SIDE SCAN SONAR FOR HYDROGRAPHY

AN EVALUATION
BY THE CANADIAN HYDROGRAPHIC SERVICE

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INTRODUCTION

Hydrographic surveys have improved in accuracy and efficiency over the last few decades with advances in electronics and data processing. Electronic positioning systems with automatic data loggers now make it possible to survey accurately at greater speed. Improved data processing systems eliminate the time-consuming, laborious task of scaling and plotting. The modern surveyor, however, is still plagued with the lack of knowledge of what lies between his sounding lines.

Sonar developments promise to improve this situation as commercial equipment becomes available. Omnidirectional scanning sonars can view large areas of the bottom and display the features on a CRT display; searchlight type sonars yield range, azimuth and depression angle with the potential of making depth measurements far removed from the survey vessel; multiple beam sonars simultaneously sound sectors along the vessel path and side-looking sonars delineate features of the bottom on wide swaths, either side of the survey craft.

This paper deals with the latter type, the dual side-scan sonar, specifically the type produced by E.G. & G. and Klein Associates of the United States. The principles of operation are presented, the results of an evaluation are given, and the use of the sonar over a field survey season is outlined.

PRINCIPLES OF SIDE-SCAN SONAR

A dual side-scan sonar system consists of a towed fish containing a pair of transducers with associated electronics, a tow cable that serves as an electrical as well as a mechanical link to the tow vessel, a chart recorder capable of simultaneous presentation of two channels of acoustic information and an operator with the task of optimizing system parameters, such as gain, gain slope, and detection threshold, to produce the best possible representation of the bottom topography from the acoustic signals (figure 1).

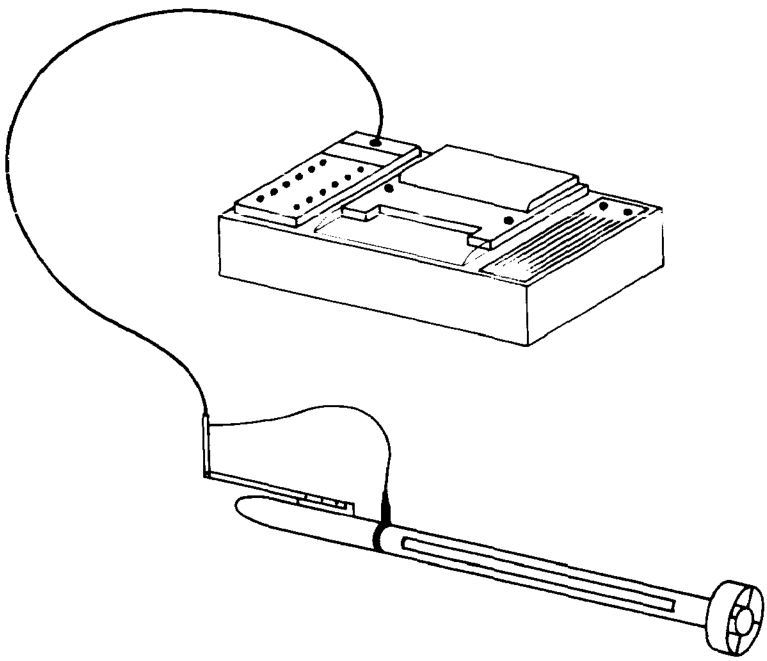


FIG. 1. — Side-scan Sonar System.

The two fish transducers radiate fan-shaped beams to port and starboard with a horizontal beam width of approximately one degree and a vertical beam width of 20 degrees depressed ten degrees from the horizontal. A short transmitted pulse (0.1 millisecond at 100 kHz) combined with the narrow beam yields a high resolution, typically 0.15 metres in range and one to two metres longitudinally.

A pictorial representation of the acoustic signals is produced by the recorder with range shown transversely and longitudinal paper advance related to the forward motion of the fish. The darkness of the mark produced on the record is proportional to the signal strength of the acoustic return. The operator interprets the resulting record to yield information on the depth and material of the bottom along the survey path.

The amplitude of sonar returns is a function of the size, shape and density of the target material. Calculations showed that the sonars tested have sufficient sensitivity and transmitted power to easily detect 0.25 metre radius spheres at full range (400 m). Sensitivity is therefore not considered a limiting factor in target detection. The sonar returns consist of backscatter from the bottom and the surface, as well as occasional specular reflections from objects in the water or on the bottom. Changes in this backscatter, due to the geometry and properties of the material, primarily determine the sonar presentation. The equipment's ability to resolve small changes in signal level in a high clutter background determines its sensitivity and usefulness as a hydrographic survey instrument.

The signal backscatter from mud, sand and gravel for different angles of incidence is shown in figure 2 [1], [2]. The fourth curve shows Lambert's law of backscatter, plotted in the form: $S(dB) = 10 \times \log(\sin^2\theta) - 6$. When the fish is operated at a height of 10% of maximum range, the sonar grazing angles are from 5 to 60 degrees and produce signal level changes of up to 20 dB in addition to normal range effects. If the system is operated over a flat bottom of uniform material, the gain of the system can be adjusted electronically to yield a uniform response across the entire range. Any change in bottom slope will alter the scatter from that area and change the relative signal strength. The changes in slope required for discernible (3 dB) and definite (6 dB) detection are shown in figure 3. This can be related to height of a detectable object if it is assumed that a mark on the graph representing 2% of full range is discernible. Figure 4 shows the size of object that can be detected with this criterion. Objects or depth changes of one to two metres occurring over short distances are then readily detected. The difference between a continuous slope and a flat bottom, however, cannot be easily resolved.

