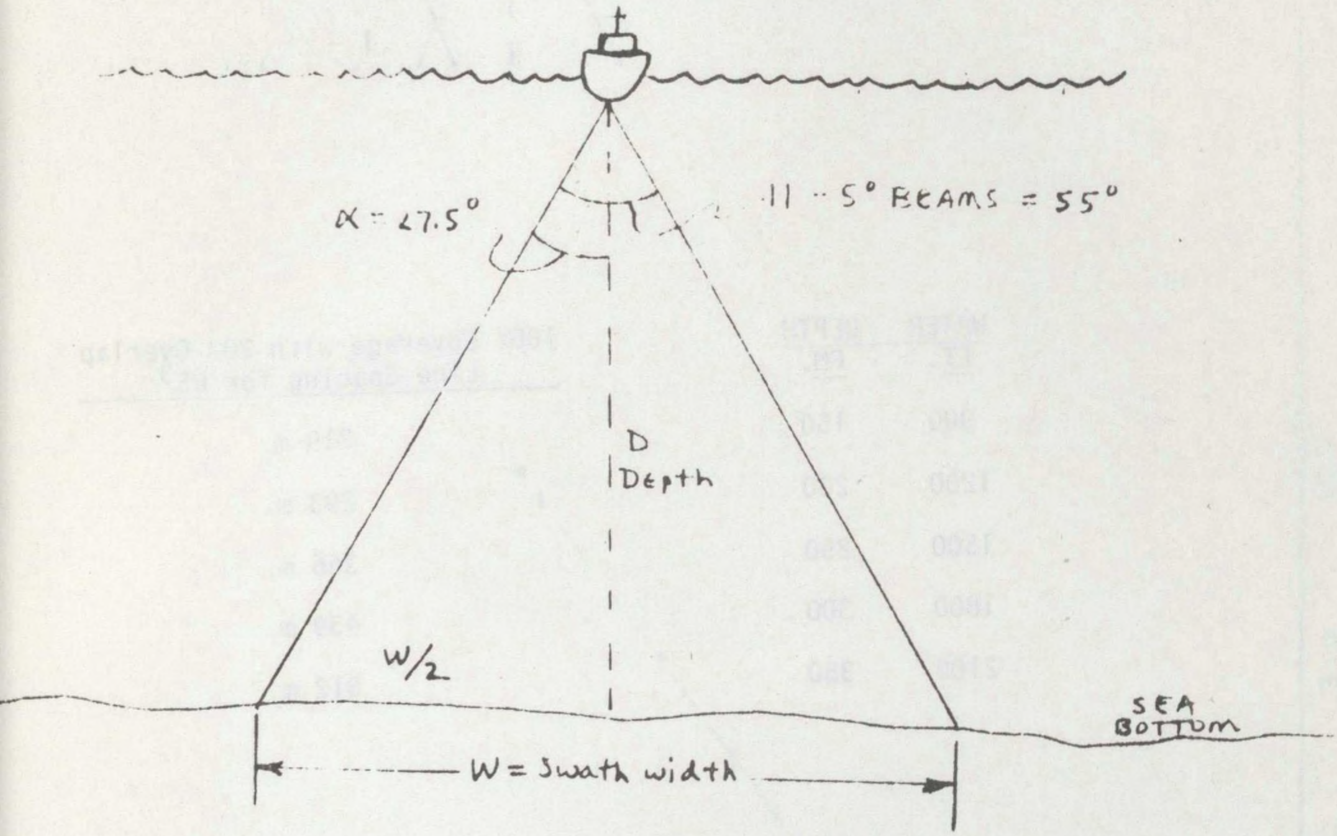
Rule of Thumb for BS^3 Line Spacing vs. Depth For Complete Coverage with at Least 20% Overlap - 21 Beams

Least Depth Expected on Swaths	BS^3 Line Spacing
7 - 14 fm.	25 m.
>14 - 21 fm.	50 m.
>21 - 28 fm.	75 m.
>28 - 55 fm.	100 m.
>55 - 80 fm.	200 m.
>80 - 110 fm.	300 m.
>110 - 130 fm.	400 m.

NOTE: In water deeper than 130 fm, only the 11 center beams are intended to be effective (see 11 Beam Table).

BS[3] SWATH WIDTH

11 BEAMS



$$\tan \alpha = \frac{W/2}{D}$$

$$.5206\ D = W/2$$

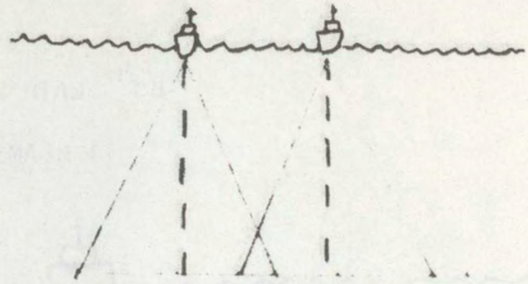
$$W = 1.04\ D$$

For ease of calculation and to allow a small safety factor, assume:

Swath width = Depth

for 11 Beams

FLAT BOTTOM
Assume Swath Width = Depth
11 Beams

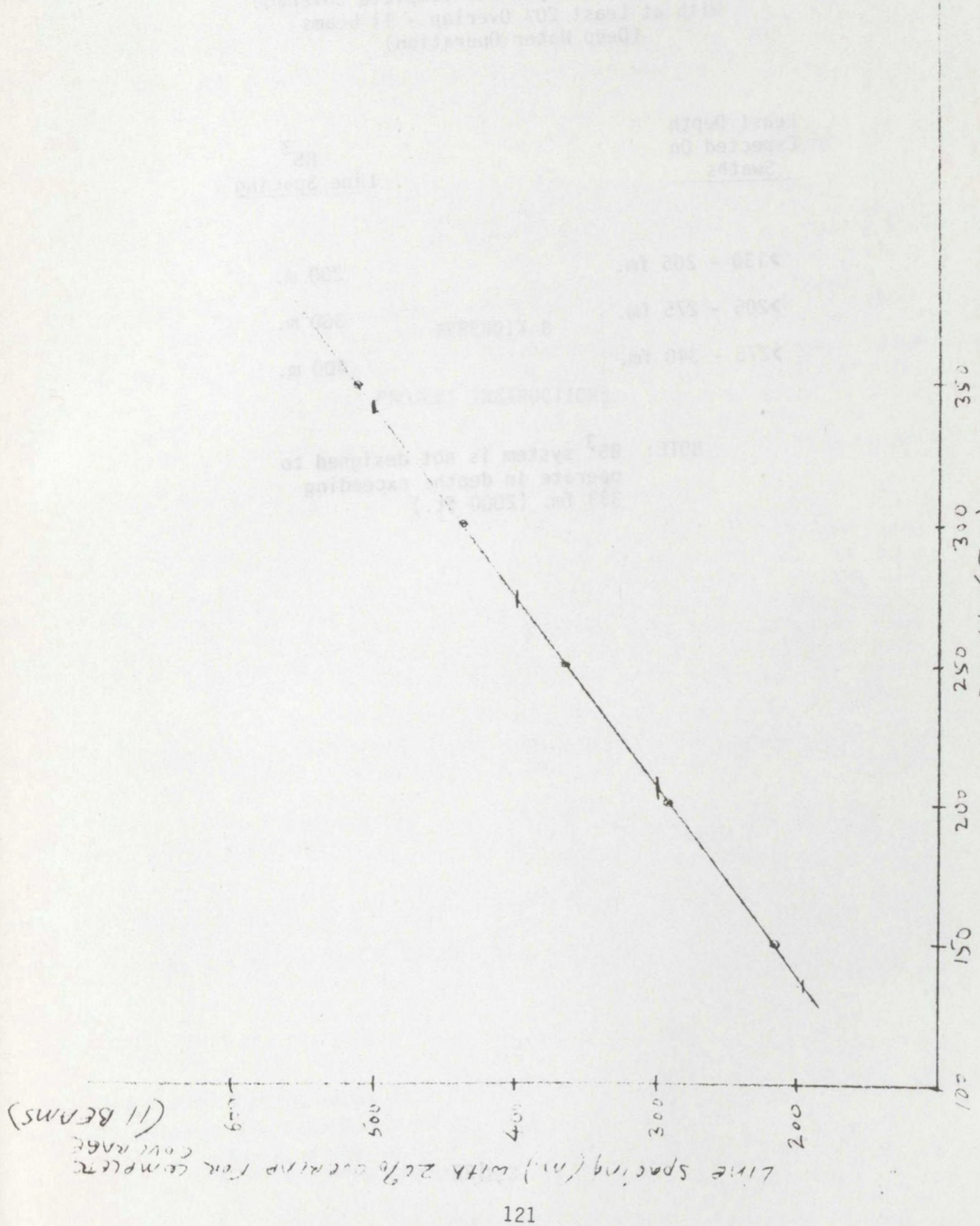


WATER FT.	DEPTH FM.	100% Coverage with 20% Overlap Line Spacing for BS^3
900	150	219 m.
1200	200	293 m.
1500	250	366 m.
1800	300	439 m.
2100	350	512 m.

FORMULA

Spacing (m.) = Depth in fm. x 1.8288 x .8

(1.8288: Fathoms to meters; .8: 20% overlap)


Depth (Fm.)
100
150
200
250
300
350
200
300
400
500
600
Line Spacing (m.) with 20% overlap for complete coverage (11 BEAMS)

FLAT BOTTOM

Rule of Thumb for BS^3
Line Spacing vs. Depth For Complete Coverage
With at Least 20% Overlap - 11 Beams
(Deep Water Operation)

Least Depth Expected On Swaths	BS^3 Line Spacing
>130 - 205 fm.	200 m.
>205 - 275 fm.	300 m.
>275 - 340 fm.	400 m.

NOTE: BS^3 system is not designed to operate in depths exceeding 333 fm. (2000 ft.)

APPENDIX B

PROJECT INSTRUCTIONS

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL OCEAN SURVEY
Rockville, Md. 20852

MAR 20 1981

OA/C351:CBE

Received EDO
3/23/81

Project Instructions

Commanding Officer
NOAA Ship DAVIDSON

S-N905-DA-81, BS3 Characterization Tests, Puget Sound Area and Washington Coast

1.0. GENERAL

1.1. Introduction: During 1980, several major problems in the Bathymetric Swath Survey System (BS3) were addressed and rectified in order to conduct a definitive set of underway tests. This project is designed to characterize the present capabilities of the BS3 under various field operating conditions. Information will also be obtained concerning the reliability of the system. The format for standard project instructions has been modified for this project. The specialized nature of these tests and the time limit imposed on the project have necessitated that portions of the work will be in variance with requirements set forth in the Hydrographic Manual. It is the responsibility of the Chief of Party to ensure that methods are used which provide data consistency such that adequate comparisons may be made between BS3 and HYDROPLOT data within the areas where the acquisition of data using both systems is specified.

1.2. Location: There are five different general areas in which primary tests will be conducted. These areas are designated "A," "B," "C," "D," and "E." Areas "A," "B," and "C" are located in the northern portion of Puget Sound, and areas "D" and "E" are in the Pacific Ocean near the entrance to the Strait of Juan de Fuca. Alternative areas "F" and "G" are located near the Columbia River entrance and may be selected in place of areas "D" and "E" if logistics so dictate. Three optional test areas "H," "I," and "J" have been selected in the vicinity of Seattle, Washington. These tests should only be conducted if time allows. All lettered areas and their requiredorientations are shown on attached chartlets.

1.3. Time Frame: This project will be conducted from late March to late April 1981.

1.4. Priority: It is the intent of these instructions that all tests "A" through "E" will be conducted during the time frame allotted. The alphabetic order assigned defines the priority.

1.5. Security Classification: National security is not involved in this project.

1.6. Previous Instructions: These instructions supersede all previous project instructions for BS3.

1.7. Charts Affected: No data gathered during these tests are intended for use in nautical charting.

1.8. Scope: It is emphasized that the primary purpose of these tests is to characterize the operation of the BS^3 system. A basic hydrographic survey will not be produced during this project. However, certain portions of the tests will require HYDROPLOT survey data to be acquired and processed.

1.9. Quality: The accuracy standards described in the Hydrographic Manual shall govern, to the extent possible, all hydrographic operations.

2.0. PARTICIPATION

The Ship DAVIDSON will be the only survey unit assigned to this project. The Engineering Development Office (OA/TE2) will provide the Field Test Manager who will be responsible for the conduct of the tests.

Test details furnished by the Field Test Manager shall be considered a part of these instructions. Modifications shall be made by mutual agreement between the Commanding Officer and the Field Test Manager. OA/C351 shall be notified of any substantial changes in the test plans.

3.0. GEODESY

3.1. Site Selection: The vessel and PMC will coordinate selection of the required control stations following the guidance of section 4.4.3.4 of the Hydrographic Manual.

3.2. and 3.3. Not applicable.

4.0. TOPOGRAPHY: Shoreline manuscripts are not required for this project and none will be furnished.

5.0. TIDES

5.1. Purpose: All tide requirements in these instructions are in direct support of the specialized BS^3 tests and HYDROPLOT comparison data. The Tide Measurement Subsystem (TMS) and bubbler gages will be operated in support of this project.

Because the desired result is to ensure data which are internally consistent within each test, and because the TMS requires line-of-sight transmission distances, gages will be installed where convenient near each test area for the purposes of this project. The operation of bubbler tide gages shall be in accordance with precautionary measures described in section 5.4.2 of Hydrographic Survey Guideline No. 9. Hourly heights from the bubbler gages are required for times of hydrography.

5.2. through 5.6. Not applicable.

5.7. Datum: The vertical datum for all tide corrections to BS^3 and HYDROPLOT data shall be established as "staff zero" in each test area. Although true depths on chart datum will not be a result, using a "staff zero" datum will provide internal consistency of tide correctors and will expedite data analysis.

Although the usual requirements for establishing tide gages are waived for this project, appropriate measures shall be taken to ensure that the gages are functioning properly for the period of each test, and that the "staff zero" datum does not change during the period each gage is in operation.

5.8. Not applicable.

5.9. Predicted Tides and Zoning: Predicted tides may be used for preliminary field plotting of HYDROPLOT data. Time and height ratios to be applied to the predicted tide at the appropriate reference stations are listed below:

Survey Area	Zoning	Reference Station
Offshore, west of Cape Flattery	No Corrections Necessary	-
Inshore, South of Cape Flattery	- 46 Minutes High Water - 45 Minutes Low Water x 0.84 Height Ratio	Aberdeen
West of Blake Island	+ 01 Minute High Water + 07 Minutes Low Water x 1.03 Height Ratio	Seattle
Rosario Strait	+ 16 Minutes High Water + 28 Minutes Low Water x 0.89 Height Ratio	Pt. Townsend
Bellingham Bay	+ 50 Minutes High Water + 1 Hour 06 Minutes Low Water x 1.00 Height Ratio	Pt. Townsend
Presidents Channel	+ 41 Minutes High Water + 53 Minutes Low Water x 0.98 Height Ratio	Pt. Townsend
Lake Union	Not Applicable No Tidal Influence	Lake level gage at Chittenden Locks
Cape Disappointment	- 1 Hour 08 Minutes High Water - 1 Hour 16 Minutes Low Water x 0.94 Height Ratio	Astoria

6.0. HYDROGRAPHY

6.1. Introduction:

Several HYDROPLOT surveys are required in specific areas covered by the tests described below. Data for these "designated" surveys shall be smooth plotted and verified. (See section 6.13 of these instructions.) Although the survey data are to be plotted at 1:5,000 scale, the standard positional accuracy requirements for surveys at that scale are waived.

Where the HYDROPLOT system is run concurrently with the BS^3, and is collecting "nondesignated" survey data, it must be run on a not-to-interfere basis. However, these data shall be considered a part of the BS^3 records and shall be retained but not smooth plotted.

6.2. Primary Characterization Tests

6.2.1. Test Area "A"--Flat Area Test (Smooth Water)

The purpose of this test is to evaluate the accuracy and repeatability of the BS^3 vertical and side beams under carefully controlled conditions.

This test shall be undertaken in an area 1-nautical mile square centered in latitude 48°41.93'N, longitude 122°34.57'W in Bellingham Bay, Washington. General depths are 15 fathoms ± 1 fathom over the entire area.

An aluminum triplane target and a pressure sensor shall be planted by the ship in the test area.

Basic ground truth over the test area shall be established by running a 1:5,000-scale HYDROPLOT survey at 50-meter line spacing, with at least two crosslines.

BS^3 swaths shall be run in a figure "8" pattern centered over the test area. The number and location of the swaths and the locations of the planted devices will be prescribed by the Field Test Manager. The figure "8" BS^3 swaths will permit determination of the bias and variance of the BS^3 data. Runs will also be conducted over the triplane to determine the response to a target of small extent.

6.2.2. Test Area "B"--Slope Test, Pinnacle Test, and Shoal Indication Test

6.2.2.1. Slope Test (Area B1)

The purpose of the slope test is to evaluate the best direction in which to run BS^3 swaths on relatively steep slopes and to determine if the programed "gating" of the beams react satisfactorily in all directions. Also, to determine whether the "gating" is a determining factor on optimum swath direction.

This test shall be undertaken in the San Juan Islands, Washington, south of Patos Island in a rectangular area (0.25 by 0.5 nautical mile) centered in latitude 48°46.04'N, longitude 122°57.43'W. The bottom in this area rises abruptly from about 70 fathoms to 13 fathoms.

A 1:5,000-scale HYDROPLOT survey shall be run over the test area with 50-meter line spacing oriented about 45° to the slope. The BS^3 system will be operated simultaneously. Two sets of additional BS^3 swaths will be run at 90° to the slope and parallel to the slope. Overlapping coverage is required for swaths parallel to the slope. Swaths spaced 100 meters apart are adequate for swaths run at an angle to the slope.

6.2.2.2. <u>Pinnacle Test (Area B_2)</u>

The purpose of this test is to evaluate the capability of the BS^3 to indicate to the hydrographer the existence of pinnacles, and the relative ease with which the hydrographer can locate and determine the least depths on such pinnacles. (NOTE: A conscious use of prior survey or charted data should <u>not</u> be made during this test to determine, in advance, where sounding lines or swaths should be run. In this way, biasing the results will be avoided.) This test shall be undertaken in the San Juan Islands, Washington, south of Patos Island in a rectangular area (0.5 nautical mile by 1 nautical mile) centered in latitude 48°44.25'N, longitude 122°57.75'W. This area contains two major features projecting about 30 fathoms above general depths of 60 fathoms.

A 1:5,000-scale HYDROPLOT survey shall be run over the test area with 100-meter line spacing in an east-west direction, with additional lines run to adequately develop the features, and to determine their least depths. Since 60 fathoms might be the least depth expected in this area (assuming that the pinnacles are unknown), BS^3 line spacing shall be run at 200 meters (providing complete bottom coverage in 55- to 80-fathom depths). The hydrographer shall note whether indications of the pinnacles are observed, on any swath, of sufficient magnitude to prompt further investigation. If so, the minimum number of subsequent swaths shall be run in each case to sufficiently delineate the features, with one swath running over the approximate peak of each feature. The hydrographer shall compare the effectiveness of both methods (HYDROPLOT vs. BS^3) in detecting pinnacles, delineating the extent of the features, and locating and determining their least depths.

Another pinnacle (Area B_3) on which this test can be repeated, but only if time permits, falls to the southward, west of Point Doughty, Orcas Island. The feature rises to 23 fathoms from about 60-fathom depths. The recommended survey area is a rectangle (0.25 nautical mile by 0.5 nautical mile) centered in latitude 48°42.60'N, longitude 122°57.60'W.

6.2.2.3. <u>Shoal Indication Test (Area B_2)</u>

The purpose of this test is to evaluate the capability of the BS^3 to alert the hydrographer to the existence of a shoal indication, and its capability to subsequently verify or disprove the critical nature of such a shoal indication in comparison with the usual system of split lines normally required to answer this question with the HYDROPLOT system. The HYDROPLOT survey required under paragraph 6.2.2.2 shall suffice for this test. Within the area of the Pinnacle Test (section 6.2.2.2 of these instructions) the hydrographer shall identify two shoals which protrude at least 10 percent above the surrounding depths (Hydrographic Manual, section 1.4.3). One shoal will not protrude much more than 10 percent of the general depths off the bottom, indicating that any subsequent investigation would be unproductive. The other shoal will have a least depth substantially above the surrounding depths, therefore justifying a subsequent investigation. One BS^3 swath shall be run over each shoal, positioned such that the vertical beam strikes a portion of the shoal which is 10 percent above the general bottom. While running these swaths, the hydrographer shall note the results on the on-line BS^3 plot in an attempt to determine, from that information alone, which shoal indication should be investigated further.

6.2.3. Test Area "C"--Wreck Location Test

The purpose of this test is to evaluate the capability of the BS^3 to detect the existence of submerged features of relatively small extent (such as wrecks), and its capability to determine a least depth over such features. This test shall be undertaken in Rosario Strait where two portions of the tanker BUNKER HILL are charted in latitude 48°25.67'N, longitude 122°44.59'W and latitude 48°25.05'N, longitude 122°44.48'W. The tanker exploded, broke in two, and sank in flames in March 1964. The least depth over each wreck was reported to be about 28 fathoms. Both sections were wire dragged and cleared to 74 feet at MLLW. Copies of the background information concerning BUNKER HILL will be furnished. BS^3 swaths shall be run with 20 percent overlapping coverage in the area of the charted wreck symbols. Once the wrecks are located, subsequent test runs should be made to characterize the detection capabilities of the outer beams. At least one BS^3 swath, with vessel track directly over each of the wrecks, should be run for least depth determination.

Two additional wrecks for possible investigation are described in Optional Test Areas "H" and "I."

6.2.4. Test Area "D"--Flat Area Test (Rough Water)

The purpose of this test is to evaluate the accuracy and repeatability of the BS^3 vertical and side beams under dynamic conditions. The rough waters likely to be encountered in this area will provide a good test of the operation of the HIPPY heave, roll, pitch sensor and the corrections applied therefrom. This test shall be undertaken in an area 1 nautical mile square centered in latitude 48°15.06'N, longitude 124°45.25'W approximately 8 nautical miles south of Cape Flattery, Washington.

Basic ground truth over the test area shall be established by running a 1:5,000-scale HYDROPLOT survey at 100-meter line spacing, with at least two crosslines. The effects of heave shall be carefully scanned from the graphic depth records, and all soundings appropriately corrected. BS^3 swaths shall be run in a figure "8" pattern centered over the test area. The number and location of the swaths will be prescribed by the Field Test Manager.

NOTE: Test Area "F" may be used as an alternative in the event that an area near the Columbia River entrance is preferred for logistic reasons.

6.2.5. Test Area "E"--Deepwater Test and Canyon Transit

6.2.5.1. Deepwater Test (Area E_1)

The purpose of this test is to characterize the operation of the BS^3 near its deepest limit of capability.

This test shall be undertaken in an area 1 nautical mile square centered in latitude 47°56.0'N, longitude 125°42.3'W about 48 nautical miles west-southwest of Cape Flattery, Washington. The number and location of BS^3 swaths in this area will be prescribed by the Field Test Manager. A deepwater depth recorder shall be operated concurrently with the BS^3 swaths. If the deepwater depth recorder can provide digital depths to the HYDROPLOT system, basic ground truth over the test area shall be established by running a 1:5,000-scale HYDROPLOT survey at 200-meter line spacing, with at least two crosslines. All soundings should be appropriately corrected.

NOTE: Test Area "G_1" may be used as an alternative site in the event that an area near the Columbia River entrance is preferred for logistic reasons.

6.2.5.2. Canyon Transit (Area E_2)

The purpose of this test is to obtain BS^3 data in a steep-sided canyon to characterize its operation under those conditions.

This test shall be undertaken in a rectangular area 5 nautical miles by 3 nautical miles centered in latitude 47°59.6'N, longitude 125°21.7'W over Juan de Fuca Canyon, about 34 nautical miles southwest of Cape Flattery, Washington. The number and location of BS^3 swaths in this area will be prescribed by the Field Test Manager. A deepwater depth recorder shall be operated concurrently with the BS^3 swaths.

NOTE: Test Area "G_2" may be used as an alternative site in the event that an area near the Columbia River entrance is preferred for logistic reasons.

6.2.6. Test Area "F"--Alternate Flat Area Test (Rough Water)

This area is a 1-nautical mile square centered in latitude 46°23.40'N, longitude 124°09.70'W about 7.5 nautical miles north-northwest of Cape Disappointment, Washington, near the Columbia River entrance. General depths in this area range from 84 to 100 feet. The survey requirements for this area are identical to those set forth in 6.2.4.

6.2.7. Test Area "G"--Alternate Deepwater Test and Canyon Transit

6.2.7.1. Alternate Deepwater Test (Area G_1)

This area is a 1-nautical mile square centered in latitude 45°56.0'N, longitude 124°49.5'W, about 36 nautical miles west-southwest of the Columbia River entrance. The survey requirements for this area are identical to those set forth in 6.2.5.1.

6.2.7.2. Alternate Canyon Transit (Area G_2)

This area is a rectangle 5 nautical miles by 3 nautical miles centered in latitude 46°14.5'N, longitude 124°30.2'W, over Astoria Canyon about 18 nautical miles west of the Columbia River entrance. The survey requirements for this area are identical to those set forth in 6.2.5.2.

6.3. Optional Test Areas

6.3.1. Test Area "H"--Wreck Location Test

This feature is located in the south end of Lake Union, Seattle, Washington, and is an obstruction cleared by 20 feet charted in latitude 47°38.92'N, longitude 122°20.04'W. Survey requirements are similar to those for 6.2.3.

