# Feasibility study: Usefulness of modern acoustic methods to the maritime industry in relation to changes in water depth in the Great Lakes.

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Oct. 2, 2006



Great Lakes Maritime Research Institute
A University of Wisconsin - Superior and University of Minnesota Duluth Consortium

Research Funded in part by the Great Lakes Maritime Research Institute

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## 1. Abstract

This project is a feasibility study to determine whether state-of-the-art acoustic imaging techniques, used in basic scientific research studies, can be applied in a way that is useful to the Maritime industry. It addresses Great Lakes Maritime Research Institute (GLMRI) focus area "Marine transportation and port environmental issues," and the specific research topic "Great Lakes Outflow Investigation" listed in the call for proposals.

We collected high-resolution sidescan sonar data as well as multibeam ("swath") bathymetry. The multibeam bathymetric data was used to make detailed maps of water depth and three-dimensional models of the coverage area. It can also be used to create "fly-through" animations, although this has not yet been done with the data from this project. The sidescan sonar data produces an image of the lake floor, similar to an aerial photograph, with sound instead of light. The sidescan sonar images depend on both the reflectivity and geometry of the lake floor, so that in areas of relatively high relief, acoustic shadows are cast. The sidescan sonar imagery can also be draped on the three-dimensional model of the lake floor produced from the multibeam bathymetry.

The results of our surveys show a variety of features that may be of interest to the maritime industry. These include the configuration of the harbor entrances and part of the harbor. Outside of the harbor, the former meandering channel of the Nemadji River is clearly seen, as well as structures such as the Cloquet water intake and small shipwrecks. Areas of sediment movement were clearly imaged as fields of sand waves, this despite the fact that most of the sand derived from long-shore drift from the Wisconsin shore is trapped behind the piers of the Superior entrance. We also observed glacial sediments sticking up through the lake sediments, several meters above the lake floor. This type of survey can also be used in places where water depth is critical, such as the St. Mary's River near Sault St. Marie.

## 2. Introduction: Background and Objectives

This project addresses the GLMRI focus area entitled "Marine transportation and port environmental issues," and the specific research topic "Great Lakes Outflow Investigation" listed in the call for proposals.

As background, changes in water depth due to lake-level rise or channel erosion are a major issue of concern to the maritime industry in the Great Lakes. Sediment transport near port facilities, which is partly related to lake-level changes, is another significant concern. Modern lake-floor imaging technologies, such as chirp side-scan sonar and multibeam bathymetric measurements, may be practical methods for addressing these concerns at a level that is useful for shipping and port-maintenance interests.

Water depth in the Great Lakes is a critical issue for the maritime industry because it directly affects the size of the cargos that can be shipped, such that there is a well documented monetary value placed on each foot of water depth in critical passages. Water depth is determined by two quantities: the elevation of the lake floor and the elevation of the water surface. The elevation of the water surface has been precisely measured by agencies such as NOAA and the Army Corps of Engineers for more than a century. On time scales of years to decades, it is affected mainly by climate changes that determine the amount of precipitation passing through the Great Lakes. To a lesser extent, it is affected by the long-term tilting of the Great Lakes basin as a response to unloading of the earth's crust following the melting of the last great ice sheets [1], which continues slowly today [2]. In special circumstances, it may also be affected by erosion and enlargement of narrow constrictions, such as that recently documented in the St. Claire River [3].

Increase in water depth caused by erosion of the lake floor has a counterpart in the opposite direction: deposition of sediment on the lake floor or channel. Deposition, in effect, raises the elevation of the lake floor and decreases the water depth. The latter process is typically a problem at harbor entrances, which must accordingly be dredged.

Our objectives for this <u>feasibility</u> study is to determine whether state-of-the-art acoustic imaging techniques can be applied in a way that is useful to the maritime industry, addressing almost all of the concerns discussed above. We conducted a survey of the approaches to Duluth and Superior harbor entrances, from a water depth of about 10 to 50 meters. We collected multibeam bathymetric and CHIRP sidescan-sonar data, continuously covering the study area. Together, these data sets allow us to document the following: (1) the detailed configuration of the lake floor: This will serve as a baseline for comparison to any future natural or man-made changes. It will also show whether we can determine lake-floor configurations with enough resolution to be applicable to problems such as erosion of the channel of the St. Claire River. (2) The configuration of nearshore sediment along the barrier-spit coastline of the western end of Lake Superior: This sediment is assumed to be transported from the eroding bluffs of the Wisconsin coast by longshore currents to the barrier spits, where it is deposited, tending to clog the harbor entrances. However, this assumption is not well documented. Our survey provides indications about the source and the transport direction of sediment associated with the barrier spits. (3) Evidence of former shorelines of the lake now submerged: Identification of these former shorelines would help quantify the long-term rate of tilting of the basin, which is causing the western end of Lake Superior to be submerged.