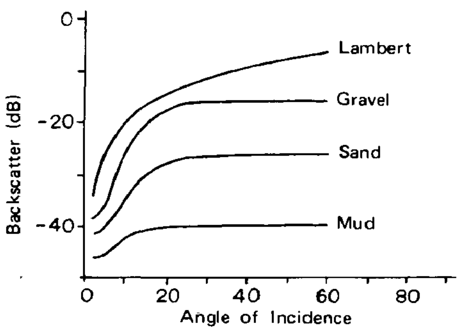


FIG. 2. – Acoustic backscatter at 100 kHz.

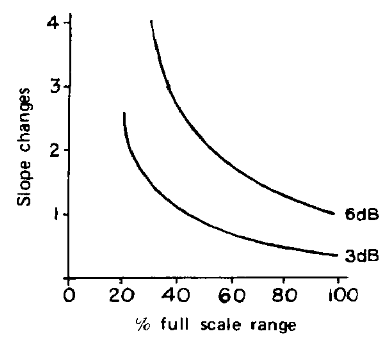


FIG. 3. – Normalized detection curve, homogeneous bottom, fish height 10 % max. range.

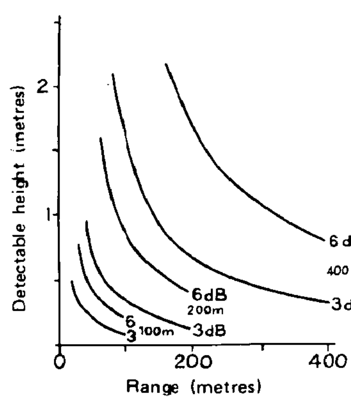


FIG. 4. — Height difference for detection, homogeneous bottom, fish height 10% max. range.

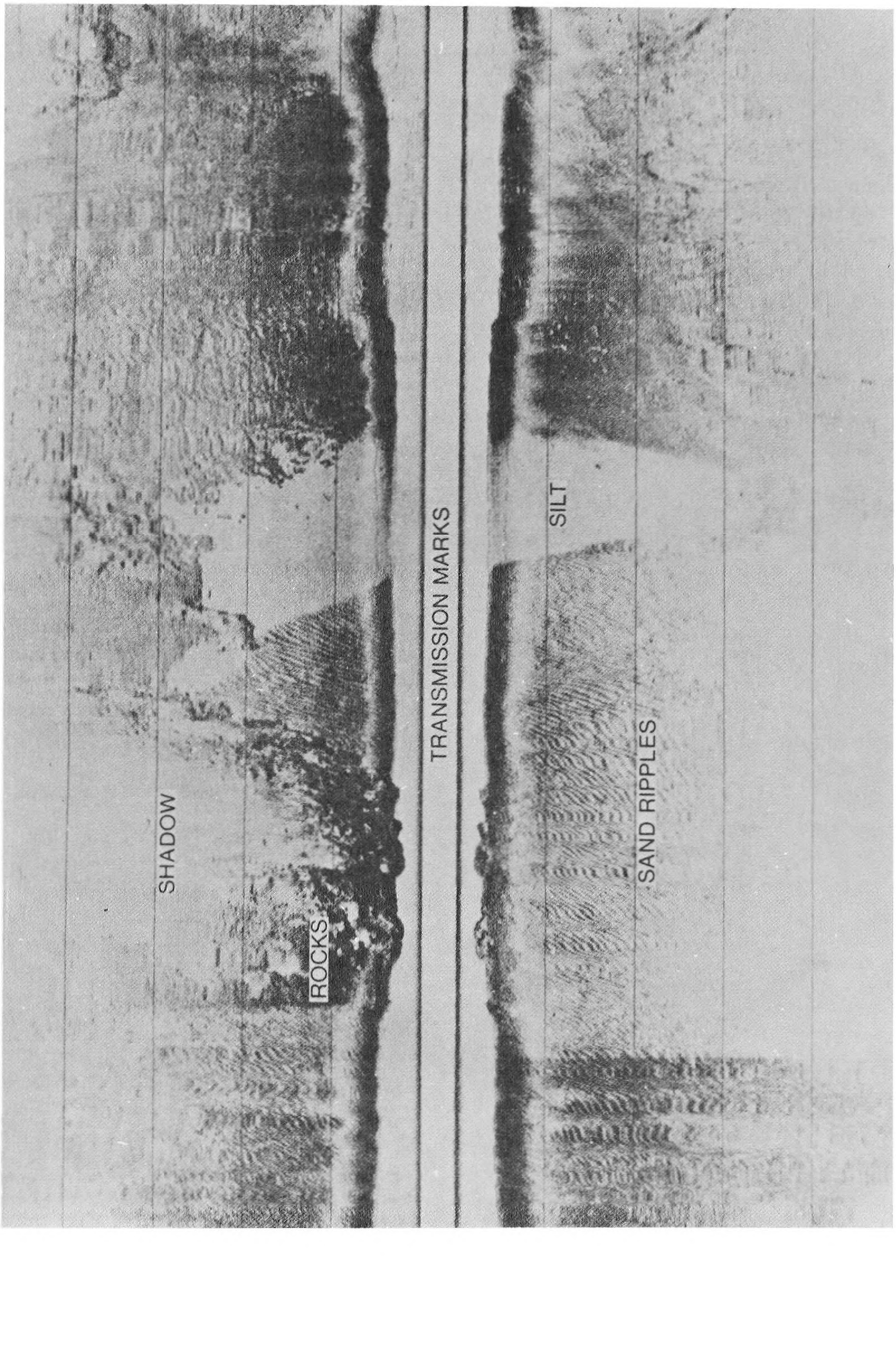


FIG. 5

A change in bottom material can change the signal strength as much as or more than a major slope change. This may cause ambiguities or yield information on the bottom material depending on the skill of the operator.

