SHOALS Airborne Laser Hydrography to Support Lake Ontario-St. Lawrence River Water Level Study

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ABSTRACT: The US Army Corps of Engineers SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) system recently participated in a comprehensive mapping effort in support of an international study of the Lake Ontario-St. Lawrence River waterway. SHOALS data provide a detailed survey of the nearshore and shoreline from land elevations to depths as great as 18 m for nearly one-third of Lake Ontario coastline. Study board participants are combining the SHOALS data with concurrently collected topographic lidar data, aerial photography, and deep water sonar data to produce a valuable set of baseline data for future studies, and for input to numerical models at the present time.

INTRODUCTION

The US Army Corps of Engineers (USACE) SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) system recently participated in a comprehensive mapping effort for the International Lake Ontario-St. Lawrence River Study Board. The International Joint Commission (IJC) directed the Study Board to "consider, develop, evaluate, and recommend updates and changes to the 1956 criteria for Lake Ontario-St. Lawrence River water levels and flow regulation, taking into account how water level fluctuations affect all interests and changing conditions in the system including climate change, all within the terms of the Boundary Waters Treaty" (IJC 2002).

The Study Board determined that an accurate evaluation of the effects of water level fluctuations on nearshore habitats and human activities could not be accomplished with existing data from nautical charts and topographic sheets because existing data were old and sparsely distributed. They decided the most economical and comprehensive approach to fulfilling shoreline mapping requirements was to utilize airborne lidar. The SHOALS system began data collection for the study in August 2001 and collected both topographic and bathymetric data in six large areas, three along the United States shoreline and two along the Canadian shoreline. Over 300 km of topographic data were collected for both low-lying coastal areas as well as for high cliffs along the lakeshore. Underwater elevations were collected to depths of 15-20 meters. In all, about one-third of the Lake Ontario shoreline was measured by the SHOALS system. All data are referenced to the International Great Lakes Datum of 1985 based on a comprehensive geodetic network established as part of the Study.

The SHOALS data provide detailed nearshore topography and lakebed depths that can be used as input for flood and erosion models to determine the impact of water level on coastal interests and to determine the relationship between water level and established habitats along the lakeshore (IJC 2002). This paper presents details of the SHOALS survey and unique data revealing many interesting hydrographic and morphologic features that influence Lake Ontario's shoreline.

COMMON DATA NEEDS

The Lake Ontario-St. Lawrence River Study Board created several Technical Working Groups (TWG) to facilitate completion of study goals (IJC 2002). Each group represents one of several varying interests in fluctuating water levels and flow in the river system. Some examples are Hydropower, Commercial Navigation, Environment/Wetlands, and Coastal Processes. The Study Board tasked the Common Data Needs TWG to meet the data requirements for all other groups and to establish a GIS for data management and data sharing.

Several TWGs required collection of contemporary data to support their analysis (W Leger, personal communication). Elevation data are required as input for flood and shoreline erosion models. Elevation data in wetland areas will help assess impacts of varying water levels on wetland ecosystems and determine relationships between wetland health and water level. Aerial photography and elevation data will aid in delineating land use areas and identifying infrastructure that may be affected by changes in water level or flow.

The Common Data Needs TWG designed a comprehensive data collection and management scheme to support each of these initiatives. The scheme included collection of several types of data in areas identified as priority zones. Topographic lidar data were collected in three zones on the US coastline (J. Hoff, personal communication) and along the St. Lawrence River. Acoustic soundings were also collected in the lower St. Lawrence River. Aerial photography, including color-infrared to determine wetland health and orthorectified imagery to accurately position the shoreline, was also collected. The final data type in the collection scheme and the subject of this paper, are SHOALS data collected for all priority zones along the US and Canadian shorelines of Lake Ontario.

THE *SHOALS* SYSTEM

SHOALS operates by scanning laser pulses at a rate of 400 Hz in an arcing pattern on the water surface forward of a Twin Otter aircraft (Figure 1, Guenther et al. 2000, Irish et al. 2000, Guenther et al 1996). Each laser pulse is composed of light at two wavelengths: 532 nm (green) and 1064 nm (infrared). Receivers in the aircraft detect the return of both wavelengths from each pulse. The red light reflects from the water surface (Figure 2, “specular interface reflection”) while the green light propagates through the water column to reflect from the sea floor (Figure 2, “reflected bottom signal” and “diffuse bottom reflection”). The surface and bottom returns are analyzed to determine a water depth for each laser pulse that is corrected for water level fluctuations due to waves and tides. During every survey, a video camera records each survey line. The video is tagged with readings from aircraft instrumentation: roll, pitch, and heading from the inertial measurement system, geographic position from the GPS, and timestamp from the SHOALS system itself.