6.3.2. Test Area "I"--Wreck Location Test

This feature is located in Elliott Bay, Seattle, Washington, near Magnolia Bluff, and is a submerged wreck PA charted in latitude 47°38.2'N, longitude 122°25.5'W. Two barges were reported sunk in 100 feet of water. Surveys requirements are similar to those for 6.2.3.

6.3.3. Test Area "J"--Sonar Test Range

The purpose of this test is to characterize the capability of the BS^3 to detect objects as small as 2 feet by 3 feet in depths of 100 to 300 feet. The test area is the Sonar Target Area charted in Puget Sound west of Blake Island in latitude 47°33.0'N, longitude 122°31.5'W. Eight targets are purported to be anchored 3 feet off the bottom in this area. A copy of Chart Letter 1312 (1975) will be furnished in which the locations of the targets are described. Survey requirements are similar to those for 6.2.3.

NOTE: This test has been designated optional because there is no assurance that these objects were actually planted at the positions reported nor is it known whether the targets are still in existence as specified.

6.4. through 6.6. Not applicable.

6.7. Sounding Unit: Soundings for all HYDROPLOT and BS^3 data shall be recorded in feet. To the extent possible, HYDROPLOT soundings shall be corrected as required by section 4.9 of the Hydrographic Manual. BS^3 data shall be corrected in accordance with procedures defined by OA/TE2.

6.8. Plotting: Not applicable.

6.9. Junctions: Not applicable

6.10. Prior Surveys:

6.10.1. The following prior surveys shall be used for general guidance during the course of the survey:

Registry Number	Scale	Year Surveyed
H-4633	1:120,000	1926
H-4639	1:120,000	1926
H-5111	1: 40,000	1930
H-5711	1: 10,000	1934-35
H-5724 & Ad Wk	1: 10,000	1934-36
H-6607	1: 10,000	1939-40
H-8320	1: 10,000	1956
H-8400	1: 10,000	1957
H-8416	1: 20,000	1958
H-8520	1: 10,000	1960
H-9413	1: 80,000	1974
H-9418	1: 80,000	1974
H-9747	1: 5,000	1978

6.11. Presurvey Review: Not applicable.

6.12. Dangers to Navigation: All uncharted shoals, rocks, wrecks, and other dangers to navigation discovered during the course of the survey shall be reported to the U.S. Coast Guard (USCG) in accordance with section 1.6.4. and 5.9 of the Hydrographic Manual. A copy of reports or a negative report shall be included in the Special Project Report.

6.13. Data Reduction: HYDROPLOT data acquired in conjunction with the designated surveys required in accordance with sections 6.2 through 6.2.6 of these instructions shall be processed and forwarded to OA/CPM3 not later than June 15, 1981. Hourly heights for times of hydrography from gages established in each of these designated survey areas shall also be forwarded to OA/CPM3. These hourly heights shall be appropriately referenced to the area for which they are applicable. The sounding datum shall be "staff zero" for both BS^3 and HYDROPLOT data. No processing of tide data by OA/C2 will be required.

All BS^3 data, and HYDROPLOT data acquired in conjunction with the tests but not pertaining to the designated surveys, shall be turned over to the Field Test Manager upon completion of the tests. The BS^3 data will be analyzed using computer techniques.

HYDROPLOT data for designated surveys shall be smooth plotted and verified by the Marine Center on a priority basis. HYDROPLOT records and verified smooth plots shall be forwarded to OA/C35 no later than August 28, 1981. No formal Verifier's Report is required. No registry numbers shall be assigned. Plotting of BS^3 data by the Marine Center may be required later this year, but only after OA/TE2 has completed its analysis. This requirement will be coordinated between OA/CPM3, OA/C35, and OA/TE2.

7.0. BOTTOM INVESTIGATIONS

7.1. through 7.11. Not applicable.

7.12. Side Scan Sonar: Should a side scan sonar unit become available to the vessel, it shall be operated in accordance with the manufacturer's recommendations to locate submerged obstructions; however, a side scan sonar survey is not considered to be adequate to disprove the existence of an obstruction.

8.0. ANCILLARY TASKS

8.1. through 8.2. Not applicable.

8.3. Velocity Corrections: A special effort shall be made to obtain definitive velocity of sound observations at each test site since the accuracy of BS^3 data relies heavily on this factor.

8.4. through 8.6. Not applicable.

9.0. REPORTS

9.1. A report detailing the analysis of the BS^3 data will be written by OA/TE2 by September 30, 1981. In addition, a Special Project Report shall be submitted through OA/CPM1 to OA/C35 by the Commanding Officer, describing the tests and the apparent results obtained. The operation of the BS^3 should be evaluated with special emphasis on its capabilities as a reconnaissance tool. The report should be submitted as soon as shipboard data processing/analysis have been completed. Other reports shall be submitted as appropriate in accordance with chapter 5 of the Hydrographic Manual.

9.2. Accomplishments shall be reported on NOAA form 12-8b (rev. 12-76) with the guidance of the "Instructions for Completing Monthly Ship Accomplishment Report, " NOAA Form 12-12 (1-77).

10.0. MISCELLANEOUS

10.1. Timely notification of planned hydrographic survey operations shall be made to the USCG for inclusion in the Local Notice to Mariners. Contact shall be made with the U.S. Navy concerning ship operations within any charted restricted areas.

10.2. Support Data: The following survey support data have been transmitted to OA/CPM3:

Data Type	Project Instruction Reference	Source	Copies	Users	Trans-mittal Date
Prior Surveys	6.10.1	OA/C353	1	DAVIDSON	March 3, 1981

10.3. Weather Observations: Sea state observations are required once each hour during these tests. The direction of the seas are from (0°-360°) and the heights of the average seas in feet from peak to trough shall be visually estimated, recorded, and forwarded with the test records.

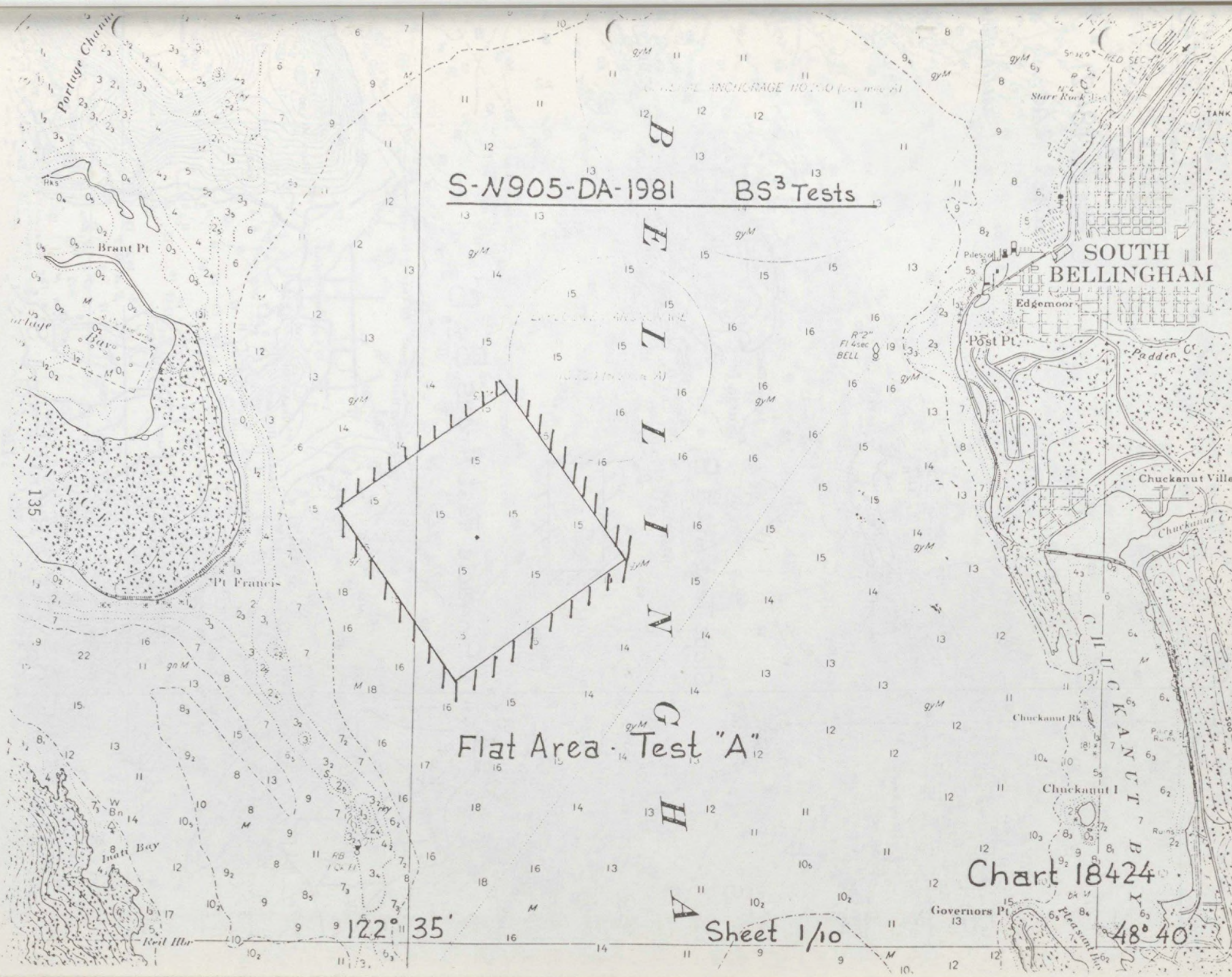
10.4. Vessel Speed: Standard speed shall be used whenever possible for these tests. When searching for features of small extent and the features are not detected at standard speed, the speed should be reduced for further search.

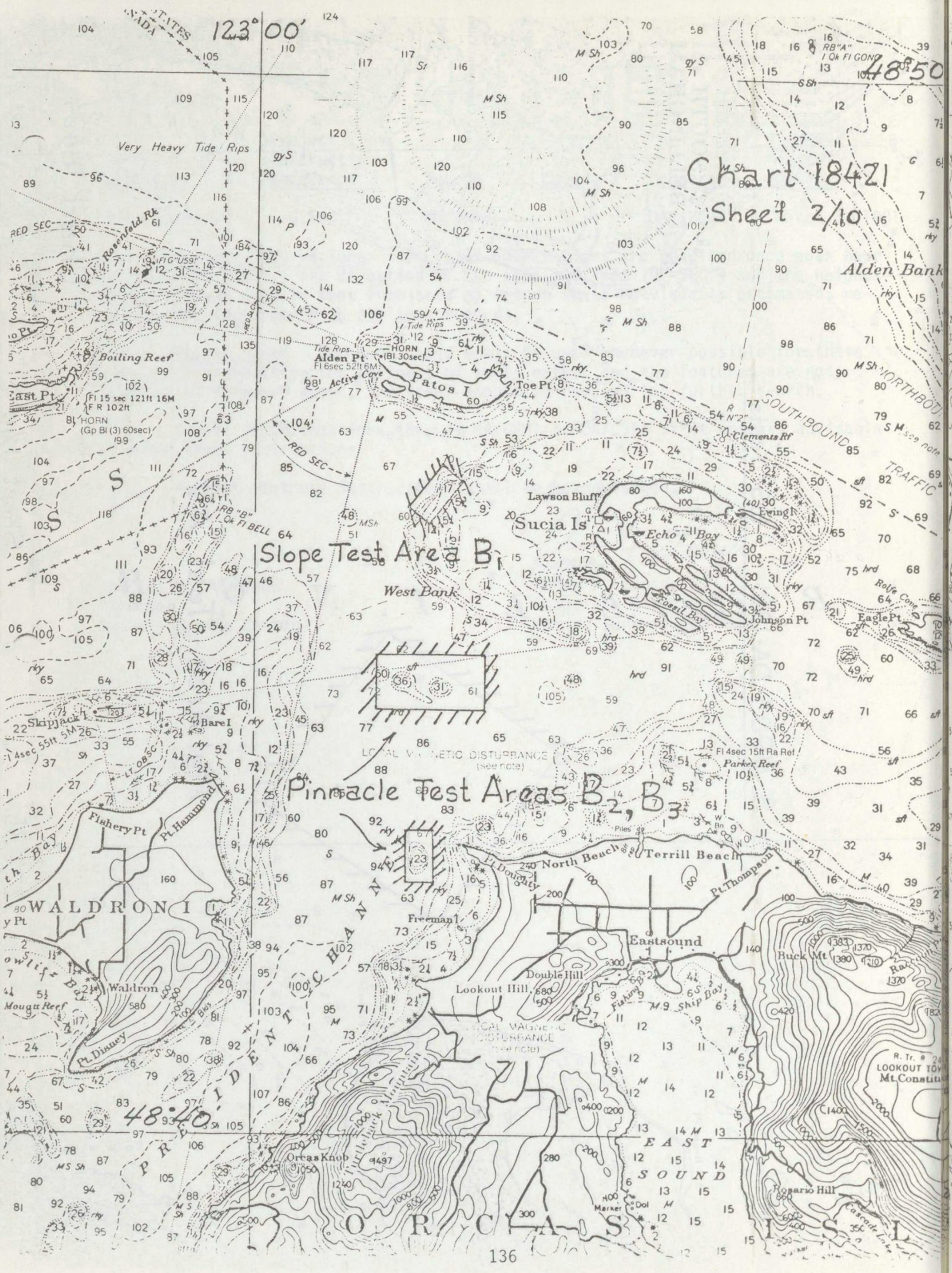
10.5. Submit recommendations through OA/CPM1 to OA/C351 if it appears advisable to amend these instructions.

10.6. Receipt of these instructions shall be acknowledged.

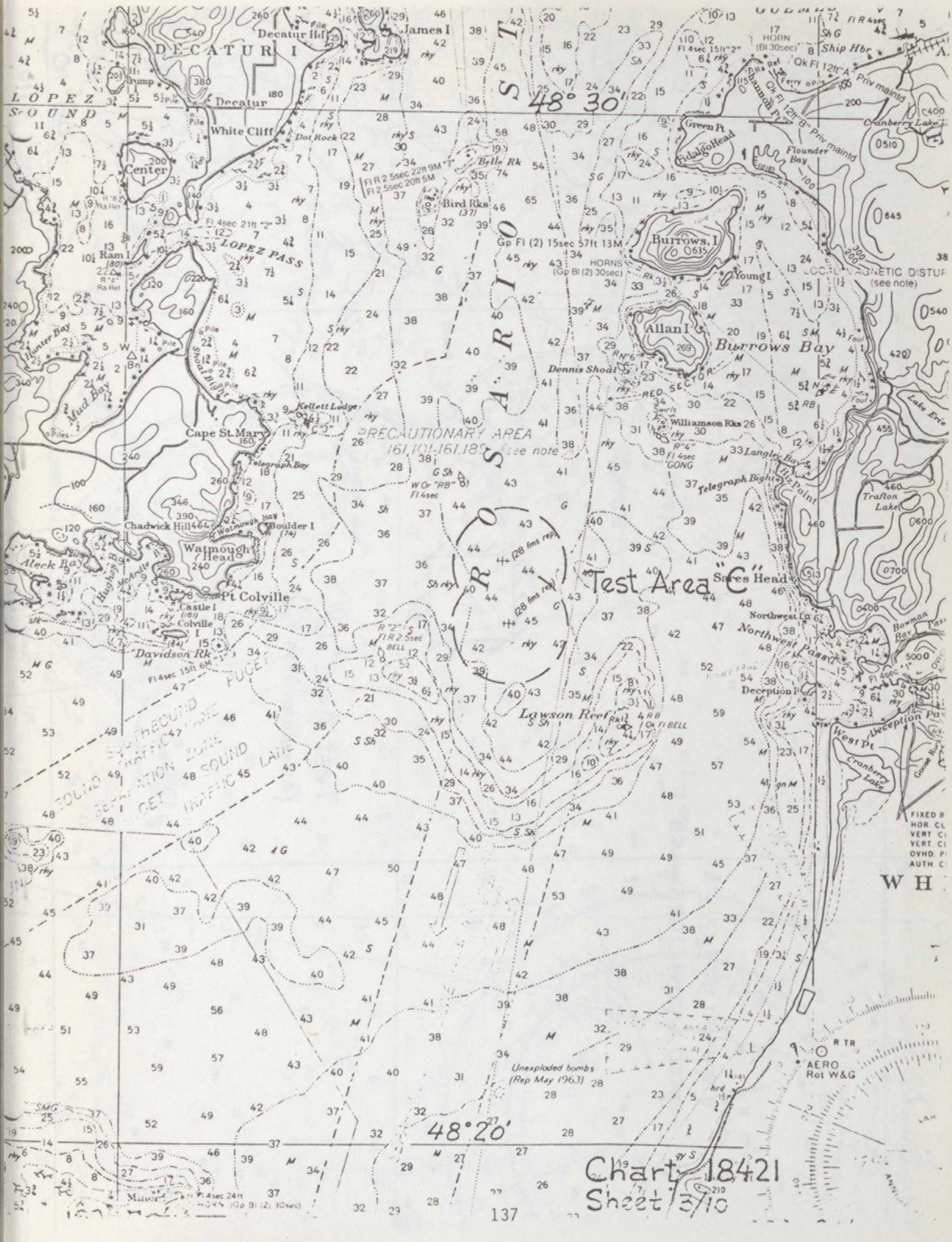
Roger F. Lanier

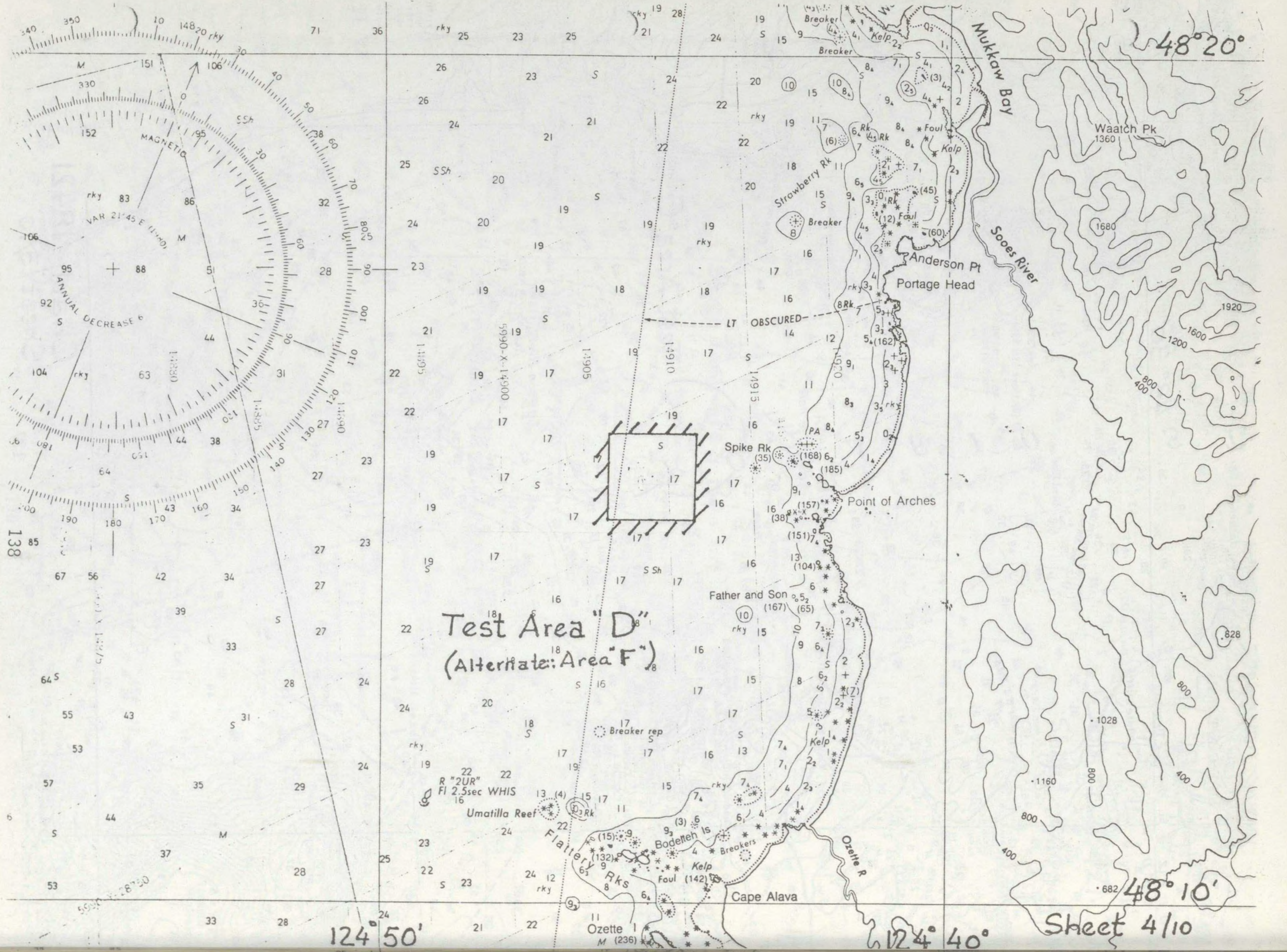
Charles K. Townsend	Roger F. Lanier
Director	Associate Director
Pacific Marine Center	Marine Surveys and Maps


S-N905-DA-1981 BS3 Tests
Flat Area · Test "A"
Chart 18424
Sheet 1/10
122° 35'
48° 40'
BELLINGHAM
CHUCKANUT BAY
SOUTH BELLINGHAM
Edgemoor
Post Pt
Padden Cr
Chuckanut Villa
Chuckanut Cr
Chuckanut Rk
Chuckanut I
Governors Pt
Pleasant Bay
Starr Rock
TANK
Brant Pt
Pt Francis
Portage Chann
Inati Bay
Reil Hbr
R "2" Fl 4sec BELL

