DETERMINING BATHYMETRY OF THE CHARLES RIVER BASIN USING COST-EFFECTIVE TOOLS

Michael J. Sacarny, MIT Sea Grant College, Cambridge, MA (msacarny@mit.edu)
Carl Zimba, Charles River Alliance of Boaters, Belmont, MA
Madonna Yoder, MIT Sea Grant College, Cambridge, MA
Ben Bray, MIT Sea Grant College, Cambridge, MA
and Chryssostomos Chryssostomidis, MIT Sea Grant College, Cambridge, MA

Determining Bathymetry of the Charles River Basin Using Cost-Effective Tools

Abstract

The Lower Charles River is a 14.5 km long body of fresh water that is heavily used for recreation. In response to concerns about sediment deposition and shoaling incidents, The Charles River Alliance of Boaters (CRAB) and MIT Sea Grant College created a bathymetric chart of the river with consumer-grade, fishfinder electronics, inexpensive water level loggers, and off-the-shelf charting software. We describe our methodology for river depth survey, equipment costs, conversion of sonar into contour data, correction for daily variations in water level, and production of charts in multiple formats, including an online version. The resulting Chart presents an objective model of the river bed, revealing shallows and bars of importance to boaters, and serves as a baseline for sedimentation study. This method may be useful to watershed associations, field ecologists, and others with an interest in water bodies lacking current bathymetry.

Keywords

Bathymetry, Fishfinder, Chartmaking, Depth Sounder

Introduction

In eastern Massachusetts, the Charles River Basin flows between Boston and Newton on the south and Cambridge and Watertown on the north. With more than 20 facilities dedicated to rowing, sailing, paddling, and power boating activities, the Basin is one of the busiest recreational rivers in the United States. On a typical day from April to October, more than 4000 rowers and several hundred sailors are on the water. The Basin is home to the MIT Sailing Pavilion, the birthplace of collegiate sailing and the most active college sailing venue, and to Community Boating, the oldest and one of the largest public sailing programs in the country, and to Union Boat Club, the third oldest rowing pavilion in America. The Basin is also the venue for the Head of the Charles, the largest two-day rowing event in the world, attracting over 11 000 athletes and thousands of spectators.

As is common with rivers that have been dammed, deposition of sediments has become a problem over time. In recent years, sediment deposits have contributed damage to watercraft and personal injuries, while also threatening the viability of several facilities. Despite the river's importance to the region, it lacked a current and comprehensive depth chart, complicating efforts in long-term planning. To address this issue, the Charles River Alliance of Boaters (CRAB) and MIT Sea Grant College formed a partnership in 2015 to chart the river depth between the Charles River Dam and the Watertown Dam (Figure 1,) a distance of 14.5 km, and to make the data available to the public in a variety of formats. Limited project funding necessitated a very restricted budget for equipment and software tools.

