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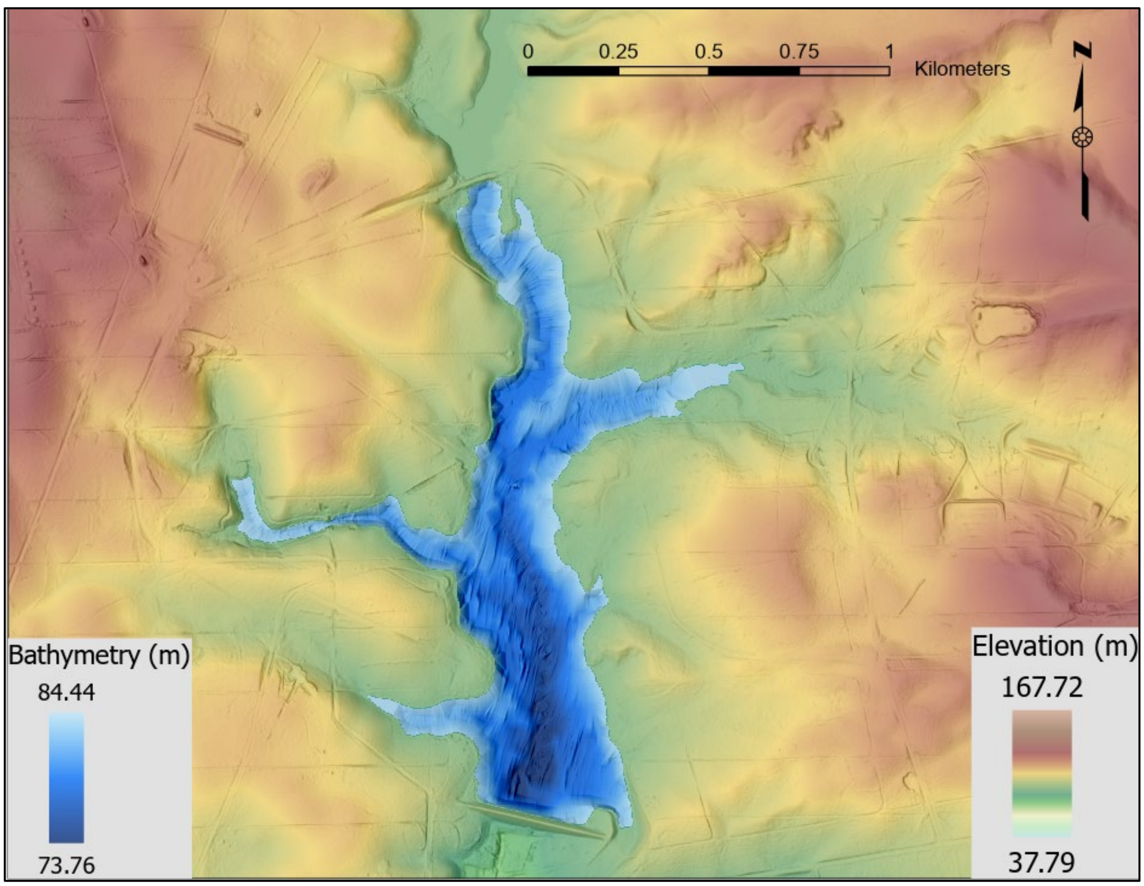
Application of Limited-Field-Data Methods in Reservoir Volume Estimation

A Case Study

Daniel Vandevort, Chandler Engel, Shaun Stanton, and Jeffrey Ellis

March 2024



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Application of Limited-Field-Data Methods in Reservoir Volume Estimation

A Case Study

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Abstract

The conventional approach to estimating lake or reservoir water volumes hinges on field data collection; however, volume estimation methods are available that use little or no field data. Two such methods—the simplified *V-A-h* (volume-area-height) and the power function—were applied to a set of six anthropogenic reservoirs on the Fort Jackson, South Carolina, installation and checked against a validation data set. Additionally, seven interpolation methods were compared for differences in total volume estimation based on sonar data collected at each reservoir. The simplified *V-A-h* method overestimated reservoir volume more than each technique in the power function method, and the categorical technique underestimated the most reservoir volumes of all three techniques. Each method demonstrates high V_{err} variability among reservoirs, and V_{err} for the Power Function techniques applied here is consistent with that found in previous research in that it is near or less than 30%. Compared with V_{err} in other studies evaluating the simplified *V-A-h* method, V_{err} in this study was found to be 10%–20% higher.

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Preface

This study was conducted for the US Army Corps of Engineers (USACE) under FWIC 8FF088, “Application of Limited-Field-Data Methods in Reservoir Volume Estimation.”

The work was performed by the Force Projection and Sustainment Branch of the Research and Engineering division, US Army Engineer Research and Development Center–Cold Regions Research and Engineering Laboratory (ERDC-CRREL). At the time of publication, Dr. Orian Z. Welling was branch chief; and Dr. John W. Weatherly was acting division chief. The work was also performed by the Terrain and Ice Engineering Group of the Remote Sensing / GIS Center of Expertise, ERDC-CRREL. At the time of publication, Dr. Meghan C. L. Quinn was group lead; and Mr. David C. Finnegan was center director. The acting deputy director of ERDC-CRREL was Ms. Kelly Swiderski, and the acting director was Dr. Ivan P. Beckman. The work was also performed by the Geotechnical Engineering and Geosciences and Structural Engineering branches of the Geosciences and Structures division, ERDC Geotechnical and Structures Laboratory (GSL). At the time of publication, Mr. Christopher Price and Ms. Mariely Majias-Santiago were branch chiefs, respectively; and Mr. James Davis was division chief. The deputy director of ERDC-GSL was Mr. Charles Ertle II, and the director was Mr. Bartley P. Durst.

COL Christian Patterson was commander of ERDC, and Dr. David W. Pittman was the director.

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1 Introduction

1.1 Background

Determining volumes of surface water stored in reservoirs, lakes, and ponds is an important component of water management. Typically, volumes are calculated by first measuring the geometry of the bed of the water body, and then recording water elevations to determine volume. With recent advances in remote sensing technology, determining accurate surface water volumes with little or no field measurements is becoming more realistic. In fact, remotely sensed data collection techniques leading to accurate volume calculations on the oceanic scale have been in place for many years (Alsdorf et al. 2007; Munk 2000). Utilizing the same or similar remote sensing technology, recent work was done to estimate water volumes of natural surface features such as prarie potholes in North America (Minke et al. 2010), alpine lakes in the Tibetan Plateu (Liu and Song 2022), zoogenic features such as beaver ponds in North and South America (Karran et al. 2017) and anthropogenic reservoirs in India (Vanthof and Kelly 2019). Each of these studies has presented methodologies to calculate surface water volumes with both minimal field measurements and no field measurements. This paper recounts the application of two of these methods (Karran et al. 2017; Vanthof and Kelly 2019) on six reservoirs of varying sizes on the Fort Jackson Military Reservation in the southeast United States. Additionally, we discuss the application of different surface interpolation techniques as they apply to volume estimation.