A target formation must have length as well as range extent in order to be recognizable to the operator. A single return will mark the paper, but it is unlikely that an operator would attach any significance to a single dot. Ten consecutive returns may be required before an operator would recognize the detection. The size of an object required to give ten returns is a function of the beam width, repetition rate, range and tow speed. A typical tow of 3 metres per second could detect 2-metre objects on short range and 10-metre targets on long range.

A record that illustrates some of the capabilities of the sonar is shown in figure 5. The two dark parallel lines along the centre of the record are the port and starboard transmission marks. The lighter lines are 50-foot (15.2 m) range marks. Note the rock outcrop with very dark returns followed by the acoustic shadow, the sand ripples, and the wedge of non-reflective material, which is most likely silt.

1972 SONAR EVALUATION

A short evaluation of two side-scan sonar systems was conducted near Killarney on Georgian Bay in August 1972. An E.G. & G. Mark 2A system was leased for a two-week period and a Klein Model 400 system was made available for two days during this period. The E.G. & G. unit was used to survey an area that had recently been surveyed by conventional means so that sounding and sonar data could be compared. Its ability to detect a known shoal under various conditions was determined and a comparative evaluation of the two systems was made.

NATURAL TARGETS

The ability of the sonar to detect natural shoal features was tested in an area where the mean water depth was 50 feet.

An isolated shoal, with a height of nearly 25 feet, was examined in detail using conventional techniques, plotted at a scale of 1/2 000 and contoured at 4-foot intervals. The result is shown in figure 6. Passes were then run with the side-scan sonar at speeds of 1.5, 3 and 6 knots, using the equipment range scales of 250, 500 and 1 000 feet. The horizontal range to the shoal was varied from zero to beyond the 1 000 foot range of the equipment.

The target was positively detected on all 10 passes using the 250-foot scale with ranges to 180 feet. Passes within 100 feet produced a good

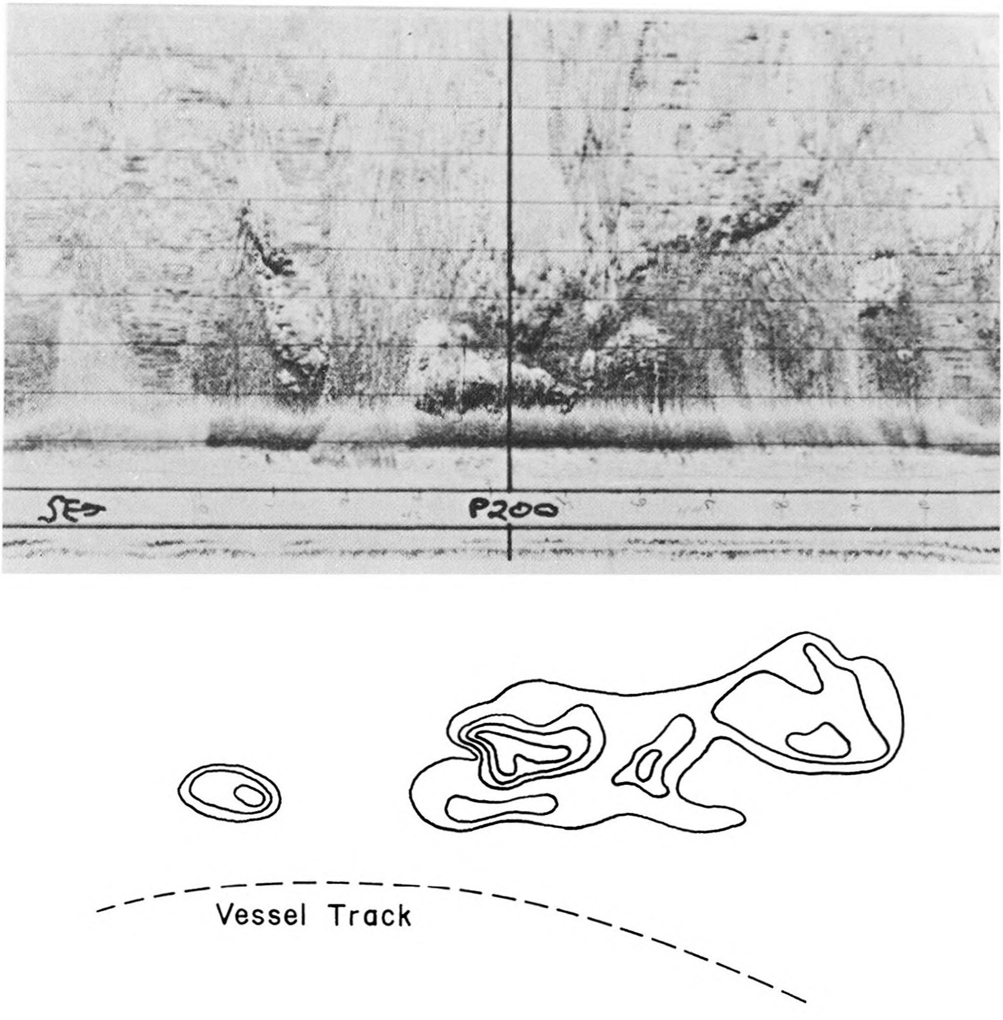


FIG. 6. — Above : Side-scan record of area.
Below : Contours derived from soundings.

