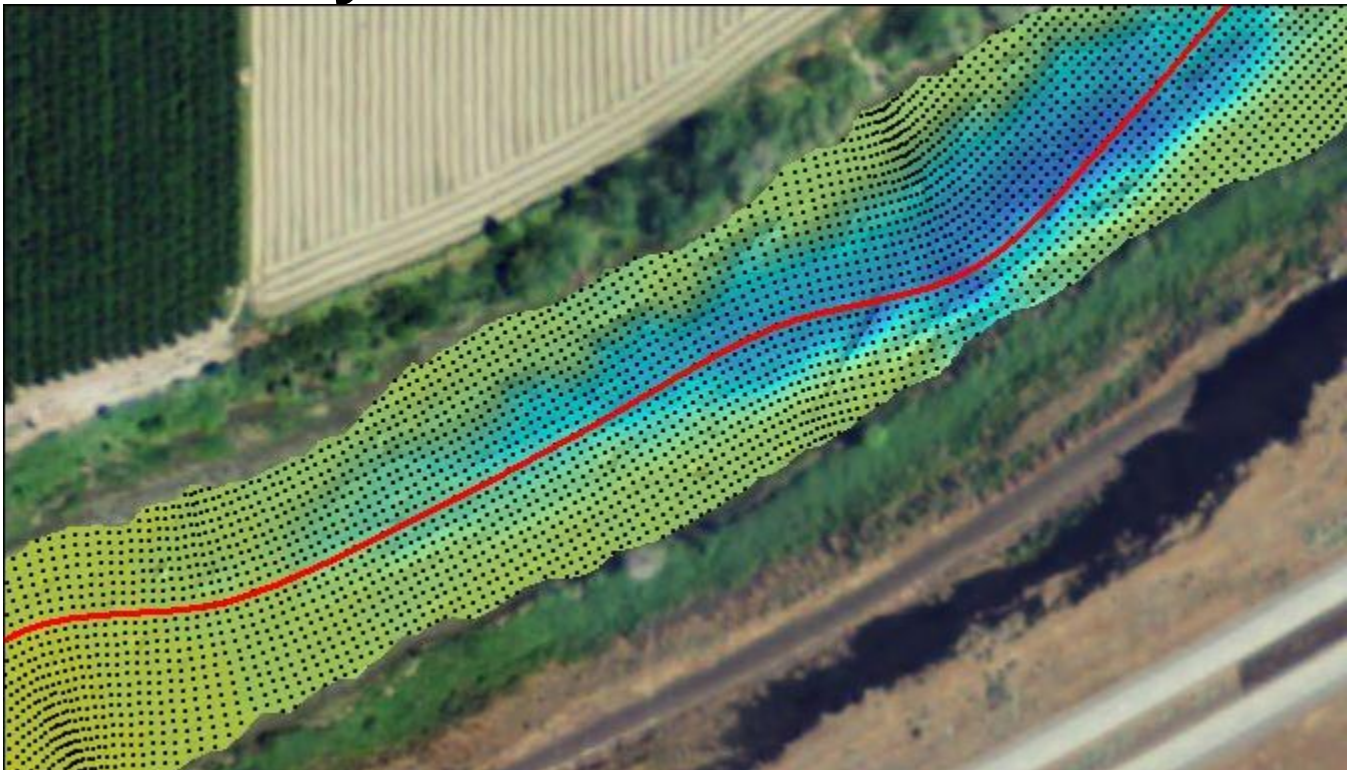


RECLAMATION

Managing Water in the West

Technical Report No. SRH-2013-24

Development of Automated Methods to Improve Surface Modeling of River Channel Geometry and Features



U.S. Department of the Interior
Bureau of Reclamation
Technical Services Center
Denver, CO

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Mission Statements


The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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1 Summary

Bureau of Reclamation (Reclamation) engineers and scientists conduct two dimensional (2D) hydraulic modeling in support of detailed hydraulic studies of river systems. These models are sensitive to the geometric representation of river channel bathymetry. Geometric representations of river bathymetry are commonly produced by interpolating a set of discrete elevation points acquired through various survey techniques into a continuous bathymetry. The overall quality of the continuous bathymetry is influenced by the methods used to gather bathymetric data and spatially interpolate these data.

Research (Merwade et.al 2005, Merwade 2009) shows that more accurate interpolation of river channel bathymetry will result if the interpolation relies on data points that are aware of their location in reference to river flow direction. Traditional approaches to interpolating discrete bathymetric points rely on techniques that function in Cartesian coordinate space and are not aware of the point sample locations in relation to the river flow direction.

