Multibeam Bathymetry Survey of the Duluth-Superior Harbor

Final Report

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Executive Summary

This project is a continuation of the Great Lakes Maritime Research Institute (GLMRI) 2006 project, 'Feasibility study: Usefulness of modern acoustic methods to the maritime industry in relation to changes in water depth in the Great Lakes' by Colman and Ricketts. We used state-of-the-art acoustic imaging techniques to address a fundamental issue for Great Lakes mariners: water depth in the Duluth-Superior Harbor. The project addresses the GLMRI focus area 'Marine transportation and port environmental issues.'

We collected high resolution multibeam bathymetry data and used the data to make detailed maps of water depth in the survey area. The data can be used to create 'fly-through' animations, although this has not yet been done with the data from the project. The results of the survey show a variety of features that may be of interest to the maritime industry, such as the configuration of the main basins in the harbor. Maximum water depths in the harbor are found in areas with the heaviest ship traffic, especially where freighters are expected to turn, for example just inside the Duluth and Superior entries, and in the northern section of the East Gate Basin. Anchor drag marks are found throughout the harbor and scour marks associated with water flowing in and out the harbor are found at both the Duluth and Superior entries.

This type of survey can be used in other areas where water depth is critical, such as the St. Mary's River near Sault St. Marie. Also the data collected here will be used as baseline data for comparison to data collected during any future surveys collected by the Large Lakes Observatory.

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Introduction

This project addresses the GLMRI focus area 'Marine transportation and port environmental issues' and is a follow-up project to Colman and Ricketts' 2006 project 'Feasibility study: Usefulness of modern acoustic methods to the maritime industry in relation to changes in water depth in the Great Lakes'.

Changes in water depth due to changes in lake-level or sediment erosion and deposition are a major issue for the maritime industry in the Great Lakes. These concerns are monitored to address shipping and port-maintenance interests using modern lake-floor imaging technologies, such as multibeam bathymetric measurements.

Water depth in the Great Lakes is a critical issue for the maritime industry because of the direct correlation between water depth and cargo size. In shallow passages, ship loads must be lightened in order that the vessel does not run aground. Reducing the load causes a loss of freight revenue, negatively impacting the economics of the operation. Water depth is determined by the elevation of the lake floor and the elevation of the water surface. The elevation of the water surface is affected on a weekly to yearly basis by the amount of precipitation and evaporation in the lake basin. On longer time scales it is affected by the ongoing tilting of the lake basin in response to unloading of the earth's crust following the melting of the last great ice sheets [1,2]. Changes in the elevation of the lake floor either increase water depth (indicative of sediment erosion) or decrease water depth (indicative of sediment deposition).

Our objective for this study is to determine the configuration of the Duluth-Superior Harbor using state-of-the-art acoustic imaging techniques addressing almost all of the concerns discussed above. We conducted a survey of the Duluth-Superior Harbor using the Research Vessel Blue Heron's multibeam sonar system. The multibeam data gives us a detailed view of the Duluth-Superior Harbor that can serve as a baseline for comparison to any future natural or man-made changes in the harbor. The survey also gives us experience using the equipment in harbor settings, which is unlike our typical survey area, allowing us to work out any problems before any similar work in the future.

Methods

The LLO has a survey-grade multibeam bathymetry system mounted on the hull of the RV Blue Heron as well as extensive computer facilities, with which we processed these data and create maps and images of the lake floor.

The Reson Seabat 8101[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 m 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 [3]. In order to do this, a TSS POS MV/320 motion sensing and positioning system[1] is used to measure the survey vessel's motion (roll, pitch and heading) to an accuracy of less than +/- 0.05 degrees and its position to less than 1 m horizontally and 25 cm vertically. Post-acquisition processing of the data was preformed using CARIS HIPS/SIPS computer programs[1].

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

Results and Discussion

We successfully collected multibeam bathymetry data of the lake floor in the Duluth-Superior Harbor. Our survey tracklines are shown in Figure 1. The composite multibeam image (Figure 2) shows a variety of features on the harbor floor. The most prominent features are the areas with especially deep water (>11 meters) found just inside both the Duluth and Superior entries and at the northern edge of the East Gate Basin. These areas are where the large freighters that enter the Harbor must brake and turn, and are probably an expression of bottom sediment being eroded by currents created by the ships' propellers as they increase speed after making the turn.