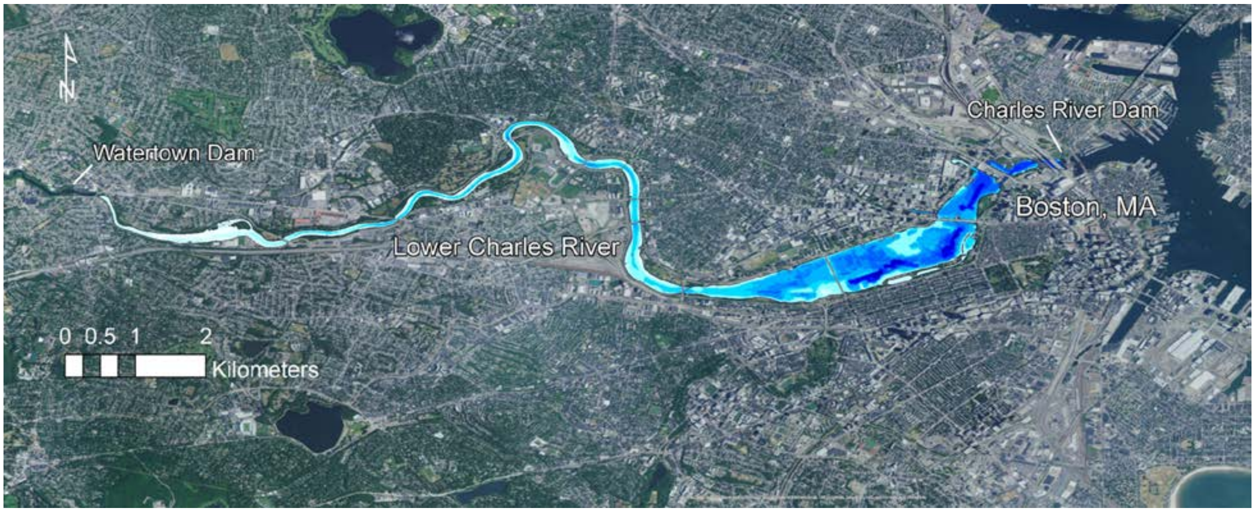

Figure 1: Lower Charles River study area. A more detailed view of the chart is available at http://seagrant.mit.edu/charleschart. Image source: Esri, Digital Globe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Nearly all of the Charles River Basin behaves as a lake, such that the watersheet has the same elevation throughout, as confirmed by this work. The uppermost kilometer of the Charles River Basin behaves at times as a river, with variations in the height of the watersheet, especially when more water is flowing over the upstream dams. The height of the watersheet of the Charles River Basin is controlled by the New Charles River Dam, opened in 1978, replacing the original Charles River Dam of 1912. A U.S. Geological Survey (USGS) gauge at First St. (USGS site #01104705 2017), approximately 1500 meters upstream of the dam, showed daily fluctuations over our survey period of from 0.03 m to as much as 0.3 m. Although there were no other government depth gauges in the survey area above this station, a USGS station upstream of our area at the Moody Street Bridge in Waltham (USGS site #01104500 2017) provided river flow rate.

Materials and methods

Sonar depth measurements

Based on pilot studies in 2015, we used a consumer-grade fishfinder mounted on a small launch boat with an outboard motor for basic depth measurements: a Lowrance HDS-7 chartplotter/fishfinder with Point-1 GPS and HST-WSBL 200 KHz broadband sonar transducer (Table 1.) We used a Lowrance LSS-2 800 KHz sidescan sonar transducer for imaging at strategic locations. Throughout this study, depth and GPS measurements were made at a rate of 10 Hz, with sonar range and sensitivity in “Auto” mode, along the driven track lines. Data was stored in sonar log files on removable SD storage cards and was transferred later to a desktop computer for archival storage and data processing.

Item	Cost ($)
Lowrance HDS-7 Gen3 chartplotter/fishfinder with Point-1 GPS, HST-WSBL 200 KHz broadband sonar, LSS-2 800 KHz sidescan sonar transducers, memory cards, batteries, and battery charger.	1908
(5) Onset HOBO Model #U20L-04 Water Level Data Loggers, (1) U-DTW-1 Data Shuttle, case, and HOBOware PRO software	1852
ReefMaster Pro 1.8 charting software with sidescan mosaic and bottom composition options	250
Minn Kota Riptide 45/T trolling motor with extension handle	355

Table 1: Cost of equipment used in survey

We mounted the sonar transducers and GPS on a single aluminum mast that could be moved between vessels as needed and clamped to the transom (Figure 2a.) Rulings along the mast made it easy to determine the depth of the sonar transducer for each survey run. For shallow areas, we used a Minn Kota Riptide trolling motor (Figure 2b.)