Each depth measurement is positioned horizontally based on the position of the aircraft as determined by differential, or pseudo-range, GPS techniques and the geometry of the system. During data collection, the depths are referenced vertically to the mean water level at the time of survey. They are later referenced to a known elevation on land using concurrently collected tide measurements. Carrier phase, or kinematic GPS post-processing techniques can improve positioning by providing the altitude of the aircraft relative to temporary base stations operating at the time of survey (Guenther et al. 1998). Including the vertical position of the aircraft in SHOALS data processing eliminates the need to collect concurrent tide measurements. SHOALS depth measurements are accurate to IHO Order 1 standards, or ± 0.15 m in the vertical and ± 1-3 m in the horizontal (Irish et al. 2000, Pope et al. 1997, Riley 1995).

The maximum water depths detectable by SHOALS are limited by water clarity, or the amount of turbidity, in the water column. As the laser pulses

Figure 1 SHOALS system deployed on a Twin Otter.

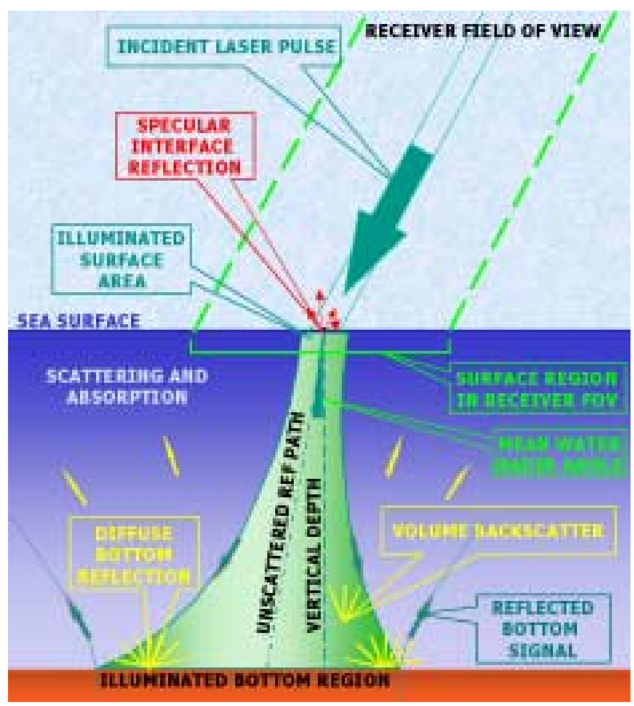

Figure 2 SHOALS operating principle.

travel through the water column, several processes occur that limit the amount of light to eventually reflect from the sea floor and return to the receivers in the aircraft. Light energy is lost during refraction and is scattered and absorbed by particles in the water and by water molecules themselves. In practice, this means SHOALS can "see" 2-3 times the Secchi, or visible, water depth. In very clear water, SHOALS can measure depths as great as 60 m.

The result of SHOALS survey is an ASCII XYZ data file that can be brought into any CAD, GIS, or digital terrain-mapping package. The XYZ data cover the coastal zone from onshore elevations, through the swash zone, to depths as great as 60 m. SHOALS can collect elevations for beaches, coastal structures, and nearshore bathymetry in a single swath with points spaced 4-8 m apart. Because SHOALS is a remote sensor, it is capable of safely collecting water depths in areas hazardous to survey vessels, or areas that are environmentally sensitive. SHOALS maintains a constant swath width regardless of water depth, allowing data collection rates as great as 25 km^2/hour.

LAKE ONTARIO *SHOALS* DATA

SHOALS data collection in the identified priority zones was completed in two weeks. The field survey crew arrived in Rochester, NY, on 31 July 2001. Data collection began the following day. During survey operations, the field survey crew operated from rented office space. The plane and flight crew operated from Greater Rochester International Airport, re-fueling at Greater Buffalo International airport on two occasions during long-duration missions. The data were collected in a series of 17 flights, one or two flights per day. Flight duration averaged about 4 hours each. A total of 446 flightlines were flown. In 65 hours of air time, 22 were spent collecting data. The remaining hours were consumed during transit to and from the survey sites.