shadow, which was used to estimate the height of the shoal at about 25 feet. The shadow extended to the limits of the paper when the shoal was more than 100 feet distant so no height estimates could be made for these records.

Ten passes made using the 500-foot scale also produced positive detection. Five of the passes showed good shadows that produced height estimates of 18-23 feet. One pass with the peak more than 500 feet away showed strong returns at maximum range produced by the lower slopes of the shoal.

By contrast, only two of the eight passes made with the 1 000-foot scale resulted in positive detection. Three passes had the peak beyond 1 000 feet, three came between 600 and 950 feet and showed nothing, a pass at 650 feet was marginal, and a pass with the peak at 820 feet showed a strong return at 750 feet. The limitation of towing the fish at 10% of the range was indicated in this test. Water depths in excess of 100 feet must exist if the 1 000-foot range scale is to be used successfully to its limit.

There was no apparent difference in detectability at different towing speeds up to 6 knots. Faster speeds were not possible with the launch used for this test.

The ability of the side-scan sonar to determine shape and size of shoal objects is illustrated in figure 6. Outlines on the sonar record can be related to the contours derived from conventional soundings.

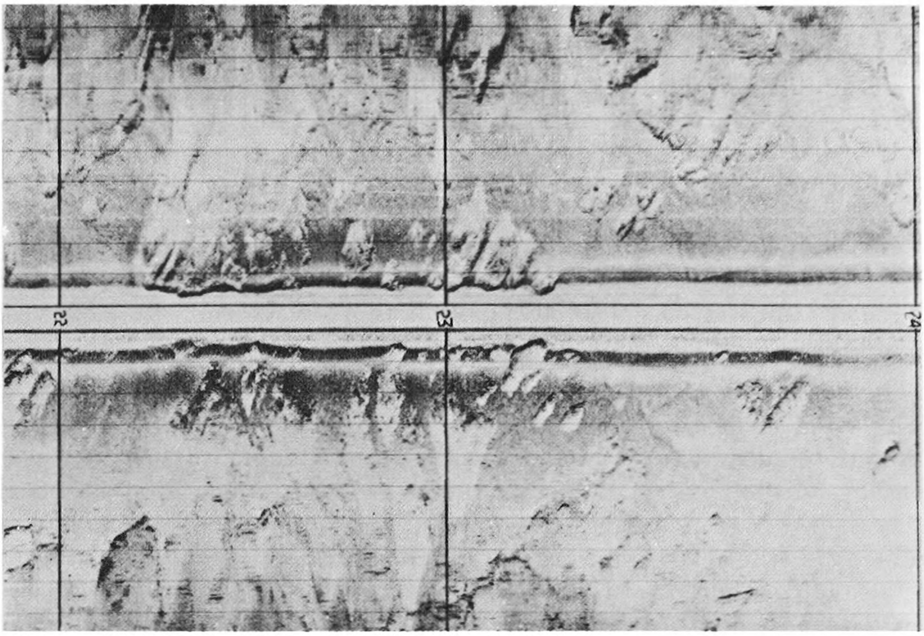
The ability of the sonar to detect hazards to navigation and topographical features was evaluated by comparing the results of a sonar survey with an existing field sheet. The original survey was conducted in 1964 near Killarney, in an area characterized by a sediment-covered bottom with significant rock outcrops. An area of eleven square kilometres was covered with the E.G. & G. sonar using the 500-foot range scale. Line spacing of 500 feet gave full overlap with the fish towed at a depth of 15 feet at 5-6 knots. Mini-Fix was used to position the tow vessel which was fitted with automatic data logging equipment.

The sonar record for each line was examined and apparent shoal areas were selected. The location of these features was plotted and overlaid on the original sheet. The detections were then divided into three categories, depending on their correlation with the field sheet data. The first category consisted of 16 sonar detected features, matching shoals that had been examined in the 1964 survey. Another 114 detections were found to correlate with soundings slightly shoaler than the surrounding figures but for which no shoal examination had been made. The third category consisted of 40 detections that could not be related to the field sheet.

