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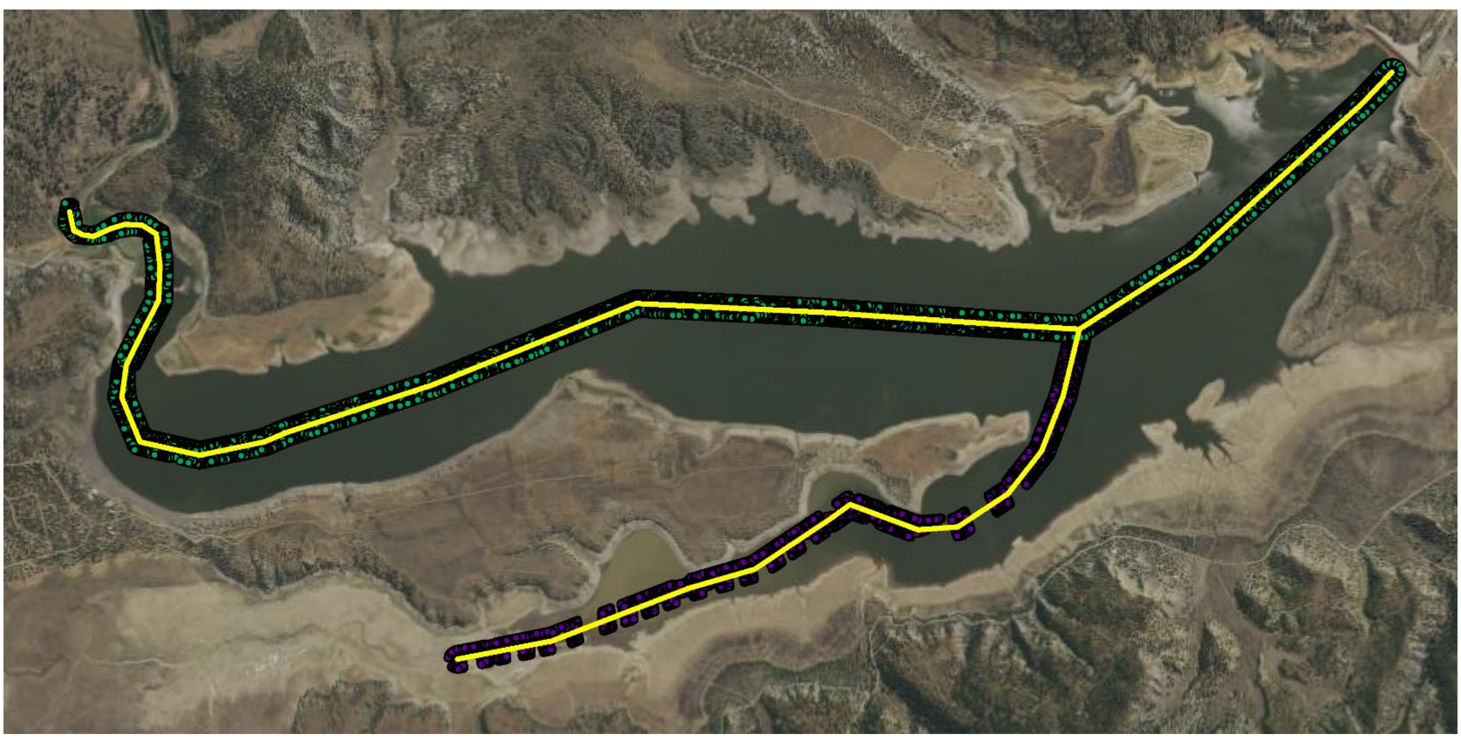
User's Guide for Reservoir Surface Development from Reconnaissance Surveys

Sedimentation and River Hydraulics,
Technical Service Center
Denver, Colorado



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Cover: An example of the boat path and sonar points that might be collected in a reservoir reconnaissance survey

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Peer Review Certification

This section has been reviewed and is believed to be in accordance with the service agreement and standards of the profession.