Erosion and sediment erosion have been studied with acoustic methods both for general scientific purposes and for specific engineering projects for many years. Two things, however, make this project unique. First, we will be using state-of-the-art acoustic (sonar) equipment, as described in the Methods section. Secondly, we will be using this equipment to directly address the question of whether we can produce data from a relatively large area that is useful to the maritime industry.

The recent development of high-frequency multibeam systems has revolutionized the hydrographic surveying of shallow water areas [4], making it possible to conduct geomorphological studies of sub-aqueous surfaces [5]. The high-resolution maps produced by these instruments can be used to study present day sea-floor processes as well as those that occurred in the past. For example, on continental shelves, high resolution multibeam surveys have been used to map and characterize sediment erosion and deposition processes map drowned glacial landforms and sediment erosion and deposition processes. Recently multibeam surveys have been used to study geologic processes in freshwater lakes [6 & 7].

Sidescan sonar has been used for a long time to image the sea floor. However, recent technical advances have greatly improved the quality of the data. In particular, the use of digital data and swept-frequency (CHIRP) sidescan sonar systems has substantially improved resolution and image quality. Recent examples of the use of sidescan sonar in marine environments include Monterey Bay [8], and in lake environments include Bear Lake [9].

## 3. Methods

The LLO has a survey-grade multibeam bathymetry system mounted on the hull of the RV Blue Heron. We have also recently acquired a state-of-the-art chirp side-scan sonar system. Finally, we have extensive computer facilities, with which we processed these data and creating maps and images of the lake floor.

The Seabat 8101 multibeam[1] used in this survey is a 240 kHz multibeam that uses 101 1.5-degree beams to measure the bathymetry of the lake floor. The width of the swath illuminated on the lake floor is approximately 7.5 times water depth in water less than 70 meters deep. The system has a range resolution of 1.25 cm. Its lateral resolution (in the absence of vessel motion and positioning error) is dependant upon water depth and the number of beams retained in the processed data. The system is capable of producing data that meets the IHO standards for hydrographic surveying (International Hydrographic Organization, 1998). In order to do this, a TSS POS MV/320 motion sensing and positioning system[1] was used to measure the survey vessel's motion (roll, pitch and heading) to an accuracy of less than +/- 0.05 degrees and it's position to less than 1meter horizontally and 25 cm vertically. Differential corrections for the positioning system were sent via a radio link, from a temporary base station established on the lakeshore. Sound velocity profiles were collected periodically during the survey. These were used in post-acquisition processing to correct ray bending artifacts in the data. Post-acquisition processing of the data was preformed using CARIS HIPS/SIPS computer programs[1].

The sidescan sonar data were collected in a manner similar to that for the multibeam bathymetry, except that the instrument was towed behind the RV Blue Heron. We used a dual frequency CHIRP EdgeTech 512 system[1]. The width of the swath imaged on the lake floor was between 50 and 100 meters on either side of the ship. The data were processed with the same computer systems as the multibeam bathymetric data.

[1] The authors and The Great Lakes Maritime Research Institute do not endorse products or manufacturers. Trade names or manufactures names appear herein solely because they are considered essential to this report.

## 4. Results and Discussion

We successfully collected sidescan sonar data over swaths of the lake floor off Minnesota Point. The survey grid for both the sidescan-sonar and multibeam data are shown in Figure 1. The sidescan sonar mosaic (Fig. 2, small format here; large format image at the end of the printed report) of the entire area off Minnesota Point shows a variety of features on the lake floor. Especially prominent are the drowned, meandering channel of the Nemadji River and the dark patches that represent glacial sediments that emerge from the lake sediments and rise several meters above the otherwise smooth lake floor. The glacial sediments are presumably kept free of lake sediments by currents and waves in this nearshore environment, and they are probably in the process of being eroded down to the level of the rest of the lake floor by the same processes.


Figure 1. Distribution of ship tracklines in the study area for the sidescan sonar data and the multibeam bathymetry data.


Figure 2. Sidescan sonar mosaic of the entire area outside the harbor with the northwest portion at the top, and the southeast portion at the bottom. Inset shows the portion of the survey covered by each image.

Single track images of the sidescan data also show interesting features in greater detail. (Fig. 3). The area contains fields of sand waves, indicative of sediment transport. The sand waves occur northwest of the Superior entrance, whose piers capture most of the sand transported by longshore drift along the Wisconsin shoreline. Maps of historic changes in the shoreline [10] demonstrate the accumulation of sand on the southeast side of the Superior entry. Although these maps do not show erosion on the northwest side of the Superior entry, sand must be moving along Minnesota Point, with a source either there or from onshore movement of relict nearshore sand.