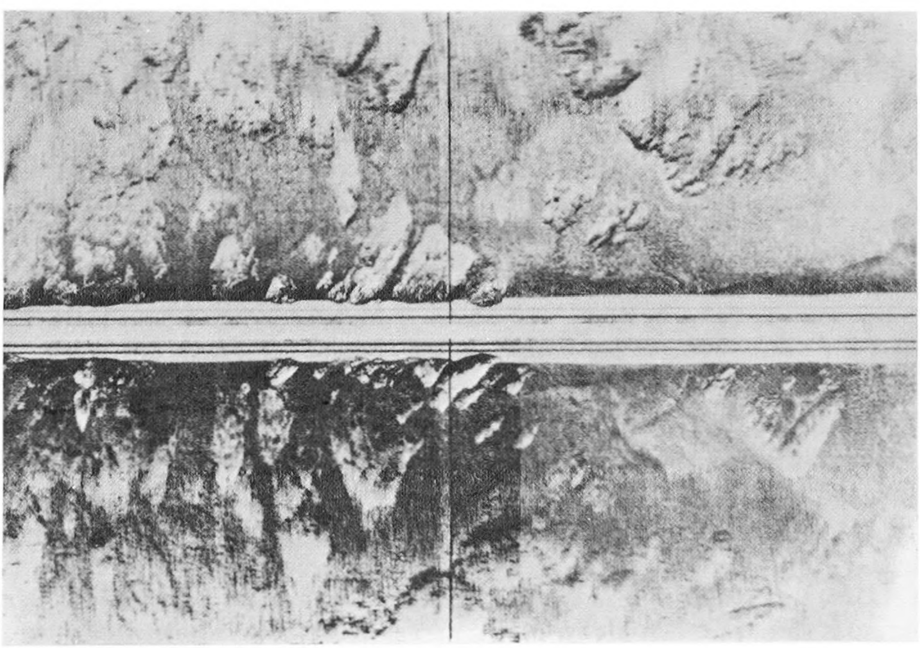
All charted hazards to navigation were detected with the sonar and their charted positions showed good agreement with the plotted features. The size and shape of these features were shown on the sonar records and could be used as an aid to contouring. Many of the detections in the second category showed the extent of shoal areas indicated by only single shoal depths on the original sheet. The remaining detections were either features that lay completely between the sounding lines or changes in bottom material wrongly interpreted as a shoal. A number of these areas were examined conventionally after the sonar survey and several small features 5 to 10 feet in height were discovered that could have been potential hazards in critical areas.

The E.G. & G. and Klein side-scan sonars were compared by towing the two in tandem over the same area. The lead launch towed the Klein sonar and a second launch, which in turn towed the E.G. & G. equipment. Simultaneous fixing facilitated comparison of the records.

Generally, features presented on one system were also on the other without marked difference in detectability. The effects of improper gain setting were evident on both records as clear features on one were masked or weak on the other. Neither system was clearly better in this regard. The E.G. & G. system had better contrast with more sharply defined leading edges and shadows, which resulted in easier hydrographic interpretation. The Klein system on the other hand showed a greater range of target levels that showed better continuity of features which is particularly advantageous to the geologist. The Klein system also had a better time varying gain fit with good uniformity of display, and showed less cross-talk than the E.G. & G. system. Both systems were judged to be adequate for hydrographic survey requirements (figure 7).



EG & G



KLEIN

FIG. 7. — Comparative records.

1973 FIELD OPERATIONS

The Canadian Hydrographic Service, Central Region, is based at the Canada Centre for Inland Waters, Burlington, at the western end of Lake Ontario. The survey of all inland waters to the Alberta border, plus Hudson and James Bay, is the responsibility of this region. This wide base of responsibility provided the opportunity to evaluate the sonar performance in many diverse environments.

Favourable reaction to the 1972 evaluation resulted in the purchase of a Klein Model 400 Dual Side Scan Sonar in time for the 1973 field season. A field hydrographer, Mr. J.H. WELLER, was trained in the operation of the equipment and given the task of organizing and conducting an evaluation of the equipment in the field. He was to visit each field party, demonstrate the equipment to the hydrographers and use the equipment to assist the field operations of that particular party. He spent from several days to two weeks with each survey and, in the course of the summer, worked in Hamilton Harbour, the Thames River and Lake St. Clair, the Lake Ontario navigation ranges, the St. Lawrence River, Lake Winnipeg and James Bay (figure 10).

The indoctrination and training phase in Hamilton Harbour illustrated the effectiveness of the sonar for checking dredging work. Figure 8 is a record obtained of an area at the entrance to the Harbour that had been dredged from a depth of 5-10 metres to a depth of 15-20 metres. Two