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Acronyms and Abbreviations

3D	Three dimensional
DOI	Department of the Interior
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
Reclamation	Bureau of Reclamation
TIN	Triangulated Irregular Network
TSC	Technical Service Center

About this Manual

A reconnaissance survey measures a longitudinal profile along the reservoir. A comparison of this profile with a predam reservoir profile provides an estimate of the maximum sedimentation thickness along the reservoir length. A new, simplified surface can be created from the reconnaissance profile survey by extrapolating the elevation data to the reservoir valley margins and combining those extrapolated elevation data with a prior reservoir surface where the previous surface is higher or outside the boundary of the reconnaissance surface.

This manual was written for engineers or scientists who are familiar with reservoir surveys and the application of ArcGIS. This manual describes how to use a new ArcGIS tool to create an approximate bathymetric surface of a reservoir from the data collected during a reconnaissance survey and a previous reservoir surface.

Contents

Figures

1. Introduction

Periodic reservoir sedimentation monitoring is needed "for water storage reservoirs to determine the current surface area and storage capacity tables for reservoir operations and to help estimate when dam and reservoir facilities may be impacted by sedimentation" (Randle and Larsen, 2021). A full bathymetric survey measures the elevation of the reservoir bottom and valley walls or side slopes that are below the water surface. Full bathymetric surveys may take a crew of three or more people with one or more boats several days to weeks to complete. However, a reconnaissance survey along the reservoir centerline or thalweg can be completed using much fewer resources, equipment, and time.

"A reconnaissance survey measures a longitudinal profile from the dam, along the primary upstream river channel, to the top surface of the reservoir delta" (Randle and Larsen, 2021). Additional survey profiles along any major tributary arms of the reservoir would provide more complete sedimentation information. The techniques for reconnaissance surveys are described by Ferrari (2006).

A longitudinal profile can be created from reconnaissance survey data and compared to a previous survey or the predam topography to estimate how the maximum sedimentation thickness generally varies along the reservoir. The elevations along the longitudinal profile can be extrapolated laterally to the reservoir margins to approximate the sedimentation surface. This extrapolated sediment surface can be combined with a surface of the reservoir margins (side slopes) produced from a previous survey. This new (combined) surface can then be compared to a previous reservoir surface to estimate the sedimentation volume and remaining reservoir storage capacity.

This document describes a GIS tool that automates the process of developing this combined bathymetric surface from reconnaissance survey data.

2. Required Input Data

The input dialog window for the ArcGIS tool is shown in Figure 1. The data required to create an approximate bathymetric surface from a reconnaissance survey are:

1) **One or more sets of bathymetric survey points.** The points must include elevations in the point shapefile (PointZ). It is not sufficient to include elevation in a field in the attribute table. If the survey included multiple profiles, each profile must be contained in a separate shapefile.
2) **One or more polyline boat paths.** This polyline shapefile depicts the survey boat path during the reconnaissance survey for each set of survey points. This will typically be hand drawn, but it could be derived from a boat position record. This data needs to be supplied in the same order as the bathymetric survey points so that the algorithm (described below) can match each set of survey points with a survey boat path. An example input dataset is shown in Figure 2.

3) **An elevation averaging interval.** This value is used to bin points along the boat path so the average elevation of points within each bin can be computed. The elevation averaging interval should be chosen to reflect the expected longitudinal range of variation in elevation. A larger averaging interval will produce larger bins and smooth out variation in a highly irregular surface. For a smooth, gradually varying surface, the algorithm is less sensitive to the choice of the averaging interval.
4) **A previous topographic or bathymetric surface in the triangulated irregular network (TIN) format.** This TIN surface is used to define the lateral extent of the output surface and to limit the output surface to areas that are above the previous surface.
5) **The location where the new TIN surface will be stored.**

