Integration of Topographic and Bathymetric Digital Elevation Model using ArcGIS

Interpolation Methods:

A Case Study of the Klamath River Estuary

by

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A Thesis Presented to the
FACULTY OF THE USC GRADUATE SCHOOL
UNIVERSITY OF SOUTHERN CALIFORNIA
In Partial Fulfillment of the
Requirements for the Degree
MASTER OF SCIENCE
(GEOGRAPHIC INFORMATION SCIENCE AND TECHNOLOGY)

May 2015

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Dedication

I would like to dedicate this work to my wonderfully supportive and understanding

Dog, Hurley. For all the missed sunny days we spend indoors in front of the computer not

chasing Kong.

Acknowledgements

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Special Terms and Acronyms

ArcGIS – Product developed by Esri, currently the leading GIS software internationally.

Bathymetry – The below water ground surface, usually measured as a depth value from the reference water.

Covariance – A scaled version of correlation by illustrating the correlation between the direction and distance of the pairs of values and their locations. In graph form, the y-axis is representing the similarity of values and the x-axis represents the distance relationship between them.

DEM (Digital Elevation Model) – A raster data model recorded as a regular grid representing the height values of elevation for the (earth's) surface.

Deterministic – In interpolation, this refers to the input data having a known influence on the interpolation model algorithm based on the dataset's statistical distribution.

EBK (Empirical Bayesian Kriging) – A deterministic interpolation method, which automates the parameter values compared to traditional Kriging interpolation methods.

ESDA (Exploratory Spatial Data Analysis) – Functionality available in Esri's Geostatistical Analyst Extension to investigate the data points prior to interpolation, which is highly suggested.

Esri   (Environmental Systems Research Institute) - The world's leading GIS software developer. Creator of ArcGIS software suite.

Extension – Additional software sold by Esri for use with the ArcGIS platform, includes many additional tools and functionality not included in the standalone ArcGIS software.

Geospatial Analyst – An Extension to ArcGIS software with additional functionality for Geostatistical data review and analysis

GIS (Geographic Information System) – A computer based system to manage geographic information for use in visualization, analysis and modeling.

GPS (Global Positioning Systems) - A network of space-based and ground-based equipment used in the mathematical calculation of a physical location.

Inverse Distance Weighting (IDW) - A Deterministic interpolation method it which uses the exact data variables when creating the surface. Available in both Spatial Analyst and Geostatistical Analyst Extensions of ArcGIS.

Interpolation – Estimation of surface values at unsampled locations based on known values of neighboring points.

Interpolation Algorithms - Using known data points to with a mathematical algorithm in order to create a surface.

Kriging – An algorithm used in interpolation of surfaces, which using the surrounding measured values are weighted to derive a predicted value for an unmeasured location.

LiDAR (Light Detection and Ranging) – A remote sensing technique used in the detailed collection of surface measurements.

Natural Neighbor (NN) - An algorithm used in interpolation of surfaces, which is based on Voronoi (Thiessen) polygons of a neighboring points which weights them based on proportionate areas to interpolate a value.

Normal distribution – Where the values of the dataset are clustered overwhelmingly near the mean value, also called a bell-shaped curve. Usually visualized on a histogram.

Normal QQ (Normal Quantile-Quantile) – Usually represented in a graph of the point data to compare the distribution of the data to a standard normal distribution.

Optimize (Parameter Optimization) - Optimization process for each model is used to change the parameter(s) in order to minimize the mean square error.

Parameter – Values or settings within a tool or Wizard which can be modified by the user or maintain their default setting.

Radical Based Function (Spline) - A deterministic algorithm which interpolates to ensure the estimates values are exact using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points.

Raster – A cell based data model used to store information for faster processing and analysis within a computerized environment. Sometimes referred to as a grid.

RMSE (Root Mean Square Error, RMS error) - a measure of cross validation in which comparisons are performed from the predicted values to the observed values for values.

Semivariogram – Usually represented in a graph or chart form illustrates and quantifies the amount of auto-correlation.

Sonar (Sound Navigation and Ranging) – a remote sensor used in the collection of underwater elevation measurements. Common types include Multi-beam r, Single-beam and Side Scan Sonar.

Spatial Analyst – An Extension to ArcGIS software with additional functionality for analysis of spatial features, one such spatial feature is the interpolation from points to a raster surface.

Spatial Auto-correlation (Tobler's First Law of Geography) – Principal within GIS that features that are closer together have a greater relationship than feature further apart.

Spatial Statistics (Geostatistics) – Using the location or value statistics in different types of analyses, including pattern analysis, shape analysis, surface modeling and surface prediction, spatial regression, statistical comparisons of spatial datasets, statistical modeling and prediction of spatial interaction, and more

Spline Regular - A type of spline interpolation. Regularized Spline modifies the minimization criteria leading to smooth, gradually changing surface with values that may lie outside the sample data range

Spline Tension - A type of spline interpolation. Tension Spline modifies the minimization criteria leading to a less smooth surface with values more closely constrained by the sample data range.

Stationarity - the statistical relationship between two points which depend on the distance between them. Usually viewed by plotting the points on Voronoi map to illustrate the change.

Surface – A raster grid model consisting of values which are representative of the elevation of the earth with either build environment or the bare elevation.

Tool – A user interface within ArcGIS, assessed by the ArcGIS Toolbox(s) to perform complex procedures.

Topo to Raster - An algorithm used in interpolation of surfaces, which is designed for the creation of hydrologically correct DEM. This interpolation can take a variety of data models as inputs rather than just points to create the surface.

Topography – The ground surface in an arrangement of the natural and artificial physical features of an area, usually represented in a raster surface.

Transects (Profile) - a straight line or narrow section through an across the earth's surface, along which observations illustrated in profile graphs. Showing the 3D representation of the elevation variation.

Trend(s) – Data being clustered in any form within a dataset. Procedures are available for removing trends within a dataset such as Box-Cox, arcsine, and log transformations which turn the data to a normal distribution.

USGS (U.S. Geological Survey) – An independent fact-finding agency within the Department of the Interior.

Wizard - A user interface within ArcGIS, which walks the user through a multiple step process in order to perform complex procedures.

Abstract

High quality topographic (land elevation) and bathymetric (water depth) data is targeted by the USGS and other Federal agencies as a need for update and modernization, particularly with the rapidly advancing technological innovations for use in modeling hydrological and environmental changes. Esri's ArcGIS provides advanced and various options to interpolate surfaces using two ArcGIS Extensions: Spatial Analyst and Geostatistical Analyst. These extensions provide access to advanced mathematical algorithms used in the interpolation of measured points into an elevation surface, through a user-friendly interface with pre-defined, yet highly technical input parameters.

Using Light detection and Ranging (LIDAR) elevation measurements and Single Beam Sonar on the Klamath River Estuary, this project compares interpolation methods provided by ArcGIS in the Spatial Analyst and Geostatistical Analyst Extensions, in order to determine how varying the parameter settings affect the resulting surfaces. This case employs seven commonly use interpolation algorithms: Inverse Distance Weighting, Natural Neighbor, Spline Regular, Spline Tension, Kriging, Empirical Bayesian Kriging, and Topo to Raster, all of which can be used in Digital Elevation Model (DEM) surface creation. Understanding the differences between the two extensions and modifying parameters in each interpolation algorithm results in statistically reliable elevation surfaces. The results prove that modifying the default interpolation parameters to fit the statistical variability, which is completed by the optimization of the Geostatistical Analyst Wizard, improves the functional use of the study area raster surface.

Chapter 1 introduces the study's necessity. Chapter 2 describes the technical background, and provides all of the necessary information for understanding the results. Chapter 3 provides the related works. Chapter 4 describes the methodology and explains how to interpret the results. Chapter 5 presents the results from the case study on the Klamath River. Chapter six provides the conclusion and discussion.

Chapter 1: Introduction

Elevation is a fundamental component in any geographic study, utilized as a concrete measurement of the Earth's surface above sea level. Thus for this study, Klamath River Estuary which currently uses a DEM developed in the 1970's requires an more timely and reliable elevation surface (Stoker, et al. 2013). Teams of surveyors historically collected elevation measurements, performing what is known as geodetic leveling. Geodetic leveling measures the relative elevation from one area (usually the ocean or benchmark) to the area of interest (Stoker, et al. 2013). Today, this time-intensive and rather inaccurate process has been reduced to a series of fly-overs from remote, passive or active sensors to acquire the measurements. The traditional definition of elevation is considered the above water measurement of topographical features, but in order to enhance the knowledge of global environmental factors, underwater elevation or depth must be measured as well. Underwater elevation measurements, also known as bathymetry, historically used line measurements to obtain depth values. Today passive or active sensors are utilized by boats and even aircraft to measure elevation (Kearns and Breman 2010). Integrating these two elevation datasets (topography and bathymetry) into a seamless Topographic/Bathymetric Digital Elevation Model, has recently been targeted as a spatial need with little guide for the procedure (NOAA Coastal Services Center 2007, Bernstein, et al. 2011, Evans 2013).

The sensors used to obtain the measurements of elevation or depth can vary, but are generally standardized. Topography can be measured by either Synthetic Aperture Radar

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(SAR) or LiDAR. Airborne LiDAR has become the industry standard due to its high accuracy and precision as well as the wealth of information (Newkirk 2005). Bathymetry collection technology has not changed as rapidly as elevation technology, but recently a variation of the LiDAR technology is being utilized as well as multi and single beam Sonar (Sound Navigation and Ranging) transducers (Kearns and Breman 2010). When determining what technology to use for elevation measurement collection, factors such as expense, availability, and quality of required data points are all integral. The most common sensors utilized for obtaining topography and bathymetry is LiDAR and multi beam sonar. These sensors provide point elevations at varying accuracies, level of detail and measurement spacing. Using known values to estimate the values of areas without measurements, these measured points are then interpolated into a raster grid surface for use in modeling and mapping (Stoker, et al. 2013).

Digital Elevation Models (DEM) are used in many types of analytical studies related to many topics. The importance of deriving the topography and bathymetry measurements into seamless DEMs can be contextualized by hydrodynamics for tsunami, flood or drought modeling, sea-level change, as well as the geophysical erosion, subsidence and coseismic uplift (Goodchild 2000, NOAA Coastal Services Center 2007, Stoker, et al. 2013). These processes and events rely immensely on accurate, timely and precise elevation measurements of topography and bathymetry to perform such studies. Traditional DEM's only used topographic measurements to interpolate the earth's surface, leaving underwater elevation as a single constant value. Integrating both

topography and bathymetry into a single seamless dataset can enhance the level of understanding of their environment for geospatial managers in both coastal and riverine communities (Evans 2013, Stoker, et al. 2013). Although obtaining the most precise and accurate DEM using any technology is difficult, utilizing the highest density elevation measurement point spacing as well as the most recent data collection can mitigate other potential errors arising from interpolation. The choice of interpolation algorithms used when creating the Topographic/Bathymetric DEMs cause variation in the raster surface.

Technology and methodology development revolutionizes the geospatial field every few years with version releases of Esri's ArcGIS Geostatistical Analyst Extension. The analytical ability to generate interpolated surfaces has increased, yet many professionals are still relying on the Spatial Analyst Extension. This project examines the variation between the interpolation methods provided by ArcGIS in its Spatial Analyst and Geostatistical Analyst Extensions in order to determine how varying the parameter settings affects the resulting surfaces. This Klamath River Estuary use case will employ seven commonly use interpolation algorithms, including Inverse Distance Weighting, Natural Neighbor, Spline Regular, Spline Tension, Kriging, Empirical Bayesian Kriging, and Topo to Raster in DEM surface creation. Understanding the extensions differences and modifying the parameters in each interpolation algorithm results in statistically reliable elevation surfaces.

Chapter 2: Background

The Klamath River Estuary, the study area, is located in Del Norte County of Northern California (Figure 1). The Klamath River flows from Oregon where it encounters a series of dams and impediments. There is also climatic variability between the headwaters and the estuary that can cause river flow rate to change day to day and year to year. This variability in hydrological flow can influence the deposition of sediments, which affect the impact of tsunamis, storm surges, and sea level changes on the surrounding community. The ability for the community to prepare depends on pre-disaster elevation modeling using the most recent information. The currently available DEM from the USGS, specifically from the study area, was created using synthetic aperture radar in the 1970's (Stoker, et al. 2013) with unknown river flows. This unknown timing of data acquisition and the DEM's continued influence over all environmental planning of the region can be improved by incorporating all available elevation information. Agencies are now looking into a "whole environment" approach to resource and land management, incorporating topographic and bathymetric elevation that can improve environmental planning.

Figure 1: Map illustrating Study area.

2.1 Elevation Measurement

The technology for measuring elevation has improved with the utilization of Global Positioning Systems (GPS). GPS and computerized mathematics have simplified the process of obtaining point measurements of greater accuracy than ever before. Centimeter accuracy and the ability to validate the measurements using real-time base stations allow for overall confidence in the DEM creation from remote sensors.

2.1.1 LiDAR

LIDAR is a remote sensing technology traditionally deployed from an aircraft which uses light in the form of a pulsed laser to measure distances to Earth. The laser, pointed at a targeted area on the ground, transmits a beam of light and as the light is reflected by the surface, it receives the signal back (Raber and Cannistra 2005). Calculating the transmitted and received signals as well as the position and orientation

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data generated from integrated GPS and inertial measurement unit systems. The result is dense point measurements, which can be used to visualize the surface of the earth and all its features (Newkirk 2005). Specialized sensors can also penetrate water to obtain bathymetric information by modifying the laser, but because of the high cost, this technology was not utilized in this project (NOAA Coastal services center 2014).

2.1.2 Sonar

Sound Navigation and Ranging (Sonar) technology uses sound waves similar to that of LiDAR, where it transmits a sound pulse and receives a signal once reached a feature below the water (Breman 2010). The calculation of information from the position and orientation data generated from integrated GPS and inertial measurement unit result in high-density point measurements of depth. Sonar technology has several varieties commonly used in bathymetric data collection such as Multi-beam Sonar, Single-beam and Side Scan Sonar, each with their own applications for measurement collections. Complicating the measurements is the level of reference of the water; most surveys cannot be completed within the same tidal influences so manipulation and modification of the data must be post-processed into the resulting dataset. For this project, the bathymetry point dataset was collected using single beam sonar technology and was post-processed to equalize the tidal discrepancies.

The point values from the LiDAR and single beam sonar sensors provide individual elevation measurements. Both technologies are generally accepted as accurate and commonly used in DEM surface creation. The surfaces are created by estimating the

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values between the measured points, using the theory of spatial auto-correlation which identifies that values closer together are more likely to be similar than those that are farther apart (Stoker, et al. 2013). The estimation of the values in-between the measurements is known as interpolation. The interpolation method can be based on a mathematical formula or a series of formulas; all points are influenced by the measured point elevations contained in the input datasets and their statistical variation.

2.2 Spatial Statistics Influence

Spatial Statistics is a concentration, of GIS, which is often overlooked (ESRI 2001) (Lynch and Krause 2014). The ability to analyze data for variability and integrity should be required as part of the validation and verification of a dataset's applicability. The point data used in the interpolation of the surface feature, depending on the spatial or statistical distribution, modifies the surface (Kravchenko 2003). Interpolation methods can be accomplished with either sparse or dense datasets, although the more points contained in an area, the more likely the surface is to mimic the true conditions. Datasets need to be analyzed prior to interpolation in order to determine the suitability of the algorithm or method. Factors such as normal distribution, Data Stationarity, Trends, and spatial auto-correlation can sway the decision for an algorithm (Chiles and Delfiner 1999, ESRI 2001, Bohling 2005, Kalkhan 2011).

2.2.1 Normal Distribution

In statistics, normal distribution is described as a case where the value points of the dataset are clustered overwhelmingly near the mean value. This normal distribution is

also known as a bell-shaped curve, when visualized on a histogram (Berry n.d.). The histogram must not contain values too distant from the mean and median values. Some cases where the data is not normally distributed can be also seen in a Normal Quantile-Quantile (Normal QQ) plot the existence of outliers, clusters or grouping of data can raise an issue within some of the modeling algorithms by creating skewness in the distribution. The skewness factor should be near zero, signifying the mean and median are near equal. If the data is not normally distributed, then applying a transformation might resolve some of the irregularities. Transformations modify the histogram by using either empirical or Logarithm (Log) empirical in order to reduce the data's skewness (Berry n.d., Kalkhan 2011, Lynch and Krause 2014).

2.2.2 Data Stationarity

If the data is stationarity the statistical relationship between two points depend on the distance between them. If the data is not stationarity, transformations might stabilize the variances or the utilization of certain interpolation algorithms, which do not require stationarity. To visualize stationarity the Voronoi map is utilized, symbolized by entropy or standard deviation. Entropy polygons are categorized using five classes based on a natural grouping of data values (smart quantiles). The value assigned to a polygon is the entropy that is calculated from the polygon and its neighbors—where entropy is the proportion of polygons that are assigned to each class (Kalkhan 2011, Lynch and Krause 2014).

2.2.3 Trends

Identifying trends contained in a dataset is essential to understanding the changes of the data values across the study area. The Trend analysis within ArcGIS can be completed using Exploratory Spatial Data Analysis (ESDA) tool can be used to find global trends within the dataset. Trends in the X, Y, or Z axis can be visualized by manipulating the three dimensional (3D) graph. If the data shows signs of trends, there might be problems with the dataset but they might be indistinguishable from auto-correlation and anisotropy. Trend removal tools or a deterministic interpolation method (for example, global or local polynomial), can reduce this global trend influence.