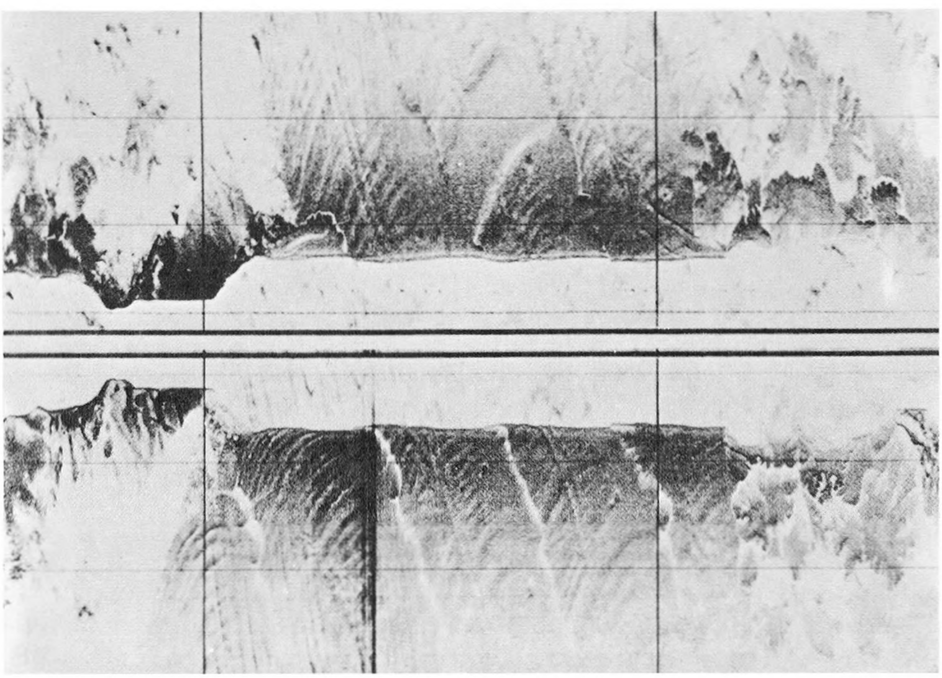


FIG. 8. Dredging Hamilton Harbour.

dredging techniques are clearly visible as well as areas that have been missed by the dredges.

The Thames River in Canada bears little relationship to its namesake. It is a pleasure boat route with a maximum depth of 7 metres and a width of 50 to 200 metres. A sweep of the river provided an interesting test of the equipment in shallow water. The fish was towed from the bow of an 18-foot Boston Whaler about one metre below the surface. The records revealed the location of sand bars, outlined the deep water path, and located an obstacle in the channel.

Successful searches were conducted with the sonar in Lake St. Clair to locate a submerged pipe and crib that could not be located with normal sounding techniques, and, in Lake Erie, to locate a submerged lighthouse foundation.

The navigation ranges used by small craft to enter the harbours of Lake Ontario were swept with the sonar as part of the normal survey party activity. No uncharted hazards were found, but an interpretation problem arose. Weeds growing in the area produced very strong returns with shadows behind them looking very similar to the rock outcrops seen in Georgian Bay. These returns masked any returns that may have been produced from objects on the Lake bottom (figure 9).

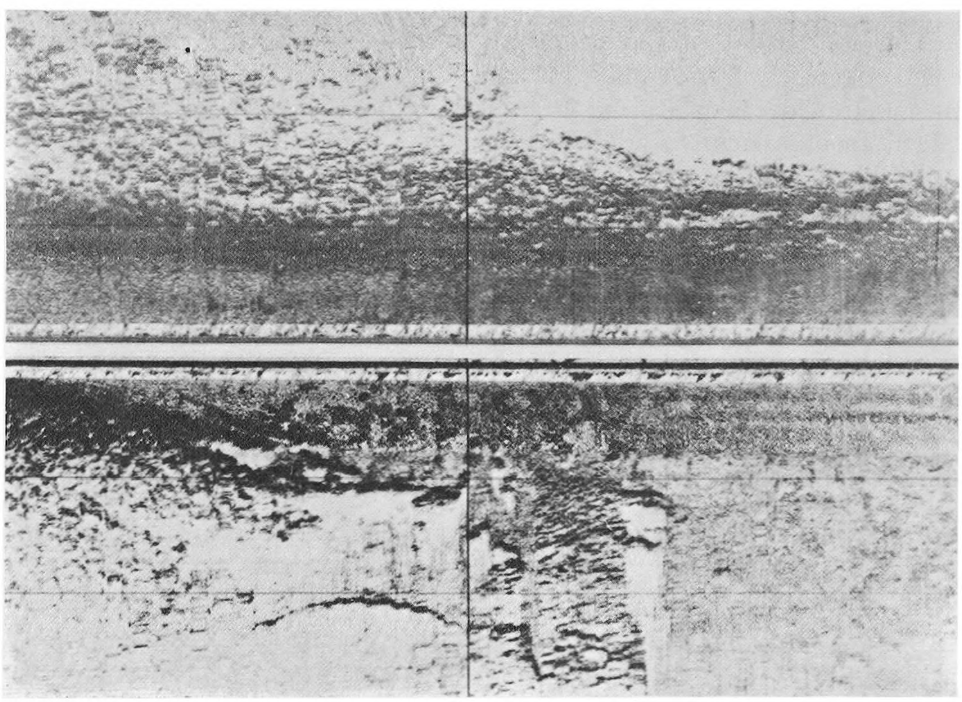


FIG. 9. — Weeds — Brighton — Lake Ontario.

The area downstream from Isle d'Orleans in the St. Lawrence River is currently being dredged and is an area reported to have sub-aqueous sand dunes. It was felt that an investigation of these formations with side scan sonar, correlated with bottom sampling, might help determine the sediment transport mechanism.