The Installation Management Command (IMCOM) is responsible for the operation and maintenance of over 200 dams and their associated reservoirs located on Army installations (ADTIP 2022). The IMCOM has an interest in estimating the volume of reservoirs for a number of reasons including inventory management, water supply availability, and flood risk mitigation. From an inventory management perspective, per public law, structures impounding a reservoir are considered a dam and managed as such if the volume of impoundment is greater than 50 acre-ft and more than 6 ft in height or the height of the structure is greater than 25 ft and the storage is at least 15 acre-ft (The National Dam Inspection act of 1972; US Army 2008).* Some installations manage reservoirs for water supply purposes, including as a source for potable water distribution or for fire suppression. Installations manage dams and reservoirs to both provide flood risk reduction, by temporarily storing flood water and to avoid damage to the structures from extreme storm events. In all of these cases, it is critical to know the total safe storage volume of a dam, and in many cases also the current storage volume. Traditional volume estimates depend on accurate bathymetric data collection and measurements of the water surface elevation. This study aims to investigate the use of improved surface reservoir volume estimation techniques based on remote sensing to improve situational awareness of water storage and reservoir capacity across the IMCOM dam portfolio.

1.2 Objectives

The objectives of this research are to (1) evaluate the application of known remote-sensing-based volume estimation techniques to a sample data set of six reservoirs in the southeast United States and (2) discuss the effect of different bathymetric surface interpolation techniques as they relate to water volume estimation.

1.3 Approach

We evaluated the performance of two limited-field-data volume estimation techniques against the known volumes of six reservoirs derived from sonar surveys. Different base surfaces were developed using seven different surface interpolation techniques available in geospatial software and we compared the subsequent volumes against the two volume estimation methods from the literature (Karran et al. 2017; Vanthof and Kelly 2019). We also discuss the interpolation aspects of the surface creation techniques and their performance in creating a usable base surface for volume estimation in reservoirs.

* For a full list of the spelled-out forms of the units of measure used in this document and their conversions, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52 and 345–47, https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf.

1.4 Reservoir Sample Set Characteristics

The six anthropogenic reservoirs which were used to evaluate the volume estimation techniques are located on the Fort Jackson Military Reservation in the southeast United States (Figure 1 and Figure 2*A*–*E*). Each dam is an earthen embankment dam, and reservoir spatial proximity ranges from almost 17 km between the two farthest apart to less than 20 m between the closest. Further characteristics are in Table 1.

Table 1. Reservoir characteristics and locations.

Reservoir	Coordinates	Terrain	Max Surface Area (m^2)	Max Volume (m^3)	Avg. Depth (m)	Max Depth (m)
Upper Legion	80°55′50″ W 34°0′1″ N	Low-relief hills bordering Atlantic coastal plain	5.5×10^4	1.12×10^5	2.3	4.1
Lower Legion	80°55′51″ W 33°59′54″ N		1.9×10^4	3.9×10^4	1.7	3.55
Upper Davis	80°45′2″ W 34°2′12″ N		1.0×10^5	1.01×10^5	2.5	3.8
Messers	80°47′15″ W 34°4′17″ N		2.9×10^5	3.4×10^5	1.2	3.14
Dupree	80°48′42″ W 34°5′33″ N		2.2×10^5	3.2×10^5	2.4	4.6
Weston	80°49′51″ W 34°0′17″ N		8.3×10^5	3.8×10^6	6.6	12.4
—	—	—	—	**Mean (all):**	**2.8**	**5.3**

Figure 1. Case study reservoir set on Fort Jackson Military Reservation. Six Reservoir set, Fort Jackson, South Carolina (powered by Esri).