In all, nearly 17 million soundings and nearshore elevations were collected in the priority zones, representing over 300 km, or nearly one-third, of Lake Ontario coastline. The data were collected on an approximate 8-m grid. Figure 3 shows a graphical representation of the SHOALS data collected. The data are displayed in shades of blue, with lighter shades indicating shallower depths and darker shades indicating deeper depths. The priority zones are labeled by the designation of the Study Board. The following paragraphs will describe the data collected for each zone, using the Study Board designations for reference.

Canada-1

The zone identified as Canada-1 is located on the southwestern shoreline of Lake Ontario, on the Canadian side. This section of coastline contains headland features and beaches, as well as the outlets of the Welland Canal and the Niagara River from Lake Erie. A sample of data collected in this area is shown in Figure 4. In the figure, the color brown indicates land, while other colors are depths, relative to the low water datum published for Lake Ontario (74.2 m IGLD85). Some interesting features shown in Figure 4 are the eastward trending shoal areas offshore of perturbations in the shoreline (indicated by arrows). The entrance of Forty Mile Creek

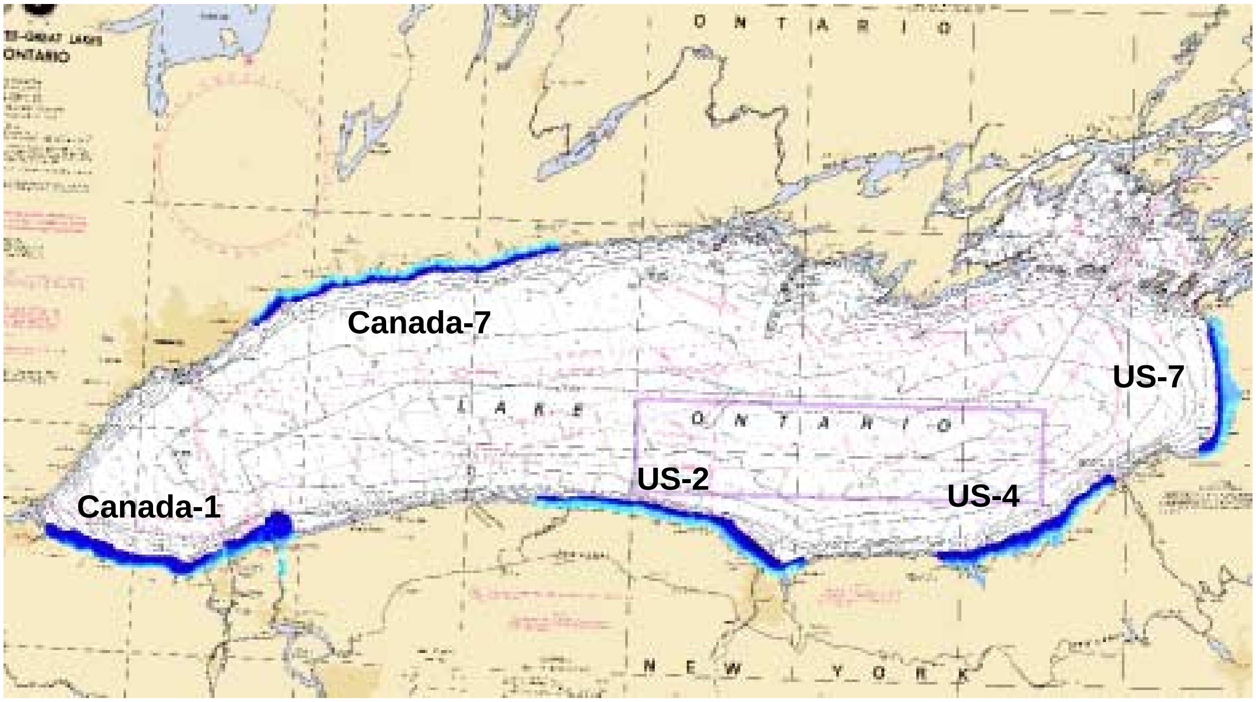

Figure 3. SHOALS data collected in priority zones are shown in shades of blue.