There are no known available automated methods that transform discrete bathymetric survey points into a coordinate system that is referenced to river flow direction prior to interpolation and then return interpolated results to a Cartesian coordinate system. This study demonstrates the steps taken to build an automated technique that utilizes an interpolation method which produces predictive bathymetric surface measurements in a manner that is cognizant of the spatial relationship of input survey points to river flow longitudinal direction.

2 Introduction

The accurate portrayal of river bathymetry is a critical component to numerical modeling efforts conducted by Reclamation. Reclamation engineers and scientists routinely perform numerical modeling to support hydrodynamic, sediment transport, vegetation, riparian habitat, and geomorphic analyses. These modeling efforts typically require a continuous bathymetric surface representation that is spatially interpolated from a collection of surveyed points acquired with SONAR and GPS equipment mounted to a boat or raft.

2D hydraulic modeling is increasingly being utilized for detailed hydraulic studies, including modeling in-river structures such as fish screens and weirs, bed and bank erosion, and aquatic habitat. Increasing demands on model resolution and precision result in increasingly growing demand for detailed channel surveys and continuous representations of channel bottom surfaces that closely match reality. The most critical input to any hydraulic model is the geometric representation of the channel and floodplain surface. Incorrect representation of the modeling surface will result in a misrepresentation of channel hydraulics within the hydraulic model which in turn will lead to erroneous conclusions. For example, an inaccurate modeling surface can lead to a reduction in channel capacity values within the hydraulic model which will falsely quantify channel velocities and the discharge at which a given discharge exceeds bank height and begins to flood adjacent lands.

2.1 Bathymetric interpolation challenges

The overall quality of the geometric representation of a bathymetric surface derived from the interpolation of bathymetric survey points is influenced greatly by the chosen interpolation method (Merwade 2009). Decisions made when choosing the interpolation method will determine the character of the derived surface.

Historically, Geographic Information System (GIS) software tools have been employed to perform the spatial interpolation of bathymetric survey data. GIS software provides a variety of interpolation techniques packaged as ready to use tools that use sampled point values as input data to produce a continuous predictive surface. With each interpolation technique, different assumptions are made of the input data. Certain interpolation techniques are more applicable for specific data and each produces predictions using different calculations (ESRI, 2012).

A concern when using any standard GIS interpolation method on riverine bathymetry is that the relative positioning and distance between neighboring input survey points should ideally be oriented in the direction of river flow (Merwade et.al 2005). Standard GIS interpolation tools assume a straight-line distance between input points as if the points reside on a two-dimensional plane. This assumption can lead to misleading predictions when producing a continuous river channel bathymetric surface because the straight-line distance between any two points is typically different than the actual flow length between the same points.

2.2 Previous Studies

Previous studies link the accuracy of 2D hydraulic modeling to the accuracy of the underlying bathymetric surface (Horritt et.al. 2006; Crowder 2000). Research efforts that explore the transformation of discrete bathymetric survey points into a coordinate system oriented to river flow direction have been also been studied (Merwade et.al. 2005). These studies indicate that orienting discrete bathymetric survey points parallel to river flow direction prior to creating a continuous surface through interpolation leads to more accurate elevations at unmeasured, interpolated locations.

2.3 Study goals and objectives

Currently, no known automated methods exist for transforming a collection of bathymetric survey points into coordinate system oriented to river flow direction, interpolating transformed points into a continuous bathymetric surface, and returning continuous elevation data to the coordinate system of the input data. Performing these tasks in a non-automated way would prove time consuming, inefficient, and non-repeatable.

The objective of the current study is to develop an easy to use tool that utilizes an interpolation method which produces predictive bathymetric surface measurements in a manner that is cognizant of the spatial relationship of input survey points to river flow direction. This study will leverage the ideas contained in previous research (Merwade et.al. 2005). Specifically, the study will focus on techniques that:

1. transform surveyed bathymetric point data from a surveyed coordinate system to a system that references each point to its longitudinal distance along and lateral distance from a linear river thalweg
2. perform an appropriate interpolation on the transformed data
3. transfer the results of the interpolation back to the coordinate system of the input data

The techniques described above will be the building blocks of automated methods that will be contained in a custom GIS interpolation tool that can be used by non-GIS professional engineers and scientists in support of current and future hydraulic modeling efforts.

3 A Coordinate System based on River Flow Direction

A description of the differences between a coordinate system based on river flow direction and a standard Cartesian coordinate system is illustrated in Figure 1.

