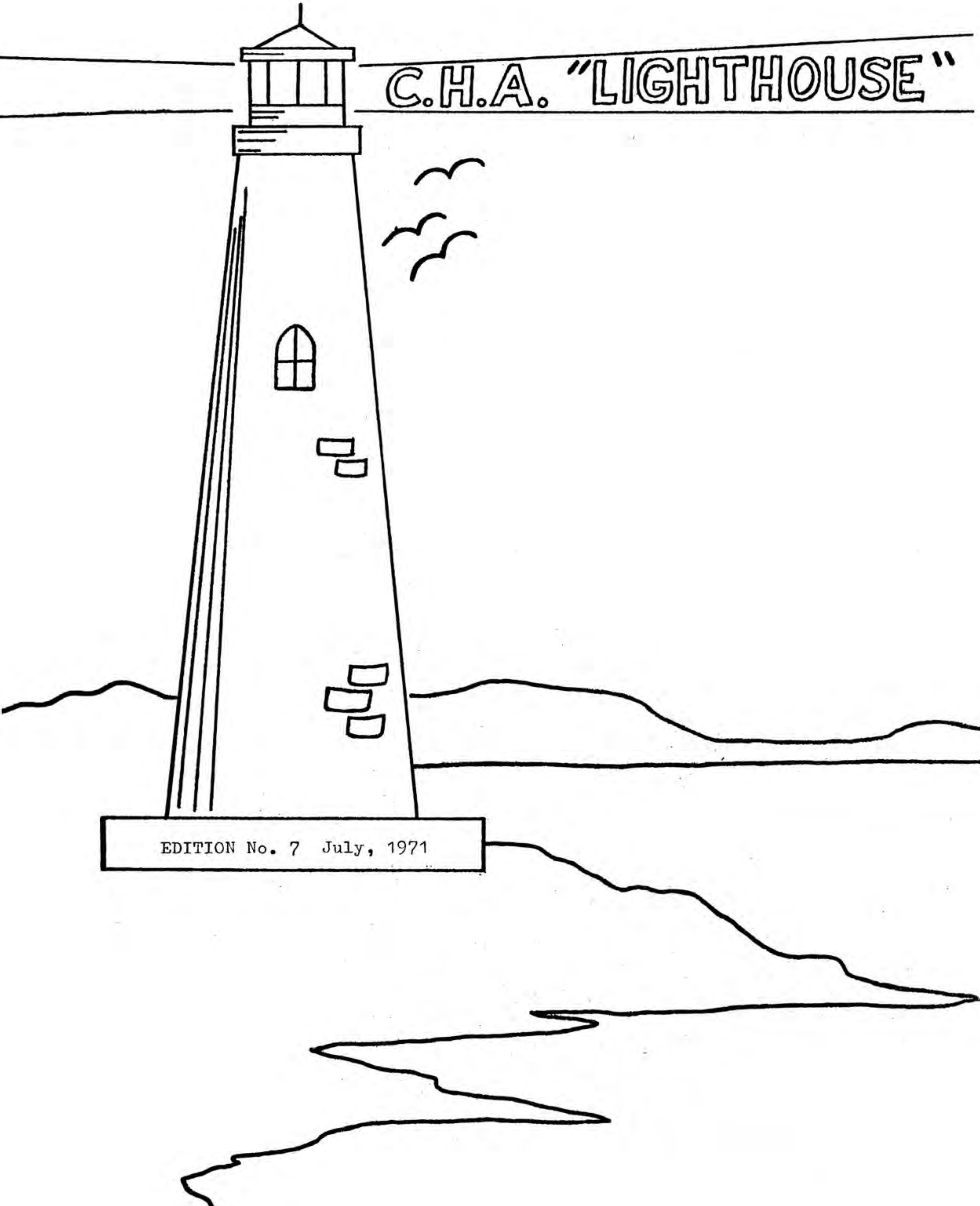
C.H.A. "LIGHTHOUSE"



EDITION No. 7 July, 1971

This is the seventh edition of the CHA "LIGHTHOUSE" and we, the Editors, sincerely believe that each new edition is improved over the past. This has been possible because of the many contributions from all Branches and the hard-sell efforts of a few individuals with special credit due to Mr. G. Macdonald. The "LIGHTHOUSE" is the official publication of the Canadian Hydrographers' Association and as the association grows we hope the Lighthouse will also grow to reflect the Hydrographic and Offshore surveying interests for all of Canada.

The "LIGHTHOUSE" can only grow in direct proportion to the interest expressed by all members. Your articles and comments on the "LIGHTHOUSE" are sincerely invited.

While most articles in this issue are of a technical nature, we invite any interesting articles of any length, which are in any way related to Hydrography or Offshore surveying.

Please send your technical articles, humorous anecdotes, short stories, letters, rumors, complaints or any other bits of information to:

The Editor
Canadian Hydrographers Association
Marine Sciences
P.O. Box 5050
BURLINGTON, Ontario

The Association appreciates the support and encouragement of the Canadian Hydrographic Service, without which this publication would flounder.

LETTER TO THE EDITOR

Burlington, Ont.,
April 1971.

Dear George,

In reference to the article in the April, 1971 edition of the CHA Lighthouse by Mr. A.D. O'Connor, concerning the MRB-2 operation on the "William J. Stewart", I would like to make some comments.

The writer of that article mentions that he realizes that statistics can prove anything etc. If that is the case then he should have indicated why, for instance, on June 8th only 6.6 miles were sounded with MRB-2 and 49 miles with sextant. What problem did arise during that day and any other days where the daily mileage obtained with the hydrodist is considerably less than that obtained with the sextant method? The writer also indicates that 2 hydrographers were used for the sextant method and 3 for the hydrodist mode. However this is a deceiving statement. What was the total complement of manpower used in each case? In Central Region we use only one hydrographer for a hydrodist operation. However, the total complement varies from 3 to 4. We use 1 remote operator (a student assistant), 1 hydrographer on the launch with a coxwain and 1 seaman to operate the sounder. When the digitizer is used the seaman is no longer necessary.

From experience in Central Region it has been shown that the average daily mileage can be between 20 and 30 miles as proven in 1969 on the Batiscan/Lake of Two Mountains Survey. (Sextant work never reached this.) This amount of daily sounding took no more than 5 minutes to ink on the boatboard at the end of the day and another 5 minutes to space the work. A lattice was used that showed the distance circles at every 50 metres at a scale of 1:10,000 and also showed the radii of each and every degree.

During 6 months of almost continuous use there were no equipment failures caused by the hydrodist units themselves.

The writer of the above-mentioned article states "inability to receive a trackable signal for no apparent reason" and subsequent equipment checking revealed no apparent faults. I suggest to him that one should not attempt to work with hydrodist on days when the water surface approaches the characteristics of a mirror. Multiple reflections will occur in this situation and cause multiple circles on the CRT, making it impossible to to trace the "blip". This becomes worse when the dipoles have little elevation.

......cont.

Several of Central Regions set-ups had the remote station no more than a few feet above High Water and the launches sounded as far as 7300 metres away from it, while still receiving a good signal.

Our "shore crew" (one man) always takes his lunch with him and no arrangements have to be made for him. We too had problems at times getting him ashore because of waves and/or tides. I agree that a fair amount of time is lost by this but we made up by being able to come back with more sounding done (more accurately) and no splitters to be run afterwards, using hydrodist during a shortened working day as compared with sextant sounding with a full day available.

I fail to see why hydrodist is not flexible as compared to sextant sounding. If landing is not possible I would assume that the seas are too rough. I wonder how accurate sextant sounding in this type of weather would be. Sextant fixing is also rather inflexible. What happens when no accurate fixes can be obtained? One would have to establish additional sounding marks to eliminate this and considerable time is lost doing this.

As far as Mr. O'Connor's comments on elevations are concerned I suggest that only a short but sturdy tower will increase the range of the MRB-2 considerably. For instance, if the elevation of the boat "dipole" is 12 feet (average in Central Region) and the shore "dipole" is increased from 5 to 10 feet, then the line of sight distance will be increased by 1 nautical mile.

In Central Region we also use Motorola PT 300 radios and, although they are found to be inferior for general use, they were quite good for use with hydrodist. One was always within line of sight range of both the MRB-2 and the Motorolas because the Motorola aerials were mounted on top of the masts that support the dipoles. Special "star-antennas" made by our electronics section to improve reception were mounted underneath the Motorala "whip".

In Central Region it has been recommended to use headphones with the Motorolas to increase the operator's perception of the transmissions, when the loud noise of the boat engines interfere.

This brings to mind another comment concerning radio communications. What does this have to do with hydrodist? Granted it is very essential to its operation, but it has nothing to do with the internal operation of the set. If the radios are no good, why continue to use them? Having the trucking company

....cont.

on the same frequency is no fault of the MRB-2.

The fact that the batteries ran down is certainly not an "unexplained failure" of the MRB-2 (if it is checked and nothing found wrong), but simply poor charging. Our batteries have enough "juice" left at the end of the day to be used again the next day. However, it is bad policy to let the batteries run down too much and we charge them every night. Usually towards the end of the season these batteries had to be replaced. If the same batteries were used every day they would not last more than five to six hours.

I am surprised that Mr. O'Connor did not mention visibility. I know that fog is as common on the west coast as haze is in Central Region. This makes hydrodist as limited as sextant work. However, range can be improved by mounting flashing amber lights on the launches, which will show up really in haze and light fog, and increases the value of hydrodist as compared to sextants. Incidentally, Central Region did not mount these lights for that reason. While using the lights as a warning (caution) symbol to other traffic their benefit to hydrodist was discovered.

For full fledged information on any methods I recommend the reports by Messrs. P. Dal Bianco (1969, Lower St. Lawrence River) and J.I. Robichaud (1968-69 Batiscan/St. Lawrence River).

In conclusion, although Central Region surveys have been planned and executed around hydrodist, I agree that it is not a major tool and is used mainly in selected situations. However, is not every method of positioning limited to ots particular application? The reason there is such a variety of positioning systems is to make sure that in any given situation the best system would be available.

G.H. GOLDSTEEN

Editors Note: "This might get something going."

CONTENTS

EVALUATION OF THE KLEIN ASSOCIATES
SIDE SCAN SONAR

BY

G.E. RICHARDSON

In the leadline days a thorough search of the seabed was impossible. Nowadays even with the continuous profile given by a vertical echo sounder a thorough search is still very difficult.

An economical and expedient method of obtaining 100% bottom coverage would now be welcomed and may soon be a necessity in most hydrographic surveys.

This report describes some of the tests with the Klein Associates Side-scan Sonar carried out during June and July, 1970.

This is just one more episode in a continuing search for an instrument that will let us clearly "read between the lines".

DESCRIPTION OF EQUIPMENT

The Side Scan Sonar Technique

A side scan sonar utilizes a towed underwater fish which sends out short high-frequency, high-intensity sound bursts. The sound is beamed to either side of the towed fish in a direction perpendicular to the direction of travel. The sound beams are narrow in the horizontal plane and wide in the vertical plane.

On the ship a graphic recorder sends out trigger pulses to the underwater transducers. These transducers then emit the sound pulses. When echoes are received from targets on the ocean floor, they are converted to electrical signals which are processed and sent up the tow cable. They are then further processed into a form suitable for the graphic recording mechanism. The shipboard recorder simultaneously makes a permanent strip-chart recording of both channels of incoming information. The recorder scales are calibrated so that distance to a target can be accurately determined.

The Basic System

The Klein Associates Model MK-300 Side Scan Sonar consists of the Model MK-300A Recorder and the Model MK-300B Towfish plus an inter-connecting tow cable and a power input cable. The towfish contains linear arrays of piezoelectric crystals which are used both as transmitters and receivers. Self-contained inside each transducer is a transducer driver, a preamplifier and a buffer amplifier which drives the towing cable. Power for the transducer driver and the amplifiers as well as a trigger signal is sent down the cable from the shipboard recorder.

The recorder takes the incoming DC power and converts it to the various voltages needed for electronic circuits. The recorder contains trigger circuits, time-variable-gain circuits and controls, power controls, range and paper speed circuits and controls. The dual-channel graphic recording mechanism, as well as all electronics, is self-contained in the recorder and towfish packages.

The towfish is normally towed by the cable supplied. This cable is water-blocked and contains a special woven dacron strength member. It has a rugged, abrasion resistant polyurethane jacket.

The towfish is towed either off the stern, either side, or off a boom anywhere on the ship. Towing depth used will depend on the type of terrain and the mission involved. The fish has adjustable diving planes which can be tilted to create a downward force as the fish is pulled through the water.

System Specifications

KLEIN ASSOCIATES

Model MK300 Side Scan Sonar

Tentative Specifications

Operating Frequency	50 Kilohertz
Pulse Duration	0.1 milliseconds
Horizontal Beamwidth	two (2) degrees
Vertical Beamwidth	twenty (20) degrees (tilted down 10 degrees from the vertical)
Input Voltage	23 to 30 volts direct current
Input Power	150 watts
Range Scales	100 meters, 200 meters and 400 meters
Paper Speeds	Continuously variable
Paper Width	19 inches (48 cm)
Printing Width (each channel)	8 inches (20 cm) approximately
Size	Shipboard unit 8½" high (21.59 cm) 31" wide (78.74 cm) 19¼" deep (48.90 cm) Towed unit 48" long (91.44 cm) High 14" (25.40 cm) Wide 13"
Weight	Shipboard unit 100 lbs. (45.4 kg) Towed unit variable, according to tow depth
Scale Lines	every 20 meters
Tow Cable Diameter	0.375 inches (0.95. cm)
Standard Cable Length	100 meters (longer lengths available on special order)

Specifications are subject to change without notice.

Description of Tests

A standard 27 foot wooden hull launch, the "Owl", with a top speed of about 7 knots and a 25 foot Bertram with top speed of about 18 knots were used for the tests. To avoid kinking and sharp bends the towfish cable was snubbed around a short piece of 10 inch diameter pipe fixed upright at the stern of each launch.

The Bertram launch was equipped with mini-fix and this launch and positioning system was used for the first week of tests. The "Owl", equipped with a Motorola RPS positioning system was used for the remainder of the time.

The Klein side scan sonar was leased for a period of one month commencing June 23, 1970. A representative of Klein Associates accompanied the gear for the first four days primarily to give instruction in the use of the equipment.

First tests were conducted in the shallow water of Victoria Harbour. (See figure 3 for location of test areas.) Good targets (a breakwater, concrete wharves, pilings, etc.) at short range gave promising resolution. (See figure 2.)

Two weeks of testing around Coghlan Rocks and in the Brodie Rock to Lee Rock area failed to produce conclusive results. These areas are shoals of 20 feet or less and consequently abound with kelp and other marine growth. This probably caused some attenuation of the returning signal. However, several electronic failures although repaired were felt to have affected the strength of the transmitted signal.

On July 6, Mr. M. Klein, the builder of the equipment visited us and did some fine tuning to the transducer and made minor modification to the transmitter and receiver components. Subsequent trials around Brodie Rock showed some improvement in resolution but the range still was under 300 m.

The last tests on July 10 were in conjunction with a shoal exam of an 8 fm patch out in the deep water of Haro Strait.

It was on these tests that for the first time I was able to achieve a proper balance of tuning on all the controls. A series of lines 200 meters apart with the sonar set to scan 200 m. each way were run, covering the shoal out to the 50 fm. line. Also for the first time shadowing (absence of any signal return) was quite evident. Shoal areas and areas of changing topography were easily identified.

The area was fairly deep and there was probably very little weed growth. This, I think, was a factor in the clarity of the signal but finally achieving the correct tuning was as big a factor.

No changes were made to the factory setting of weight or dive fins on the transducer fish. Between 4-5 knots was found to be the best tow speed. With 20m. of cable out the fish would travel at about 8 m. deep.

CONCLUSIONS - POTENTIAL

Side Scan Sonar would seem to offer great potential for describing the ocean floor but there are several reasons why it has not been more widely used.

(1) The sound energy can return as multiple echoes from the bottom or the water surface as well as returns from, interfaces, schools of fish, or bubbles within the water itself.

(2) The absence of returning signal can have several interpretations (shadow behind a strong target, smooth mud bottom, bottom falling sharply away).

(3) Distorted graphic records. Laterally the graph can be set to one of several fixed scales, along the track the scale will vary with the speed of the launch and the speed of the paper.

(4) The lateral range of the equipment tested is 400 meters and does not seem to exceed 800 m. in any other commercial equipment.

(5) The transducer must be towed, and preferably within 50 m. of the bottom.

The first three of the previous items can produce a very confused graphic display but it is not beyond interpretation of a well-trained and experienced operator. (See figure 1).

The limited lateral range is a problem in deep ocean areas where we want to go further, quicker. It will not be a hindrance in harbours or inlets less than a mile wide.

Although towing can be troublesome and costly (if you lose the fish) one great advantage of a towed body is that the direction of travel of the body is determined by the water flow past the body. Therefore, the crabing motion of the vessel in wind and current or the momentary course corrections necessary for line keeping are in general not transferred to the body.

Several uses were envisaged for side scan sonar prior to the tests:

(1) As a sweep giving 100% bottom coverage between lines of sounding, in shipping channels, harbours, dredged areas, etc. - this is quite feasible if conducted at the same speed as a normal wire sweep and with about 25% - 30% overlap. The limits of a dredged channel could be easily identified but it would take a very experienced operator to say with any certainty that there was nothing shoaler between the lines.

(2) Detection of wrecks and deadheads: - The location of wrecks should be relatively routine particularly more recent ones which have not had time to break up or silt over.
The location of deadheads will be more difficult. On the 400 m. scale the transducer puts out just under 2 pulses per second. At 5 knots any specific point 150 meters or less away will return less than 3 pulses. With the paper speed at 100 lines to the inch this probably won't be detectable. By setting the range at 100 m. which has 7.5 pulses per second, then using a slower and more detailed search pattern most deadheads should show up. This would be the same as the sweep mentioned in Item 1.

(3) Shoals reported by navigators or existence doubtful shoals shown on current charts: - Considerable time is spent every year looking for these generally non-existant shoals, usually concluded with a wire sweep covering a large area. These shoals as reported are generally isolated peaks surrounded by deep water. Under these conditions Side Scan Sonar produces a relatively clear picture and this may be the biggest single use for this equipment. With the range set to maximum, a fairly large area (about 8 square miles) can be covered in one day. Anomalies only can be investigated in detail rather than the whole search area.

(4) The normal spacing of sounding lines may be spread out in deeper generally featureless areas: With the high speed sounding launches about 3 times more linear distance can be covered than with the Side Sonar launch, in any given period. Spacing more than every third line may not give enough detail for contouring. Therefore, this may not be any advantage until we can go much faster with a towed transducer.

(5) Identify bottom composition: - The trained observer would be able to identify rock, mud, or sand, however, coral, gravel and particle size would be very difficult and colour would be impossible. This use is therefore limited.

Several theoretical uses have come to mind while doing the research for this report.