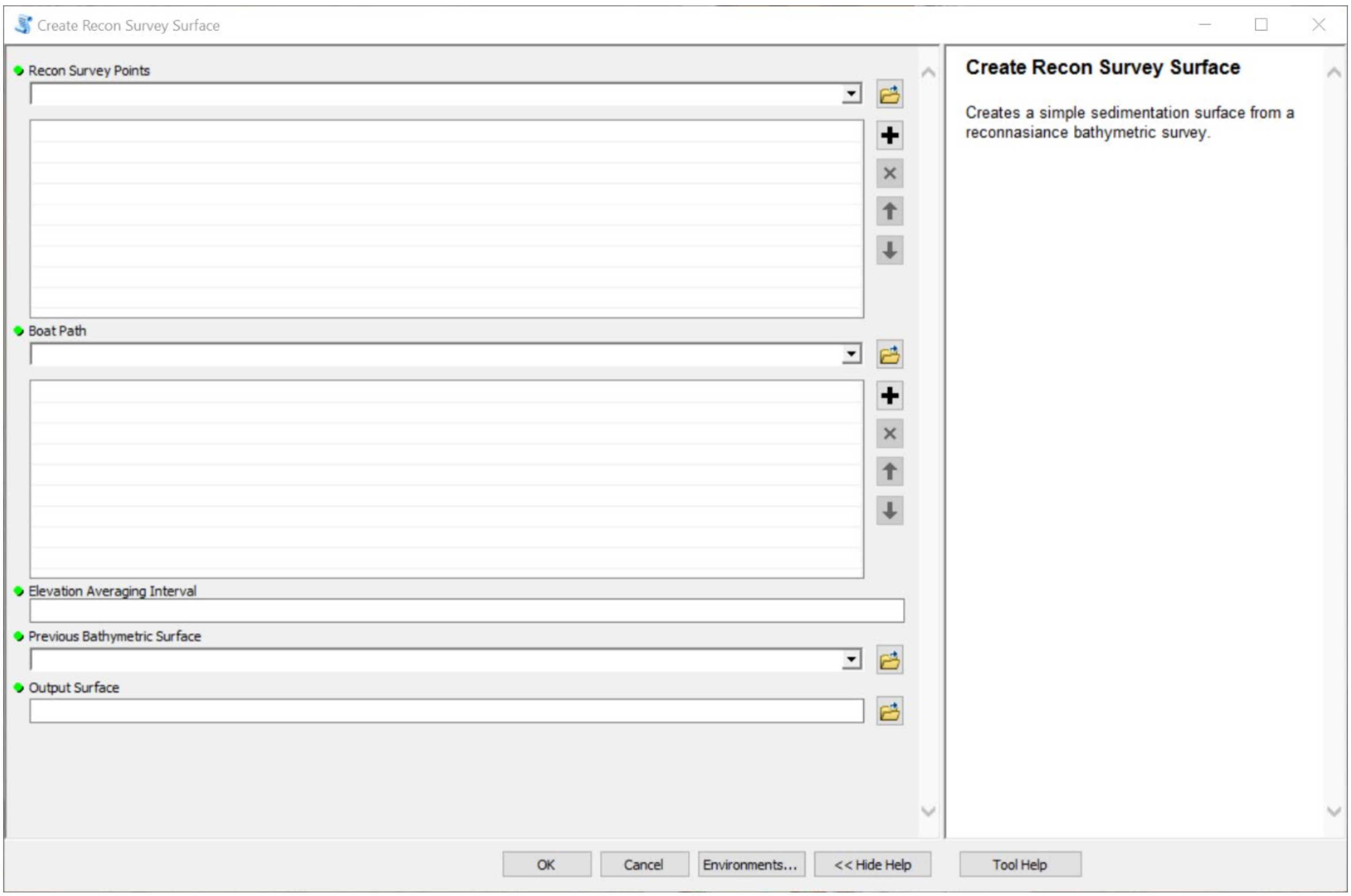

Figure 1. The ArcMap toolbox input dialog for the Reservoir Reconnaissance Survey Surface tool.

