Lower Charles River Bathymetry: 108 Years of Fresh Water

by

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Abstract

The Lower Charles River has been a heavily utilized urban river that runs between Cambridge and Boston in Massachusetts. The recreational usage of the river is dependent on adequate water depths and there have been no definitive prior studies on the sedimentation rate of the Lower Charles River. The river transitioned from tidal to a freshwater basin in 1908 and the study area for historical comparisons was from the old Charles River Dam to the Boston University Bridge. This study surveyed the river, digitized three prior surveys that spanned 114 years, calculated volumes and depth distributions for each survey, and estimated sedimentation rates from fits to the volumes over time. The average sedimentation rate is estimated as 5-10 mm/year, which implies 1.8-3.5 feet sedimentation since 1908. Sedimentation rates and distributions are necessary to develop comprehensive management plans for the river.

Introduction

The Lower Charles River in Massachusetts runs 9.5 miles from the Watertown Dam at the upstream end of the original estuary to the new Charles River Dam just below Zakim Bridge (Weiskel, Barlow, and Smieszek). Currently, the Lower Charles River Basin is home to numerous boat houses, yacht clubs, and docks that rely on the availability of sufficiently deep water. The river is heavily used for recreation and borders Boston, Cambridge, Allston, Brighton, Newton, and Watertown. Although the USGS has several gauge stations on the Charles River and its tributaries and the EPA monitors water quality, remarkably little is known about bottom of the Charles River or its rate of sedimentation. The Charles river has undergone several major changes since the turn of the 20^{th} century including the transition to a freshwater body, the construction of the Esplanade and its subsequent expansion for Storrow Drive, the transition to the new Charles River Dam, and the separation of sewage from combined sewage drains

(Weiskel, Barlow, and Smieszek). This study provides both a comprehensive modern survey of the river and an analysis of the depth distribution and volume of the river from 1902 to 2016.

The Lower Charles River has been heavily used for industry, recreation, and waste disposal since the settlement of Boston in 1630. Prior to the construction of the old Charles River Dam in 1908, the entirety of this section of the river was tidal with exposed mud flats and salt marshes. The vast majority of salt marshes in areas such as Back Bay and Cambridge had already been filled before the old Charles River Dam was proposed in the 1850s and more fill occurred before the dam was constructed (Pritchett and Freeman). Construction of the dam resulted in a stable water height 8 feet above the previous mean low water level in the basin, which covered the sewage-strewn mudflats and led to the reimagining of the river as the central feature of Boston. Olmsted and a team of landscape architects designed the Storrow Memorial Embankment, which was first completed in 1936 and expanded for Storrow Drive in 1949 (Haglund). This study investigates changes in the Lower Charles River from the old Charles River Dam (near the Craigie Drawbridge) to the Boston University Bridge (BU Bridge) since 1902.

Historical bathymetric data on the Charles River is sparse both temporally and spatially. Historical charts of bathymetric contours of the Lower Charles River were produced in 1902, 1976, and 1998 at varying resolutions. This study grew out of the production of a modern chart during the summer of 2016, which has the best resolution of the four charts available. The four charts were produced by various groups for varying purposes and precise methodology is not available for the historical charts.

The 2016 chart (Appendix 1a) has major contours every 3 feet with minor contours every foot and has been corrected for water level at the time of sampling for each point. All measurements were measured, recorded, and processed electronically with very little opportunity for human error. Exact methods of measurement, correction for gauge height, and chart production are described below.

In summary, the Lower Charles River is used extensively for recreation and commercial operations that rely on sufficient water depth. This study produced a detailed chart of the river over the summer of 2016 and digitized three historical charts. These four charts were analyzed to calculate volumes and the volumes of the basin were compared over time. The change in volumes is attributed to sedimentation, which has historically been an issue in shallow areas upstream of the study area, and an estimate of the sedimentation rate is calculated. Extensions of this study include expansion of the study area to the remainder of the Lower Charles River, production of charts detailing the differences between the historical charts, and comparison of the differences between historical charts to the chart of sediment depth produced in conjunction with the 1998 chart.

Historical Charts

The 1902 chart (Appendix 1b) has major contours at 5 foot intervals and minor contours at 1 foot intervals. This chart was produced under the supervision of the chief engineer of the Committee on [the] Charles River Dam, which was investigating the desirability, feasibility, and cost of construction of the initial Charles River Dam near Craigie Bridge (Pritchett and Freeman). Exact methods for the survey are unknown but the chart was considered accurate enough for navigation by the committee. Other measurement of height in the committee’s report are precise to hundredths of feet and there are no visible artifacts of interpolation in the chart. In this investigation, only the major contours were analyzed. Of the three historical charts, the 1902 chart has the finest resolution and the highest precision.

The 1976 chart (Appendix 1c) has the lowest resolution of the four charts with heavily smoothed contours at 5 foot intervals. This chart was produced from “depth information collected during various river surveys" for the Charles River Lower Basin Artificial Destratification Project (henceforth destratification project) in 1976 in order to locate the best locations for bubblers to mix the stagnant waters of the Charles (Ferullo, DiPietro, and Shaughnessy). The goal of the destratification project was to mix the extensive salt water wedge at the bottom of the river with the lighter fresh water at the surface to aerate the entire water column and expedite the flushing of salt water from the basin. The salt wedge created an anaerobic zone, leading to the production of hydrogen sulfide and the subsequent fish kills and noxious odors when the river did overturn. There was concern that the flood control pumps in the new Charles River Dam would flush the anaerobic salt wedge into the harbor when activated, leading to a fish kill and noxious odors in one of the most commercially active areas in Boston. Since the Metropolitan District Commission only needed a general sense of the deepest locations in the river, attention was not paid to detail in the generation of the chart, which is illustrated best by the discrepancies in fixed shoreline proportions relative to modern imagery and by the dramatic smoothing of the contours.