Additional man-made features include anchor drag marks, best seen in the images that are enlargements of the different sections of the harbor (Figures 3, 4, 5 and 6), as well as the deeper water found in a channel to the east of the main channel of the Duluth Harbor Basin (Figure 3), probably an indication of sediment being moved by currents created by the propellers of freighters that are 'cutting the corner' and taking a shorter route to the East Gate Basin. More 'natural' features include scour marks found near the Duluth and Superior entries (Figures 3 and 6) presumably caused by inflowing and outflowing water generated by the Nemadji and St. Louis Rivers and by seiches. These features are approximately 20 cm in depth, 4 meters wide and 100 meters long and are best seen near the Superior entry (Figure 6).

The multibeam data provides a detailed bathymetric chart of the harbor. Although not shown here these charts can be viewed as a three-dimensional model, from any designated perspective, and the three dimensional perspectives can be combined to create a virtual 'fly through' of the survey area. Obviously, detailed bathymetric data are 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. During this project we collected 6.1 gigabytes of data within approximately 130km of ship track lines over a period of six 12 hour days. This gave us high resolution data of approximately 7 km^2 of the harbor bottom, a task that would take much longer using traditional single-track soundings. Although the shallow nature of harbors makes the area of coverage of a multibeam swath narrower than that found in deeper waters, as can be seen by the 'holes' of missing bathymetric data on the various multibeam figures shown here, this is a problem that can be corrected using closer survey lines.

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. We plan to process the data further, creating three-dimensional views of the data and virtual 'fly throughs' of the survey areas, and we plan to make all of the images available to the public through the Large Lakes Observatory web site.

Potential Economic Impacts

Water depth in the Great Lakes is a critical issue for the maritime industry since it directly affects the size of cargos that can shipped. This project illustrates the use of high resolution acoustic imaging equipment in mapping the bathymetry of the Duluth-Superior Harbor. In combination with the results of the Colman and Ricketts 2006 GLMRI project, we have shown that the Large Lakes Observatory and the Research Vessel Blue Heron are extremely capable in mapping shallow water areas of interest to the maritime industry. Using multibeam sonar equipment and side-scan sonar equipment (the 2006 project), we can image the lake floor, describe submerged features and document sediment erosion and deposition. Since erosion and deposition affect water depth, a better understanding of erosional and depositional processes is useful to the maritime community. Changing practices in how ships are operated may influence sediment deposition and erosion, as can be seen by the presence of deep water near the Duluth and Superior entries and in the East Gate Basin, presumably caused by ship traffic. Future surveys of the area using multibeam and side-scan sonar will be able to reference this work to delineate any changes in the morphology of the lake bottom. This information would be useful to harbor planners when considering future dredging, keeping costs down and limiting disruptions to harbor operations.