2.2.4 Spatial Auto-correlation

Spatial auto-correlation, also known as Tobler's First Law of Geography, is visualized by the Semivariogram /Covariance Cloud tool in ArcMap. This tool examines the local characteristics of spatial auto-correlation contained in a dataset. The Semivariogram value is the squared difference between the values of two data points making up a pair representing the y-axis and the distance between the two points on the x-axis. With the Semivariogram the values variation should increase with distance. The Covariance graph illustrates a scaled version of correlation by illustrating the correlation between the direction and distance of the pairs of values and their locations, where the y-axis is representing the similarity of values and the x-axis represents the distance relationship. With the Covariance graph, the function should decreases with distance. These two graphs are used in understanding the relationship the points have within their geographic space (Kalkhan 2011, Lynch and Krause 2014). For this analysis, the

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utilization of two datasets collected using two different methods and therefore two different accuracy standards, processing requirements, and spatial constraints. Accuracy is assumed from the data producer. If the interpolation method selected does not generally conform to the parameters of the interpolation model, then the data will not be as accurate. When analyzing the various point datasets, the identification of the spatial trends, the spatial dependency, the point distribution of values and locations, and the Stationarity of the dataset must be taken into consideration for use with the various interpolation methods.

2.3 Surface Interpolation Algorithms

Interpolation is necessary due to the incomplete measurement of a feature within an area. For the interpolation of ground surface, measurements are taken at a series of locations, then using an interpolation algorithm; the elevation values between the points are estimated. Interpolation of the ground surface is where the theory of spatial auto-correlation, where points closer together are more similar to each other than points further away. The basic two principals of interpolation algorithms based on 1) the definition of neighborhood area and 2) the neighboring values to determine the mathematical algorithm for the interpolation.

The choice of algorithm or formula used can influence the estimated elevation surface, which is created from interpolation. Understanding the interpolation algorithms and their assumptions can assist when creating any interpolated surface. Two classifications of interpolation methodologies are Deterministic and Geostatistical.

Deterministic models estimate data relationships utilizing priori models, which are directly based on the surrounding measured values. Geostatistical models utilize the entire dataset to infer similar relationships for use in the neighborhood value interpolation.

2.3.1 Inverse Distance Weighting (IDW)

Inverse Distance Weighting (IDW) is a type of Deterministic interpolation method it uses the exact data variables when creating the surface. IDW initially created by engineers for use in the petroleum field (Philip and Watson 1982, Watson and Philip 1985). The parameter setting for IDW is a power function, where the power function illustrates the weight for the values that are proportional to the distance (Lu and Wong 2008). This method is widely used by Geoscientists, because of the ability to easily explain the IDW methodology summarized by the implementation of spatial auto-correlation (Kalkhan 2011). IDW is an appropriate interpolation methodology when interpolating from point datasets that are non-clustered, spatially correlated, contain no data outliers, and are non-directionally dependent. For elevation surfaces, IDW results in flattening peaks and valleys unless these sites have a high point density.

2.3.2 Natural Neighbor (NN)

Natural Neighbor (NN) is a type of IWD deterministic function. NN can perform both interpolation and extrapolation. It preserves localized minimum and maximum values. This interpolation method was created by Robin Sibson as a simple interpolation which aims to create a smooth elevation surface (Sibson 1981, D. Watson 1992). As

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compared to traditional IWD, NN selects the closest points to create a convex hull around

the interpolation point, and weights their values by proportionate area which is also

known as Delauney Triangulation. Natural neighbor provides very little parameters for

modification, only the size of the raster cell. NN is not available in the Geostatistical

Analyst Extension due to its complexity of integrating various outsourced datasets, but it

can be accessed as a tool within the Spatial Analyst toolbox. Due to limited assumptions

made by the natural neighbor model, it generally works well with a variety of type of data

inputs including uneven points in distribution and density.

2.3.3 Spline

Spline, also known as a radical basis function, is another Deterministic

interpolation method that tries to ensure a smooth surface (Franke 1982, Mitas and

Mitasova 1988). This is achieved by finding a function that minimizes the tradeoff

between fitting the points and the smoothness of the surface. Both IDW and Spline rely

on spatial auto-correlation. In comparison to IDW, Spline is able to predict values above

and below the measured values, using the neighboring values as well as not requiring

quantification of spatial auto-correlation. Regular and Tension Spline are investigated in

this study. Regular Spline curve produces a flowing, sometimes irregular representation

of the measured points. Tension Spline curve is a flatter representation of the data,

staying closer to the measured values. The Kernel parameter controls the scales of

variation within the surface, where higher values equate to a smoother surface. Spline

functions produce smoother results when the measured points are not rapidly changing or

highly dense.

2.3.4 Kriging

Kriging is a complex Geostatistical interpolation methodology, discussed in numerous scholarly journals (Royle, Clausen and Frederiksen 1981, Burrough 1986, Heine 1986, Press, et al. 1988, Oliver 1990). The primary intention of Kriging is to produce the most accurate surface not a smooth surface. Kriging is able to provide the prediction of uncertainty. Kriging assumes spatially correlated points, Normally Distributed, Stationarity of the data and does not represent a trend. This interpolation type measures distances between all possible pairs of sample points and uses the information to model the spatial auto-correlation in order to derive the surface. The Kriging interpolation has several types, which slight variation, each have different application. For this research, we will focus on Ordinary and Universal Kriging types. Ordinary Kriging uses several potential Semivariograms models and Universal Kriging uses linear with linear drift or quadratic drift. There are also more advanced parameters for lag size and modifying the variograms parameters for major range, partial still, and nugget. The ability for the Kriging tool also provides for modifying the search radius for either fixed or variable as well as transformation and trend removal options. Kriging provides a wealth of variability in the parameter choices and methodologies, but the outputs from this interpolation method can held to a higher standard due to the uncertainty value the model provides.

2.3.5 Empirical Bayesian Kriging (EBK)

Empirical Bayesian Kriging (EBK) is a type of Kriging methodology, which allows for accurate predictions of non- Stationarity data (Chiles and Delfiner 1999, Pilz

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and Spock 2007). This algorithm uses repeated simulations to obtain the best-fit

Semivariogram where the parameters are implemented using a restricted maximum

likelihood. EBK uses local models to capture small-scale changes in the data; it also does

not assume one model fits the entire dataset. The ability to predict the standard error is

more accurate than with traditional Kriging methods. The EBK model provides many

parameters, just as ordinary Kriging due to the complexity of the interpolation and

prediction methods. The model parameters such as the maximum number of points in the

local model, the model area overlap, and the number of simulations can be changed. The

search area parameters can also be modified for the type of search neighborhood, the

radius, maximum or minimum neighbors, sector type and angle. EBK has the ability to

manage highly complex data rich datasets with ease. This method using both global and

local scales for use in the interpolation has fostered EBK's use in non-traditional

interpolations.

2.3.6 Topo to Raster

Topo to Raster uses ANUDEM methodology from Australian National

University, Canberra that the latest version of ANUDEM is included within ArcGIS.

Inputs for topo to raster include point elevations, contours, and others with hydrological

applicability. Topo to raster is not available in the Geostatistical Analyst due to its

complexity of integrating various outsourced datasets, but it can be accessed as a tool in

the Spatial Analyst toolbox (Liu, Zhang and Peterson 2009). Topo to Raster provides the

functionality of incorporating other types of geographic features, which can assist in the

creation of a DEM. The parameters required for topo to raster are mostly optional to

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change from the default. Spot elevation, contours, cliffs, lakes, coasts and other boundary information can be inputted and can be utilized in creation of the final raster surface. The drainage enforcement within the tool will ensure a mostly hydrological correct surface. For this project, point elevation features were used (ESRI 1995-2013).

Overall, these interpolation methodologies provide the basic requirements of testing the integration of the topographic and bathymetric point elevation values in order to create a single raster elevation surface. Although the point datasets vary in their distribution, spatial dependency, spatial trends, and the stationarity, the surfaces created using the interpolation methods can visualize the basic differences between the surfaces created. If the point datasets were to meet the assumptions of the interpolation method, that surface would provide the most accurate prediction for the elevation within that area. Even with the Spatial Statistics taken into account for use in the interpolation, the parameters within the interpolation still influence the resulting surface (Childs 2004). Within ArcGIS, several interpolation methods have various extensions of how they can be accessed. The utilization of an interpolation from one ArcGIS Extension may have slightly different parameters, which causes changes to the resulting surface models when compare to the same points interpolated using a different extension.

2.4 ArcGIS Extensions for Interpolation

Esri's ArcGIS is the driving force of GIS development and implementation globally. Within their software suite, elevation data can be represented in several ways. Elevation is known as a functional surface, where for every X, Y coordinate pair, a Z or elevation

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value exists (X, Y, Z). Within ArcGIS Elevation can be represented in points, contours, Triangular Irregular Networks (TIN), or Grids. Points are the measured point elevation, where the only X, Y, Z coordinate to have elevation is the measured locations. Another representation of elevation is contours, which are representative lines of equal elevations. TINs represent an initial representation of a functional surface, where triangles are connecting the closest measured points. Raster grids are regular spaced cells of equal size, where the cell represents a surface of equal elevation. Grids are currently the most utilized spatial data structure for elevation (Childs 2004).

The transition from measured point to the grid data structure depends on the data density relative to the required cell size. If the points are dense and the cell size is large, than a simple tool within ArcGIS can be utilized (Point to Raster) to create a functional surface but if the points are sparse, then an estimation or interpolation of value must occur. This estimation of the values is achieved by interpolation algorithms, which use the measured points to derive the surface. Slight changes in the algorithms or modification of the parameters within the algorithm drastically alter the resulting surface, which sometimes occurs when accessing the interpolations via different software extensions.

Esri provides several software extensions, which can perform the interpolation of the gird or raster surface. Many GIScientists rely on the extensions available to them, which they are comfortable using, but potentially unexplored extensions and tools might be able to provide a more reliable surface. Contrasting the same tools accessed from two different

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extensions and comparing the results might encourage the use of future investigations.

This study will focus on are ArcGIS's Spatial Analyst and Geostatistical Analyst

comparing and contrasting their ability for interpolation. These two extensions can be

used for interpolation to a surface using many of the same algorithms, although some of

the resulting surfaces have slight variation between them (ESRI 1995-2013 , Childs 2004,

Krivoruchko 2012, a).

2.4.1 Spatial Analyst Extension

The Spatial Analyst Extension provides many interpolation algorithms in the form of

tools or scripts within the extension. Spatial Analyst is widely used for interpolation due

to the extensions other functions within GIS. Spatial Analyst allows for the manual

modification or tool parameters, which requires extensive knowledge of the Spatial

Statistics influence on the model. Without the Spatial Statistics knowledge regarding

which parameters to modify, ArcGIS does offer default parameter settings, which can be

used (ESRI 1995-2013 , Childs 2004).

2.4.2 Geostatistical Analyst Extension

The Geostatistical Analyst Extension provides access to the interpolation algorithms

by use in a dynamic Wizard. The Wizard walks the user through the various steps in

parameter assignment; some interpolation methods retain the generic default where others

require optimization for each dataset. The optimization can be done by default within the

Geostatistical Wizard or be optimized by selecting the setting. The optimization uses the

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Spatial Statistics of the input dataset to assign the parameter values in order to reduce the

standard error of the resulting surface (ESRI 2001, Krivoruchko 2012, a).
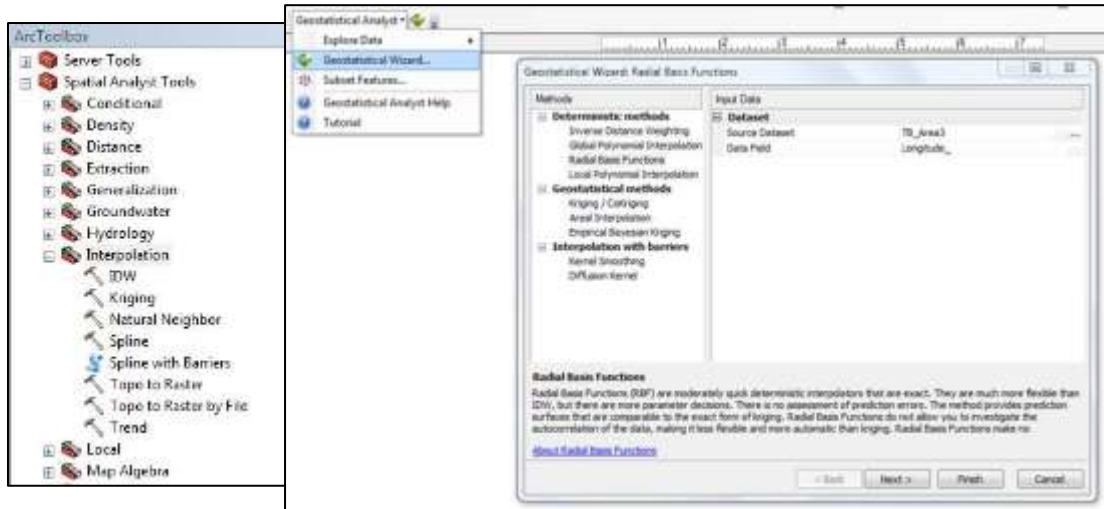
Figure 2: Screenshot of the Spatial Analyst toolbox (left) and the Geostatistical Wizard (right). These two extensions provide an easy-to-use accessibility of point to Raster Grid Surface.

The ArcGIS Extensions of Spatial Analyst and Geostatistical Analyst contain several

comparable interpolation algorithms, but not all interpolation algorithms are available

within the Geostatistical Wizard. As well as some interpolations within the Geostatistical

Wizard do not have the optimization option, several are optimized by default.

Table 1: ArcGIS 10.2 Extensions and Interpolation Comparison.

Interpolation Method		Esri ArcGIS Desktop Extension	
		Spatial Analyst Tool	Geostatistical Analyst Wizard
Inverse Distance Weighting		✔	✔ ✦
Natural Neighbor		✔	✦ ✦ ✦
Spline	Regular	✔	✔
Spline	Tension	✔	✔
Kriging		✔	✔ ✦
Empirical Bayesian Kriging		✔ ✦	✔
Topo to Raster		✔	✦ ✦ ✦

✦ Available as a tool in the Geostatistical Toolbox.

✦ ✦ Needs selection of the parameter for optimization.

✦ ✦ ✦ Not Available in Geostatistical Analyst Wizard.

Although EBK is not available within the Spatial Analyst Toolbox, in this document it is referenced as such. This is due to the ability to access EBK through the toolbox for the Geostatistical Analyst. This is an important distinction, and has been completed due to the finding of different parameter choices from the Wizard and the toolbox specifically within the Geostatistical Analyst Extension (Krivoruchko 2012, a & b).

The following section provides a general review of the previous work completed on the general topics of the study. First, the review investigates the previous work completed on the comparison of interpolation methods. Second, the review investigates the previous cases of topographic and bathymetric integration to create a Topographic/Bathymetric

DEM. Special notes are be made for the areas where the study lacked the detail to truly

inform the reader regarding the extension utilized to access the interpolation algorithm.

Chapter 3: Related Work

The previous sections emphasized the technical documentation of elevation data

acquisition, Spatial Statistics, interpolation algorithms and the use of various ArcGIS

specific extensions; this section summarizes some of the existing case studies. Since there

is no functional way to compile the case studies related to this thesis, classifications of

the topics in this section is divided into Spatial Statistics, interpolation comparisons and

the Topographic/Bathymetric integration.

In summary, the Spatial Statistics of the point dataset can influence the study

depending on interpolation methodology. Without the studies mentioning the specific

extensions and software utilized, results of interpolation cannot be recreated. The point

dataset has various results of accuracy and suitability when comparing interpolation

algorithms surfaces. The use of pre-existing DEM surfaces with unknown interpolation

origins cannot be held as reliable without understanding the pre-interpolated point data or

without a large amount of measurement verifications.

3.1 Spatial Statistics Importance

Spatial Statistics, in particular Geostatistics is challenging because of the

complicated interaction of geography and parameter values. Greater consideration should

be assigned to Spatial Statistics and its roll in analysis (Scott 2010). The value taken into

consideration when interpolating is not necessarily important other than the requirement

of spatial auto-correlation. The study by A. N. Kravchenko (2003) details the

interpolation method using soil samples. It concluded that the spatial structure of the

dataset plays a greater role than the variability of the data points. Additionally Heritage et al. (2009) reinforces A. Kravchenko's research that the impact of the terrain and density of the points have a greater influence than the interpolation models although it is important in terms of representative accuracy. The two studies follow the technical documentation that understanding the Spatial Statistics within the point dataset can foster a better understanding of the interpolated surface. As mentioned in several accredited journals the interpolation algorithm used in creating a surface directly affects the accuracy of the DEM (Erdogan 2009, Aykut, Akpinar and Aydin 2012, Eakins and Grothe 2014).

The spatial auto-correlation of a large riverbed effects the representation of the correlation and trends within the dataset. This is illustrated by a series of research articles writing by V. Merwade (2009) which discusses a methodology to reduce the impact by converting the X, Y coordinates into a channel fitted coordinate system essentially straightening the river meanders. The impact of this change within the datasets, better accounts for the variability and potential issues that might arise from interpolating river bathymetry datasets. These studies although very important were outside of the scope of this project. It is important to note that without Merwade methodology the Trends and the visualization of the Semivariogram /Covariance Clouds might not follow the traditionally expected results.

The optimization of parameters is reliant on the spatial statistics for any number of interpolation methods. Lu and Wong (2008) identified the importantce of modifying the parameters in the IDW interpolation methodology to create an surface.