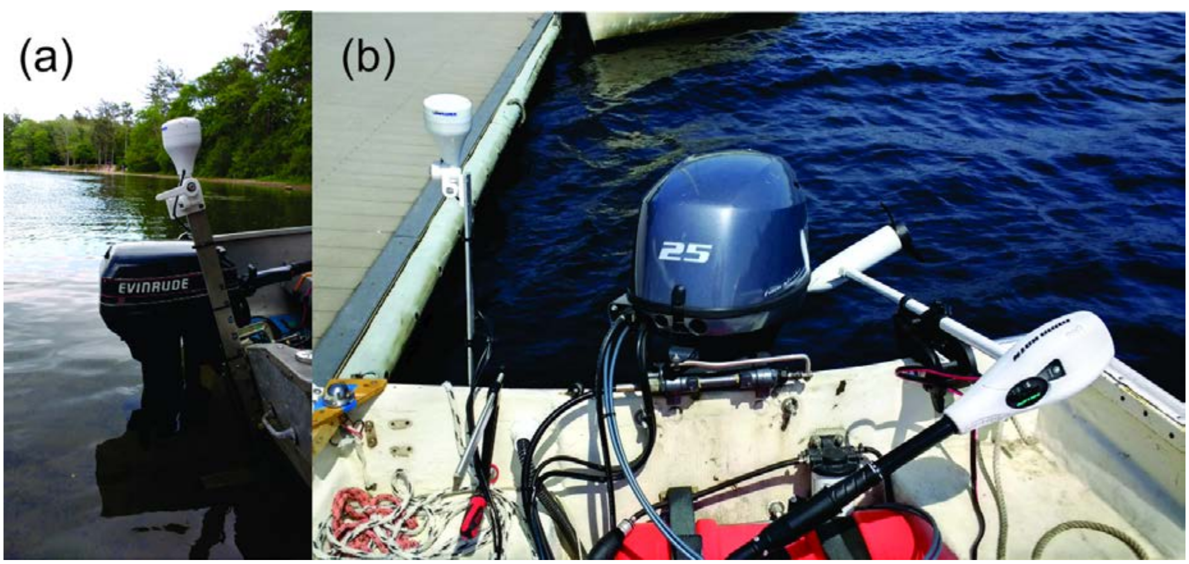

Figure 2(a): GPS, broadband, and sidescan transducer mast. Note depth markings on mast near transom. (b) Stern of survey vessel, showing clamped mast, outboard, and trolling motor

In areas where the river was wide, we drove track lines 9 m to 18 m apart in a decreasing spiral (Inset of Figure 3) at speeds generally between 5.5 kph (3 kts) and 8.9 kph (4.8 kts.) Driving these patterns efficiently required focus and skill. Where the river was narrow, several passes were made up and down the river over multiple trips. The survey took approximately 17 days of sonar field work, plus training and calibration runs, spread over four months in 2016 and 2017. We used an AdirPro16-Foot aluminum grade rod fitted with a paddle end to perform evaluations of select sonar depth readings.

Water-level logging

The measured sonar depths also included any changes in the height of the watersheet. To obtain the true depth, a correction was applied to the measured sonar data corresponding to the difference in the measured height of the watersheet and the design height of 107.5 ft. MA MDC base.