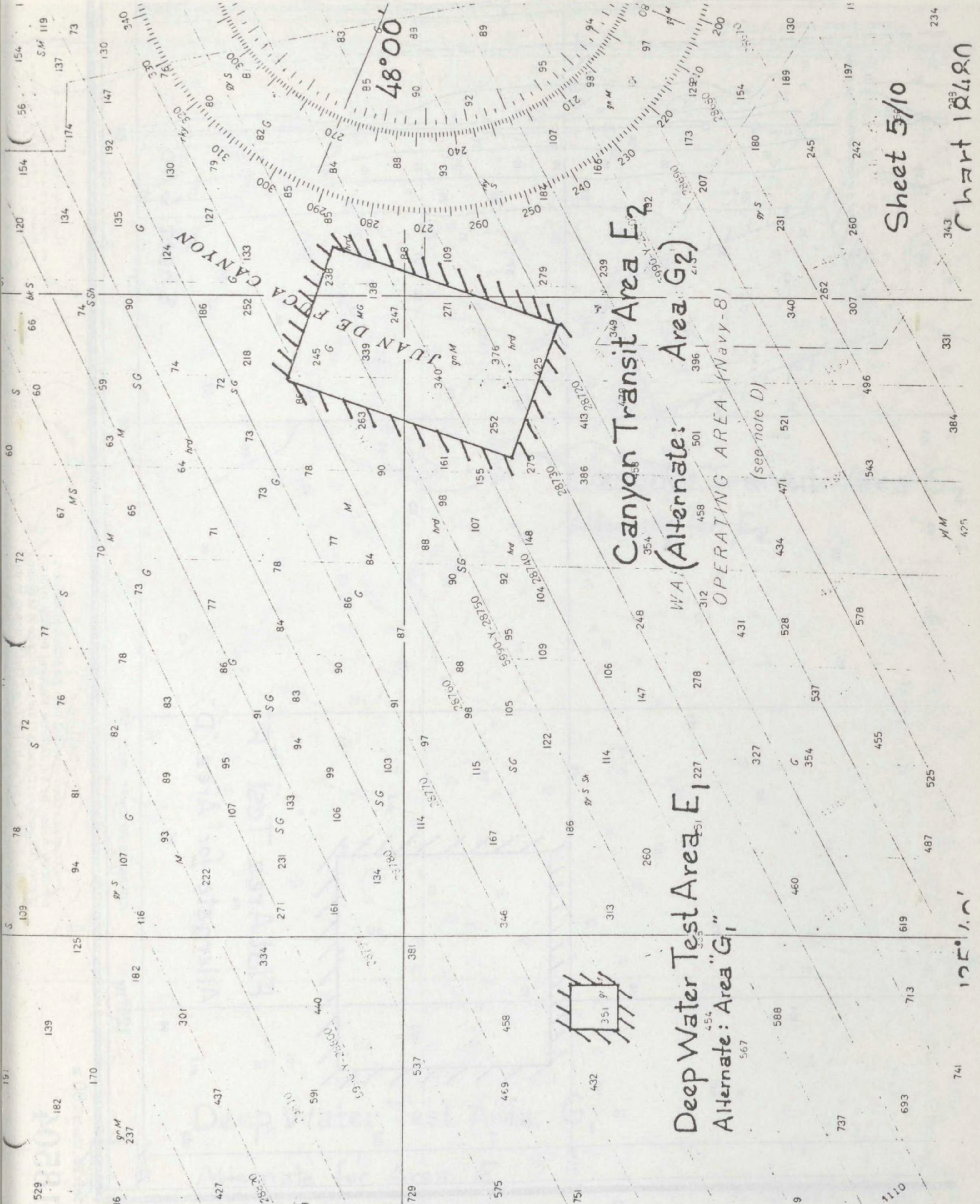


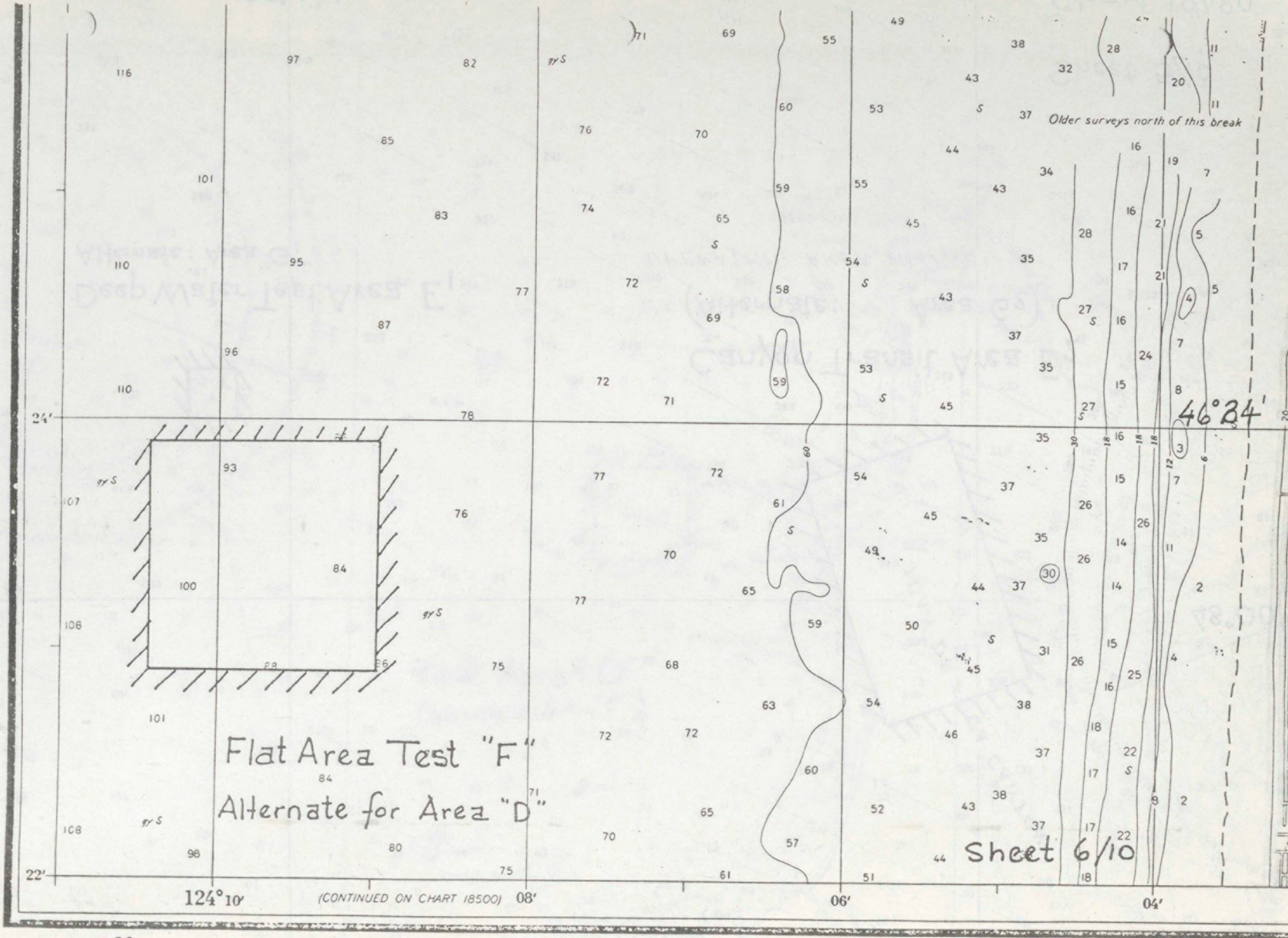
123° 00′
48°50′
48°40′
Chart 18421
Sheet 2/10
Slope Test Area B1
Pinnacle Test Areas B2, B3
Very Heavy Tide Rips
Rosenfeld Rk
Boiling Reef
East Pt
Alden Bank
Alden Pt
Patos I
Active Cove
Toe Pt
Clements Rf
SOUTHBOUND
NORTHBOUND
TRAFFIC
Lawson Bluff
Sucia Is
Echo Bay
Fossil Bay
Ewing I
Johnson Pt
West Bank
Eagle Pt
Rolfe Cove
LOCAL MAGNETIC DISTURBANCE
(see note)
Parker Reef
Skipjack I
Bare I
Fishery Pt
Pt Hammond
WALDRON I
Waldron
Mouatt Reef
Pt Disney
Cowlitz Bay
North Beach
Terrill Beach
Pt Thompson
Pt Doughty
Freeman I
Eastsound
Double Hill
Lookout Hill
Fishing Bay
Ship Bay
Buck Mt
LOOKOUT TOWER
Mt Constitution
PRESIDENT CHANNEL
EAST SOUND
Orcas Knob
Turtleback
Rosario Hill
Cascade Lake
ORCAS ISL


DECATUR I
Decatur Hd
James I
LOPEZ SOUND
Decatur
White Cliff
Dot Rock
Center I
Belle Rk
Bird Rks
LOPEZ PASS
Ram I
Hunter Bay
Mud Bay
Shoal Bight
Kellett Ledge
Cape St Mary
Telegraph Bay
PRECAUTIONARY AREA
Chadwick Hill
Watmough Bay
Boulder I
Watmough Head
Aleck Bay
Pt Colville
Castle I
Colville I
Davidson Rk
ROSARIO STRAIT
48° 30'
Green Pt
Fidalgo Head
Flounder Bay
Burrows I
Young I
Allan I
Burrows Bay
Dennis Shoal
Williamson Rks
Langley Bay
Telegraph Bight
Trafton Lake
Sares Head
Test Area "C"
Northwest Pass
Deception I
Deception Pass
West Pt
Cranberry Lake
Lawson Reef
Bowman Bay
Lake Erie
Ship Hbr
HORN
HORNS
SOUTHBOUND TRAFFIC LANE
SEPARATION ZONE
PUGET SOUND
Unexploded bombs (Rep May 1963)
AERO Rot W&G
48°20'
Minor I
Chart 18421
Sheet 3/10



48°20°
48°10'
124°50'
124°40°
Sheet 4/10
Test Area "D"
(Alternate: Area "F")
Mukkaw Bay
Waatch Pk
Sooes River
Anderson Pt
Portage Head
Strawberry Rk
LT OBSCURED
Spike Rk
Point of Arches
Father and Son
Umatilla Reef
R "2UR"
Fl 2.5sec WHIS
Breaker rep
Bodelteh Is
Flattery Rks
Cape Alava
Ozette R
Ozette
MAGNETIC
VAR 21°45'E
ANNUAL DECREASE
5990-X-14900


Canyon Transit Area E2
(Alternate: Area G2)
WA OPERATING AREA (Navy-8)
(see note D)
JUAN DE FUCA CANYON
48°00'
Deep Water Test Area E1
Alternate: Area "G1"
Sheet 5/10
Chart 18480



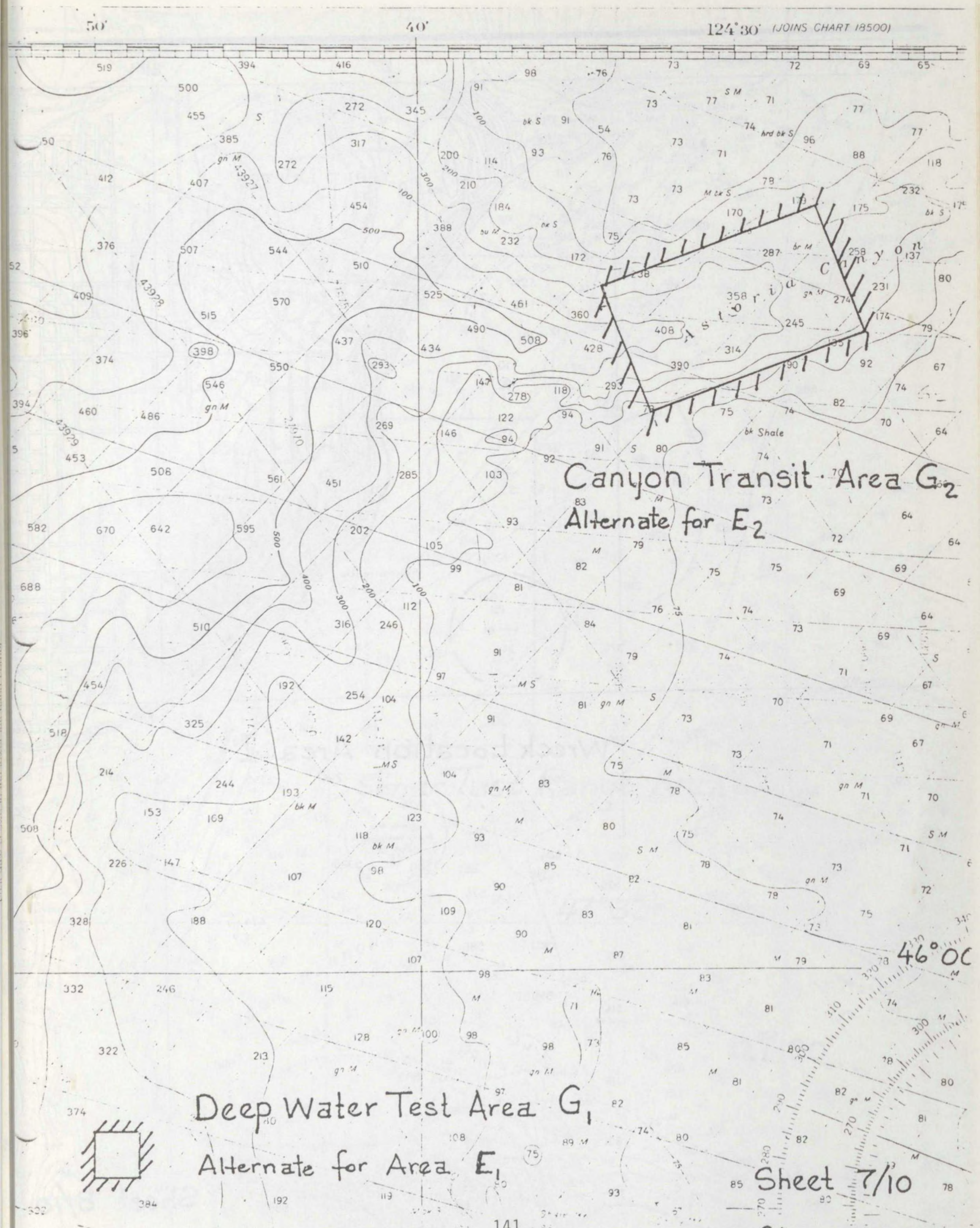
56th Ed., Mar. 15/80

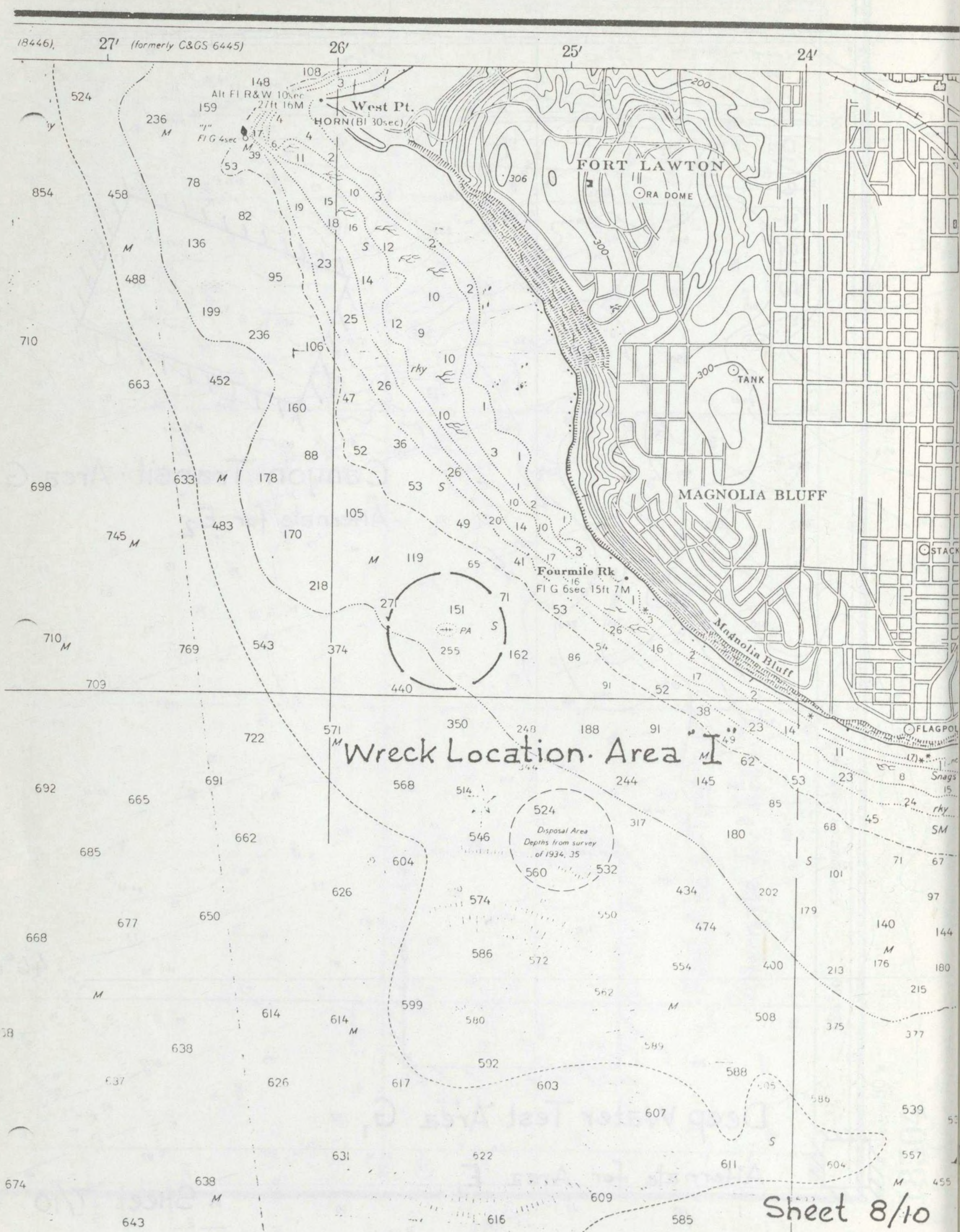
18504

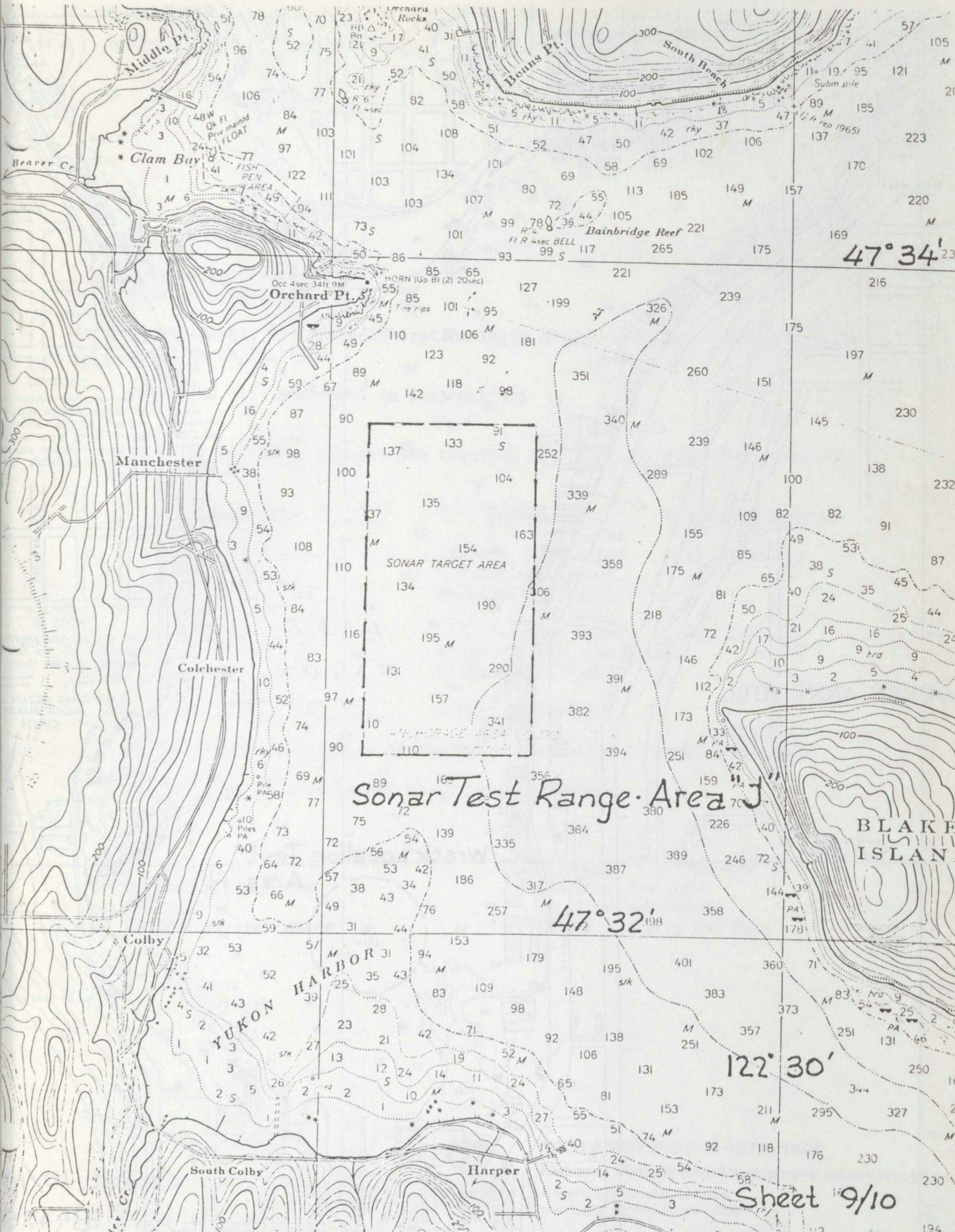
CAUTION

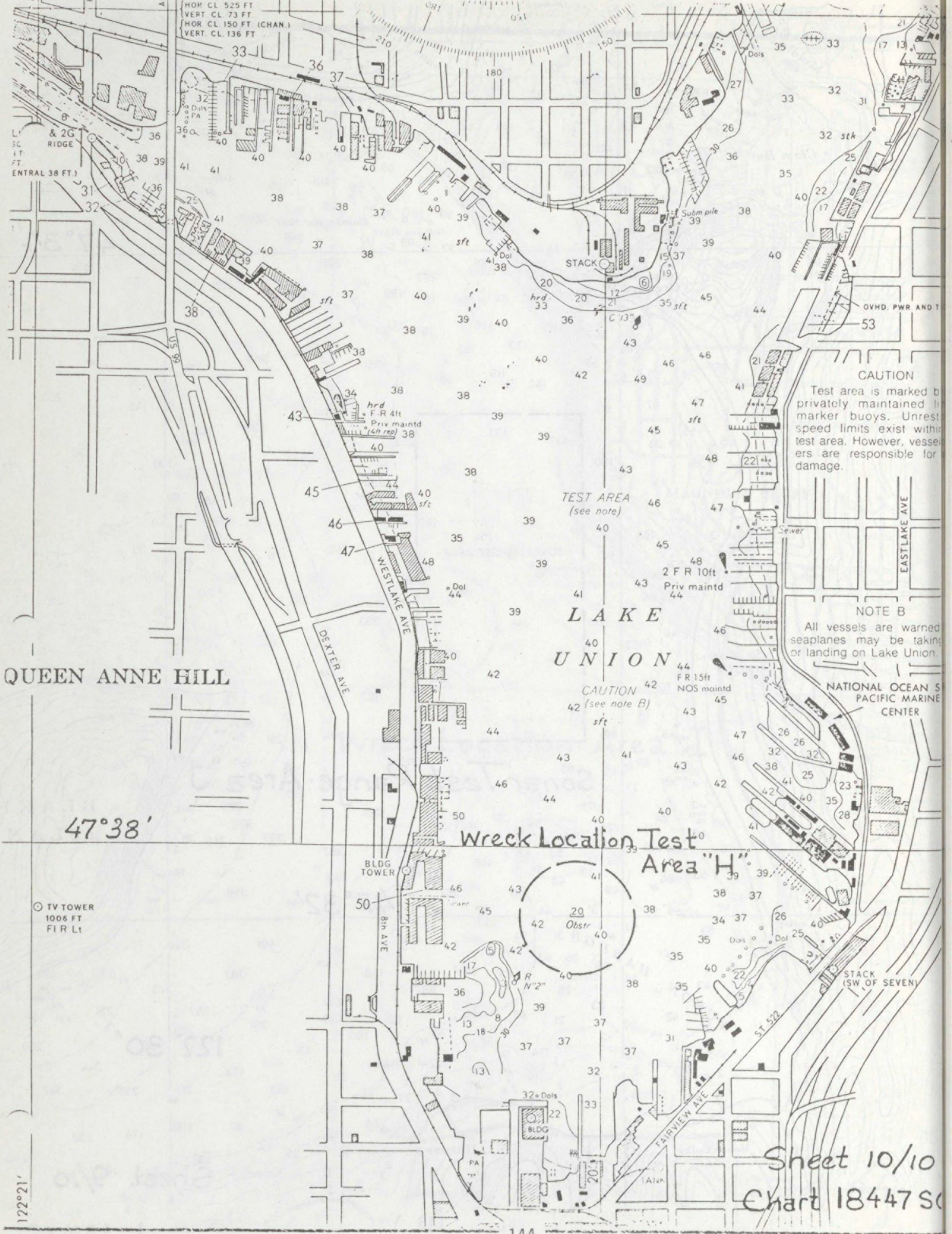
This chart has been corrected from the Notice to Mariners published weekly by the Defense Mapping Agency Hydrographic/Topographic Center and the Local Notice to Mariners issued periodically by each U.S. Coast Guard district to the print date shown in the lower left hand corner.