3.2 Interpolation Comparison

The selection of interpolation algorithms has led to numerous studies comparing and contrasting the interpolation algorithms. No comprehensive study has been completed on the suitability of one algorithm over another (Krivoruchko and Gotway 2002). Studies focus either on topographic interpolation, bathymetric or on some combing the two (Liu 2008, Erdogan 2009, Heritage, et al. 2009, Merwade 2009, Aykut, Akpinar and Aydin 2012).

Erdogan (2009) interpolates topographic elevation by using the interpolation algorithms: IDW, ordinary Kriging, multiquadratic radical based function, and thin plate Spline using the Geostatistical Analyst Extension within ArcMap, looks at the effect of the density of the raw data, the interpolation techniques, the impact of interpolation on accuracy on hilly terrain, and examines methods for uncertainty. The results of this study concluded that IDW produces greater overall uncertainty, due to exacerbated results by low density of point data. The use of the Geostatistical Analyst for interpolation and the reduction in point density lead to further investigation on the Spatial Statistical influence on the models and the parameters (Erdogan 2009).

Aykut, Akpinar and Aydin (2012) discuss the comparison of seven interpolation methodologies, but is not explicit on the software utilized for interpolation or the

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parameters implemented. The conclusion states that the interpolation is important for the overall accuracy of the DEM and in general, Kriging methodology is most suitable for low-density single beam sonar datasets. P.V. Arun (2013) discusses the comparison of several interpolation methodologies, as with the previous study only mention of ArcGIS was stated but no explicit mention of software extension (Arun 2013). The need to identify not only the software but the extension us for interpolation is gravely important.

Looking into the interpolation methodology using the ArcGIS Geostatistical Analyst Extension, Badea (2013) discusses the need in geomorphic modeling for comparing models with the same data. This includes utilizing the same interpolation methods, but modifying the parameters for optimization (Badea 2013). In summary, there is no interpolation algorithm, which is best for all datasets. The statistical and data variability when comparing two or more interpolation algorithms, some criteria must be met to provide justification for over method to be chosen over another. This accuracy assessment can be defined as representative against the true surface, or statistically valid using Root Mean Square Error, or by simple visualization of what would seem to be a functioning surface.

Badea (2013) concludes that there is no practical methodology for accuracy assessment, but utilization of the Root Mean Square (RMS/ RMSE) Error prediction can augment the understanding of accuracy using cross validation. RMSE is a measure of cross validation in which comparisons are performed from the predicted values to the observed values for all point values used in the creation of the surface raster. The

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utilization of RMSE for the interpolation methods provides a valuation of the interpolated error but many particularly within the Spatial Analyst Extension do not provide RMSE. Therefore, it is important to identify and estimate errors enforcing the concept of understanding the spatial variability and Spatial Statistics of the dataset (Erdogan 2009, Liu, Zhang and Peterson, Evaluation of the preformance of DEM interpolation algorithms for LiDAR data 2009, Badea 2013). The documentation for the Geostatistical Analyst Extension does not mention the "best" interpolation or "most accurate" it simply states that the reliability of a surface and ease for the user is important (Krivoruchko 2012, a).

Creation of Topographic/Bathymetric DEM is not a new; geographers have placed the two type of information side-by-side for oceanic navigation purposes. Integration of River Bathymetry has failed to develop do to the constantly changing riverbed morphology. Ever complicating the advanced analysis of bathymetric data collection, is that the measured points are not taken in a random sequence, rather a method of measuring in straight lines called transects is the preferred method. This causes obvious complications for data dependency and spatial Trends. Merwade (2009) resolves this issue, which also accounts for the morphology of river channels. The factors of the morphology will impact the data analysis of spatial auto-correlation for the different Project Areas, but the solutions posed by Merwade (2009) is not preformed within this study therefor the spatial variation of the dataset may seem untraditional.

3.3 Topographic/Bathymetric DEM integration

The USGS and NOAA lead the data integration process of Topographic/Bathymetric DEMs using a variety of datasets from historical nautical charts to advanced multi-color laser sensor LiDAR technologies. Their overall process is to take previously created DEMs and preform a merging procedure (Gesch and Wilson 2002, Barnard and Hoover 2010, Medeiros, et al. 2011, Foxgrover and Barnard 2012, Dewberry Consultants LLC 2013). It does not take the point values in which the surfaces are create into account, creating a dataset with compounding errors.

According to Foxgrover and Barnard (2012) and Barnard and Hoover (2010), when creating a Topographic/Bathymetric model for San Francisco Bay and Southern California, details the systematic procedure to integrate various topographic and bathymetric DEM datasets, these rely on the already created DEM's from LiDAR and Sonar point datasets and integrates. The implemented methodology as the standard within the USGS lacks the integrity of an algorithmic interpolation method as well as inheriting the interpolation uncertainties from the previous creation of the various DEMs. Although the methodology creates a compilation dataset, issues such as data overlaps and data gaps are , the research in this study is looking into the interpolation algorithms of point to surface and not on surface to surface.

Gesch and Wilson (2002) uses a similar procedure with the existing DEM's as was done for San Francisco Bay, although the variation includes converting the existing DEM's into points contains the derived elevation. Then the points were processed using

the ArcGIS tool entitled TopoGRID (in ArcGIS 9.X+ this tool is called Topo to Raster), which uses a Thin Plate Spline which is optimized for creating topographic surfaces. The detailed methodology used in both Tampa Bay studies attempts to provide an overall hydrological enforced interpolated surface. In this study, adding the Topo to Raster toolset as an interpolation algorithm is an interesting comparison, although no version of the tool exists within the Geostatistical Analyst Extension.

The NOAA requested a report be compiled detailing the steps in the creation of a California Coastal Topographic/Bathymetric DEM, this report is entitled "Coastal California Data Merge Project" (Dewberry Consultants LLC 2013). It discusses the procedure utilized to create and integrated DEM by focusing on the data inputs and additional post-processing of the dataset to classify the data into a hierarchy of suitable datasets. The hierarchy is then used to create a Topographic/Bathymetric DEM and again is preceded with smoothing algorithms, void identifications, and other post DEM creation methodology. Most of NOAAs projects emphasize the ocean bathymetry, leaving the near-shore and river bathymetry as data voids. The methodology is helpful in large-scale project analysis, but community-planning level does not benefit for this type of large-scale data integration. This project will tackle integrating some of the local data products into a seamless datasets for future integration into larger compilation DEMs.

A hydrodynamic interpretation of combining topographic and bathymetric data for Bogue Inlet, North Carolina is published in the U.S. HYDRO 2011 (Bernstein, et al. 2011). It discusses the challenges of integrating the various interpolation methods with

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the different and ever-changing morphology of the coastal/river inlet. This study reinforces and details some of the challenges of measuring river and tidal channels for perceived accuracy, when conditions are ever changing. The conclusion of the study focuses on the need for advanced field surveying techniques and flexible interpolation methodology. It suggests selecting the interpolation methodology based on the measured point density of the surveys, although it does not state which software or extensions were used in the creation of their final dataset.

The government developed studies complete the Topographic/Bathymetric DEM creation with an general understanding of accuracy as defined by "best available" information as the input, but some of the "best available" is over twenty years old. The changes in morphology and sedimentation occur on a shorter time scale. The methodology presented in the government case studies seems appropriate when the raw data cannot be acquired, but only used as a last option.

The integration of the Topographic/Bathymetric datasets focused on the "seamless" data products from existing datasets, where a focused need for continual mentoring of coastal waters to ensure the reliability of the datasets. The study in the Bogue Inlet of North Carolina hints at the need for generating data products using more recent data collection techniques, technology, and post-processing interpolation.

Chapter 4: Methodology

Many past studies have lacked investigation on the interpolation algorithm and the extensions influence on the surface model. This framework offers that it is a useful methodology on any study where interpolation is used to understand and select the most suitable interpolation algorithm. In order to reproduce the exact results within this study, the exact data requires identical configuration. Any slight variation in data inputs, geography shifts, or the distribution of the data and the results will changes the data's reaction to the algorithm.

This study mainly implements Spatial Analyst Extension Toolbox or the Geostatistical Analyst Geostatistical Wizard (Seen in Figure 2). For the Toolbox, a particularly selected interpolation algorithm runs under the default settings and parameters. The Geostatistical Wizard runs under the default settings and optimized parameters. This creates up to three surfaces for a single Project Area for one interpolation algorithm. Comparisons of these surfaces illustrate the variability within the Spatial Analyst and Geostatistical Analyst parameters of the algorithm and its effect on the surface. The algorithms used as part of the comparison include IDW, NN, Spline Regular, Spline Tension, Kriging, EBK, and Topo to Raster. These interpolation methods were most prevalent in the literature for interpolation of elevation surfaces.

The methodology process is simple although understanding the resulting surfaces is complex and essential for making a determination for usability. The study area

geomorphology and the data utilized within this project have a direct impact on the surfaces output.

4.1 Klamath River Study Area

The Klamath River, spans from north-west Oregon to the Pacific Ocean in California. Many natural and man-made conditions affect the flow of the river and the river's ability to flush sediments into the Ocean. The Klamath River Estuary located in the town of Klamath, CA develops the sediment buildup, which can modify the river's natural flow from day to day. The study area was selected due to the recent multi-agency data collection efforts and future removal of dams upstream.

The Study Area of the Klamath River Estuary divided into 5 Project Areas, (See Figure 3) to investigate the river flow influencing on sedimentary layers. Each Project Area is approximately 10 acres, spanning the entire river, and encompassing at least 200 ft. of land on either side of the River's banks. Although the Project Areas are referenced in detail within this document, understanding the relationship to the larger study area is important because their impact on the Spatial Statistics on the Topographic/Bathymetric DEM surface creation.

Figure 3: Map of the Klamath River Estuary with the selected Project Areas highlighted.

4.2 Datasets

The LiDAR and Sonar datasets are vastly different in terms of measurement

technology and therefore have different accuracy standards, processing requirements, and

spatial constraints (NOAA Coastal Services Center 2007).

The topographical datasets were collected using a LiDAR sensor from aircraft

under the project title of the California Coastal LiDAR Dataset under the supervision of

NOAA, USGS, etc. The data was collected over the Klamath River on approximately

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November 8 through December 7, 2010. The data producers verified all the accuracy standards, performed post-processing to remove artifacts, and completed the final reporting as stated within the contract.

The California Coastal LiDAR Dataset is free to download via the http://coast.noaa.gov/ website. The dataset consists of several configuration options for representing the LiDAR data by the classified points: "Ground," "unclassified," "water surface," "overlap"; as well as return types: "any," "first," and "last". The selection for modifying the coordinate information is also available. For this analysis, the classified "ground" point features of "any" return type were selected from the download website with associated X,Y,Z values in ASCII format in a projected coordinate system California State Plane North American Datum of 1983 (NOAA Coastal Services Center 2007, NOAA Coastal services center 2014). No other post processing was completed on the dataset. For the Study Area around the estuary of the Klamath River, the data consisted of 6,394,830 measurements, with an average measurement density of 2.28 points per square foot (See Figure 4).
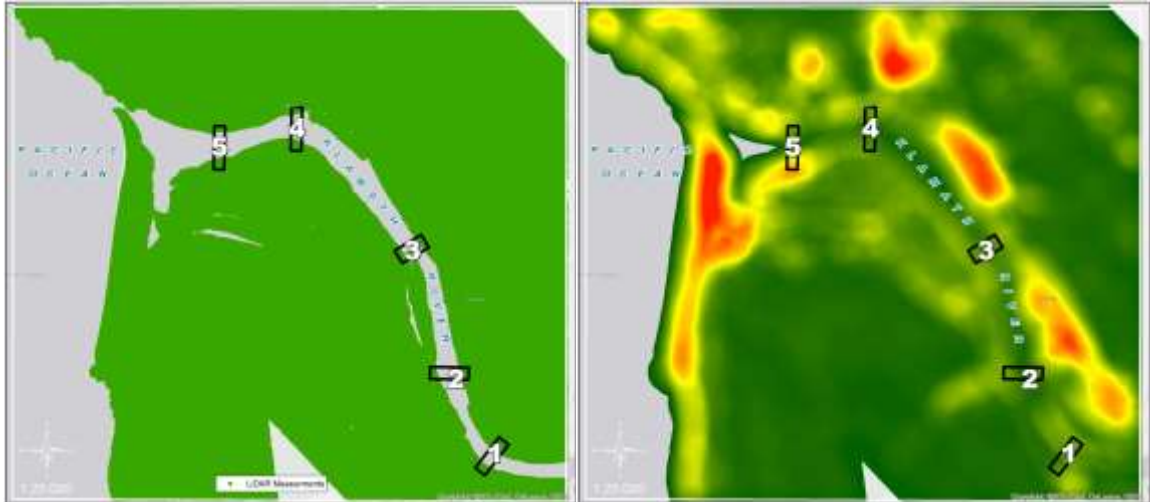
Figure 4: (Left) Individual LiDAR point measurements. (Right) Density map of the LiDAR measurements averaging 2.28 points per square foot.

The bathymetry data, as part of a project by the Yurok Tribe between July 16 and 23, 2013, was collected using single-beam sonar or echo sounder system. The data collection, processing, quality assurance was completed by a contractor specializing in hydrographic surveys while training the Yurok Tribe staff in the technical requirements of collection, processing, and quality assessment which were completed to the industry standards set by the Army Corps of Engineers Hydrographic Survey Manual. The final data and report products are not publicly available, although requests can be made to the Yurok Tribe. The horizontal control is set by California State Plane North American Datum of 1983 and the vertical control is referenced to North American Vertical Datum of 1988 (NAVD88) as detailed in the unpublished survey report. The quality assessment process, detailed in a report that was attached to the geographic dataset when requested. The bathymetric dataset for the Klamath River estuary consists of 16,510 measurements, with an average measurement density of 9.68 points per square feet (See Figure 5).

Figure 5: (Left) Individual Sonar point measurements. (Right) Density map of the Sonar measurements averaging 9.68 points per square foot

Due to the final product consisting on a single DEM, the points from the LiDAR and Sonar technologies were merged geographically. Merging the point files prior to interpolation reduces the propagation of errors seen in the government case studies, although some slight overlapping of data points do occur due to the gap in time between LiDAR and Sonar collections. This reduces the challenge in creating a seamless DEM as well as accepting the point distribution within the datasets.

When analyzing the various point datasets the identification of the spatial Trends, the spatial dependency, the point distribution of values and locations, and the stationarity of the dataset must be taken into consideration for use with the various interpolation methods.

4.2.1 Statistics

The importance of the Spatial Statistics has been discussed within the background section of this document. Understanding the data's distribution, stationarity trends, and spatial auto-correlation are factors, which influence the decision of choosing an interpolation algorithm. For this project and review of the data used, the visualizations of the factors will not be illustrated-- only the resulting conclusion derived from the visualizations.

Interpolation algorithms do not have a limit on the number of points they can interpolate, but due to the limitations of visualization and characterization of the various methodologies, the selection of Project Areas are limited. From various Project Areas, the LiDAR and Sonar points were randomly selected to create subset datasets with 250 points of LiDAR and Sonar respectively. This resulted in the five various Project Areas to have each 500 elevation measurements equally derived from LiDAR and Sonar. These subset datasets were used to create the interpolated surface elevations and the various other results (Table 2, Figure 6).

Table 2: Statistical comparison of the entire Project Area to the subset dataset used to create the interpolated surfaces.

		Number of Measurements	Min	Max	Mean	Median	Std. Dev
Project Area 1	Entire Area	13,107	-16.0	116.5	14.7	5.7	19.6
	Subset	500	-16.0	105.9	3.6	0.9	18.3
Project Area 2	Entire Area	4,976	-9.0	41.9	9.2	9.3	7.4
	Subset	500	-9.0	39.7	2.5	0.7	8.7
Project Area 3	Entire Area	10,765	-19.7	42.4	11.2	4.7	14.1
	Subset	500	-19.7	42.2	1.2	0.4	14.7
Project Area 4	Entire Area	9,984	-31.6	72.0	9.5	10.3	11.4
	Subset	500	-31.6	70.4	-0.2	0.2	13.8
Project Area 5	Entire Area	19,072	-17.9	90.6	7.2	5.3	7.3
	Subset	500	-17.7	51.4	-2.6	0.4	11.2
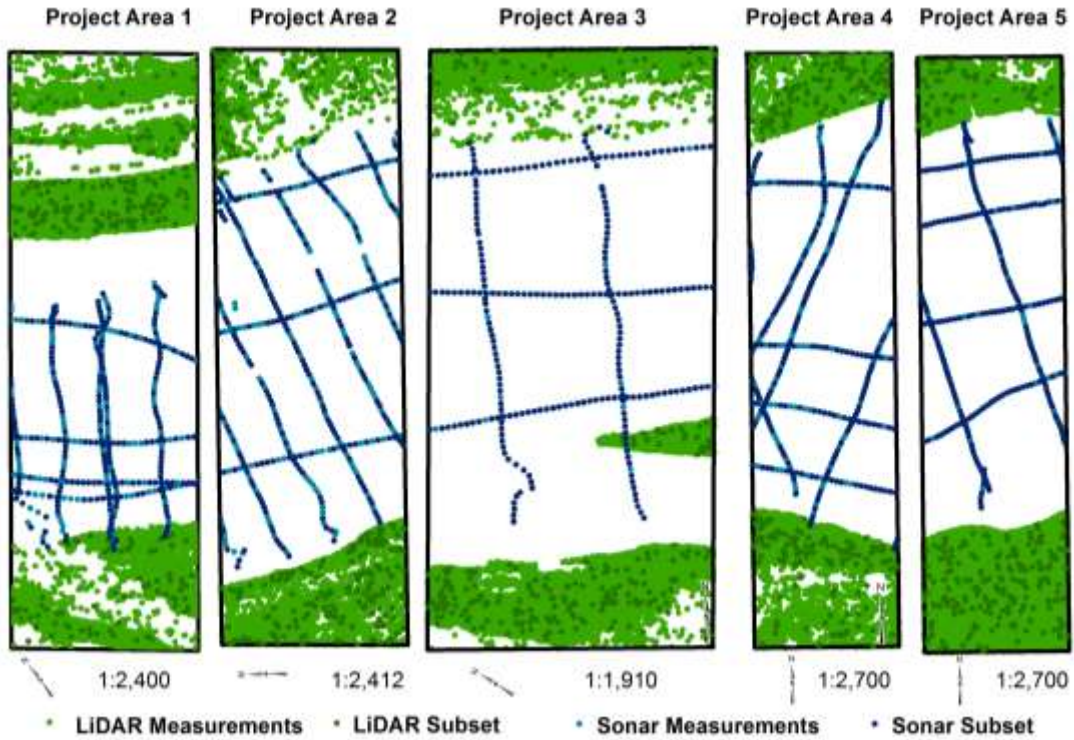
Figure 6: Maps of Project Area(s) with LiDAR - Sonar Measurements with the Subset data used in the creation of the surface profiles.