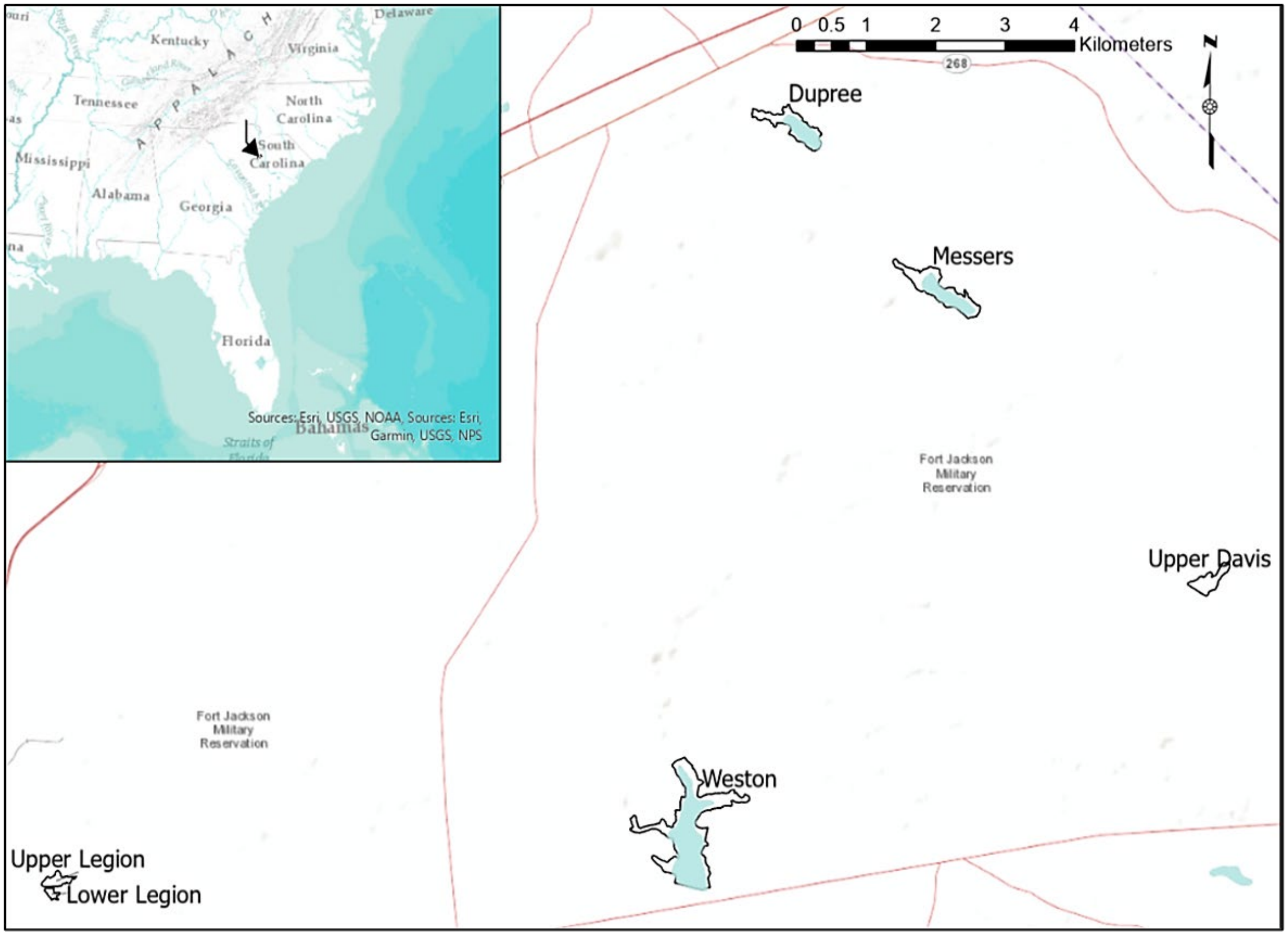
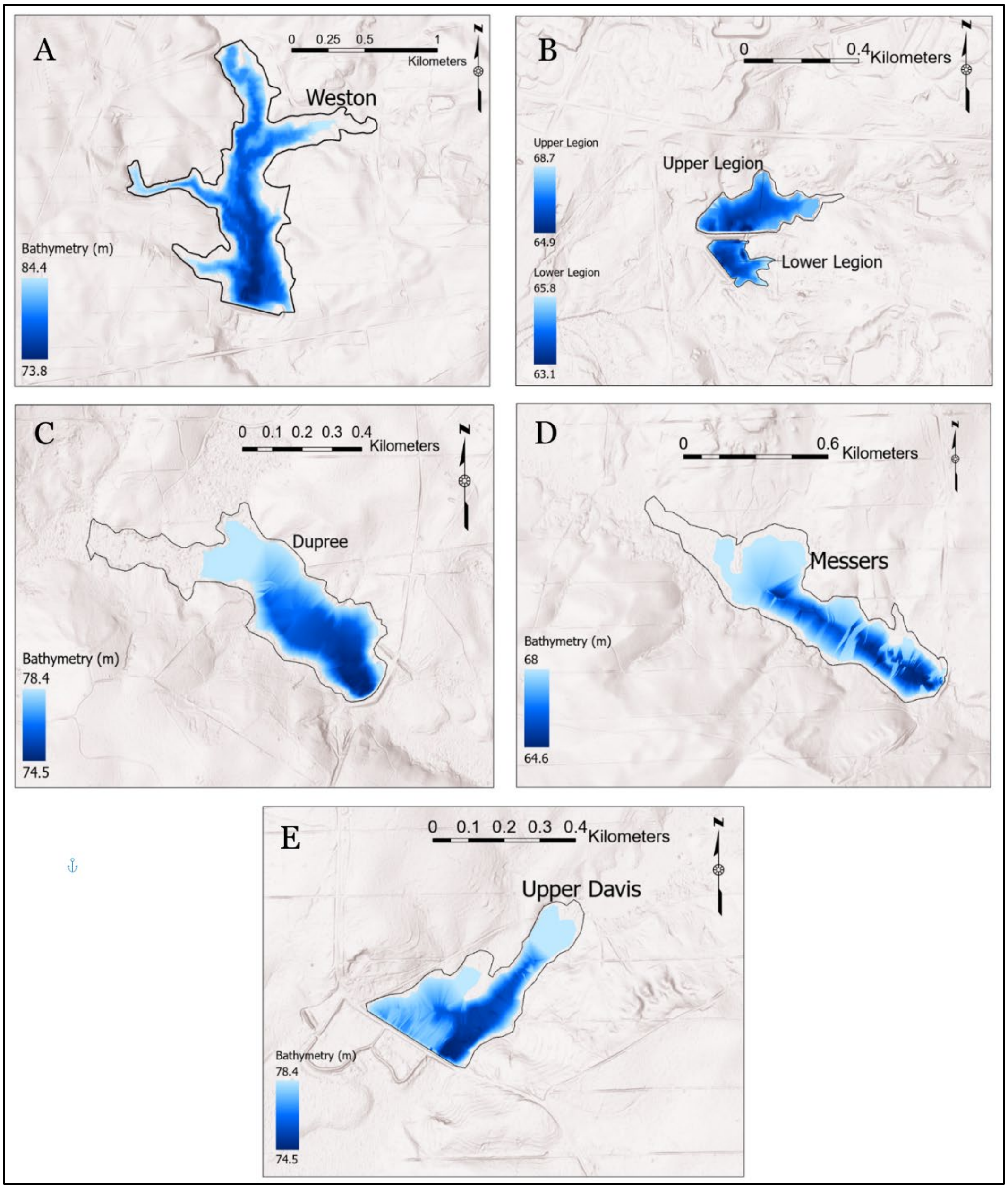


Figure 2. Symbolized reservoirs (*A–E*) on 1 m digital elevation model (DEM). *Black outline* around each reservoir represents maximum water surface area at maximum dam height. Terrain exaggerated by a factor of two.



2 Application of Limited Field Data Methods

2.1 Simplified *V-A-h* (Volume-Area-Height) Method

Karran et al. (2017) and Minke et al. (2010) developed their methodologies based on the formulas presented by Hayashi and van der Kamp (2000) as the simplified *V-A-h* (volume-area-height) method for determining area (A) and volume (V) for wetland ponds

$$A = \left(\frac{h}{h_o}\right)^{2/p} \tag{1}$$

and

$$V = \frac{s}{\left(1+\frac{2}{p}\right)} \times \frac{h^{1+(2/p)}}{h_o^{2/p}}, \tag{2}$$

where h is the height of the water above the lowest point in the reservoir, h_o is unit height of the water (e.g., h_o = 1 m), and the s and p coefficients describe the reservoir environment. Minke et al. (2010) defines s as ". . . the actual area of the wetland when water depth is equal to the unit depth ($h = h_o$)," and p as "a power coefficient that represents the wetland as a symmetrical, concave depression." Subsequently, s can be calculated from

$$s = A_1 \left(\frac{h_1}{h_0}\right)^{-2/p} \tag{3}$$

and p from

$$p = 2\left(\frac{\log(h_1/h_2)}{\log(A_1/A_2)}\right), \tag{4}$$

where h_1 and h_2 are arbitrary depths at which their respective areas (A_1 and A_2) are measured (Minke et al. 2010). It should be highlighted that any h_i is measured from the lowest point in the reservoir and that $h_1 < h_2$. In this case study h_1 and h_2 can be represented as percentages of the maximum dam height (h_{max}) of each reservoir if the dam height is defined as the distance between the lowest elevation in the reservoir and the crest of the dam. In their application of limited field data volume estimation techniques to evaluate surface water storage in beaver ponds, Karran et al. determined that ". . . fairly accurate estimates of surface-water storage. . ." are possible when h_1 is between 18%–74% of h_{max} and

h_2 is between 42%–98% of h_{max} (2017). Therefore, we chose arbitrary values of h_1 = 30% and h_2 = 60% of h_{max} for each reservoir in this evaluation. Table 2 lists the different h values, areas, and subsequent s and p values for each reservoir. Areas at depths h_1 and h_2 were obtained by calculating polygon geometry for the relevant polygons extracted from surface contours created for each reservoir in ArcGIS Pro 3.1.