The 1998 chart (Appendix 1d) relies heavily on computer-generated interpolation between its 8,000 points of measured depth and the shorelines, which is particularly evident at walled shores and other sharp features. This chart also displays contours in 5 foot intervals but its resolution is much higher that the resolution of the 1976 chart. The points of measured depth were generated by videotaping the outputs of a GPS unit and a sonar unit and then selecting and writing points by hand (Breault et al.). Typical fish-finder sonar units measure in increments of 0.1 feet and the number of decimal places used for the latitude and longitude during this survey is unknown. Additionally, the 8,000 points were distributed along the entire length of the Lower Charles River, of which the study area is 62% by area. This gives an average of one point every 350 m^2 in the sailing basin, or about 1/75th of the sampling density of the 2016 survey.

Methods

Summer 2016 Survey

The Charles River Alliance of Boaters (CRAB) and the Sea Grant College Program at MIT partnered to produce a bathymetric chart of the Lower Charles River with data collected by Sea Grant starting the summer of 2016. The project was led by Michael Sacarny and Carl Zimba and assisted by Madonna Yoder. Sacarny and Yoder jointly collected the majority of the sonar data used in the production of the chart and also developed the chart production process. The production of the chart consisted of generating a model of water height changes on the Lower Charles River, collection of sonar data from the new Charles River Dam to the Watertown Dam, processing of the sonar track files, and design of the chart display.

Water height data were collected from three water level loggers at Riverside Boat Club (Riverside), Herter Park, and Community Rowing, Inc (CRI) and were corrected for ambient atmospheric pressure with a fourth logger located at the MIT Sailing Pavilion. The water level loggers recorded the average value of the water height above the sensor in 15 minute increments. This averaging eliminated signals from wakes and other short-term variations in water height. The loggers were first deployed on July 1, 2016 and redeployed on August 3, 2016 to correct the alignment of sampling times relative to the USGS gauge station at First Street in Cambridge. Prior to August 3, data were linearly interpolated to match the USGS timestamps. Data were collected from the loggers approximately once every two weeks. Since water height in the Lower Charles River is periodic with two major release events per day at low tide, the distribution of water level loggers along the length of the river was necessary to determine whether the water level was dependent on distance from the new Charles River Dam as well as on time. After correction for atmospheric pressure using HOBOware software, the data from the three water level loggers and the gauge station at First Street in Cambridge were analyzed for any delay in transmission of the twice daily decrease in water height along the length of the river. Full details of the data analysis are below. It was found that the maximum value of the cross-correlation occurred at 0 lag for each time series, which indicates that any propagation of water level on the Charles River operates on a timescale of less than 15 minutes. During late summer 2016 a typical drop in water height during release from the dams was 0.1 feet over 6 hours and since the river equilibrates in a timescale of less than 15 minutes, any potential gradient in water height over the course of the river was negligible for the purposes of the survey. Effectively, the Lower Charles River is a freshwater pond with a variable water surface elevation. Therefore, our corrections to depths measured took the form of a tide file based on the Riverside water level logger and were applied to measurements taken along the entire river.

Bathymetric data were collected in a small powerboat with a Lowrance GPS and fish-finder sonar connected to a chart-plotting display. These data are in the form of .SL2 format tracks with depth sampled at increments of 0.1 feet at a rate of 10 samples per second and a boat speed of up to 5 knots. The .SL2 format is a proprietary format used by Lowrance and ReefMaster for data with timestamps, GPS locations, and other attributes including depth. Track spacing was between 10 and 20 m and tracks were run over the area from the new Charles River Dam to the Watertown dam, excluding extremely shallow and extremely vegetated areas where the boat could not operate normally. Additionally, some spans of bridges were excluded due to construction or lack of the knowledge of navigability under the span. Track spacing was maintained by using the chart-plotting display to visualize the locations of previous tracks relative to current boat position. Tracks were driven from the perimeter of an area inwards by spiraling in with each pass of the boat. Each individual measurement is accurate to within 5% of the actual depth and has a precision of 0.1 feet. Sonar tracks were imported into ReefMaster for processing and were corrected for transducer offset below the surface and also corrected to a constant water surface height. The baseline river surface height of 107.5 feet is the target management water level and the long-term average since 2007 for the Lower Charles River during the recreational season (May to October) as measured by the 1st Street gauge station. This correction was performed in ReefMaster by applying a tide file generated from the atmospheric pressure-corrected depths provided by the water level loggers through HOBOware software. Anomalously shallow or deep points were attributed to vegetation or other interference and were removed by hand from each track.

The Lower Charles River has several distinct types of shorelines. Some areas have vertical walls, others have steeply sloping reinforced banks, and others more gently sloping banks. For sloped banks, it is a good approximation to treat the shoreline as a depth 0 contour and to interpolate between the nearest data point inside the maximum interpolation distance and the shore to generate a model of bottom elevations. However, the rapid change in depth at vertical walls makes this interpolation both inaccurate and misleading. The track processing software ReefMaster requires that a shoreline either be given a value of zero or null and that all shorelines are closed polygons. To minimize interpolation at walled shores, the Lower Charles River was modeled as two sections split at the center of the Boston University (BU) Bridge. The upper section has fewer walls and the setting to interpolate to the shoreline as a zero-depth contour was selected. The lower section is mostly walled and the shoreline was set to a null depth value. To counteract gaps formed at walled shores, tracks were driven as close to the walls as possible. This approach maximized the benefit of interpolation in shallow areas where the boat could not collect data, minimized the cost of both interpolation and gaps as walled shores, and disguised the seam in the sections under a bridge in the final chart display.