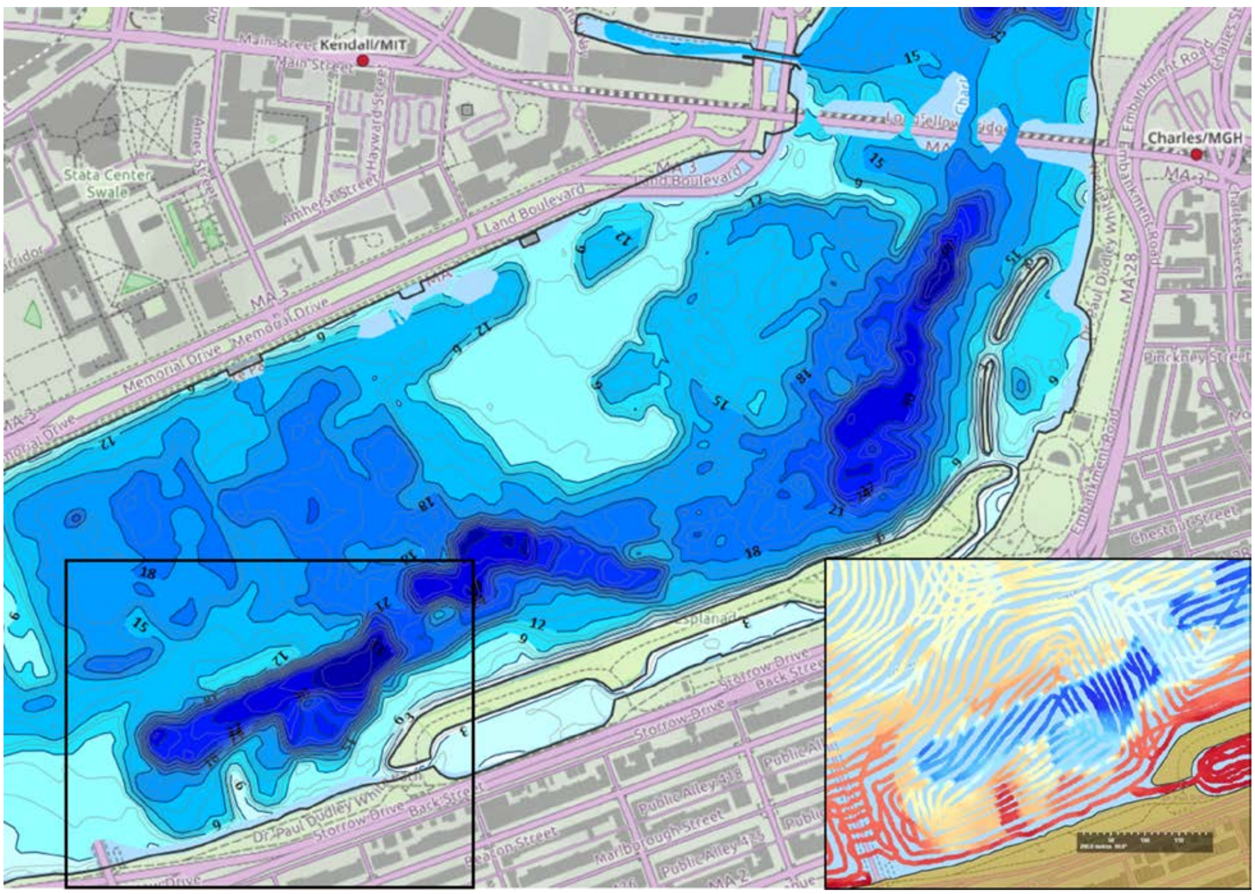

Figure 3: Contour view of chart section in ReefMaster before refinement in ArcMAP. Inset shows detail of survey sonar tracks. Scale bar is 200 m long. Red indicates shallow portions of the track, blue deeper

To measure the height of the watersheet, the project team installed three Onset HOBO Model #U20L-04 Water Level Data Loggers at locations 4.1, 7.7, and 10.4 km upriver from the USGS First St. gauge station in 2016. The loggers were each nested in a pvc pipe mounted on a pressure-treated board with a Crain 4 ft stream gauge board. Data from an additional logger above the water line was used to correct water level data for variations in atmospheric pressure. In 2017, we installed a fourth logger at First St. Data from each logger was retrieved approximately monthly.

Over a 55-day period between 8/3/2016 and 9/27/2016, 5177 data points were collected at 15-minute intervals from each of the three data loggers and the USGS gauge at First St. In general, the heights of the watersheet measured by the four gauges moved in unison, suggesting that this section of the river is indeed behaving as a lake. Differential heights, obtained by subtracting the measured height of one gauge from that of another gauge, were nearly constant, confirming that the height of the water sheet was moving in unison within our study area. The absolute height measured by each sensor was determined by combining the as-measured data with the average differential height relative to the USGS First St. gauge and the calibrated height measured at the USGS First St. gauge.