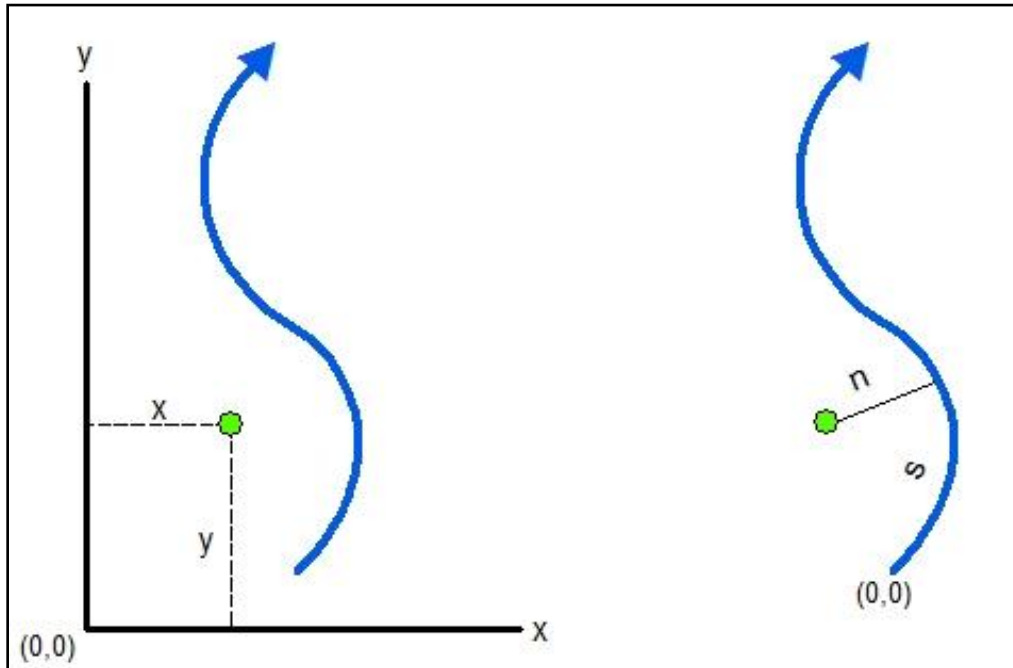


Figure 1: Left- A point shown in Cartesian (x,y) coordinates. Right – The same point shown in river flow direction with s representing distance of the point along the thalweg and n representing the perpendicular distance of the point to the thalweg.

Bathymetric survey points are commonly collected in some form of a projected spatial reference that utilizes Cartesian coordinates to orient each point in relation to the fixed origin of the spatial reference. When describing a point in Cartesian coordinates, the x-coordinate describes the distance of that point to the y axis while the y-coordinate describes the distance of the point from the x axis.

The location of the same point can be described using a coordinate system based on the point's relation to a segment of a river thalweg. Using this coordinate system, the origin is the beginning node of a river thalweg segment, the s-coordinate is the positive longitudinal distance along the thalweg segment in the flow direction, and the n-coordinate is the nearest perpendicular distance from any point to the thalweg. Points perpendicular right of the thalweg assume positive n-coordinate values and points perpendicular left assume negative n-coordinate values.

4 Automated Method Development

4.1 Development environment

ESRI ArcGIS software was used as the platform for the development of the custom interpolation tool. The tool was designed as an Add-In for ArcGIS using Microsoft Visual Studio. The ArcGIS Add-In model was chosen because Add-In customizations are easily shared between developers and users and do not require installation programs or Component Object Model (COM) registration.

4.2 Automated method logic and interface design

The major steps that describe logic behind the custom programming are presented in Figure 2. An illustration of user interface is displayed in Figure 3.