Table 2. Depths (h), areas (A), and defining coefficients (s and p).

Reservoir	h_{max} (m)	h_1 (m)	h_2 (m)	A_1 (m²)	A_2 (m²)	p	s
Upper Legion	4.1	1.23	2.46	7,610	43,956	0.94	5,321
Lower Legion	3.6	1.08	2.16	1,165	16,345	0.71	1,782
Upper Davis	3.8	1.14	2.28	4,769	23,082	0.82	3,503
Messers	3.14	0.94	1.88	47,208	90,009	1.51	4,1805
Dupree	4.6	1.38	2.76	33,961	73,905	1.42	17,609
Weston	12.4	3.72	7.44	75,105	387,283	0.99	6,601

For calculation of maximum surface water volume, Karran et al. also recommended using their median p coefficient (p = 0.91) in

$$V_{max} = \frac{A_{max} \times h_{max}}{1+2/p}, \tag{5}$$

only when dam heights are available (2017).

2.2 Power Function Method

In their investigation of surface water storage in small anthropogenic reservoirs in southern India, Vanthof and Kelly (2019) used a simple power function to describe the V-A (volume-area) relationship for three models; a model specific to individual reservoirs, a categorical model based on area, and a general model for all reservoirs in their study. The idea was that for a ". . . geomorphologically homogeneous region. . ." the expression

$$V = aA^b, \tag{6}$$

where a is a scaling coefficient and b is an exponential growth rate indicator, could "calibrate" V and A (Vanthof and Kelly 2019). In this case study, we apply the a and b parameters developed for Vanthof and Kelly's categorical—where reservoirs were grouped into four size categories based on increasing water surface area—and general models in a plug-and-play style to evaluate their efficacy in this set of anthropogenic reservoirs. Each reservoir's size category at maximum dam height and associated parameters are given in Table 3. The *a* and *b* parameters for the general model are 0.00871 and 1.4, respectively (Vanthof and Kelly 2019). Similar parameters for *a* and *b* were also identified for a reservoir in Ghana (Liebe et al. 2005).

Table 3. Reservoir size category and parameters at maximum dam height.

Reservoir	Size Category[a]	*a*	*b*
Upper Legion	1	0.00277	1.5
Lower Legion	1	0.00277	1.5
Upper Davis	2	0.00599	1.4
Messers	3	0.00734	1.4
Dupree	3	0.00734	1.4
Weston	4	0.01116	1.3

[a]Calculated using data from Table 5 in Vanthof and Kelly (2019).

As with the application of the simplified *V-A-h* method, the baseline areas and volumes at specific dam heights were derived by extracting geometry from surface contours based on sonar surveys. Systematic *a* and *b* parameters were applied to each reservoir according to their area at a given dam height.

2.3 Method Comparison

For each reservoir, field bathymetry values from sonar were used to interpolate surfaces of the reservoir bottom. Between these surfaces and polygons of set heights representing the maximum inundation extents before water would theoretically overtop the dam, surface water volumes were computed (Table 1). These volumes functioned as baseline reference volumes to which each applied method was compared. This same process was used to generate reference volumes where methods were compared at different values of h_{max}. For each reservoir, each model of the power function method (*Gen* [general] and *Cat* [categorical]) was compared with the simplified *V-A-h* method based on calculated *s* and *p* values (*calc-p*). The comparisons were made at 1 m intervals from the lowest point in each reservoir to h_{max} and were based on the difference in volume between the estimation techniques and baseline volumes from the sonar survey (Figure 3*A*–*F*). Since Equation 5 is only applicable for estimating maximum storage capacity, it was compared with each method separately based on the difference in volume from the baseline volumes as a percentage (Figure 4).

Figure 3. Power function methods (*Gen* [general] and *Cat* [categorical]) and the simplified *V-A-h* method (*calc-p*) for the Upper Legion (*A*), Lower Legion (*B*), Upper Davis (*C*), Messers (*D*), Dupree (*E*), and Weston (*F*) reservoirs.