4.2.1.1 Project Area 1

Project Area 1 is characterized by a deep channelization of the river on the southwest corner, as well as a gradual sloping riverbank on the opposite side of the river. This area contains 13,108 measured points, 12,724 points resulting from LiDAR and 384 points from Sonar. The points used in the interpolation of the surface contain a randomized sample of 250 LiDAR and 250 Sonar Points (Table 2).

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Figure 7: Graph illustrating the distribution of the merged LiDAR and Sonar points used in the creation of the surface profiles for Project Area 1.

Normal distribution within the point dataset is an important factor to account for when choosing an interpolation method. Project Area 1, for the subset and Project Area dataset is slightly skewed to the right with a skewness factor of 2.3 (Figure 7) and 1.9. The statistical distribution of the full point datasets varies slightly in the minimum, mean, median and max. Although the datasets do not equally reflect each other and are skewed, they are considered normally distributed and do not require any transformation. The representation of the Normal QQ plot illustrates the dataset as compared to a standard normal (Gaussian) distribution, which is shown as a solid line. The variation of the dataset is not enough to confirm the findings of the histogram and require any data modifications. The data reduction has very little effect on the results as seen on the histogram and Normal QQ plots.

The stationarity of the dataset is the statistical relationship between two points, which depends on the distance between them. The Voronoi map are used illustrated the

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stationarity for Project Area 1 the subset dataset, the data is stationary. Visualization of

trends within Project Area 1 can be seen functionally within a 3D environment, due to the

morphology.

The spatial auto-correlation as illustrated by the Semivariogram and Covariance

Cloud contains the spatial relationship between the individual points within the dataset.

Within Project Area 1, both do not represent what would normally be illustrated within

the Semivariogram and Covariance Cloud graphs. This issue is illustrated and accounted

for in research performed to account for the morphology of river channels (Merwade

2009) is not preformed within this study therefor the untraditional spatial auto-correlation

of the datasets.

These representations of the spatial and statistical variation within the dataset are

important to keep in mind when performing the interpolation. Understanding the

relationship the points have within their geographic space is the bases of the interpolation

algorithm methodology. From Project Area 1, the distribution of the dataset is normal,

with little stationarity and no trends, and the data is spatially auto-correlated. The effects

of Project Area 1's spatial and statistical variation will be compared in the results section.

4.2.1.2 Project Area 2

Project Area two is characterized by a general straight flow of the river, with distinct

riverbanks. The area is notorious for containing underwater impedances due to old bridge

pilings. This Project Area contains 4976 number of measured points, with 4552 from

LiDAR measurements and 424 from the Sonar collection. The points used in the

interpolation of the surface contain a randomized sample of 250 LiDAR and 250 Sonar
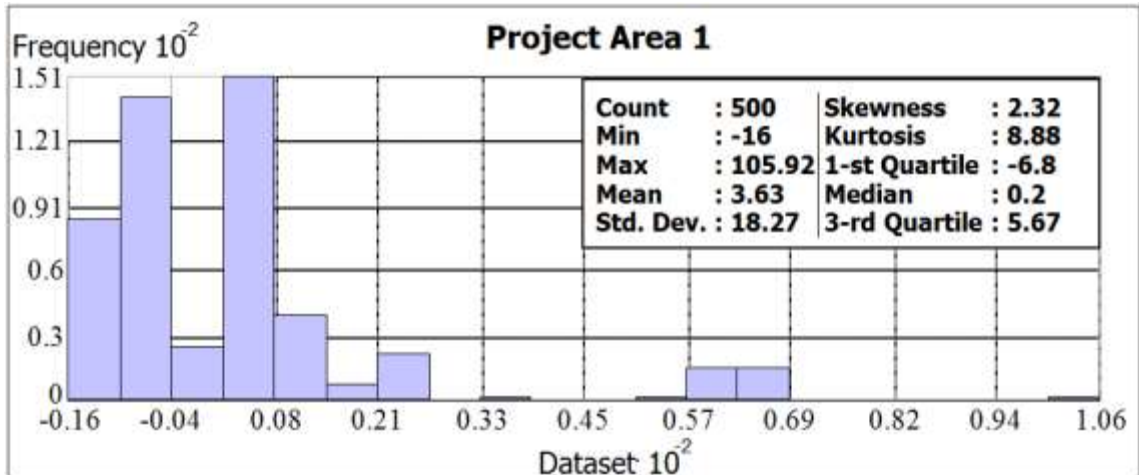
Points (Table 2).

Figure 8: Graph illustrating the distribution of the merged LiDAR and Sonar points used in the creation of the surface profiles for Project Area 2.

The statistical variation between the entire Project Area and the subset dataset can be

illustrated in the histogram with a skewness factor of 0.82 as seen in Table 2 and Figure

8. The point values on the histogram vary slightly from a traditional normal distribution,

but this variation is not large enough to require the use of a transformation. Normal QQ

plot illustrates that project are 2 points, follows relatively close to a standard normal

distribution.

Voronoi map are used to visualize the stationarity of the dataset and it shows very

little variation with the dataset for Project Area 2 the subset dataset. The trends shown in

the 3D environment illustrate the relationship for the data to their environment.

The Semivariogram and Covariance Cloud illustrate the spatial relationship between the individual points within the dataset or the spatial auto-correlation. Within Project Area 2, the clouds are not illustrating the expected results. The reasoning is due to the theory discussed within Project Area 2, where the river morphology influences the spatial relationship of the points.

Within Project Area 2, analysis of the point dataset reviles that the spatial and statistical variation in the dataset can be seen that the data is normally distributed, has little to no stationarity, no trends which need to be removed, and that the data is spatially auto-correlated. From these illustrations of the spatial and statistical variation within the dataset for Project Area 2, a majority of the interpolation methods can be utilized without much concern for the applicability. The spatial and statistical variation within the dataset for the entire Study Area is still important when comparing the interpolation methodologies.

4.2.1.3 Project Area 3

Project Area 3 is the most complex Project Area, not with respect to river morphology, but with respect to having a peninsula within the Project Area. This Project Area is a representation of the data inconsistencies that might occur when there is a time delay in LiDAR or Sonar data collections discussed in the USGS publication for the Conceptual Prototype for the Next-Generation National Elevation Dataset (Stoker, et al. 2013). The peninsula during the LiDAR collection was visible, but through the bathymetry collection, either the river level was higher or the morphology changed to

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remove the sedimentation that had created the spit. This influences the Spatial Statistical

variation within this Project Area and is something to note and revisit within the results.

This Project Area contains 10,765 numbers of measured points, with 10,505 from LiDAR

measurements and 260 from the Sonar collection. The points used in the interpolation of

the surface contain a randomized sample of 250 LiDAR and 250 Sonar Points (Table 2).
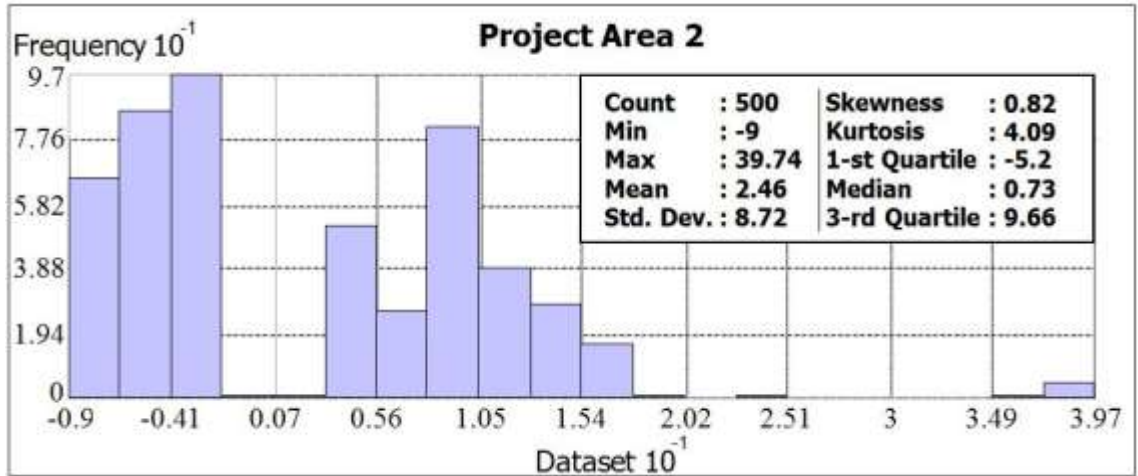

Figure 9: Graph illustrating the distribution of the merged LiDAR and Sonar points used in the creation of the surface profiles for Project Area 3.

The histogram and the Normal QQ plots both provide the visualization that the data is

normally distributed to such a degree that transformation is not required. The scattering

of the data points can be seen by the statistics contained within the histogram. The

histogram looks skewed with a value of 1.41 as seen on Figure 9. The data is slightly

clustered towards the lower data values, but extends out to the high values provides a sort

of equalization.

For Project Area 3 the subset dataset the variation seen in the Voronoi map is a method to describe the stationarity of the dataset, shows that the data is stationary. The trends shown in the 3D environment illustrate the relationship for the data to their environment.

Visualizing the spatial auto-correlation of the datasets is performed by analyzing the Semivariogram and Covariance Clouds. These graphs within Project Area 3 illustrate the geographic relationships between the datasets and although they do not exactly fit the expected result of increasing with distance and decreasing with distance, their general trend leans toward this conclusion.

The visualizations for Project Area 3 illustrate that the point dataset is normally distributed; stationarity with little trends and follows the spatial auto-correlations. These factors can be used with selecting an interpolation method, as some are better-suited data distribution types.

4.2.1.4 Project Area 4

Project Area 4 has a gradually sloping bankline with deep channelization of the river due to the force of the water upstream and has a sharp incline into the land once again via a levee feature and boat docks. This Project Area contains 9,984 of measured points, with 9,623 from LiDAR measurements and 361 from the Sonar collection. The points used in the interpolation of the surface contain a randomized sample of 250 LiDAR and 250 Sonar Points (Table 2).
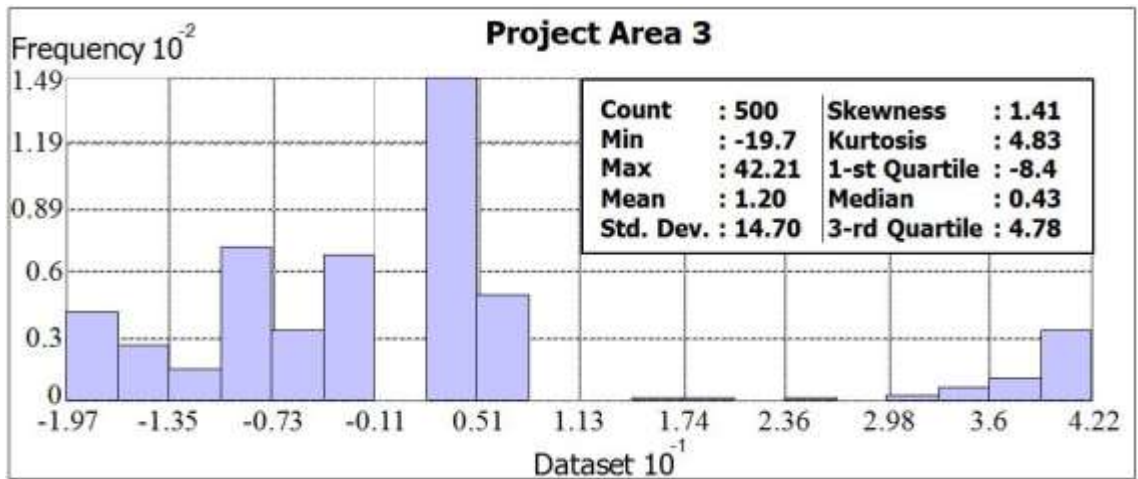
Figure 10: Graph illustrating the distribution of the merged LiDAR and Sonar points used in the creation of the surface profiles for Project Area 4.

This point dataset plotted on a histogram can determine if that data is normally distributed. This distribution although visually skewed with a value of 1.90 as seen in Figure 10, offer enough distributed variation to not require any transformation processes. The Normal QQ plots for Project Area 4 generally follow the Gaussian distribution, which is shown as a solid line. There are a few outliers, but their impacts on the overall dataset are very little.

The Voronoi map for Project Area 4 illustrate that the dataset is stationarity when classified by entropy. The darker colors represent the higher rates of change of the values within the dataset for neighboring point values. Project Area 4 has very little obvious trends within the dataset, aside from the river channelizations.

The Semivariogram and Covariance Clouds illustrate the level of spatial auto-correlation contained within the dataset. The representations of the geographic

relationships are not within the expected range, but the relationship tends to follow the traditional variation.

The point dataset for Project Area 4 demonstrates that the point dataset is normally distributed; that the dataset have little to no trends and that the data is known to be spatial auto-correlations. These features should be used when wanting to create a surface feature, due to influence that these features have on the interpolation parameters.

4.2.1.5 Project Area 5

This project Area 5 contains a low elevation wetland island, with a deep channel river outlet as the water flows near the ocean to a manmade levee and boat ramp. This Project Area is most susceptible to tidal influence, although we are not accounting for tidal flow into the measurements. This Project Area contains 19,072 of measured points, with 18,791 from LiDAR measurements and 281 from the Sonar collection. The points used in the interpolation of the surface contain a randomized sample of 250 LiDAR and 250 Sonar Points (Table 2).
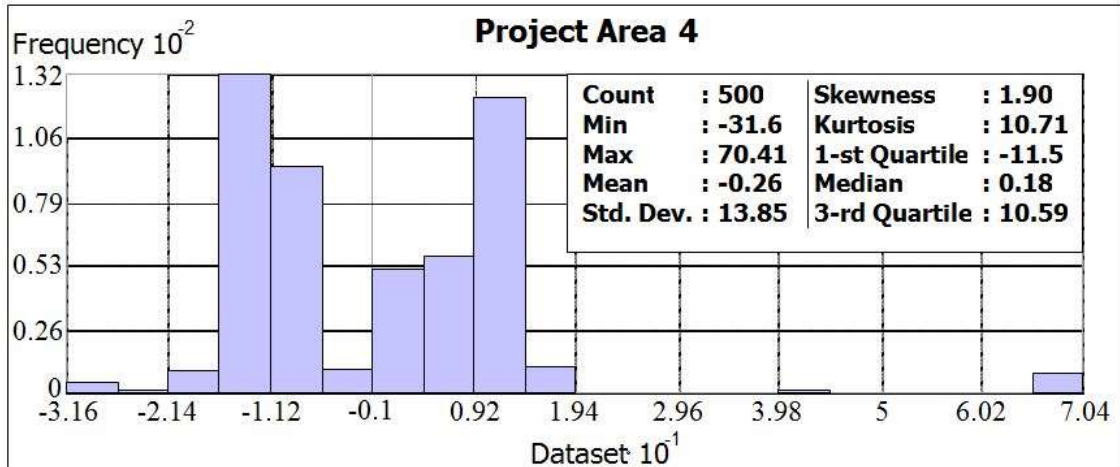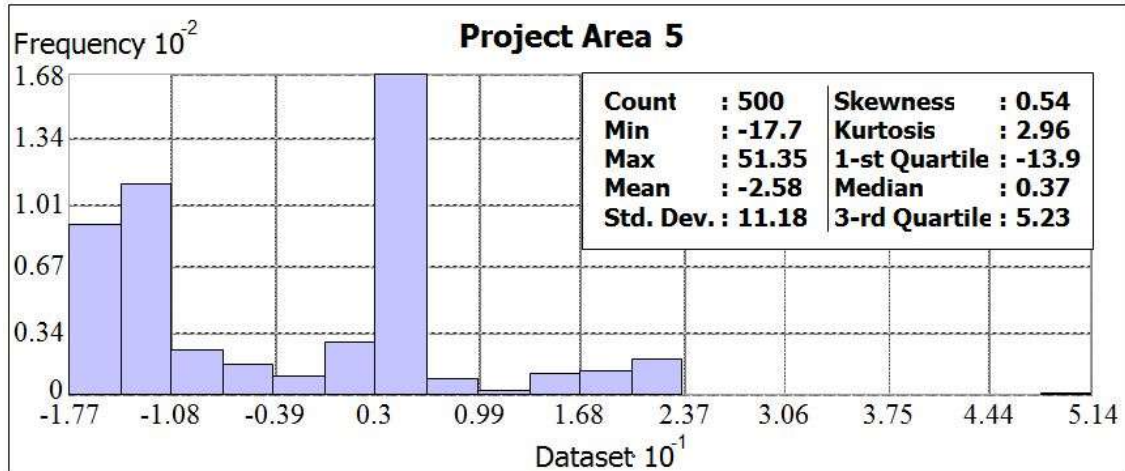
Figure 11: Graph illustrating the distribution of the merged LiDAR and Sonar points used in the creation of the surface profiles for Project Area 5.