Within each ReefMaster project file, contours were generated at intervals of 3 feet for major contours and 1 foot for minor contours. The maximum interpolation distance was 25 meters (the minimum setting) and a grid smoothing value of 15 was used. Once the contours were generated, they were added to a user map file in ReefMaster, which was then exported to shapefiles. These shapefiles of the contours and the isobath polygons between the contours were added to an ArcGIS map document and formatted to create a poster display format, a chart booklet, and exports to Google Maps, Google Earth, and ArcGIS online. These exports are publicly available at http://www.charlesriverallianceofboaters.org/chart.html.

Historical Survey Digitization

In addition to analyzing contours from the modern (2016) survey, three prior charts of the river were digitized and analyzed. The first chart was compiled in 1902 for the Committee on Charles River Dam with surveys and soundings taken in August and September of 1902 and has 1 foot contour intervals with major contours every 5 feet (Pritchett and Freeman). The second chart was compiled in 1976 for use in the Charles River Destratification Project and has contours every 5 feet with less detail that the other charts analyzed (Ferullo, DiPietro, and Shaughnessy). The third chart was compiled by the United States Geological Survey (USGS) in 1998 from about 8000 depth soundings using submerged sonar readings and GPS locations for each point (Breault et al.). Using ArcGIS software, these soundings were converted into a TIN model and a raster of depths and a chart was produced with 5 foot contours. These three charts were digitized in ArcMap at 1:2000 scale by hand using the procedure below.

Each high-resolution scan of a chart was converted to either a .jpg or .tif file format, imported into ArcMap in a new map document, and georeferenced to the current photographic basemap in the GCS_WGS_1984 coordinate system by matching road intersections using the Georeferencing toolbar. The major contours and shorelines of each chart were traced at 1:2000 scale to create new polyline files that formed closed polygons and were labeled by depth. Each polygon was assigned a point with the value of the shallowest depth contained within the polygon. Using the Feature to Polygon and Spatial Join tools, these polygons were made into their own files with depths assigned to each polygon and were then added to the map and assigned a color scheme matching the colors of the modern survey. Labels were added to the major contours as annotation to create an easily understandable display chart for each digitized survey. This display was used to identify the locations of sinks (local depressions) in the chart, which were then marked with a point and assigned a depth. The shoreline was also converted to a single polygon (with holes over the islands in the three later charts) to use as a boundary in raster operations. The Topo to Raster tool was used with the shoreline polygon as a boundary, the sink points as sinks, and the major contours and shoreline polylines as contours. The resulting rasters were converted to the NAD 1983 StatePlane Massachusetts FIPS 2001 (US Feet) coordinate system with cell sizes of 5x5 feet and then the values for each raster cell were rounded to the nearest tenth of a foot. Volumes were calculated from the count of cells at each depth from the Old Charles River Dam to the BU Bridge.

Results and Analysis

Changes in area surveyed

The study area lost approximately 30% of its surface area between 1902 and 1976 due to two expansions of the Esplanade (Table 1). These expansions dredged material from the bottom of the river to fill the banks, which is the cause of the deep trench between Harvard Bridge and Longfellow Bridge. Therefore, the net change in volume due to this construction is less than would be predicted by filling alone. Intermittent dredging has occurred along the river and there have been many construction projects on the bridges spanning the study area, but there is no comprehensive estimate of changes to the volume of the river caused by humans over the last 14 years. There have been no changes in shorelines in the study area since 1949, so fractional changes in area measured between 1976 and later surveys are due to survey and digitization error, not any changes in the physical landscape. Both the 1998 and 2016 shorelines were derived from aerial imagery of the study area. The largest differences in volume and depth distribution were expected between 1902 and 1976 and the smallest differences were expected between 1998 and 2016.

Survey	Area, million square feet	Fractional change in area since previous survey
1902	24.650	
1976	17.474	-0.2911
2000	18.764	0.0738
2016	18.766	0.0001

Table 1: Shoreline changes over time: The 1902 survey shoreline included the full lengths of the Broad and Lechmere Canals and the survey was completed before the two expansions of the banks for the Esplanade. The 1976 survey shoreline excluded both canals and also excluded the section of the river under the Memorial Drive underpass at Longfellow Bridge. The 1998 survey shoreline included Lechmere Canal but not Broad Canal and the 2016 survey shoreline included both canals but did not have measurements in Broad Canal or the Esplanade pools.