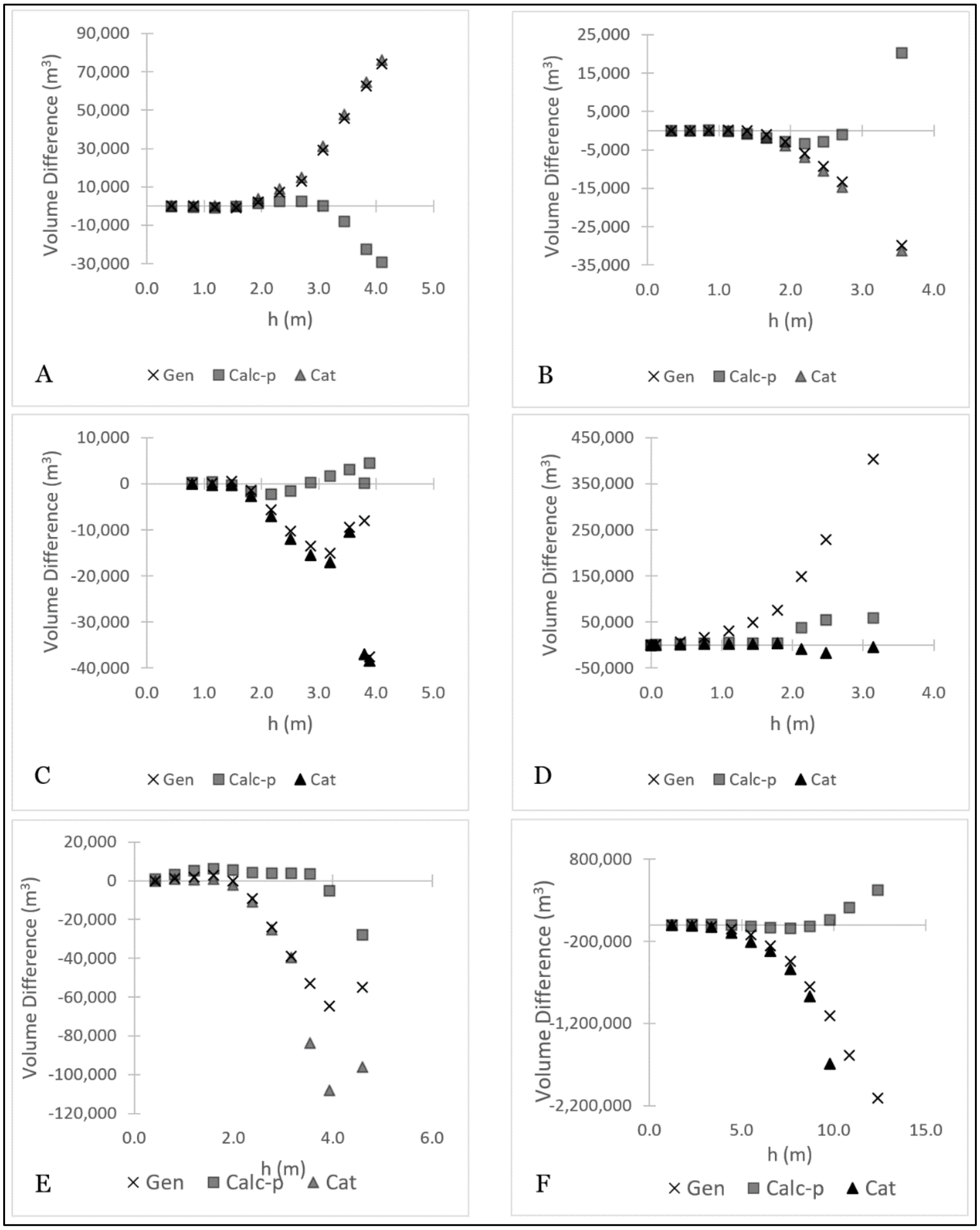
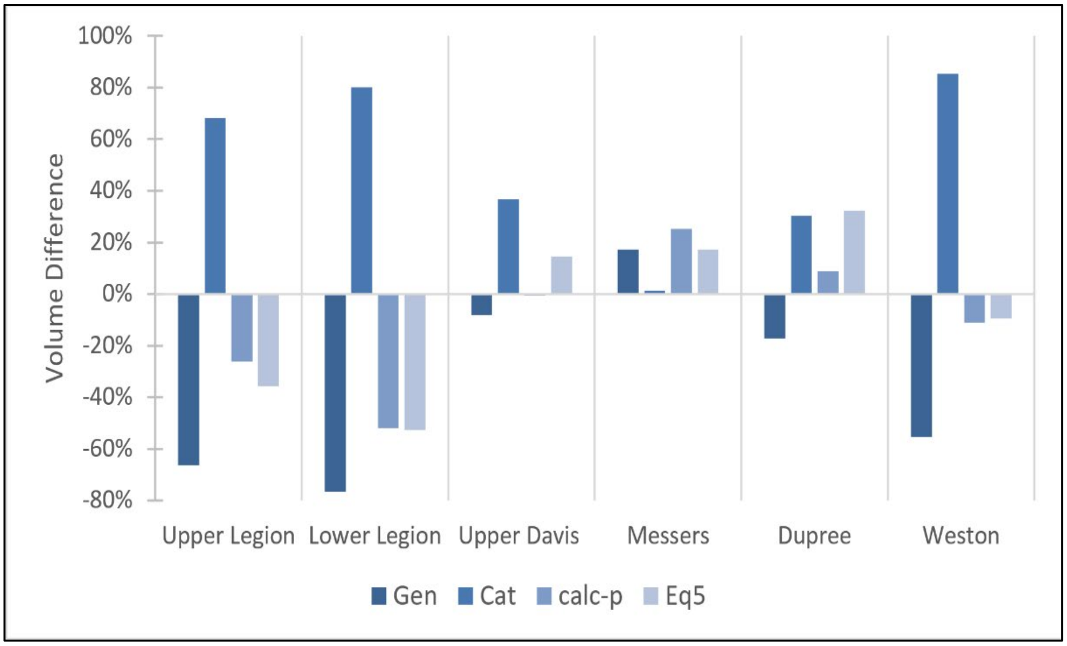


Figure 4. Volume differences by method at maximum dam height (h_{max}).



In a similar manner as previous studies (e.g., Minke et al. 2010; Karran et al. 2017; Vanthof and Kelly 2019), volume estimation technique accuracy was characterized by a normalized root-mean-squared error (RMSE) process. First the RMSE was calculated at 1 m depths intervals for each estimation method (except for Equation 5) in each reservoir according to

$$RMSE = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(V_{base} - V_{est})^2}, \tag{7}$$

where m is the number of samples, V_{base} is the baseline volume derived from the sonar survey and V_{est} is the estimated volume. Next, the volume error (V_{err}) was determined by dividing the RMSE by the maximum baseline volume for each reservoir so that cross comparison could be made regardless of reservoir size (Figure 5).

Figure 5. V_{err} by estimation technique for each reservoir. *Gen* and *Cat* are power function methods and *calc-p* is the simplified *V-A-h* method.

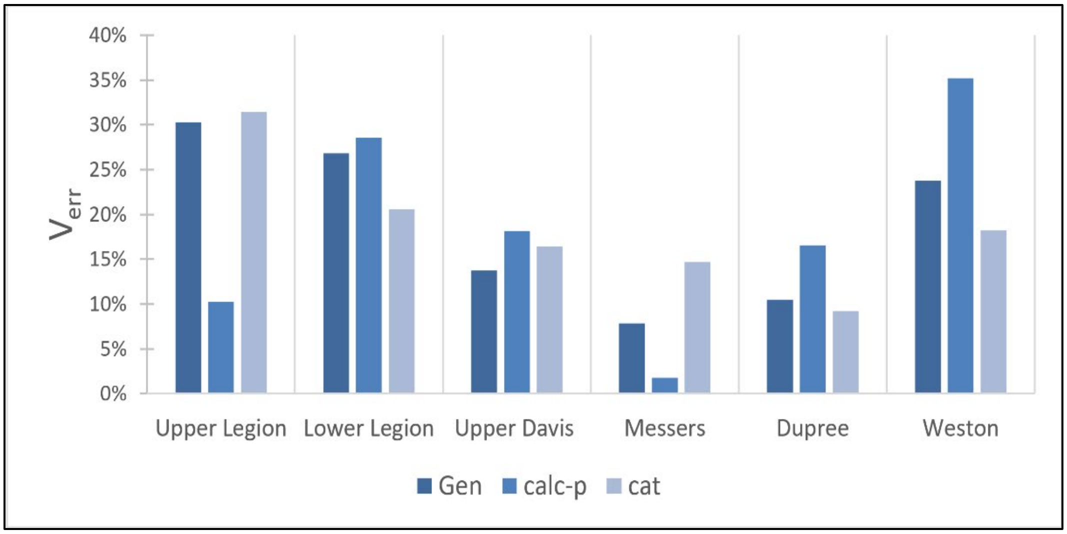


Table 4 shows the trends in over- or underestimation of water storage volume for each reservoir by estimation technique for increasing water surface areas approaching maximum *h*. It suggests that methodological over or underestimation is not correlated with water surface area size. The simplified *V-A-h* method (*calc-p*) overestimated reservoir volume more than each technique in the power function method, and the categorical (*cat*) technique underestimated the most reservoir volumes of all three techniques (Table 4).