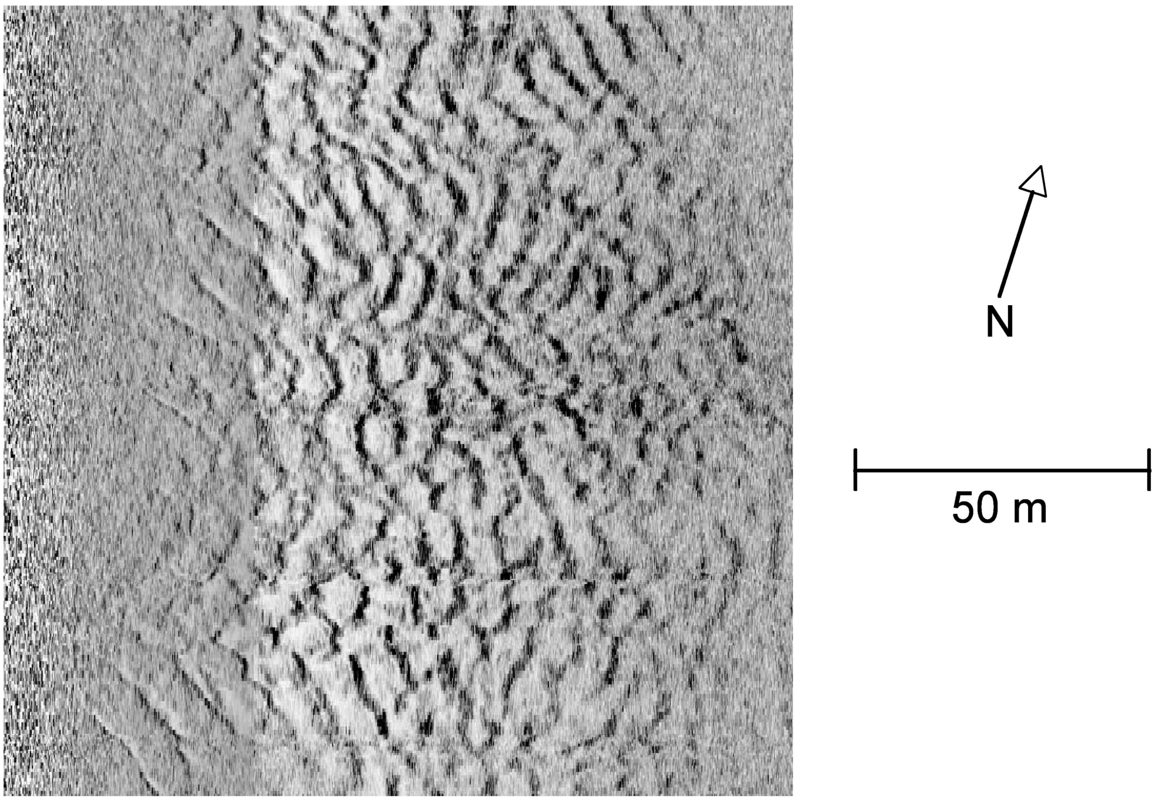


Figure 3. Single track (detailed) sidescan sonar image showing sand waves on the lake floor. Scale and north arrow at right.

Other single-track details of the sidescan sonar mosaic show a variety of man-made features, including the Cloquet water intake (Fig. 4), a small ship wreck (Fig. 5), and anchor drag marks (Fig. 6). These images show that our sidescan sonar system would be potential useful for inspecting structures or searching for man-made objects in the lake. Detailed images of structures inside the harbor reinforce this conclusion. Detailed images included here are the entrance piers for the Duluth entry (Fig. 7) and the footings for the Blatnik Bridge (Fig. 8). The sidescan sonar data would also be useful for examining the integrity of the steel sheet pilings around the harbor.

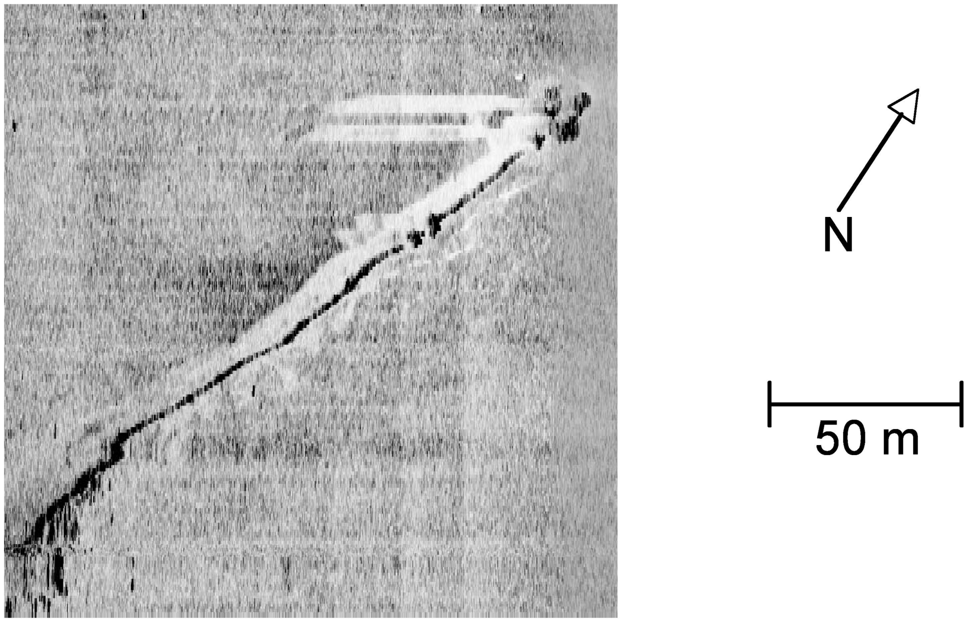


Figure 4. Single track (detailed) sidescan sonar image showing the Cloquet water intake structure. The white areas to the left of the intake and the pipe are acoustic shadows. Scale and north arrow at right.