A Side Scan Sonar reconnaissance of an uncharted area could be used to get a general picture of the area for planning purposes. Using only a radar and the coastline for control one trip up and back would provide two vertical profiles plus bottom coverage of up to 1600 m. (5250 feet) wide. In many inlets this would be complete coverage. Scales, line spacing, etc. and perhaps even the priority of the survey could than be planned with more certainty.

In rivers where the safe channel may change from year to year, a survey must be done quickly and the information passed to the mariner as soon as possible. Once reasonably good control has been established perhaps one pass (maybe two) with the Side Scan Sonar could delineate this channel. A chart could be quickly produced showing just the line of track sounding plus the estimated limits of the safe channel. Considerable time is saved by placing the emphasis on where the hazards "aren't" rather than where they are.

Plotting as you go on a previously prepared base sheet, showing shoreline, control, ranges, etc., data could be returned to H.Q. every couple of days and a finished product could be ready only a short time after the survey was finished.

In shallow water areas such as this the advantages of a towed transducer may be outweighed by the single disadvantage of grounding resulting in damage or loss. A fixed strut transducer might have to be used.

We should continue to investigate Side Scan Sonar as changes in frequency and/or beam angle may give us the definition that we require. I would definitely want more field experience with Side Scan Sonar before I could profess to any degree of competency as an interpreter.

EXPLANATORY NOTES ON FIGURES 1 & 2

Figure #1:

A reproduction of a typical side scan sonar graph (approx. 1/3 size). The scale lines are at 20 meter intervals. The track of the towing vessel is along the line of fix numbers. (Fixes are approx. 250 meters apart.) The first heavy straight line on each side is the transmission line. The second lighter straight line is the signal return from the water surface. The distance between the transmission line and this line indicates the depth of the transducer fish. In this case about 8 meters. The irregular line is signal return from the bottom directly below the transducer. Subsequent returns out to 200 meters on each side make up the remainder of the graph. On the port side, 100 meters out from Fix #32 can be seen the beginning of a ridge leading to a 13 fathom head 200 meters out from Fix 33. On the starboard side is a similar ridge leading to a shoal beneath the transducer just past Fix 33. Note the multiple echos in lower left corner.

Figure #2:

Sonar graph entering Victoria Harbour. See Figure 4 for approximate track. Range is set to 100 meters. Although the horizontal beam width is only 2 degrees, there are side lobes which are quite strong at these short ranges, consequently the shape of the wharves is somewhat distorted. The bottom on the port side is mud, sloping gently away from the boat and very little signal is returned.

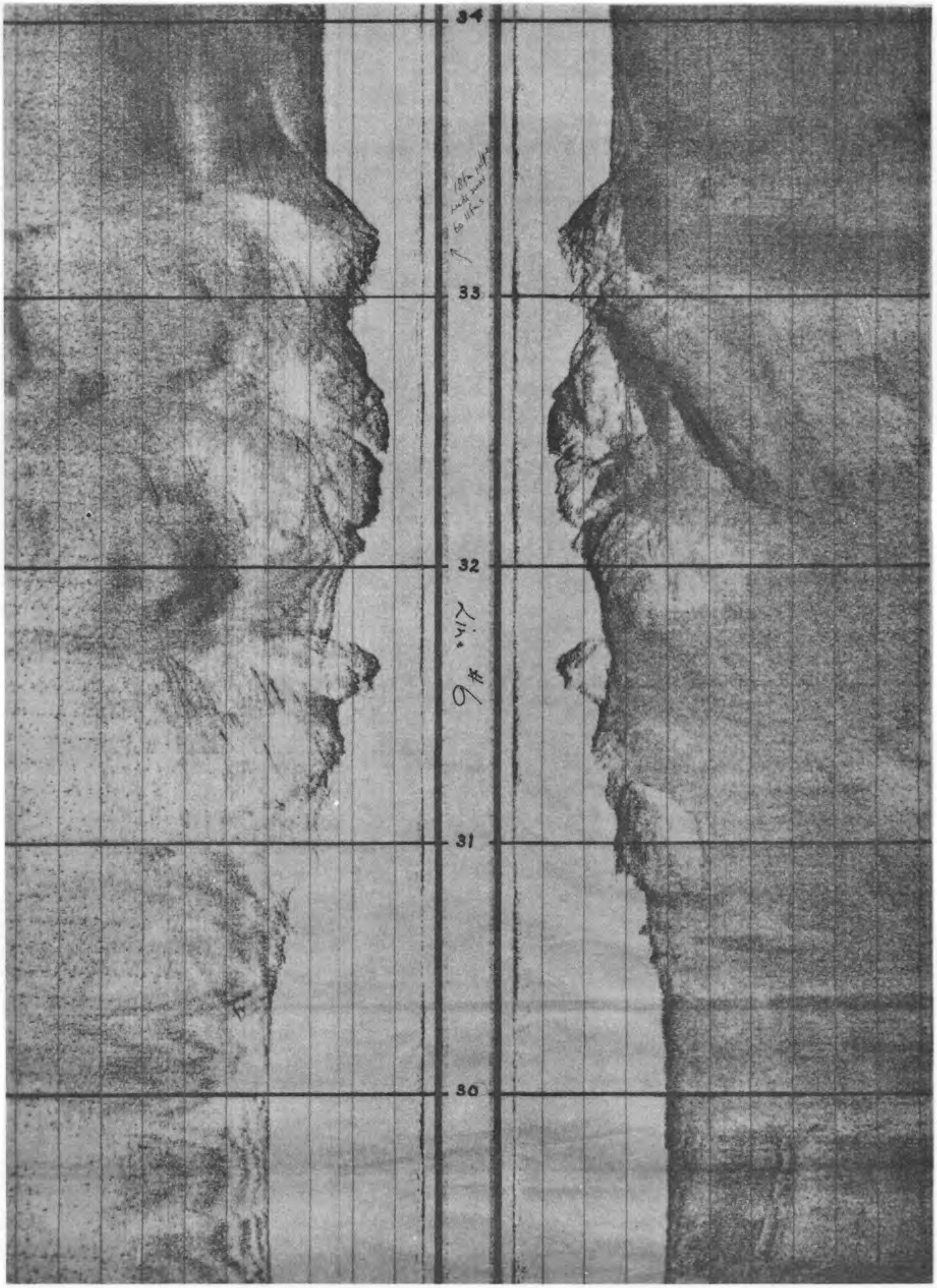


FIGURE #1

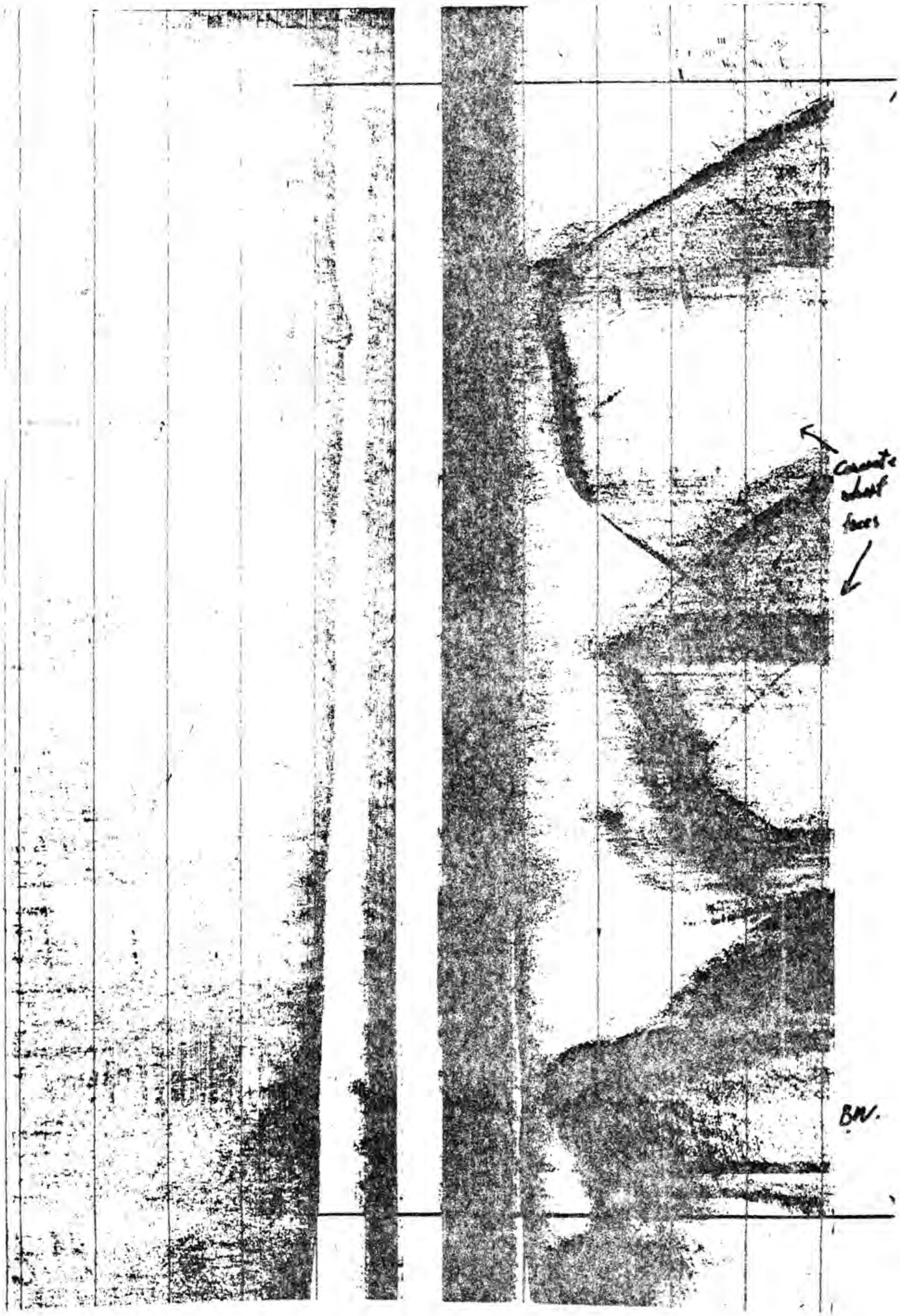
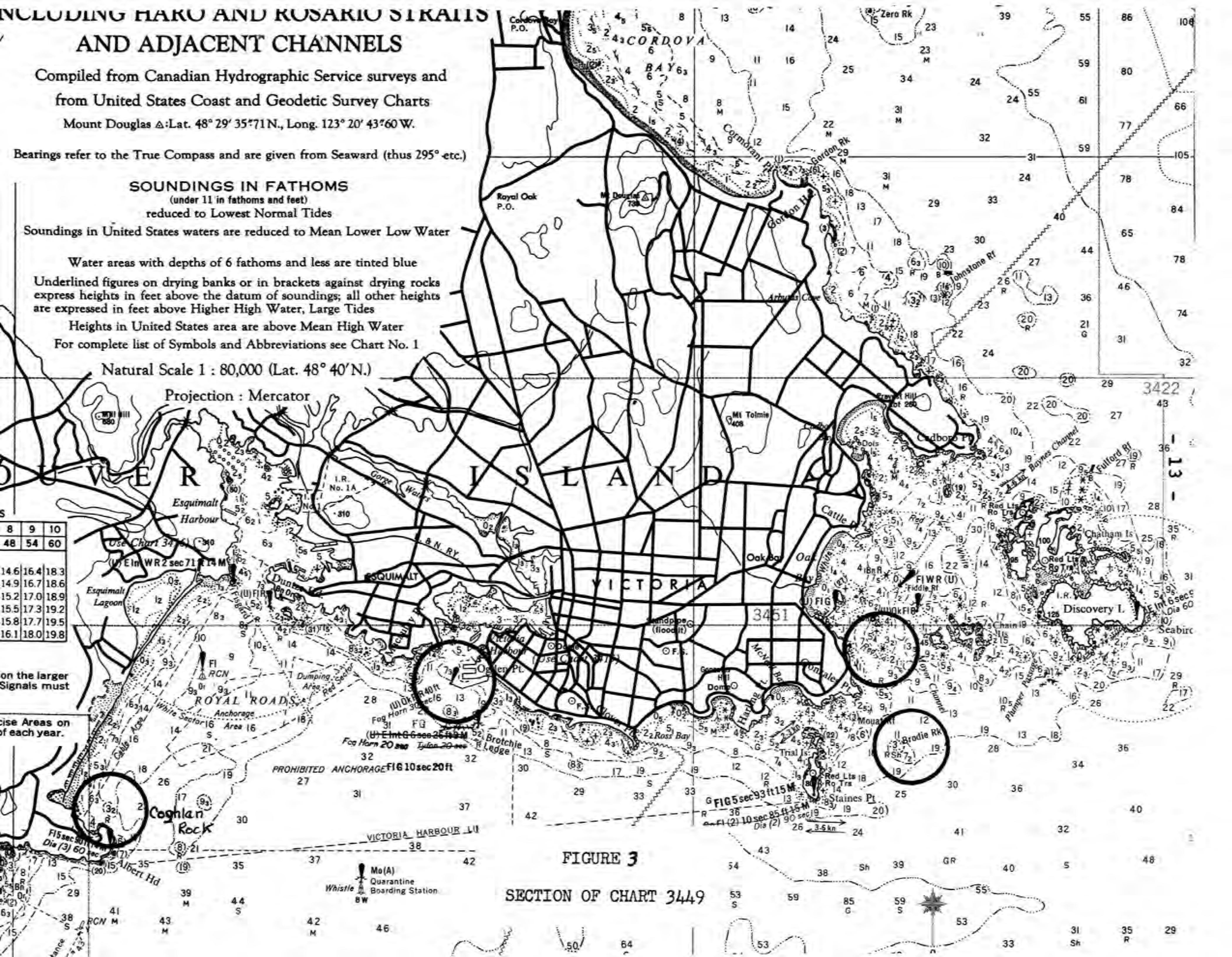


FIGURE #2



NCLUDING HARO AND ROSARIO STRAITS
AND ADJACENT CHANNELS

Compiled from Canadian Hydrographic Service surveys and
from United States Coast and Geodetic Survey Charts
Mount Douglas △:Lat. 48° 29′ 35″71 N., Long. 123° 20′ 43″60 W.

Bearings refer to the True Compass and are given from Seaward (thus 295° etc.)

SOUNDINGS IN FATHOMS
(under 11 in fathoms and feet)
reduced to Lowest Normal Tides
Soundings in United States waters are reduced to Mean Lower Low Water

Water areas with depths of 6 fathoms and less are tinted blue

Underlined figures on drying banks or in brackets against drying rocks express heights in feet above the datum of soundings; all other heights are expressed in feet above Higher High Water, Large Tides

Heights in United States area are above Mean High Water

For complete list of Symbols and Abbreviations see Chart No. 1

Natural Scale 1 : 80,000 (Lat. 48° 40′N.)

Projection : Mercator

FIGURE 3

SECTION OF CHART 3449

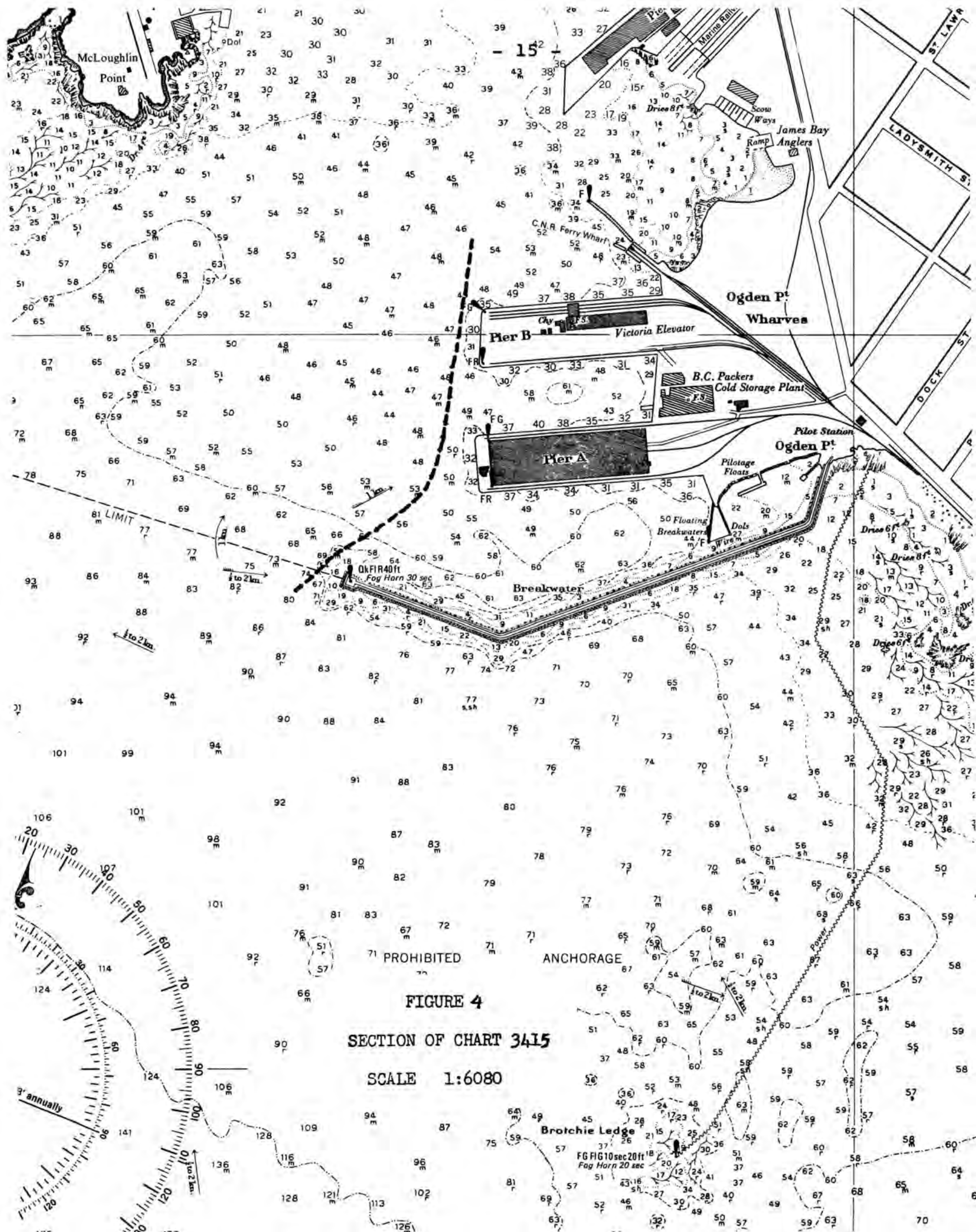


FIGURE 4

SECTION OF CHART 3415

SCALE 1:6080

NAVIGATIONAL RANGES SURVEY
(1969 & 1970)

BY

E.F. THOMPSON

Introduction

A range, used in this sense, or a leading line is an imaginary line followed by vessels to provide safe passage through narrow channels or into harbours. The imaginary line is formed by lining up two range structures on shore.