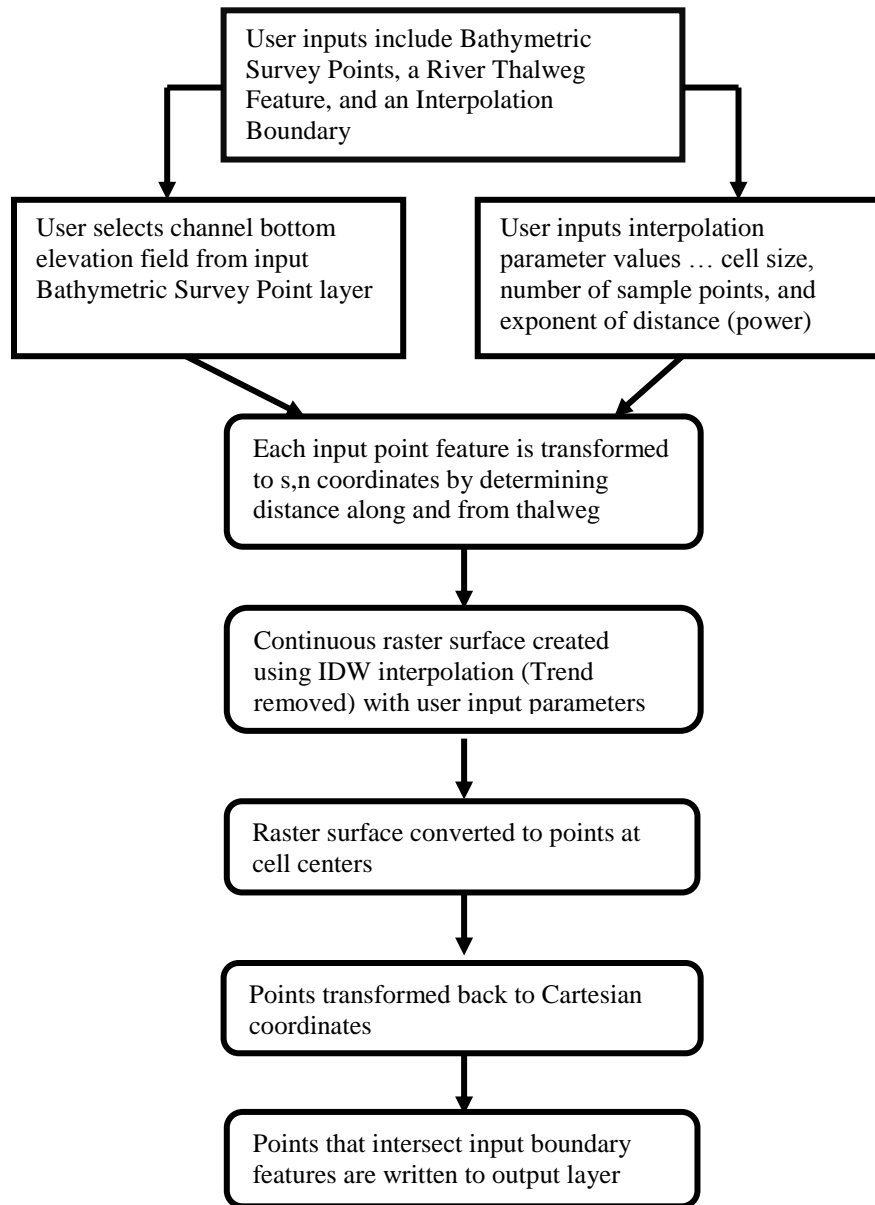


Figure 2:Flowchart illustrating major programming steps

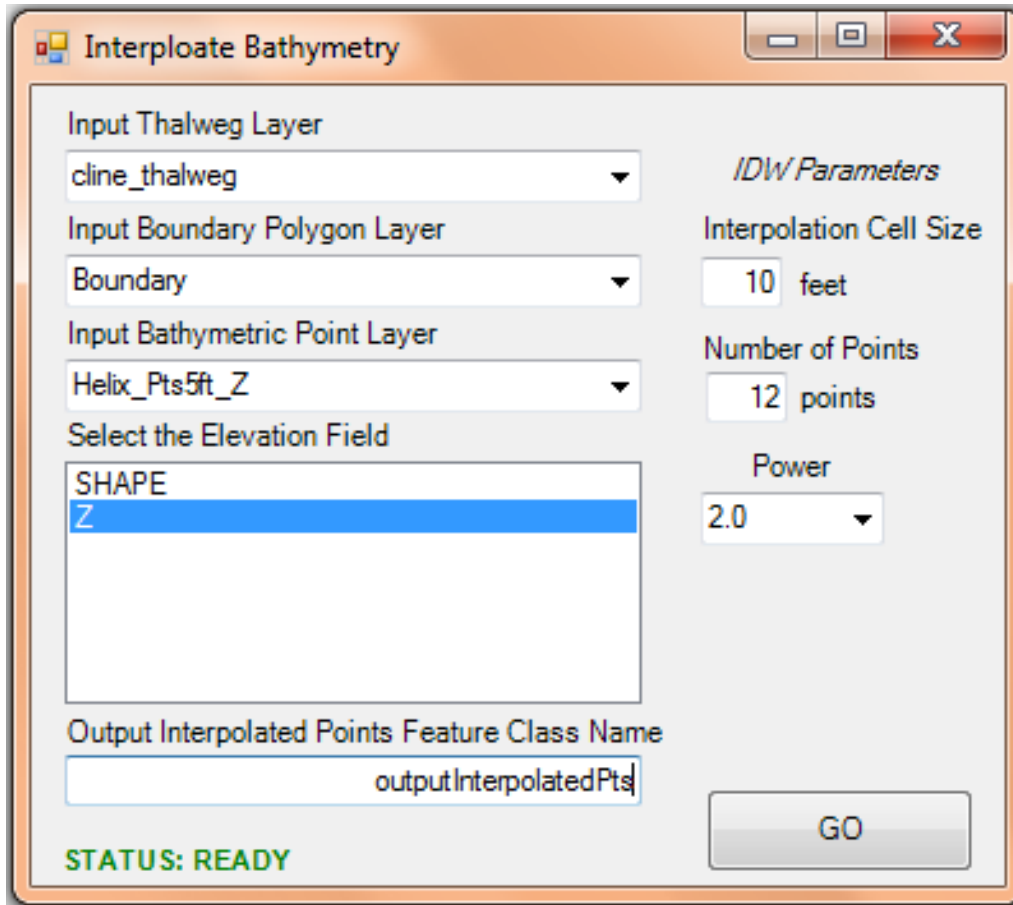


Figure 3: Customization user interface showing user input and interpolation parameter inputs.

5 Automated method steps

The tool functions inside ESRI ArcGIS 10.x ArcMap software. The tool requires that input data layers are present in the active Dataframe and that the Dataframe has a defined projected spatial reference with map units set to meters or feet. The tool can reside on any ArcMap toolbar and is instantiated with a button click which opens the tool's front end interface.

5.1 User input

The tool requires the following user inputs:

1. Thalweg layer: A polyline feature layer present in the active Dataframe. This layer should contain one polyline feature that represents the thalweg and is oriented in the direction of river flow.
2. Boundary layer: A polygon feature layer present in the active Dataframe. This layer should contain one polygon feature that represents the interpolation area (usually the area inside a river segment's bank lines).
3. Bathymetric point layer: A point feature layer present in the active Dataframe. This layer contains the collection of discreet bathymetric point data to be interpolated.
4. Elevation field: The attribute field that contains the elevation values for the input bathymetric point features. The Shape field is appropriate if the input bathymetric point layer is Z-enabled.
5. Output feature class name: The name of the output feature class. The output feature class is stored in the same workspace as the input thalweg layer's feature class.

The tool also requires that valid interpolation parameter values are identified. These values include:

1. Interpolation cell size: This value determines the resolution of interpolation and therefore the spacing of the output interpolated point data.
2. Number of points: This value indicates the number of nearest input sample points to be used to perform interpolation.
3. Power: The exponent of distance. This value controls the significance of surrounding points on the interpolated value.

5.2 Transformation to *s,n* coordinates

The tool loops through and creates a copy of each input point. Each copied point has an initial blank geometry but maintains its user defined elevation value. To populate the new geometry of each copied point, the *s* coordinate (longitudinal distance along the thalweg) is determined by querying the point on the thalweg closest to the input point and the *n* coordinate (distance from

thalweg) is determined by querying the minimum distance between the thalweg and the input point.