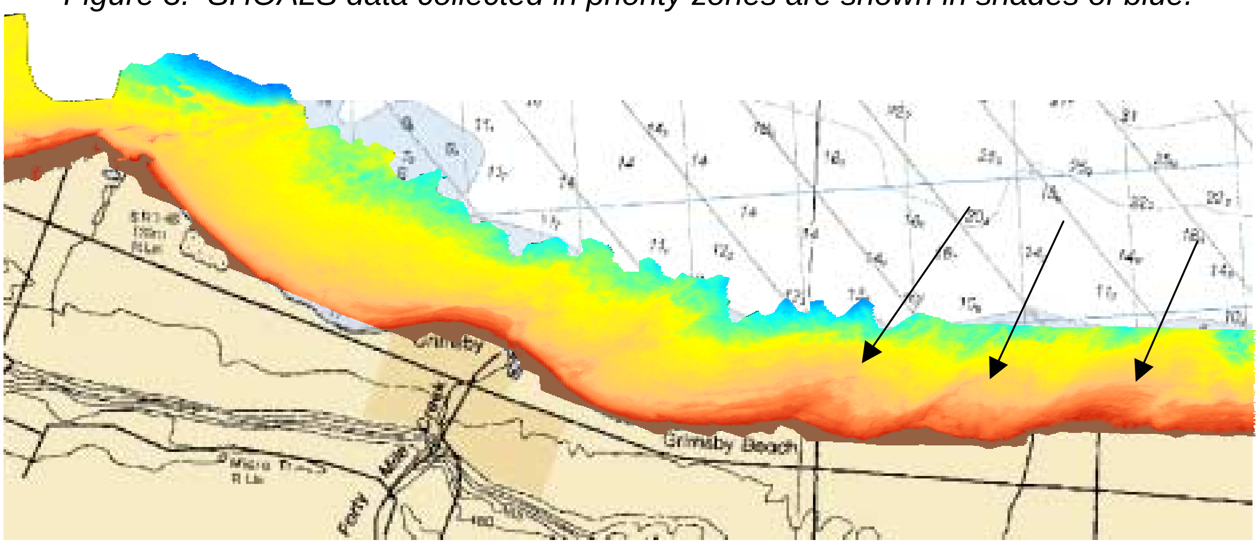

Figure 4. SHOALS data collected near Fifty Mile Point and along Grimsby Beach, Canada-1 shoreline of Lake Ontario.

to the lake has impacted the shape of the contours near Grimsby. The maximum depth detected in Canada-1 is near 14 m, and the highest elevation is near 36 m. The average distance surveyed offshore was 1.5 km, giving a total area surveyed of nearly 125 km^2.

Canada-7

The zone identified as Canada-7 is located on the northern shoreline of Lake Ontario, on the Canadian side. This section of coastline also contains headland features and beaches, as well as some small bays and harbors. A sample of data collected for this zone is shown in Figure 5. The color scheme is the same for this figure, with brown for land and other colors for bathymetry. Features of interest for this section of shoreline are the many headlands and embayments. Note the navigation structures for each harbor and the impact of McLaughlin Bay on the offshore contours. The maximum depth detected in Canada-7 is near 14 m, and the highest elevation is near 38 m. The average distance surveyed offshore was 1 km, giving a total area surveyed of nearly 100 km^2.

US-2

The zone identified as US-2 is located on the south-central shoreline of Lake Ontario, on the US side. This section of coastline is made up of headland features and small ponds, and contains many New York State Parks. A sample of the data collected in this zone is shown in Figure 6. Note the differences in bathymetry between Braddock Point and Irondequoit Bay, both shown in this figure. Near Braddock Point the bottom bathymetry is very irregular, with several large shoal features. Moving to the south, the shoals features disappear, leaving smooth shore-parallel contours near Rochester Harbor Entrance and the entrance to Irondequoit Bay. The maximum depth detected in US-2 is near 19 m, and the highest elevation is near 37 m. The distance surveyed offshore ranged from 1.5 to 2 km for the north-facing and northeast-facing section of shoreline, respectively, giving a total area surveyed of nearly 130 km^2.