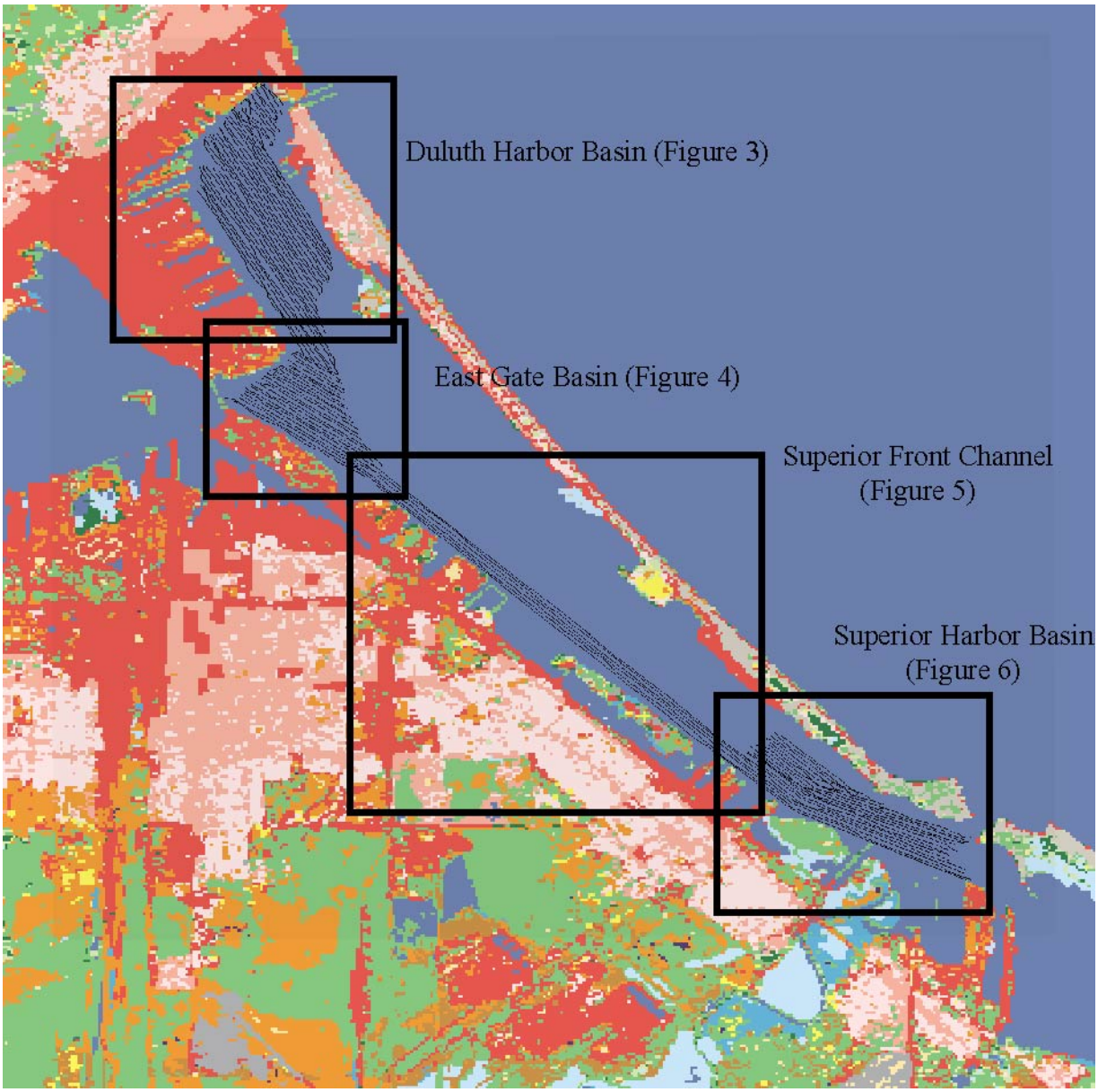

Figure 1: Ship tracklines for the multibeam bathymetry data.

Figure 2: Multibeam bathymetry data for the Duluth-Superior Harbor.