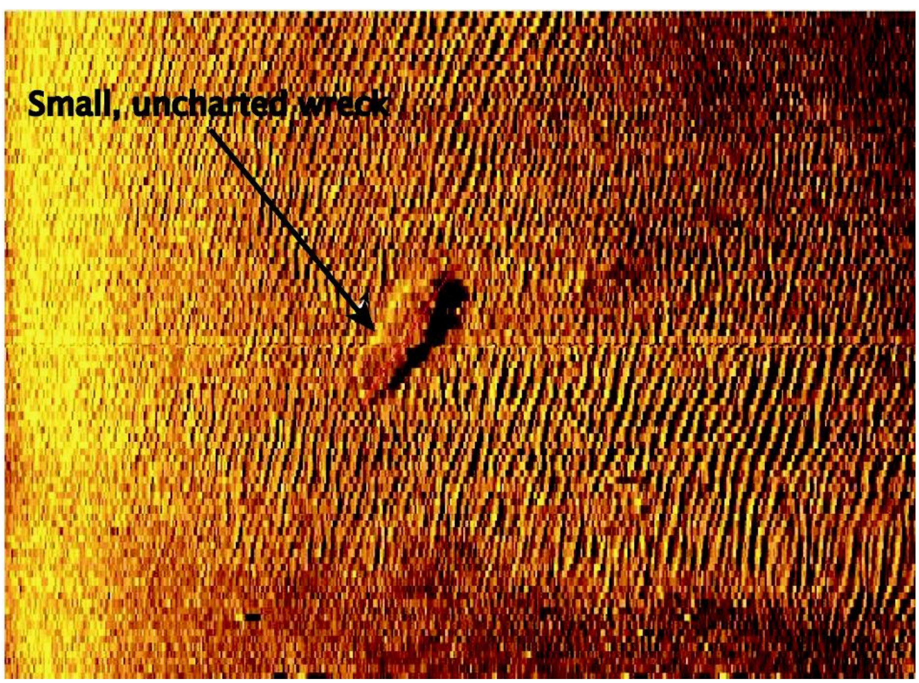


Figure 5. Single track (detailed), false color, sidescan sonar image showing a small ship wreck lying on a field of sand waves. Top-to-bottom dimension is about 100 meters.