In May 1968, the Canadian Hydrographic Service accepted the responsibility for determining and checking the true bearings of all navigational ranges established by Federal agencies as shown on Canadian navigational charts.

This responsibility was undertaken by C.H.S. as a result of the collision between the two ships HERMES and TRANSATLANTIC on the St. Lawrence River in April 1965. It was subsequently discovered that a range marker was displaced and a decision of the courts was made to award substantial damages to the vessels' owners. This incident also brought to light the fallibility of assuming, year after year, the correctness of range bearings indicated on a chart.

Each region (Atlantic, Central and Pacific) of the Canadian Hydrographic Service assumed responsibility for establishing priorities for its range survey work. Initially Central Region has elected to concentrate its efforts on those ranges marking the St. Lawrence Ship Channel and Seaway, since this is the major shipping waterway within the Region's jurisdiction, and is, of course, also the major shipping route in the nation.

All the existing range structures between Montreal Harbour and Cape Brûlé were re-positioned and each range line bearing verified by the 1969 and 1970 Navigational Ranges survey party.

Survey Techniques
(see definitions below if you're not familiar with hydrographic terms)

Pre-established horizontal control points supplied by the Geodetic Survey of Canada, the St. Lawrence Ship Channel and the Canadian Hydrographic Service, all based on the NA 1927 datum, were located in the vicinity of the range structures. Secondary survey stations were then strategically placed such that each range structure formed a coincidental apex in two independent, well conditioned triangles. These new stations were then "tied in" by Tellurometer traverses starting from the pre-established control stations, and in most cases, closure was made on the original starting point.

In a few cases the range structures themselves were incorporated into the Tellurometer traverses. However, in the majority of cases triangulation was the method employed to obtain the range positions.

From the positions obtained for the ranges, an inverse computation is worked between each pair of front and back range structures to give the range line bearings. These bearings are then verified by direct solar and/or gyro-theodolite observations.

Example

		Range Line Bearings	
Range Line	Computed	Gyro Theodolite	Astro Observation
Petite Traverse Contrecoeur	225 42'06"	225 42'12"	225 42'03"
Contrecoeur Course	213 10'27"	213 10'12"	213 10'59"

Profile sounding is also carried out, both across the "swept" ship channel and along the visual range line. The soundings are controlled by horizontal sextant fixes. These soundings clearly show the relationship of the range line with the channel limits as well as providing check soundings along the range line limits.

Conclusions

Due to the continuing program of widening and straightening of the St. Lawrence Ship Channel new range structures are being erected for the aid of the mariner. Therefore, there is a continuing need to constantly re-survey and update any new or re-located range structures. The 1971 Navigational Ranges survey party will be continuing upstream from Montreal Harbour to Kingston along the St. Lawrence Seaway. In future years, range surveys will focus on all other channels or routes used extensively by commercial shipping, other major harbours, all other channels and harbours, along with revising ranges positioned in previous years.

Definition of Terms

Horizontal control point: A point on the earth's surface with a known position and referenced to a pre-determined datum (in our case, the 1927 North American Datum).

1927 N.A. Datum: A system of reference to define geographic positions (latitude and longitude) on the surface of the North American continent using the elipsoid of which the dimensions were established in 1927. The reference station for this datum is located at Meades Ranch in Kansas.

Coincidental Apex: When the apex of two independent triangles fall on the same point.

Well-Conditioned Triangle: Triangles in which the angles and sides are approximately equal.

Tellurometer Traverse: A traverse consists of a connected series of lines of sight on the earth's surface, the lengths and bearings of which are measured. By these measurements the relative positions of various points in the traverse can be found. The Tellurometer is an electronic instrument used to measure each of the lengths of the lines in the traverse by means of phase comparison.

Closure: When the traverse commences and terminates on the same horizontal control point.

Triangulation: This consists of measuring angles between the survey stations erected in the survey area and the range structures, in a methodical manner, using these measured angles to calculate the positions of the range structures relative to the survey stations.

Inverse Computations: A calculation worked to determine the bearing and distance between two known control points, i.e. between the front and back range structures to give range line bearings.

Direct Solar Observation: The bearing of the range line can be determined by observing the sun through a theodolite, which is set up on the range line. The precise direction, azimuth, of the sun is calculated from the point where the theodolite is situated. By measuring the angle between the sun and range line at the exact time the sun is observed a fairly precise bearing of the range line can be arrived at.

Theodolite Observation: The bearing of the range lines can also be determined by taking a gyro observation on the range line. An angle is measured from the range line to approximately true north, with a theodolite. The gyro is then attached to the theodolite. By means of measuring and taking means of the oscillations of the gyro through true north the observed angle is adjusted to true north. By either adding or subtracting the adjusted angle from true north the bearing of the line can be derived.

SATELLITE NAVIGATION

BY

R.M. EATON

Late in 1957, a scientist of the Applied Physics Laboratory, Johns Hopkins University, was listening to the radio signals from Sputnik I. He must have detected the Doppler shift in the frequency received as the satellite passed by, and realised that if the shift was very abrupt, it must mean that the satellite was passing almost overhead, whereas if the frequency change were gradual, the satellite's path was a long way from him. Being a physicist, he wasn't satisfied until he had "put some figures in", and it was presumably then that he realised that precise measurement of the Doppler shift at a known point on earth could be used to determine the satellite's orbit; and, conversely, that measurements at an unknown point on a satellite whose orbit was known would fix the unknown point.

Ten years later, the security blanket was lifted from the Navy Navigation Satellite System which resulted from this idea, and the Bedford Institute bought two receivers. After two years, operational experience of the system's enormous usefulness in giving a position anywhere in the world correct to about ± 1/4 mile every four to six hours, regardless of weather, virtually no oceanographic cruise is undertaken nowadays without "Satnav."

The Principles: Frequency Comparison and the Doppler Shift.

You have a radio receiver; in addition to the signal you are receiving, you feed in a very stable reference frequency. You want to find the difference in frequency between this reference signal and the received signal, in order to detect and measure Doppler frequency shift in the received signal. One way of doing this is to count the number of cycles performed by each one at a given time interval.

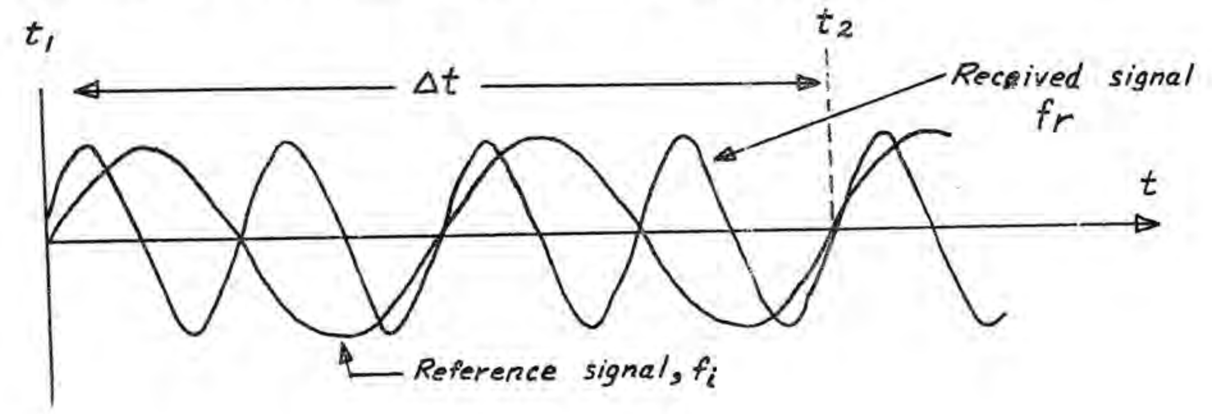


Figure 1: Frequency Comparison

In the example, figure 1, the frequency f_r received by the radio is double this internally-generated reference frequency f_i. Over the particular time interval $\Delta t = (t_2 - t_1)$ shown, the count, known as the "Doppler Count" in a Satnav. receiver, is $(N_r - N_i) = (4-2) = 2$.

You are probably all familiar with the Doppler effect. If you are walking along the road and a motorist approaches you with his fist on the horn, the pitch of the horn drops sharply at the instant he passes you. The same thing happens to radio waves as to sound waves; if you happened to be carrying a frequency comparison receiver, and if the approaching vehicle happened to be transmitting radio-waves at the same frequency as that generated internally as reference by your receiver, you would register a higher incoming signal as the vehicle approached; the exact same frequency as it passed; and a lower frequency as it went away.

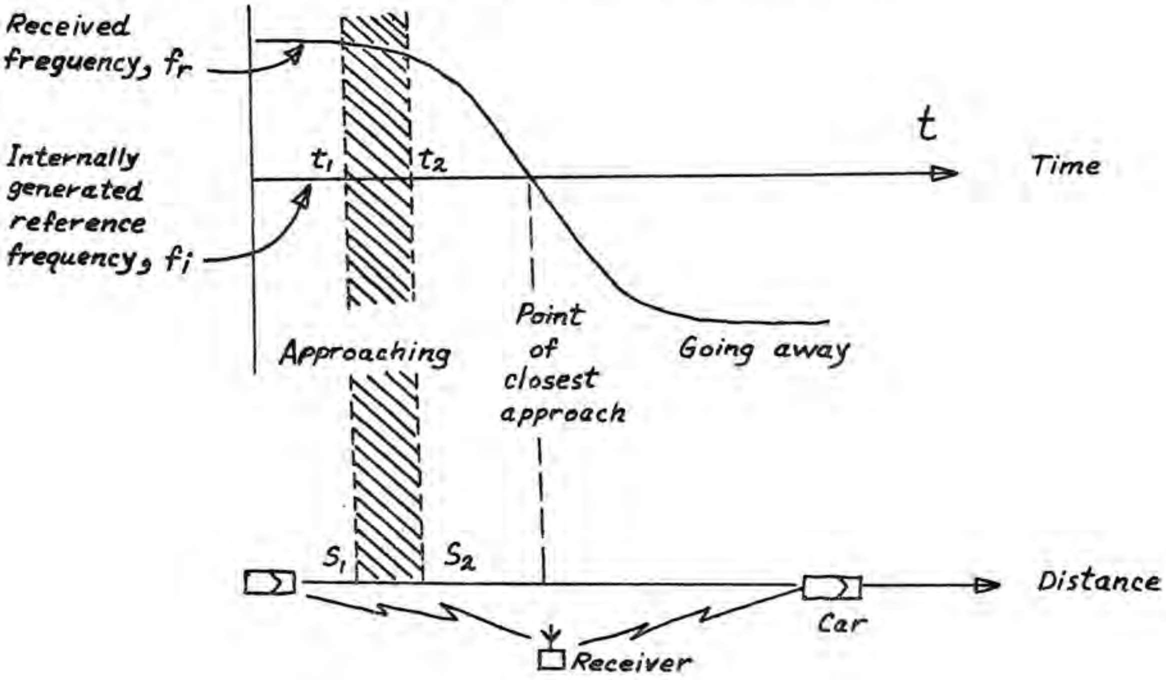


Figure 2: Doppler Effect; the relation between time and distance

How the System Operates

Four satellites are permanently maintained in orbit for the U.S. Navy Navigation Satellite System. Periodically one dies (their life is about five years) and another is put into orbit. Their orbit is polar (its plane contains the earth's axis) and their height is about 1100 kilometres (compare with the earth's radius of 6400 kilometres). They are spaced roughly 45 degrees apart, and can best be visualized as forming a birdcage around the earth, its orientation in space remaining fixed while the earth spins around inside it.

The satellite's orbital period is 107 minutes, and in that time the earth revolves about 26 degrees. The satellites are high enough that at latitide 45 degrees you see each one at least twice while your part of the world is under it, and you see it twice more 12 hours later. Four 'passes' a day from four satellites gives an average interval of 1½ hours between passes. However, satellites are not in synchronous orbits, and the actual interval varies from two different satellites being received simultaneously, to about three hours between passes.

Each satellite carries a very stable radio transmitter, and the shipborne receiver also contains a very stable oscillator generating a frequency which is ideally the same as the satellite's (and in practice very close to it.). As the satellite approaches you, at about 15,000 mph, the Doppler effect will make the frequency received from it appear markedly higher than the reference frequency generated by your receiver. When the satellite goes overhead, the frequency drops to the same as that generated, and when it is going away its frequency will appear lower (figures 1 and 3).

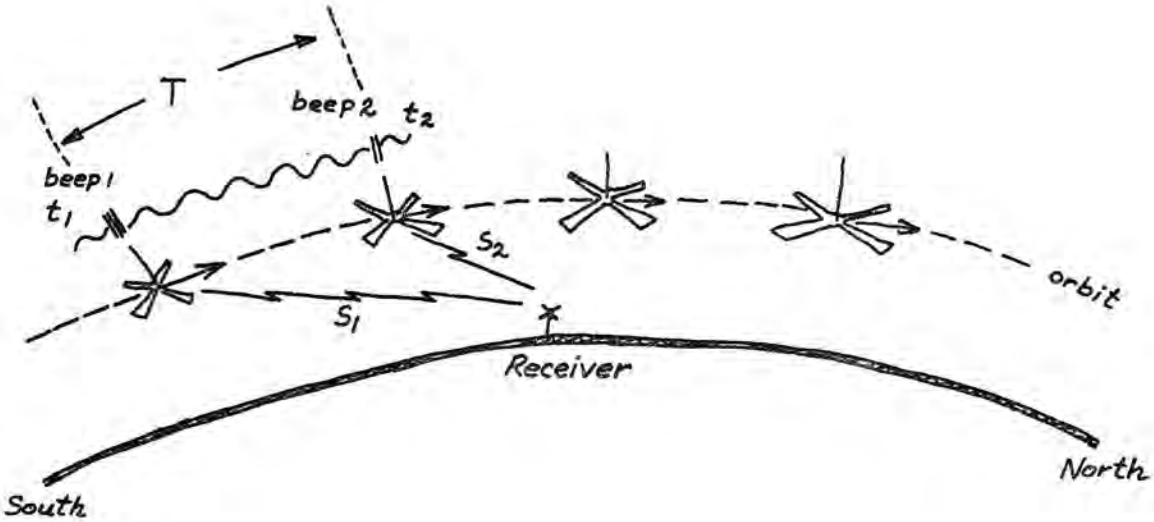


Figure 3: Satellite Pass

The measuring system uses the Doppler shift.

The satellite emits timing beeps at precise intervals ($T=t_2-t_1$). During each interval the receiver accumulates a Doppler count ($\Delta N=N_T-N_i$) of the difference between the number of cycles transmitted by the satellite (N_T) and the number generated by the receiver's internal oscillator (N_i). If the satellite is approaching, the Doppler shift is high, and the Doppler count should be positive *, and this works out as follows.

Beep 2 has a shorter transmission path, and so a shorter time delay than beep 1. Hence it arrives sooner (and stops the count sooner) than the receiver would 'expect' if it were controlling the interval T itself. In this shortened period, the receiver will count fewer than a full periods-worth of its own internally generated cycles (N_i). On the other hand, the satellite has transmitted its full quota (N_T) of cycles for the period T, and all these must be received by the receiver. So (N_T) is greater than (N_i).

Using this argument, it is easy to show that the Doppler count:

$$\Delta N = (N_T-N_i) = f_i/c\ (s_2-s_1) + T\Delta f$$

where f_i = the internally generated reference frequency of the receiver, c = speed of propagation of radio waves,

Δf = unknown shift in frequency between satellite and receiver.

Experienced hyperbolic surveyors will immediately recognize that (s_2-s_1) is a range difference and implies a hyperbolic position line passing between the satellite positions at t_1 and t_2. However, this is a three-dimensional case, so (s2-s1) gives a position somewhere on the surface of a hyperboloid in space. A second Doppler count gives a second hyperboloid, and the intersection of these two surfaces with the earth's surface defines your position. (A third Doppler count is, in fact, required to solve for the unknown frequency shift (Δf) before a solution can be found). This is the basis of the method.

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* Those who are familiar with Satnav will know that the Doppler counts actually given by the receiver are inverted, being lowest during the approach and rising throughout the pass. This is because they are measured from an arbitrary reference frequency which is higher than the highest Doppler shifted frequency (in a manner analogous to the use of False Eastings in U.T.M.).

To compute a fix, you need to know the position of the satellite at each time beep in order to determine the hyperboloid, and you also need to know the height of the geoid at the receiver position. The satellite's position can be calculated if its orbit is known exactly, and this is determined by four tracking stations stretching from Maine to Hawaii. Orbital parameters are predicted from tracking observations, and twice a day each satellite receives a memory injection from one of the tracking stations with predictions for the following 12 hours. Thereafter the satellite continually broadcasts its data by a code superimposed on the measuring frequency.

Variations in the geoid (the actual sea level surface of the earth) are related to gravity anomalies, and give rise to perturbations in the orbit of satellites. These can be detected by tracking the satellite, and from them the first really comprehensive picture of the shape of the earth has emerged. The ellipsoid which gives the closest fit to the actual shape of the earth is not quite as flattened as Clarke thought in 1866. The "Mercury" (satellite) figure for flattening is 1/298.3, against 1/295 according to Clarke. The local divergences between this reference ellipsoid and the geoid are large - up to 70 metres. Figure 4 shows a cross-section and figure 5 a plan view of the earth illustrating this. Figure 5 is used to give the geoidal height in calculating a satellite fix.

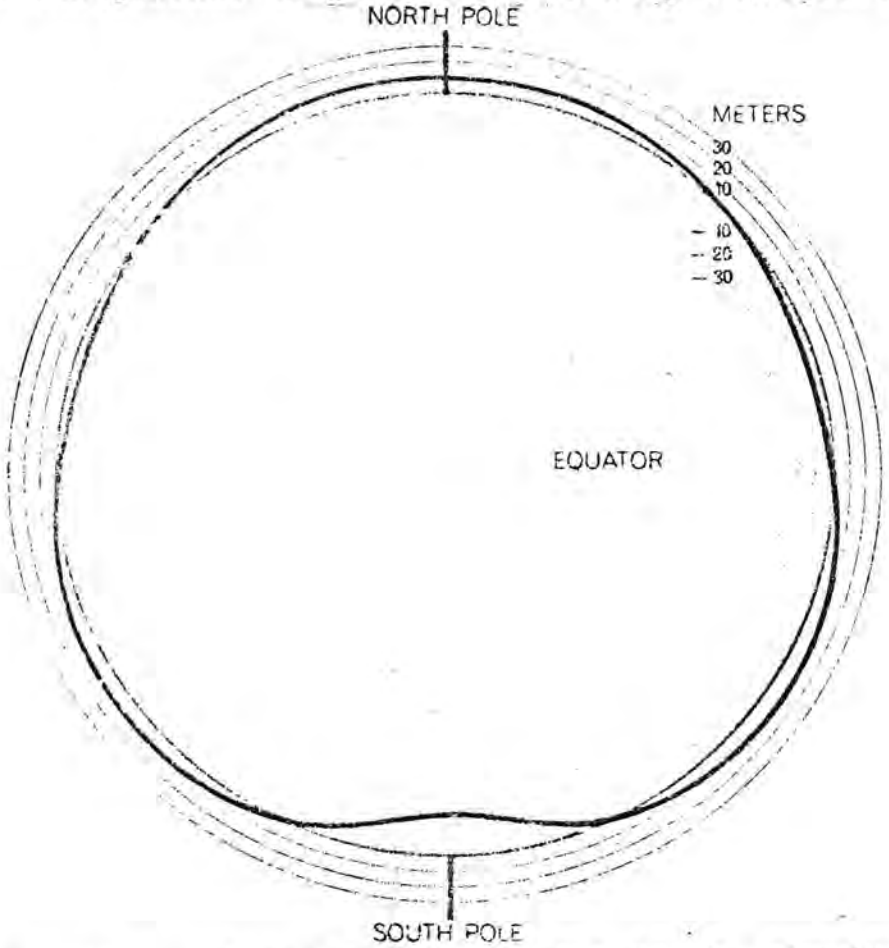

Figure 4: Cross Section of the Earth, showing Geoid (after King-Hele, 1967)

There is an inconvenient consequence of this difference between the Clarke and Mercury ellipsoids. Satellite positions are calculated on Mercury datum, and so are Satnav fixes using them. Consequently they are 'shifted' relative to North American datum (which uses Clarke's ellipsoid) by an amount which varies with positions relative to the point of origin. At Bedford Institute the mean position by Satnav is about 45 metres northeast of an unimpeachable survey position.