WARNING


50'
40'
124°30' (JOINS CHART 18500)
Astoria Canyon
Canyon Transit · Area G2
Alternate for E2
Deep Water Test Area G1
Alternate for Area E1
Sheet 7/10
46°00


(8446),
27′
(formerly C&GS 6445)
26′
25′
24′
West Pt.
Alt Fl R&W 10sec 27ft 16M
HORN(Bl 30sec)
"1" Fl G 4sec
FORT LAWTON
RA DOME
TANK
MAGNOLIA BLUFF
STACK
Fourmile Rk
Fl G 6sec 15ft 7M
Magnolia Bluff
FLAGPOL
PA
Disposal Area
Depths from survey of 1934, 35
Snags
rky
Wreck Location Area "I"
Sheet 8/10


Middle Pt.
Orchard Rocks
Bonus Pt.
South Beach
Subm pile
Clam Bay
Beaver Cr.
FISH PEN AREA
Bainbridge Reef
Fl R 4sec BELL
47° 34'
Orchard Pt.
Occ 4sec 34ft 9M
HORN (Gp Bl (2) 20sec)
Tide rips
Manchester
SONAR TARGET AREA
Colchester
Sonar Test Range · Area "J"
BLAKE ISLAN
47° 32'
Colby
YUKON HARBOR
122° 30'
South Colby
Harper
Sheet 9/10


HOR CL 525 FT
VERT CL 73 FT
HOR CL 150 FT (CHAN.)
VERT. CL. 136 FT
CENTRAL 38 FT.)
& 2G
RIDGE
US 99
QUEEN ANNE HILL
WESTLAKE AVE
DEXTER AVE
8th AVE
STACK
Subm pile
TEST AREA
(see note)
LAKE
UNION
CAUTION
(see note B)
F R 4ft
Priv maintd
2 F R 10ft
Priv maintd
F R 15ft
NOS maintd
OVHD. PWR AND T
CAUTION
Test area is marked b
privately maintained li
marker buoys. Unrest
speed limits exist withi
test area. However, vesse
ers are responsible for
damage.
EASTLAKE AVE
NOTE B
All vessels are warned
seaplanes may be taking
or landing on Lake Union.
NATIONAL OCEAN S
PACIFIC MARINE
CENTER
47°38′
Wreck Location Test
Area "H"
Obstr
BLDG
TOWER
TV TOWER
1006 FT
Fl R Lt
R
N"2"
STACK
(SW OF SEVEN)
ST 522
FAIRVIEW AVE
BLDG
TANK
Sheet 10/10
Chart 18447 Sc
122°21′

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL OCEAN SURVEY
Rockville, Md. 20852

OA/C351:CBE

MAR 3 1 1981

Project Instructions

Commanding Officer
NOAA Ship DAVIDSON

S-N905-DA-81, BS^3 Characterization Tests, Puget Sound Area and Washington Coast, dated March 20, 1981

CHANGE NO. 1: Amendment to Instructions

1. The following changes are required for the tidal zoning provided in section 5.9:

Survey Area	Zoning	Reference Station
Rosario Strait	-23 min. High Water - 7 min. Low Water x0.87 Height Ratio	Pt. Townsend
Presidents Channel	+52 min. High Water +1 hr. 08 min. Low Water x1.03 Height Ratio	Pt. Townsend
Elliot Bay	Direct on Seattle	

2. All other provisions of the basic instructions remain unchanged.

3. Receipt of this CHANGE shall be acknowledged.

Charles K. Townsend
Director
Pacific Marine Center

Roger F. Lanier
Roger F. Lanier
Associate Director
Marine Surveys and Maps

APPENDIX C

TEST PLAN

BS^3 CHARACTERIZATION TESTS

BELLINGHAM HARBOR

TEST AREA I

CHARTS: 18421, 18424
SURVEY: H8320 (1956)
1:10,000

DEPTH: 90 ft. MLLW
BOTTOM: flat, mud
SURFACE CONDITIONS: calm

OBJECTIVES: baseline accuracy tests
point target detectability

OPERATIONS:

1. Set-Up - positioning (2 MINIRANGER stations)
   tides (1 TMS)
   bottom samples (Shipek Sediment Sampler) (1 at origin)
   install target and ground truth instrument (deployment procedure attached)
   sound velocity profiles (XSTD, Martek, and XSV if available)
   prepare boat sheets and tables for SURVEY
   preliminary data set from 1 slow figure 8

2. HYDROPLOT Survey - 1:5000, 1 square mile,
   50 meter spacing with at least 2 cross lines
   42 linear miles
   normal HYDROPLOT operation, BS^3 operating simultaneously

3. Patch Test - Lead line checks at origin at beginning of test

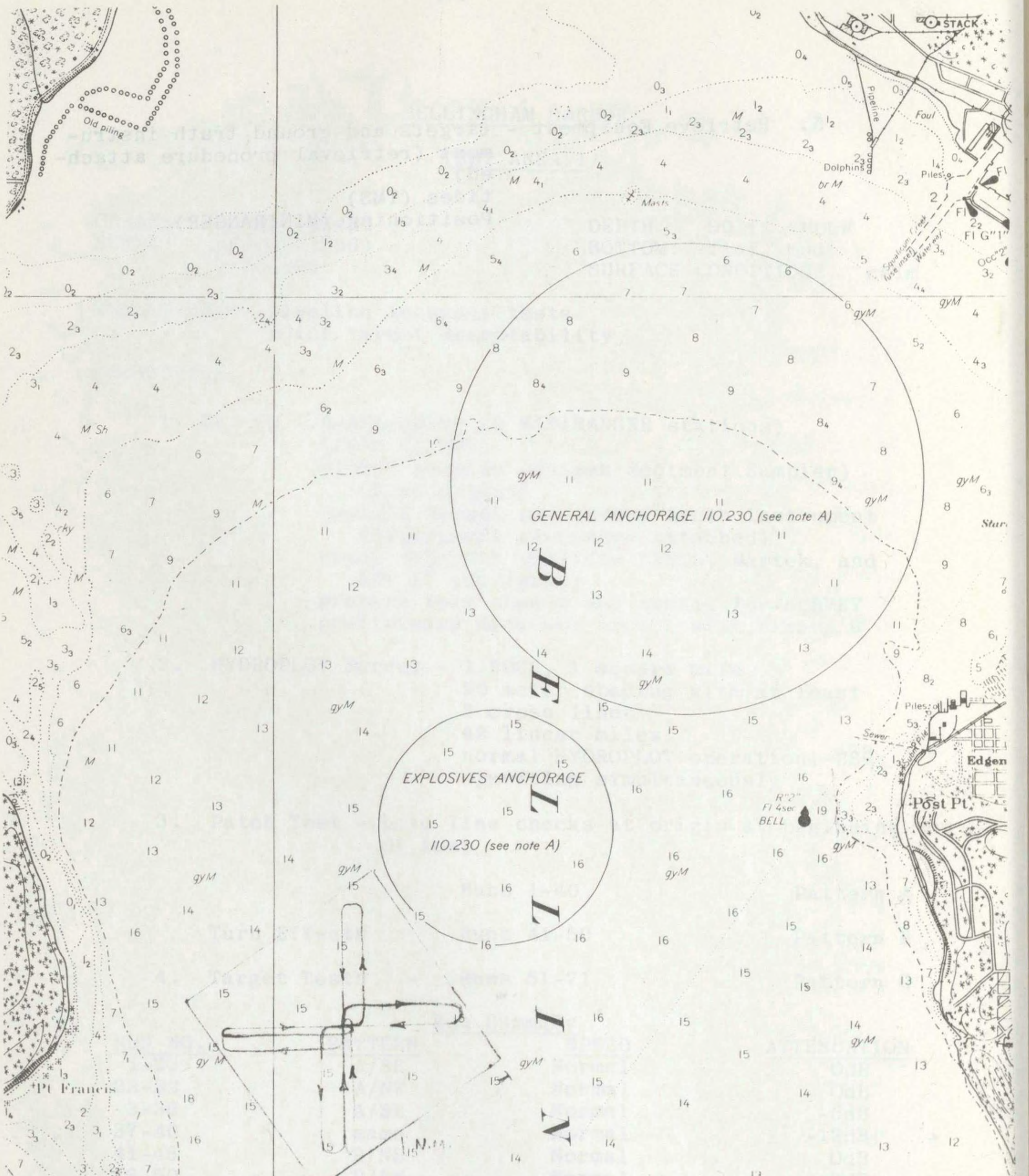
	Runs 1-40	Pattern A
Turn Effects	Runs 41-50	Pattern B

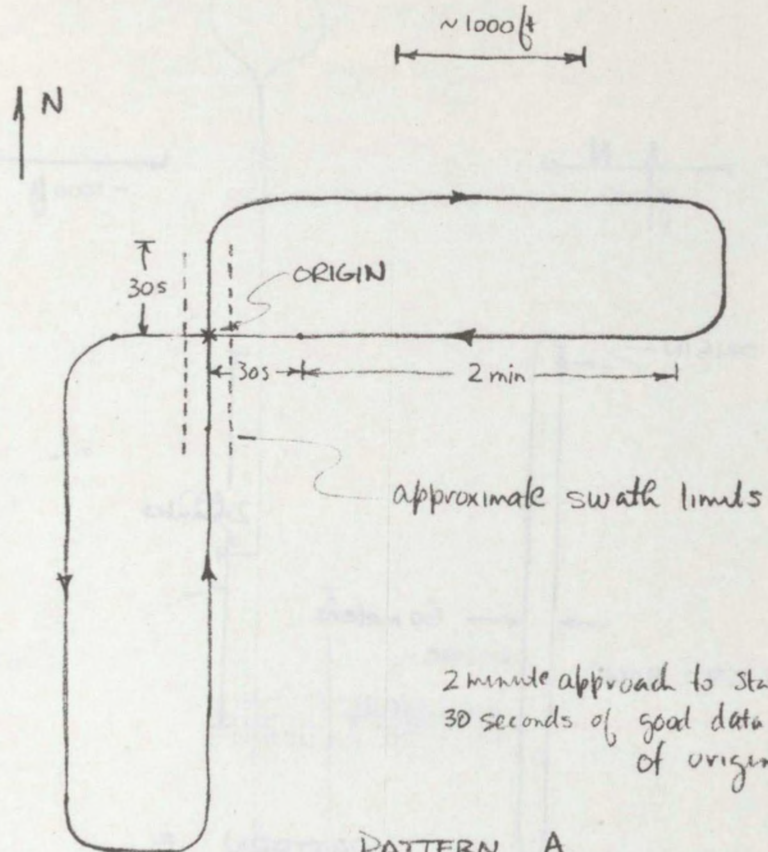
4. Target Tests - Runs 51-71 Pattern C

Run Summary

RUN NO.	PATTERN	SPEED	ATTENUATION
1-22	A/SE	Normal	OdB
23-32	A/NW	Normal	OdB
3-36	A/SE	Normal	-6dB
37-40	same	Normal	-12dB
41-45	B/NS	Normal	OdB
46-50	B/EW	Normal	OdB
51-61	C	Normal	OdB
62-71	C	To Be Selected	To Be Selected

5. Retrieve Equipment - targets and ground truth instrument (retrieval procedure attached)
   tides (TMS)
   Positioning (MINIRANGER)

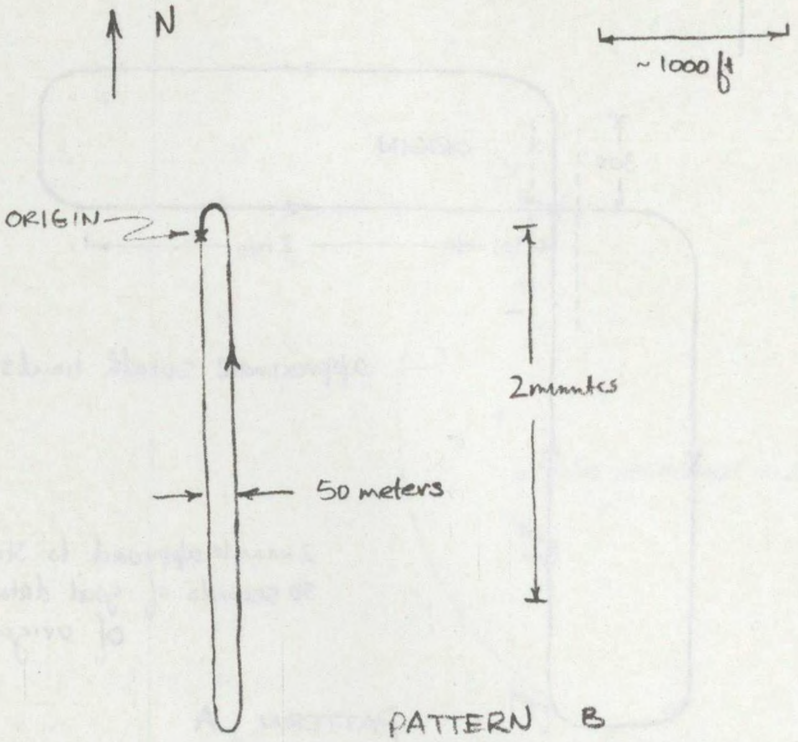

Old piling
STACK
Pipeline
Foul
Dolphins
Piles
Masts
GENERAL ANCHORAGE 110.230 (see note A)
EXPLOSIVES ANCHORAGE
110.230 (see note A)
B E L L I N G
Piles
Sewer
Edgen
Post Pt.
R"2"
Fl 4sec
BELL
Pt Francis
N.M.
SITE I
CHART 18424
Chuckan



PATTERN A

PATTERN ILLUSTRATED SHOWS APPROACH TO ORIGIN
FROM S AND E — DESIGNATED PATTERN A/SE

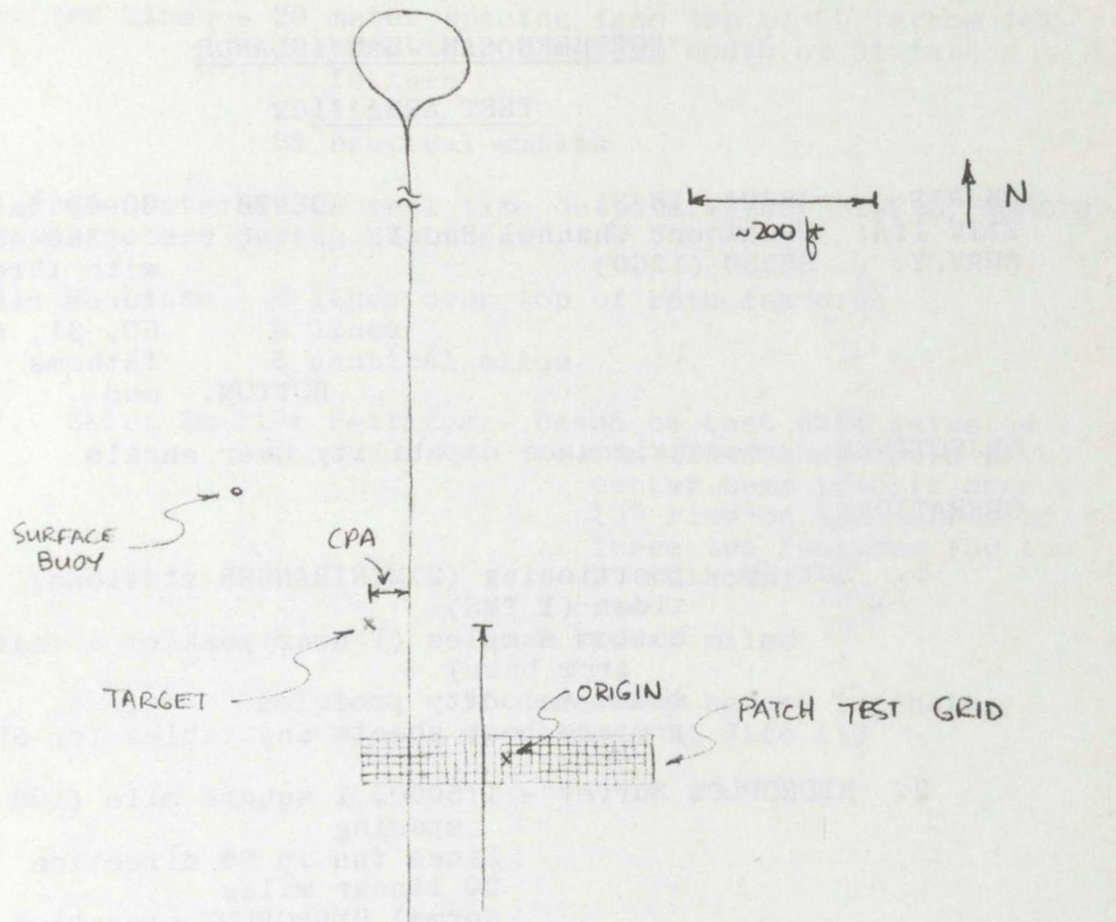
SIMILAR PATTERN WILL BE REQUIRED APPROACHING
FROM N AND W — DESIGNATED PATTERN A/NW



PATTERN ILLUSTRATED SHOWS APPROACH TO TURN FROM SOUTH — DESIGNATED PATTERN B/NS

SIMILAR PATTERN WILL BE REQUIRED APPROACHING FROM WEST — DESIGNATED B/EW

CONDITIONS AT ORIGIN SHOULD BE TYPICAL FOR START OF LINE — WILLIAMSON TURN MAY BE REQUIRED


N
~200 ft
SURFACE BUOY
CPA
TARGET
ORIGIN
PATCH TEST GRID
30 sec
2 min
CPA FROM 0 TO 100 FT
IN 10 FT INCREMENTS
PATTERN C

NORTHERN SAN JUAN ISLANDS

TEST AREA II

CHARTS: 18421, 18431
SITE IIA: President Channel Shoal
SURVEY: H8250 (1960)

DEPTH: 60-80 fathoms (360-480 ft.) with three features rising to 50, 31, and 36 fathoms
BOTTOM: mud

OBJECTIVES: reconnaissance capability over shoals

OPERATIONS:

1. Set-Up - positioning (2 MINIRANGER stations)
   tides (1 TMS)
   bottom samples (1 near peak of a feature, 1 from base)
   sound velocity profiles
   prepare boat sheets and tables for SURVEY

2. HYDROPLOT Survey - 1:5000, 1 square mile (100 meter spacing
   lines run in EW direction
   20 linear miles
   normal HYDROPLOT operation, BS^3 operating simultaneously
   HYDROPLOT and BS^3 operating as if normal survey

3. BS^3 Survey - 1:5000, 1/2 square mile (200 meter spacing
   lines run in EW direction
   5 linear lines
   additional lines if indicated to develop features
   one line over peak of each feature

4. HYDROPLOT Development - run additional lines as judged necessary to develop featurs based on data from HYDROPLOT Survey. Data from BS^3 should not be allowed to influence this development. Normal HYDROPLOT operation.

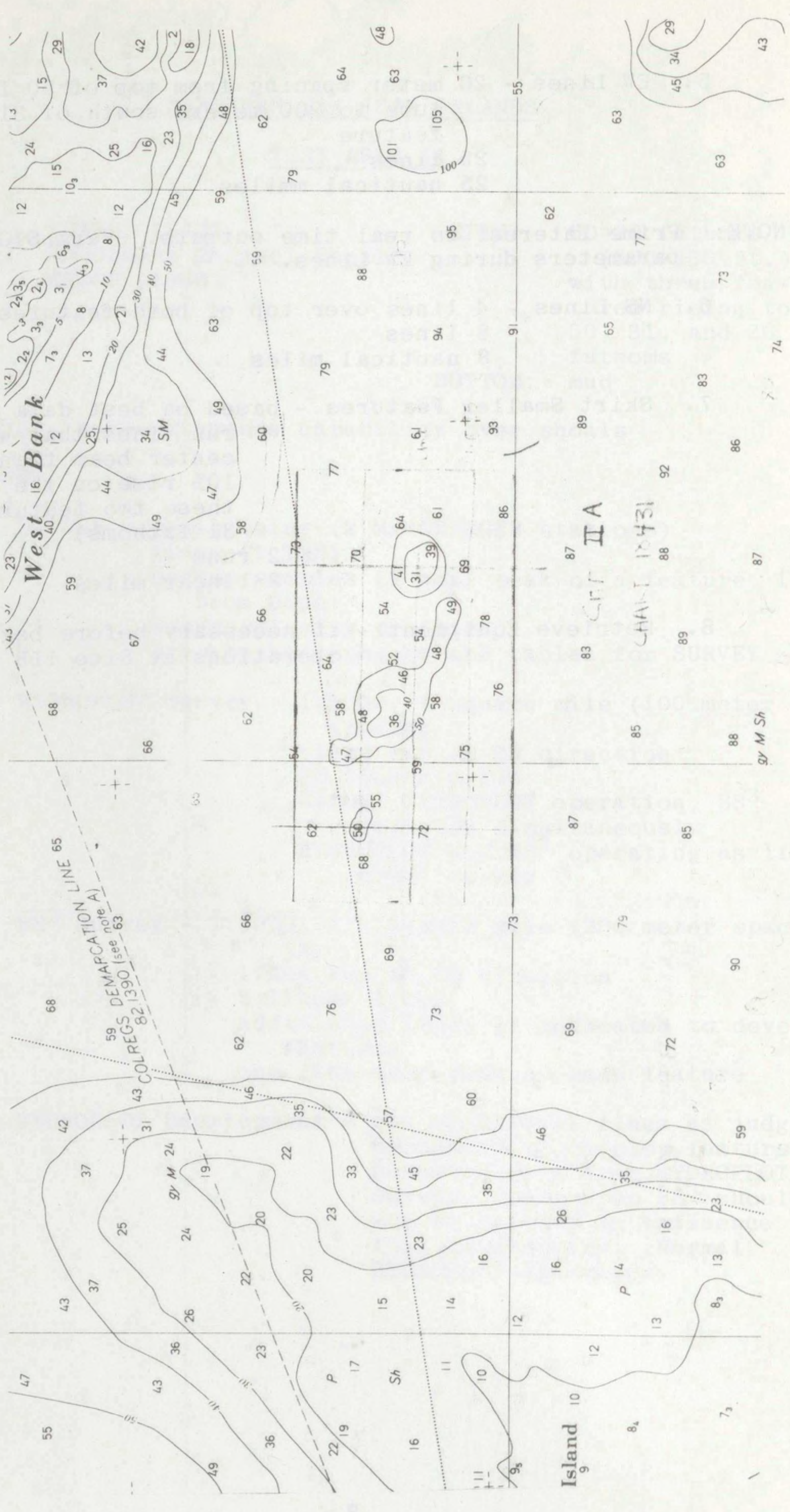
5. EW Lines - 20 meter spacing from top of 50 fathom feature to 200 meters south of 31 fathom feature
   25 lines
   25 nautical mmiles

NOTE: Prime interest in real time outputs. Vary SIGNAL, SMOOTH parameters during EW Lines.

6. NS Lines - 4 lines over top of both features
   8 lines
   8 nautical miles

7. Skirt Smaller Features - based on best data gathered run lines that would have center beam transit over a 10% rise on the skirts of these two features (50 and 31 fathoms)
   2 runs
   2 linear miles

8. Retrieve Equipment - if necessary before beginning operations at Site IIB


SITE IIB
West Bank
SITE IIA
SITE IIC
COLREGS DEMARCATION LINE
82 1390 (see note A)
Island

SITE IIB:	S. of Patos Island Steep Slope	DEPTH:	5-75 fathoms (30-450 ft.)
SURVEY:	H8520 (1960) 1:10,000	BOTTOM:	Sand, Mud, Shells
		SURFACE CONDITIONS:	calm

OBJECTIVE: Accuracy on Slope

OPERATIONS:

1. Set-Up - positioning (only if necessary to be relocated from Site IIA)
   bottom samples (1 at origin)
   sound velocity profiles
   prepare boat sheets and tables for SURVEY

2. HYDROPLOT Survey - 1:5000, 1/8 square mile, 50 meter spacing, 45° to slope
   10 linear miles
   normal HYDROPLOT operation; BS^3 operating simultaneously

3. BS^3 Survey

   A. Parallel to contours - 1:5000, 1/8 square mile, overlapping coverage, 3-4 linear miles. Overlapping coverage to be selected according to the following rule:

EXPECTED LEAST DEPTH	SPACING
7-14 FM	25 M
14-21	50
21-28	75
28-55	100
55-80	200
80-110	300
110-130	400

In this area it is expected first line along the deep edge of the area will be 100 m from the edge. The next four lines will be spaced by 50 m.

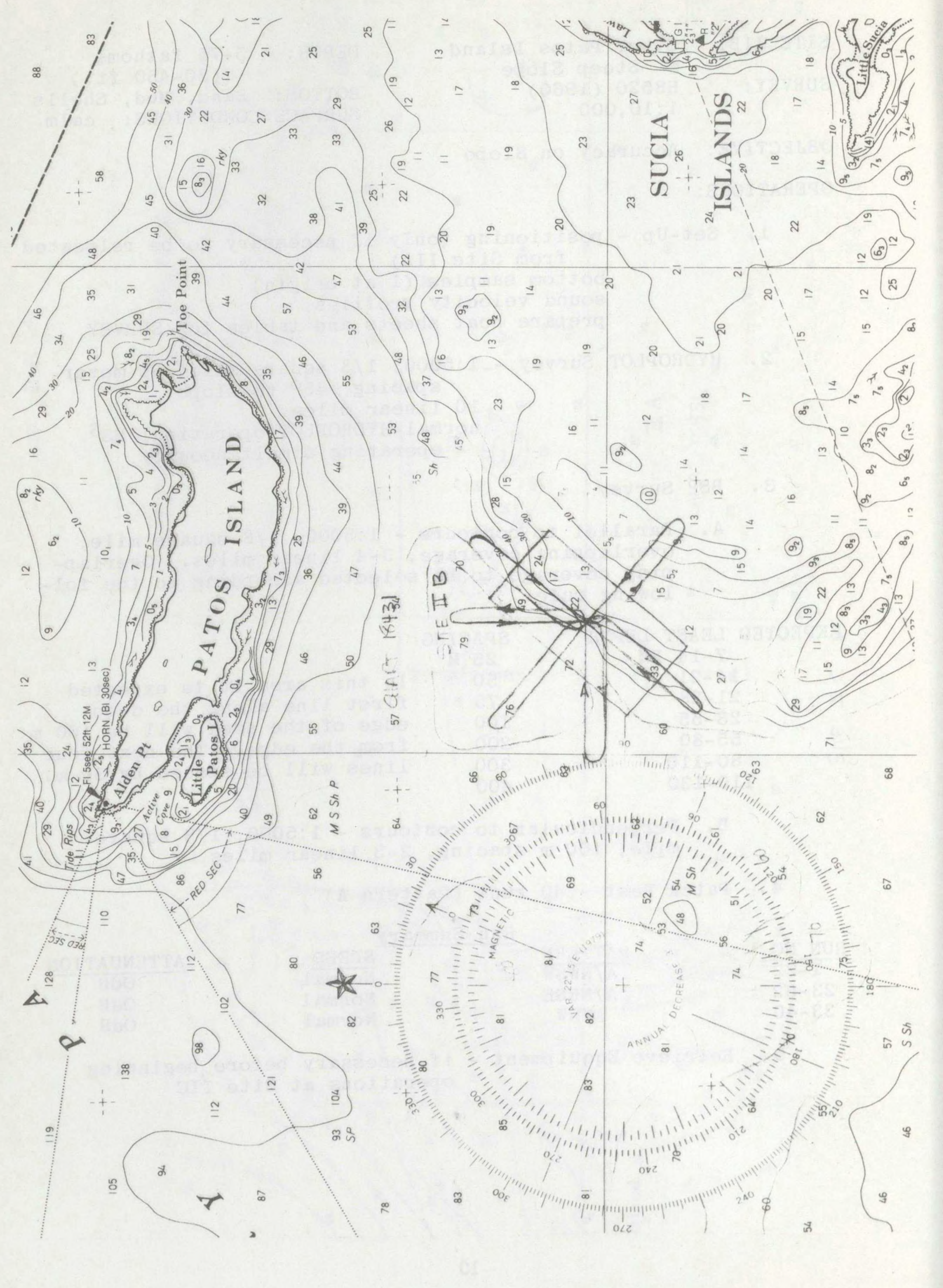
   B. Perpendicular to contours - 1:5000, 1/8 square mile, 100 m spacing, 2-3 linear miles

4. Patch Test - 40 runs (Pattern A)

Run Summary

RUN NO.	PATTERN	SPEED	ATTENUATION
1-22	A/NWSW	Normal	OdB
23-32	A/NESE	Normal	OdB
33-40	A/NW	Normal	OdB

5. Retrieve Eqquipment - if necessary before beginning operations at Site IIC


PATOS ISLAND
SUCIA ISLANDS
Toe Point
Alden Pt
Little Patos I.
Little Sucia
Active Cove
Tide Rips
HORN (Bl 30sec)
Fl 5sec 52ft 12M
RED SEC
MAGNETIC
ANNUAL DECREASE
rky
M S Sh P
S Sh

SITE IIC: President Channel Pinnacle off Point Doughty
DEPTH: 23 fathoms (138 ft.) rising from 90 fathoms

SURVEY: H8400 (1957) 1:10,000
BOTTOM: unknown
SURFACE CONDITIONS: calm

OBJECTIVE: reconnaissance capability

NOTE: If tests have fallen behind schedule at this point, tests at this site may be omitted.