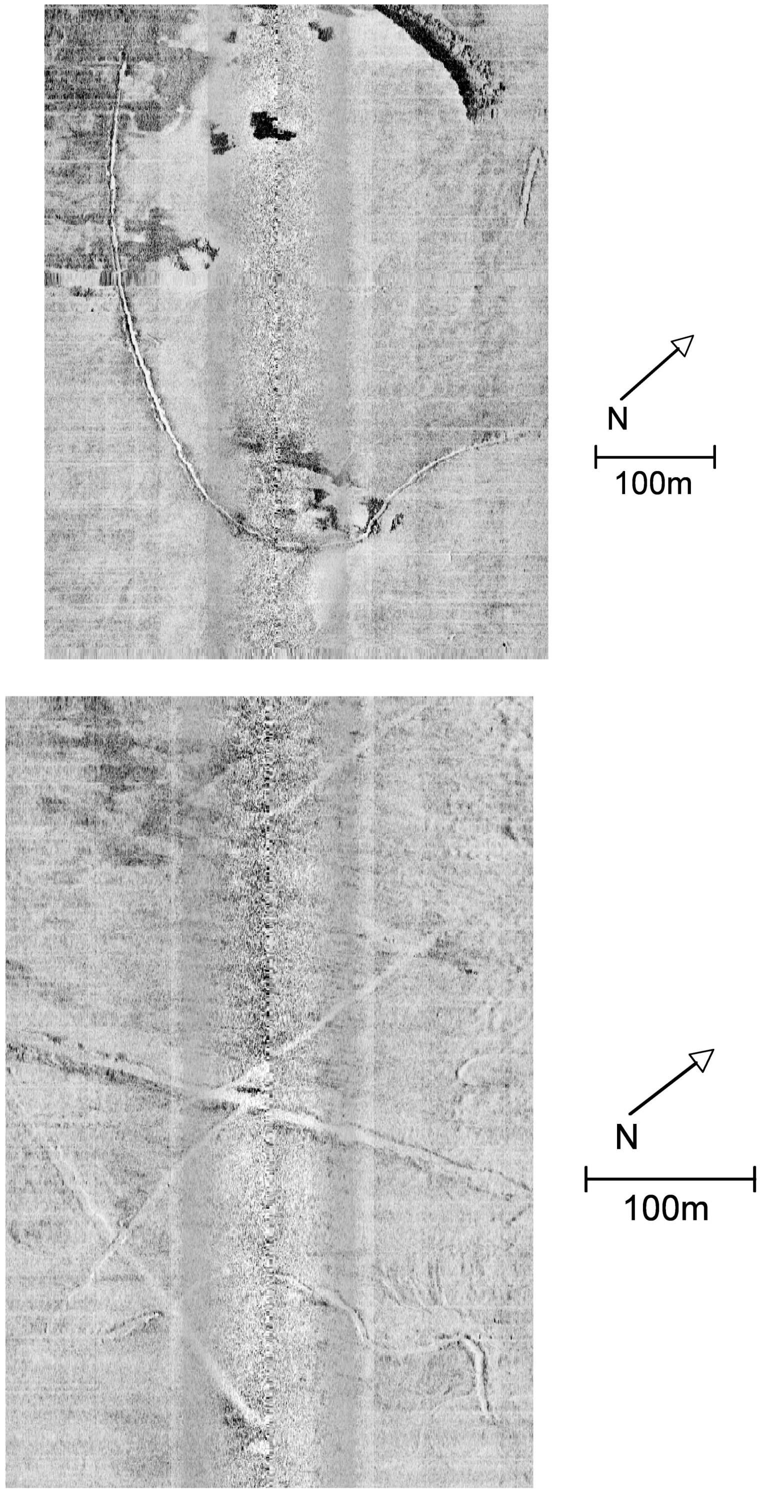


Figure 6. Single track (detailed) sidescan sonar images showing anchor drag marks off the Superior entry. Scales and north arrows at right.

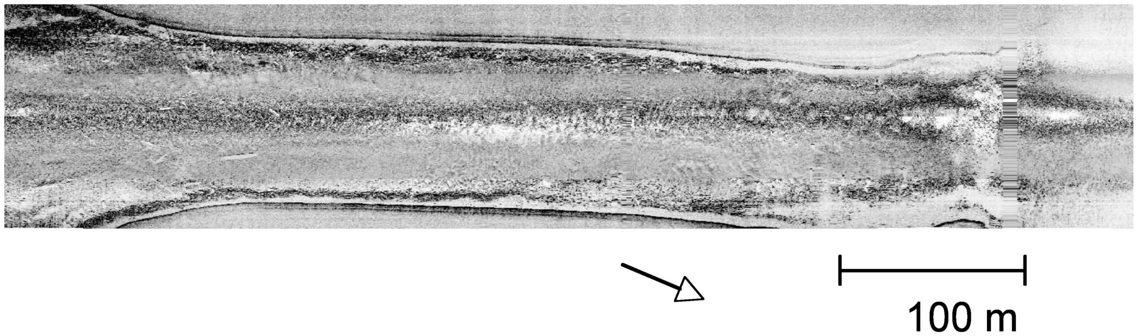


Figure 7. Single track (detailed) sidescan sonar image showing the piers of the Duluth entry. Scale and north arrow at bottom.