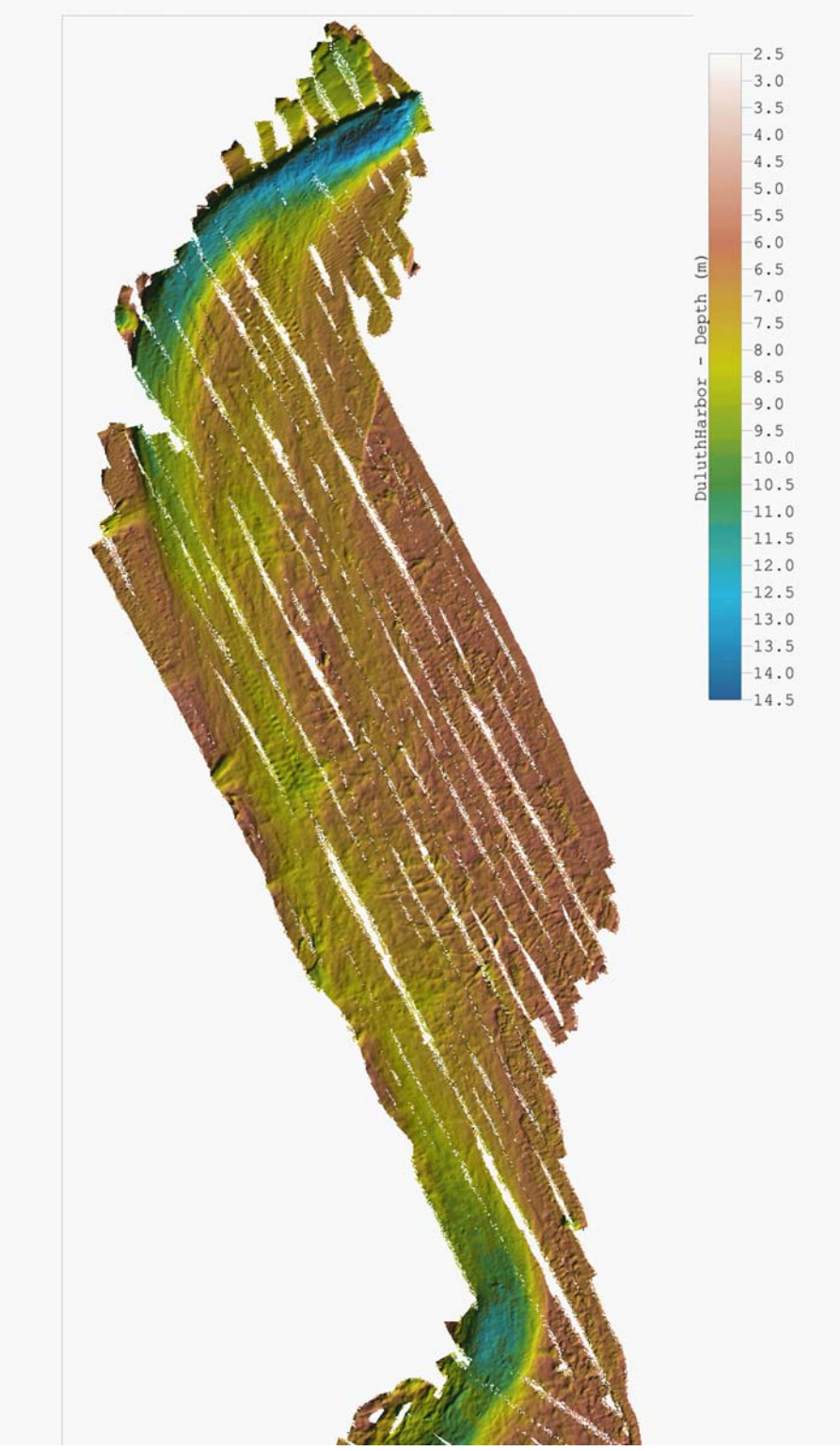

Figure 3: Multibeam bathymetry data for the Duluth Harbor Basin.