Table 4. Volume under (*red downward arrow*) or overestimation (*green upward arrow*) trends close to maximum *h*.

Reservoir	Max surface area (m^2)	*Gen*	*Cat*	*Calc-p*
Lower Legion	19,929	↓	↓	↓
Upper Legion	54,806	↑	↑	↓
Upper Davis	104,414	↓	↓	↑
Dupree	219,643	↓	↓	↓
Messers	298,745	↑	↓	↑
Weston	832,254	↓	↓	↑

3 Discussion of Applied Methods

Each method demonstrates high V_{err} variability among reservoirs, and V_{err} for the *Gen* and *Cat* techniques applied here is consistent with that found by Vanthof and Kelly (2019), in that it is near or less than 30%. Compared with V_{err} in other studies evaluating the simplified *V-A-h* method (Karran et al. 2017; Minke et al. 2010), V_{err} in this study typically was found to be 10%–20% higher. Two features of this study which may contribute to this difference are the greater mean average and maximum depths of individual reservoirs and the fact that the total data set (six reservoirs) was relatively small (Table 1).

Estimation techniques from both methods are similar in that they present a general method for estimating surface water volume as well as more nuanced approaches developed from iterative research. One difference is the eligibility of each method's general formula (e.g., Equation 5, and *Gen*) in estimating volumes other than the maximum. Where Karran et al. (2017) limits their general method (Equation 5) to estimation of maximum surface water storage only, Vanthof and Kelly (2019) indicate their general method is best used at fractions of the total dam height, and the dam heights in their study where limited to 3 m. Greater magnitudes of volume differences as the dam height approaches maximum in this study (Figure 3) are consistent with their observation, so it is possible that new a and b parameters may need to be developed for deeper reservoirs. A performance difference is the method divergence of estimated volume differences. Figure 3 (especially *A*, *B*, and *F*) shows that the volume differences of the simplified *V-A-h* method (*calc-p*) diverge from those of the power function method with increasing dam heights (h). The divergence may be related to the sensitivity of the simplified *V-A-h* method to reservoir morphometry whereas the power function may not be as sensitive. Karran et al. notes that the success of the simplified *V-A-h* method is largely dependent on finding the "optimal points" for h_1 and h_2 (2017); however, this application was intended to be a plug-and-play style simulating the method's use on arbitrary water bodies under the literature recommendations (Karran et al. 2017). In half of reservoirs in this study, the performance of the power function methods and simplified *V-A-h* method were relatively similar (Lower Legion, Upper Davis, and Dupree) which suggests these methods can potentially be used in estimating water storage capacity of similar reservoirs.

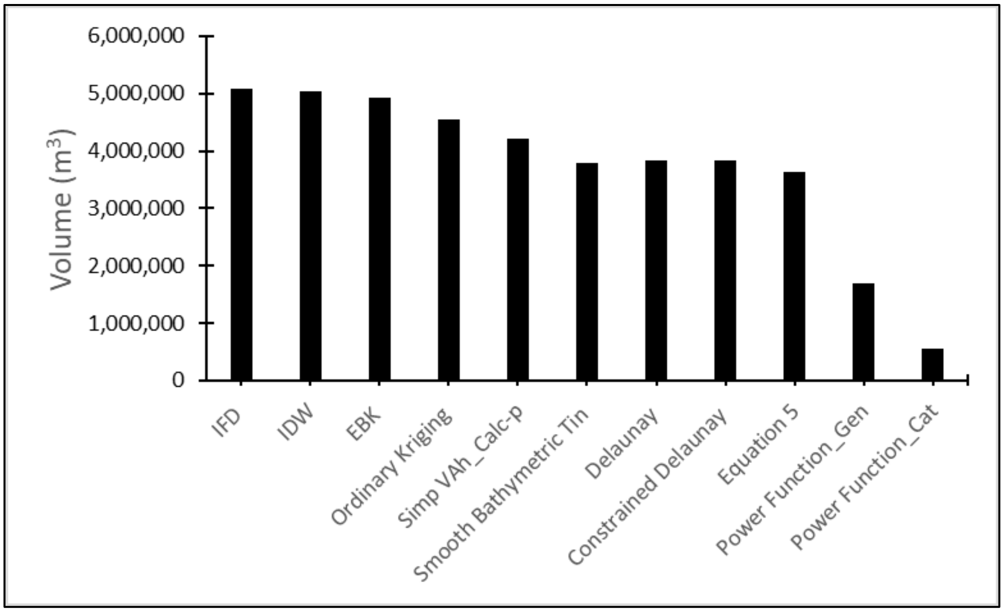
An aspect of variability common to this study as well as other studies (Young et al. 2017; Sawunyama et al. 2006; Annor et al. 2009) is the difficulty in precisely delineating reservoir water surface area extent due to dense surrounding vegetation. From a remote sensing standpoint, dense vegetation may interfere with satellite remote sensing of surface area boundaries, and from a field data collection standpoint, it may also interfere with surface area boundary delineation because operating watercraft or even walking on foot around boundaries may be difficult or time consuming. Additionally, dense vegetation or mild elevation changes in the landscape may limit the use of techniques that interpolate lake bathymetry based on the extension of the surrounding topography (e.g., Liu and Song 2022).

One final aspect of consideration is the effect of reservoir sedimentation on the parameters for the simplified *V-A-h* method and those of the power function method. In other studies where the power function and simplified *V-A-h* were used to estimate surface water volumes, the water bodies were either not reservoir-type (Minke et al. 2010) or were shallow and seasonally transient (Karran et al. 2017; Vanthof and Kelly 2019) limiting the possibility for significant sediment buildup. Some studies in Africa developed power functions for water volume estimation for specific regions (Annor et al. 2005; Damalie et al. 2008), and in the former study sedimentation was considered in their model development. However, their analysis determined that the effects of sedimentation could be "marginalized" due to an assumption of minimal sedimentation level change over a five year period and local small-scale dredging of sediment in the reservoir (Annor et al. 2005).

4 Review of Surface Interpolation Methods

In this section, we discuss surface interpolation methods that can be used to generate predicted reservoir bed surfaces and how they relate to subsequent volumes. The fundamental idea of surface interpolation is geospatial similarity—the closer to objects or events are to each other, the more similarities they share. For example, if it is snowing on one side of the street, predictions can be made with high confidence that it is snowing on the other side too. However, confidence decreases for the prediction of snowfall on, for example, the other side of town. Subsequently, samples with high spatial proximity are more likely to be similar than those farther apart. Here, some reservoirs were much closer than others (e.g., Upper and Lower Legion ponds compared to Dupree Pond). The data sources for each reservoir bottom surface were georeferenced sonar survey points with high spatial proximity (Figure 2). Two types of surfaces were used as the foundations for volume estimation; raster based and Triangulated Irregular Network (TIN) based. In the former, four types of geostatistical prediction methods were used to generate raster surfaces from which volumes were computed. Three types of TIN creation methods were also executed, and the same tool was used to compute their subsequent volumes—the surface volume tool in ArcGIS Pro 3.1. In Figure 6, the maximum reservoir volumes computed from both types of surfaces are compared to those estimated with both methods discussed in Section 2 (e.g., the *Gen* and *Cat* techniques of the power function method and Equation 5 and *calc-p* of the simplified *V-A-h* method).