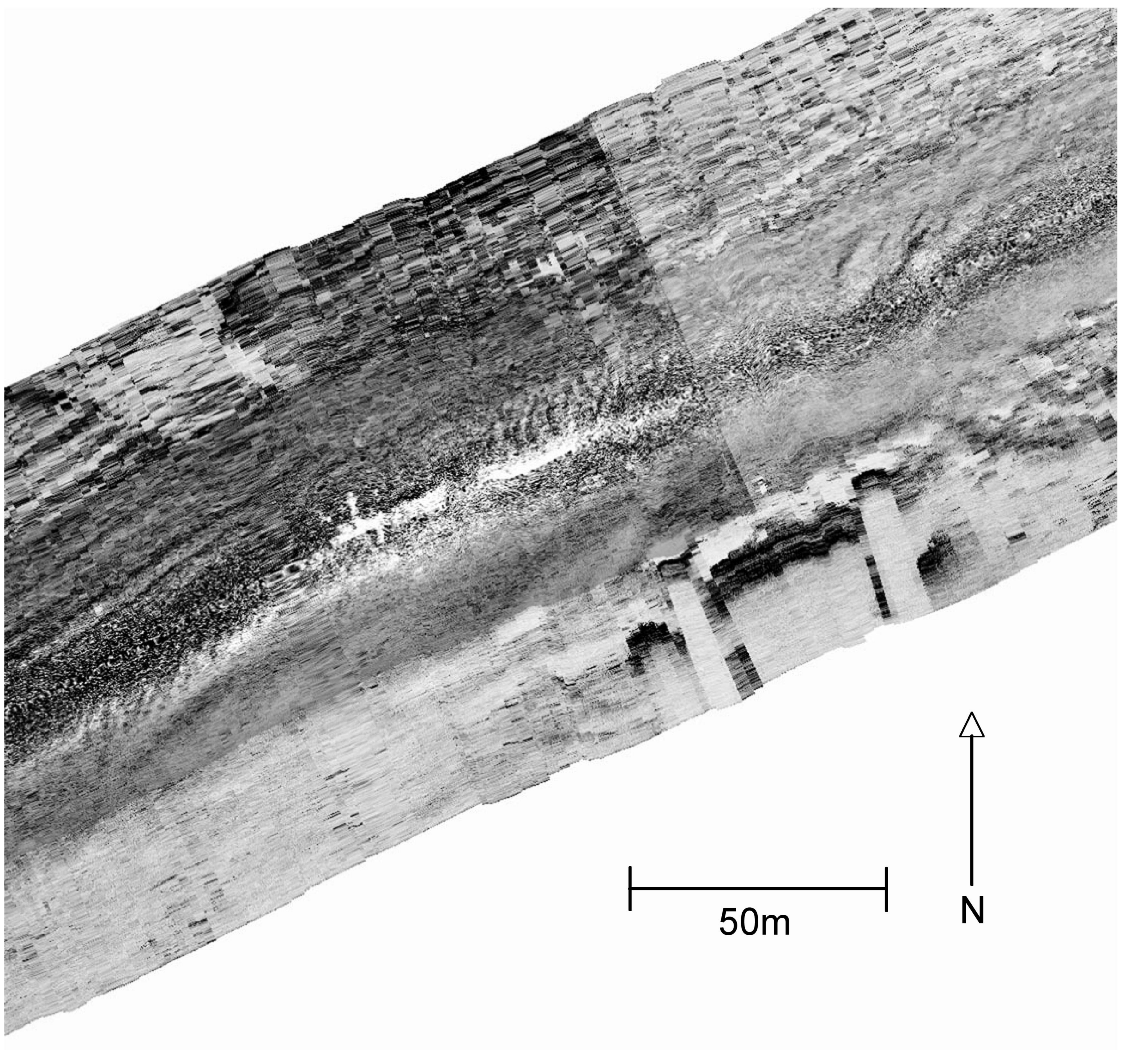


Figure 8. Single track (detailed) sidescan sonar image showing the footings for the Blatnik Bridge (lower right). Scale and north arrow at bottom.

The multibeam data provide a detailed bathymetric map of the entire survey area (Fig. 9). In close-ups of the bathymetry, smaller features, such as the drowned channel of the Nemadji River (Fig. 10) and glacial deposits that rise above the smooth surface of the lake sediments (Fig. 11) can be seen.