Histograms and the Normal QQ Plots can visualize the distribution of the point dataset within Project Area 5. The histograms illustrate the datasets distribution around a normal distribution curve, the skewness of the dataset falls within the limits of not requiring any transformations at a value of 0.54 in Figure 11. The Normal QQ Plots which create a linear feature to attempt to best fir the dataset.

The Voronoi map for Project Area 5 illustrate that the dataset is stationarity when classified by entropy. The darker colors represent the higher rates of change of the values within the dataset for neighboring point values. Project Area 5 has very little trends within the dataset. The 3D view of the point dataset

The Semivariogram and Covariance Cloud in Project Area 5, the clouds are not illustrating the expected results. The clouds show the representation of the data's distribution of the points for the area verse the distance between the points themselves.

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Project Area 5, has an interesting point distribution which reviles the spatial and statistical variation in the dataset can be seen that the data is relatively normally distributed. This dataset has little to no stationarity, no trends which need to be removed, and that the data is spatially auto-correlated. The illustrations of the spatial and statistical variation within the dataset for Project Area 5, shows that a majority of the interpolation methods can be utilized for this dataset.

For the 5 Project Areas datasets, none of the Project Areas follows exactly the expected results of the data analysis. Even with this variation, the irregularities are not great enough to require modification of the datasets themselves. The datasets, with the traditional distribution and variation which are used in the creation of the various raster surfaces.

4.3 Interpolation

For processing, the point datasets for the various Project Areas Esri software was utilized, particularly Esri's ArcGIS Desktop 10.2.1 software access to the Spatial Analyst and Geostatistical Analyst Extensions. The Spatial Analyst tools were accessed through the ArcToolbox window, Spatial Analyst toolbox. The Geostatistical Analyst accessed through the Geostatistical toolbar and performed the interpolations the Geostatistical Wizard. The Geostatistical Analyst Extension and Wizard requires users to interface with the Wizard prompts having an overall greater functionally.

The Geostatistical Wizards use of the optimization settings within the Wizard has been proven in the research (Krivoruchko 2012, Badea 2013). This optimization modifies

the parameters within the interpolation methods to better fit the point dataset. Although this optimization can only enhance the resulting interpolated surface, it is not always defaulted parameter within the Wizard. Manual selection is required in Geostatistical interpolation methods IDW and Kriging. Not all interpolation algorithms are available within the Geostatistical Wizard.

This project will investigate the variation between the Spatial Analyst Extension's default parameters and the default and optimized parameters of the Geostatistical Analyst Extensions Wizard, see Figure 3 for summary of interpolation methods available in which extension. The IDW and Kriging are the only interpolation algorithms to require the three surfaces creation; this is due to the Geostatistical Wizard not automatically optimizing the parameters. Spline Regular and Spline Tension have results with the Spatial Analyst tool and the optimized by default Geostatistical Wizard. The algorithms of Topo to Raster and Natural Neighbor are not accessible via the Geostatistical Wizard as well as EBK not being a part of the Spatial Analyst toolset, but are important interpolation algorithms to the creation of Topographic/Bathymetric surfaces in many studies.

4.4 Illustrating Results

The results from the interpolation into a Topographic/Bathymetric DEM can be visualized in several such as statistical tables, profile graphs and maps for each raster Project Area.

The non-geographic tables provide a way to analyze statistically, the entire interpolated raster surface as a set of values. The variation provides a broad understanding of the underlying raster surfaces, particularly important within Geostatistical interpolation models. The local and global variation of the measured values can assist in understanding how might the data distribution's effect on the interpolated surface. The comparisons of the tables are for each individual Project Area. Illustrating the non-geographic variation in the elevation values within the interpolated raster surfaces of the subset Project Area. The raster surface created with the Spatial Analyst tools does not have a valuation for the root means square error (RMSE). As discussed in chapter 2, not all interpolation algorithms are available within the Extensions of Spatial or Geostatistical Analyst, nor have all the parameters within the Geostatistical Wizard have been optimized.

The profile views provide the comparison of the various interpolated surfaces to make a determination of the suitability and continuity of the dataset for the topography and bathymetric datasets integration. The entire selected Project Areas contain Land-Water-Land surfaces and are visualized by three transects of the Land-Water-Land integration. The graphs, labeled A, B, and C respectively, depending on the interpolation methodology can have between one and three raster datasets represented, which illustrate the tool, the default Wizard and the Wizard optimized. The measured points are also illustrated on the graphs represent a 50ft area around the interpolated transect as potential

measurements used to create the surface, although the points may not have been accounted for within that surface.

The general visualization or maps of the entire Project Areas surface raster's is helpful to see the overall elevation variation. Although comparing the distinct elevations is challenging in map visualizations, the visualization of the difference between the tool and the interpolation with the least RMSE was also completed. Each dataset is classified in order to exaggerate the elevation variation between the merged datasets, at the water surface by classifying the data values as follows: -30, -25, -20, -15, -10, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 10, 15, 20, 25, 30, 35, 40, 50, 60, 70, 80, 90, and100. This visualization lacks the ability to compare the interpolation's differences.

Chapter 5: Results

The results of this study provide difference between the Spatial Analyst and the

Geostatistical Analyst Extensions. Those can also help GIS Professionals to make an

informed choice when tasked with creating an interpolated surface. The results chapter

consists of two subsection; 1) parameter variation section illustrate the software

variability of the seven different interpolation algorithms, and 2) interpolation section

provides statistical and visual (Surface Raster's and Transects) examples of the impact on

the resulting surface with the variability on the interpolated surfaces by use of case study

of the Klamath River estuary. These comparisons are conceptually interesting, and should

increase awareness of the complicated role of the data's statistics influence on the

interpolated surface, which can be completed by using Geostatistical Analyst Extension's

optimization setting, but it also provides the proof that documenting the interpolation

algorithms used should be part of the metadata of all raster surfaces.

5.1 Parameter Variation

   ArcGIS is known for having multiple ways to access a function within their software.

The implication of this is that many GIS Professionals assume standardization between

the two functions with the same name. With interpolation, this is not the case.

Standardization between the interpolation methodologies of the Spatial Analyst

Extension and the Geostatistical Analyst Extension vary, resulting in surface features

with large variability. The visualization of the Spatial Analyst tool and Geostatistical

Wizard are shown to identify parameter differences in naming as well as having a

reference for the differences illustrated in the tables (Table 3, 4, 5, 6,and 7) . The tables

compare the parameter values from the tool defaults, Wizard defaults, and Wizard

optimization for each Project Area. The comparisons should broaden the understanding

of the functional differences of interpolation within the Geospatial Community.

5.1.1 IDW

The variability in the IDW interpolation tool in the Statistical Analyst Extension and

the IDW interpolation in the Geostatistical Analyst have noticeable differences (Figure

12), particularly when it comes to the selection of the points used in the interpolation

process. The IDW tool has a default setting of a variable search type with the selection of

12 measured points. By default, the distance parameter is left blank. The Geostatistical

Wizard has slightly different terminology as the tool, where the search type has become

the neighborhood type. The Geostatistical Wizard's neighborhood type is Smooth with a

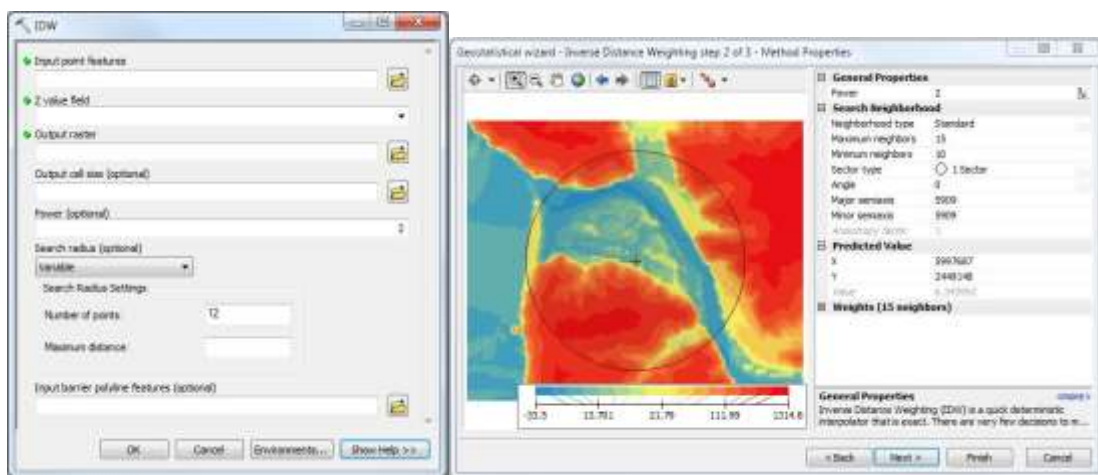maximum neighbors of 15, minimum neighbors of 10 and a 1-sector search type.

Figure 12: IDW interpolation prompts, accessed via the Spatial Analyst Toolbox (left) and the Geostatistical Wizard (right).

Detailed differences are seen in Table 3. The power setting for the IDW, which is the weighted measure, in both the Statistical Analyst tool and the Geostatistical Wizard default parameters has a power value of 2. When the Geostatistical Wizard is optimized for Project Area 1, the power becomes 3.01. For Project Area 2-5, the optimized power values are as follows 3.32, 2.00, 2.98, and 9.87 respectively. IDW Wizard offers an estimation of this variability can later be seen in the raster surface and the transects of the various Project Areas. The power setting should be influenced by the statistical variability within the point dataset used as the input in the interpolated surface.

Table 3: Table illustrating the differences between the IDW interpolation parameters in the Tool, the Wizard's default and the optimized settings.

IDW	Tool	Wizard	Wizard Optimized per Project Area				
	Default	Default	*PA 1	*PA 2	*PA 3	*PA 4	*PA 5
Power	2	2	3.01	3.32	2	2.9	9.87
Search Neighborhood type		Std.	Std.	Std.	Std.	Std.	Std.
Maximum Neighbors		15	15	15	15	15	15
Minimum neighbors		10	10	10	10	10	10
Search Radius	Variable						
Search Radius # points	12						
Search Radius Max Distance	Blank						
Sector type		1	1	1	1	1	1
Angle		0	0	0	0	0	0
Major Semiaxis		Opt	Opt	Opt	Opt	Opt	Opt
Minor semiaxis		Opt	Opt	Opt	Opt	Opt	Opt
Anisotropy factor		1	1	1	1	1	1

*PA – Project Area

5.1.2 Spline

The Spline interpolation tool within the Spatial Analyst Extension (Figure 13) and the Geostatistical Wizard (Figure 14) vary, within the Geostatistical Wizard Spline is termed

as a Radical Based Function. Changes in the terms used to describe the parameters of the

interpolation algorithm also occur. For the Tool, Spline Type options are Regular or

Tension, where in the Geostatistical Analyst the term Kernel Function is used to describe

the same parameters as Completely Regularized Spline and Spline with Tension as seen

in Figure 10 and 11. As with the IDW comparison, the method for selecting the

interpolating points varies for the weight given to the points and the number of points

used in the interpolation. The Spatial Analyst tool has a weight of 0.1 and number of

points as 12. The Geostatistical Wizard terms the weight as Kernel Parameter that is

optimized by default, with a standard neighborhood, maximum neighbors of 15,

minimum neighbors of 10 and a 1-sector search type.
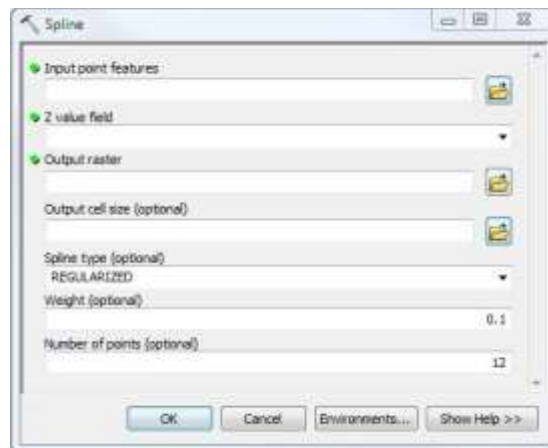
Figure 13: Screen shot of the Spline interpolation prompt, accessed via the Spatial Analyst Toolbox.
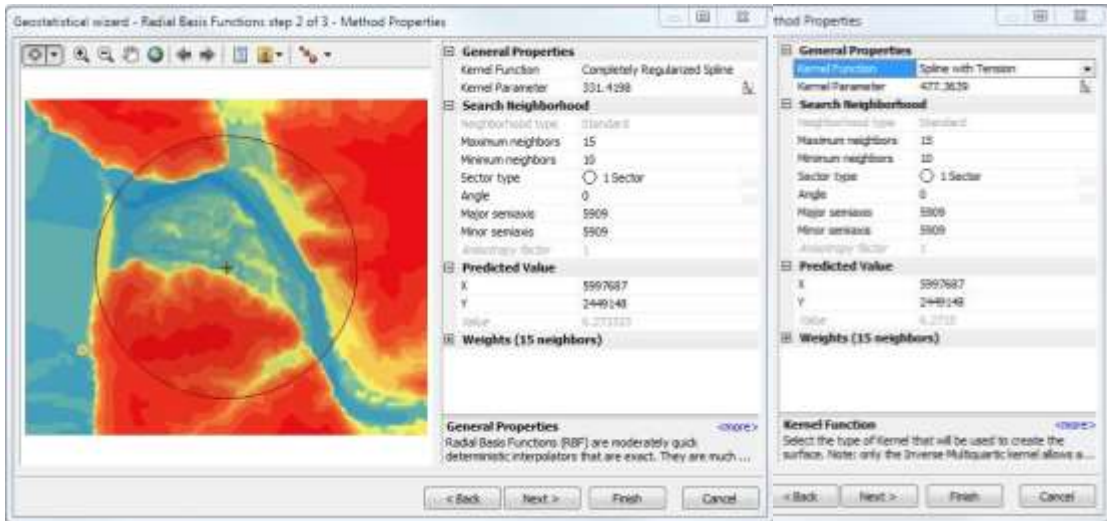
Figure 14: Screen shot of the Geostatistical Wizard prompts for the Spline Regular (left) and the Spline Tension (right).

The modification of the parameters for Spline interpolation algorithm is visualized in

Table 4 and 5. The Kernel Parameter is optimized within the Geostatistical Analyst

Extension by selecting the value, which produces the lowest RMSE for the selected

Kernel Function type. The Kernel Parameter for the Completely Regularized Spline

Project Areas 1-5 are: 0.14, 0.31, 0.19, 0.12, and 0.18 respectively. The Kernel Parameter

for the Spline with Tension Project Areas 1-5 are: 0.003, 0.007, 0.006, 0.009, and 0.004

respectively. Comparing these values within the Geostatistical Analyst Wizard with the

automatic selection of 0.1 within the Spatial Analyst Tool, the variability seems slight

with the Completely Regularized Spline, but with the Spline with Tension, the variation

can cause large manipulations within the raster surface.

Table 4: Table illustrating the differences between the Spline Regular interpolation parameters in the Tool, the Wizard's default and the optimized settings.

Spline Regular	Tool	Wizard Default which is Optimized per Project Area				
	Default	*PA 1	*PA 2	*PA 3	*PA 4	*PA 5
Kernel Function/Spline Type	Regular					
Kernel Parameter		0.14	0.31	0.19	0.12	0.004
Search Neighborhood type		Std.	Std.	Std.	Std.	Std.
Weight	0.1					
Num Points	12					
Maximum Neighbors		15	15	15	15	15
Minimum neighbors		10	10	10	10	10
Sector type		1	1	1	1	1
Angle		0	0	0	0	0
Major Semiaxis		5,909	5,909	5,909	5,909	5,909
Minor semiaxis		5,909	5,909	5,909	5,909	5,909
Anisotropy factor		1	1	1	1	1

* Project Area

Table 5: Parameter variation of the Spline with Tension interpolation.