OPERATIONS:

1. Set-Up - positioning (only if necessary to be relocated from Site IIB)
   bottom samples (1 at origin)
   sound velocity profiles
   prepare boat sheets and tables for SURVEY

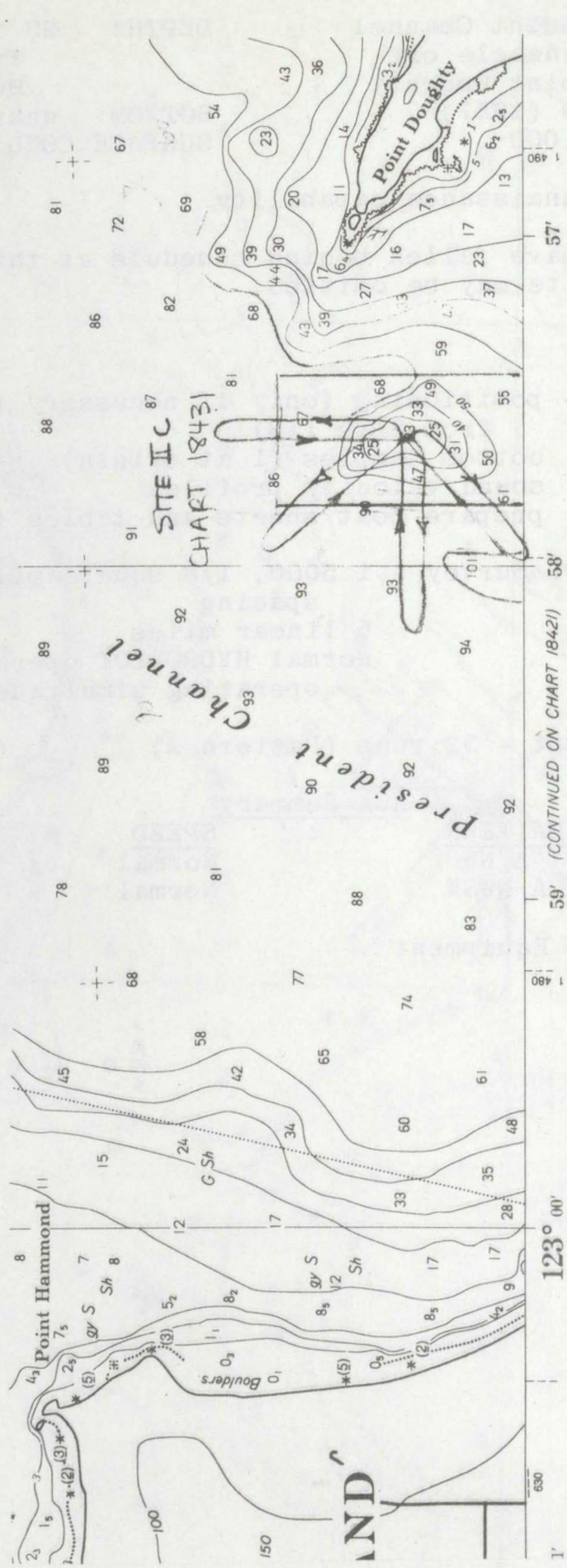
2. HYDROPLOT Survey - 1:5000, 1/8 square mile, 50 meter spacing
   5 linear miles
   normal HYDROPLOT operation; BS^3 operating simultaneously

3. Patch Test - 32 runs (Pattern A)

Run Summary

RUN NO.	PATTERN	SPEED	ATTENUATION
1-22	A/NW	Normal	OdB
23-32	A/NWSW	Normal	OdB

4. Retrieve Equipment


SITE II C
CHART 18431
President Channel
Point Doughty
Point Hammond
(CONTINUED ON CHART 18421)
Boulders

ROSARIO STRAIT

TEST AREA III

CHARTS: 18421, 18428
SURVEY: H9283 (1972)
1:20,000
wire drag

DEPTH: 45 fathoms (270 ft.)
2 wrecks with least depth of 28 fathoms (168 ft.) reported in 1964
BOTTOM: shells
SURFACE CONDITIONS: moderate seas

OBJECTIVE: obstruction detection

OPERATIONS:

1. Set-Up - positioning (2 MINIRANGER stations)
   tides (1 TMS)
   bottom samples (1 near one of the two wrecks)
   sound velocity profiles
   prepare boat sheets and tables for SURVEY

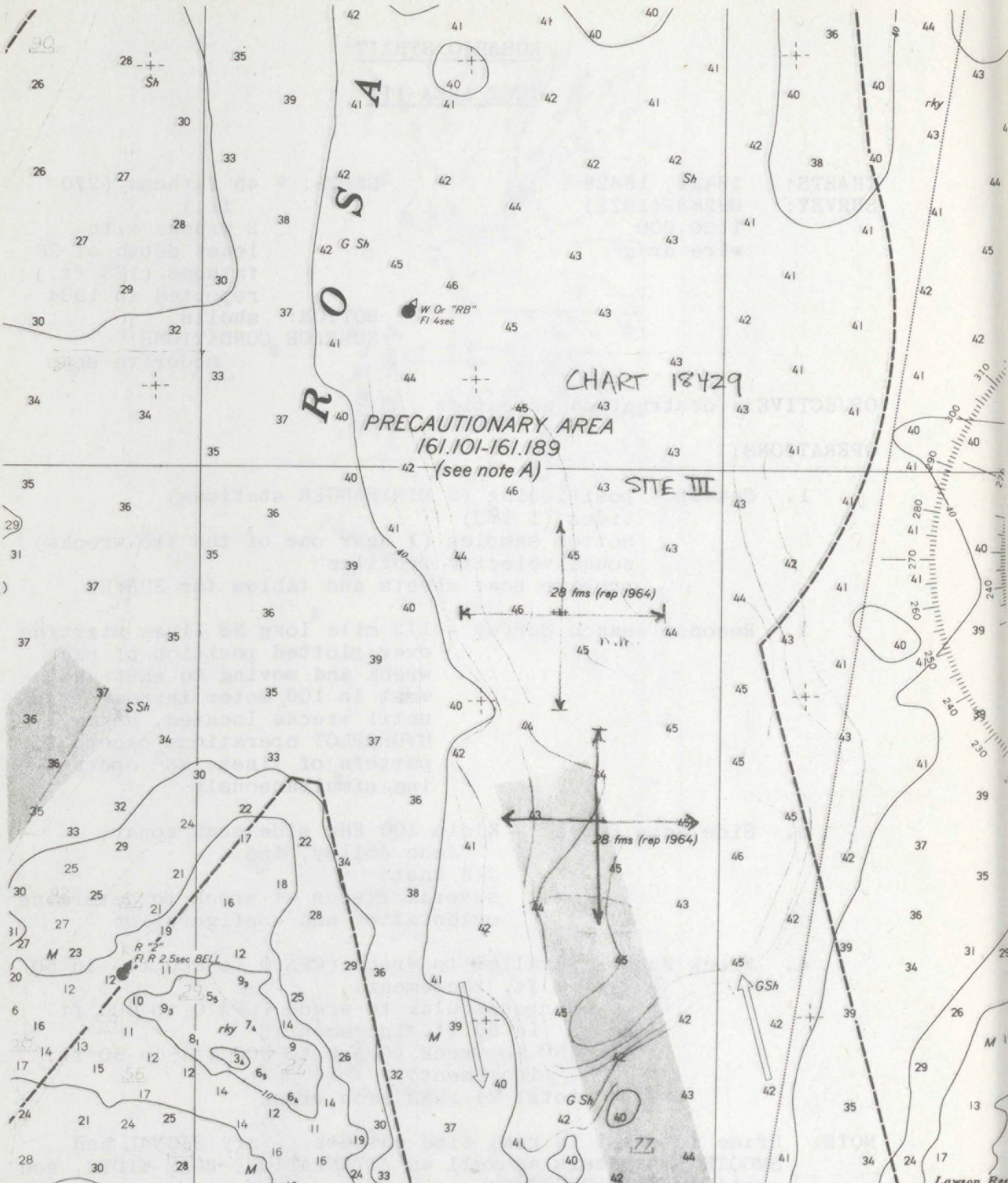
2. Reconnaissance Survey - 1/2 mile long NS lines starting over plotted position of each wreck and moving to east and west in 100 meter increments until wrecks located, normal HYDROPLOT operations except for pattern of lines, BS^3 operating simultaneously

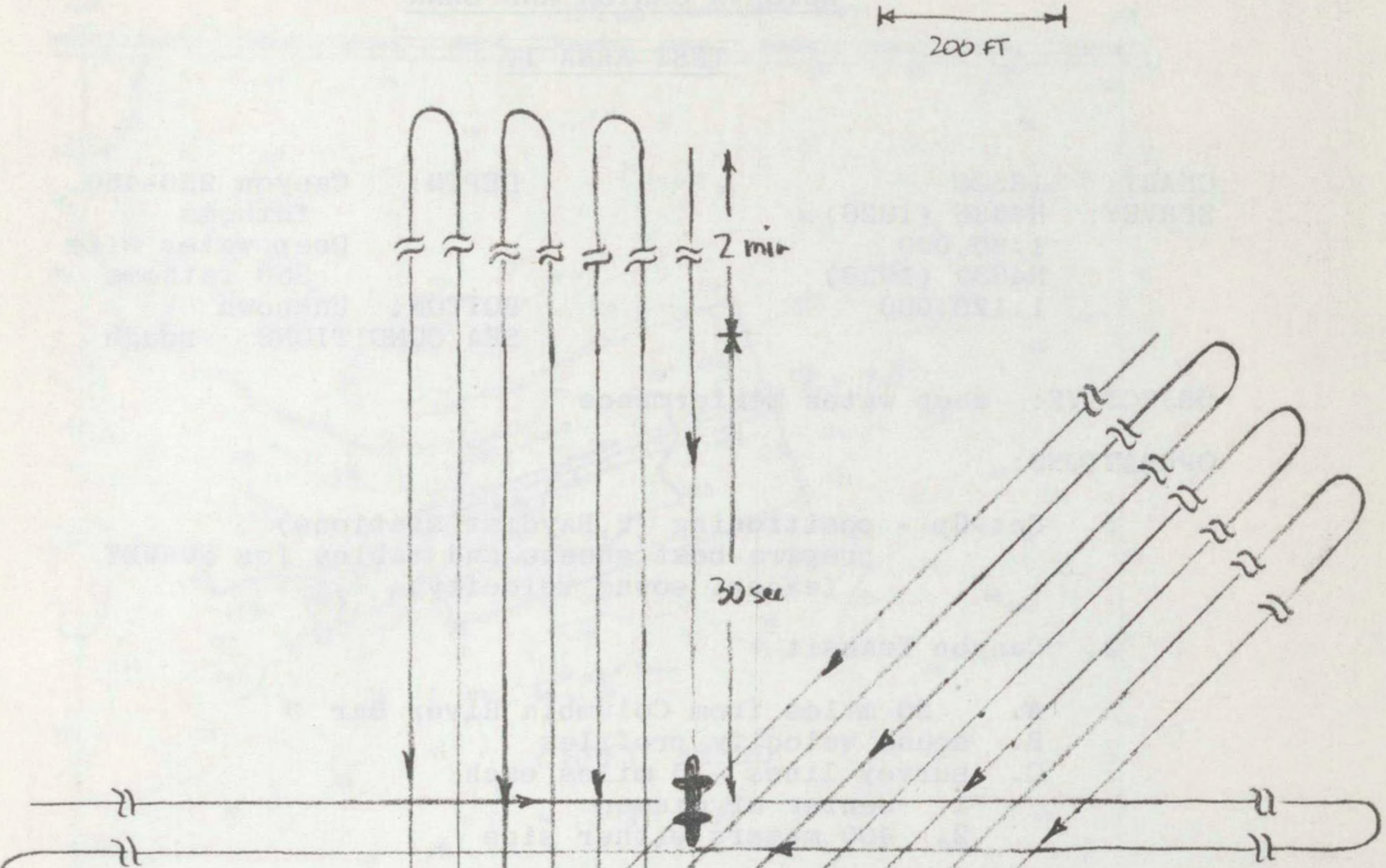
3. Side Scan Survey - Klein 100 KHz side scan sonar, John Jolley, Inc.
   2-3 knots
   several passes at wreck to determine orientation and configuration

4. Wreck Runs - parallel to wreck (CPA 0 to 300 ft. in 50 ft. increment)
   perpendicular to wreck (CPA 0 to 300 ft. in 50 ft. increment)
   45^o to wreck (CPA 0 to 300 ft. in 50 ft. increment)
   total 21 runs each wreck

NOTE: Prime interest in real time outputs. Vary SIGNAL and SMOOTH parameters as well as ATTENUATION, BEAM WIDTH, and possibly SHIP SPEED.

5. Retrieve Equipment


R O S A
CHART 18429
PRECAUTIONARY AREA
161.101-161.189
(see note A)
SITE III
28 fms (rep 1964)
28 fms (rep 1964)
W Or "RB"
Fl 4sec
R "2"
Fl R 2.5sec BELL



PATTERN E

WRECK RUNS

ASTORIA CANYON AND BANK

TEST AREA IV

CHART: 18520
SURVEY: H4636 (1926)
1:80,000
H4639 (1926)
1:120,000

DEPTH: Canyon 250-450 fathoms
Deep water site 350 fathoms
BOTTOM: Unknown
SEA CONDITIONS: rough

OBJECTIVE: deep water performance

OPERATIONS:

1. Set-Up - positioning (2 Raydist stations)
   prepare boat sheets and tables for SURVEY
   (except sound velocity)

2. Canyon Transit -

   A. 20 miles from Columbia River Bar
   B. sound velocity profiles
   C. survey lines - 5 miles each
      1. center of canyon
      2. 400 meters either side

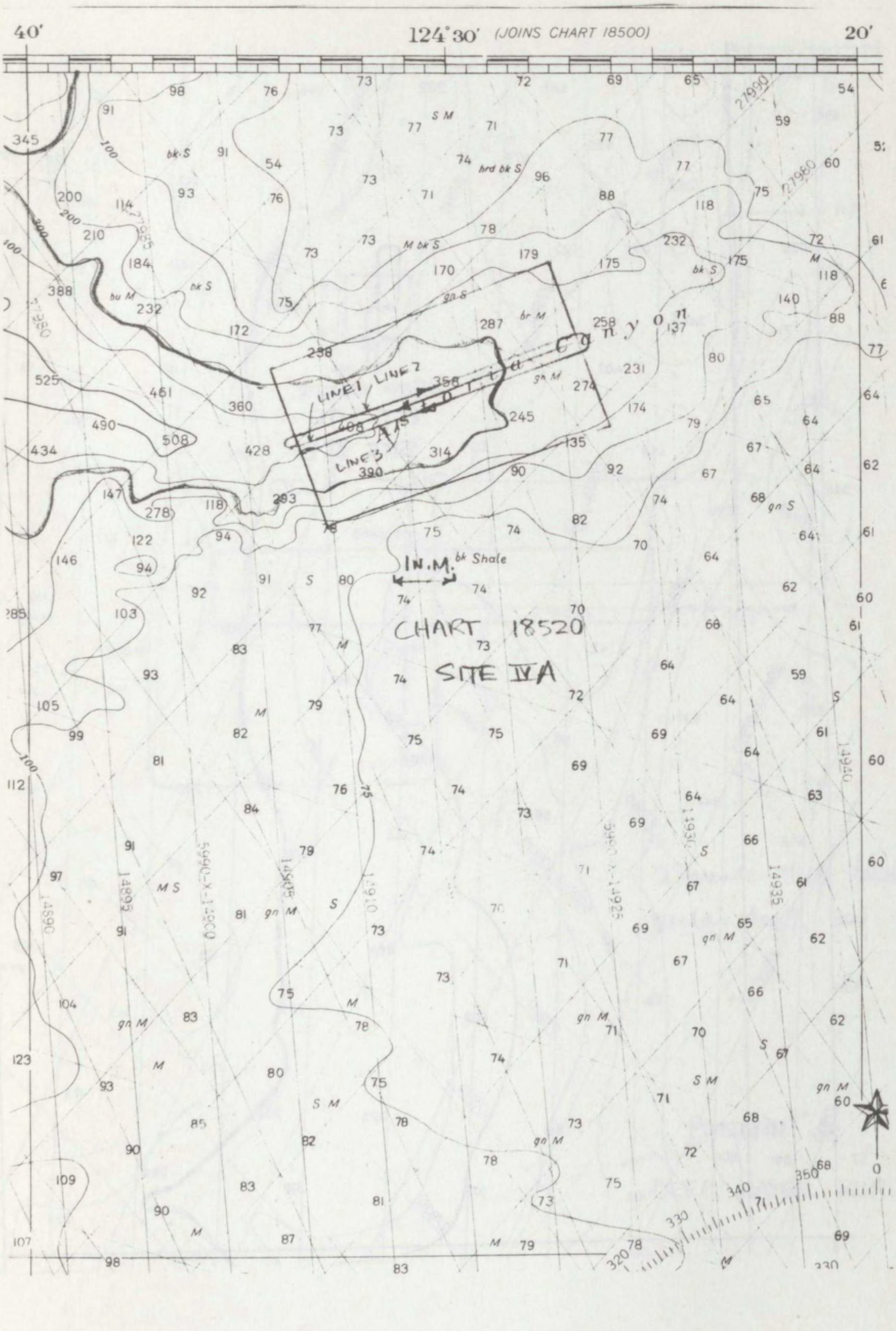
3. Deep Water Test -

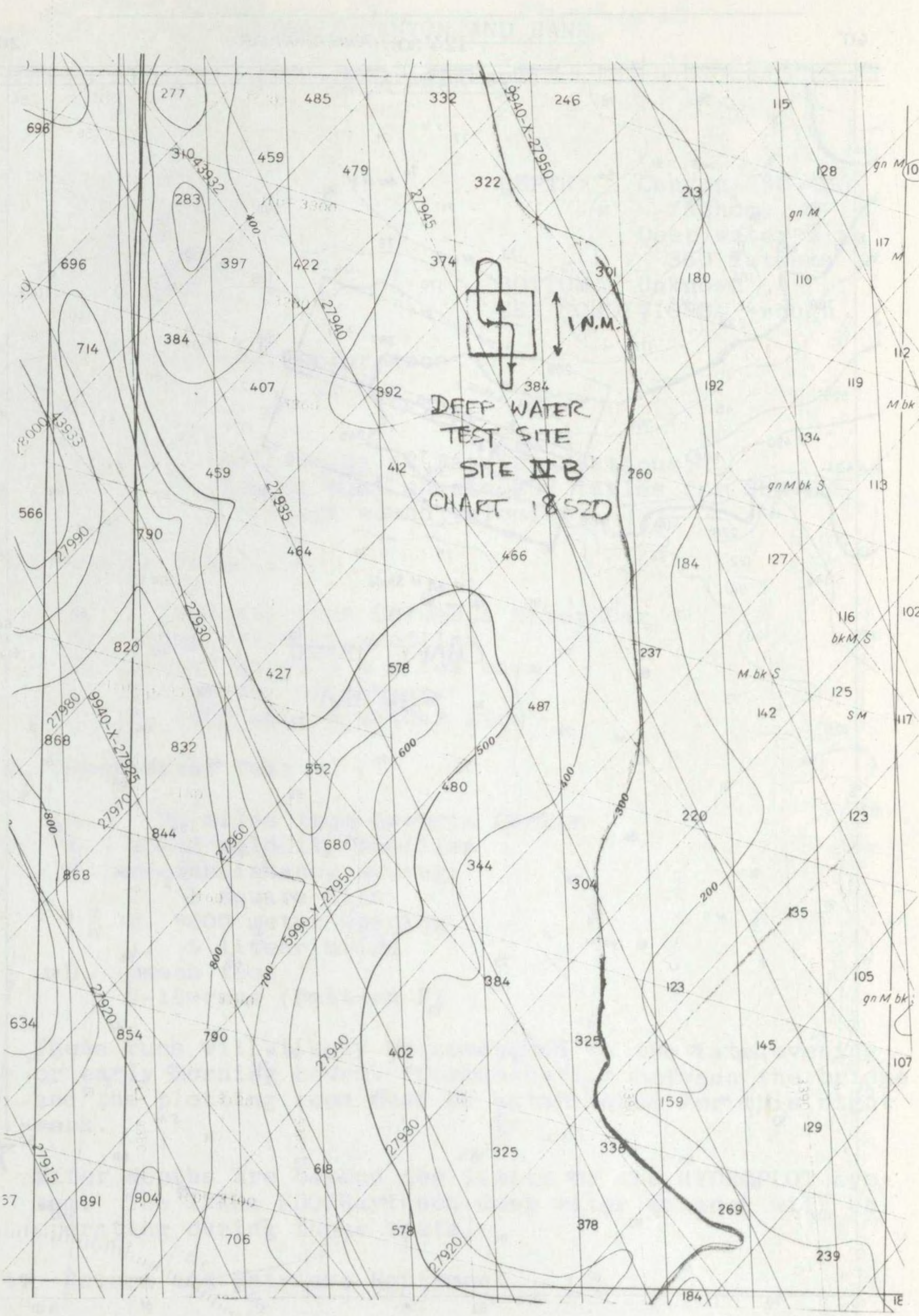
   A. 30 miles from Astoria Canyon
   B. sound velocity profiles
   C. reconnaissance survey
      1. 1 square mile
      2. 400 meter spacing
      3. 5 linear miles
   D. patch test
      8-16 runs (Pattern F)

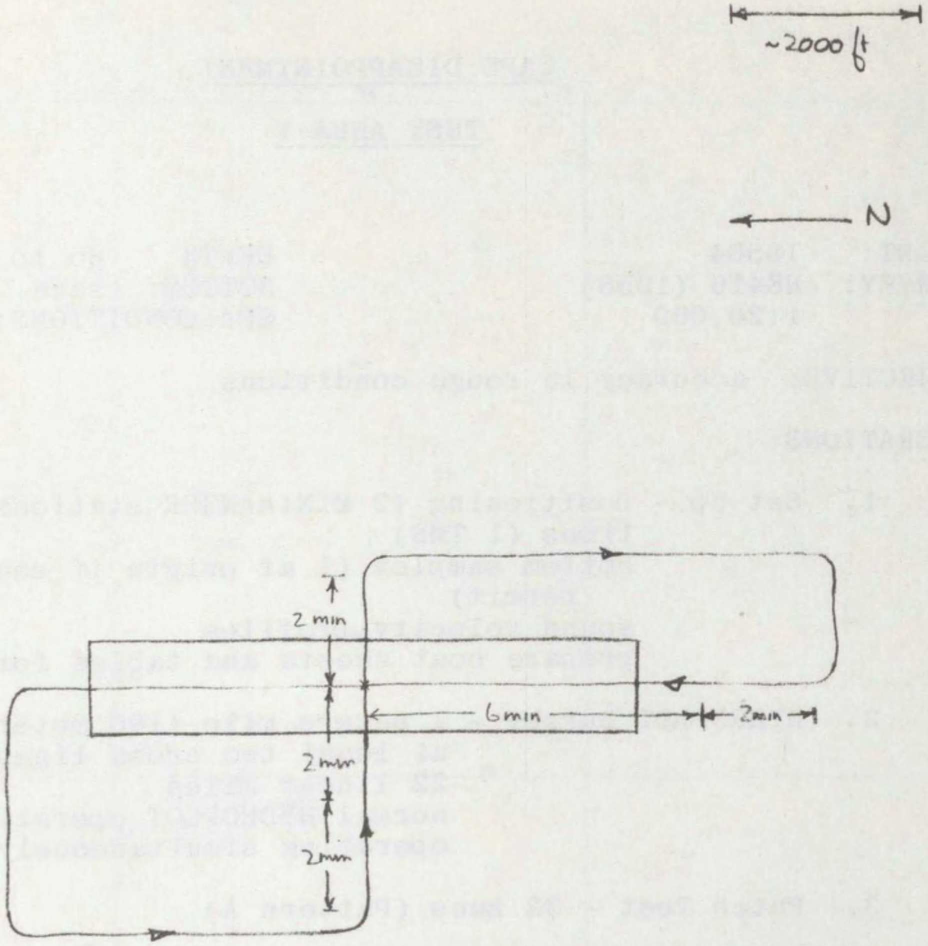
NOTE: These runs will likely be conducted in the late evening or early morning hours. Communication between the bridge and the plotting room must be established for this night work.

NOTE: Water depths are beyond the limits of the HYDROPLOT system. The 12KHz EDO/Raytheon deep water sounder will be operating during these tests.