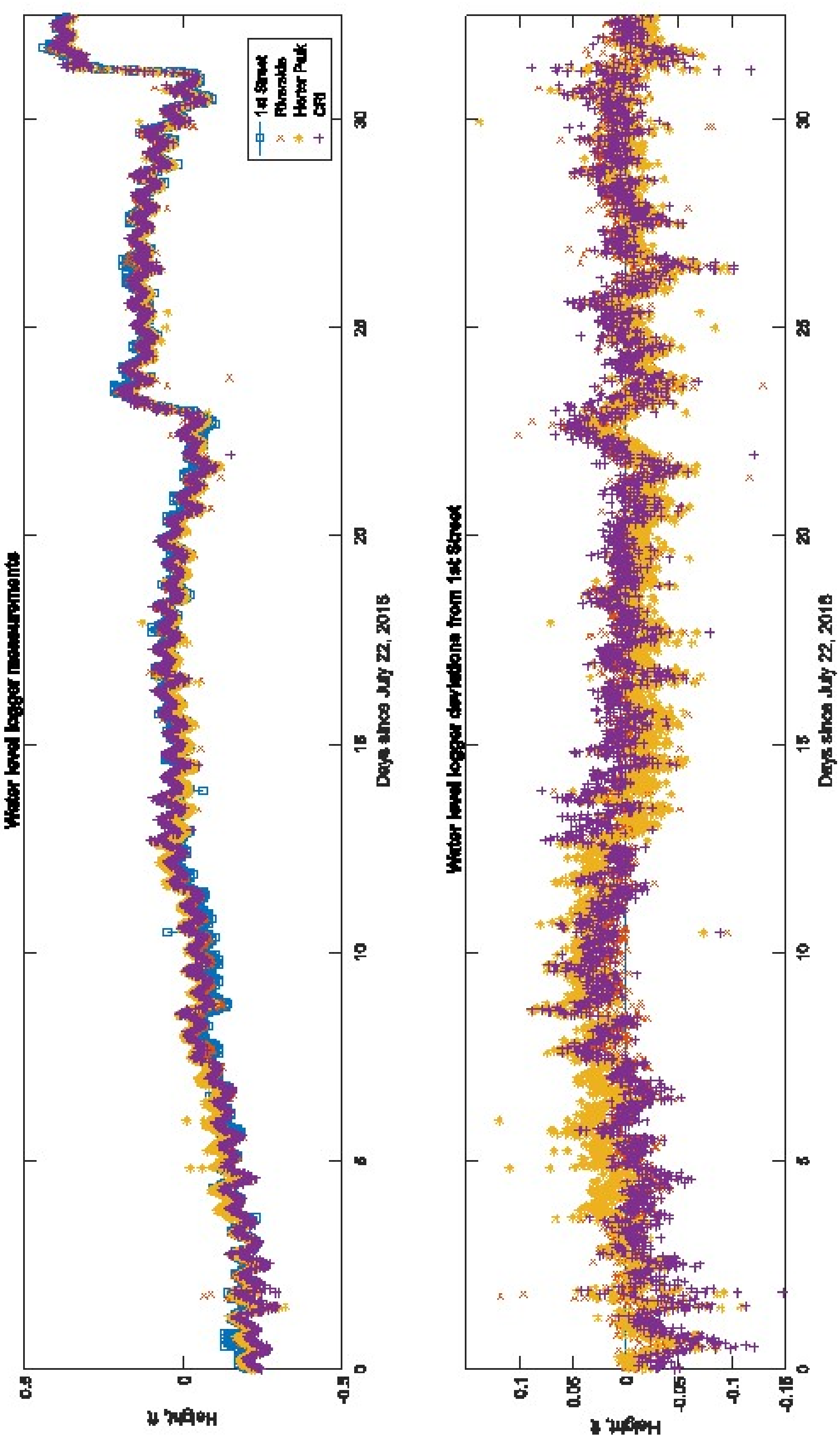
River Model Formation

Water level data from the installed loggers at Riverside, Herter, and CRI from July 22 to August 23, 2016 were analyzed and compared to the USGS gauge station at First Street. This interval was selected because it featured continuous data from First Street and represented a full month of typical data. Each point represents a 15 minute average of water height, starting on the hour. The selected water level logger data were normalized to a mean of zero to eliminate any constant offset between the time series and plotted both as normalized measurements and deviations from USGS measurements (Figure 1). Of the 3116 points for each dataset, only 0.008% of points were outside of the Lower Charles River management goal of ±0.5 feet range in water height and only 0.214% of points from the water level loggers had a deviation of greater than 0.1 feet from the USGS measurements. MATLAB's t-test was used to test the null hypothesis that the mean of each set of deviations was equal to zero and for each water level logger, and in each case the null hypothesis was not rejected at the 5% significance level (Table 2).

T-test	Null hypothesis	p-value
Riverside	Mean=0	0.9202
Herter Park	Mean=0	0.9508
CRI	Mean=0	0.9676

Table 2: T-test of deviations from First Street measurements: The mean of each set of deviations is equal to zero with high certainty. This implies that the deviations from First Street measurements are randomly distributed with no time offset.

Figure 1: Water level logger measurements and deviations from First Street



Normalized measurements and deviations from First Street from July 22 to August 23, 2016. Mild scatter is observed in the initial measurements as well as the deviations, with 0.008% of measurements lying outside the ±0.5 feet management window and 0.214% of points deviating from First Street measurements by more than ±0.1 feet. The apparent trend in the first 13 days of data is likely due to interpolation while the times of sampling were misaligned with First Street. Loggers were redeployed on August 3 with the correct alignment.

Additionally, cross-correlation between each logger and First Street was calculated for ±12 steps of lag, which corresponds to three hours of data (Figure 2). The maximum of the cross-correlation function is at zero lag for each dataset, which confirms that there is no delay at the 15-minute timescale between water heights at the First Street and water heights at CRI. Therefore, it was concluded that each water level logger showed the same measurements and that any water level logger could be used as the basis of a tide file to correct the depths measured during the survey. The water level logger at Riverside was chosen to be the reference tide height due to its central location with respect to upstream distance relative to other loggers.