US-4

The zone identified as US-4 is located on the southeastern shoreline of Lake Ontario, on the US side. High-relief coastal cliffs and large bays dominate this section of coastline. Sodus and Little Sodus Bays, and Oswego Harbor all have navigation

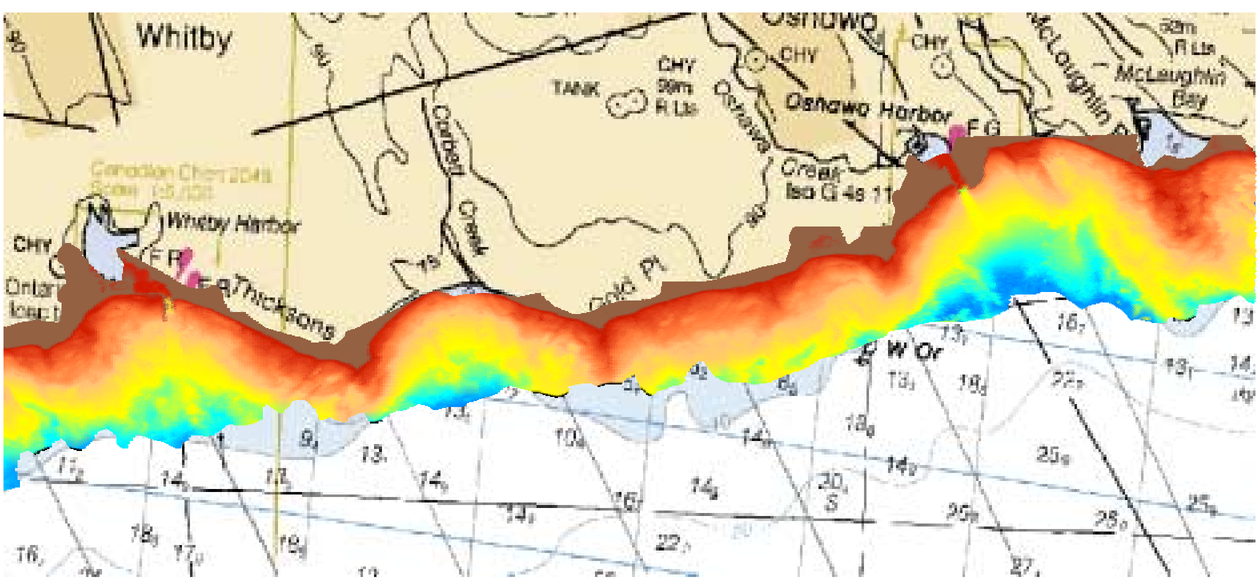

Figure 5. SHOALS data collected near Whitby and Oshawa Harbors, Canada-7 shoreline of Lake Ontario.