This coordinated motion of the water sheet height had a few deviations that could be correlated to significant rainfall events and flood control water releases. To reduce the effect of such deviations in water level during sonar surveys, we tried to survey at least two days after heavy rainfalls, when the river had resumed lower stream flow as indicated by the Waltham gauge.

For the calculated differential height data, any deviations from the average value must arise from actual differences in height at the two gauges, random fluctuations in the height of the watersheet, and random fluctuations due to the accuracy and precision of the gauge. The 95% confidence level of our measurements is estimated to be +/- 0.011 m and that the uncertainty of any single measurement of the height of the watersheet is estimated to be +/-0.008 m.

Creating the draft chart in ReefMaster

We used ReefMaster Pro 1.8 mapping software to process raw sonar track files into a draft form of the depth chart. First, we imported raw sonar files into ReefMaster, converting them from the proprietary Lowrance format. Then, we adjusted each track for the depth of the transducer below the waterline. Next, we reviewed each track to confirm that ReefMaster was able to determine a clean bottom line from the sonar. Most of the time, the automatic determination was satisfactory, but in some areas, particularly shallow, vegetated regions, editing was required.

Erratic depth readings in shallow regions caused us to more closely investigate the performance of the broadband sonar transducer. Specifications for the transducer do not include a minimum depth; this had to be determined from field experience, and varied from unit-to-unit. We strongly recommend qualifying transducers in shallow water at the start of a survey. We were successful in determining bottom to depths as low as 0.3 m under the transducer, but tried to survey vegetated regions before vegetation growth became a problem.

We adjusted for varying watersheet level by converting the time-series Hobo logger data from absolute depth to depth relative to the design height of the watersheet. We imported these relative depths to ReefMaster in a plain text 'tide station' file. For example, if the river at a particular time of the survey was 0.1 m over the design height, the tide station file had a value of 0.1 m, and ReefMaster reduced the sonar depth at that time by 0.1 m.

In ReefMaster, map boundaries define lake, river, or ocean shorelines and islands. These also can instruct ReefMaster to use the boundary to provide depth information to the map generation process. In our case, we created river boundaries in ArcGIS and transferred them as Esri shape files.

Sonar tracks in ReefMaster are organized into Map Projects which can be viewed as track line maps, contour maps, or 3D maps. Figure 3 shows a small portion of our sonar track lines and gives some indication of the labor and concentration involved in charting with this method.

We determined the major and minor contour interval, interpolation, and smoothing of the contour map in ReefMaster Contour View (Figure 3.) Our tracklines were spaced closely enough that an interpolation setting of 25 m resulted in very occasional, small gaps in the resulting map. We exported the contour map isobaths, major, and minor contours as a series of Esri shape files for refinement in ArcGIS.

While not a focus of this publication, we did use the ReefMaster suite of tools for reviewing and combining sidescan sonar recordings, resulting in photo-like images of the survey area.

Development of chart products in ArcMap

We transformed basic contour data into more developed charts in ArcGIS/ArcMap. Although ArcMap is not inexpensive and has a steep learning curve, it is widely available in academic environments, is in common use, supports Python scripting, and has a huge variety of toolsets. Free and open source GIS tools are available (eg QGIS) that could be used in a similar manner.

We constructed several map layers as components for our charts, including:

- **Landmarks** describing prominent facilities and locations
- **Shorelines** describing shorelines and islands drawn from satellite imagery
- **Elevated structures** describing docks, buildings, roadways, etc. that are drawn on top of depth data
- **Major contours** from the imported ReefMaster Esri shape file
- **Contour Annotation** and **Mask** layers that label major contours
- **Minor contours** from ReefMaster
- **Isobaths** from ReefMaster
- **Historical chart** raster scans

We created a series of ArcMAP Map Documents that included the map layers and were used to produce the charts in a variety of formats:

- Online version: It is straightforward to export an ArcMAP Map Document to the 'Map Package' format required by ArcGIS Online. The web version of the chart is the result of a workflow combining ArcGIS and open-source webmapping frameworks. The refined, multi-layered map package is uploaded to ArcGIS Online, where the individual layers are made available as Web Map Services (WMSs). WMSs are then used to import the ArcGIS Online layers into a mobile-friendly, highly-customizable web environment coded in Leaflet and Bootstrap javascript frameworks.
- Google Earth and Google Map versions
- Chart Booklet: A printable PDF file that includes a keyed guide page of the entire survey area and subsections
- Large Format Overview: Intended for poster-sized printout, this presents a view of the entire survey area and a summary of the project

  The online chart has selectable layers for isobaths and images of historic charts. An opacity control facilitates comparison with current bathymetry.