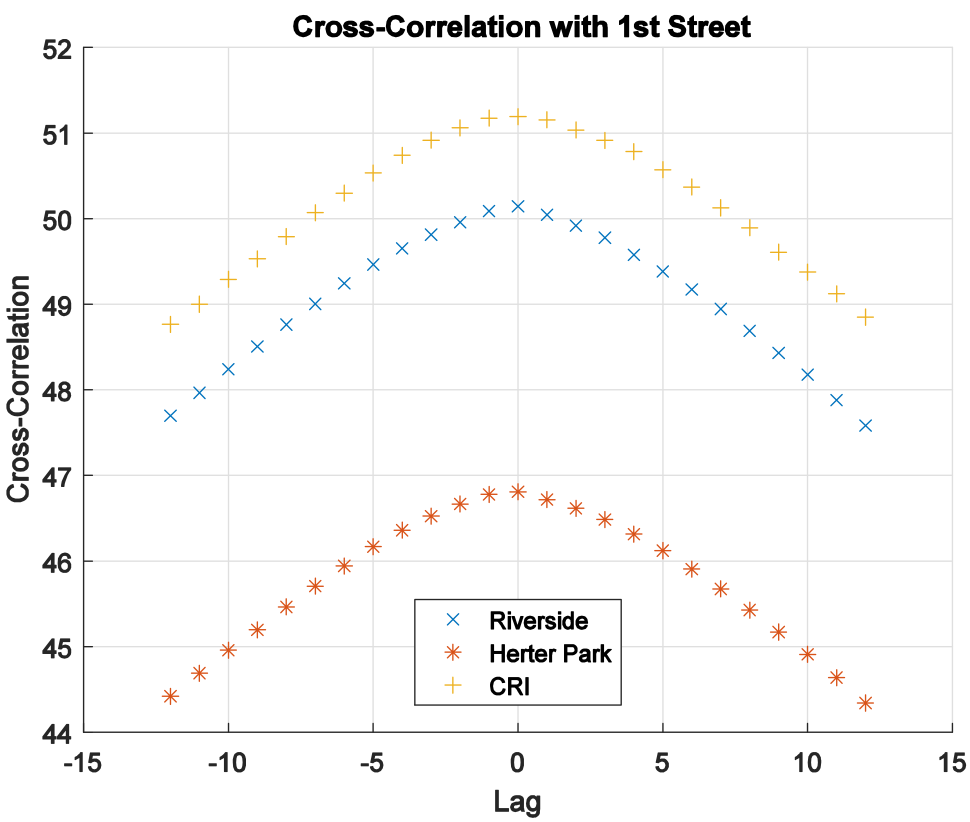


Figure 2: Cross-correlation between water level loggers and First Street: Cross-correlations have a maximum at the lag value that most closely aligns the two time-series. The maxima of the cross-correlations between each time-series and First Street are at zero lag, as predicted by the statistical tests in Table 1. Lag measures the offset in points from exactly aligned time-series. Each point is separated by 15 minutes.

Raster analysis method

Rasters produced from the contours of each survey were analyzed and used to produce cumulative frequency plots for the depth distributions of the surveys. Images of the rasters for each survey are available in Appendix 2. The rasters were discretized into depth intervals of 0.1 feet using ArcGIS' Raster Calculator tool and the number of cells at each depth were exported to text files. From this data, volumes were calculated for each survey by summing the volumes of water at each depth interval (Table 3, Figure 3). Cumulative depth frequencies were calculated for the comparative hypsogram (Figure 4) by taking the cumulative sum of the fractions of the total number of cells from shallow to deep values of depth. Each pair of cumulative frequency distributions were compared using the Kolmogorov–Smirnov test (K-S test) to quantify the similarity between each of the distributions (Table 4). The 1902 and 1976 distributions were most different (significant, α=0.05) and the 1998 and 2016 distributions were the most similar.

Survey Date	**Volume, million cubic feet (mcf)**	**Average Depth, feet**	**Estimated Error, mcf**
1902	382.8	15.6	19.1
1976	269.8	15.8	13.5
1998	273.6	14.7	13.8
2016	254.2	13.8	12.7

Table 3: Raster calculations: Volumes and average depths for the four surveys using the raster method with 0.1 foot depth increments. Estimated error is 5% of the calculated volumes.