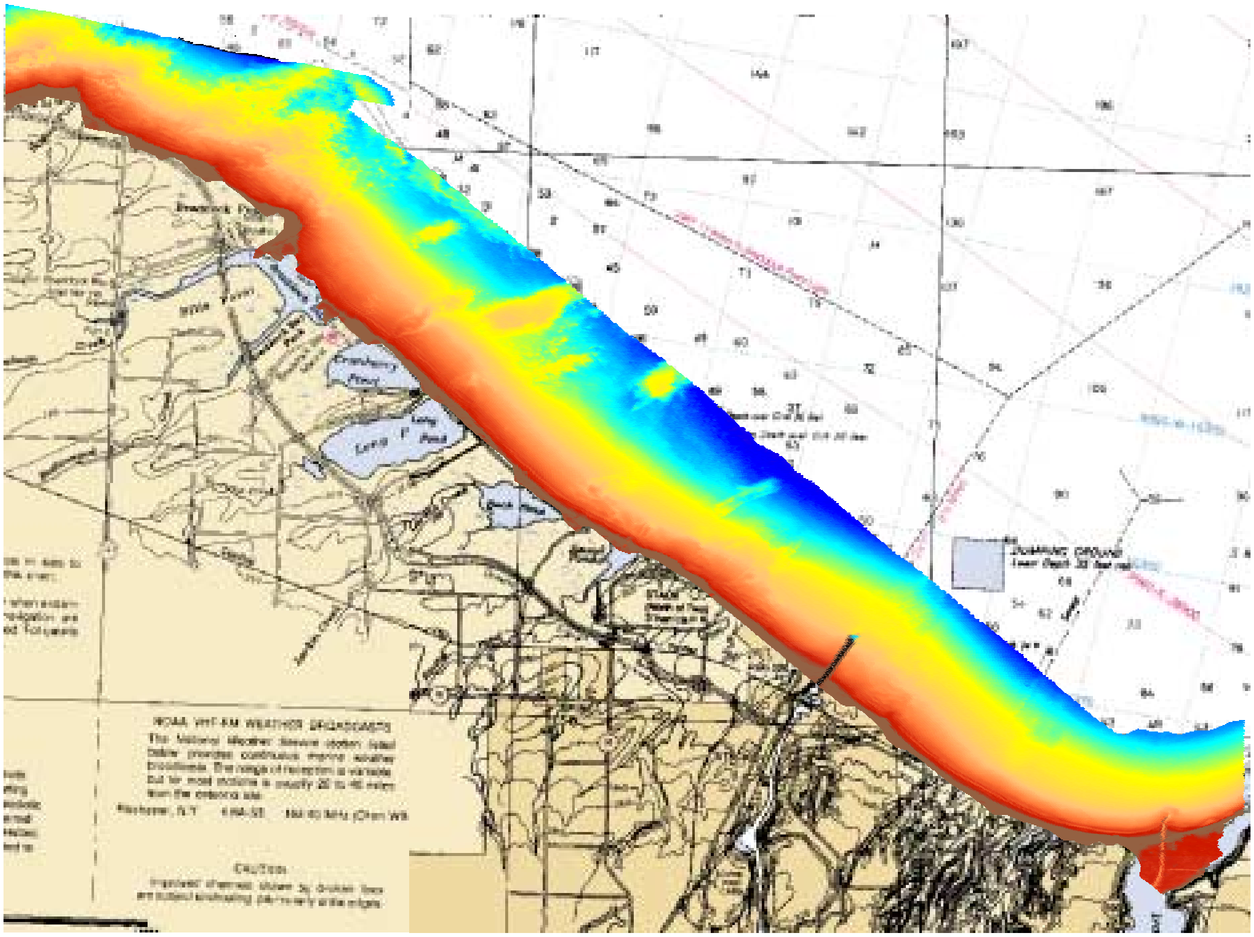

Figure 6. SHOALS data collected from Braddock Point to Irondequoit Bay, US-2 shoreline of Lake Ontario.

channels maintained by the USACE. A sample of the data collected for this zone is shown in Figure 7. Features to note in this area are the shallow waters of Blind Sodus Bay and the navigation structures of Little Sodus Bay, as well as the deep holes in the nearshore bathymetry immediately offshore of these bays (shown in blue in Figure 7). The maximum depth detected in US-4 is near 14 m, and the highest elevation is near 41 m. The average distance surveyed offshore was 1.5 km, except in a large central embayment, where the offshore survey extent was 3 km. The total area surveyed in this zone is nearly 110 km^2.

US-7

The zone identified as US-7 is located on the eastern shoreline of Lake Ontario, on the US side. In this zone, low marshy areas at the coast front high bluffs. There are many creeks and large coastal ponds. A sample of the data collected for this zone is shown in Figure 8. Features of interest in this area are Drowned Island, the shoal feature toward the top of the figure, and the natural outlet of Sandy Brook into the lake from Lakeview Wildlife Management Area. The maximum depth detected in US-7 is