Spline Tension	Tool	Wizard Default which is Optimized per Project Area				
	Default	*PA 1	*PA 2	*PA 3	*PA 4	*PA 5
Kernel Function/Spline Type	Regular					
Kernel Parameter		0.003	0.007	0.006	0.009	0.004
Search Neighborhood type		Std.	Std.	Std.	Std.	Std.
Weight	0.1					
Num Points	12					
Maximum Neighbors		15	15	15	15	15
Minimum neighbors		10	10	10	10	10
Sector type		1	1	1	1	1
Angle		0	0	0	0	0
Major Semiaxis		5,909	5,909	5,909	5,909	5,909
Minor semiaxis		5,909	5,909	5,909	5,909	5,909
Anisotropy factor		1	1	1	1	1

* Project Area

5.1.3 Kriging

The Kriging interpolation algorithm is the most complicated of the interpolation algorithms within this study due to the sheer number of potentially modified parameters. The variation from the Spatial Analyst tool and the Geostatistical Wizard are intensive and within the Geostatistical Wizard, the selection of optimizing the parameters is required. The windows for the Spatial Analyst Tool for Kriging can be seen in Figure 15, 16 and 17. The Semivariogram properties determine types of Kriging algorithm. The Kriging method and the Semivariogram model, which are defaulted to Ordinary and Spherical respectively, is the second step of the Geostatistical Wizards Kriging methodology. There is an option for selecting the advanced parameters for the Kriging algorithm, but by default, these are blank but options include Lag Size, and the variograms parameters of Major Range, Partial Still and Nugget. The search Parameter within the Tool is identical to IDW and Spline, with the Variable search radius, number of points 12 and a blank selection for a maximum distance.
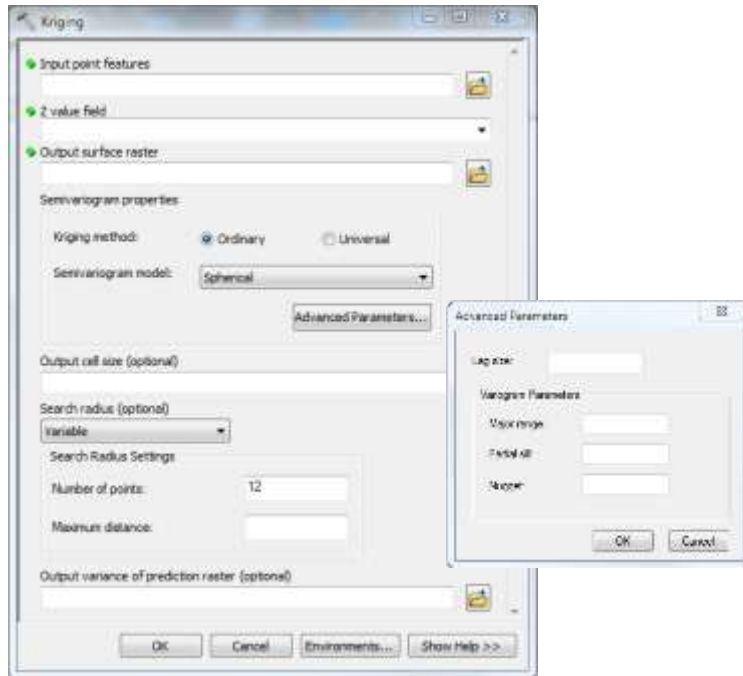
Figure 15: Screen shot of the Kriging interpolation window from the Spatial Analyst toolbox. The sub-window of the advanced parameters has been open to illustrate the further functionality in not used by default.
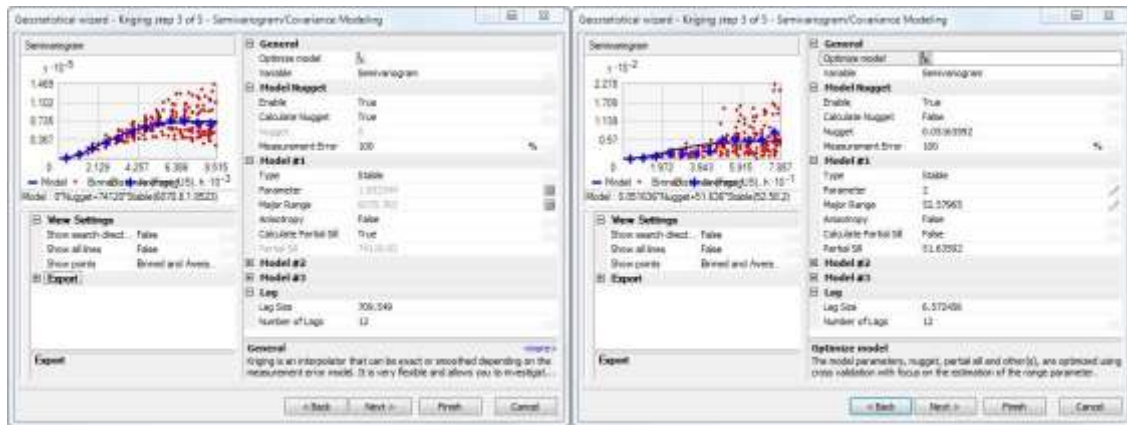
Figure 16: Screen Shots of the Kriging interpolation, third step in using the Geostatistical Wizard for this interpolation methodology. Semivariogram on the left is the default Wizard values, on the right are the optimized setting.
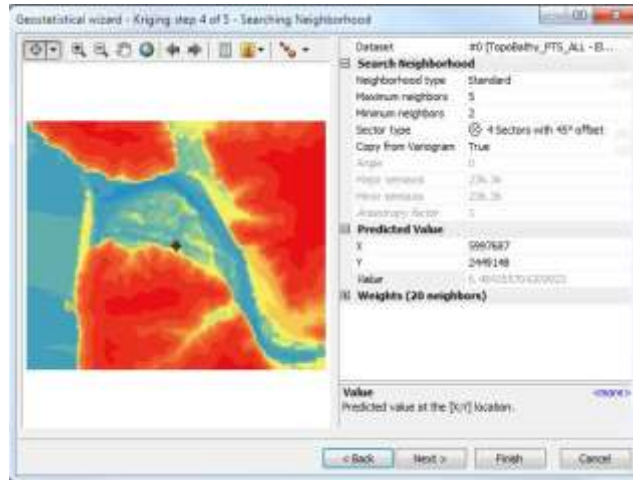
Figure 17: Screen shot of the Geostatistical Wizard's fourth step for the Kriging interpolation. The search neighborhood is the same for both the default Wizard and the optimization setting.

The Geostatistical Analyst Extension has a large selection of parameters for the Kriging algorithm, which requires multiple steps within the Wizard. The first step of the Wizard is the selection of the Kriging type, which by defaults is Simple, but for comparison purposes, Ordinary Kriging was selected, there are options for Transformation Type and Trend Removal, but both have None selected. The next step in the Wizard has specific details of the Kriging algorithm; the variation for each study area can be seen in Table 6. The point selection for the Geostatistical Analyst has a Search Neighborhood Type of Standard with a Maximum of 5, Minimum of 2, and a Sector Type of 4 with a 45 degree off-set. The Wizard offers the ability to see the surface Raster's predicted error given in terms of a Regression Function, Root-Mean-Square, Mean Standardized, Root-Mean-Square Standardized, and Average Standard Error.

Table 6: Kriging parameter variation: O - ordinary, P - Prediction.

Kriging	Tool	Wizard per Project Area						
		Project Area 1		Project Area 2		Project Area 3		Pro
	Default	Default	Optimized	Default	Optimized	Default	Optimized	Default
Kriging Type	Ordinary	O	O	O	O	O	O	O
Output Surface Type	Prediction	P	P	P	P	P	P	P
Semivariogram Model	Spherical							
Transformation Type		None	None	None	None	None	None	None
Order of trend removal		None	None	None	None	None	None	None
Variable		Semivariogram	Semivariogram	Semivariogram	Semivariogram	Semivariogram	Semivariogram	Semivariogra
Model Nugget enabled		TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Calculate Nugget		TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Nuggets Size	Blank	0.45	0	0	0.29	0.21	0.07	0
Measure Error		100%	100%	100%	100%	100%	100%	100%
Model Type		Stable	Stable	Stable	Stable	Stable	Stable	Stable
Parameter		2	1.52	1.35	1.95	2	2	1.5
Major Range	Blank	465.38	940.44	735.53	267.76	320.57	60.32	531.45
Anisotropy		FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Calculate Partial Sill	Blank	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE
Partial Sill Size		455.97	671.03	117.07	65.87	207.51	6.04	257.62
Lag Size	Blank	74.42	117.55	88.84	33.47	51.09	7.54	78.46
Number of Lags		12	12	12	12	12	12	12
Search Radius # points	12							
Search Radius Max Distance	Blank							

60

Search Neighborhood type	Variable	Standard	Standard	Standard	Standard	Standard	Standard	Standard
Maximum Neighbors		5	5	5	5	5	5	5
Minimum neighbors		2	2	2	2	2	2	2
Sector type		4 w/ 45deg	4 w/ 45deg	4 w/ 45deg	4 w/ 45deg	4 w/ 45deg	4 w/ 45deg	4 w/ 45deg
Angle		0	0	0	0	0	0	0
Major Semiaxis		465.38	940.44	735.53	267.77	320.57	60.32	531.45
Minor semiaxis		465.38	940.44	735.53	267.77	320.57	60.32	531.45
Anisotropy factor		1	1	1	1	1	1	1

5.1.4 EBK

EBK, being a recently created Geostatistical interpolation method has many

parameters when are optimized by default, the parameters can be seen of the screen

capture of the Geostatistical Wizard in Figure 18. Although EBK is not available within

the Spatial Analyst toolbox, it is available within the Geostatistical Analyst toolbox with

only slightly different parameters when those available within the Geostatistical Analyst

Wizard (Figure 19). The only parameter that was identified as different between the

methods was the search radius of the neighborhood (Table 7). Although this variation is

slight, it seems to have an effect in the resulting surface. The Wizard offers the ability to

see the surface Raster's predicted error given in terms of a Regression Function, Root-

Mean-Square, Mean Standardized, Root-Mean-Square Standardized, and Average

Standard Error.
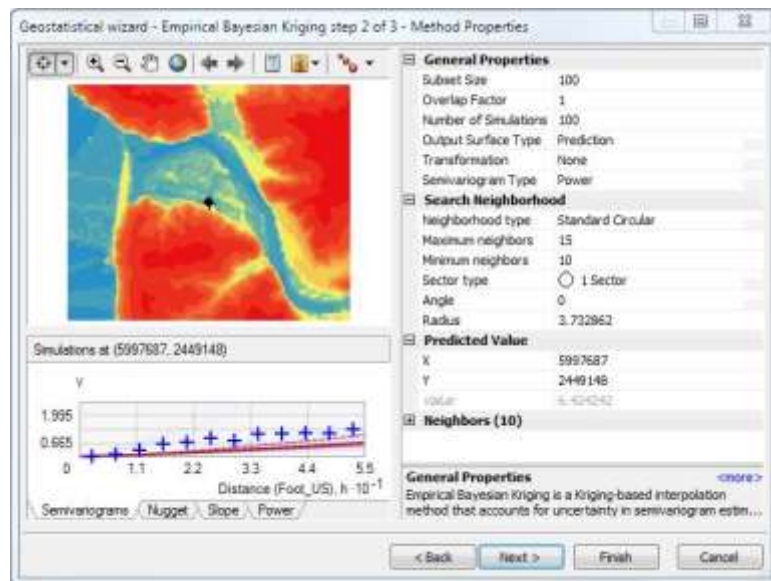
Figure 18: Screen capture of the EBK interpolation accessed via the Geostatistical Wizard.
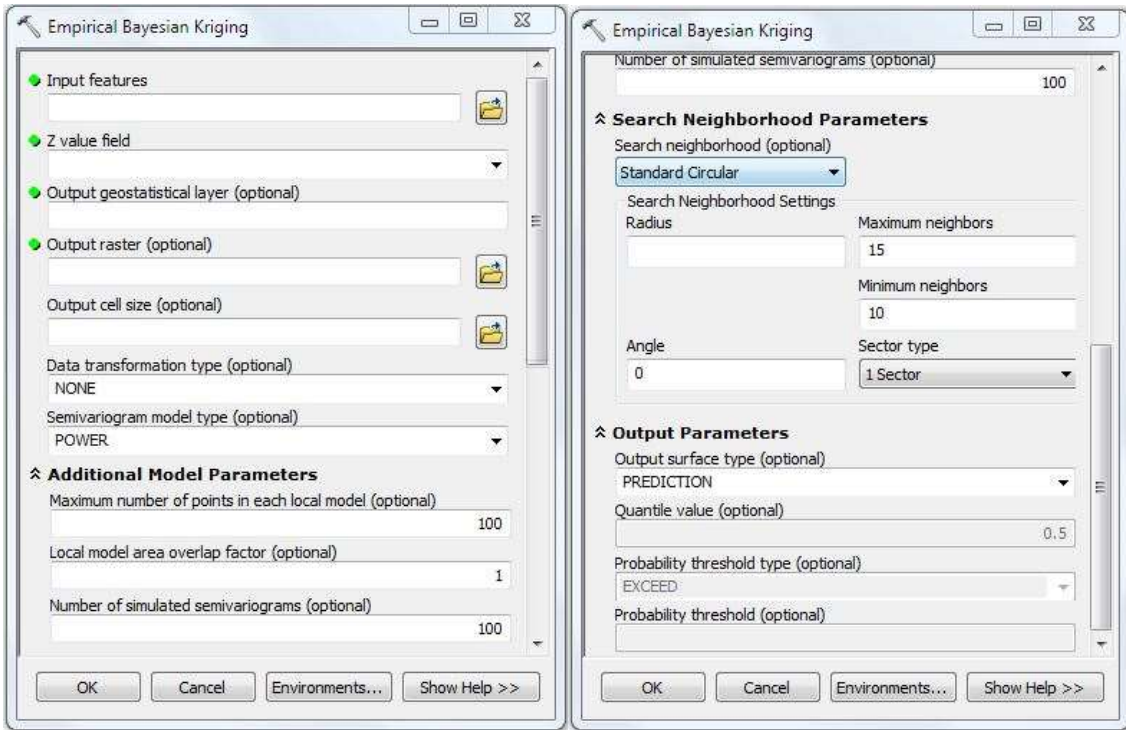
Figure 19: Screen capture of the EBK interpolation accessed via the Geostatistical Analyst Toolbox.

Table 7: Table of EBK interpolation parameters.

	Tool	Wizard
Subset Size	100	100
Overlap Factor	1	1
Number of Simulations	100	100
Output surface Type	Prediction	Prediction
Transformation	None	None
Semivariogram Type	Power	Power
Search Neighborhood type	Standard Circular	Standard Circular
Maximum Neighbors	15	15
Minimum neighbors	10	10
Sector type	1	1
Angle	0	0
Search Radius	Blank	Opt

5.1.5 Natural Neighbor & Topo to Raster

Both Natural Neighbor and Topo to Raster interpolation methodologies are not

available within the Geostatistical Analyst Wizard. The surfaces models are a result of

using the default setting with only the point dataset as input. Screen shots of the Topo to

Raster tool can be seen in Figure 20, note the additional vector capabilities. These

methods are used within the interpolation literature.

Figure 20: Screen capture of the Topo to Raster tool available in the Spatial Analyst Extension.

The search neighborhood, weight of proximity, and algorithm differences account for the variation within the same geographic area. This variation can cause large discrepancies in the volumetric calculation used in flood and sea level change modeling due to the raster surface differences. The comparison of the raster surfaces are completed below and illustrate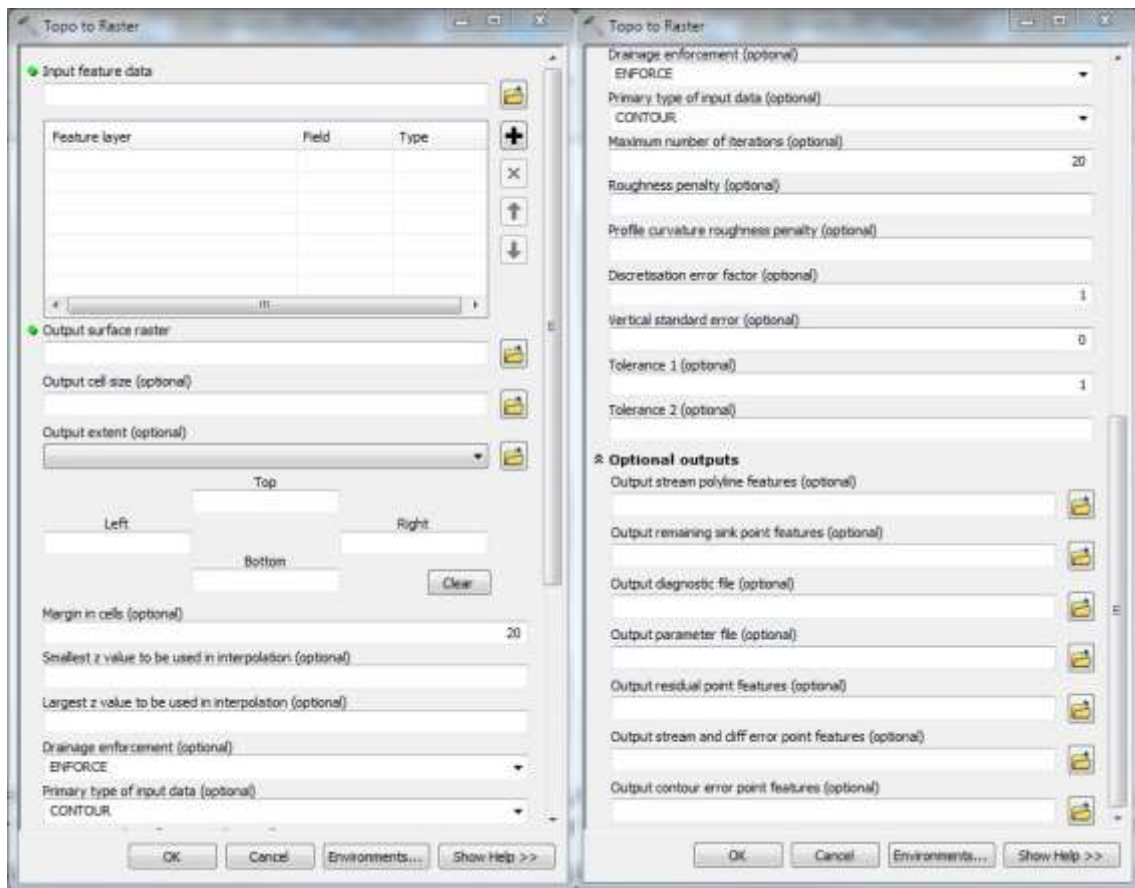 the impact of the discrepancies of the Spatial Analyst Extension and the Geostatistical Analyst Extension was well as the variation between the interpolation algorithms available in each.