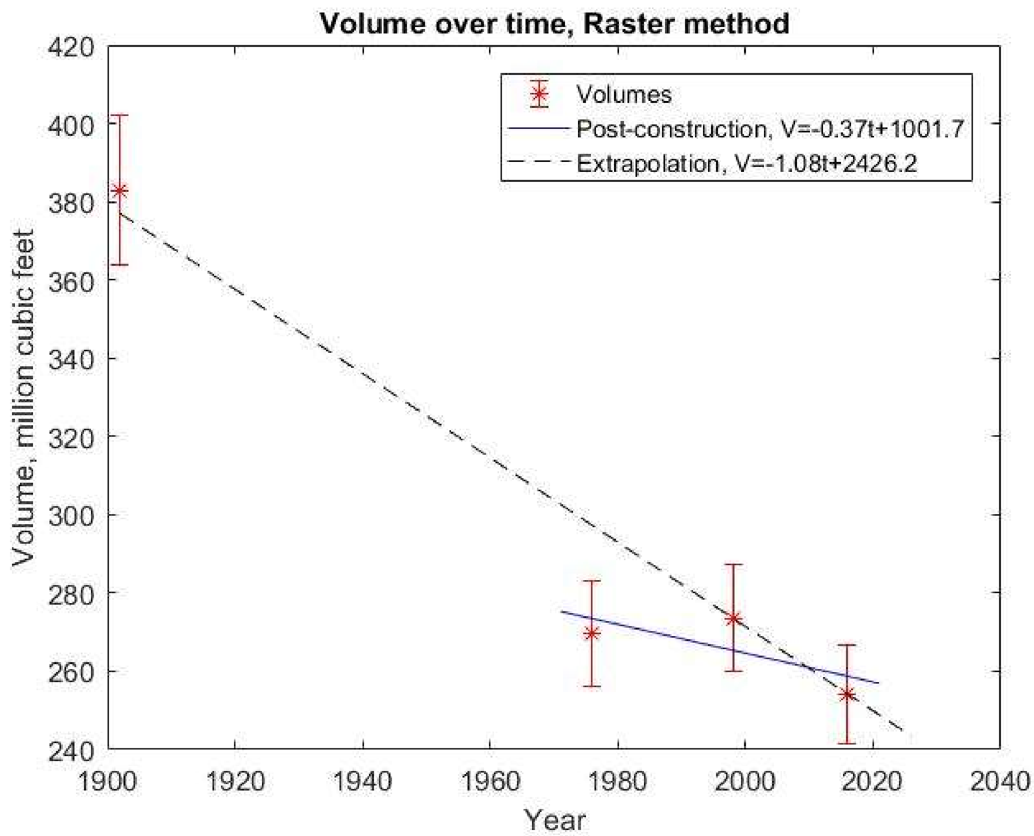


Figure 3: Volume vs. time, raster analysis: Plot of volume (Mcf) against time (years), with two fits. The blue trend line uses only the three surveys after the Esplanade islands were in their current configuration and the dashed extrapolation is a fit through the two most recent surveys. Note that the 1976 survey falls below the general trend. The two fits correspond to sedimentation rates of 6 and 18 mm/yr, respectively.

Polygon analysis method

The polygons between contour depths were also analyzed to confirm the results from the raster analysis. Images of the polygons for each survey are available in Appendix 2. Each polygon was assigned the average depth of its bounding contours and the areas of every polygon were used to compute volumes for each survey. The average depth of the bounding contours is a good approximation for the depth of the polygon when that average depth splits the polygon into two regions of equal area. For heavily smoothed depressions, this method overestimates volume because the separation of the two region is uneven, with the deeper areas occupying less space than the approximation predicts. The 1902, 1998, and 2016 surveys have sufficient contour detail to be approximated by this method but the 1976 survey is heavily smoothed. Differences in the volumes obtained for the 1976 survey were greater than the differences for the other surveys.

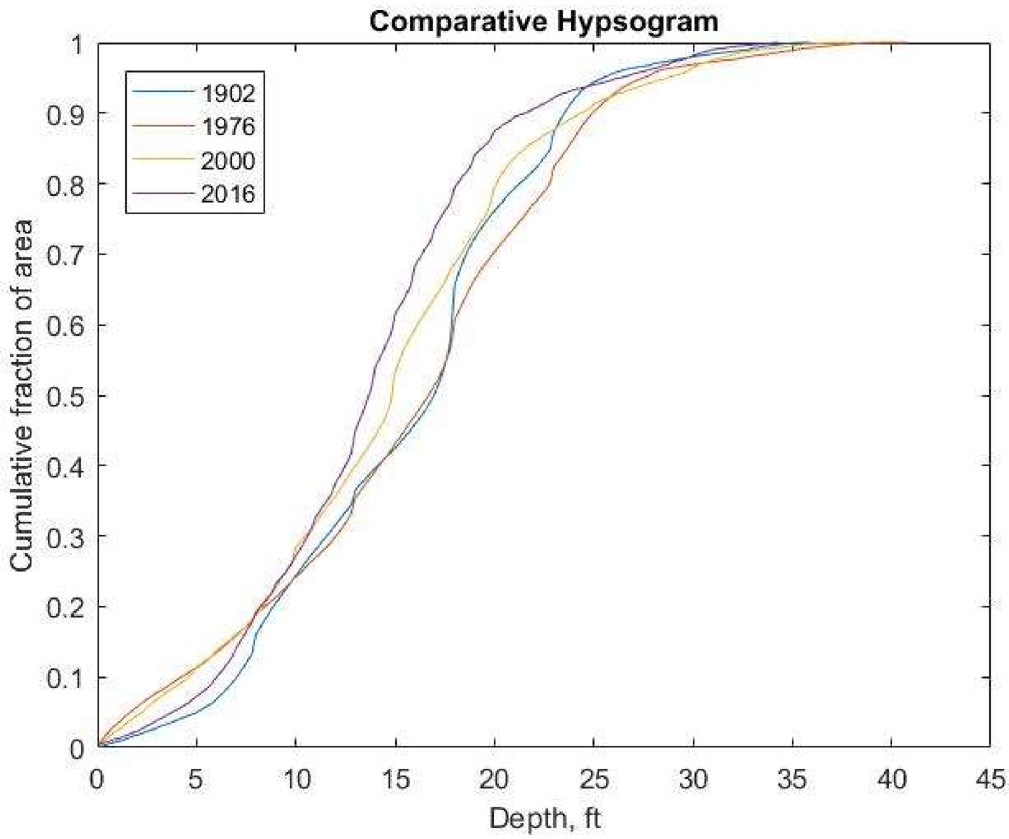


Figure 4: Cumulative depth frequency from shallow to deep: Cumulative depth frequency plot for all four surveys. Bumps in the distributions are observed at contour depths, which occur every 5 feet for historical surveys and every foot for the 2016 survey.

Comparison	Null Hypothesis	Rejected at 5% confidence	p-value
1902-1976	Same distributions	Yes	0.0258
1902-2000	Same distributions	No	0.0965
1902-2016	Same distributions	No	0.2076
1976-2000	Same distributions	No	0.1608
1976-2016	Same distributions	No	0.0653
2000-2016	Same distributions	No	0.4401

Table 4: Cumulative distribution Kolmogorov-Smirnov test results: Results of the K-S test for all six possible comparisons between the four depth distributions. The significant difference between the 1902 and 1976 depth distributions can be attributed to human construction activity that increased the deepest depth and decreased the surface area of the study area between the two surveys.