Figure 6. Maximum volume comparison for representative reservoir (Weston).



4.1 Raster Based

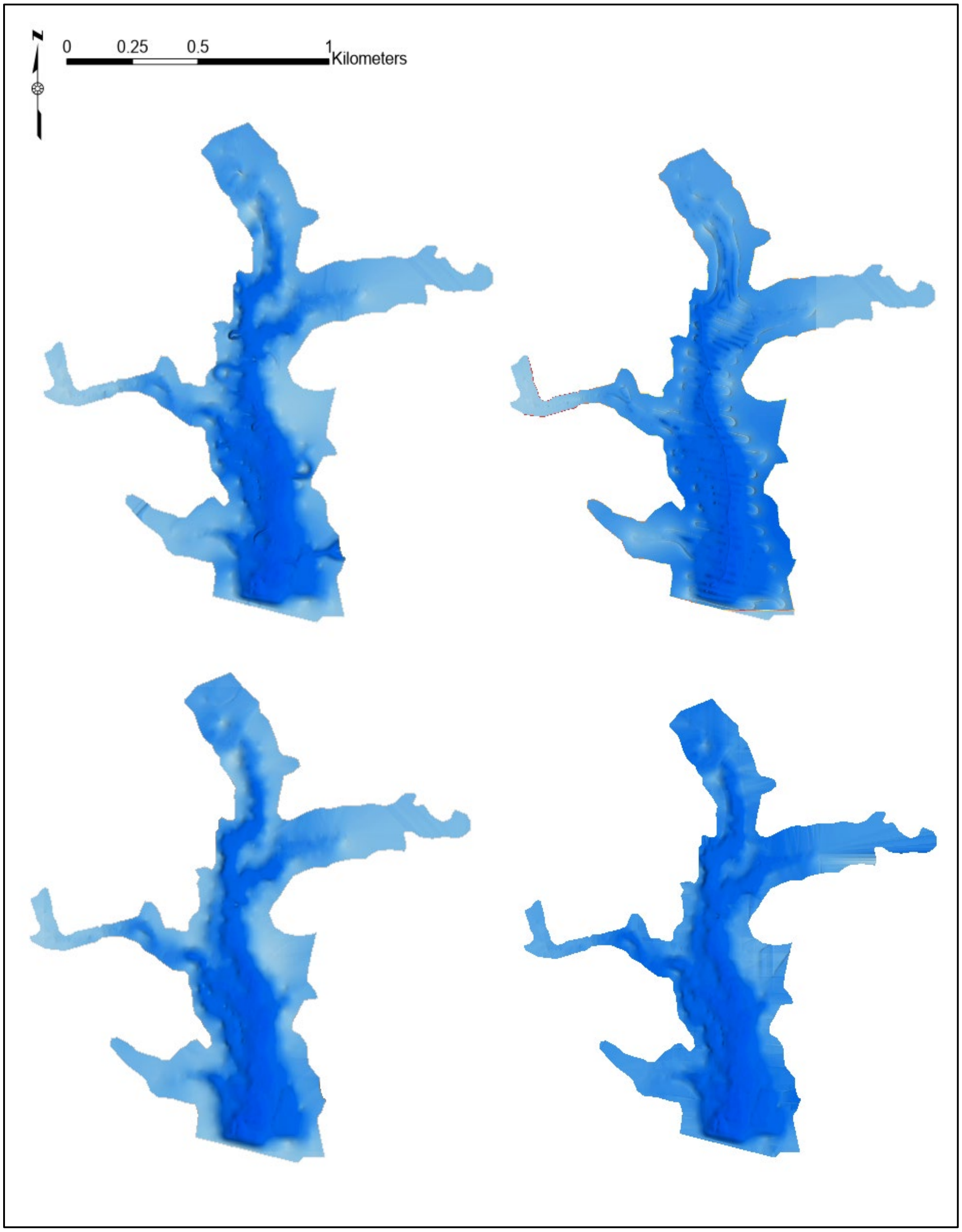
Raster-based surfaces interpolate values to cells of specified size from known point data. Some advantages of raster data are that they tend to be more readily available than TIN data and processing times can be faster. However, raster interpolation may tend to smooth highly variable terrain reducing resolution (Walsh 2022). Smoothing can result in greater values for volume estimation then those based on TIN surfaces as is the case in this investigation (Figure 6). Four raster surface interpolation techniques were used; inverse distance weighting (IDW), ordinary kriging, empirical Bayesian kriging (EBK), and an iterative finite difference (IFD) interpolation method (Hutchinson 1989). Complete descriptions of each of these methods are beyond the scope of this work, but those interested could see Armstrong (2012) or Webster and Oliver (2007). Instead, a brief description of each follows:

- IDW weights points closer to the cell being estimated more heavily than points farther away.
- Ordinary kriging measures the variability according to their distance from the cell of interest and fits a model to them based on their spatial autocorrelation. Interpolated surface values are then determined based on that model—spherical in this study.

- EBK shares the same fundamentals as any kriging method but differs in that it accounts for the error introduced by estimating the underlying semivariogram (Esri 2023a).
- Hutchinson’s (1989) IFD method interpolates raster cell values while ensuring a connected drainage structure and correct representation of ridges and streams from input contour data (Esri 2023b).

For each method, surfaces representing the bottom of each reservoir were used as the base surface for reservoir volume estimation at maximum dam height (h). Demonstrations of the differences in each interpolated surface are in Figure 7. The sonar survey lines are vaguely visible in the surface generated with IDW, demonstrating the heavier weight assigned to points closer to the known values. Generally, the surface generated with the iterative finite difference method displays the most bathymetric diversity, and the surface generated with EBK displays the least. Lake bottom surface interpolation overall does not appear to have major differences between the methods demonstrated here, and any one method may be sufficient for hydrologic computations. Spatial location of survey points and their accuracy are key contributors to the output surface, and different survey patterns may yield slightly different interpolation results.