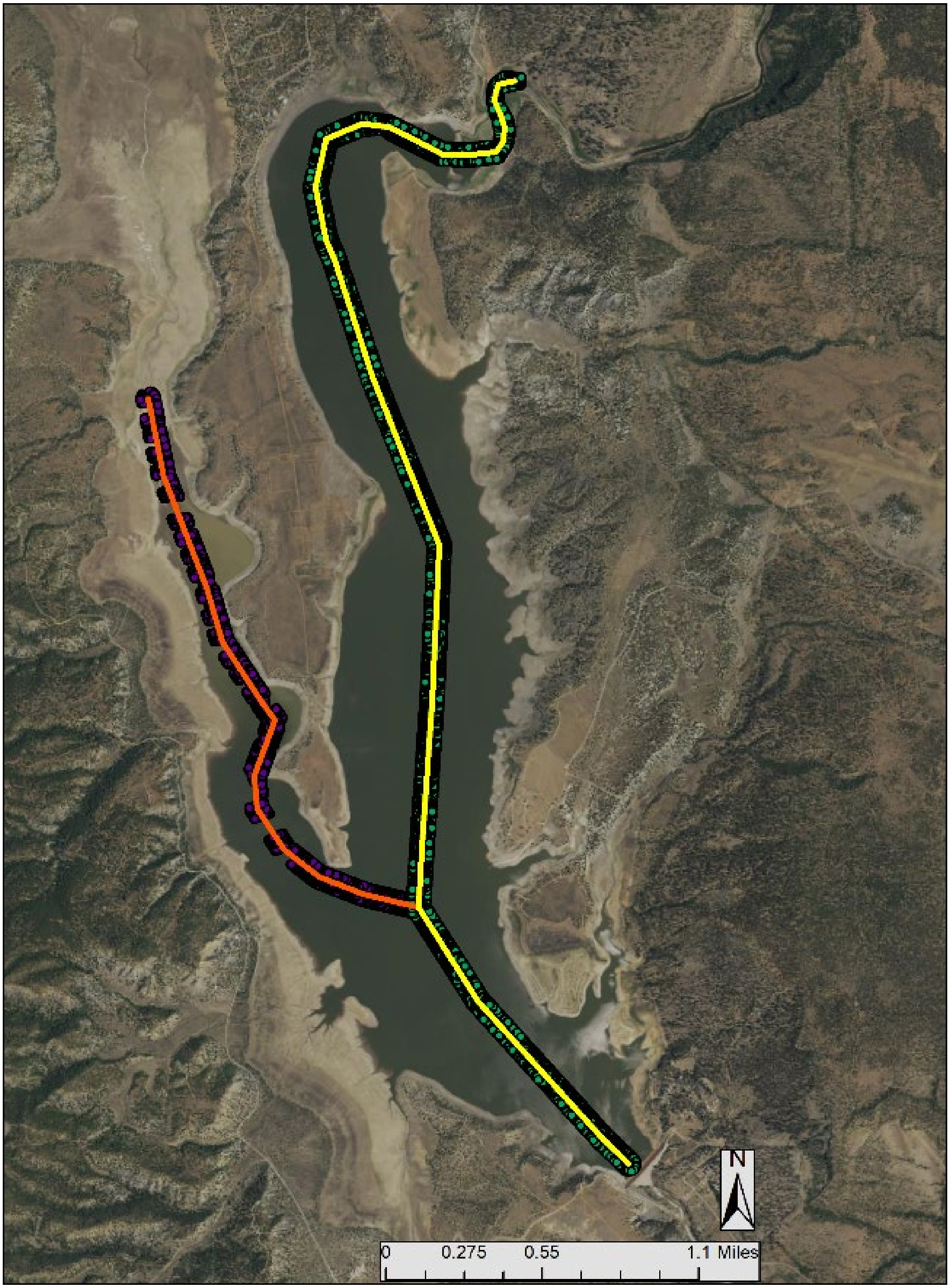

Figure 2. An example of the survey points and boat paths needed for reconnaissance surface creation. This example is simulated from a 2018 survey of El Vado Reservoir in New Mexico.

3. Surface Creation Algorithm

The reconnaissance surface is generated automatically using the following steps.

1. The boundary of the previous topographic or bathymetric surface is converted to a set of points using the ESRI TIN Domain and Feature Vertices to Points tools.