If the receiver is in a ship under way, its motion relative to the satellite orbit will affect the Doppler count. The computer will allow for this, but only if the correct course and speed is fed to it; a 1-knot error in north-south velocity (the worst case) can cause an error of up to 1 kilometre in position.

The process of calculating a fix is as follows:

(1) The receiver measures the Doppler counts and records the position information which the satellite broadcasts about itself.

(2) The computer checks the data for self-consistency. This is called 'majority voting'.

(3) The operator enters: time of first beep (an even 2 minutes); latitude and longitude (within ± 3 degrees); height of antenna (geoid height plus topographic height); and course and speed.

(4) The computer calculates the position in space of the satellite at each time-beep of the pass.

(5) It computes the range differences (s_2-s_1) which would be observed by a receiver at the position given by the operator; compares these with the range differences actually measured from the Doppler counts; and then improves the receiver position and recalculates until it gets good agreement between calculated and measured range differences.

When our first Satnav receiver arrived at Bedford Institute in 1968, we set it up on the roof to check on the surveyors. After receiving 50 passes we rejected 8 which gave positions more than 300 metres from the mean position, and the rms radial spread of the remainder about the mean position was then 119 metres. Perserving and becoming more choosy, we rejected all but 47 out of 439 passes (on criteria such as elevation above 7°.5 to avoid refraction; Doppler counts symmetrically distributed about point of closest approach, etc.) and reduced the rms radial scatter to 59 metres. This indicates that the position from one 'good' pass (roughly one out of three) at a stationary receiver is probably within 100 metres of the true position on Mercury datum. At sea, uncertainty

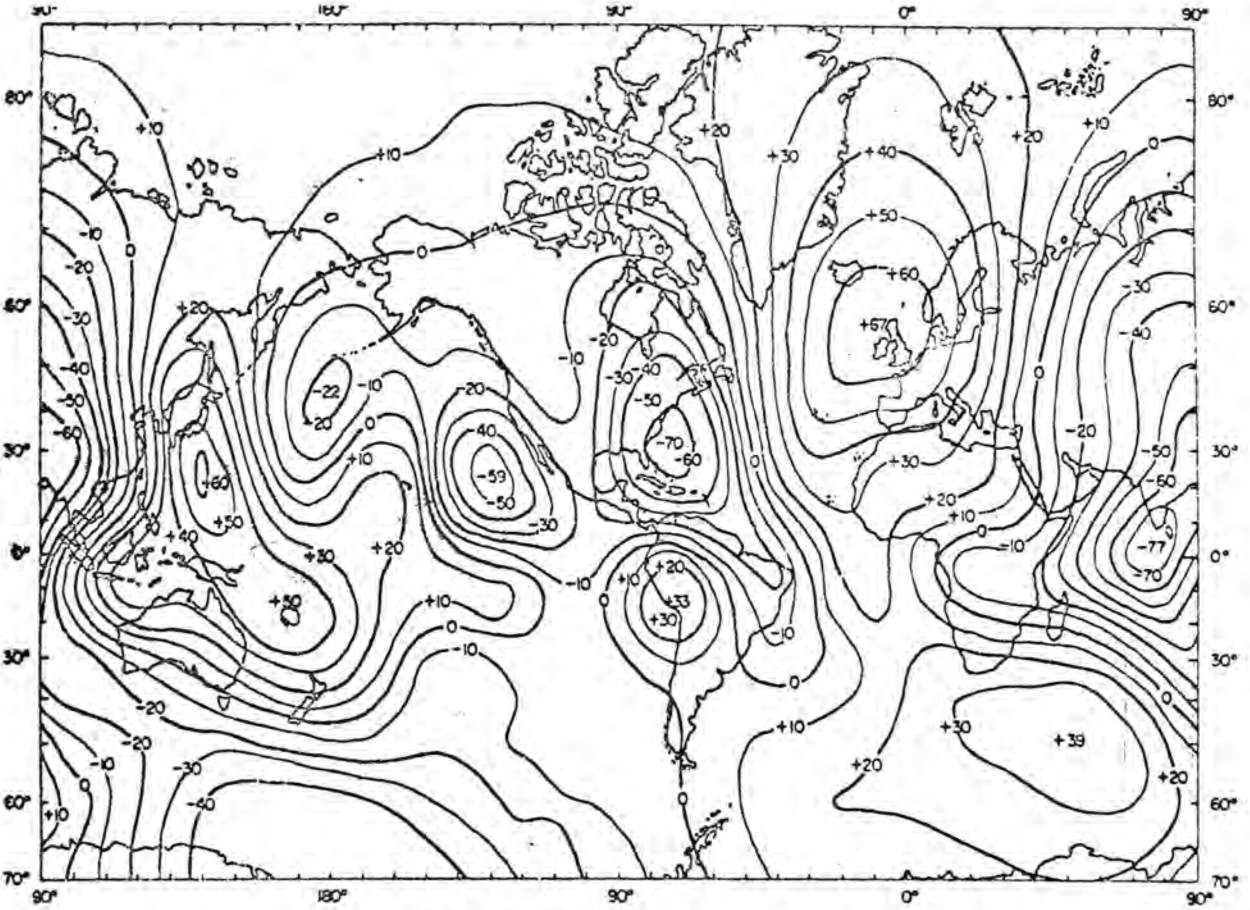

Figure 5: Geoidal Height Map
(from Guier, 1965)

over ship's velocity swamps other doubts. However, 500 metres accuracy will usually be obtainable from one good pass. To a hydrographer, ± 500 metres sounds a pretty sloppy sort of position! But in presatellite days the only method of fixing at sea was by sextant, and a very good navigator might produce a fix accurate to ± 1 or 2 miles after observing morning or evening stars. Using Satnav, HUDSON laid a string of subsurface current meters between Cape Horn and the South Shetland Islands early in 1970. She recovered them a few weeks later, navigating to within 1 kilometre of each buoy in order to actuate the sonic release gear. This accuracy would have been impossible by celestial navigation, quite apart from the fact that the area is always overcast and you might wait a month for one celestial fix.

Refinements are possible, such as improved computer programs, the 'translocation' procedure using a receiver at a known point to adjust fixes obtained simultaneously at an unknown point, etc. A considerable refinement was tried out in November, 1970, when five receivers were set up on known shore points distributed from Goose Bay to Fredericton to act, in effect, as a tracking network to position a sixth receiver on a drilling rig near Sable Island. Using this 'simultaneous' method it may be possible to locate survey receivers to 10 metres accuracy relative to control points hundreds of kilometres away. This puts Satnav firmly in the market for Arctic reconnaissance surveys. The results of this particular experiment, a joint effort between Shell (Canada) Ltd., the University of New Brunswick, and Bedford Institute, will be known by mid-1971.

SOURCES, AND FURTHER READING

Reading on navigation is spotty; there are books and articles on specifics, but there is no good general review. D.E. Wells' proposed book (see below) should remedy this, when it is published.

"Navigation Lecture Notes", D.E. Wells. Canadian Hydrographic Service Technical Note, 1970. A professional and comprehensible introduction, full of useful information. To be published in expanded form as a book in 1972.

"The Navy Navigation Satellite System", T.A. Stansell Navigation, Fall 1968. Reprinted in International Hydrographic Review, January 1970. Standard reference on Satnav.

"Experience with Satellite Navigation Equipment during Summer 1968", D.E. Wells and D.I. Ross. Report BI 1969-6. Source of Satnav results quoted in this paper.

"Geodesy for the Layman", R.K. Burkard. U.S.A.F. Aeronautical Chart and Information Center, 1968. Excellent introduction to geodesy.

"Introduction to Geodesy", C.E. Ewing and M.M. Mitchell. Elsevier, 1969. A clear textbook.

"The Shape of the Earth", D. King-Hele. Scientific American, October 1967. An interesting article on how satellites are used to find the shape of the earth.

* THE HISTORY OF HYDROGRAPHIC SURVEYING IN BRITISH COLUMBIA

by

R.W. Sandilands

Most cartographers are aware of the requirements for maps or charts in the development of a country. Possibly the need for charts is greater than that for maps, as on land you can always see ahead, you can stop in your tracks, you can alter your direction of advance easily. However at sea this is not possible. Unseen dangers lurk under the water; ships, and especially sailing vessels, are not easily stopped and have limited manoeuvrability. Thus the need for adequate hydrographic surveys is essential for the colonization and development of a coast, and we have to thank the early exploring hydrographers who risked their ships and their lives for the safe passages we make today. This article describes the work of the men who opened the sea lanes of British Columbia and who in no small measure laid the foundations for the prosperity enjoyed in that province today.

The numerous early explorers kept careful records of their journeys and in particular described the coasts seen by them and the meteorological conditions experienced. We are fortunate that so many of them were so keenly observant and capable of putting in writing and in sketches the material they collected.

The great period of British hydrography started in the second half of the 18th Century and fortunately it coincided with the beginning of true scientific surveying so that the immense growth and expansion of British seapower, both naval and commercial, during the 19th Century was accompanied by surveying of a strikingly high standard. The first recorded surveys of the Canadian northwest coast were those of the Spaniards and British towards the end of the 18th Century. This statement must be amplified slightly by pointing out that the information obtained by the Spaniards was not generally published or made freely available due to a policy of secrecy on the part of the Spanish Navy. As will be mentioned later, Vancouver used Spanish work in his grand chart of the coast but that information was obtained by personal contact. Likewise there will be no mention of the work of La Perouse who did some exploratory work in Dixon Entrance and the west coast of the Queen Charlotte Islands. This information was hidden in the archives of the French Admiralty for many years and consequently none of the names he applied remain in that area with the exception of a few which were added much later as an historical reminder that he had visited those parts on his voyages. However, Lloyd Arnold Brown points out that:

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* Reprinted from "The Canadian Cartographer".

> "The very nature of the work performed by the various Hydrographic Surveys precluded isolation and secrecy and from the beginning the benefits to be derived from international co-operation were apparent to all countries. In this case it was not a matter of uniting in the common cause of science, it was a union of the seafaring men of the world against the common perils of the deep. Moreover, the seas were so vast that little headway could be made in nautical surveying without the combined effort of every ship and every nation that sailed them."

At this time naval captains were normally commanded to make such surveys, navigational plans and soundings as they could on their voyages of exploration. To co-ordinate the gathering, evaluating, compiling, publishing and disseminating of the information gathered, the British Admiralty set up a Hydrographic Office of the Admiralty in 1795. The first Hydrographer of the Navy was Mr. Alexander Dalrymple, who had been Hydrographer with the Honourable East India Company. It is interesting to read the Board of Admiralty Minute which established the office:

> "The great inconvenience, especially when ordered abroad, felt by officers commanding His Majesty's ships respecting the navigation, had led us to consider the best means for furnishing such information, and preventing the difficulty and danger to which His Majesty's fleet must be exposed from defects of this head. On an examination of charts in office, we find a mass of information requiring digest, which might be utilized, but owing to the want of an establishment for this duty, His Majesty's officers are deprived of the advantages of these valuable communications ... We therefore propose that a proper person be fixed upon to be appointed Hydrographer to the Board, to be entrusted with the care of such charts etc., as are now in office, or may hereafter be deposited, and to be charged with the duty of collecting and compiling all information requisite for improving navigation. For the guidance of Commanders of His Majesty's ships. The extent of such an establishment not to exceed the sume of £ 650 per annum ......"

From such small beginnings and on such a limited budget did the Hydrographic Department of the Admiralty develop. Amongst the "mass of information" mentioned were the charts and sailing directions compiled by Captains Cook and Vancouver.

In 1778 Captain Cook, commanding HMS RESOLUTION, visited the northwest coast and did much exploratory work including a surveyof the Nootka area. As a direct result of his voyages the trade in sea otter skins developed, which in turn resulted in the first trading post being established at Nootka. The Meares incident[1] at Nootka is well chronicled, but its importance as far as hydrography is concerned is the fact that Vancouver was sent out from Britain to negotiate with the Spaniards, under Quadra, and to demand resitution. Chance gave Vancouver the opportunity to blaze his name on the coast, as originally the British Government had planned a scientific expedition to the Pacific under the command of a Captain Roberts, and plans were laid in 1789 to implement this project. Then when first reports of the Meares affair reached England this expedition was planned with the ships SIRIUS, GORGON and DISCOVERY. This in turn was cancelled, Captain Roberts received another appointment to the West Indies, and Vancouver was appointed to lead the final expedition, with the ships DISCOVERY - 340 tons, with a crew of 134, and CHATHAM - 135 tons, with a crew of 55.

Vancouver was no stranger to the north-west coast as he had sailed with Cook as midshipman on the RESOLUTION. Bligh, that much maligned officer of BOUNTY notoriety, was also on the RESOLUTION serving as Cook's Sailing Master, and Bligh Island at Nootka was named for him.

In addition to his commission to negotiate with Quadra at Nootka, Vancouver received instructions to make an accurate survey of the coast of North America from latitude 30 degrees towards Cook Inlet, "principally with a view to ascertain the existence of any navigable communication between the North Pacific and the Atlantic Oceans." On May 7, 1792, sailing in the DISCOVERY and accompanied by Broughton in the CHATHAM, he arrived at Port Discovery in Juan de Fuca Strait. From there the

[1] John Meares, a British navigator and trader, had formed a company which built a trading post at Nootka Sound. In 1789 the Spaniards, who claimed the whole region by reason of a Papal Bull of 1493, seized the post and several ships that were in harbour. The British demanded restitution from Spain and backed the demand with the threat of military action. The matter was solved when Spain yielded to the British in 1790. Many historians point to this incident as the first renunciation of Spain's vast claims in the Americas and, by extension, the beginning of the collapse of the Spanish Empire in the New World.

first of the boat expeditions that were to survey the numerous inlets and islands of the coast left his vessels to enter Puget Sound. Returning from Puget Sound the two navigators met the vessels of the Spaniards Galiano and Valdez, and the British and the Spaniards continued together their survey of the Strait of Georgia. In spite of the tense situation between Britain and Spain two years previously, there was an interchange of information and Vancouver incorporated some of the Spanish work in his chart of the coast. Leaving the Spaniards, after about three weeks, the British vessels passed through Johnston Strait, emerging into Queen Charlotte Sound and conducted their last boat expedition of the season from an anchorage in Fitzhugh Sound. On completion they sailed to Nootka. Leaving Nootka on 13 October, the expedition sailed to Monterey in California. Broughton left for England with despatches. Lieutenant Peter Puget was promoted to command of the CHATHAM and accompanied Vancouver to winter in the Hawaiian Islands.

Vancouver and Puget resumed their survey in the spring of 1793 from an anchorage in Burke Channel. On 23 July the DISCOVERY and CHATHAM were anchored in Observatory Inlet and remained there unti 17 August, whilst Vancouver conducted the boat expedition that surveyed Observatory Inlet, Portland Canal and Pearse Canal. Vancouver wrote:

> "We had traversed seven hundred geographical miles without having advanced our primary object of tracing the continental boundary more than twenty leagues from the station of our vessels. Such were the complexing, tedious and laborious means by which alone we were enabled by degrees to trace the northwestern limits of the American Continent."

On leaving Observatory Inlet, Vancouver and Puget continued their work northward, their most northerly anchorage of the season being at Port Protection at the north end of Prince of Wales Island.

In 1794 both ships returned from wintering in the Hawaiian Islands to Cook Inlet. From the Russians, Vancouver was allowed to copy a chart executed in 1789 -- 1790, from which he adopted for his own grand chart of the coast the coastline from Cape Trinity to Point Banks. On 19 August the last boat party returned to the DISCOVERY and CHATHAM, anchored at Port Conclusion at the south end of Baranoff Island, from which point Vancouver and Puget concluded their survey of the northwest coast of the continent. The charts executed by Vancouver's expedition continued to be the most reliable source of information regarding many parts of the coast until some time after the purchase of Alaska by the United States.

The traders operating on the coast during the period between the voyages of Cook and Vancouver also played their part in the construction of Vancouver's chart. Reports and sketch surveys from Duncan, Hanna, Meares, Barkley, Dixon and Portlock, and the Americans Gray and Kendrick, were noted and further investigated by Vancouver. Portlock and Dixon had been shipmates with Cook on his last voyage before they entered the trading business. Duncan had served in the Royal Navy as a Master and traded the coast on the PRINCESS ROYAL. He had made some small charts of various localities and these were published in 1790. One of them, dated 1788, shows the entrance to the Strait of Juan de Fuca, giving a sketch of the land and of Fuca's Pillar. We know that these charts were on board the DISCOVERY as Vancouver makes mention of them in his journal.

After Vancouver's departure there was little hydrographic activity on the coast for several years. Britain was still engaged in the Napoleonic Wars and required every ship available.

In the meantime, the Northwest Company and the Hudson's Bay Company had joined forces under the name of the latter company and we find a published record of a survey carried out by Aemilius Simpson, in the Hudson's Bay schooner CADBORO, of the mouth and part of the Fraser River. This was done at the time of the founding of Fort Langley and we find in the historical records of the Fort that the CADBORO "...for nine days searched for a channel through the sand-heads."

The company also founded Fort Vancouver on the Columbia in 1828, and the next trace we find of organized hydrographic work on the coast was when the SULPHUR, with Commander Belcher and the STARLING, with Lieutenant Kellett, charted the river up to Fort Vancouver. In 1839 Belcher also carried out a survey of Friendly Cove and the expedition checked some of Vancouver's observations for longitude, time, azimuth, etc. at Nootka and Yakutat Bay in Alaska.

