Varying Bathymetric Data Collection Methods and their Impact on Impoundment Volume and Sediment Load Calculations

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ABSTRACT

Two bathymetric datasets and various subsets for Conowingo Pond on the Lower Susquehanna River were analyzed and compared to explore the potential effects of four survey designs on impoundment volume and sediment load estimates. Collecting data at representative cross-sections and few longitudinal transects yielded similar results when compared with a more detailed, longitudinal-based approach; as such, the costs of data collection can be reduced through careful development of survey design. However, despite relatively good bathymetric accuracy, when analyzed over a large spatial scale, extrapolated levels of error provided questionable accuracy for quantification of changes to impoundment volume. The accuracy threshold identified for the Conowingo Pond surveys which were examined was ± 9.3 cm bed elevation change on average, which is the equivalent of ±2.89 million cubic meters. As such, use of impoundment-scale results should be limited to broad-scale characterization of change rather than fine-scale quantification.

INTRODUCTION

Over the past 10 years, several bathymetric surveys have been conducted by various entities on the Lower Susquehanna River in Pennsylvania and Maryland, including at Conowingo Pond. Each group used different underlying survey designs to guide field data collection. The goals of the surveys have included: (1) determining changes in bed elevation and water depth over time; (2) determining annual deposition or erosion rates; (3) examining the impact of high flow events on sediment transport within the study area; and (4) calculating sediment loads to the Chesapeake Bay. Bathymetric data were used for a variety of applications, including geospatial and geostatistical analyses; 1-D hydraulic modeling; and 3-D hydrodynamic sediment transport modeling.

Survey design is an important component for balancing accuracy and precision of results with the level of effort and cost expended. Survey designs are often tailored to specific study goals and objectives, but attempts may also be made to maintain consistency with previous surveys. Variations in survey design may yield different bathymetric surfaces from the same underlying landscape, potentially adding bias calculations pertaining to the survey goals, which could have broad implications for management (i.e., determining sediment deposition rates and outflowing loads). Here, four survey designs were compared from two datasets collected during 2014, to determine whether different survey designs introduced bias into results, or if data collection could be performed in a more efficient manner. Additionally, the applicability of impoundment volume estimates derived from bathymetric data collection was evaluated.

STUDY AREA

Conowingo Pond is impounded by Conowingo Dam, which is the most downstream dam on the Susquehanna River. The dam is situated 15.5 km from the river mouth at Chesapeake Bay, with a drainage area of approximately 70,189 km^2. The impoundment spans approximately 22.5 km in southern Pennsylvania and Northern Maryland, covering approximately 3,440 hectares.

METHODS

Two primary bathymetric datasets were incorporated into the analysis; both were collected during 2014. One was collected by Gomez and Sullivan Engineers, DPC (GSE) using a boat-mounted Sontek M9 Acoustic Doppler Current Profiler (ADCP) connected to a Real-Time Kinematic Global Positioning System (RTK-GPS). The goal of the survey was to estimate impoundment volume, such that changes in sediment storage in the impoundment could be monitored. The survey design consisted of 59 cross-sections and five longitudinal transects. Twenty-six of the cross-sections were chosen to align with previous surveys conducted by the U.S. Geological Survey (USGS) (Langland 2009), and the remaining transects were added for better coverage and to improve the survey's representativeness of the impoundment. The longitudinal transects were added to the design to provide additional coverage over thalweg areas and breaks in slope. Along the survey track, the ADCP collected measurements every second, and the boat was typically operated around 1.5-2.4 m/s. The other dataset was collected by Maryland Geological Survey (MGS) along narrowly-spaced (~125 meter) longitudinal track lines using a Knudsen 320B/P dual-frequency, single-beam echosounder and a GPS with real-time network corrections (Van Ryswick and Sylvia 2015). Bathymetric data collection was supplementary to data collection for a side scan sonar survey, with a goal of informing the selection of sediment core sample locations. At an average speed of around 2 m/s, measurements were collected approximately every 0.5 meters.

Digital terrain models (DTMs) were constructed using ArcGIS software for Conowingo Pond using bathymetric survey points and shoreline contours created from LiDAR data. DTMs were based on data from four primary survey designs (Figure 1; Table 1). The full MGS dataset, given its detail and systematic method, was used as a baseline for which all other designs were evaluated against given that the design should yield the least biased and most detailed results. Impoundment volumes were calculated assuming a pond elevation of 33.28-meters (NGVD29).