4. Return and Retrieve Equipment


40′
124°30′ (JOINS CHART 18500)
20′
CHART 18520
SITE IVA
LINE1 LINE2
LINE3
IN.M.
bk Shale
Canyon


DEEP WATER
TEST SITE
SITE IV B
CHART 18520
1 N.M.
9940-X-27950
5990-X-27950
9940-X-27925



assumes ship speed ~6 knots
water depth 300-400 fathoms

PATTERN G

DEEP WATER RUNS

CAPE DISAPPOINTMENT

TEST AREA V

CHART: 18504
SURVEY: H8416 (1958)
1:20,000

DEPTH: 85 to 100 ft.
BOTTOM: sand
SEA CONDITIONS: rough

OBJECTIVE: accuracy in rough conditions

OPERATIONS:

1. Set-Up - positioning (2 MINIRANGER stations)
   tides (1 TMS)
   bottom samples (1 at origin if sea conditions permit)
   sound velocity profiles
   prepare boat sheets and tables for SURVEY

2. HYDROPLOT Survey - 1 square mile (100 meter spacing)
   at least two cross lines
   22 linear miles
   normal HYDROPLOT operation, BS^3 operating simultaneously

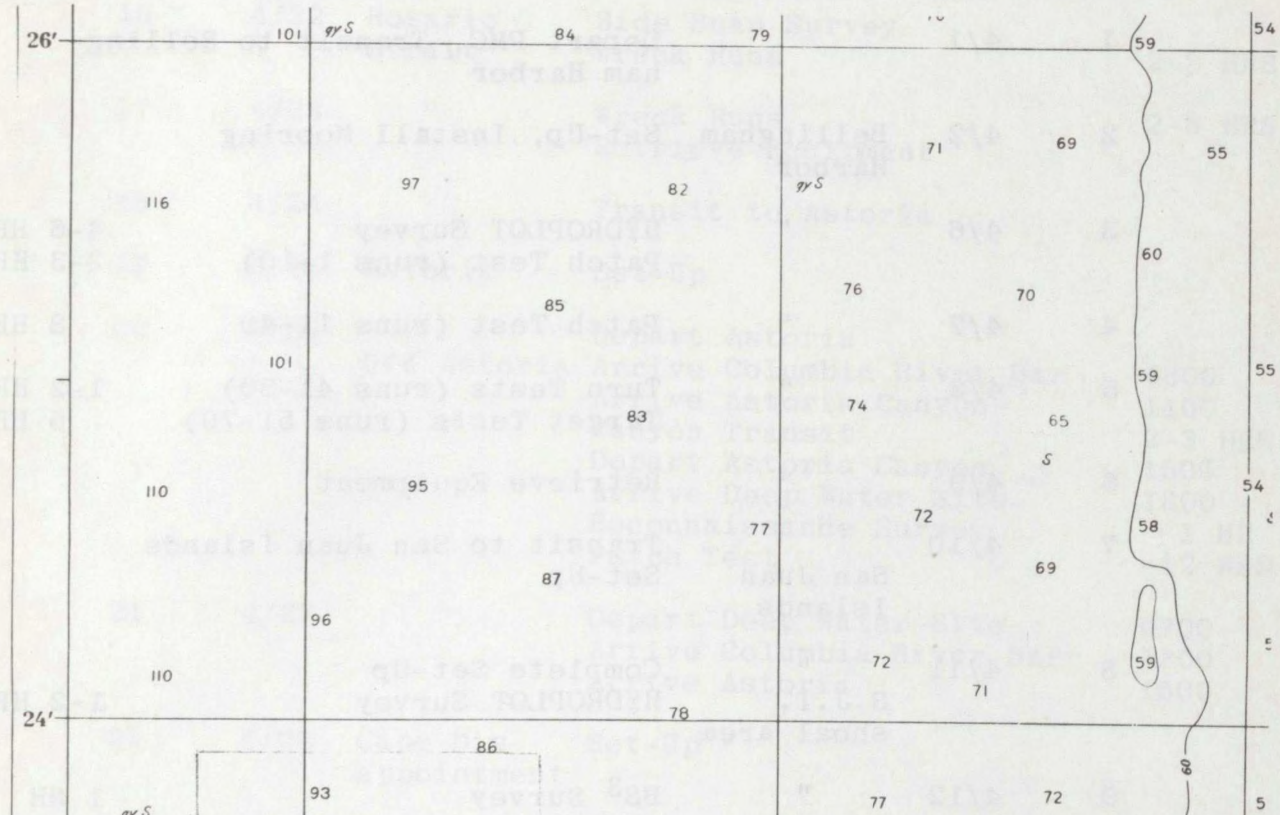
3. Patch Test - 32 runs (Pattern A)

Run Summary

RUN NO.	PATTERN	SPEED	ATTENUATION
1-22	A/SW	Normal	OdB
23-32	A/NE	Normal	OdB

4. Retrieve Equipment

REV. 1


26′
24′
22′
124° 10′
08′
06′
(CONTINUED ON CHART 18500)

PROPOSED SCHEDULE

SEA DAY	DATE	LOCATION	OPERATION	TIME
1	4/1		Depart PMC, Transit to Bellingham Harbor	
2	4/2	Bellingham Harbor	Set-Up, Install Mooring	
3	4/6	"	HYDROPLOT Survey Patch Test (runs 1-10)	4-6 HRS 2-3 HRS
4	4/7	"	Patch Test (runs 11-40	8 HRS
5	4/8	"	Turn Tests (runs 41-50) Target Tests (runs 51-70)	1-2 HRS 5 HRS
6	4/9	"	Retrieve Equipment	
7	4/10	San Juan Islands	Transit to San Juan Islands Set-Up	
8	4/11	" S.J.I. shoal area	Complete Set-Up HYDROPLOT Survey	1-2 HRS
9	4/12	"	BS^3 Survey HYDROPLOT Development EW Lines NS Lines	1 HR 1-2 HRS 2-4 HRS
10	4/13	S.J.I. slope area	Adjust Set-Up if Necessary HYDROPLOT Survey BS^3 Survey Patch Tests (runs 107-128)	1-2 HRS 2 HRS 4-5 HRS
11	4/14	S.J.I. pinnacle	Patch Tests (runs 129-146) Adjust Set-Up if Necessary	4-5 HRS
12	4/15	"	HYDROPLOT Survey Patch Tests	1-2 HRS
13	4/16	"	Complete Patch Tests Retrieve Equipment Transit to Anacortes	8 HRS
14	4/20	Rosario Strait	Transit to Rosario Strait Set-Up	
15	4/21	"	Complete Set-Up Reconnaissance Survey	

REV. 1

PROPOSED SCHEDULE (Cont'd.)

SEA DAY	DATE	LOCATION	OPERATION	TIME
16	4/22	Rosario Strait	Side Scan Survey Wreck Runs	 2-3 HRS
17	4/23	"	Wreck Runs Retrieve Equipment	2-3 HRS
18	4/24		Transit to Astoria	
19	4/25	Astoria	Set-Up	
20	4/26	 Off Astoria	Depart Astoria Arrive Columbia River Bar Arrive Astoria Canyon Canyon Transit Depart Astoria Canyon Arrive Deep Water Site Reconnaissance Survey Patch Test	 0800 1100 2-3 HRS 1500 1800 1 HR 12 HRS
21	4/27	"	Depart Deep Water Site Arrive Columbia River Bar Arrive Astoria	0700 1300 1500
22	4/28	Cape Dis-appointment	Set-Up	
23	4/29	"	Depart Astoria Arrive Cape Disappointment HYDROPLOT Survey Patch Test	0700 1100 3-4 HRS 10 HRS
24	4/30		Depart Cape Disappointment Arrive Astoria	0500 0900
25	5/4	"	Retrieve Equipment	

REV. 1

OVERALL RUN SUMMARY

RUN NO.	PATTERN	SPEED	ATTENUATION	SIGNAL	SMOOTH	LOCATION
1-22	A/SE	Normal	OdB	3	0	Bellingham
23-32	A/NW	Normal	"	"	"	"
33-36	A/SE	Normal	-6dB	"	"	"
37-40	Same	Normal	-12dB	"	"	"
41-45	B/NS		OdB	"	"	"
46-50	B/EW	"	"	"	"	"
51-61	C	"	"	"	"	"
62-71	C		----To Be Selected----			"
72-96	D/EW		----To Be Selected----			San Juan Isl Shoal
97-104	D/NS	Normal	OdB	3	0	"
105-106	D/SKIRT	"	"	"	"	"
107-128	A/NWSW	"	"	"	"	San Juan Isl Slope
129-138	A/NESE	"	"	"	"	"
139-146	A/NW	"	"	"	"	"
147-168	A/NW	"	"	"	"	San Juan Isl Pinnacle
169-178	A/NWSW	"	"	"	"	"
179-199	E		----To Be Selected----			Rosario Wreck 1
200-220	E		----To Be Selected----			Rosario Wreck 2
220-223	F	Normal	OdB	3	0	Astoria Canyon
223-239	G	Normal	OdB	3	0	Deep Water Site
240-261	A/SW	"	"	"	"	Cape Dis-apppointment
262-271	A/NE	"	"	"	"	"

SUPPORT REQUIREMENTS

LOCATION	POSITIONING	TIDES	BOAT SHEETS	BOTTOM SAMPLES	SV PROFILES	HYDROPLOT SURVEY	OTHER	TEST PERSONNEL ABOARD
Bellingham Harbor	2 MINIRANGER Stations	1 TMS	2 HYDROPLOT 2 BS^3	1 at Origin	3 First Day 1 Each Subsequent Day	1 Square Mile	Deploy & Retrieve Mooring Lead Line Measurements at Origin	5
San Juan Islands - Shoal	2 or 3 MINIRANGER Stations	TMS	2 HYDROPLOT 3 BS^3	1 at Peak 1 at Base	2 or 3 at Base 1 at Peak	1 Square Mile	Hydrographer to Evaluate BS^3 real-time outputs	
- Slope			2 HYDROPLOT 4 BS^3	1 at Origin	3 at Origin	1/8 Square Mile		3
- Pinnacle			2 HYDROPLOT 2 BS^3	1 at Origin	3 at Origin	1/8 Square Mile		
Rosario Strait	2 MINIRANGER Stations	1 TMS	2 HYDROPLOT 2 BS^3	1 Near One of Two Wrecks	2 or 3 Near Each Wreck		Assistance With Deploying Side Scan System	3
Astoria Canyon and Deep Water Site	2 RAYDIST Stations		1 BS^3 2 BS^3 Water Site		2 or 3 in Canyon and at Deep Water Site		Deep Water Sounder Operation	4
Cape Dis-appointmen	2 MINIRANGER Stations	1 TMS	2 HYDROPLOT 2 BS^3	1 at Origin if Conditions Permit	3 at Start of Operations	1 Square Mile		4

NOTE: Post-docking tests will determine whether BS^3 operates satisfactorily with MINIRANGER If not Raydist Stations will be required at all sites.

NOTE: The HODROPLOT System will be operated during most of the test period but only data from designated SURVEYS need be plotted.

BSSS TRIPLANE MOORING EXPERIMENT

1. PURPOSE & EXPERIMENT AREA

The purpose of the triplane mooring is threefold: first, to provide an acoustic target for assessment of the BSSS transducer characteristics at various ranges; second, to provide depth verification by the internally recording pressure sensor; third, to provide a visible surface marker for navigation during the test and recovery upon completion.

The mooring is to be deployed in Bellingham Bay, Washington, as shown in Figure 1 (excerpt of NOAA Chart 18421). The general area of deployment is shown in greater detail in Figure 2 (excerpt of NOAA Chart 18424). It is desired to deploy the mooring in a Northwesterly direction with the pressure transducer at the origin of North-South and East-West baselines. The exact location of the baselines will be coordinated with the DAVIDSON, considering manueverability and positioning constraints.

The mooring has been designed as simply as possible to meet the test objectives and facilitate a hand over hand deployment from a survey launch. Retrieval can be implemented by a strong back method from the survey launch or the DAVIDSON's deck handling equipment can be utilized.

Since anchor weight has been minimized, there is potential for movement of the mooring under adverse conditions. Also a long term deployment will be subject to vandalism and ship traffic. A light and flag have been provided as aids to navigation. If a long term deployment is envisioned, a Notice to Mariners should be issued by DAVIDSON personnel.

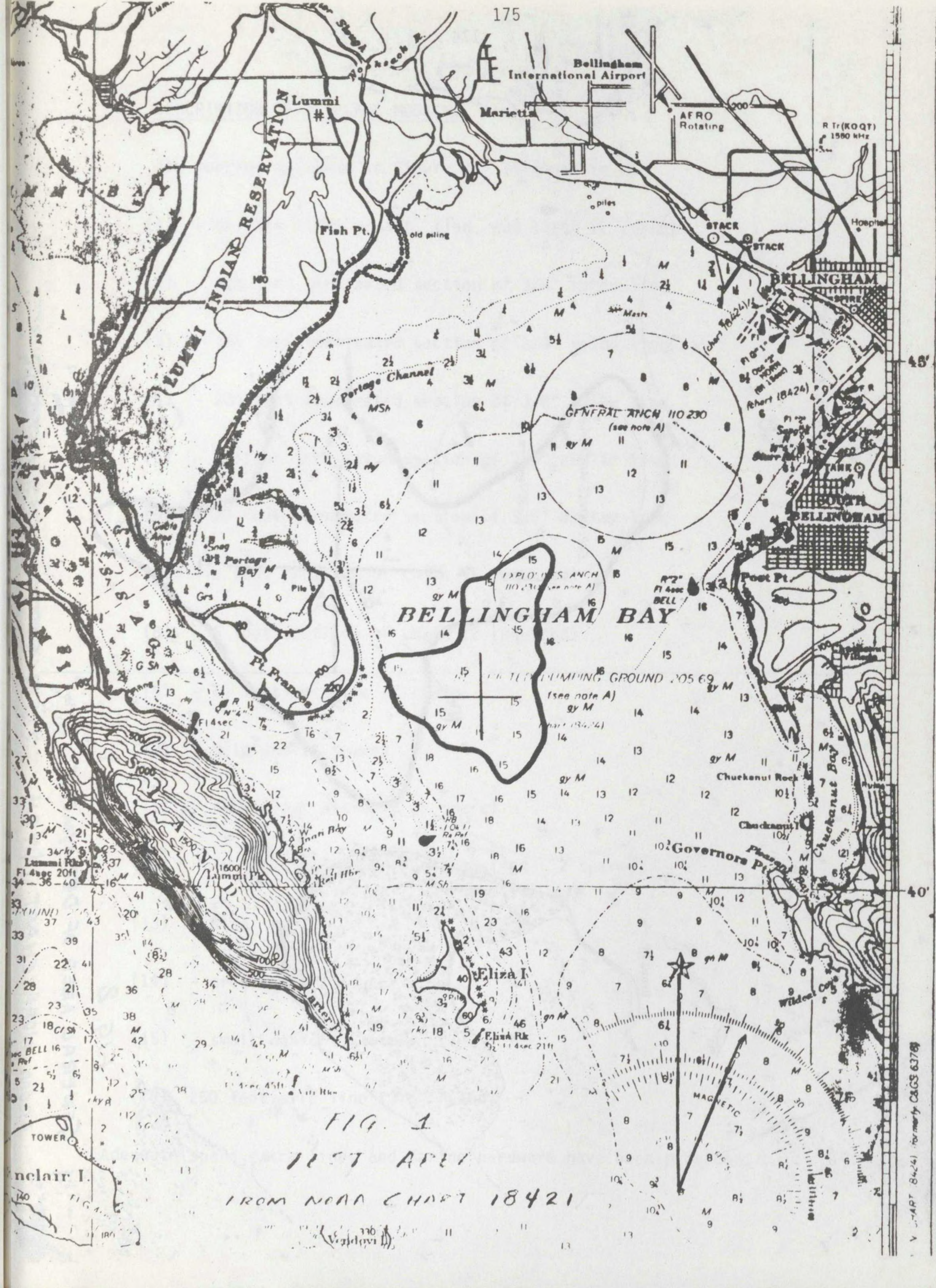


FIG. 1

TEST AREA

FROM NOAA CHART 18421

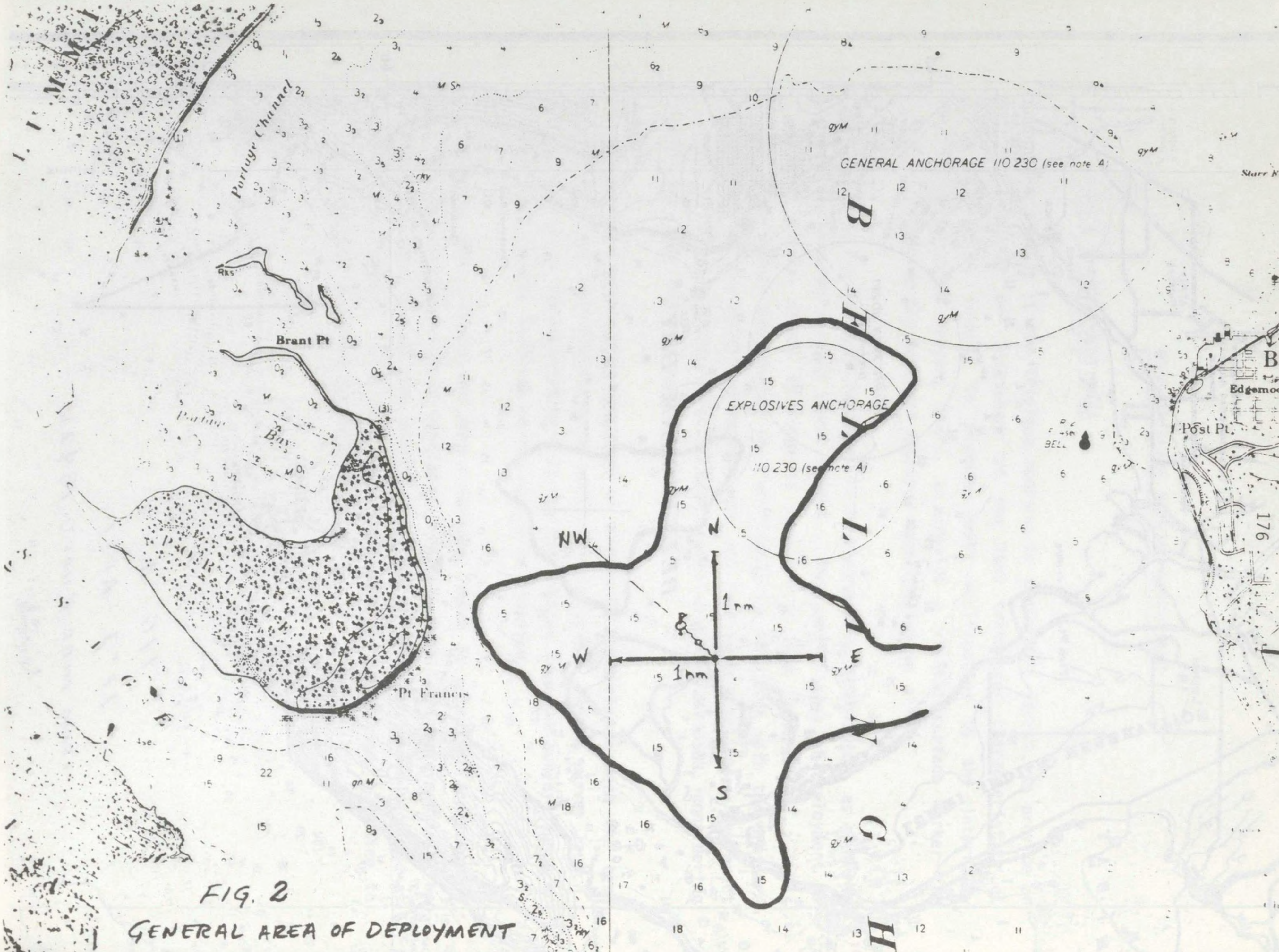


FIG. 2

GENERAL AREA OF DEPLOYMENT

FROM NOAA CHART 18424

2. DESCRIPTION OF TRIPLANE MOORING

The mooring is shown in Figure 3. It consists of:

(1) - surface float w/mast, flag, and light (1 spare)

(2) - 110 feet terminated section of 3/8" nylon line

(3) - 150 feet terminated section of 3/8" nylon line

(4) - 200 feet terminated section of 3/8" nylon line

(5) - 12 feet terminated section of 3/8" kevlar line

(6) - 20 feet terminated section of 3/8" kevlar line

(7) - 2 foot sections of chain (5 required)

(8) - 5 foot sections of chain (2 required)

(9) - 10 foot sections of chain

(10) - triplane (1 spare)

(11) - viny float assembly (1 spare)

(12) - 75 lbs clump anchors (2 required - 2 spares)

(13) - sled

(14) - pressure transducer

(15) - small danforth anchor

(16) 250 feet slip line (3/8" nylon)

Adequate spare extra lines and marine hardware have been provided.

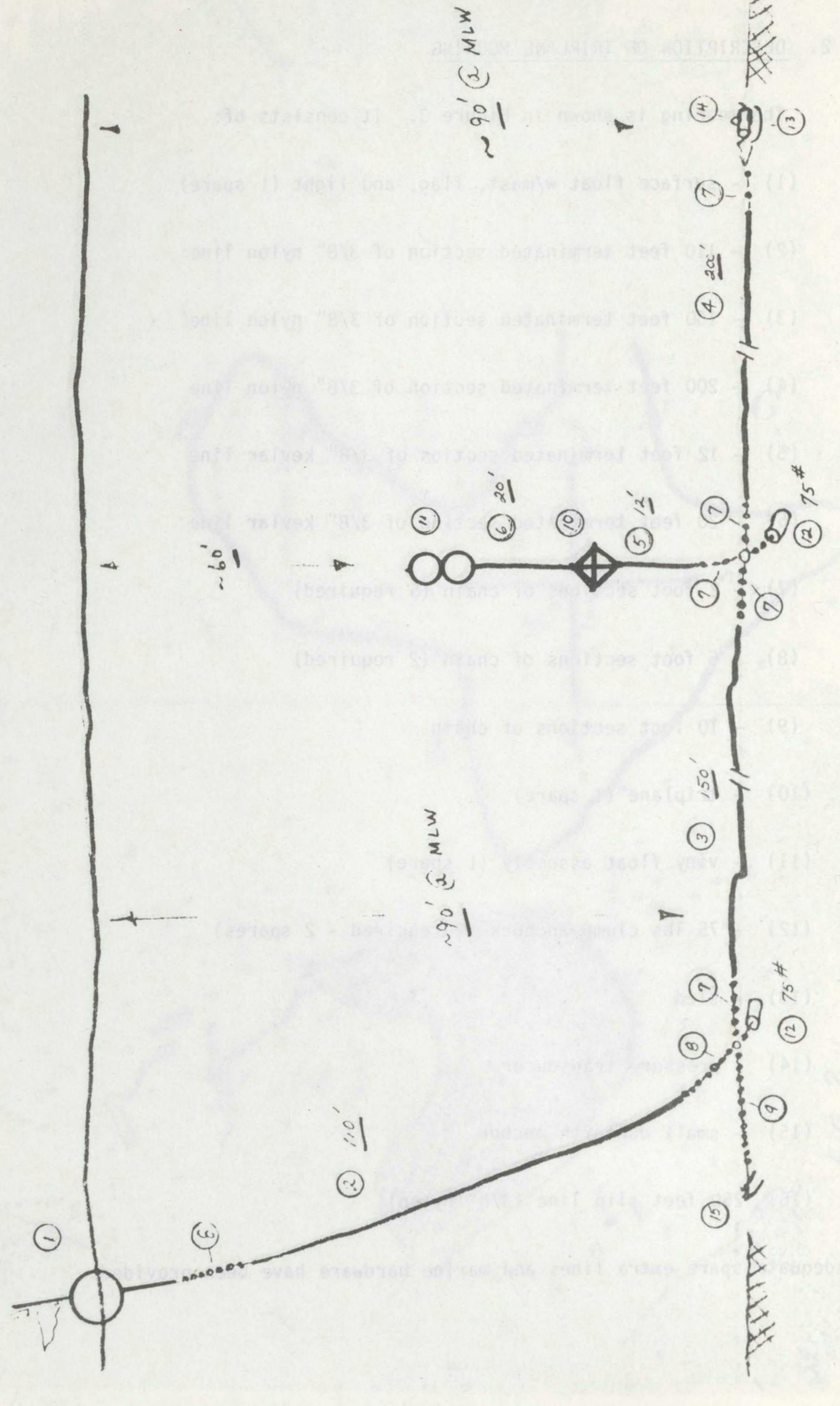


FIG. 3 BSSS TRIPLANE MOORING

3. DAVIDSON REQUIREMENTS

The triplane mooring will be shipped to the DAVIDSON as complete as possible. This includes premade nylon and kevlar lines with terminations, floats, triplane, sled, and marine hardware. The DAVIDSON will be required to assist in the following areas:

a. Assemble the surface float mast sections; insert in the empty float and inflate fully; install flag; and install batteries in light and verify operation.

b. Purchase premixed bags of concrete; mix and pour concrete into the provided buckets with the chain installed and allow to cure; verify weight.

c. Assemble the triplane pieces with the hardware provided.

d. Assemble the mooring components with the marine hardware provided following the engineering drawing and I.D. tags. Seize all shackles with the provided seizing wire.