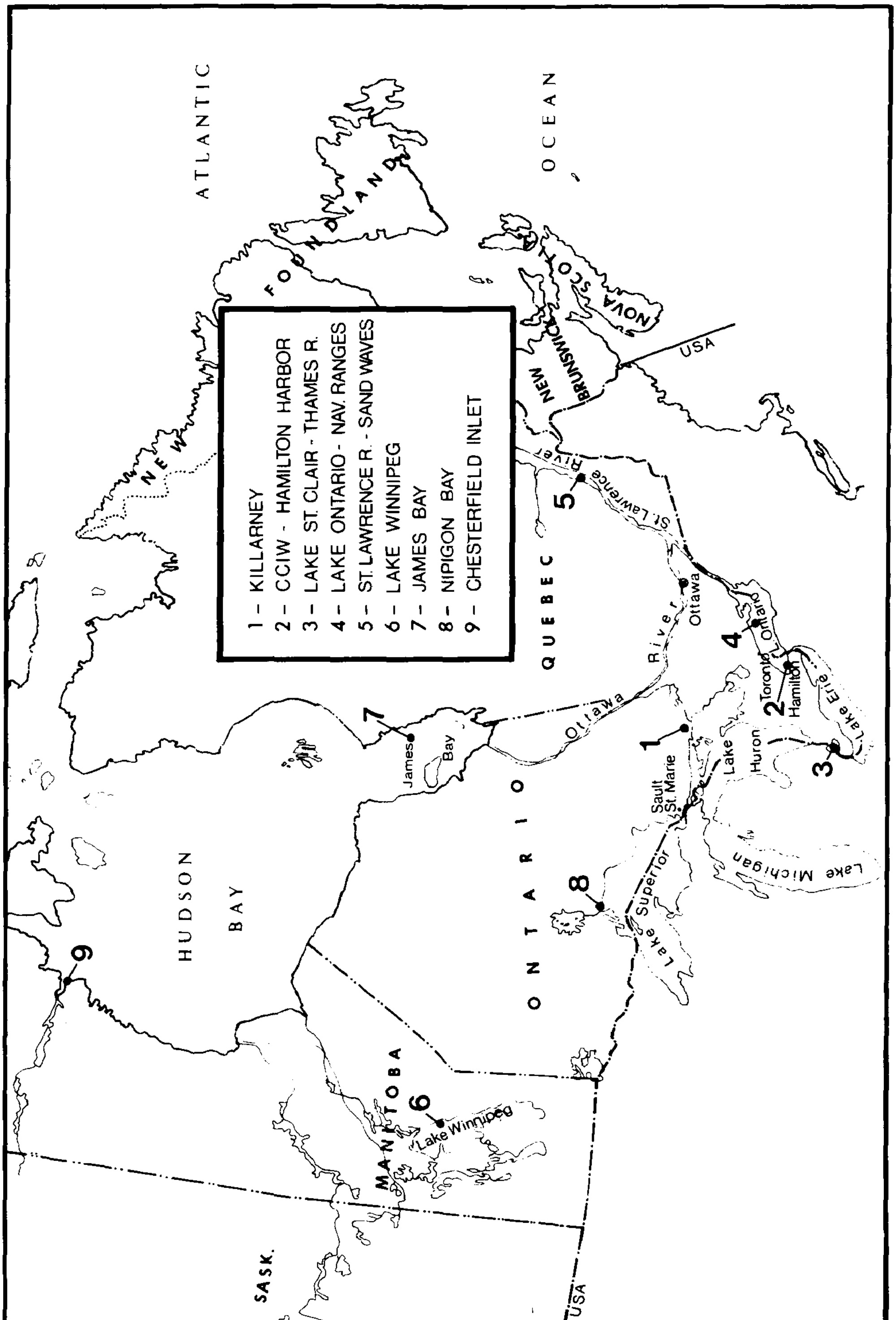


FIG. 10. — Sonar operation areas.