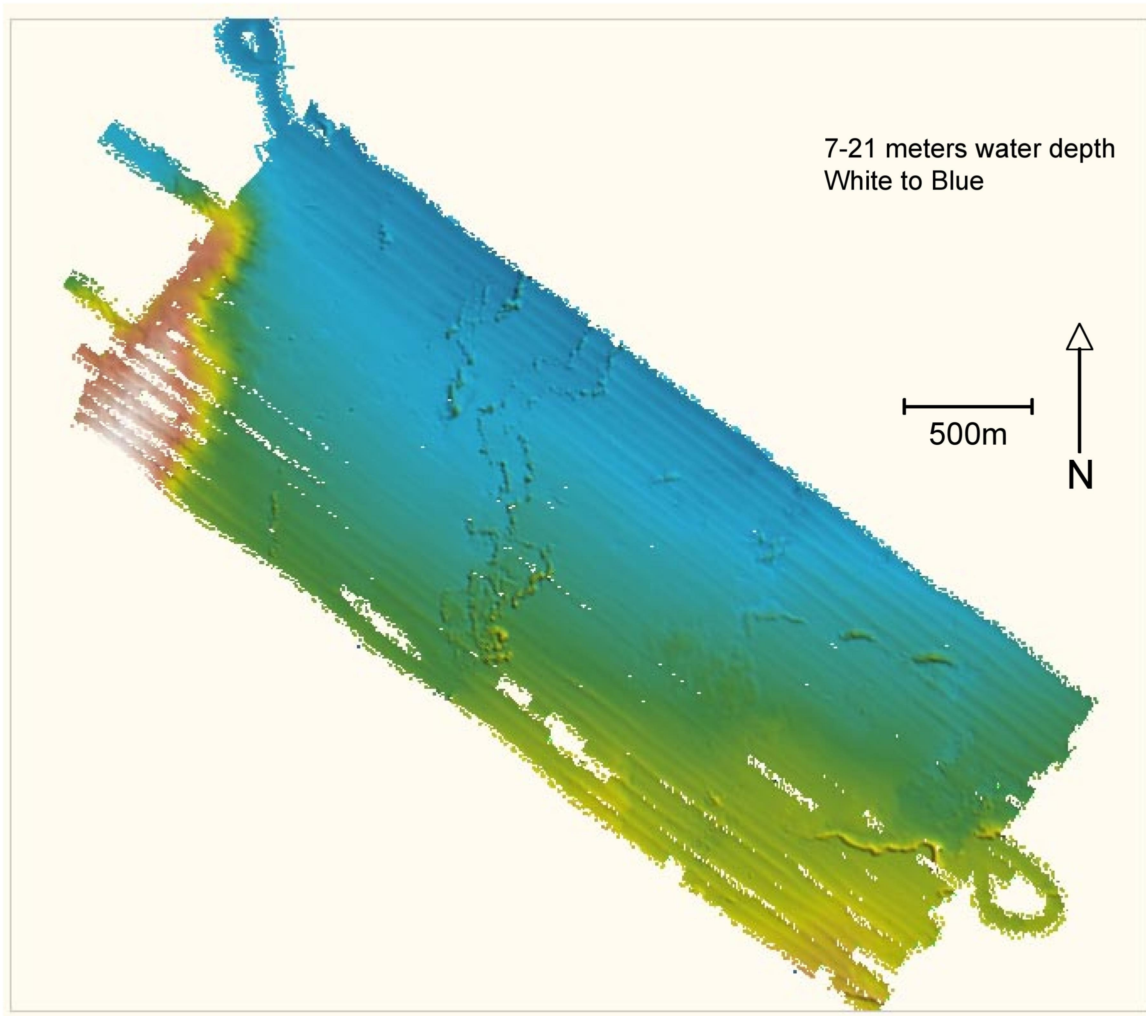


Figure 9. Detailed multibeam bathymetry map of the entire survey area outside the harbor, color coded by depth. Scale, north arrow, and color coding at upper right.

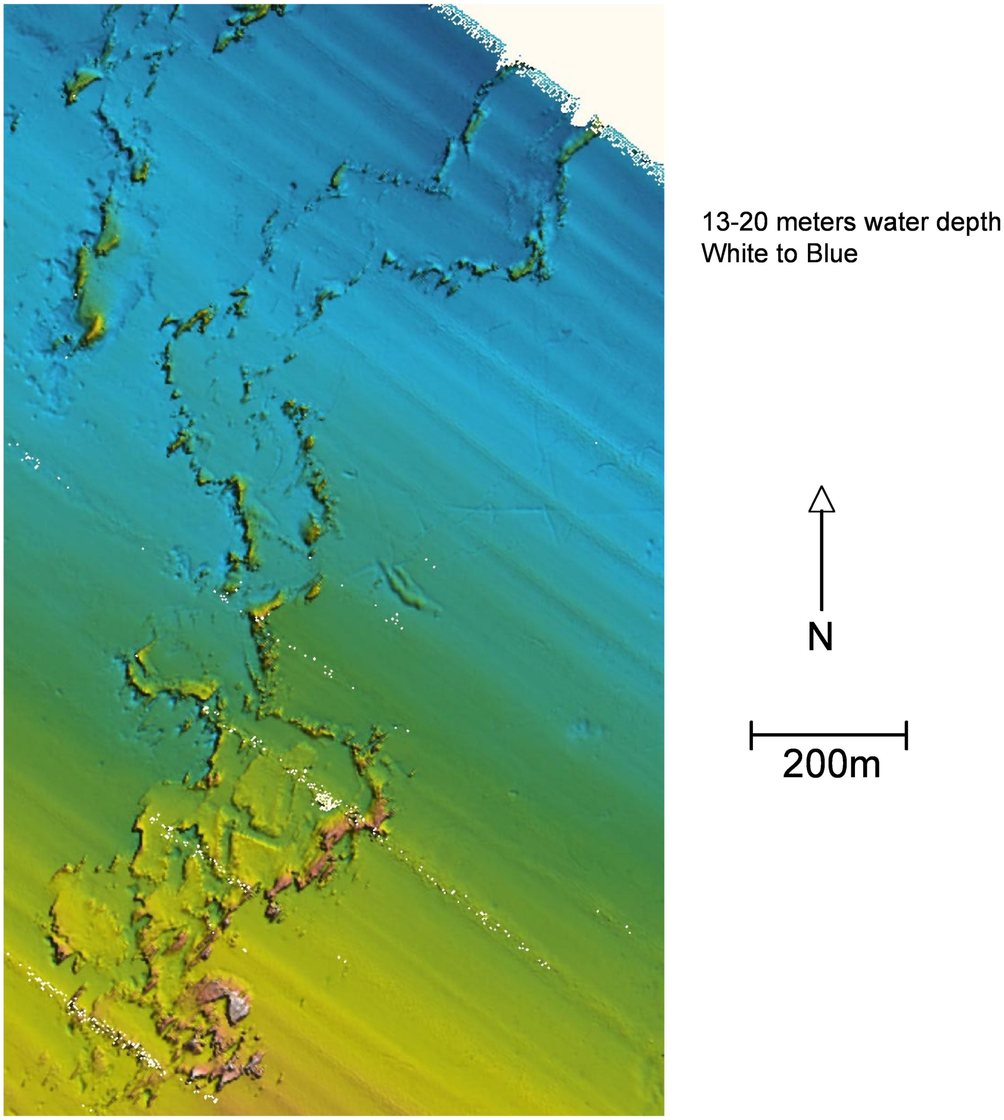


Figure 10. Detailed multibeam bathymetry map of the drowned channel of the Nemadji River, color coded by depth. Scale, north arrow, and color coding at upper right.