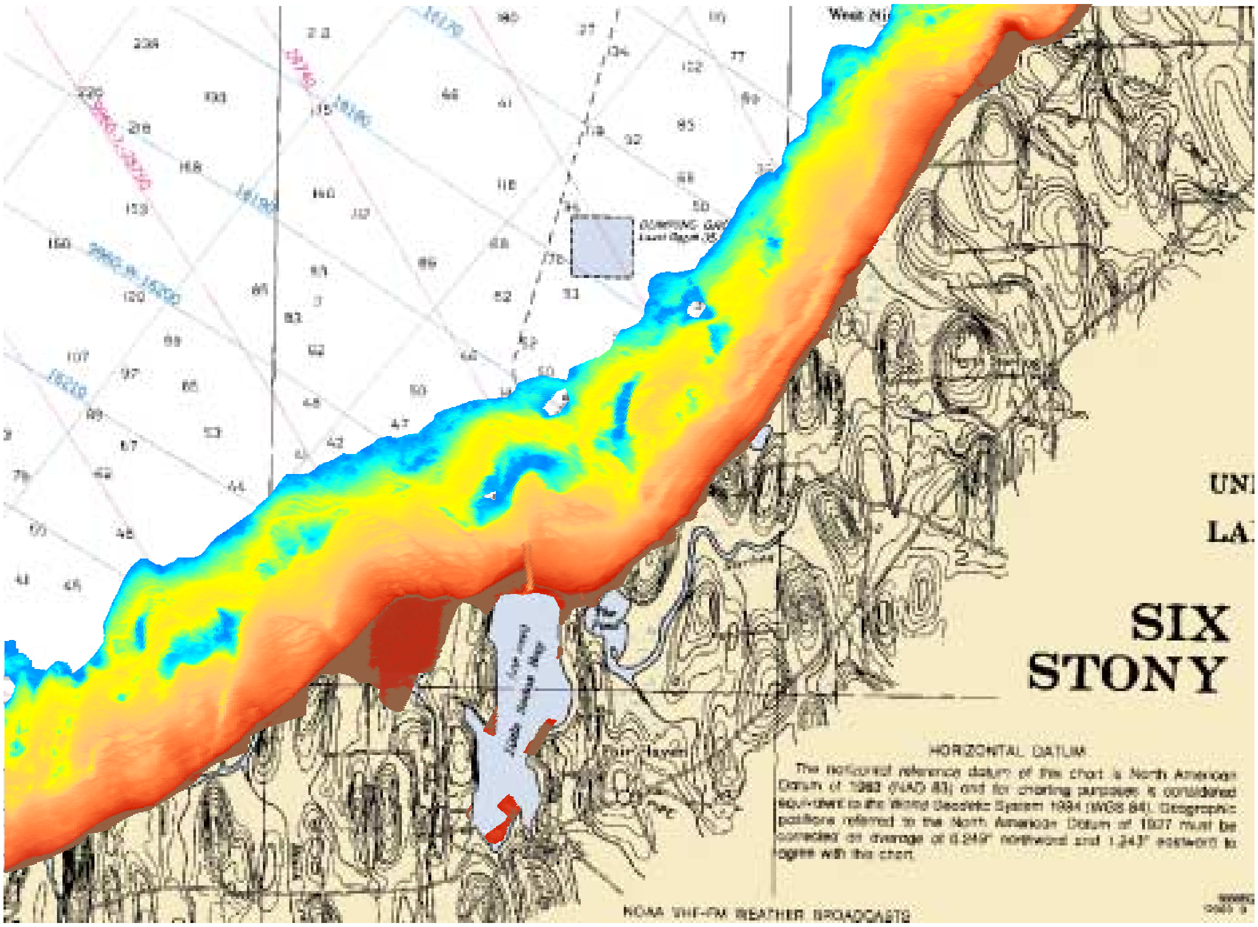

Figure 7. SHOALS data collected near Little Sodus Bay, US-4 shoreline of Lake Ontario.

near 14 m, and the highest elevation is near 38 m. The average distance surveyed offshore was 2 km, giving a total area surveyed of nearly 80 km^2.

DISCUSSION

The three primary data sets required by the TWGs to support their research were aerial photography, topographic data, and bathymetric data. The Common Data Needs TWG designed a survey program in which all three data types were collected by instruments flown on airborne platforms. However, each instrument required its own aircraft, operating altitude, and flight speed. Survey operations required three different flight plans and three different data processing pipelines. This particular data collection program points to a need for a single survey system, operating from a single aircraft, and collecting all three types of data.

The US Navy through the Joint Airborne Lidar Bathymetry Technical Center of Expertise awarded a contract through Technology Partnerships Canada to Optech, Incorporated, of Toronto, for the creation of just such a system, called CHARTS (Compact Hydrographic Airborne Rapid Total Survey). CHARTS is an integrated survey system that contains a hydrographic lidar sensor, a topographic lidar sensor, and a digital camera. CHARTS design is focused on sensor fusion, miniaturization of existing lidar technology, and automation of current lidar processing algorithms. The hydrographic lidar component operates at 1000 Hz, while the topographic component operates near 10,000 Hz. The digital camera will sample the survey area during flight at a rate of 1 Hz. The lidar sensors have separate transmitting components, but share receivers. All three sensors share GPS, IMU, and data logging to reduce hardware requirements. CHARTS is designed to deploy and operate easily from most photogrammetric aircraft of opportunity. The new system will be field-tested in August 2003, and will be commercially available thereafter as SHOALS-1000.