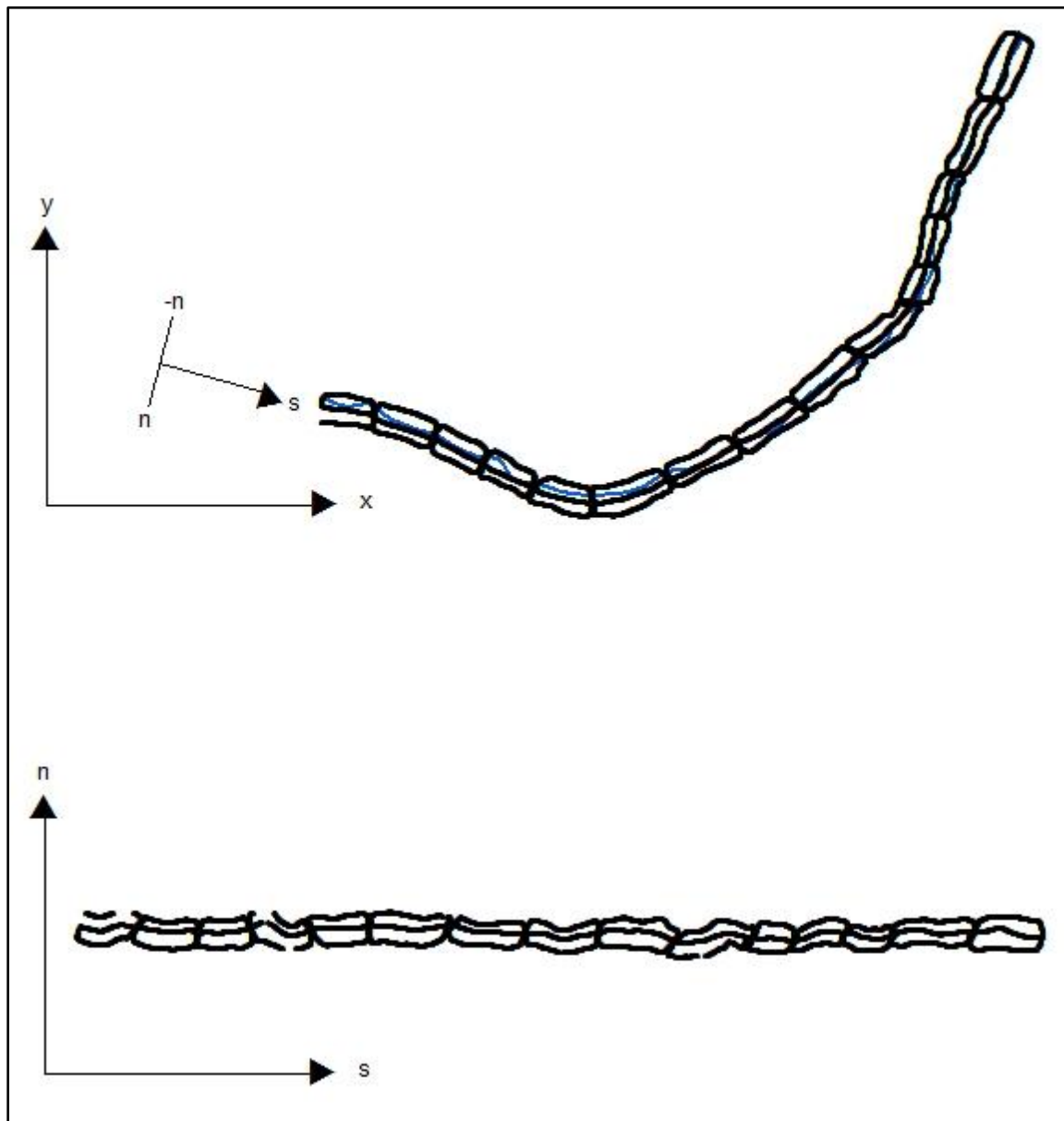


Figure 4: Top- Bathymetric survey points and thalweg in x,y coordinate system. Bottom – The same bathymetric points transformed to s,n coordinates.

5.3 Trend removal

Once the discrete input points are transformed into s,n coordinates, the tool interpolates a global third order (cubic) polynomial elevation trend surface using the elevation values of the points. The trend surface captures both lateral and longitudinal patterns in the data. In almost all instances, the gradual longitudinal profile of a river reach will contrast sharply with the more abrupt lateral profile. It is important to be aware of and reduce the influence of lateral vs. longitudinal trend before conducting any type of distance based interpolation on discrete bathymetric points (Merwade, 2009). To reduce the influence of trend, the tool subtracts the interpolated trend value from the elevation value of each input point to create residual elevation values prior to interpolation. Trend values are re-added to interpolated elevation values post interpolation.

5.4 Interpolation

Residual elevation values are interpolated to create a continuous raster surface using an Inverse Distance Weighted (IDW) technique. IDW interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. User input values set three IDW interpolation parameters. The first parameter is the cell size of interpolation. Cell size determines the resolution of the interpolation. The second parameter is number of nearest input points to be considered for the interpolation of any given cell. The third parameter is the exponent of distance which controls the significance of surrounding points on the interpolated value. A higher value results in less influence from distant input points.

5.5 Conversion to points and re-addition of trend

Raster cells of the IDW interpolated surface are converted to point features with residual elevation attribute values transferred from the same values in the surface. Trend values that were removed prior to IDW interpolation are now re-added back to the residual elevation values for each point.

5.6 Transformation to x,y coordinates

The tool loops through each interpolated point. Each of these points has its geometry modified to reflect northings and eastings of the input Cartesian coordinate system. The final Cartesian coordinates of each interpolated point are determined by using each point's existing s,n values to relocate the point along (positive s value) and away from (positive or negative n value) the input thalweg. Output points with final x,y coordinates that intersect the input boundary polygon are written to the output feature class. A layer representing the output feature class is added to the ArcMap display. An illustration that contrasts the original bathymetric survey point pattern with the interpolated output points is provided in Figure 5. The interpolated output point features represent continuous bathymetric features and can be formed into a continuous surface model (Figure 6).