Belcher was a Nova Scotian, his father being a judge or magistrate, and he was the first native-born son to become a distinguished hydrographer. He seems to have been a remarkably able man. He was a diplomat, linguist, and during a spell ashore he "followed the study of natural pholosophy". His diplomatic activities earned him the following rebuke from Beaufort, then Hydrographer of the Navy:

> "Your last letter of 1845 is really all Hebrew to me, ransoms and dollars, queens, treaties and negotiations. What have I to do with all these horrible things, they far transcend my limited chart-making faculties. That you may have been doing good service to the country I will not doubt but the harvest I look for at your hands does not stretch beyond the reach of a deep sea lead."

However their work was in conjunction with other surveys south of the equator. Passage to the Pacific coast was round the treacherous Cape and little was known of the South American coast. Some idea of the problems facing the Hydrographic Department can be obtained from sections of Belcher's sailing directions:

> The extent of coasts along the western side of America is so great that the utmost energy will be requisite in conducting the necessary observations, and can be effected in any reasonable time only by skilfully combining them with the changes of season which take place at alternative periods of the year to the north and south of the equator. On the approach, therefore, of the monsoon to the coast of Peru, you are to make the utmost expedition in removing both vessels 'north'. Little is known of this great country except that it is rapidly increasing in population and commerce ... it contains but few harbours ... its shores steep and approaches bold.

In 1846, due to the Oregon country dispute, there were six ships of the Royal Navy in this area. Included in these were the surveying ships HERALD and PANDORA, commanded by Captain Kellett and Lieutenant Wood. These ships carried out surveys of Esquimalt and Victoria harbours, and some work in the Straits of Juan de Fuca, including the anchorages at Fort San Juan, Neah Bay, Port Townsend, Becher and Pedder Bays, and Cordova Bay.

Lieutenant Wood was assisted in the survey of Esquimalt harbour by a Mr. Inskip who was a naval instructor on board the FISGARD, which was also on station in that year and the points, islands, etc. in the harbour were named after various officers of that ship: Captain Duntze (Duntze Head); Lieutenant Rodd (Rodd Hill); Lt. Marines Richards (Richards Island); Surgeon Dunn (Dunn's Nook) and so on. Again, this work was in conjunction with work further south on the Pacific coast and the two ships were only in northwest waters from June to August of 1846. The HERALD was detached to assist in the search for Sir John Franklin and the PANDORA continued her work along until 1848.

From the surveys of Kellett and Wood one of the earliest Admiralty charts of the area, and one which provided base material for several editions, was the chart of the Strait of Juan de Fuca. Wood wrote detailed sailing directions for the Strait area and this in effect was the first chapter of a British Columbia *Pilot*. However this report, which was published in the NAUTICAL MAGAZINE in 1851, predated the first published Admiralty *Pilot* by more than ten years. Wood commented that:

> "Vancouver's description was sufficient as far as the southern shore was concerned but on the northern, or island side, by the time Race Rocks was reached, some better guide would be necessary."

1846 saw the Oregon Treaty signed between the United States and Britian and with it came a lessening of naval activity on the coast. Three years later Britain gave Vancouver Island colonial status and a new era in naval activity began. Primarily the role of the Navy was to guard against infiltration from the United States and to maintain law and order amongst the coastal tribes. Though there were no specialist surveying ships on the coast at that time the normal practice of charting on passage and surveying anchorages (thus adding to the basic information provided by the surveyors) was carried out by ships on station.

As a result of gold discoveries in the Queen Charlotte Islands there was a rush of prospectors from the United States. In 1854 the THETIS and VIRAGO in the course of patrolling northern waters produced surveys of Port Kuyper, Naden Harbour, Masset and Houston Stewart Channel in the Queen Charlottes, and Port Simpson, the northern H.B.C. post on the mainland. During VIRAGO'S patrols in the Charlottes it was first ascertained that the Queen Charlotte Group consisted chiefly of two islands, Graham and Moresby.

The VIRAGO was a steam paddle sloop and was the first naval ship since the days of Vancouver to navigate much of the inside passage. Commander Prevost added much to Vancouver's information about this sheltered route to the north. He also did considerable work in the San Juan and Gulf Islands of the Strait of Georgia.

In 1853 officers of the Hudson's Bay Company surveyed Nanaimo and Departure Bay, coal having been discovered there the previous year. These soundings were added to by Mr. Inskip of the VIRAGO, who later became a Captain in the Royal Navy; he was a brother of the Inskip mentioned previously in connection with the Esquimalt survey. He was in charge of the hydrographic surveys carried out by the VIRAGO and became extremely interested in surveying as he served exclusively in the surveying branch after his return to England in 1855.

Whilst in the San Juan Islands in 1853, Prevost had noted that there seemed to be much variance of opinion as to where the boundary with the United States ran and that the 49th parallel was not marked on the mainland coast at Semiahmoo Bay. It was as a result of lack of information on the boundary on the coast that the next phase of intensive hydrographic surveying began. Captain Prevost, late of the VIRAGO, who had been promoted to command the SATELLITE, a screw corvette of 1,462 tons, and Captain Richards, in command of the PLUMPER (figure 1), were both appointed as British Commissioners to the Boundary Commission. They reached the northwest waters in June and November respectively in 1857.

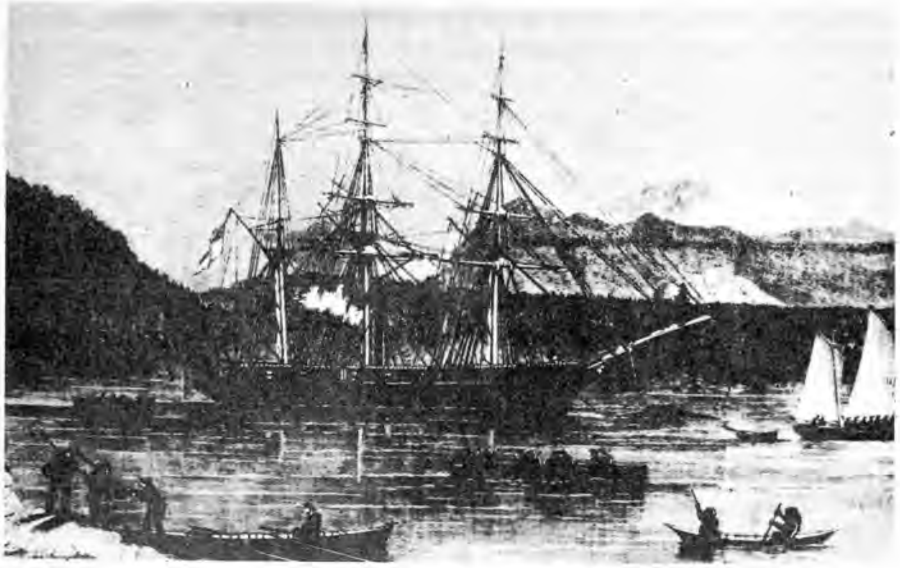

Figure 1

The HMS PLUMPER, an auxiliary steam sloop barque-rigged, was specially fitted as a survey ship. The photograph shows surveying boats leaving for the day's work in Port Harvey, Johnstone Strait. (From London Ill. News, 1860.)

The British Government and the Admiralty were determined to gain more precise geographical information on the waters involved. The PLUMPER worked on hydrographic surveys nearly full time and the SATELLITE assisted when her 21 guns were not required for law enforcement duties.

To digress for a moment, it is interesting to consider what the effect of extensive hydrographic surveys in this area prior to 1846 would have been. The original treaty of Oregon read: "The line of boundary ... shall be continued westward along the 49th parallel of north latitude to the middle of the Channel which separates the Continent from Vancouver's Island and thence through the middle of the said Channel and the Fuca Straits to the Pacific Ocean ..." The subsequent boundary difficulties arose from the apparent misunderstanding in drawing up the Treaty in assuming that there was only one channel, and also ignorance of the existence of any islands at all, whereas in reality there are three channels which might be taken as that mentioned in the Treaty. The British claim was based on Rosario Straits or the eastern channel, whereas the U.S. Government claimed Haro Strait or the western channel. Perhaps the lack of hydrographic surveys cost Canada the San Juan and part of the Gulf Islands.

However, Richards' first job was to determine the exact spot where the 49th parallel crossed the short of Semiahmoo Bay, as it was from this point that the boundary line would be extended back to the Rockies and on into the Strait of Georgia. Naturally a survey of Semiahmoo Bay was carried out at the same time. The PLUMPER's movements can be traced by the record of surveys that Richards left: 1857 -- Roche Harbour; 1858 -- Friday Harbour area, Haro Strait; some work on the Fraser River, Burrard Inlet; additional work in the Esquimalt, Royal Roads area; 1859 -- Ladysmith; completion of Haro and Rosario Straits; additional work around Victoria. It is of interest to note that on the charts published from the 1858 Esquimalt and 1859 Victoria surveys we see the beginning of the land surveys of Surveyor-General Pemberton being incorporated.

In 1860 the PLUMPER ranged further afield and surveyed Texada Island, Nanoose Bay, Pender Harbour, Seymour Narrows, as well as work in the Johnston Straits area including Port Harvey, Port Neville, Beaver Harbour and Alert Bay. She was assisted in part of this work by the HAVANNAH, hence the naming of Havannah Channel in this area. Later in the year the PLUMPER worked in Goletas Channel and Bull Harbour and then started south on the west coast of Vancouver Island with a survey of Quatsino Inlet dated that year. Still moving south, the charting continued during the following year with work in Clayoquot and Barkley Sounds. Later in the year still further work was done by Richards in the Victoria and Esquimalt areas, and the townsite of Victoria is shown at this time. Pemberton was still the Surveyor-General of the Colony and by this time street names were shown on the Victoria chart.

Most of the names have been kept to modern times, but it would appear that Broughton Street was originally Kane Street, Courtenay Street was Rae Street, and that St. John Street became Pendray Street.

The PLUMPER was proving inadequate for the task and she left the coast in 1861. Richards and his surveyors transferred to the HECATE, a paddle wheel sloop of 860 tons, early in 1861. HECATE arrived on the coast late in 1860 and remained on station till 1863. Most of her surveys were on the west coast of Vancouver Island with surveys of Klaskino, Klaskish, Nachatlitz, Esperanza and Nootka Sound and further work in Quatsino and Nasparti.

The shore headquarters for the immense flow of hydrographic surveying data was half of one of the original three buildings erected by Governor Douglas for the Royal Navy at Esquimalt base as a hospital during operations against the Russians during the Crimean War. This was converted into a drawing office for the officers of the PLUMPER in 1858 and marks the beginning of a shore connection between hydrographic surveying and the Victorian area which exists to this day.

Most of the charts were printed and published in Britain as the data from these surveys were added to the printing plates which had the earlier surveys on them; some however, were printed on the coast. In 1862 Richards requested that the Royal Engineers at New Westminster lithograph 120 copies of the new survey of Nanaimo Harbour for sale locally. The survey had been completed prior to this date but Richards spent some time in November of that year buoying the harbour, and at this time he wrote Douglas that the volume of traffic was sufficient to warrant application of the Harbours Act and the appointment of a Harbour Master for the port.

In 1863 Captain Richards was recalled to Britain to become Hydrographer of the Navy, a post he held with the rank of Rear Admiral till 1874.

As a last act before leaving the coast Richards made a final and important contribution to the surveys of the northwest. He knew that when the HECATE left the station there would be no naval ship available for purely hydrographic work. He persuaded the Admiralty that the surveys should continue and was informed that a sum of £3,500 would be made available for charter of a local vessel and that certain of his personnel could remain on the coast. The company wanted £4,000 per year for her and it looked as if Richards would have to abandon his plan till he appealed to Governor Douglas who was sufficiently far sighted to see the advantages to the young colony of a well-surveyed coast, and so he guaranteed the balance of £500 from the Colonial Treasury.

The BEAVER continued charting the coast from 1863 till 1870, by which time she had ranged from the southern tip of Vancouver Island to the southern tip of Alaska and north to the head of the Portland Canal and Observatory Inlet. New anchorages were discovered and routes opened to almost every seaward corner of the province. One minor interruption occurred in 1864 when the Chilcotin Indians massacred a road crew working on Mr. Waddington's road from the head of Bute Inlet out to Fort Alexandria. The BEAVER was sent to patrol the area and a survey of Bute Inlet appeared, dated about that time, so obviously Pender had not wasted the opportunity of furthering the surveys of the coast.

The BEAVER ended her career as a hydrographic vessel in 1870 with surveys in Blackfish Sound; Farewell Harbour was so named because it was the last place surveyed and that in the BEAVER; to quote Pender:

> "They had fared well and now it was Goodbye, Farewell." She was handed back to the Hudson's Bay Company on 21 December in James Bay. Pender returned to England and supervised the publication of charts based on the wealth of information he had gathered in the BEAVER. He later became Assistant Hydrographer to the Admiralty.

Though not a specialist ship, the BOXER made reconnaissance surveys for the Admiralty of inlets suitable for a terminus for the Canadian Pacific Railway in particular in the Ursula Channel, Gardner Canal area. Sanford Fleming acknowledges them in his report dated 1877, though the surveys must have been dated about two years previous to that as the BOXER left the Pacific Station in 1875.

Preliminary surveys of the entrance to the Skeena were made by the DARING in 1877 and many of the names of locations in that area are those of the officers of that ship.

In 1888 the US Coast and Geodetic ships PATTERSON and COSMOS started surveys from Cape Muzon to the head of the Portland Canal and this work carried on till 1891. It was discontinued at the request of the Canadian Government because the boundary between Alaska and Canada was still under consideration.

However, in general the Admiralty must have considered that when the BEAVER paid off, the coast of British Columbia was sufficiently well surveyed to allow normal coastal trade to ply the coast in safety as almost thirty years elapsed before another surveying ship was appointed to the Pacific station. This was the EGERIA, destined to be the last hydrographic ship of the Royal Navy to be stationed on the coast and which was to form the link between the Admiralty surveys and the present Canadian Hydrographic Service (Figure 2).

Figure 2

HMS EGERIA, a steam screw sloop of 940 tons, the last R.N. hydrographic ship to be stationed on the Pacific Coast.

Much of the EGERIA's work consisted of re-survey, but these were modern surveys, on larger scales in places where definite settlements had taken root, and filling in the gaps that had been left as being unimportant during the initial coastal surveys. She arrived out from England in 1898 and remained on station continuously till 1910, recommissioning on station. Her first commanding officer was Commander Smyth and he commenced surveys in the Strait of Georgia area. However the threads of continuity were already picked up by the Canadian Hydrographic Service.

In 1886, the CPR reached Port Moody and their steamships linked with the Orient. Four years later, in 1890, the Canadian Pacific liner PARTHIA struck a shoal in Vancouver Harbour and as a result of an Order-in-Council a surveyor was detached from the Georgian Bay surveys to come to Vancouver to carry out hydrographic work in Burrard Inlet. This was the first Canadian salt water hydrographic survey. The man was William J. Stewart, who was later to be in charge of the Georgian Bay surveys and to become the first Chief Hydrographer of the Canadian Service. However, the results of his work were incorporated in the Admiralty chart of the area published in 1893 and so this cannot be considered the first Canadian chart of the coast. That honour fell to the chart of Prince Rupert published as a result of surveys carried out in 1906/1907. Mr. George Blanchard Dodge of the Surveyor-General's Office, Department of the Interior, Ottawa, was engaged on hydrographic work in Prince Rupert in 1906. In 1907 Mr. Musgrave came out to the coast accompanied by Mr. L.R. Davies. Henri Parizeau joined them and the three surveyors were employed in completing the Prince Rupert survey. Seemingly there was close co-operation between the officers of the EGERIA and Musgrave's party. At the end of the year Musgrave's party returned to Victoria and set up office above the present CPR office on Government Street. These three men -- Musgrave, Davies and Parizeau -- along with Mr. W.K. Willis, who transferred from the east coast in 1917, were the founders of the Canadian Hydrographic Service surveys on the BC coast and between them had charge of the Regional office till 1953.

In 1908, the hydrographic service commissioned their own ship, the LILLOOET. She was built by the BC Marine Railways Limited at Esquimalt and went to Prince Rupert to start her work in June of that year. In 1909 Parizeau and Cowley were detached from the LILLOOET for the summer and charted Telegraph Creek at the entrance to the Skeena. This was the first recorded Canadian detached shore party on the BC coast. Work from the ship continued in the Prince Rupert area through to 1910 with work in the Queen Charlotte Islands being started that year. The LILLOOET was based in Esquimalt at that time and in 1910 the shore office was moved from the Government Street premises to the dockyard. The Service had gradually started to expand. However World War I reversed this trend and by 1918 the LILLOOET was laid up at Esquimalt and the only work done was resurveys of Victoria and Esquimalt harbours. That year the shore office was moved from the dockyard to the BC Permanent Loan Building in Victoria, presumably due to pressure of space for naval requirements at the dockyard.

A definite pattern can be seen in the early work (1906-18) of the Canadian Hydrographic Service. The Admiralty work was being accepted for the standard coastal routes but now hydrography was becoming of value to the industries of the province. Surveys were made of the Prince Rupert area -- the cargoes from the Orient coming in and Prairie grain going out; Observatory Inlet -- the ore from Anyox and Alice Arm; Skeena and Pacofi -- information for the fishermen engaged in the salmon industry; Port Alberni -- a sheltered port for lumber and forest exports; Ocean Falls -- the pulp and paper industry.

The history of hydrographic work on the BC coast following World War I is one of consolidation and updating of charts. In the main, the whole coast was surveyed, then when new echo sounders became available the task of resurveying to modern standards was started, and today, with the exception of a few inlets well off the normal routes, the coast is completely surveyed. In 1918 about one hundred charts of Canada were published in Canada; this rose to 315 by 1939. By 1969 this number had grown to 984 (possibly the largest domestic chart catalogue in the world) and over 318,000 charts were sold.

The work of the hydrographer is never-ending. A few years ago the six-fathom line was accepted as the danger line for navigation. With modern bulk carriers the ten-fathom line is not even adequate. Shoals that formerly were not dangerous assume a new significance and require a more rigorous standard of survey.

The work that began with Vancouver and was carried on by Richards, Pender, Parry and Parizeau still carries on. The goal is still on the horizon and like Lewis Carroll's Red Queen "It takes all the running we can do to keep in the same place. To get somewhere we must run at least twice as fast as that."

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Preliminary Results
of
Loran C on the Lower Great Lakes

February, 1971

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The Marine Sciences Branch of the Department of Fisheries and Forestry has the responsibility of providing positioning and navigation systems for the various disciplines operating from the Canada Centre for Inland Waters. The accurate positioning of survey vessels on the lakes has and continues to be a problem, however, we are striving to eliminate or reduce these problems by research into electronic positioning systems and evaluation of such systems as they become available. One such system with coverage over the Lower Great Lakes and considerable potential is the Loran C system. A study on positioning systems for Inland Waters sponsored by the Inland Waters Branch in 1968 recommended the use of Loran C for positioning ships within the lower Great Lakes.

Because Loran C to date has been used mainly as a navigation system, rather than a precision survey system, and because little was known about the Loran C signals in the Great Lakes area, this study was undertaken, so that many of the obvious and standard questions could be answered.