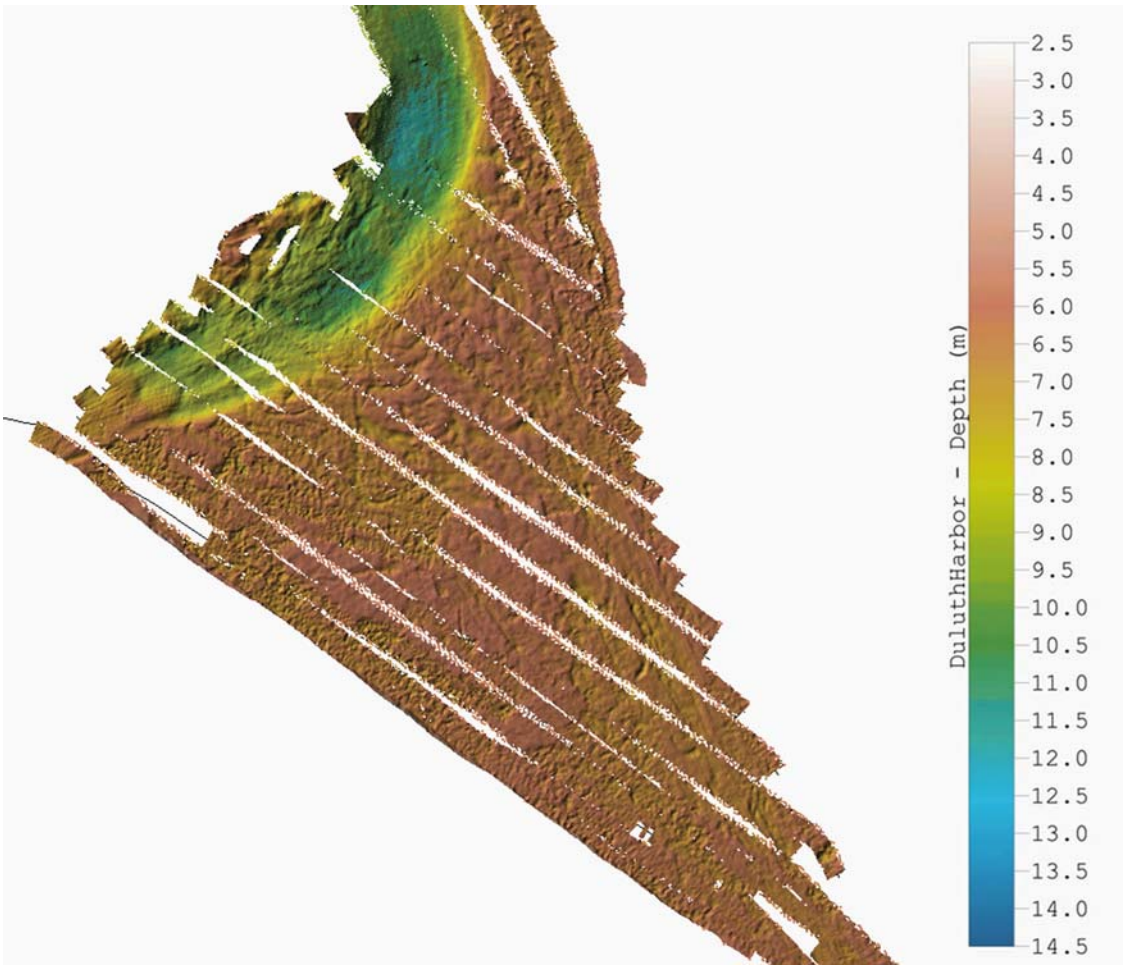

Figure 4: Multibeam bathymetry data for the East Gate Basin.

Figure 5: Multibeam bathymetry data for the Superior Front Channel.

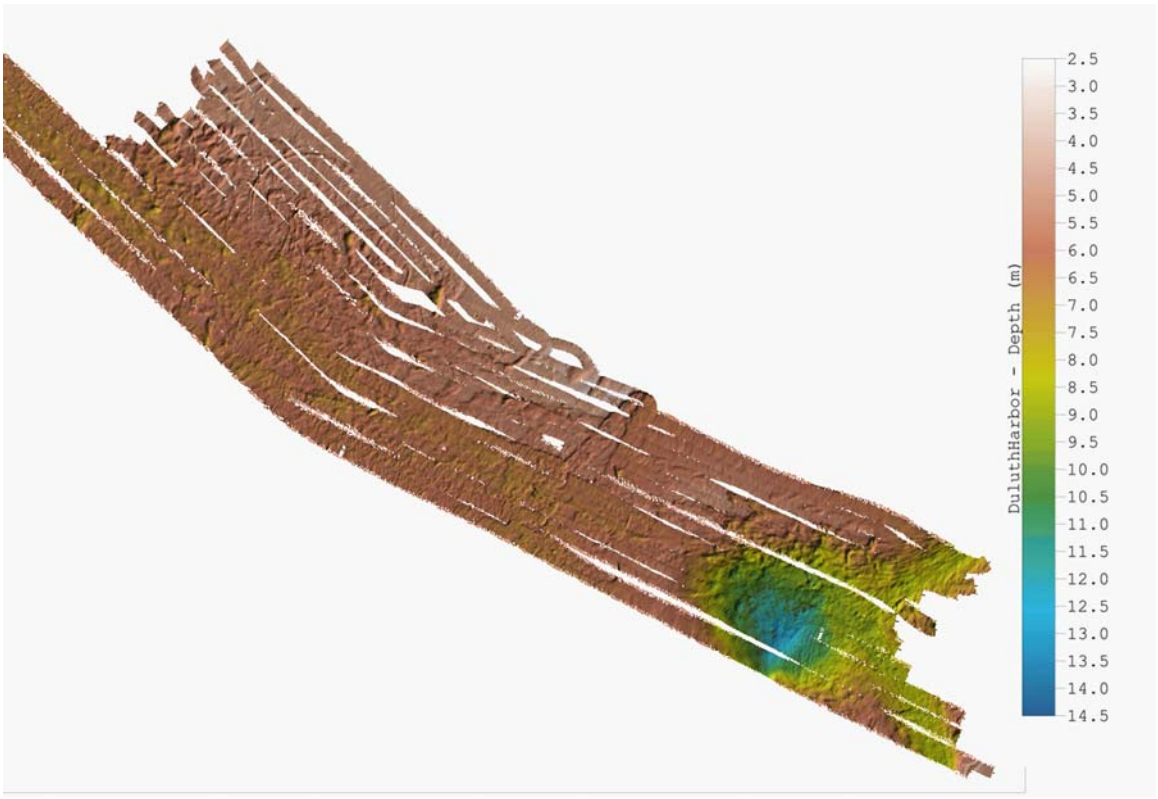

Figure 6: Multibeam bathymetry data for the Superior Harbor Basin.

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