5.2 Results of Multiple Interpolation Methods

The results provide an overall picture of the surface created from the seven interpolation algorithms and parameter options. In each Project Area, tables and multiple figures are provides for an overall understanding of the interpolation's influence on that area.

A table is provided with minimum, maximum, mean, standard deviation and for some interpolation methods an RMSE, this table should be compared to the entire Project Area and the subset Project Area statistics to see it's comparison of the interpolation's processing of the point data into a surface.

The project map, organized in the same order than the table, shows the actual interpolated surface (instead of the statistics of the surface as in the table), these surfaces were created using the same data, the variation lies with the interpolation algorithm and the ArcGIS Extension utilized. The colorization is the same for each surface, where blue

represents color in the below water and green representing above water. This colorization is applied in each Project Area in the study.

Difference maps provide a method to contrast the Spatial Analyst Tool surface with the Geostatistical Analyst Wizards optimized setting surface for the interpolation algorithms, the difference maps which are colorized to exaggerate the differences, darker red the color the greater the difference in either positive or negative elevation measurement between the surfaces.

From the interpolated surfaces, 3 transects were created for each Project Area, these transects can are represented in profile graphs of the surface. Transects illustrate the smoothness of the data integration better than the color scales are able to. Each transect, labeled A,B, and C, are representing the same ground surface the only variation lies in the interpolation algorithm and extension used to create the surface, where on the graphs, the various lines within the graph represent the extensions used.

Together these representations of the interpolated surfaces facilitate an overall understanding of the need to optimize the parameters of the interpolation algorithm used

5.2.1 Project Area 1

Project Area 1 is characterized by a deep channelization of the river on the southwest corner, as well as a gradual sloping riverbank on the opposite side of the river. The three profiles encompass changes in the bank morphology.

Table 8: Statistical distribution of the raster surfaces created from the various interpolation methods in Project Area 1.

Project Area 1

	Entire Project Area Points							Subset Project Area Points					
	Count	Min	Max	Mean	Median	Std. Dev		Count	Min	Max	Mean	Median	Std. Dev
	13107.0	-16.0	116.5	14.7	5.7	19.6		500.0	-16.0	105.9	3.6	0.9	18.3

		Tool					Wizard Default					Wizard Optimized				
		Min	Max	Mean	Std Dev.	RMSE	Min	Max	Mean	Std Dev.	RMSE	Min	Max	Mean	Std Dev.	RMSE
IDW		-16.0	105.9	2.3	15.5		-16.0	105.9	2.2	15.4	3.0	-16.0	105.9	2.3	15.5	3.0
Natural Neighbor		-16.0	104.9	5.1	16.6											
Spline	Regular	-123.3	123.3	2.8	26.9		-19.3	106.2	2.7	15.2	3.3					
	Tension	-18.2	109.9	2.1	15.9		-17.9	109.8	2.5	16.3	2.8					
Kriging		-15.7	92.8	2.5	15.4		-52.9	119.4	1.5	17.5	2.8	-16.8	106.9	2.6	15.8	2.7
EBK		-16.7	104.1	2.5	16.2		-16.3	104.2	2.4	15.9	2.7					
TopoRaster		-16.0	105.3	2.9	14.6											

Use Table 8 to compare the statistical variation within Project Area one subset data. The Kriging methodology, using the Wizard default settings, caused a drastic minimization of the mean values within the area when compared to the tool and the Wizard optimized setting which provides less dramatic variation in the surface created. Spline Regular identifies drastic changes from the distribution of the measured points. The natural neighbor tool skews the mean of the subset data from 2.3 to 5.1. These variations are interesting within the Project Area, but can only foster a limited understanding of the entire Project Area. The maps of the raster surface, seen in Figure 21, provide a visual comparison of the interpolation and parameter variation results.
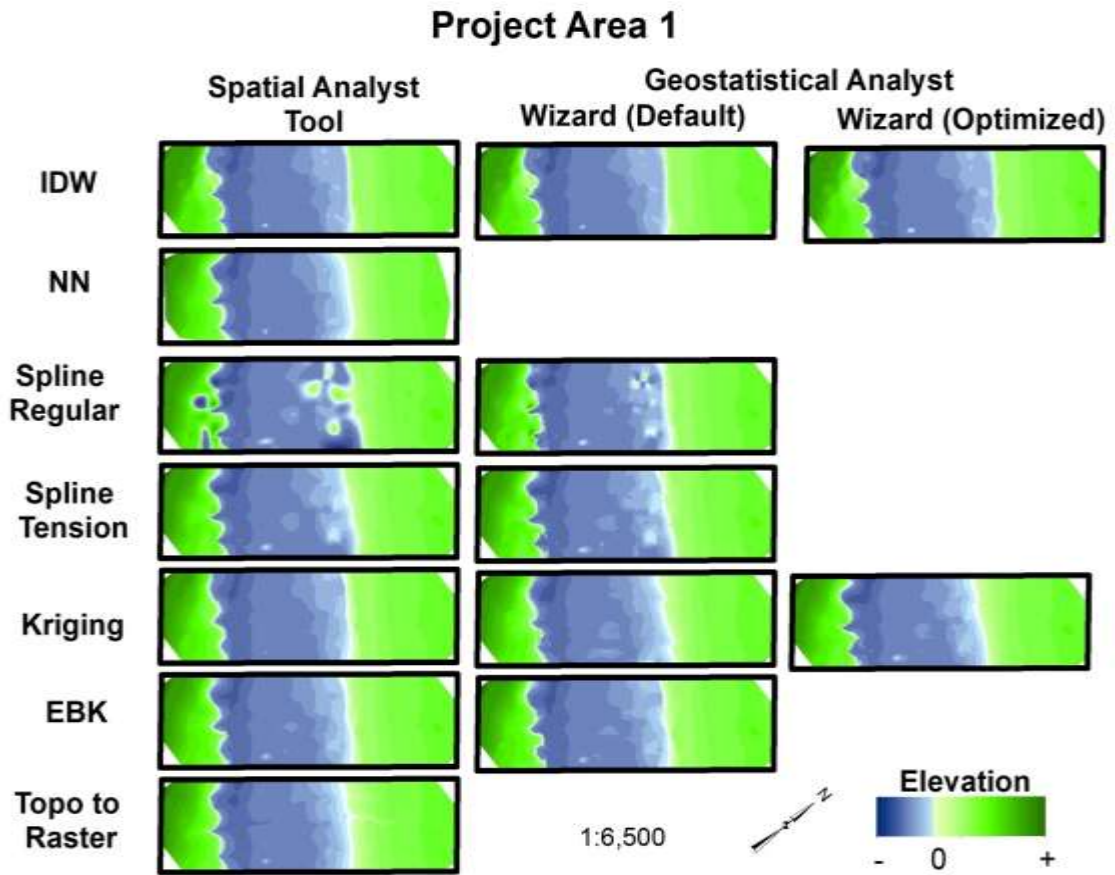
Figure 21: Surface raster maps of interpolation algorithms. Note the differences between the different interpolation algorithms.
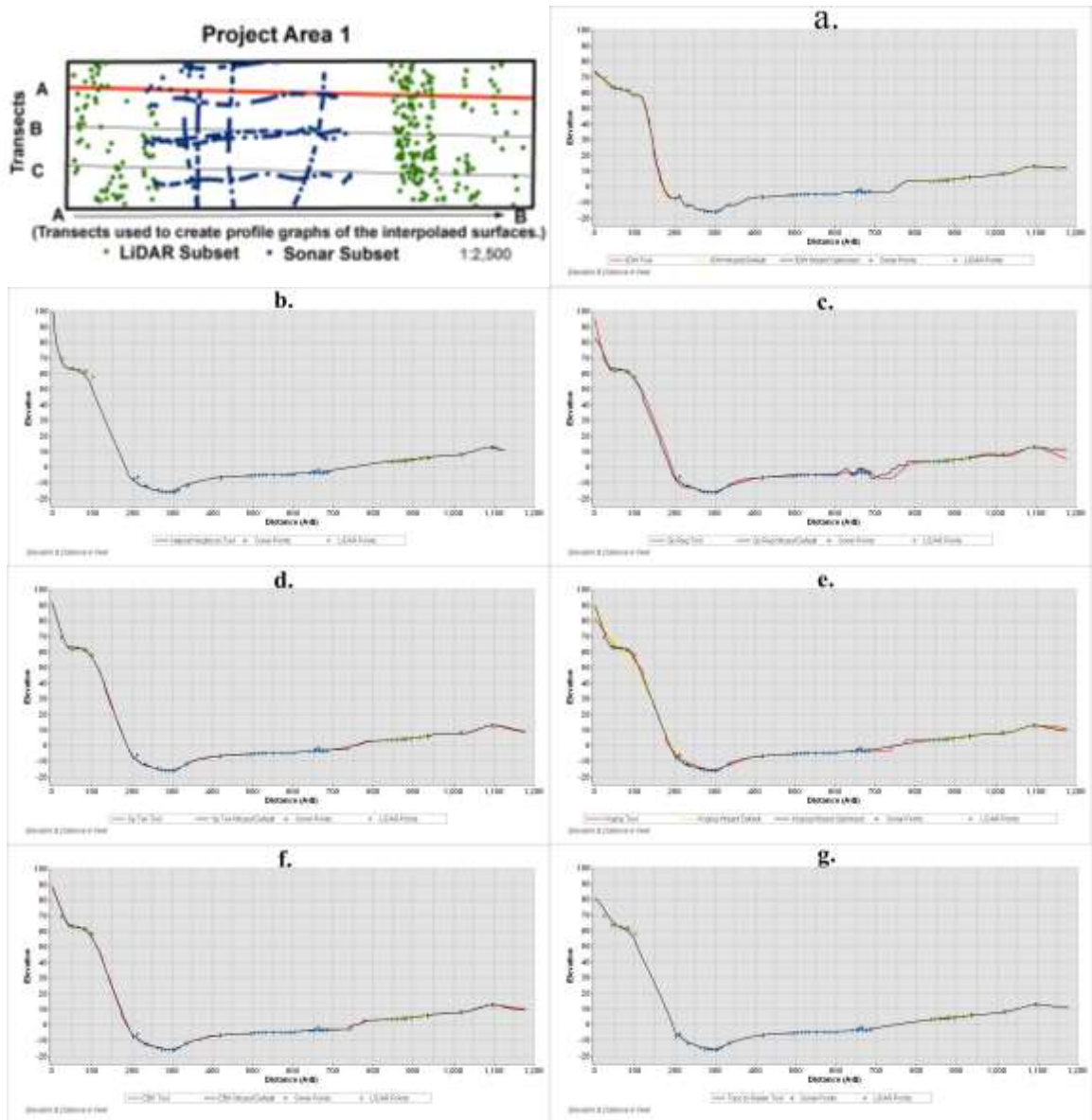
Figure 23: Profile graphs of transect A for Project Area 1. Each graph represents an interpolation algorithm, and all graphs represent the same transect within the Project Area: a. IDW, b. NN, c. Spline Regular, d. Spline Tension, e. Kriging, f. EBK, g. Topo to Raster.
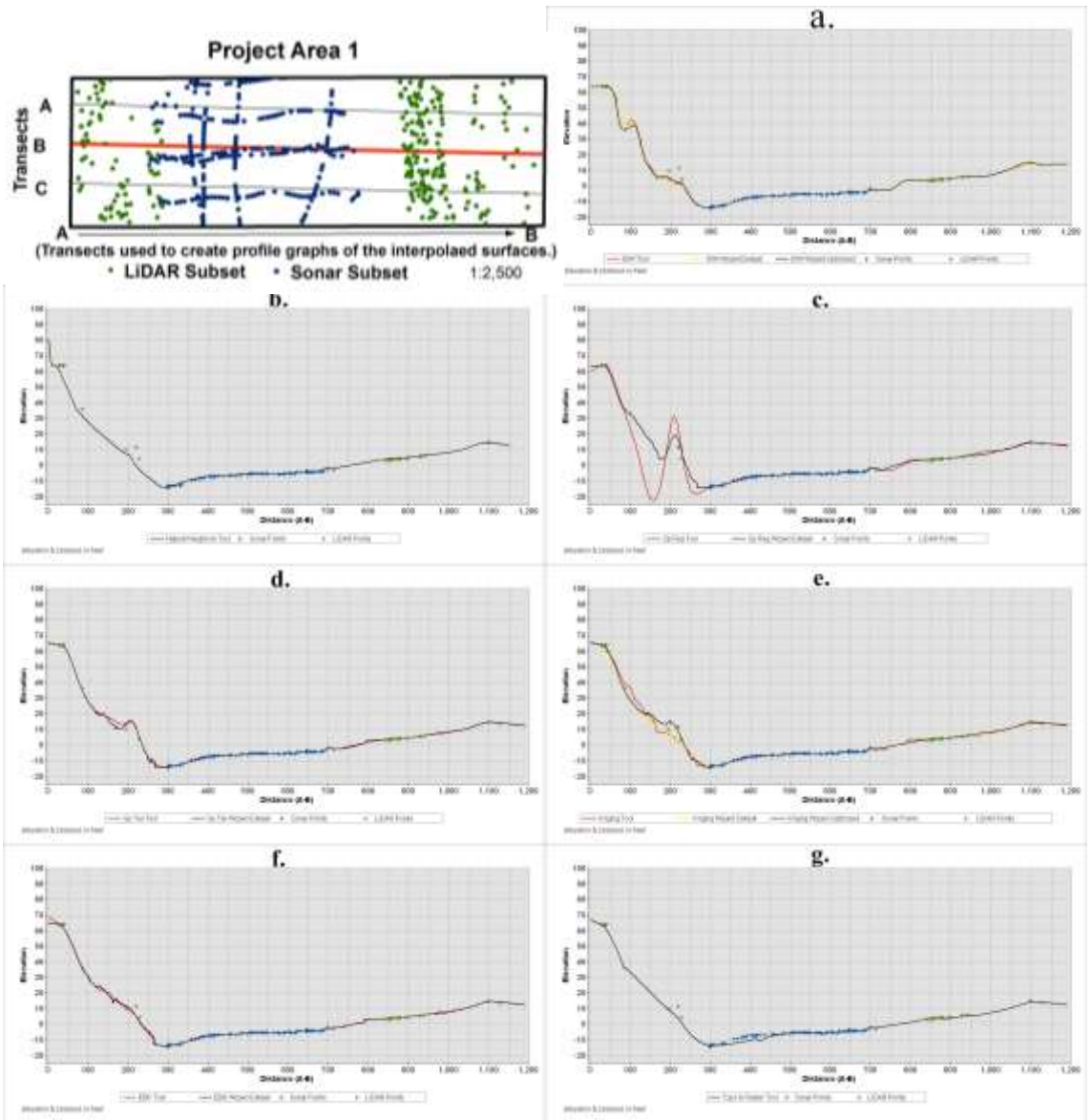
Figure 24: Profile graphs of transect B for Project Area 1. Each graph represents an interpolation algorithm, and all graphs represent the same transect within the Project Area: a. IDW, b. NN, c. Spline Regular, d. Spline Tension, e. Kriging, f. EBK, g. Topo to Raster.
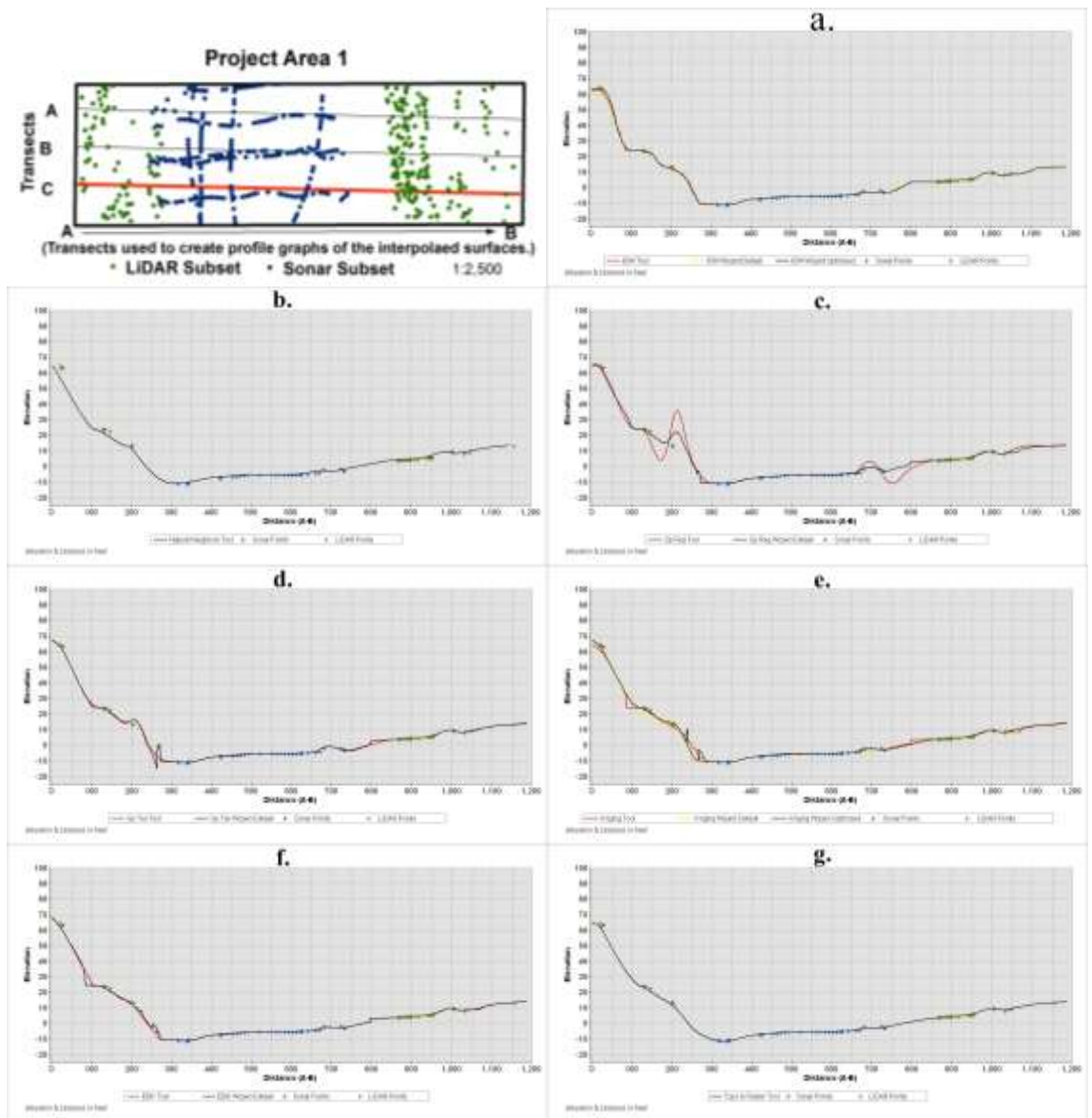
Figure 25: Profile graphs of transect C for Project Area 1. Each graph represents an interpolation algorithm, and all graphs represent the same transect within the Project Area: a. IDW, b. NN, c. Spline Regular, d. Spline Tension, e. Kriging, f. EBK, g. Topo to Raster.