These steps are repeated for each survey point set and corresponding centerline boat path:

2. The reconnaissance survey points are assigned a longitudinal station coordinate along the boat path and binned by station according to the elevation averaging interval supplied by the user.
3. The average elevation of all points in each bin is computed and that value is assigned to a point at the center of each bin.
4. The bin center points are converted to a three-dimensional (3D) ESRI Polyline Geometry object that represents the reservoir bathymetry along the boat path.
5. The TIN boundary points (from step 1) are assigned station and distance coordinates (longitudinal station and normal distance to the boat path) corresponding to the bathymetry polyline created in step 4. For reservoirs with major tributaries and multiple longitudinal profile survey lines (boat paths), the algorithm has logic to correctly assign elevation data from a survey boat path to the reservoir margin. If the normal distance is less than a previously assigned distance to another boat path, the TIN boundary point is assigned the elevation of the 3D bathymetry polyline at that station along the line.
6. After all of the sets of survey points and boat paths have been processed, the TIN boundary points now have elevations that reflect the average elevation at their station along the nearest survey boat path. This is designed to produce a sedimentation surface that is laterally level between points along the boat path and the corresponding points along the reservoir boundary.
7. The reconnaissance survey points and TIN boundary points are used to generate a new output surface TIN that includes the sedimentation surface, using the ESRI Create TIN tool.
8. The new TIN is compared to the previous TIN with the ESRI Surface Difference tool and edited (with Edit TIN) so that the new TIN contains only areas where the new surface is higher than the previous surface.
9. The nodes of the previous survey TIN that are outside the boundary of the reconnaissance surface are converted to points using the ESRI TIN Node tool and deleted using the Erase tool.
10. A new TIN is created using the points from step 9 and the nodes of the reconnaissance surface TIN and written to the user specified output location. The elevations in this TIN are a compilation from the reconnaissance survey where the sedimentation surface is higher than the previous reservoir bottom surface and from the previous surface elsewhere along the reservoir margins.

4. Sample Results

To simulate the data that would be collected during a reconnaissance survey, we developed three sets of synthetic reconnaissance survey points by clipping data from the full bathymetric surveys of Willow Creek Reservoir (Montana, 2019), El Vado Reservoir (New Mexico, 2018), and Elephant Butte Reservoir (New Mexico, 2017) to a polygon surrounding a synthetic survey boat path. These reservoirs were chosen as test cases because two full bathymetric surfaces surveyed at different times were available for each reservoir. An example dataset is shown in Figure 2. The previous bathymetric surfaces were developed from surveys performed in 2002 for Willow Creek Reservoir and 2007 for El Vado and Elephant Butte Reservoirs.

The Willow Creek Reservoir full survey surface (2019) and the simulated reconnaissance surface are compared in Figure 3. Purple lines on the simulated surface outline areas where the estimated reconnaissance surface is higher than the previous surface. Areas outside the purple lines have elevations derived from the 2002 survey, as described in Step 9 of the surface creation algorithm.

The El Vado Reservoir (2018) full survey surface is compared with the simulated reconnaissance surface in Figure 4. The simulated surface reveals a weakness in the surface generation algorithm: the elevations in the main arm of the reservoir near the junction with the western arm are higher than they should be because the TIN boundary points along the eastern edge of the peninsula that separates the two arms are closer to the survey boat path in the western arm. Therefore, their elevations were derived from survey points along the western arm.

The Elephant Butte Reservoir full survey surface (2017) and simulated reconnaissance surface are compared in Figure 5. The simulated reconnaissance is quite similar to the 2017 surface, with a few discrepancies. At the upstream end of the reservoir, the 4358-4378 foot elevation band (brown) extends further to the north in the simulated surface. The 4337-4358 foot band (dark red) also extends further north in the simulated surface but is interrupted by the 4358-4378 foot band on the eastern side of the reservoir. The other significant discrepancy is a missing area of the 4276-4296 foot band (green) in the simulated surface at the southern end of the reservoir.