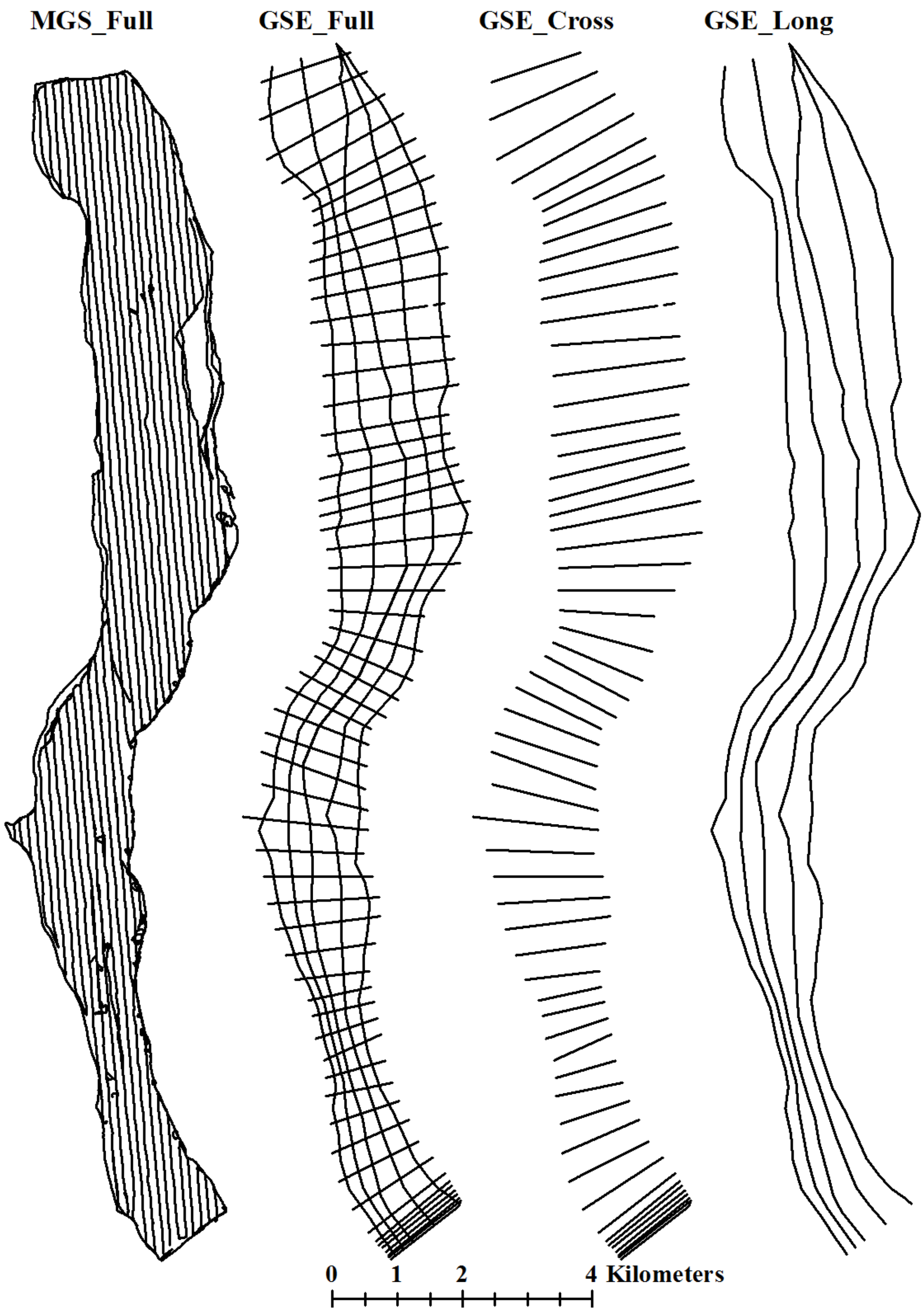

Figure 1: Track lines for four survey designs analyzed on Conowingo Pond.

Table 1: Codes and descriptions of the survey designs analyzed.

Code	Survey Design Description	Survey Track Distance (km)
MGS_Full	All data from the MGS survey, fine-scale longitudinal-based	318
GSE_Full	All cross-sections and longitudinal transects from the GSE survey.	194
GSE_Cross	Subset of data from the GSE survey at all GSE cross-sections, but no longitudinal transects	98
GSE_Long	Subset of data from the GSE survey at all GSE longitudinal transects but no cross-sections	96

The estimated accuracy of the bathymetry for the MGS dataset is listed at 0.03 m plus 1% of depth (Van Ryswick and Sylvia 2015), and the GSE dataset likely has similar accuracy given the combined accuracy of water level data plus the accuracy of the ADCP (1% of depth). As such, at an average Conowingo Pond depth of 6.24 m, the estimated accuracy in Conowingo Pond would be approximately ±9.3 cm overall, which extrapolates to ±2.89 million m^3 of impoundment volume across the survey area (3,117 ha of the impoundment). Comparisons between designs were evaluated based on these estimates of accuracy.

RESULTS

To ensure that no systematic measurement bias was present between the two datasets, points from both surveys that were within 0.5 m horizontally were examined. Of 2,524 measurement comparisons, the median difference between the post-processed elevations provided by the surveys was -0.6 cm, and the distribution around the median was relatively uniform (Figure 2); therefore, no systematic bias was observed. Differences within the 9.3 cm instrumentation accuracy were bounded by the 32.5% and 74.5% percentiles.