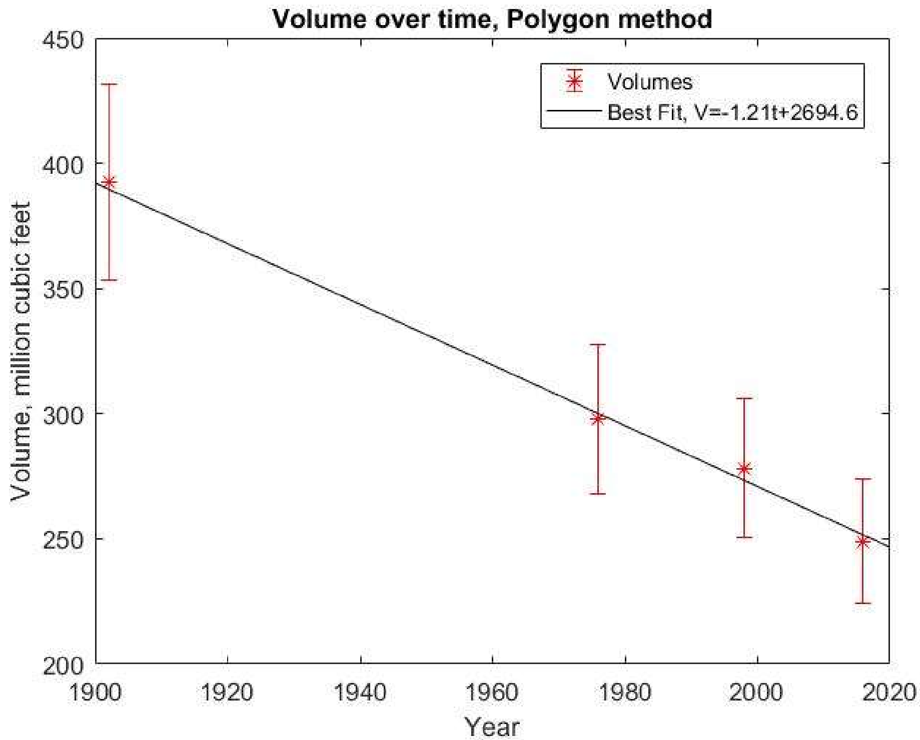


Figure 5: Volume vs. time, isobaths analysis: Plot of volume (Mcf) against time (years), with a linear trendline. Note that the 1976 survey falls very close to the overall trend in this plot but was below the trend for the raster method. This fit gives a sedimentation rate of 20 mm/yr.

Survey	Volume, mcf	V(Isobaths)-V(raster), mcf	Average depth, ft.	Estimated Error, mcf
1902	392.52	9.706	15.9236	39.2
1976	297.89	28.129	17.0470	29.8
2000	278.09	4.504	14.8205	27.8
2016	248.94	-5.254	13.2655	24.9

Table 5: Polygon Method Calculations: Polygon method results and differences from the raster method. Note that the 1976 survey volume change from the raster method is three times higher than the next highest change in volume. Estimated error is 10% of the calculated volumes.

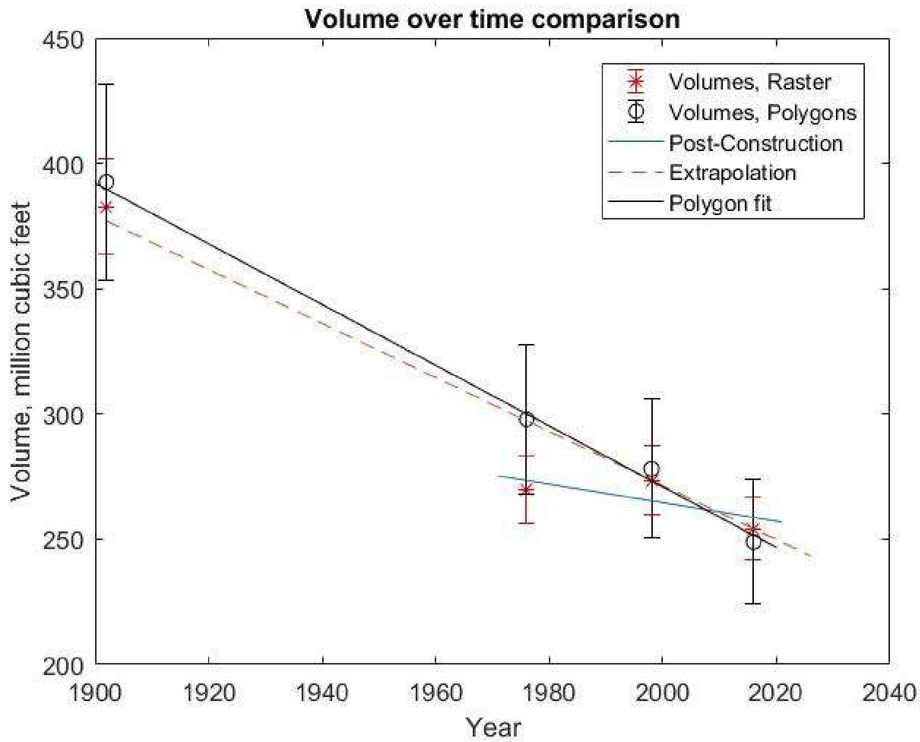


Figure 6: Comparison of methods: Polygon method volumes are greater than raster method volumes except for the 2016 survey, which had several un-surveyed areas within the shorelines that were covered by the raster. This is expected from the assumptions of the polygon method. These two methods are closely matched except for the 1976 survey, which has greater bias in the polygon method due to heavy smoothing.