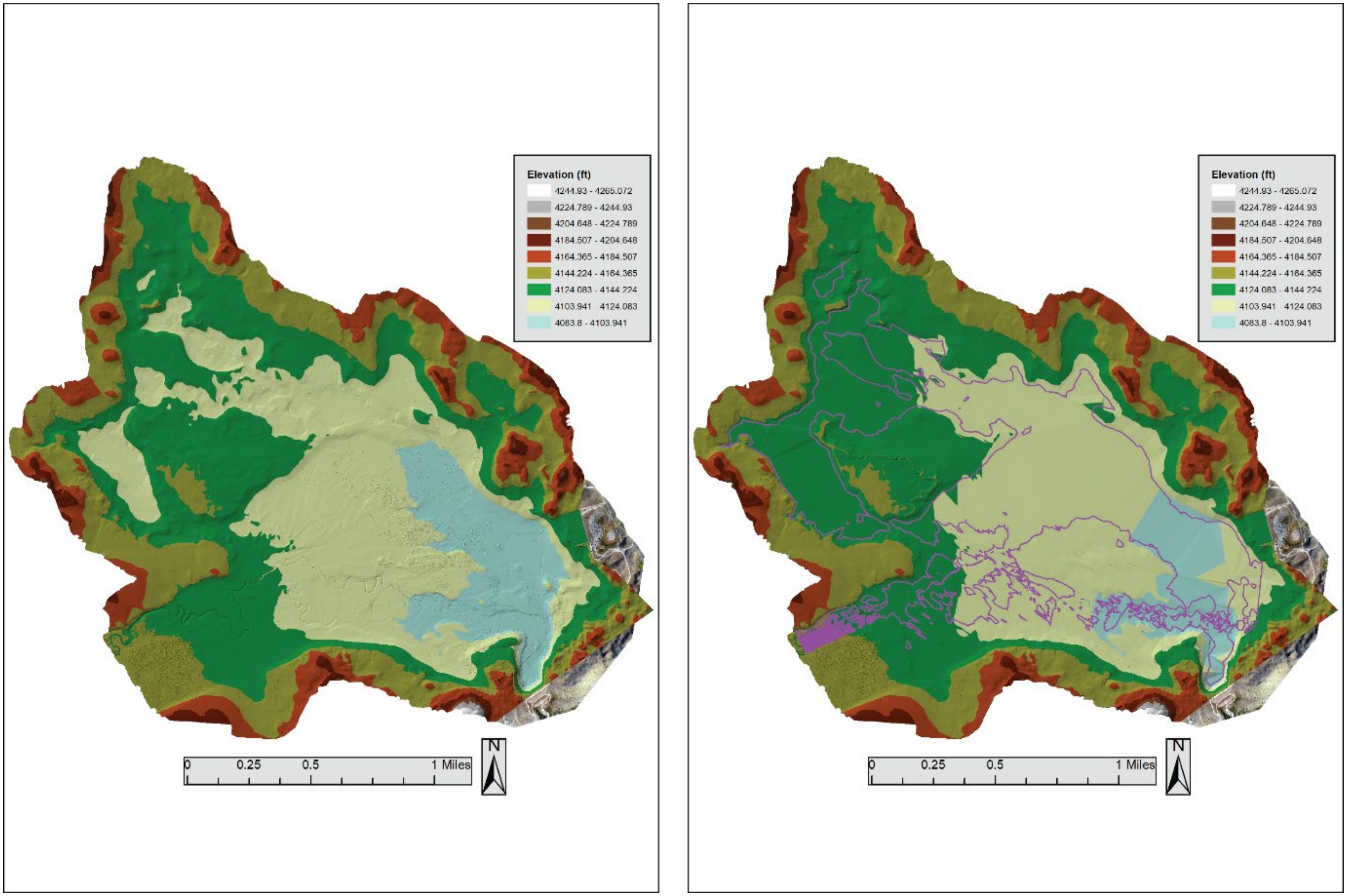

Figure 3. The 2019 Willow Creek full bathymetric surface (left) and the simulated reconnaissance survey surface (right) developed from a small subset of the 2019 survey points.