This report contains preliminary results and summary of the recent Loran C evaluation. These tests were, in the main, carried out by H.P.L. Engineering, under contract to Marine Sciences Branch, Central Region. At the time of this writing, not all data have been adequately analized, and it is to be understood that figures quoted in the following report may be slightly altered to reflect final results.

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Loran C System

The Loran C system is basically a hyperbolic navigation system which operates on a single frequency of 100 KHz. The system was developed through the efforts sponsored by the U.S.A.F. in the early Fifties and in the late Fifties the entire system was placed under responsibility of the U.S. Coastguard where it remains to date.

Each Loran C chain consists of a Master and Slaves, with each station transmitting accurately synchronized phase coded groups of pulses. The stations each transmit a group of eight pulses (the master transmits a ninth pulse for identification) on a time sharing basis.

The receiver within the Loran C chain can look at either a single pulse or the entire pulse group, or it can look at the pulse group as well as the continuous wave which is transmitted within the pulse. It is obvious that the pulse or envelope matching receiver will only provide a coarse reading while the receiver which looks at the cycles (cycle matching) of the CW will provide a much finer measurement. It is mandatory for any survey requirement that receivers with a cycle matching capability be used.

Loran C coverage on the Great Lakes is provided by the East Coast Chain with transmitters as folllows:

Master, Cape Fear, North Carolina	34-03-45.61 N 77-54-47.20 W
Slave, Dana, Indiana	39-51-07.48 N 87-29-11.51 W
Slave, Nantuket Island	45-15-11.98 N 69-58-40.51 W
Slave, Jupiter Inlet, Florida	27-01-59 N 80-06-53 W
Slave, Cape Race, Newfoundland	46-46-32.70 N 53-10-31.76 W

Coverage and Geometry

Loran C coverage of Lakes Ontario and Erie is as shown in Figure 1. Lines of position are shown for all of the above Master-Slave combinations, however, for our recent trials only the Dana and Nantuket Slaves were used. Reception of the Florida and Newfoundland slaves was demonstrated on one brief occassion, however, the reception reliability is marginal.

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On Figure 1, the Cape Fear - Dana pattern is anotated SSO-Z, and the Nantuket - Cape Fear pattern is shown as SSO-Y.

All points on Lake Ontario and Lake Erie are less than 650 miles from any of the three stations used, or less than half the defined ground wave range. The Geometry of hyperbolic intersections for the two pairs of transmitters is excellent in this prime coverage area. Intersection angles are no less than 60 degrees and hyperbolic expansion is less than a factor of 2 in all areas of both Lakes. Therefore, good resolution of position in terms of time differences is possible.

Evaluation Objectives

The trials had three major objectives:

1. Assess the signal quality at surface level along the shores of Lake Ontario and Lake Erie. This assessment to include; signal strength - stability of Loran C signals - order of accuracy relative to North American 1927 datum - nature of diurnal variations - nature of variations due to atmospheric or other noise, and stability of chain transmitters.
2. Assess the accuracy improvement resulting from the use of the differential mode of operation.
3. Assess the properties of competative Loran C receivers, considering performance, stability, reliability, and cost, and recommend a type for possible purchase.

Conclusions have not been reached on all of the above objectives, at this time, however, sufficient information is available to conclude on some of the more important points.

These points are as follows:

a) Short term variations

b) Long term variations or those which can be eliminated by differential operation

c) The selection of the most appropriate velocity of propagation and determination of residual error.

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Field Trials

Field trials were conducted by operating a receiver with the antenna situated at known geographic points, for a period of twenty-four hours or more at five widely separated points on the north shores of the two lakes.

The location of these points is as follows:

Kingston
Cobourg
Burlington
Port Stanley
Wheatly

Short period observations were also obtained at Port Colborne and Scarborough, and in addition, a short period of operation was carried out at Tobermory.

The location of these points are shown on Figure 1, and as can be seen, the points cover an area of approximately 300 miles.

The observations at all of the above points, with the exception of Tobermory, were carried out in the differential mode, that is a receiver was operating at Burlington simultaneously with observations at all of the other points. In addition, a receiver was operated at CCIW (about 2 miles distance from above Burlington location) for the entire period of the trials.

Most of the above trials were taken with the following Loran sets:-

Epsco Airborne (AN/ARN-94)
Epsco Manpack (AN/PSN-2)

The receiver operational at CCIW and Tobermory, was a Litcom AN/UPN-35, which was on loan to Central Region from the US Coastguard.

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Results

The geographic position along with the mean Loran C observations at each point are listed below: (data at present are not available from the Scarborough or Port Colborne points).

	Latitude	Longitude	Mean TDY	Mean TDZ
Kingston	44-13-50.51	76-27-39.65	50835.49	68215.86
Cobourg	43-57-22.85	78-09-52.15	51326.89	67884.75
Burlington	43-19-29.28	79-47-36.94	51872.44	67579.47
Port Stanley	42-39-32.2	81-12-48.09	52364.26	67269.90
Wheatly	42-03-47.70	82-27-48.33	52773.44	66940.36
Tobermory	45-15-25.00	81-39-46.52	51749.44	66834.05
C.C.I.W.	43-18-00.79	79-48-13.02	51881.82	67581.23

The most obvious variability in observing Loran C sets, as used during these trials, is the short term variations or jitter. The readings varied in an apparently random fashion and in most sets the variation is such that successive readings usually differed.

An example of these short term variations can be seen in Figures 2 and 3. These figures show time difference values which were recorded at approximately 1 second intervals from the UPN/35 receiver at CCIW. Similar recordings were taken for each day's operation in addition to readings at 10 second intervals during each day for periods of approximately 15 minutes duration. Figures 2 and 3 as well as other recordings show that these very short term variations fall within ± 200 nanoseconds of the mean value. These short term fluctuations, although not all recorded, were apparant to some degree in all sets used during our trials. These variations can, to a certain extent, be dampened or when taking a reading, an averaging process can be instigated to eliminate some variability; however, the effect cannot be allowed for in monitoring and a good portion of the ± 200 nanoseconds must be counted as a possible random error.

Over a long term period there is also considerable variance as can be seen in Figure 4. This figure shows 15 minute averages as determined from the UPN/35 receiver at CCIW. It should be noted that at this time these readings have not been corrected for any transmitter variations, however, also, any transmitter variation should be readily adjustable by a monitor correction.

Again as can be seen on Figure 4, the fluctuations fall within ± 200 nanoseconds of the daily mean values.

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The daily mean values as recorded at CCIW and Burlington are further portrayed on Figure 5. This is perhaps the most interesting and noteworthy figure as in addition to the daily means, it shows the variability of the daily mean and the trend that is shown by the observation at two locations a short distance apart. As can be seen, the recordings do follow similar trends with the variability of the daily means in the order of approximately ± 200 nanoseconds. The mean daily deviation is in the order of 300 nanoseconds.

By observing the variations of both receivers an estimate of the portion of this swing that is due to the chain and common propagation can be made. While this has not been done rigorously at time of writing, the two graphs indicate that for sets about 2 miles apart, a substantial portion of the variability is common, and therefore removable by monitoring.

Figure 6 shows the raw CCIW data that has been adjusted by subtracting the deviation of the daily mean observed at the Burlington site. The adjusted data lies within 200 nanoseconds of the mean in TDY and 120 nanoseconds in TDZ. It should be noted that these figures are for receivers only a very short distance apart and then making comparisons between simultaneous recordings at distances of up to 150 miles apart, the trend is not nearly so clear. The observations appear to follow a general trend in their deviations, however, the overall effectiveness of monitoring would be limited to long term trend adjustment (daily or half daily). It can be said with reasonable certainty that monitoring would increase accuracy by a factor of 2.

Propagation Considerations

One of the main and usually the largest factor affecting the accuracy of any electronic positioning system is the selection and determination of an effective velocity of propagation. This velocity is determined by comparing computed to observed values at as many points as is possible over the area of interest.

At this time, we have seven geographic positions where Loran C observations were made. The positions are listed previously in this report.

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For the calculation of predicted or computed Loran C readings at these points, we must assume a certain velocity and then make a comparison to the observed readings. Should the chosen velocity be incorrect, a certain trend should be obvious between the difference, when compared to lane number or time difference.

It should be noted that for each pattern, three different velocities can be used if required. That is, each side of the triangle of each pattern - Master to Slave - Slave to point - and - Master to point - may all have different velocities. From the start it is obvious that the Baseline Cape Fear to Nantucket will have a higher velocity, because of the sea water path, than the other paths which are mainly over land and some fresh water.

For our initial calculations we assumed a velocity of 299,550 Km/sec. for the sea water path and 299,400 for the over land paths. With this assumption, a comparison of computed to observed values was made. This listing is shown in Figure 7.

As can be seen from this table, the observed-computed values all have the same sign, therefore indicating a wrong assumed velocity. Also the large differences in the TDZ pattern are no cause for alarm -- it simply indicates that on this pattern an incorrect velocity was used on the Master-Slave baseline. By adjusting the baseline velocity, a constant correction can be made.

The results of this observed-computed table are plotted against lane number as shown in Figure 8. As is indicated on the bottom of Figure 8, the figure in parenthesis are the monitor corrections which have been added to the differences of Figure 7. The datum of these corrections is the mean of all observations at C.C.I.W.

From this table it can be seen that there is a trend in the comparisons and based on all of these points we can conclude that the error which is introduced by the choice of velocity of propagation can be said to be ± 400 nanoseconds on TDY and ± 200 nanoseconds on TDZ.

This relatively large error, especially on TDY is caused mainly by the displacement of the Kingston and Cobourg stations. It would be worth while to observe additional points in this area to confirm or reject these values as it can be seen that if these readings were adjusted the error introduced would be much smaller.

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Summary:

1) The short term variability (within one minute) is in the order of ± 200 nanoseconds (approximately ± 50 meters). This variability cannot be reduced by monitoring.

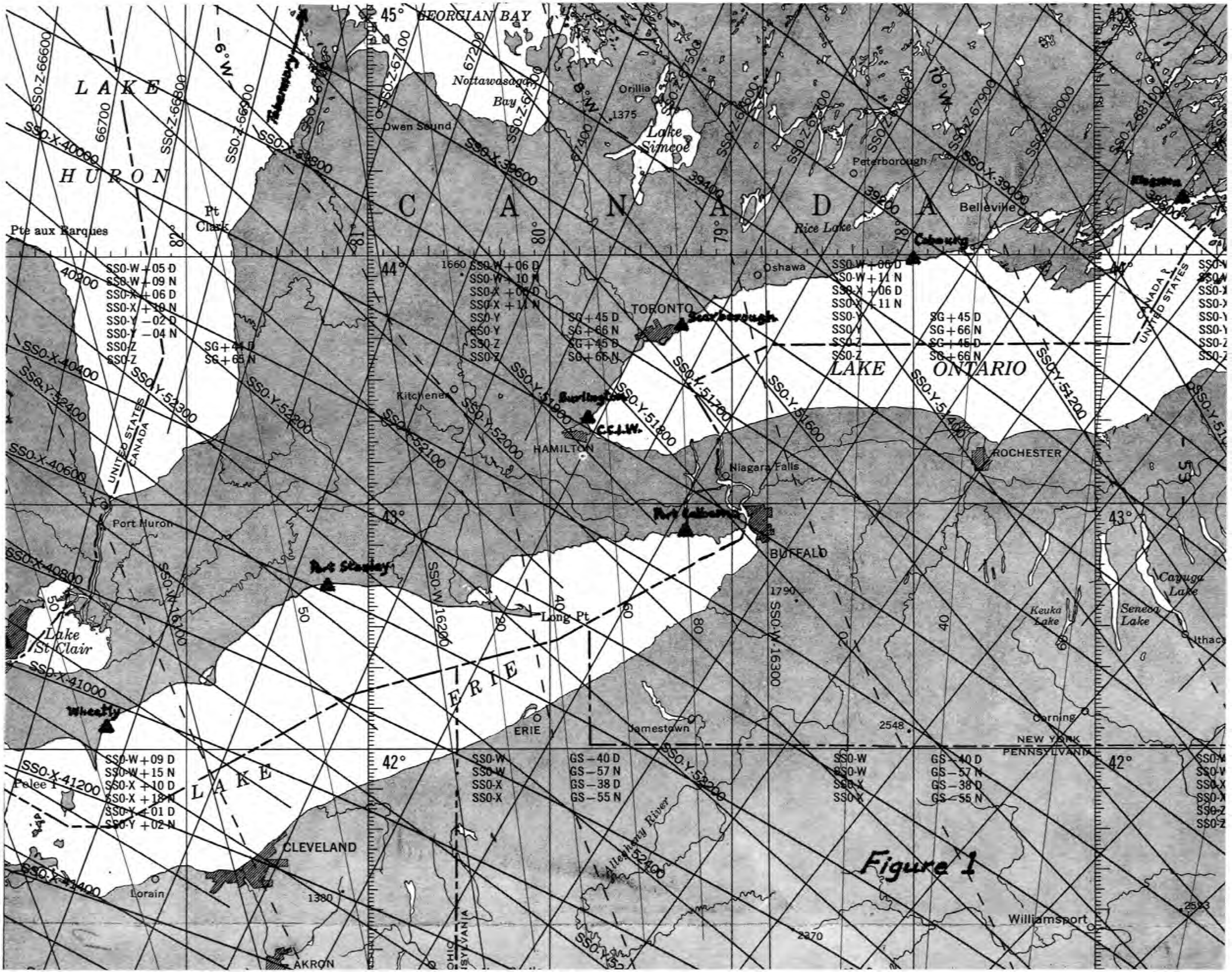
2) The hourly variability of the signals are also in the order of ± 200 nanoseconds. Approximately half of this variability can be corrected or adjusted by monitoring.

3) The variability of a period of days or daily variability is within ± 250 nanoseconds. No concrete data is available to show how much this could be improved by monitoring; however, it is estimated that most of it could be. We will assume a residual error of ± 50 nanoseconds.

4) By combining the above three points, it can be said that our results show that the repeatability of individual readings of each Loran C pattern in an unmonitored operation would be in the order of ± 650 nanoseconds or in the areas of Lake Ontario, ± 195 meters.

5) When we consider accuracy we must also allow for errors in velocity of propagation as well as plotting errors. Assuming a lattice is drawn using the best estimate of propagation, the error of ± 400 nanoseconds must be added to the above ± 195 meters repeatability figure. This would give an overall accuracy of ± 310 meters in unmonitored operation.

6) In a monitored operation, the expected accuracy should be within the order of ± 750 nanoseconds or in the areas of Lake Ontario, ± 220 meters.


LAKE HURON
GEORGIAN BAY
Nottawasaga Bay
Owen Sound
Orillia
Lake Simcoe
Peterborough
Rice Lake
Belleville
Kingston
Cobourg
Oshawa
TORONTO
Scarborough
Burlington
C.C.I.W.
HAMILTON
Kitchener
LAKE ONTARIO
ROCHESTER
Niagara Falls
Port Colborne
BUFFALO
Port Stanley
Long Pt
LAKE ERIE
ERIE
Jamestown
CLEVELAND
Lorain
AKRON
Port Huron
Lake St Clair
Wheatly
Pelee I
Pte aux Barques
Pt Clark
Tobermory
Corning
Ithaca
Keuka Lake
Seneca Lake
Cayuga Lake
Williamsport
Allegheny River
NEW YORK
PENNSYLVANIA
OHIO
CANADA
UNITED STATES
45°
44°
43°
42°
82°
81°
80°
79°
78°
6° W
8° W
10° W
SS0-W+05 D
SS0-W+09 N
SS0-X+06 D
SS0-X+10 N
SS0-Y −02 D
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SS0-X+06 D
SS0-X+11 N
SG+45 D
SG+66 N
SS0-W+09 D
SS0-W+15 N
SS0-X+10 D
SS0-X+18 N
SS0-Y+01 D
SS0-Y+02 N
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GS−57 N
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SS0-Y-52100
SS0-Y-52000
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SS0-Y-52400
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SS0-W-16200
SS0-W-16300
SS0-Z-66600
SS0-Z-66800
SS0-Z-67100
SS0-Z-67900
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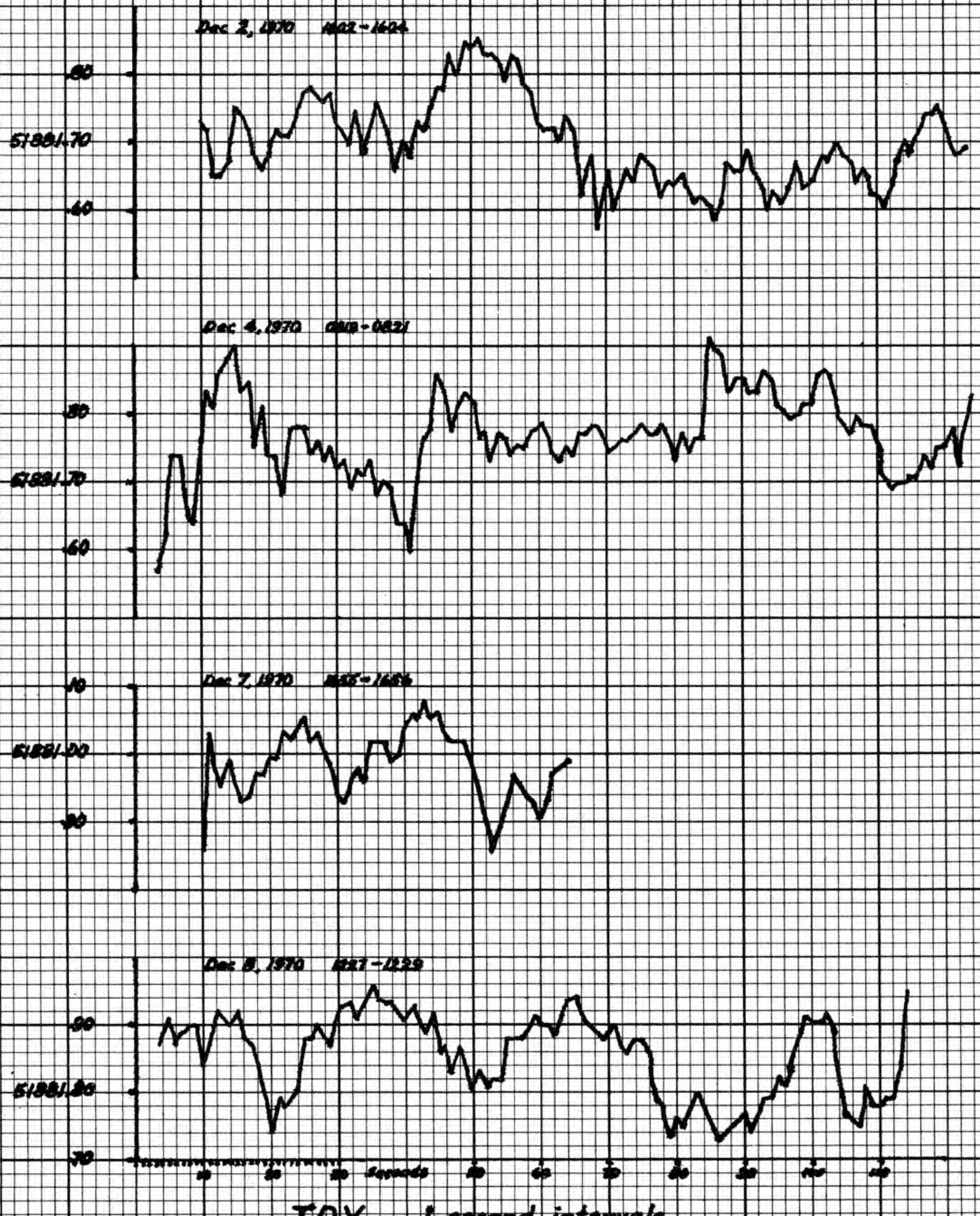
39400
39200
1375
1660
1790
2548
2370
1380