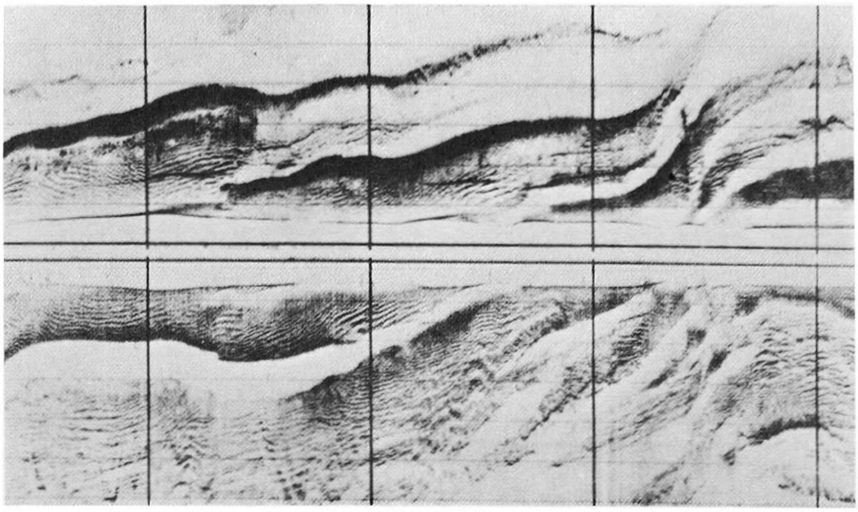


Fig. 11

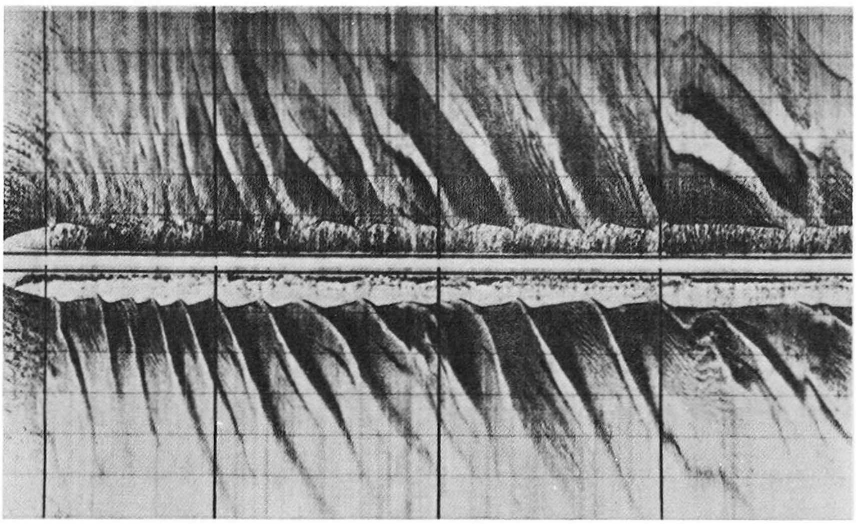


Fig. 12

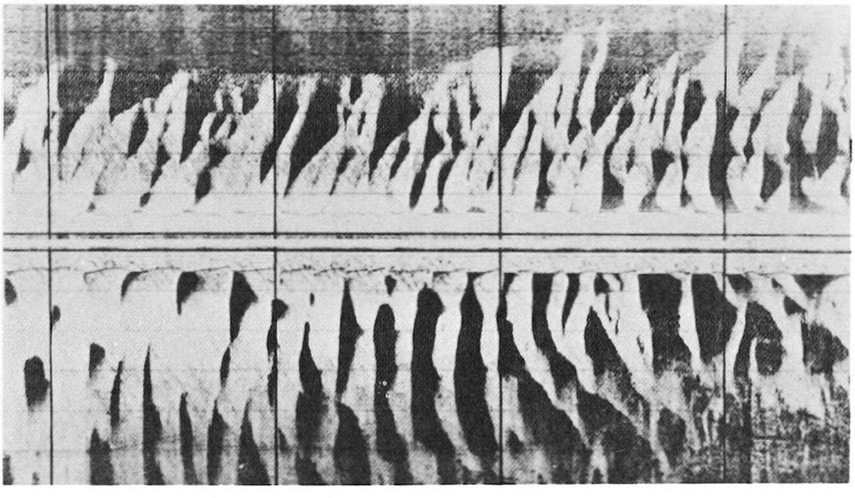


Fig. 13
Sand formations — St. Lawrence River.

The records produced an impressive amount of detail showing the location and shape of the features as well as the mini-ripples located on the wave surfaces. Figures 11 and 12 show formations with heights of four to eight metres, with a wave length of 50 to 75 metres. The sediment was found to be coarse sand. Figure 13 shows another area where bottom sampling determined that discrete waves of sand were being transported over a base of clay and gravel. Because of their different acoustic properties, the areas of sand show up distinctly lighter than the gravel base on the side scan records.

The tidal currents in this area are severe with almost no slack water periods. As a result, most records were badly distorted by the resulting skew and drift of the fish. Attempts to make a mosaic [3] from the records have not been fruitful; however, a hand-plotted chart of the sand wave crests was produced from the records.

Unfortunately, the Lake Winnipeg tests were concluded early when the fish tail-plane was destroyed on contact with the bottom. Efforts to fabricate a tail assembly from materials available were only marginally successful.

The James Bay program was only slightly more successful as the records obtained were extremely poor in quality. The fault was traced to a leak in the fish that allowed water to enter the electronics compartment. This was not discovered until the unit was returned from the field.

CONCLUSION

The evaluation in 1972 produced very encouraging results, demonstrating the potential of the side scan sonar as an aid to the hydrographer. Known features were detected within the expected constraints of the system, and the incompleteness of the previous conventional survey was illustrated.

After two subsequent seasons of operation the initial enthusiasm has been somewhat reduced. A number of equipment malfunctions have hampered field operations and the most frequent result of a side-scan operation has been to verify that all significant hazards to navigation have been discovered by conventional means. This, of course, is a great boost to the ego of the hydrographer-in-charge, but does little for the morale of the sonar operator.

The experience to date has both outlined areas where further investigation is required and demonstrated the usefulness of the system as it is presently configured. Surveyed range lines and ship channels where water depth is marginal can be swept with the sonar to verify that all potential hazards to navigation have been discovered. Alternately, the sonar can be used prior to the conventional survey to delineate areas that require careful survey. Sweeps of harbour areas are particularly useful in that dredged areas are easily identified, man-made debris is readily detected and potential anchorages can be determined by mapping the sediments.

The sonar has a potential application in survey planning in which a reconnaissance survey is conducted with the sonar. The survey line spacing and direction may then be designed to provide the most economical and yet adequate survey of the area. Sonar records also have the potential of providing the hydrographer with a better understanding of the morphology of the sea bed through pictorial representation. This should assist him in his task of interpreting the point or line data from the echo sounder and converting it into contours that describe the surface.

With this in mind the 1975 field season will feature a change in sonar usage. Visits to all survey parties will be discontinued and instead specific projects are planned. A comparative evaluation will be made of the side scan sonar and conventional high speed echo sounding as an aid to survey planning. Searches for man-made objects required by revisory survey will be carried out [4], and the sonar will be used on surveys involving harbours and approaches to reduce the possibility of undetected hazards, to accurately define dredged areas and to define potential anchorages. It is also hoped that investigation will begin to determine the role of signal processing and data processing to improve the quality of side scan sonar information.

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