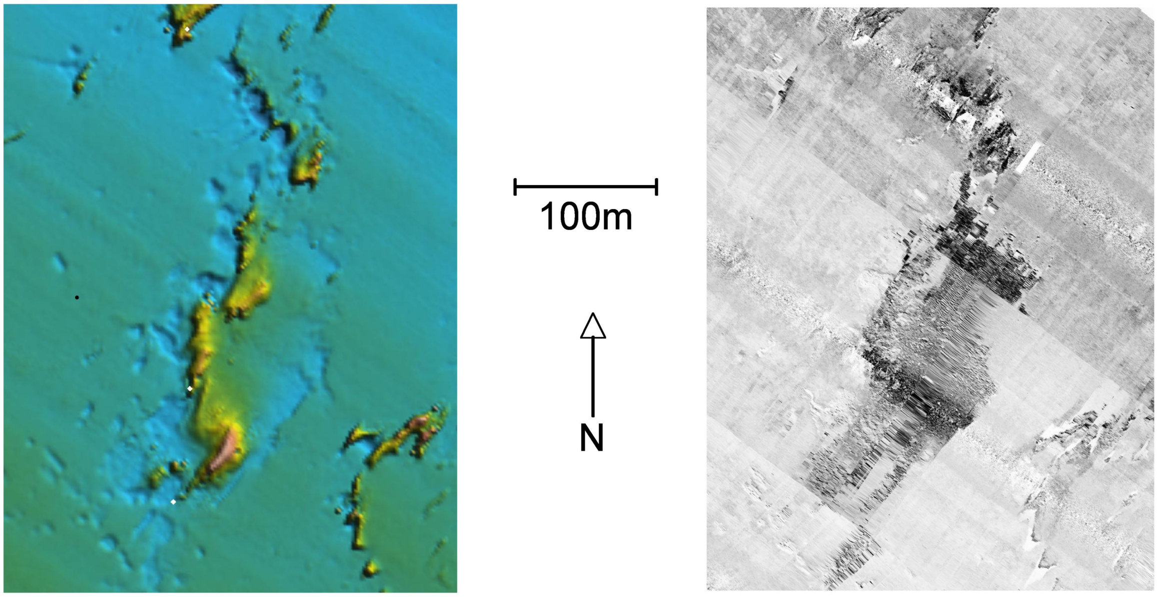


Figure 11. Detailed multibeam bathymetry map and sidescan sonar mosaic of an area of glacial deposits (dark in sidescan sonar image) rising above the smooth surface of lake sediments.

Although not shown here, these multibeam bathymetric maps can be viewed as three-dimensional models, from any designated perspective, and the three-dimensional perspectives can be combined to create a virtual “fly through” of the survey area.

Detailed bathymetric data is of great interest to the maritime community. Using multibeam swath systems is much more efficient and produces much more complete data than traditional single-track soundings. Also, the sidescan sonar mosaics can be “draped” over the multibeam perspectives to allow the two types of data to be viewed simultaneously. Such views are particularly useful for scientific interpretations.

In summary, we have shown that collecting high-quality data from the floor of Lake Superior is feasible, and that such data may be of interest to the maritime community. Both the sidescan sonar data and the multibeam bathymetry are state-of-the-art and are applicable in a wide variety of settings. In the near future, we will be having stakeholder meetings with the Army Corps of Engineers, the Duluth and Superior Port Authorities, the Coast Guard, and other members of the local maritime community.

## 5. Potential Economic Impacts of the Research Results

Because this was a feasibility study and because we achieved our goals in terms of data collection, the overall project was successful. The potential economic impacts of the project were mentioned in the introduction; specifically potential documentation of water depth changes, and sediment erosion and deposition processes. Water depth in the Great Lakes is a critical issue for the maritime industry because it directly affects the size of the cargos that can be shipped, such that there is a well documented monetary value placed on each foot of water depth in critical passages. On time scales of years to decades, water depth is affected mainly by climate changes that determine the amount of precipitation passing through the Great Lakes. To a lesser extent, it is affected by the long-term tilting of the Great Lakes basin as a response to unloading of the earth's crust following the melting of the last great ice sheets. In special circumstances, it may also be affected by erosion and enlargement of narrow constrictions, such as that recently documented in the St. Claire River. Water depth near harbors and their entrances is also caused by erosion of the lake floor and by deposition of sediment on the lake floor or channel. Deposition, in effect, raises the elevation of the lake floor and decreases the water depth. The latter process is typically a problem at harbor entrances, which must accordingly be dredged. Changes in water depth from all of the causes listed above have direct and obvious economic impacts on harbors and the maritime industry that depends on them.

Because this project was designed as a feasibility study, we intend to meet with prospective stakeholders now that the project is essentially completed. Potential local stakeholders include the Coast Guard, the Army Corps of Engineers, and the Duluth and Superior Port Authorities.

## 6. References


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