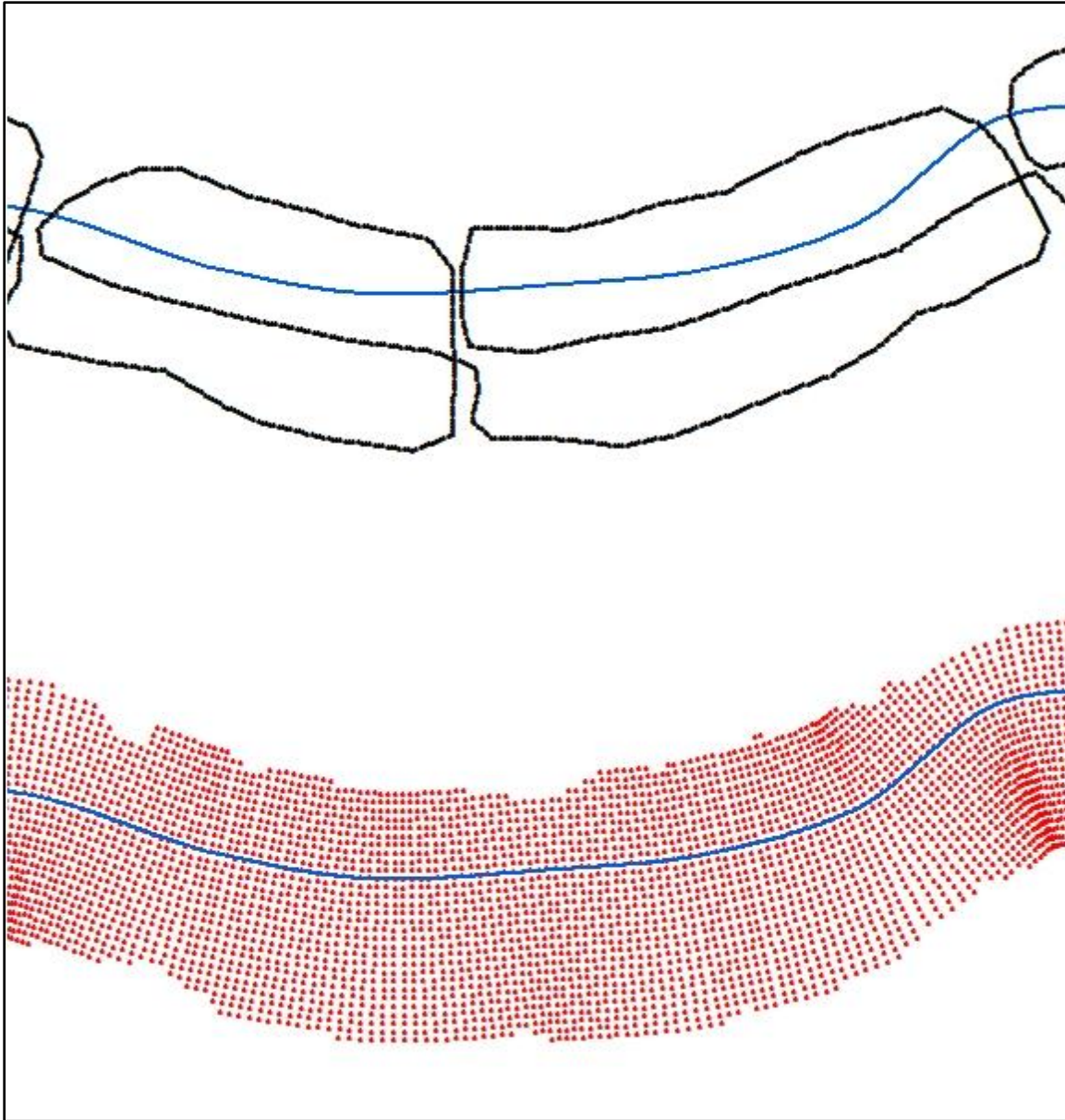


Figure 5: Top- Pattern of input bathymetric survey points and thalweg. Bottom – Interpolated output points oriented to the direction of river flow.