Discussion

None of the surveyed configurations of the river are strictly natural, as there have been large construction, dredging, and filling projects on or near the river since the 1600s. However, the transition from the pre-1908 tidal system to the post-1908 freshwater basin with the Esplanade was particularly impactful and involved substantial changes to shorelines, maximum depths, and near-shore slopes. Since the time until the next survey included large-scale changes in the study area, the 1902 chart cannot be considered the baseline for any bulk analysis of sedimentation rates. Using the three remaining charts, a sedimentation rate of 6 mm/yr is predicted from the raster method, which would lead to an average of 2.2 feet of sedimentation between 1908 and 2016. This fit is 40% higher than the empirical measurement of an average of 1.3 feet of sedimentation by 1998 over the area from the new Charles River Dam to the

Watertown Dam (Breault et al.). However, the 1976 chart was constructed from sparse data and lacks the precision of the 1998 and 2016 charts. Extrapolation from the 1998 and 2016 raster volumes lines up with the 1902 volume and predicts a sedimentation rate of 18 mm/yr and 6.3 feet of sedimentation between 1908 and 2016, which is 400% higher than the observed average sedimentation by 1998. The polygon method predicts a sedimentation rate of 20 mm/yr and 7.1 feet of sedimentation between 1908 and 2016, which is 460% higher than the observed average sedimentation by 1998.

The average sedimentation depth measured by Breault in 1998 includes two main areas that are distinct from the current study area. The upstream area from the Watertown Dam to the BU Bridge is much shallower, narrower, and sinuous than the current study area and the downstream area between the new and old Charles River Dams is similar in depth to the study area but has had less time as a freshwater body than the study area. Sediment inputs to the Lower Charles River come predominantly from the Upper Charles River at the Watertown Dam and through the Muddy River just upstream of Harvard Bridge (Weiskel, Barlow, and Smieszek). According to the sediment thicknesses measured in 1998, the upstream portion of the river has less sediment on average than the study area and the portion of the river between the locks has similar sediment thickness to the study area (Breault et al.). These two areas contain 40% of the total area of the Lower Charles River and are light in sediment overall relative to the study area, which implies that the study area has had more than 1.3 feet of sedimentation between 1908 and 1998. Assuming that the sedimentation rate has been constant since 1908, Breault's measurements imply an average net sediment deposition of 1.6 feet over the entire Lower Charles River between 1908 and 2016.

Some specific areas in the study area have had more than the average amount of sedimentation between 1908 and 2016. For example, the quarry in front of the Harvard Sailing Pavilion was nine feet from top to bottom in the 1902 survey but was only six feet from top to bottom in the 2016 survey. Additional location-specific differences between surveys is a promising direction for future analysis. Overall, the sedimentation rate in the study area is greater than the sedimentation rate for the entire Lower Charles River and likely less than the maximum rate calculated from the fits to the volumes over time. The thoroughness of the 2016 survey has laid the groundwork for future studies of sediment deposition and distribution in the Lower Charles River.

Further work is also possible with the current set of data. Potential future analyses include extension of the study area upstream to Watertown Dam and downstream to the new Charles River Dam, production of charts detailing the differences in depth between the existing surveys, and comparison of these charts to the sediment thickness survey produced by Breault in 1998 in conjunction with the bathymetric survey (Appendix 1c). The area between the BU Bridge and Watertown Dam is very highly traveled and CRAB has documented several incidents of grounding on a sandbar and collisions due to sandbar avoidance on that portion of the river. The sandbar at Faneuil Brook was recently dredged ("Charles River Dredging - A 24 Hour Operation - Charter") and the Watertown and Newton Yacht Clubs have seen dramatic reductions in water depth since the 1902 survey, so quantified evidence of sedimentation rates and distributions in that area are of great interest to state and local organizations. Future studies could also investigate the impacts of major flood events in the Muddy River on sediment deposited in the study area as well as the rate of buildup of the Muddy River delta.

Conclusions

The Lower Charles River has been heavily used recreationally and commercially for the last several centuries, but comprehensive studies of the river are surprisingly scarce. Comprehensive histories of man-made changes to the river have been compiled recently (Haglund; Seasholes) but basic details about the geomorphology and natural changes such as sedimentation rates and depth distributions are lacking. The cumulative depth distribution of the Lower Charles River has remained approximately constant since construction ended on the Esplanade before the 1976 survey, but the construction was extensive enough that the distribution in 1976 is significantly different from the distribution in 1902. Volumes calculated through the raster and polygons methods suggest trends of sedimentation with rates between 6 and 20 mm/yr and net sedimentation of 0.8-2.6 feet since 1976 on average over the study area. If this rate is extrapolated to 1908, 2.2-7.0 feet of sedimentation is expected. The true average sedimentation rate is likely between 5 and 10 mm/yr, although further detailed surveys are needed in another 10-20 years to confirm contemporary trends.

Overall, this study has shown clear evidence for reduction in volume of the area from the old Charles River Dam to the BU Bridge since 1902. Some portion of the reduction in volume is due to the construction and expansion of the Esplanade but the recent trend in volume suggests average sedimentation rates between 5 and 10 mm/yr over the study area. Further analysis and surveys of the river are required to narrow the bounds on the modern sedimentation rate and expansion of the study area to include the remainder of the Lower Charles River is highly recommended.

Acknowledgements

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Works Cited

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