Extensive use of Python (arcpy) scripting is an essential part of the maintenance of the chart and uniform production of chart products.

Chart Accuracy

Vertical Uncertainty: The charts are based on fishfinder sonar, which determine depth from the echo of the top layers of sediments. Given these readings, transducer uncertainty, and related factors, our depth accuracy is stated as +/-5%. In areas of loose sediments, manual measurements could result in depths .15 m or greater than those based on fishfinder sonar.

Horizontal Uncertainty: Based on specifications of the GPS used in the survey, horizontal accuracy is stated as 3m except in areas where GPS satellite signal is degraded, such as under bridges. Uncertainty in lateral position may give rise to additional uncertainty in depth. Also, as an artifact of chart processing, depths immediately adjacent to walled sections above the Boston University Bridge are depicted as sloped contours rather than discrete steps.

Results

We used this methodology to survey 14.15 km of the Lower Charles River. Our charts can be viewed online or downloaded in a variety of formats, all available to the public:

- http://seagrant.mit.edu/charleschart: Online current and historical charts
- http://www.charlesriverallianceofboaters.org/chart.html: Google Earth, Google Map, Chart Booklet PDF, and Wall Chart PDF variants of the chart, with additional links to historical charts and extensive reports relating to the Charles River

Reception of the chart by the river community has been very positive, resulting in a featured news article (Boston Globe 2016), numerous public meetings, and interest by stakeholders of other river systems. The technique has been applied to fish habitat characterization in several Massachusetts lakes, and provided the foundation for a study of the long-term sedimentation rate in the Charles River (Yoder 2017.)

Conclusion

Using modestly expensive instrumentation and software, we were able to create a detailed chart of the 14.5 km length of Charles River Basin. We have demonstrated that quality bathymetry can be obtained with a limited budget. This approach seems well-suited for organizations, especially community-based stewards who need to characterize bodies of water of modest size. They may even find the combination of fish-finding sonar and ReefMaster alone to be adequate for their needs. This approach could be enhanced, albeit at higher cost, with the use of more efficient and capable survey equipment and more fully-featured charting software in the hands of more experienced operators.

Acknowledgements

Generous in-kind support was provided by the MIT Sea Grant College Program, MIT Sailing Center, and Massachusetts Bays National Estuary Program (EPA Grant CE96173901). Initial project funding was provided by Boston Duck Tours, Head of the Charles Regatta, Newton Yacht Club, Riverside Boat Club, Union Boat Club, Community Rowing, and Community Boating. Further financial support was provided by Northeastern University Rowing, Watertown Yacht Club, Charles River Conservancy, and generous individuals.

References

Adams D. 2016. Clearing Muddy Waters. *The Boston Globe*. 18 Dec.

USGS (U.S. Geological Survey). 2017. USGS 01104500 CHARLES RIVER AT WALTHAM, MA. https://waterdata.usgs.gov/nwis/uv?site_no=01104500. Accessed 19 Sep 2017.

USGS (U.S. Geological Survey). 2017. USGS 01104705 CHARLES RIVER AT FIRST ST AT CAMBRIDGE, MA. https://waterdata.usgs.gov/nwis/uv?site_no=01104705. Accessed 19 Sep 2017.

Yoder M. 2017. Lower Charles River Bathymetry: 108 Years of Fresh Water (Senior UndergraduateThesis). Cambridge, MA: Massachusetts Institute of Technology