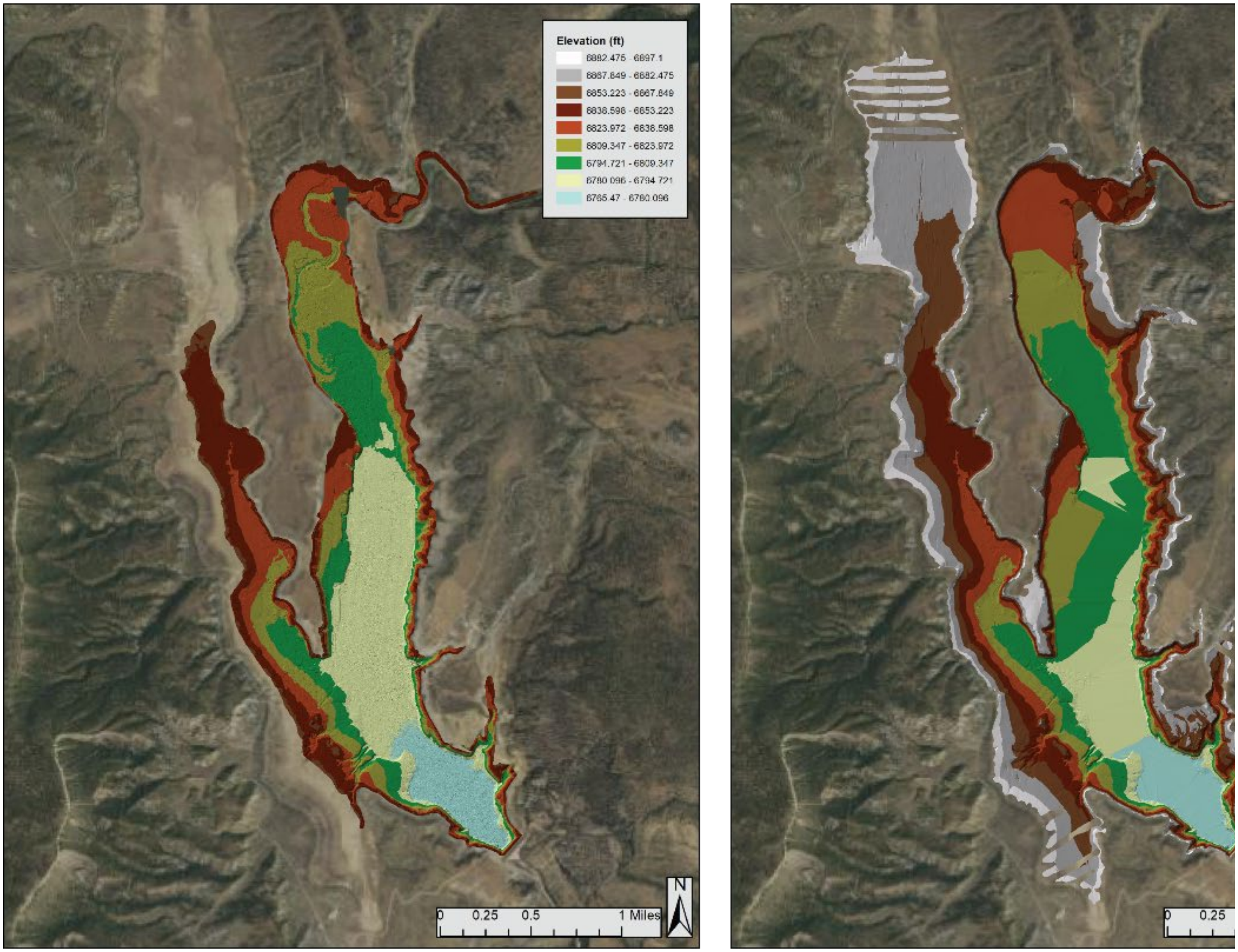

Figure 4. The 2018 El Vado full bathymetric surface (left) and the simulated reconnaissance survey surface (right) developed from a small subset of the 2018 survey points.