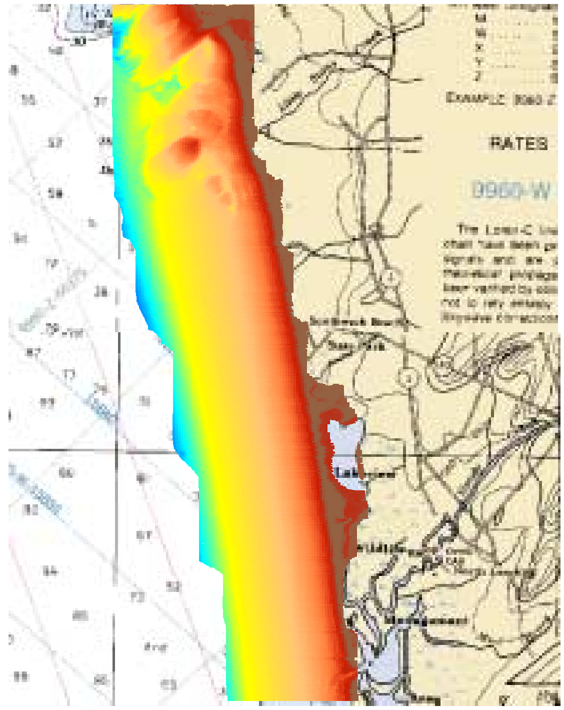

Figure 8. SHOALS data collected along Southwick Beach State Park, US-7 shoreline of Lake Ontario.

CONCLUSIONS

Collection of many types of shoreline data was required as a first step in meeting objectives of the Lake Ontario-St. Lawrence River Study Board. SHOALS data collected in priority areas along the Lake Ontario shoreline provide detailed measurement of the nearshore and coastline itself. The SHOALS data provide the baseline on which numerical models run to estimate coastal erosion, flood damage, and wetland dynamics (J. Hoff, personal communication). Used in this manner, SHOALS data are an integral part of the effort to evaluate impacts of water level and flow changes on all coastal interests along the Lake Ontario shoreline. In the near future, a survey program like that developed by the Common Data Needs TWG will be efficiently and economically achieved using SHOALS-1000, an integrated airborne survey system that will collect topographic lidar data, hydrographic lidar data, and digital imagery from a single platform.

REFERENCES

Guenther, G.C., Cunningham, A.G., LaRocque, P.E., and Reid, D.J. 2000. Meeting the accuracy challenge in airborne lidar bathymetry. *Proceedings of EARSeL Symposium 2000*. Dresden, Germany.

Guenther, G.C., Brooks, M.W., and LaRocque, P.E. 1998. New Capabilities of the SHOALS Airborne Lidar Bathymeter. *Proceedings 5th International Conf. on Remote Sensing for Marine and Coastal Environments*, ERIM International, October 5-7, San Diego, CA, Vol. I, 47-55. [reprinted in 2000, Remote Sens. Environ. 73, 247-255.]

Guenther, G.C., Thomas, R.W.L., and LaRocque, P.E. 1996. Design considerations for achieving high accuracy with the SHOALS bathymetric lidar system. *SPIE: Laser Remote Sensing of Natural Waters: From Theory to Practice*. 15: 54-71.

International Joint Commission. 2002. International Lake Ontario-St. Lawrence River Study Board. http://www.ijc.org/ijcweb-e.html. 24 April 2002.

Irish, J. L., McClung, J. K., and Lillycrop, W. J. 2000. Airborne lidar bathymetry: the SHOALS system. *PIANC Bulletin*. 2000(103): 43-53.

Pope, R.W., Reed, B.A., West, G.W., and Lillycrop, W.J. 1997. Use of an airborne laser depth sounding system in a complex shallow-water environment. *Proceedings of Hydrographic Symposium XVth International Hydro Conference*. Monaco.

Riley, J.L. 1995. Evaluating SHOALS bathymetry using NOAA hydrographic survey data. *Proceedings, 24th Joint Meeting of UJNR Sea-Bottom Surveys Panel*. Japan.