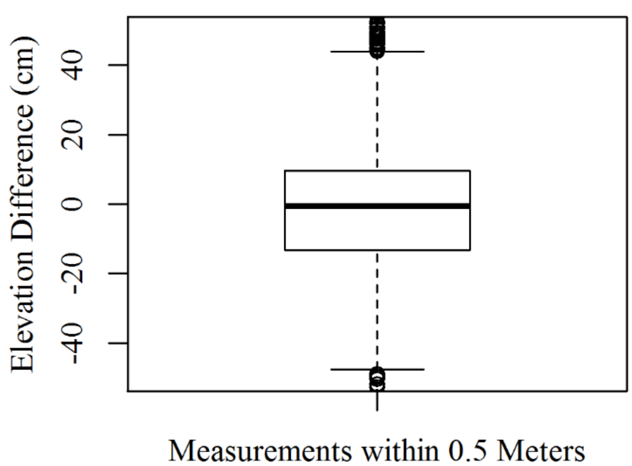

Figure 2: Comparisons of MGS and GSE elevations from nearby measurements.

Despite substantial differences in survey coverage, the impoundment volume estimated by the full MGS and full GSE designs were similar, with differences within the identified accuracy thresholds (Table 2). The GSE cross-section only design provided the highest volume estimates and the GSE longitudinal only design provided the lowest volume estimates (Table 2). Due to Conowingo Pond's large area, even small relative depth differences between the designs yielded substantial differences in the quantified variables. The accuracy threshold of ±2.89 million m^3 of impoundment volume is the equivalent of only a 1.5% difference in volume relative to the full MGS design, which had a total impoundment volume of 194.47 million m^3.

Table 2: Differences observed between results from four survey designs.

Design	Volume (m^3)	Difference from MGS_Full		
		m^3	%	Depth (cm)
MGS_Full	194,474,769	-	-	-
GSE_Full	191,856,869	-2,617,900	-1.3%	-8.4
GSE_Cross	198,294,037	3,819,268	2.0%	12.3
GSE_Long	188,739,873	-5,734,896	-2.9%	-18.4

DISCUSSION AND CONCLUSIONS

Given limited time and budget, accurate bathymetric data can be collected in Conowingo Pond, and possibly similarly-shaped impoundments, by surveying with considerably lower effort than the MGS_Full design. The cross-section-only design appeared to be slightly biased toward higher impoundment volumes, and the longitudinal only survey from the GSE design appeared to be biased low. However, when these designs were combined, that overall bias relative to the full MGS design was reduced. A closer look at the DTM for the full GSE survey used for this analysis showed anomalous peaks and valleys near the shorelines resulting from interpolation during development of the DTM. As such, the DTM for the GSE survey which was used for this analysis, given the lack of data close to the shorelines, may have benefitted from additional post-processing measures such as the addition of breaklines in GIS between cross-sections that would have minimized these interpolation errors. Alternatively, the survey design could be modified to include additional longitudinal transects near each shoreline, precluding the need for breaklines during post-processing.

Bathymetric data accuracy was an important consideration for the analyses. Even with relatively good bathymetric accuracy, when extrapolated over the large area within which these analyses were performed, potential error in impoundment volume seems relatively large in scale. To put the ±2.89 million m^3 impoundment volume error estimate into perspective, the typical storage volume of a large semi-truck trailer is approximately 108 m^3; therefore, the levels of error around the impoundment volume estimates are the equivalent of ±26,759 semi-truck trailer loads. As such, bathymetric surveys performed on a scale this large would not be suitable for precisely quantifying changes in whole-impoundment volume.

As large as these numbers appear to be, they were based on accuracy of the bathymetric measurements reported by MGS (Van Ryswick and Sylvia 2015). The reported accuracy of 0.03 m plus 1% of water depth was likely based on the accuracy of the instrumentation used to collect the data. In the case of bathymetry, this is often calculated by adding the potential error of both the depth and water surface elevation measurements that were used to calculate bathymetric elevations. Extrapolating only measurement error to an impoundment-level scale is an over-simplification, given that not all error will be evenly distributed over the span of the survey. Elevations of points from nearly the same location compared between the surveys, despite showing no systematic bias, often differed over a wider range than expected. There are many other factors such as obstructions, signal interference, or wave action that can affect bathymetric readings. On the design scale, even slight deviations in the survey track due to variations in boat navigation could yield different results given attempted replication of the survey; precision on the impoundment-scale is not likely to be high due to sampling limitations. Additionally, interpolation of bathymetric measurements to develop DTMs also introduces error. Therefore, the seemingly large levels of potential variability reported here could be underestimates of the overall level of error.

In conclusion, the use of large-scale bathymetric surveys in relation to characterizing impoundment volume should be restricted to identifying large-scale or long-term changes (i.e., changes that exceed the accuracy threshold of the survey) rather than attempted quantification of fine-scale volume changes.

REFERENCES

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