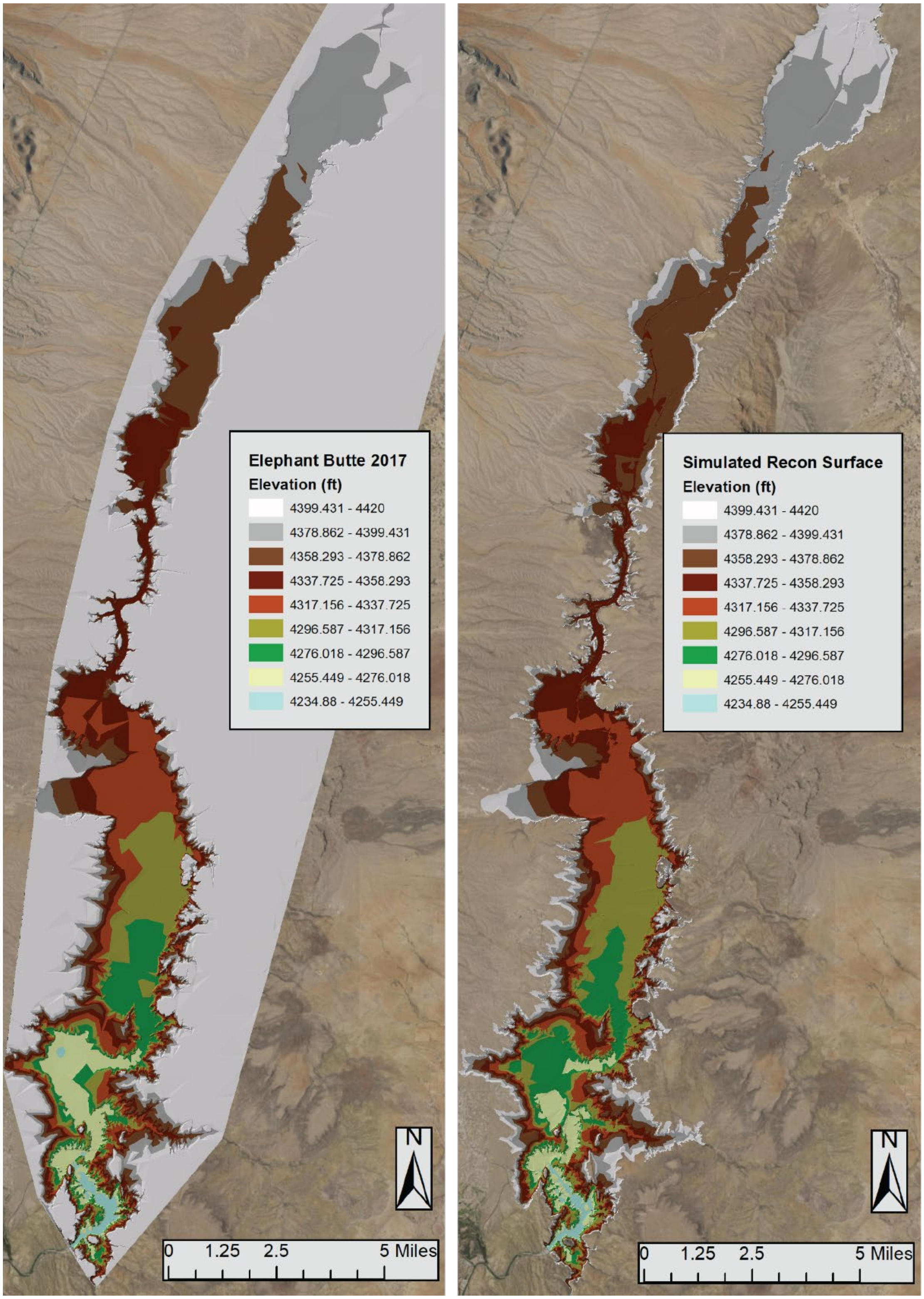

Figure 5. The 2017 Elephant Butte full bathymetric surface (left) and the simulated reconnaissance survey surface (right) developed from a small subset of the 2017 survey points.

5. Conclusions

The ArcGIS tool described here creates a new bathymetric surface of a reservoir from reconnaissance survey data. The resulting surface can be a reasonable approximation of the reservoir surface—particularly if sedimentation covers the reservoir bottom and the reservoir alignment is not highly sinuous. Best results are achieved when the previous topographic and bathymetric surface include the entire reservoir area and the reconnaissance profile survey extends the entire length of the reservoir. The simulated reservoir surface produced by this ArcGIS tool from a reconnaissance survey is not as accurate as the surface produced from a full reservoir survey conducted at the same time. However, the simulated surface is likely a more accurate representation of the present surface than the surface produced from a survey conducted decades ago, especially when reservoir sedimentation thickness are more than ten feet. New surface area and capacity tables, produced from the reconnaissance survey surface, are expected to be more accurate than previous tables when there has been significant sedimentation since the previous survey.

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