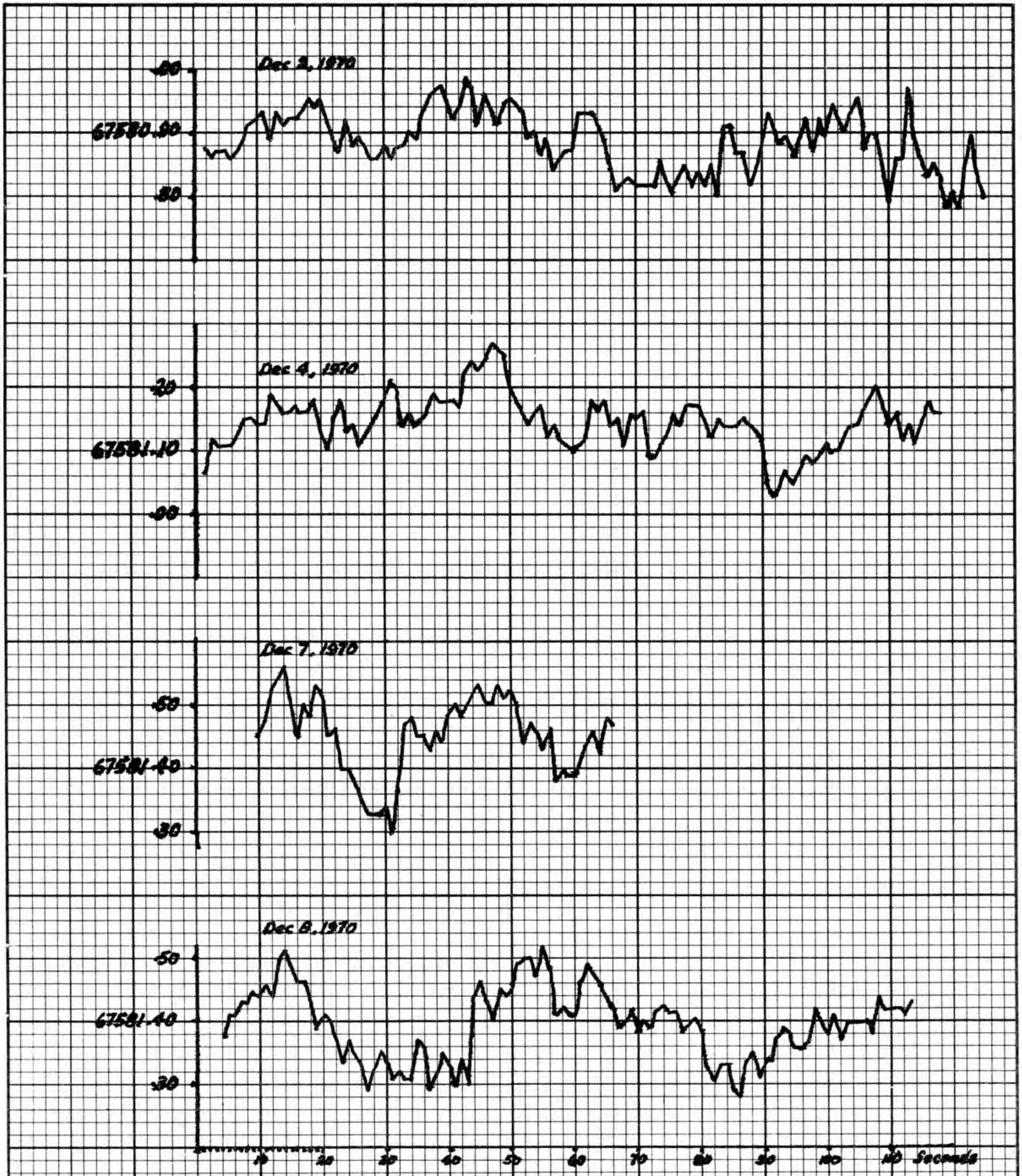
Figure 1



TDY 1 second intervals

BURLINGTON (C.C.I.W.)

Figure 2



TDZ 1 second intervals

BURLINGTON (C.C.I.W.)

Figure 3

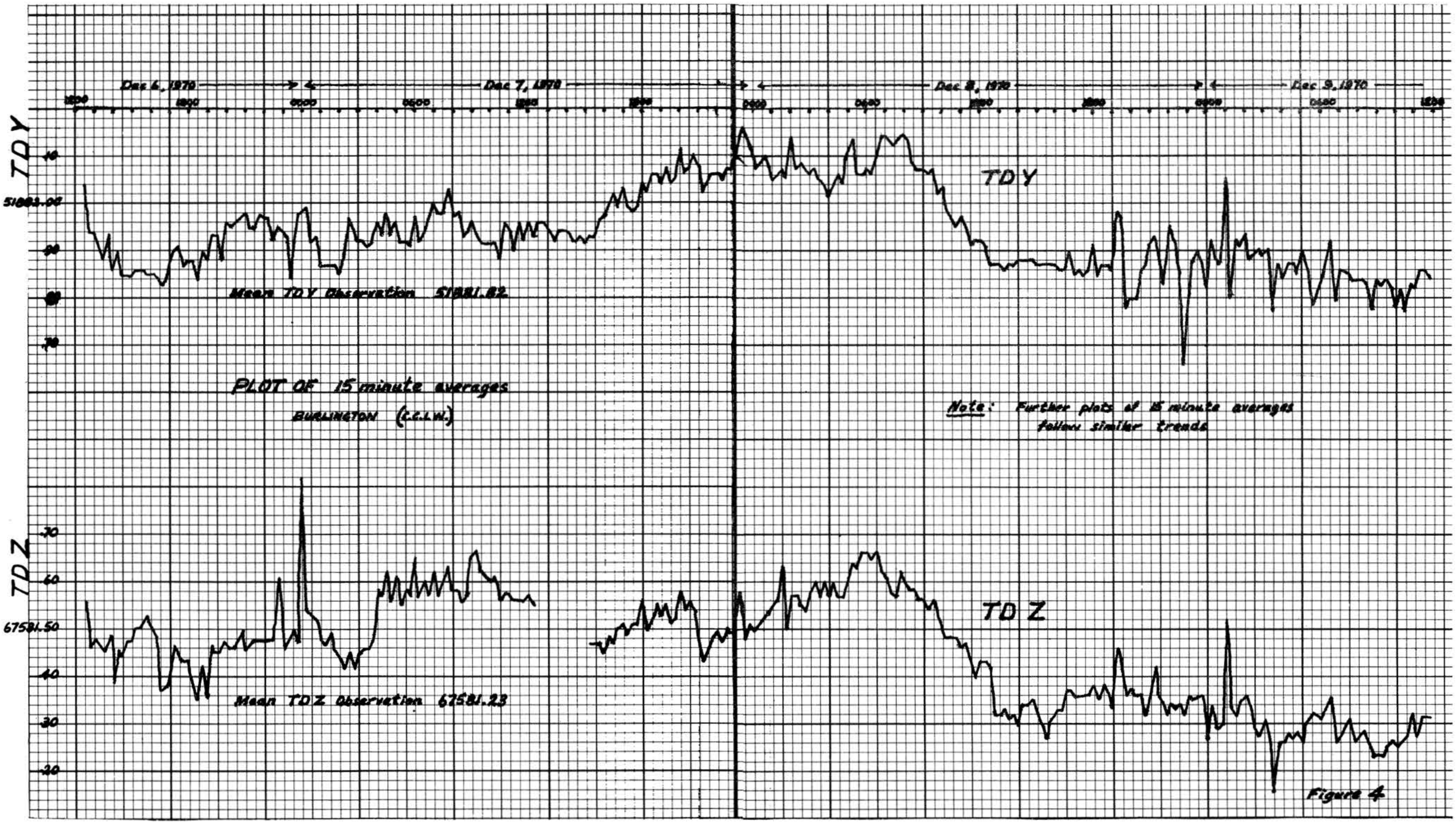
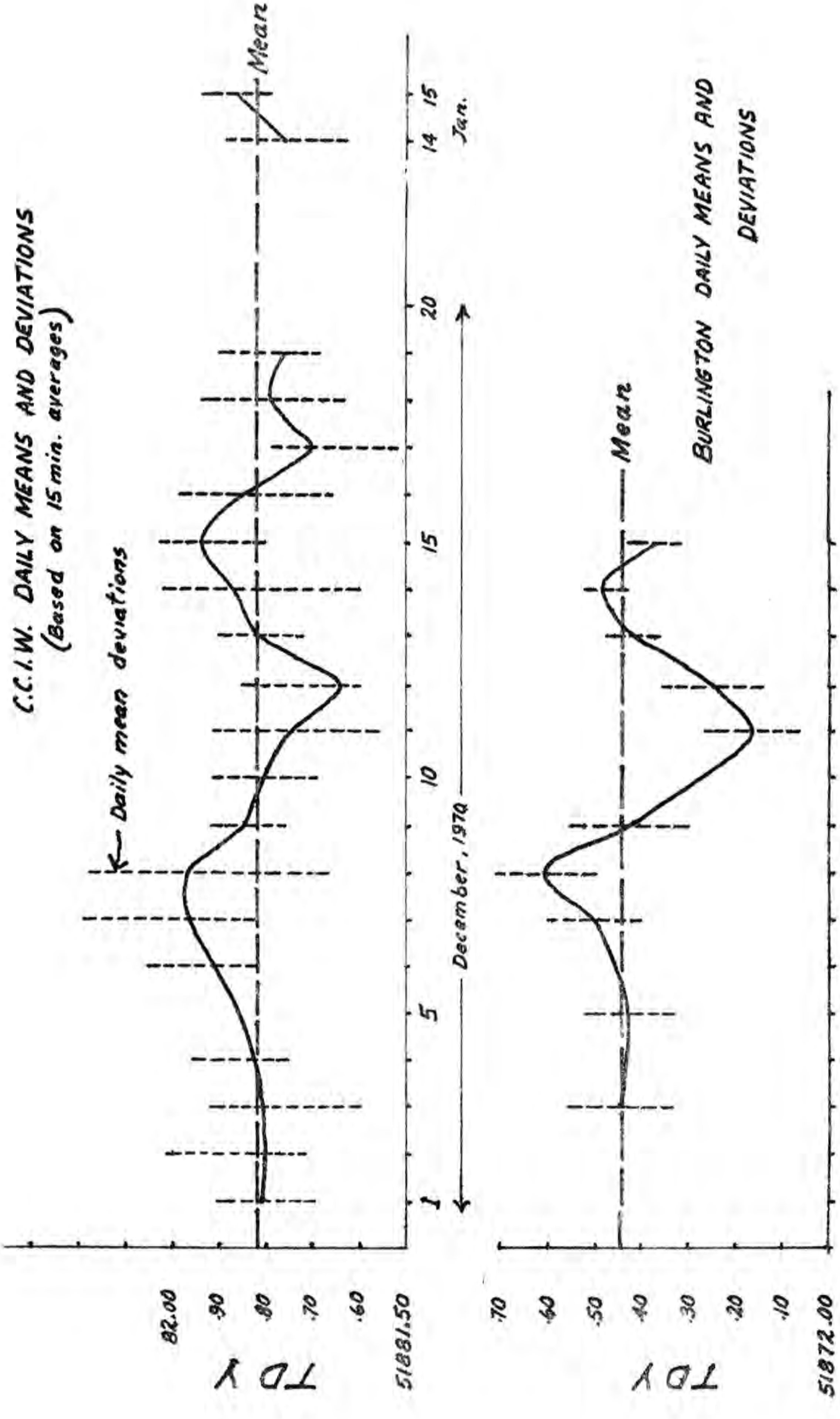

Dec 6, 1970
Dec 7, 1970
Dec 8, 1970
Dec 9, 1970
1200
1800
0000
0600
1200
1800
0000
0600
1200
1800
0000
0600
1200
TDY
10
51883.00
90
80
70
TDY
Mean TDY Observation 51881.82
PLOT OF 15 minute averages
BURLINGTON (C.C.I.W.)
Note: Further plots of 15 minute averages follow similar trends
TDZ
70
60
67581.50
40
30
20
TDZ
Mean TDZ Observation 67581.23

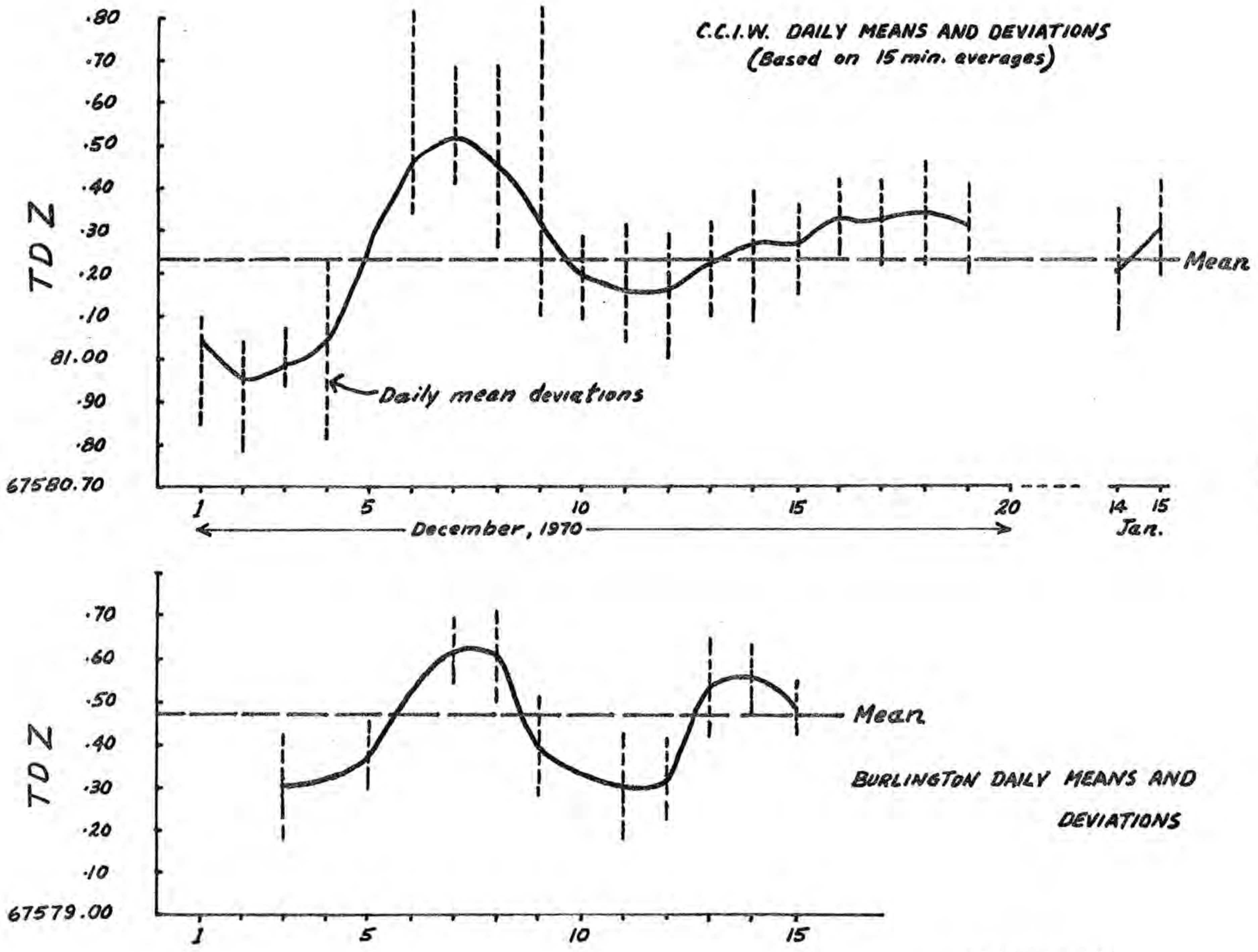
Figure 4



C.C.I.W. DAILY MEANS AND DEVIATIONS
(Based on 15 min. averages)

BURLINGTON DAILY MEANS AND DEVIATIONS

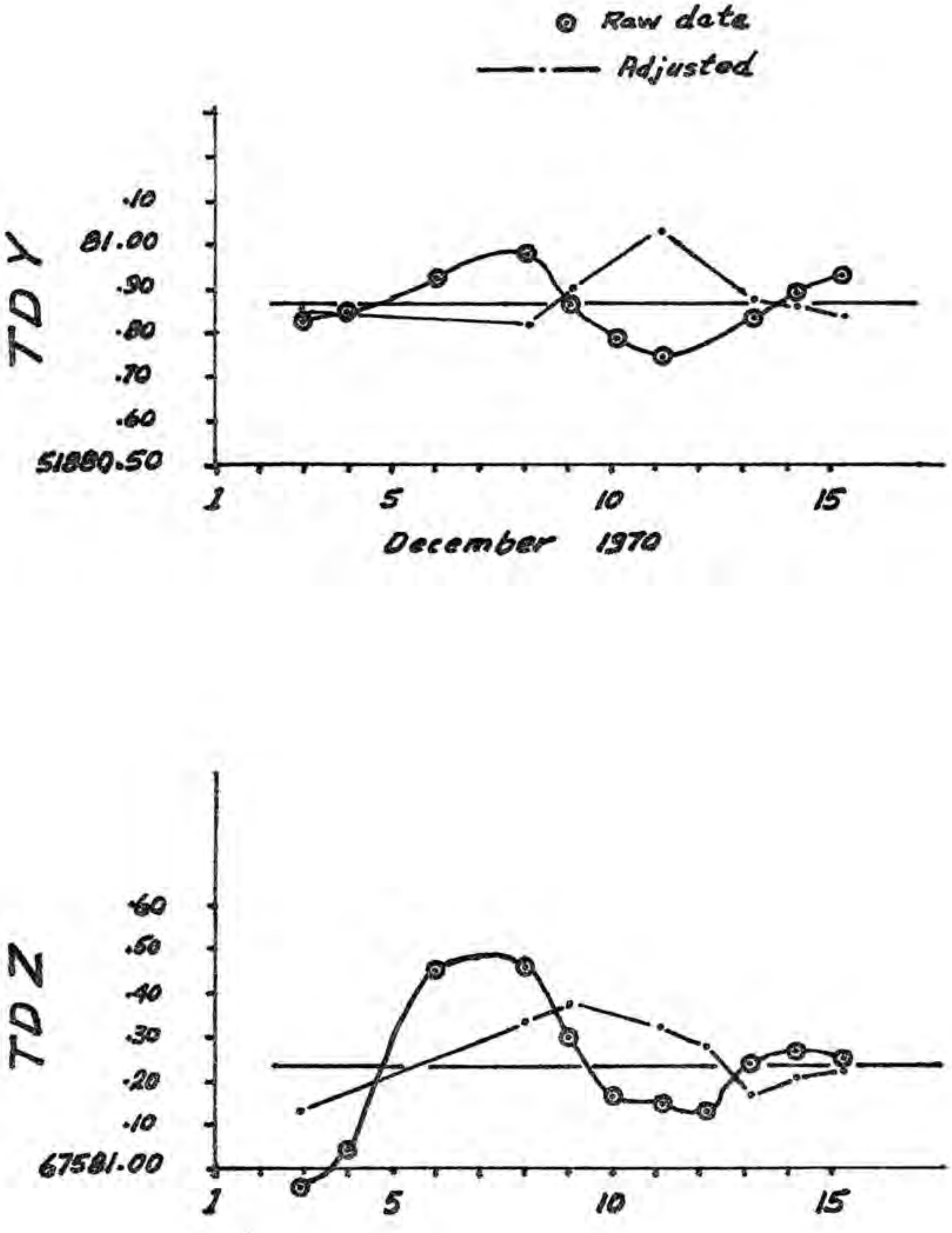
Figure 5a



C.C.I.W. DAILY MEANS AND DEVIATIONS
(Based on 15 min. averages)