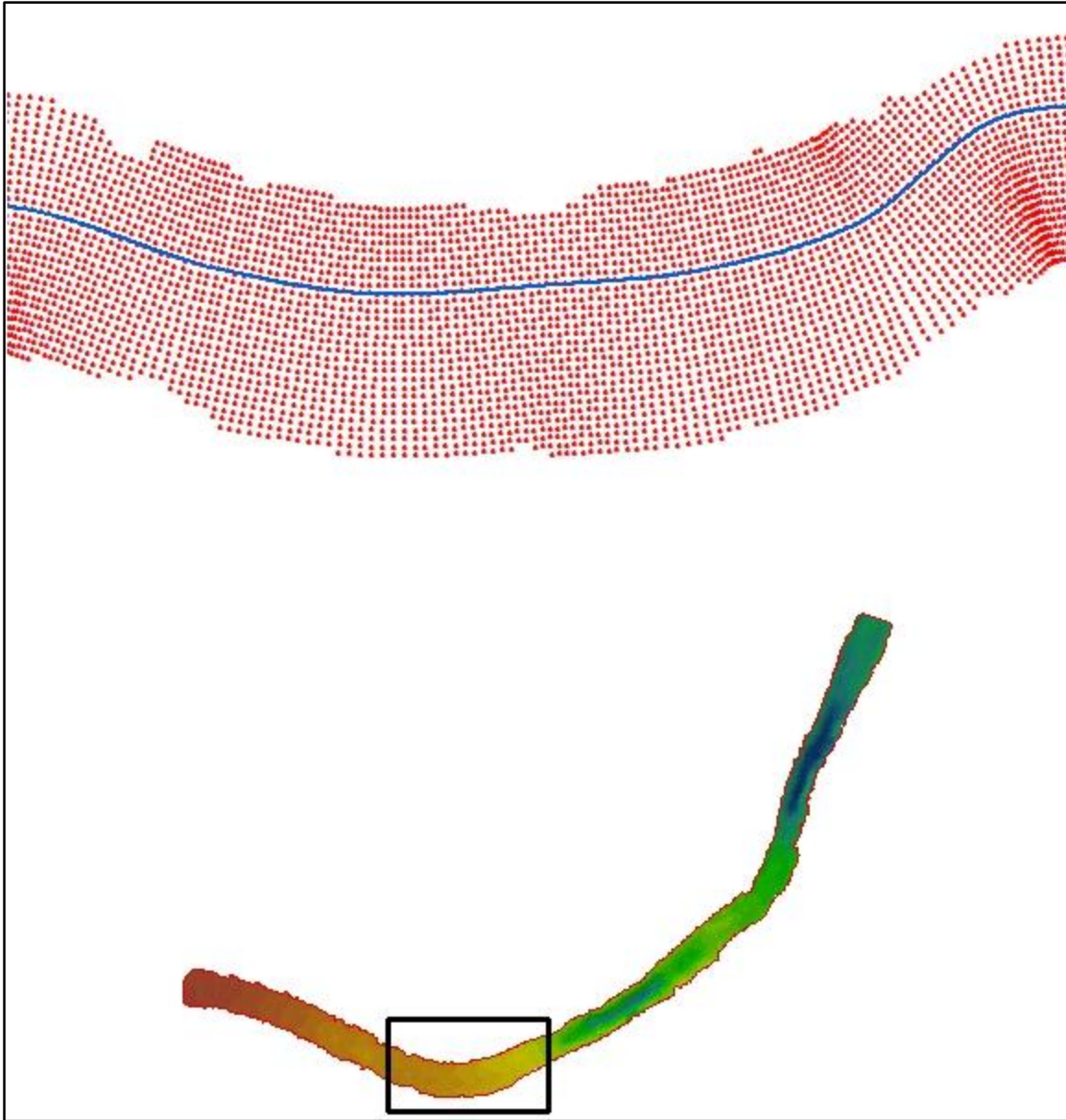


Figure 6: Top- Interpolated output points oriented to the direction of river flow. Thalweg shown in blue. Bottom – A continuous surface model constructed from interpolated output points. The red outline represents the user input boundary polygon. Black box represents area of detail shown in top image.

6 Automated Method - Results and Limitations

This effort produced a custom tool that functions inside ESRI ArcGIS ArcMap 10.x software and is designed for use by non-GIS professional engineers and scientists. The tool utilizes an interpolation method that produces predictive bathymetric surface measurements in the form of interpolated points. The interpolation is conducted in a manner that is cognizant of the spatial relationship of input survey points to river flow direction.

The interpolated bathymetric points can be integrated with breakline features and terrestrial elevation data to create a surface model that contains both wetted and non-wetted features. These surface models can be used in support of 2D hydrodynamic modeling efforts that require continuous elevations which encompass flood plain and other areas outside the wetted river channel.

The tool functions by using standardized interpolation techniques that include the identification and reduction of global lateral and longitudinal elevation trends. As such, the tool is designed to be used for river reaches that are morphologically similar and areas where the pattern and density of bathymetric survey are consistent.

The tool is useful only in single-channel environments. It is not designed to work in braided channels or in areas of stream confluence.

The accuracy of the interpolated bathymetric point features depends on the quality, density, and collection pattern of the bathymetric survey. The accuracy and usefulness of the interpolated elevation values output from this tool will be related to how well the spatial arrangement of bathymetric survey points is able to capture the entire longitudinal and lateral definitions of the channel.

7 References

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