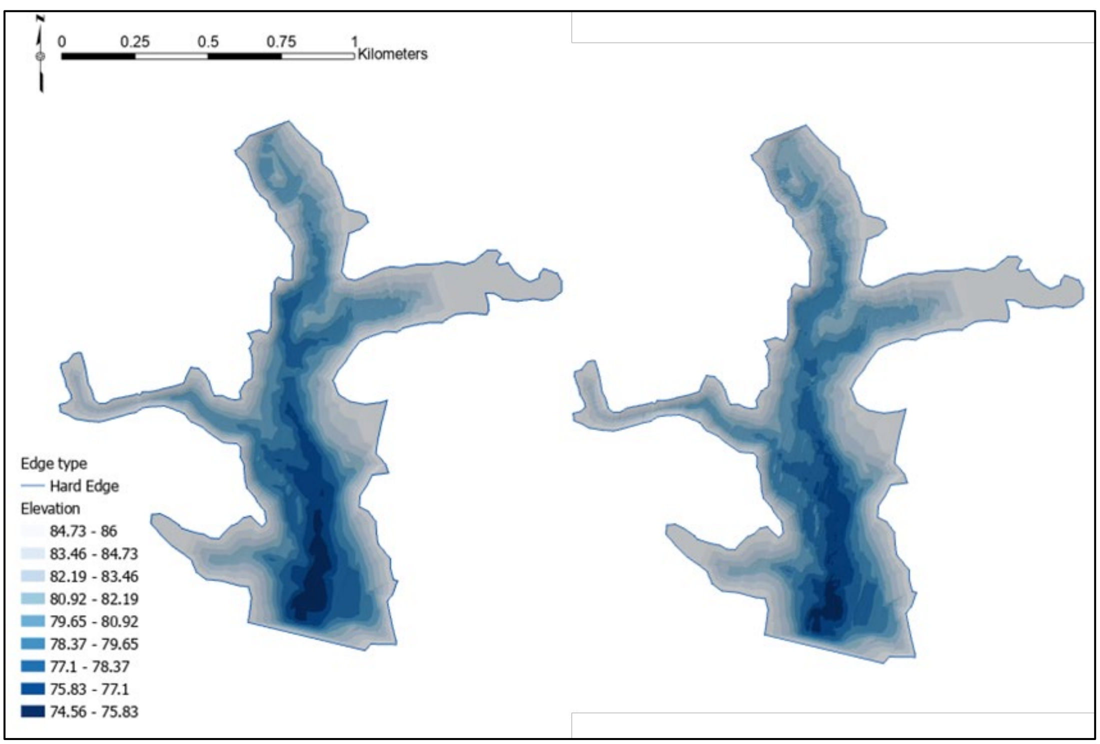
Figure 7. Weston reservoir base surfaces from the iterative finite difference (IFD) method (*top left*), Inverse Distance Weighting (IDW) (*top right*), Ordinary Kriging (*bottom left*), and Empirical Bayesian Kriging (EBK) (*bottom right*). Each surface is shaded with relief exaggerated by a factor of two.



4.2 Triangulated Irregular Network (TIN) Based

TIN surfaces are a type of digital vector topography that are generated by triangulating points according to certain criteria. Lines connect vertices to create networks of triangles. A common criterion for geospatial triangulation of points is the Delaunay criterion which triangulates points such that no point falls inside the circumcircle of any triangle (Okabe et al. 1992). This method avoids small sliver-like triangles and maximizes the minimum interior angles of each triangle. For surfaces with high variability, interpolated TINs may be of higher resolution than raster interpolations, and, subsequently, TINs can work better for creating digital topography (or bathymetry, in this case) from irregularly spaced known elevation points (Walsh 2022). However, one drawback with TIN interpolation is the potential for lower resolution on flatter terrain. Here, maximum water volumes based on three TIN generation methods—Delaunay, constrained Delaunay, and smooth bathymetric TIN—were compared, and surfaces from the Delaunay and smooth bathymetric TIN method are juxtaposed in Figure 8. For the representative reservoir, there was no difference in the surface or resultant volume from the constrained and normal Delaunay triangulation methods and a comparatively small difference for the smooth bathymetric TIN (ten iterations) (Figure 6).

Figure 8. Smooth bathymetric Triangulated Irregular Network (TIN) (*left*) and Delaunay TIN (*right*) for Weston Reservoir.



5 Recommendations and Conclusions

5.1 Recommendations

Given that the estimation of water body volumes in general is of interest in a variety of hydrologic contexts, we provide the following recommendations intended to enhance future research in this area:

- Investigate the variability between p parameters derived from raster-based versus TIN-based sources,
- Investigate volume prediction techniques for permanent reservoirs with greater dam heights (h),
- Investigate—for the same or similar data set—the performance of other prediction methods such as the "Skeleton method" of Liu and Song (2022), and
- Conduct different survey patterns on the same reservoirs and compare subsequent volumes.

5.2 Conclusions

The objectives of this case study were to apply two known water volume estimation techniques to a sample set of six anthropogenic reservoirs and compare their computed volumes as well as discuss the performance of eight surface interpolation methods as they relate to water volume estimation. The comparatively small data set of six reservoirs in this study may limit definitive conclusions about the performance of any of the volume estimation methods, but the results of the application are generally instructive in the forward research of determining water volumes with limited field data. The simplified V-A-h method yielded reasonable results compared with the volumes computed from the eight surface interpolation methods, and the power function method tended to underestimate the maximum reservoir volumes. In other studies (Vanthof and Kelly 2019; Annor et al. 2009; Liebe et al. 2005), power function models were reservoir specific, so it follows that developing reservoir-specific power functions for the reservoirs in this data set would likely yield maximum water storage volumes consistent with the simplified V-A-h and the interpolated volumes. Yet, applying the *Gen* and *Cat* methods to reservoirs in this study resulted reasonable estimates of reservoir volumes at deeper values of h.

For the representative reservoir (Weston), the raster-based interpolated base surfaces resulted in the highest estimated volumes, and the volumes based on interpolated TIN surfaces were all relatively similar.

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Abbreviations

A	Area
ADTIP	Army Dams and Transportation Infrastructure
Cat	Categorical
DEM	Digital elevation model
EBK	Empirical Bayesian kriging
Gen	General
IDW	Inverse distance weighting
IFD	Iterative finite difference
IMCOM	Installation Management Command
RMSE	Root mean squared error
TIN	Triangulated Irregular Network
V	Volume
V-A	Volume-area
V-A-h	Volume-area-height

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14. ABSTRACT
The conventional approach to estimating lake or reservoir water volumes hinges on field data collection; however, volume estimation methods are available that use little or no field data. Two such methods—the simplified *V-A-h* (volume-area-height) and the power function—were applied to a set of six anthropogenic reservoirs on the Fort Jackson, South Carolina, installation and checked against a validation data set. Additionally, seven interpolation methods were compared for differences in total volume estimation based on sonar data collected at each reservoir. The simplified *V-A-h* method overestimated reservoir volume more than each technique in the power function method, and the categorical technique underestimated the most reservoir volumes of all three techniques. Each method demonstrates high V_{err} variability among reservoirs, and V_{err} for the Power Function techniques applied here is consistent with that found in previous research in that it is near or less than 30%. Compared with V_{err} in other studies evaluating the simplified *V-A-h* method, V_{err} in this study was found to be 10%–20% higher.

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