BURLINGTON DAILY MEANS AND DEVIATIONS

Figure 5b



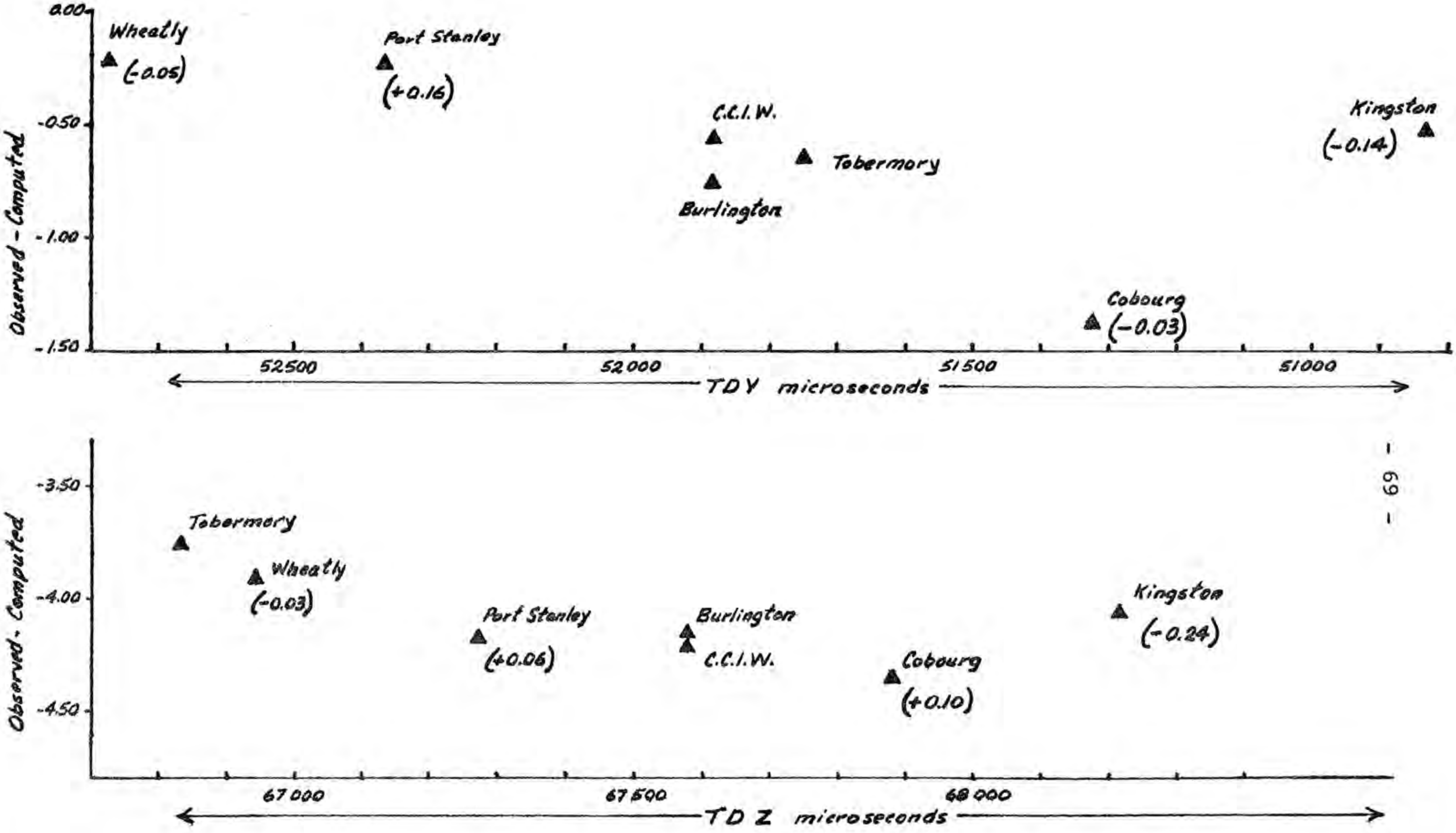
RAW and ADJUSTED DAILY MEAN VALUES

Figure 6

Station	TDY			TDZ		
	Observed	Computed	Diff.	Observed	Computed	Diff.
Wheatly	52773.44	52773.67	-0.23	66940.36	66944.25	-3.89
Port Stanley	52364.26	52364.64	-0.38	67269.90	67274.15	-4.25
Burlington	51872.44	51873.19	-0.75	67579.47	67583.63	-4.16
C.C.I.W.	51881.84	51882.41	-0.57	67581.23	67585.44	-4.21
Tobermory	51749.44	51750.07	-0.63	66834.05	66837.82	-3.77
Cobourg	51326.89	51328.25	-1.36	67884.75	67889.20	-4.45
Kingston	50835.49	50835.84	-0.35	68215.86	68219.67	-3.81

COMPARISON OF OBSERVED – COMPUTED
LORAN C VALUES

Figure 7



Figures in parenthesis indicate monitor correction applied to differences of Figure 7

LORAN C DIFFERENCES vz PATTERN READINGS

Figure 8

A Simple Subtense System

by

J.V. Crowley

During the 1970 field season, a method of controlling large scale sounding operations was used by the Canadian Hydrographic Service on wharf surveys from Tadoussac to Ste. Irenee, Quebec. For want of a better term, it has come to be referred to as the "northshore subtense system". Essentially this is a slight variation of a method that has been in use on the east coast for some time. The interest recently shown in the system probably warrants the following description.

A Boston Whaler, fitted with a Raytheon sounder, is manoeuvered by the coxswain, under radio direction from a transit-man ashore, onto a pre-determined line. At a range of an estimated 700 to 1000 feet from the wharf the launch is brought onto line toward the transit. By constantly talking to the coxswain over the Motorola PT300, the transit-man is able to keep the launch within several feet of the cross-hair, (depending on sea condition and practice). In lieu of radio communication, hand signals can be used effectively.

To obtain fixes on this sounding line, the hydrographer waits for targets, at either end of a long subtense bar, to coincide in his sextant. The bar is a home-made wooden job of fixed length with a sighting target at each end. It should be long for accuracy and short for portability -- between 20 and 25 feet should be about nominal. It is situated on a previously located point on the wharf near the transit, (usually a bollard), and kept perpendicular to the launch by a man ashore. Figure 1 shows subtense bar as used in 1970.

The bar has previously been calibrated ashore with a particular micrometer sextant, over a chained baseline of, say, 600 feet. The angle measured between the two targets has been recorded for each hundred foot station with an extra one thrown in for a 50 foot fix. For the bar used on the Lower St. Lawrence Survey, these angles ranged from 2-04.5 at 600 feet to 25-05 at 50 feet. These figures are marked on a tape stuck to the arm of the sextant for instant reference. (After setting the same seven angles in sequence for several days, the angles tend to stick in the memory as well.)

The hydrographer sets the 2-04.5 on the sextant, stands over the transducer, and presses the remote fix button as the targets coincide in the mirrors. During the 10 or 12 second wait for the next fix, the hydrographer sets on the next angle, (2-29 for 500 feet). Surprisingly the only time the hydrographer is rushed is at the 50 foot fix and that is easily coped with after a little practice. He might also find himself pressed if he is trying to work with a vernier sextant or if he is trying to phase when he should be fixing. If there is phasing to do, the coxswain should be able to do it.

No attempt was made in 1970 to run lines away from the wharf, but there is no reason why it could not work. The time used in steaming full-ahead to the outer end of the next line is used by the hydrographer to make notes on the graph, (time, fix number, etc.) and by the transit-man to set on his next angle and maybe check his reference object and level bubbles, and re-align the subtence bar.

Between the 50 foot fix and the wharf, the astute hydrographer can usually estimate a 25 foot fix and on occassion, a 12 foot fix just before the crunch. Interpolation of intermediate soundings after the 25 foot fix is not valid unless (a) the bottom is flat, or (b) the coxswain failed to slow down on approaching the wharf. (The latter wharf ramming practice is not recommended as much time can be wasted in training new coxswains.)

As the boat approaches the wharf, a significant error may be introduced if there is a substantial difference in elevation between the bar and the boat. This can best be compensated for when plotting the boatboard.

This system is most efficient when large fans can be run from each transit set-up. (Fan locations need not be limited to outside wharf corners). Transit angle intervals on fans run in 1970 varied from 5 to 2.5 to 2 to one degree. (In one instance, when running a fan at one degree intervals, a 14 foot shoal was located in 21 feet of water. This shoal, 480 feet from the wharf, did not show up on the neighbouring lines.)

Check lines were run in a novel, if somewhat cumbersome, way. A clothesline wire, measured in 100 foot lengths, was attached to a bollard at one end and to the bits in the bow of the whaler at the other end. The whaler was backed off till the wire was taut, the wheel put hard over, and the boat allowed to proceed crab-fashion, in an arc around the bollard. Fixes were obtained from the transit-man ashore. Arcs were run in this manner up to a distance of 600 feet from the wharf, (though at this range the 55 hp Chrysler outboard failed to keep the wire clear of the water.) One weakness of this procedure is that, due to the constantly changing course, launch speed tends to vary also when there is any significant wind or current. To minimize the errors from this situation, fixes must be taken fairly frequently. This method can be operated by one man, though two is nominal. (the boat drives itself). For a one-man operation there must be a varied background some distance behind the transit. The hydrographer fixes on random natural ranges, using the transit as the front range and a distinctive landmark for a back range. The angle at the transit, between the reference object and the landmark is measured later. This is not always convenient in the field and it is inconvenient to plot later, but it can be done. Figure 2 shows part of a completed wharf survey.

Bottom sample locations can be fixed by either method.

The lead line is still needed for soundings near the wharf, for shoal confirmation, and for obtaining bottom samples.

Accuracy:

A valid accuracy assessment of the subtense bar under working conditions has not been made, partly due to the lack of a more accurate system to compare it with. Nevertheless, some feel for the consistency of the techniques can be obtained from measurements between fixes on the sounding graph. A recent roll (Ottawa River, 5/6/71, Whaler #8) was analysed for statistical purposes. Sounding lines beginning with fix numbers 0, 20, 40, etc. were chosen. The distance between the nominal 200 foot fix and the 100 foot fix was assumed to be correct. Using a Gerber variable scale, the four preceeding spaces were measured at this scale. Factors, besides positioning sensitivity, which may have influenced the following results include engine speed changes, sounder man reaction time, and course sashays while attempting to hold line. Weather was not a factor in this instance, nor was current.

Statistics:

fix	100'-200'	200'-300'	300'-400'	400'-500'	500'-600'
01-06	100	101	102	102	100
21-26	100	101	97	104	99
43-48	100	103	97	101	100
64-69	100	100	88 (wrong angle, set for 400' and 500' missed)		
84-89	100	97	100	97	102
105-110	100	98	98	100	96
120-125	100	95	97	95	96
141-146	100	100	101	98	100
162-	N/A --broken line				
186-191	100	99	97	99	99
200-205	100	97	99	96	98
221-226	100	98	97	99	93
240-245	100	98	99	100	98
261-266	100	100	100	101	96
283-288	100	98	98	101	98
304-309	100	98	98	99	97
325-330	100	99	97	97	110 N/A (rough start over shallow crib)
346-351	100	102	97	101	101
AVERAGE	100	99.1	98.4	99.4	98.2
Max. variation from mean	---	4 feet	4 feet	5 feet	5 feet

The distances between fixes on the graph was usually about one inch. Time required to run a line from first fix to last, varied from one minute to 1.7 minutes. This works out to speeds of 5.6 knots and 3.3 knots. (At 5.6 knots the hydrographer has 10.6 seconds between 100 foot fixes and 5.3 seconds to prepare for the 50 foot fix).

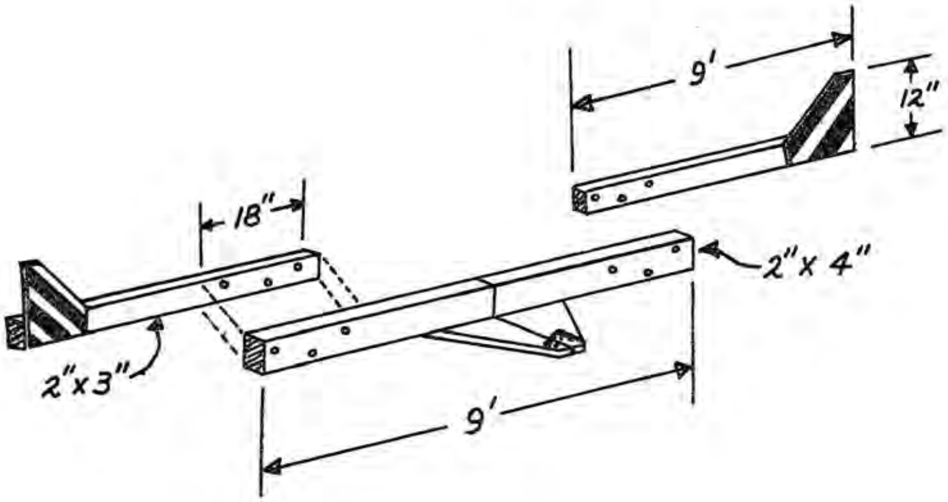


Figure 1

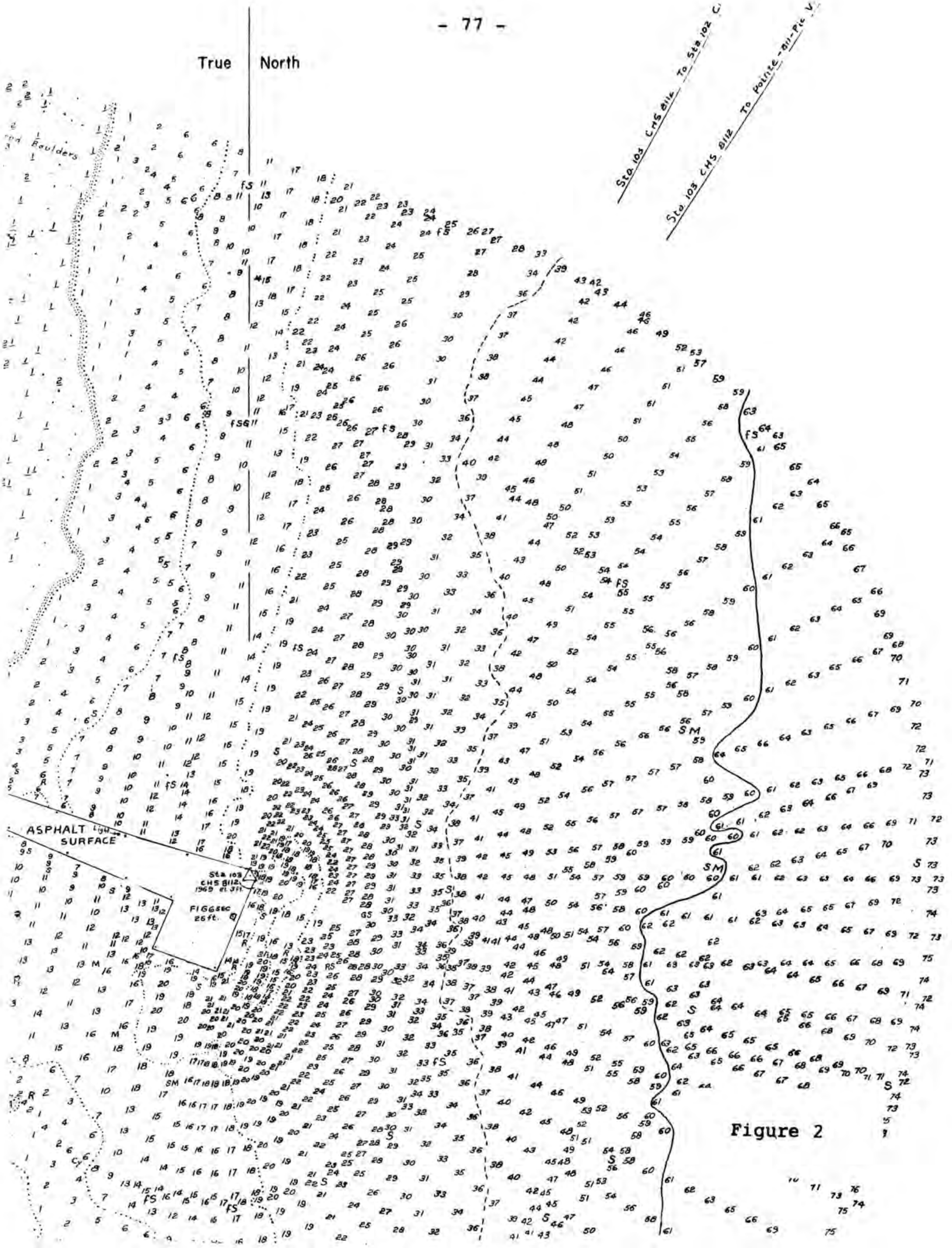

True North
Sta 103 CHS 8116 To Sta 102 C.
Sta 103 CHS 8112 To Pointe-au-Pic V.
and Boulders
ASPHALT SURFACE
Light
Sta 103 CHS 8112 1969 el. 3ft.
FIGGSEC 26ft.
FS
S
SM
R
M
GS
RS

Figure 2