4. DOCKSIDE TEST

All the personnel that will be involved with the deployment and retrieval of the triplane mooring should meet and review the Deployment and Retrieval Procedures. The personnel should include an officer, coxswain, and two or three deck crew. These procedures should be checked against vessel equipment and personnel to see if requirements and capabilities match. Changes should be made as required. The sensor equipment will be tested to insure proper working order by EDO personnel. Finally, a dry run should be performed of the deployment to familiarize everyone with the procedures involved.

5. DEPLOYMENT PROCEDURES

A bottom survey of the mooring area should be performed by the DAVIDSON or Jensen Survey Launch in conjunction with the positioning requirements. The mooring has been designed for a 90 ft. depth. If an alternate deeper site is choosen, this will require the addition of extra line between the surface buoy and anchor. A shallower site will require no modification. Assuming the launch is in the required area, the triplane mooring deployment procedures are as follows (see Figure D1-D3):

(1) The mooring should be completly assembled and flaked out to avoid tangles.

(2) Position the launch at a NW position from the origin.

(3) Place the surface float in the water and pay out the 110' line while the boat moves slowly away from the float to the SE.

(4) Stop the launch when the clump and danforth anchor is reached. Lift the anchor over the gunnel and lower it with the 150' section of nylon line into the water.

(5) When the anchor reaches the bottom slowly move the launch until the rest of the 150' line is payed out

(6) Stop the launch and place the second clump anchor on the gunnel. Be sure the 200' line is clear and the triplane and float assembly are ready.

(7) Deploy the float assembly and triplane.

(8) Lift the anchor over and pay out both the 200' nylon line and the kevlar line taking care not to tangle them.

(9) After both the triplane and float assembly disappear under the surface move the launch ahead slowly while paying out the nylon line until the sled is reached. Stop the launch.

(10) Attach a 250' double ended slip line through the sled ring. Tie one end of the line off and deploy the sled. Lower it while keeping tension on both ends of the line until the bottom is reached.

(11) Verify the exact bottom location with positioning equipment, and radio this information to the DAVIDSON. Release the loose end of the slip line and quickly pull the line from where it was tied off. Avoid any tangles while quickly pulling the line to the surface.

DEPLOYMENT

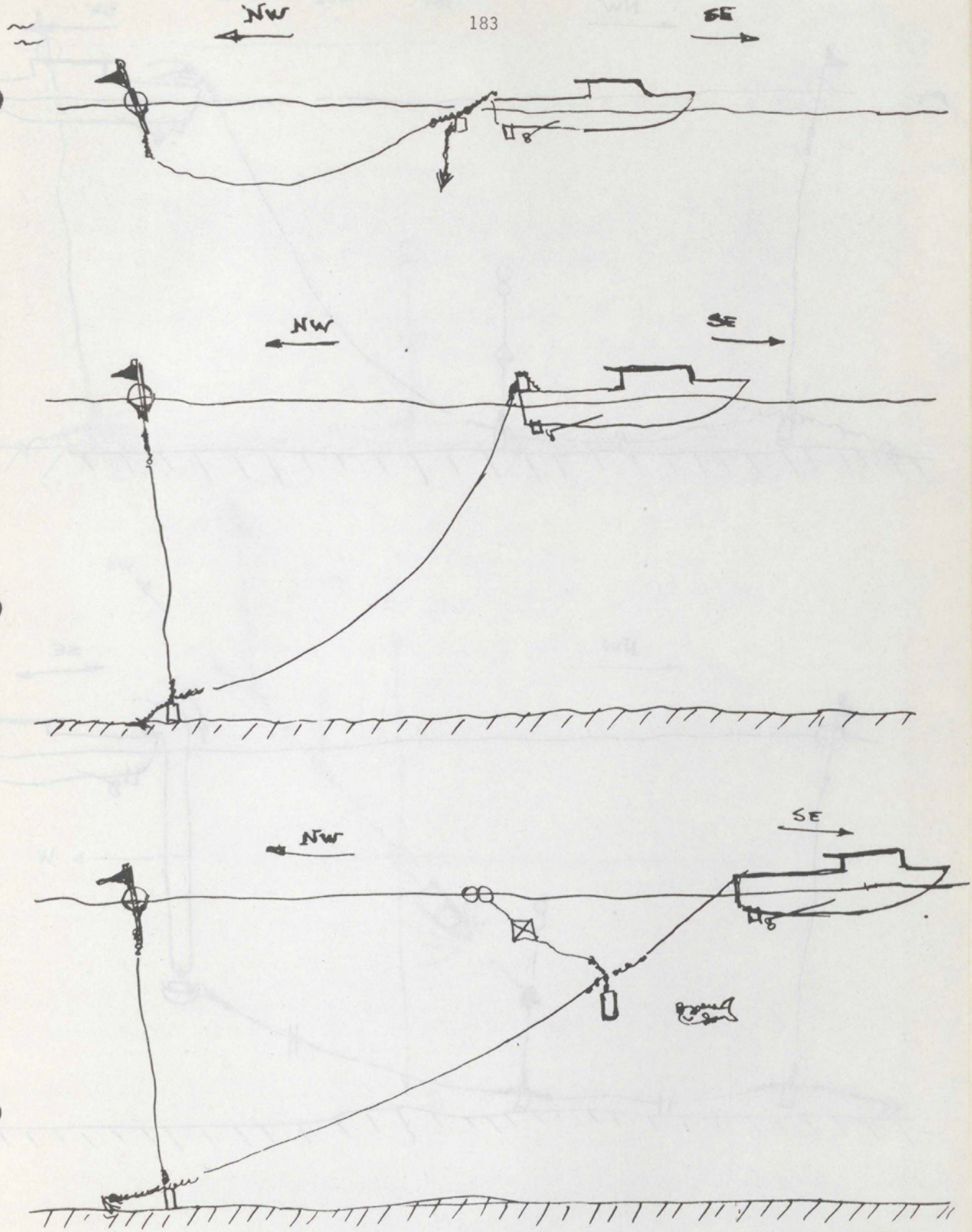


FIG - D1

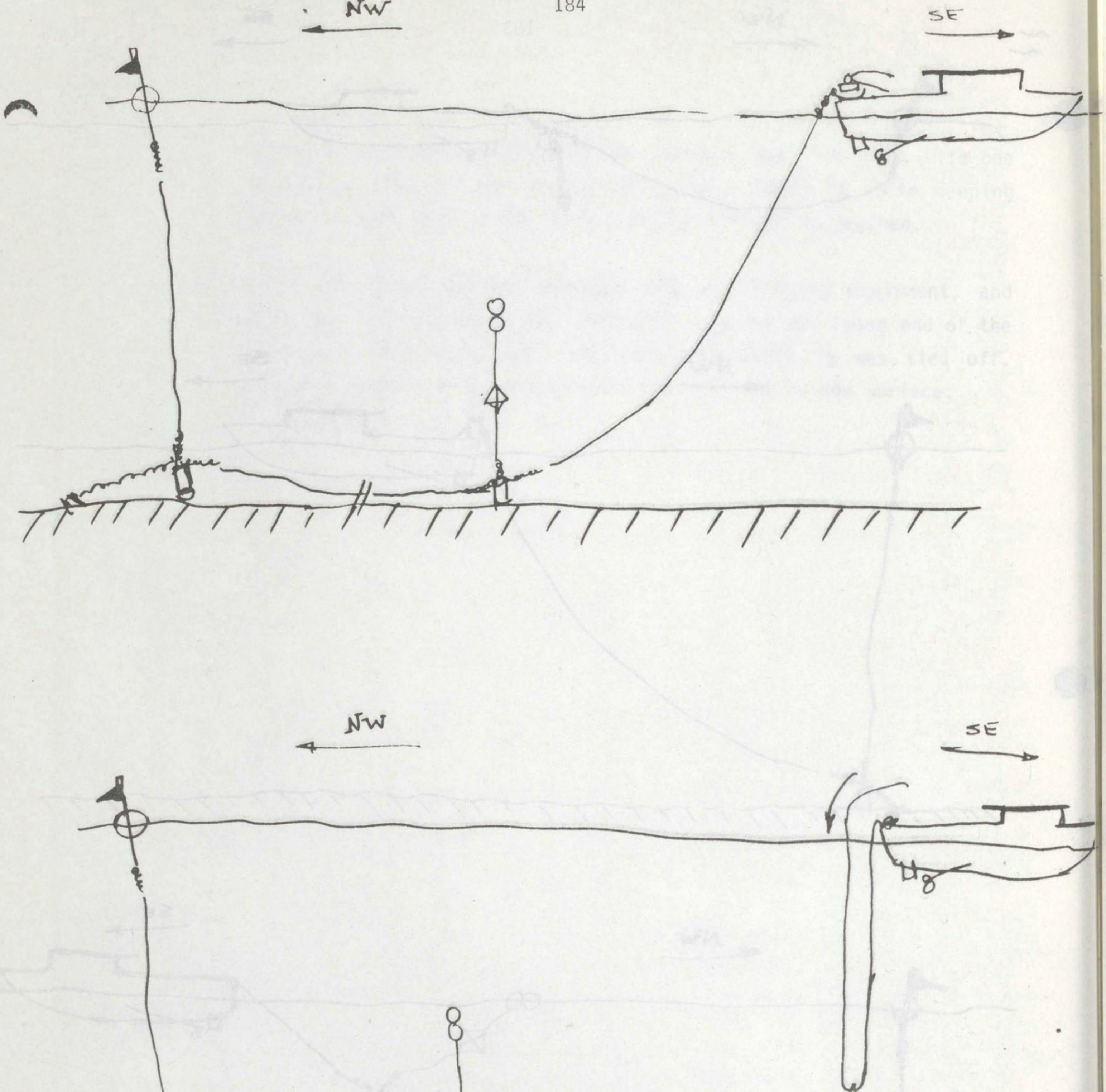


FIG - D2

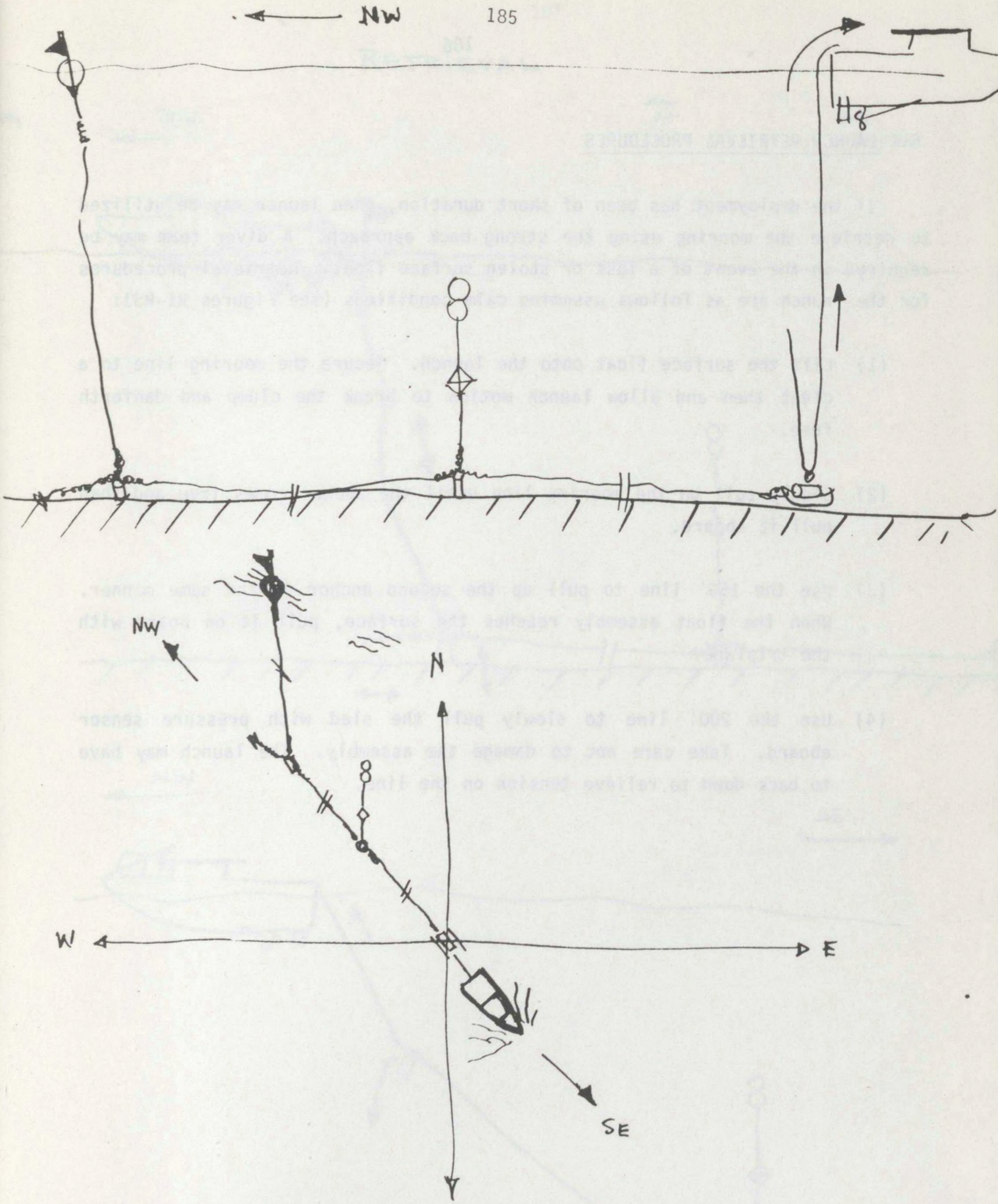


FIG - D3

6. LAUNCH RETRIEVAL PROCEDURES

If the deployment has been of short duration, then launch may be utilized to retrieve the mooring using the strong back approach. A diver team may be required in the event of a lost or stolen surface float. Retrieval procedures for the launch are as follows assuming calm conditions (see Figures R1-R3):

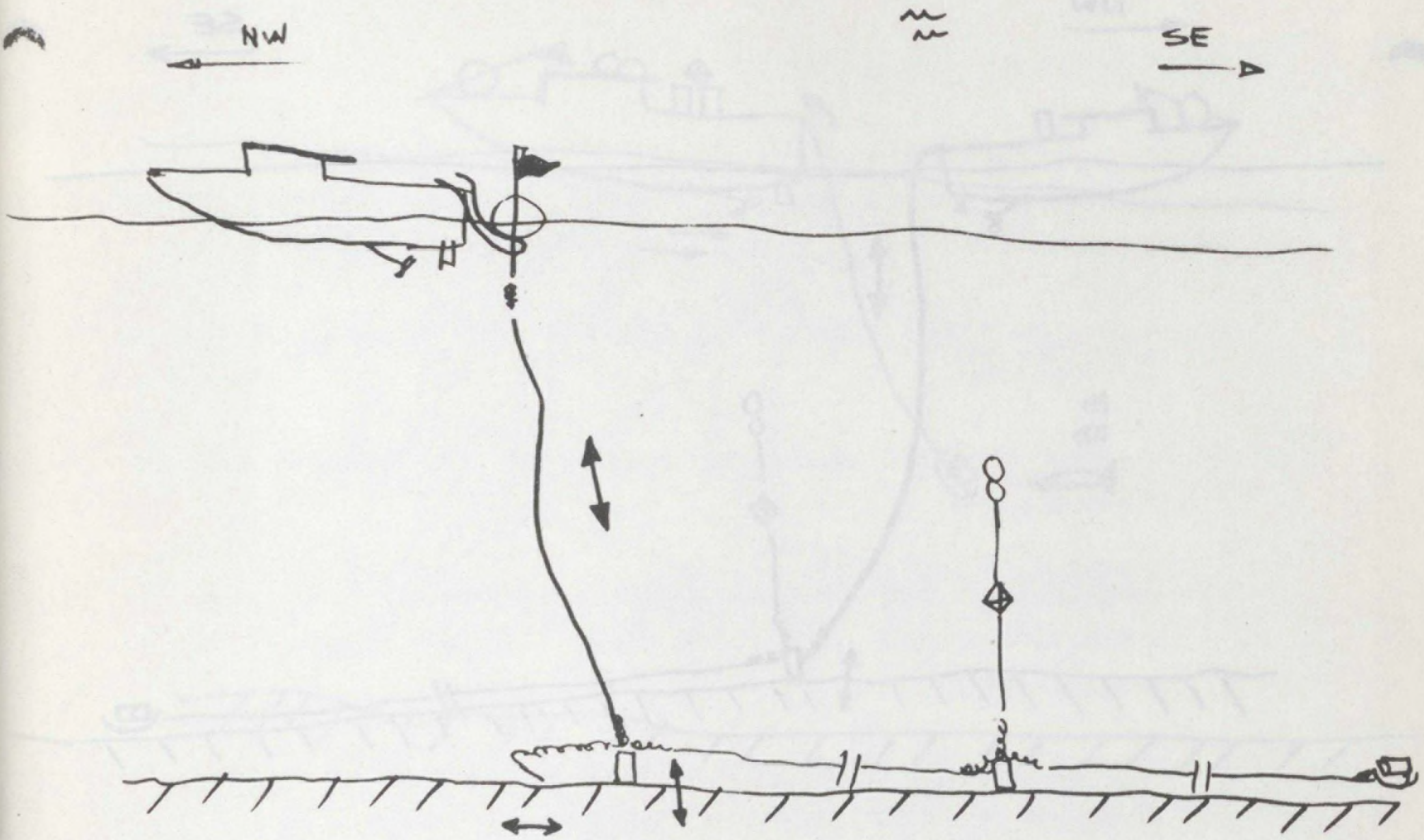
(1) Lift the surface float onto the launch. Secure the mooring line to a cleat then and allow launch motion to break the clump and danforth free.

(2) Slowly pull on the mooring line until the anchor comes free and then pull it aboard.

(3) Use the 150' line to pull up the second anchor in the same manner. When the float assembly reaches the surface, pull it on board with the triplane.

(4) Use the 200' line to slowly pull the sled with pressure sensor aboard. Take care not to damage the assembly. The launch may have to back down to relieve tension on the line.

RETRIEVAL



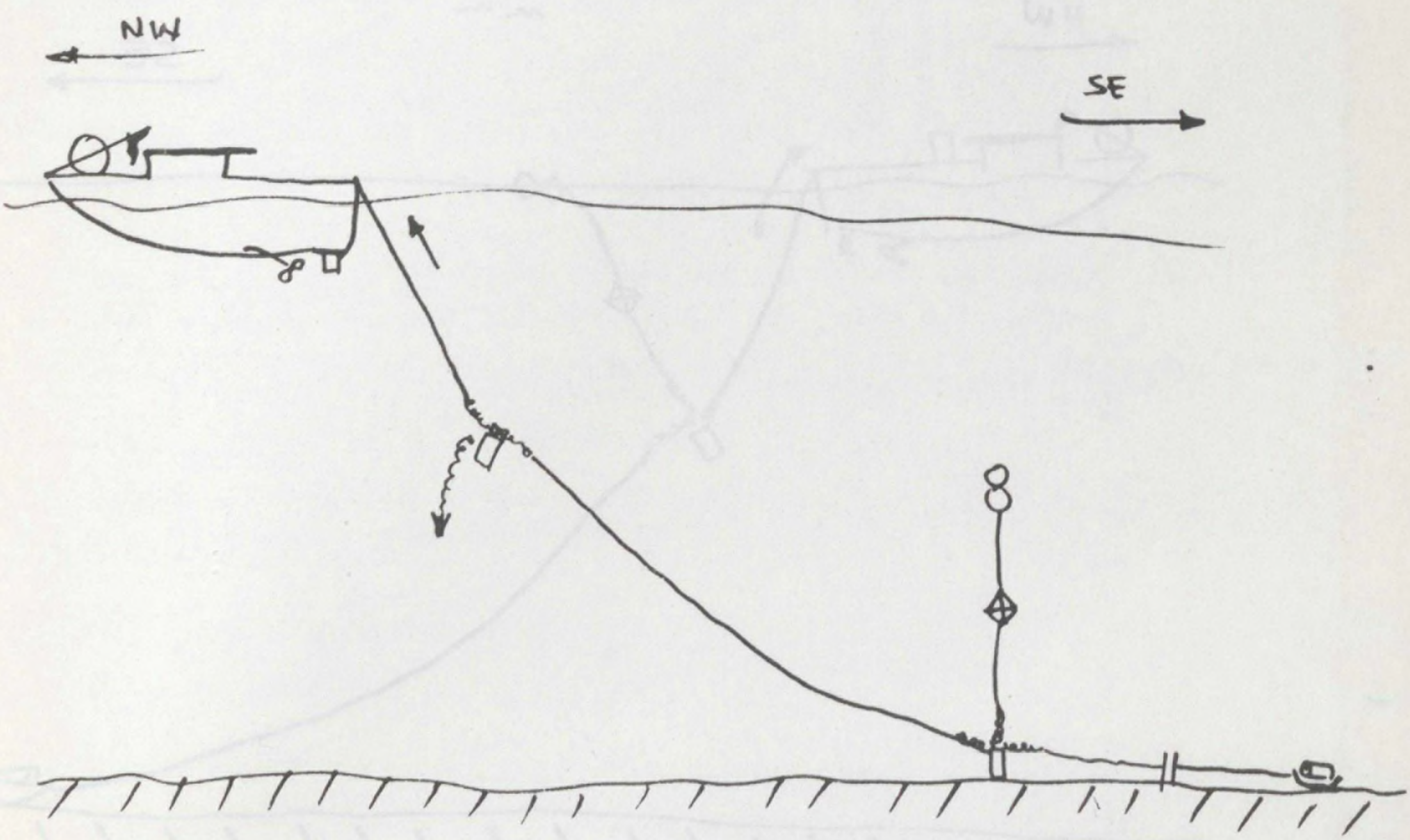


FIG. R1

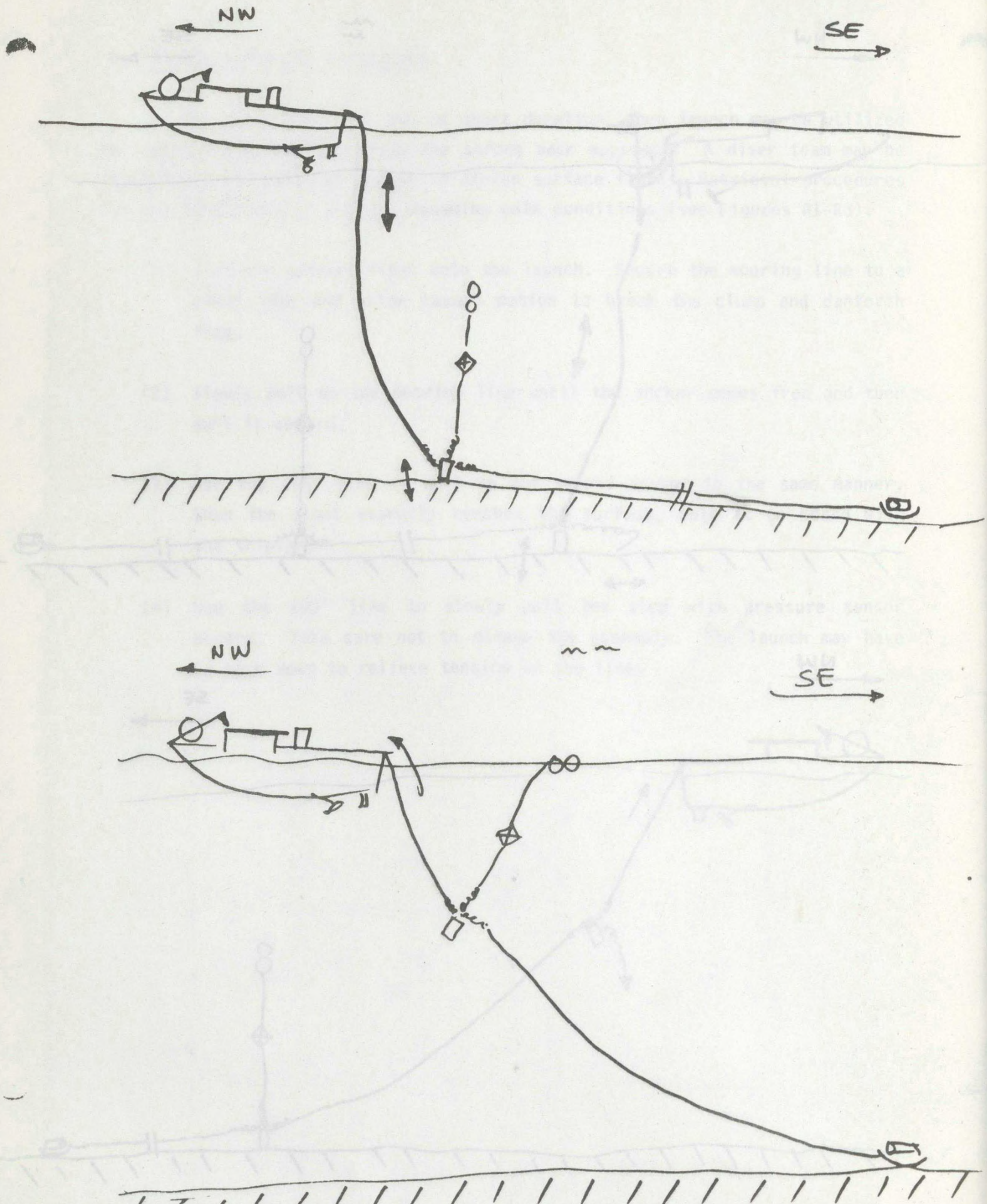


FIG. R2

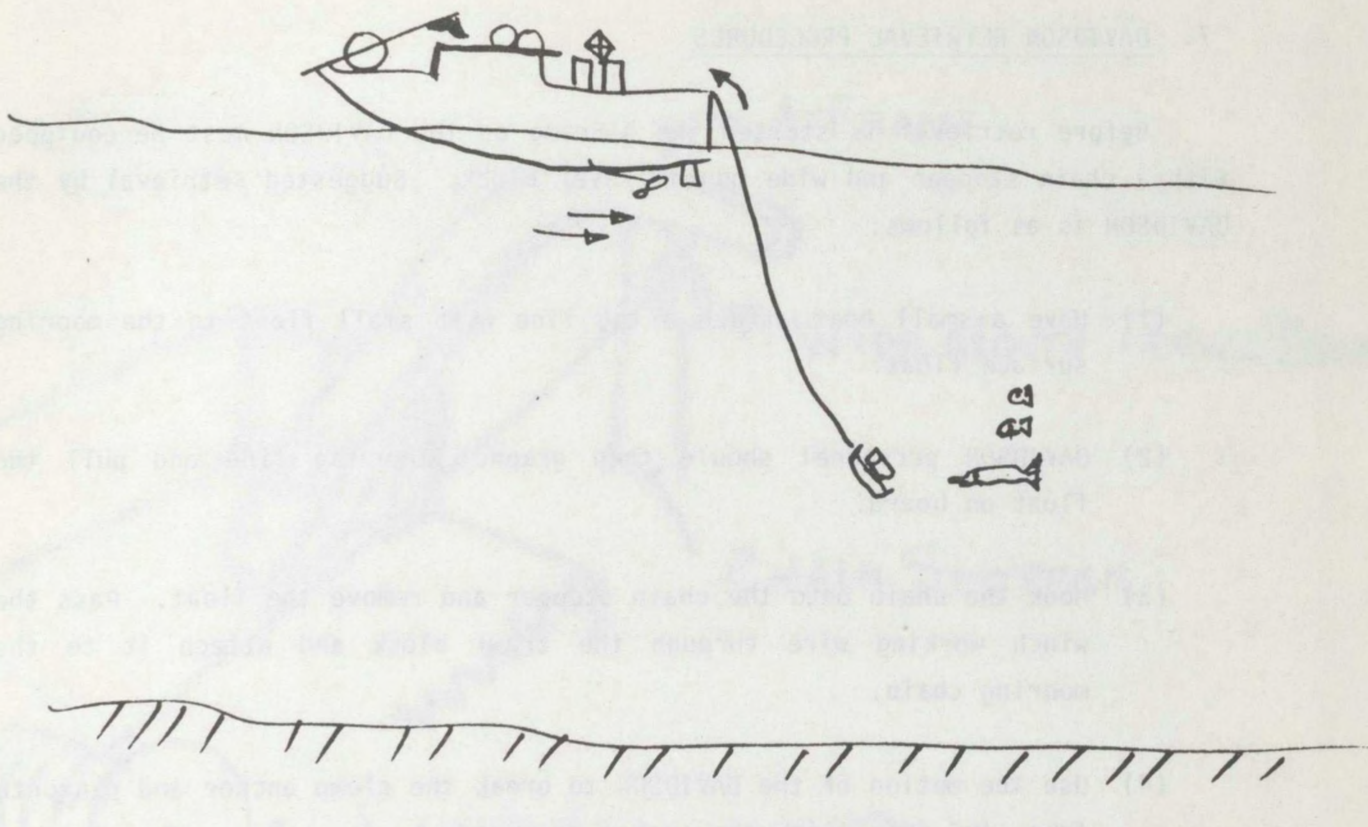


FIG. R3

7. DAVIDSON RETRIEVAL PROCEDURES

Before retrieval is started the A-Frame on the DAVIDSON must be equipped with a chain stopper and wide mouth travel block. Suggested retrieval by the DAVIDSON is as follows:

(1) Have a small boat attach a tag line with small float to the mooring surface float.

(2) DAVIDSON personnel should then grapnel the tag line and pull the float on board.

(3) Hook the chain onto the chain stopper and remove the float. Pass the winch working wire through the trawl block and attach it to the mooring chain.

(4) Use the motion of the DAVIDSON to break the clump anchor and danforth free, and then winch the anchor on board.

(5) Stopper the chain at the ground line and remove the clump anchor and small danforth.

(6) Winch on the 150' ground line until taut and then use the ship's motion to free the second clump anchor, before winching it on board.

(7) Stopper the chain at the second groung line, remove the anchor, triplane and float, and slowly winch the sled with pressure sensor on board.

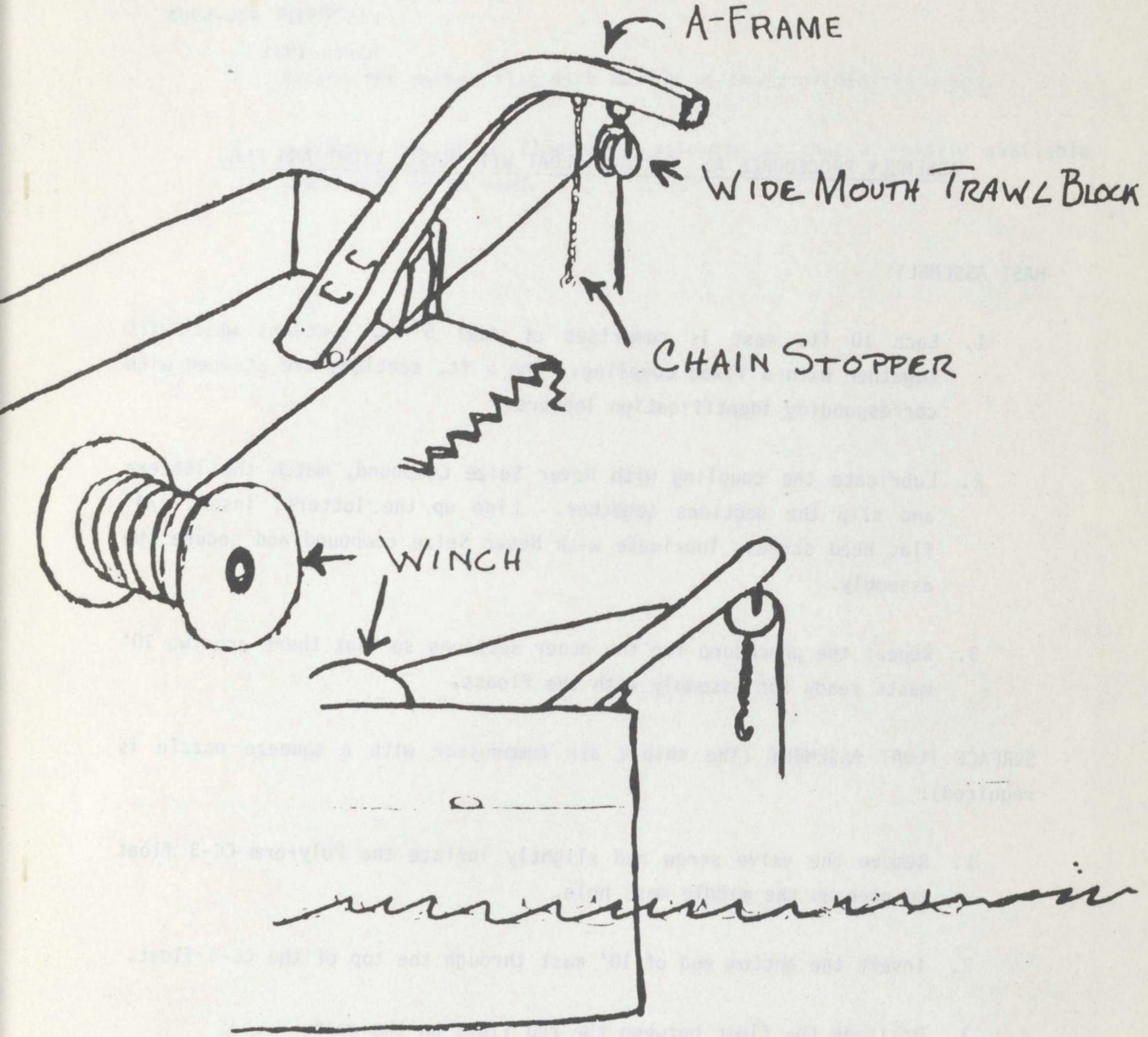


FIG. 4 DECK ARRANGEMENT

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March 1981

ASSEMBLY PROCEDURES A: SURFACE FLOAT WITH MAST, LIGHT AND FLAG

MAST ASSEMBLY:

1. Each 10 ft. mast is comprised of dual 5 ft. sections which fit together with a fixed coupling. The 5 ft. sections are stamped with corresponding identification letters.

2. Lubricate the coupling with Never Seize Compound, match the letters and slip the sections together. Line up the letters, insert 1/4" flat head screws, lubricate with Never Seize compound and secure the assembly.

3. Repeat the procedure for the other sections so that there are two 10' masts ready for assembly with the floats.

SURFACE FLOAT ASSEMBLY (The ship's air compressor with a squeeze nozzle is required):

1. Remove the valve screw and slightly inflate the Polyform CC-3 float to open up the middle mast hole.

2. Insert the bottom end of 10' mast through the top of the CC-3 float.

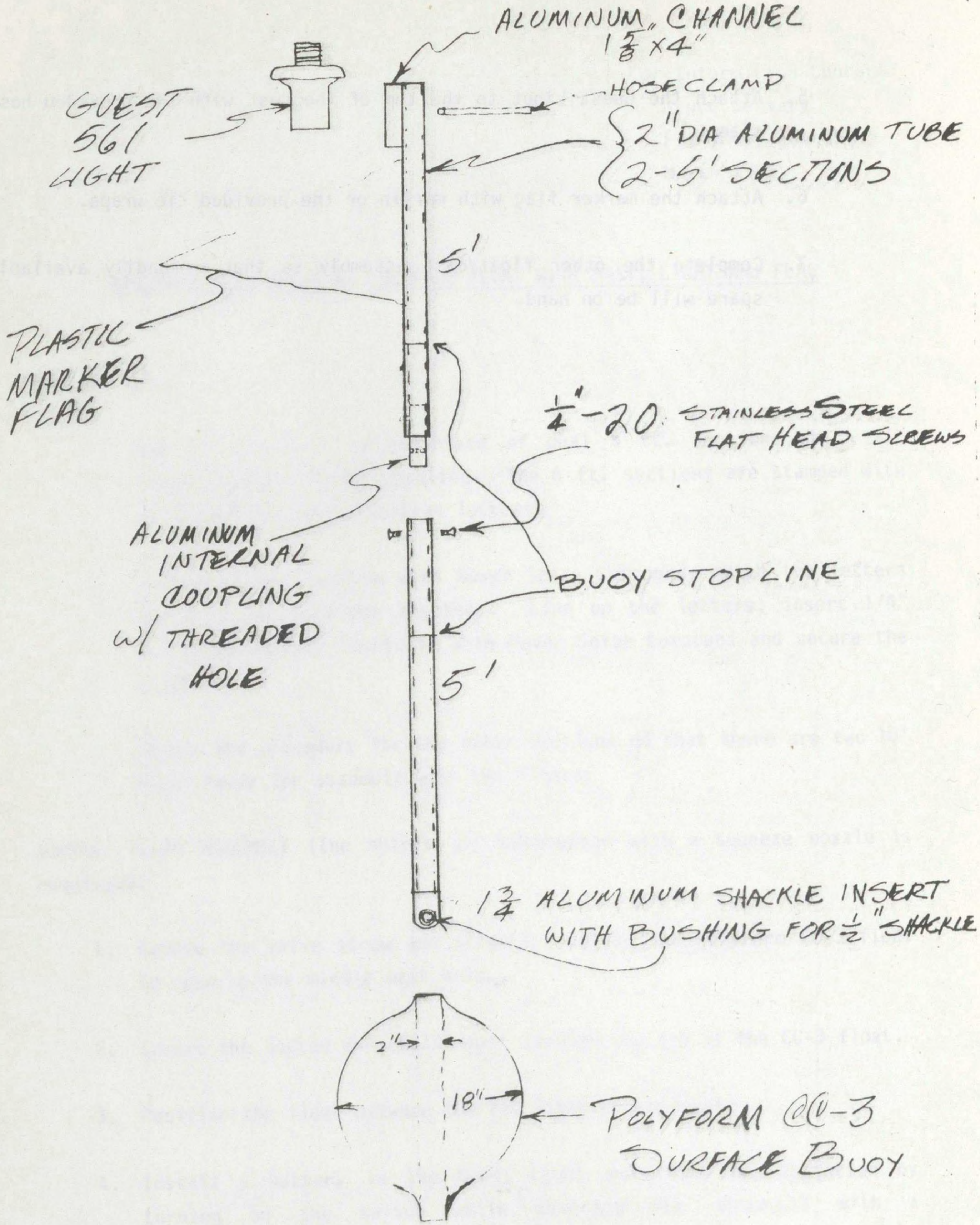
3. Position the float between the red lines on the mast.

4. Install a battery in the Guest Light and check its operation by turning on the switch while covering the photocell with a handkerchief.

5. Attach the Guest Light to the top of the mast with the provided hose clamp.

6. Attach the marker flag with marlin or the provided tie wraps.

7. Complete the other float/mast assembly so that a readily available spare will be on hand.


ALUMINUM CHANNEL
1 5/8" X 4"
HOSECLAMP
GUEST
561
LIGHT
2" DIA ALUMINUM TUBE
2-5' SECTIONS
5'
PLASTIC
MARKER
FLAG
1/4"-20 STAINLESS STEEL
FLAT HEAD SCREWS
ALUMINUM
INTERNAL
COUPLING
W/ THREADED
HOLE
BUOY STOPLINE
5'
1 3/4 ALUMINUM SHACKLE INSERT
WITH BUSHING FOR 1/2" SHACKLE
2"
18"
POLYFORM CC-3
SURFACE BUOY

For Information Contact:
Bruce Servary
FTS (301) 436-6906
March 1981

ASSEMBLY PROCEDURES B: CLUMP ANCHOR

Five clump anchors have to be poured by the ships personnel. Two are required for the primary, two are required for the spare mooring and one is a backup in case extra weight is identified during the dockside test. Six 80 lb. bags of premixed concrete are required to make these.

Fabrication procedures are as follows:

1. All buckets have been prepared with chain and rods. Mix the concrete per the bag directions. Fill all the buckets while keeping each chain vertical.

2. Let the concrete set per the bag direction.

3. Verify that each clump anchor weighs approximately 75 lbs.

4. The clump anchors should then be shackled onto the premade moorings as shown in the assembly drawing 101-035 using the I.D. tags as a guide.

APPENDIX D

PRESSURE SENSOR DATA REDUCTION

APPENDIX D

Pressure Sensor Data Reductions

Ground truth in the Bellingham tests were obtained from an Applied Microsystems TG-12A Tide Gauge. This is a compact instrument which provides in-situ sensing and recording of hydrostatic pressure and water temperature.

The tide gauge was deployed together with the triplane as described in Appendix C. The gauge was attached to a sled to insure proper orientation and to distribute its weight. The gauge weighed 11 kilograms in water. It is housed in a cylindrical case 14 centimeters in diameter and 33 centimeters long. The sled was an aluminum frame with a bearing surface of about 0.15 square meters. The gauge was switched on so that the first record was recorded at 0810 local time on 3 April (JD 93). It was placed in the water about one hour and twenty minutes later. A diver checked the assembly and set it upright. The instrument was retrieved at 1045 local time on 12 April (JD 102). It was switched off so that the last record was at 1310 local time.

The gauge was programmed to sample every minute. Each sample consisted of five ten bit words representing the following data:

pressure (MSD)
pressure (LSD)
elapsed time (N minutes)
temperature
reference number (598)

The data is recorded on 1/4 inch magnetic tape in Aanderra format. This tape was translated into a format compatable with a Hewlett Packard 9825 calculator. Tom Mero of the Engineering Services Office provided equipment and assistance for the translation.

The pressure sensor is a subassembly manufactured by Paroscientific. The accuracy is specified to be 0.01 percent. It can be modelled as a quartz crystal which varies its oscillation frequency with the total hydrostatic pressure. Each sample is the result of counting the output frequency for a fixed interval. This number is recorded as two ten bit words. The sensor's frequency is computed from:

$$F = \frac{1024\ (1024 + MSD) + LSD}{32}$$

where MSD = decimal number equivalent of the most significant word
LSD = decimal number equivalent of the least significant word

The hydrostatic pressure is given by:

$$P = A\ [1 - FT_o] - B\ [1 - FT_o]^2 \text{ millibars}$$

where A, B = calibration coefficients
T_o = oscillation period at zero pressure

A, B, and T_o as provided by the factory were:

A = 32435.5 millibars
B = 19494.8 millibars
T_o = 25.03683 microseconds

The water depth is calculated from:

$$D = \frac{P - P_a}{10\ \rho g} \text{ meters}$$

where P_a = atmospheric pressure (millibars)
g = gravitational constant = 980.6650 cm/sec^2
ρ= water column density (gm/cm^3)

Atmospheric pressure was obtained from the DAVIDSON's deck logs. The bridge watch logged atmospheric pressure at hourly intervals to a resolution of 0.1 millibars. The water column density was calculated using data from a Nansen cast at four meters depth in the vicinity of the tide gauge on

JD 102. This showed the water temperature to be 8.5 degrees C and the salinity to be 28.8 parts per thousand. The density was calculated as the reciprocal of the specific volume which is given by:

$$\alpha_{s,t,p} = \alpha_{35,\ 0,\ p} + \Delta_{s,t} + \delta_{s,p} + \delta_{t,p}$$

The four terms in this equation were evaluated from the temperature and salinity and tables in the Handbook of Oceanographic Tables (U.S. Naval Oceanographic Office special publication 68, 1966). The resulting density was 1.0225 grams/cm^3.

A plot of the time series of water depth from the TG-12 gauge is shown in Figure 10 together with hourly highs recorded from a bubbler tide gauge at the Port of Bellingham South Terminal Pier. The two data sets agree quite well. The data plotted for the bubbler gauge is the raw gauge readings after being reduced by a constant 5.4 feet. This was done so that the zero level was close to MLLW. The constant was calculated as the average difference between the raw data and predicted highs and lows from the tide tables. With respect to this approximate MLLW reference level the average of the bubbler gauge time series was 5.21 feet while that of the TG12 gauge was 96.60 feet. Thus if the bubbler showed zero tide the TG12 would read 91.39 feet. All of the survey data was corrected this same reference level. The corrected depth in the center of the patch should be 91.39 feet. Considering the likely uncertainties involved in reducing the pressure sensor data the uncertainty of this "truth" measurement is ±3 inches. Settlement of the gauge into the bottom or large variations in density through the water column would add to this.

APPENDIX E

OPERATING EXPERIENCE

Operating Experience

The following are notes on problems with system operation during these tests. The list may not be complete.

Computer

- o Crashes- Crashes occurred at an average rate of 1.6 per day or about one every five hours of operation. The frequency ranged from one to six per day. The rash of crashes on the first day of tests may have been related to loose cards in the 11/34. Some crashes may have been caused by improper operation such as the operator attempting to enter data before beginning real-time operations or operating with the Gould off-line. Modifications made on the JD 104 corrected navigation problems that may have caused crashes. Periods of large power line fluctuations observed with a line monitor seemed to correlate well with increased frequency of crashes. Bus errors were encountered restarting during power line fluctuations on JD 116.

- o Saturation and Tape Buffer Overflow - These messages were observed several times on JD 100, 105, and 106. Three times the error messages were simultaneous and occurred at the same time as paper feeds on the Gould. There were some data lost at these times.

- o Data Loss on SSF - No data was recorded on the survey summary file for a 20 minute period on JD 112. The terminal monitor tape shows activity during this period which should have been logged on the SSF. There is no record of an indication that data was not being recorded.

- o SSF Too Large - Running SMITEN during post-processing requires scratch space on the SSF disk. The SSF for JD 98 was too large to permit SMITEN to run. There are no guidelines or indicators to alert the operator that this problem is being created.

- o Bad Spots on SSF - Bad spots were found on the SSF for JD 106. Precautions must be taken to prevent such data loss.

- o Exit Too Soon - A number of runs were lost because exit was made from SURVEY before 77.2 seconds had elapsed after good data had been acquired. Since the delayed heave was not available the data could not be post processed.

- o Time Search - COP could not locate data between midnight and 0100.

- o Magtape Switching - COP does not recognize that the tapes may have been switched due to a read/write error. The data should be spliced together before running COP or errors will result from the program's assumption that the data is continuous.

Contour Plotter (Gould)

- o Paper Feeds - Short, blank sections continue to be produced randomly by the plotter. These instances are sometimes related to other system malfunctions such as saturation errors or tape buffer overflows. Paper feeds appeared to be sensitive to the ship's roll. "GD-NRDY" (Gould not ready) was observed at the same time as a 15 degrees roll on JD 117.

- o Contour Glitch - A large transient is plotted when the scale is changed to a shallower depth. This is due to a patch in the SURVEY program installed to prevent a possible crash situation.

- o Intermittent Failures - Malfunction of the BS^3 Gould was thought to be a potential crash source. This unit was replaced on JD 103 with a rental unit felt to be more reliable. The BS^3 unit exhibited several failures including refusing to advance the paper on JD 100.

Position Plotter (DP3)

- o Swath Marks - This plotter draws swath marks when it detects that the ship has moved a certain distance. Erratic positioning can cause it to believe that the ship has moved a great distance. The plotter then draws many swath marks and gets behind in plotting positions.

- o Fix Number Alignment - Fix numbers are drawn on the position plot at random orientations. The resulting plot is very difficult to read.

- o Off Chart Response - Plot errors result when the pen goes off the chart. This can result from bad navigation data. Difficulty is also encountered if the pen is off the chart when the plotter is turned on.

TMS

- o Interface - No data was recorded on the SSF after the first day of operations in most areas. No data at all was recorded in the Cape Disappointment area. In the San Juan Islands area the data first became erratic, than ceased on day 104.

- o Command Link - Command link communication was erratic on JD 96. In the San Juan Islands on JD 104 numerous error messages were received from a shore station. The shore station would not respond to commands to disable error transmissions.

- o Tide Data Handling - Post-processing software presently handles only predicted tides. The use of real-time tides from the TMS or hourly highs from marigrams requires software changes.

Positioning

- o Wild Points - Wild points were observed in all locations when operating with Miniranger. This is presumably due to mulitpaths and reflections. When operated with the pen down (not normal mode) the same erratic positioning was observed on the HYDROPLOT system. Performance at times was poor enough to create difficulty steering and force suspension of operations. The data recorded is tagged with these erroneous positions. If positioning is only mildly erratic it is observed as a fluctuation of the speed estimates used to compute the size of a plottable unit area in COP. If positioning is more erratic "BADNAV" errors are reported. Still larger errors cause problems with the position plot.

- o Reliability - There were numerous failures of the positioning equipment. Nearly all Miniranger operations were conducted with a temporary RT unit mounted on the flying bridge after the mast mounted unit was determine to be malfunctioning. One shore station failed on JD 98. Another failed on JD 106. The ship station was erratic on JD 104 and 105. It blew a fuse on JD 112 after producing bad data for several minutes. The poor reliability may have been aggrevated by operating the system at a higher update rate than normal. This was done to improve the accuracy possible from a pulsed system. Raydist was used on four days. A shore station failed on JD 101.

- o Lane Jump Handling - A lane jump may have occurred on JD 117. There is no provision to handle this possibility in post-processing.

HRP

- o Communication Errors - Several errors were reported on JD 105. The fuse on the 180 V power supply in the BOSUN blew at that time. Since the BOSUN sets the timing for the HRP communication it is possible that transients in the BOSUN were responsible for these HRP errors.

BOSUN

- o Lost Gates - There were numerous instances when the sonar gates lost track of the bottom. When this happened the system would stop logging data. No indication is made to the operator. There were instances when this condition existed for 1/2 hour before being noticed. The condition should be automatically sensed, the operator notified, and an automatic search started.

- o Lost Soundings - In certain sea conditions a large percentage of the echoes are not detected by the system. Switching between the dome and fairings may change the detection probability. JD 100 and 117 are examples of this.

- o Fuse - A fuse blew in the 180 V power supply on JD 105. No cause was identified.

- o 20 degrees/5 degrees Switch - The effect of this switch on the data quality is not clear. It apparently had little effect over the flat soft bottom of Bellingham. It may have detrimental effects on accuracy in other areas. It may improve tracking ability in some situations. The beamwidth should be fixed at five degrees unless there is clear reason for changing. If changed it should be logged in some way. Attenuation changes should also be logged.

Sound Velocity

- o XSTD - The Grundy XSTD System was the most suitable of the systems used to measure sound velocity. It, nevertheless, had significant drawbacks. First, the probes are expensive - $210 apiece. Second, the probes frequently produce bad data. In these tests eight of 28 or nearly 30 percent gave bad data. Third, it is very difficult to read the chart with the desired accuracy in depth because of its compression. Fourth, transient behavior as the probe enters the water is not repeatable. Sound velocity at the transducer depth is critical and this depth is usually in the transient region.

- o Nansen Cast - This is a very reliable and accurate method to determine sound velocity but it is very time consuming and gives only point values rather than a profile.
- o Martek - The equipment used during these tests was mismatched and consequently uncalibrated. The system is limited to shallow depths by the cable. It is deployed by hand over the side and care must be taken to avoid fouling the propellers.