Transect A (Figure 23) produces variation within interpolation algorithms based on the use of the tool, the Wizard's default parameters and the optimized version of the Wizard parameters. Spline Regular, Spline Tension and Kriging can be seen with drastic variation. The profile seems to generate a step at a distance of about 740 ft.; this can be seen by the interpolation methods of IDW, Spline Regular, Kriging and EBK.

Transect B's (Figure 24) variation of the interpolation algorithms can be seen in all the profiles with Spline Regular and Kriging being the most dramatic at a profile distance of about 50ft to 250ft. When comparing the methods, natural neighbor seem to cause increasing elevation at the beginning of the profile, where most of the other interpolations restrict the surface to create a level surface.

Transect C (Figure 25) IDW, Spline Regular and Tension as well as Kriging illustrates the differences when using the tool or the Geostatistical Wizard as seen from a distance of about 50ft to 250ft. Spline Regular causes a wave within the data, where Spline Tension and Kriging interpolations create an erratic change, even while using the Wizards' optimization options.

The variations mentioned within the profile graphs can be visually seen on the maps for each transects (Figure 21). The bank lines have slight differences as well as the depth of the water within the Project Area. Spline Regular has the most visually unsettling surface, where islands and lakes area created. The remaining interpolation methodologies, the differences are challenging to visualize, the use of a difference maps

(Figure 26). The difference within the Kriging interpolation is rather great within the topographic areas.
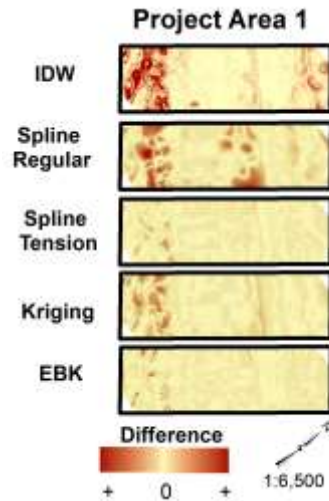
Figure 26: Difference maps, between the tool and the Wizard.

When comparing the interpolations overall the Wizard default and optimized parameters create generally smoother surfaces where the tools can create generally unpredictable results. This can be seen in most interpolation algorithms used, with the exception of Spline Regular, where both the tool and the Wizard generate unnecessary variations.

5.2.2 Project Area 2

Project Area 2 is characterized by a general straight flow of the river, with distinct riverbanks. The area is notorious for containing underwater impedances due to old bridge pilings.

Project Area 2 has a wider variety mean and standard deviations seen in Table 9. Within the Spline Regular used within the Spatial Analyst tool or Wizard and the natural neighbor tool has the greater dissimilarity. The Kriging interpolation using the Wizard default setting and the optimized setting produced similar results when looking at the RMSE, but the max elevation has a difference of around 14 ft. EBK Wizard default produces a lower minimum value than the rest of the interpolation methods with one of the lowest RMSE values. Even with the statistics of the interpolated surfaces, matching to the measured point statistics are still skewed, where the measured points had a mean of 2.5, the average interpolated mean was 0.2. Visualization of the maps Figure 27, transects Figures 28 – 30, and is necessary to identify the anomalies.

Table 9: Table of the statistical distribution in Project Area 2.

			Project Area 2													
		Entire Project Area Points							**Subset Project Area Points**							
		Count	Min	Max	Mean	Median	Std. Dev		Count	Min	Max	Mean	Median	Std. Dev		
		4976.0	-9.0	41.9	9.2	9.3	7.4		500.0	-9.0	39.7	2.5	0.7	8.7		

		Tool					Wizard Default					Wizard Optimized				
		Min	Max	Mean	Std Dev.	RMSE	Min	Max	Mean	Std Dev.	RMSE	Min	Max	Mean	Std Dev.	RMSE
IDW		-9.0	39.7	0.2	7.9		-9.0	39.7	0.2	7.9	1.5	-9.0	39.7	0.3	8.1	1.4
Natural Neighbor		-9.0	39.6	-0.2	7.5											
Spline	Regular	-64.5	78.8	0.8	9.5		-14.1	40.1	0.3	7.9	1.3					
	Tension	-14.6	58.6	0.3	8.4		-14.2	56.4	0.3	8.4	1.2					
Kriging		-8.6	42.6	0.3	8.0		-9.9	49.4	0.3	8.2	1.1	-10.0	64.0	0.3	8.3	1.1
EBK		-8.8	54.4	0.3	8.2		-8.9	54.2	0.3	8.2	1.1					
TopoRaster		-9.0	39.6	0.0	7.9											
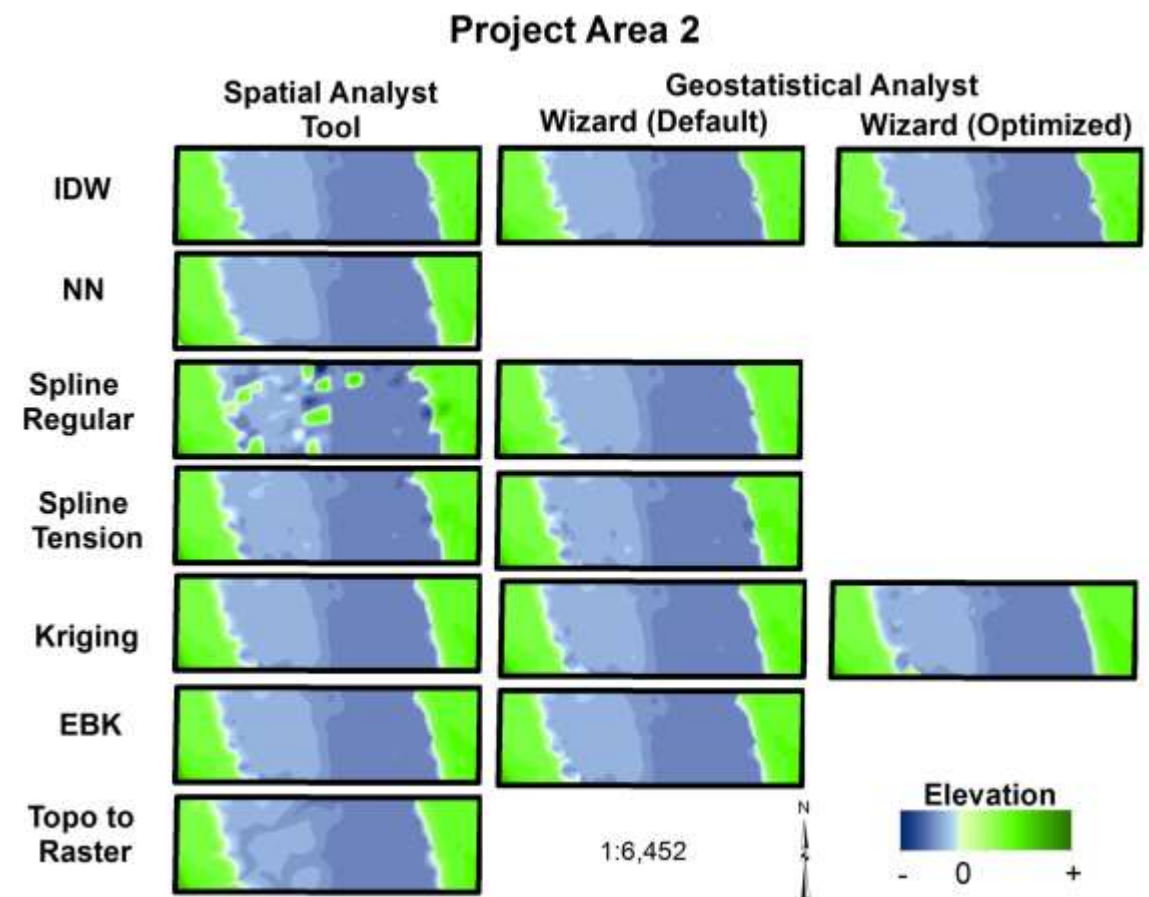
Figure 27: Surface raster maps of interpolation algorithms. Note the differences between the different interpolation algorithms.

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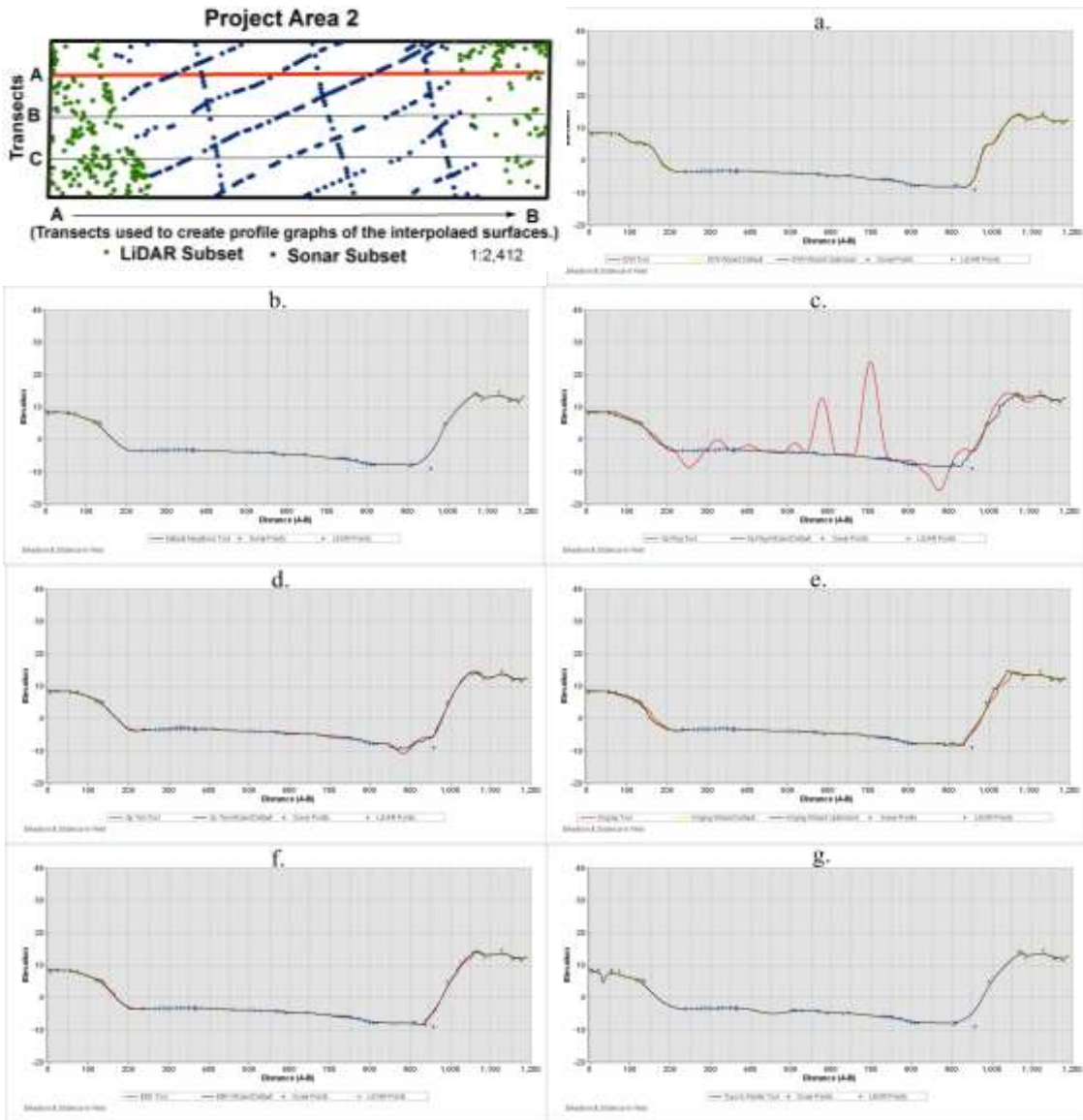
Figure 28: Profile graphs of transect A for Project Area 2. Each graph represents an interpolation algorithm, and all graphs represent the same transect within the Project Area: a. IDW, b. NN, c. Spline Regular, d. Spline Tension, e. Kriging, f. EBK, g. Topo to Raster.

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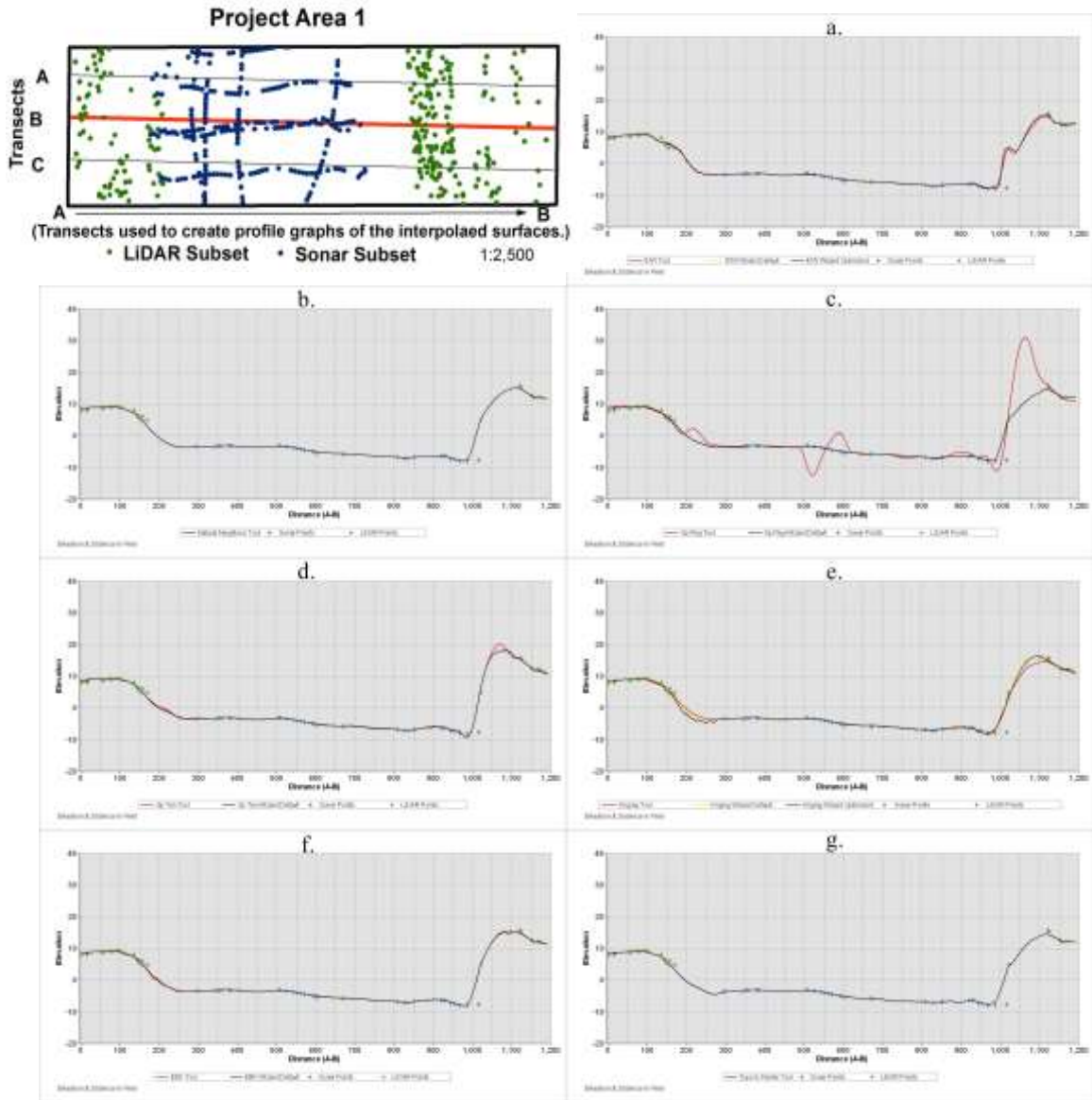
Figure 29: Profile graphs of transect B for Project Area 2. Each graph represents an interpolation algorithm, and all graphs represent the same transect within the Project Area: a. IDW, b. NN, c. Spline Regular, d. Spline Tension, e. Kriging, f. EBK, g. Topo to Raster.
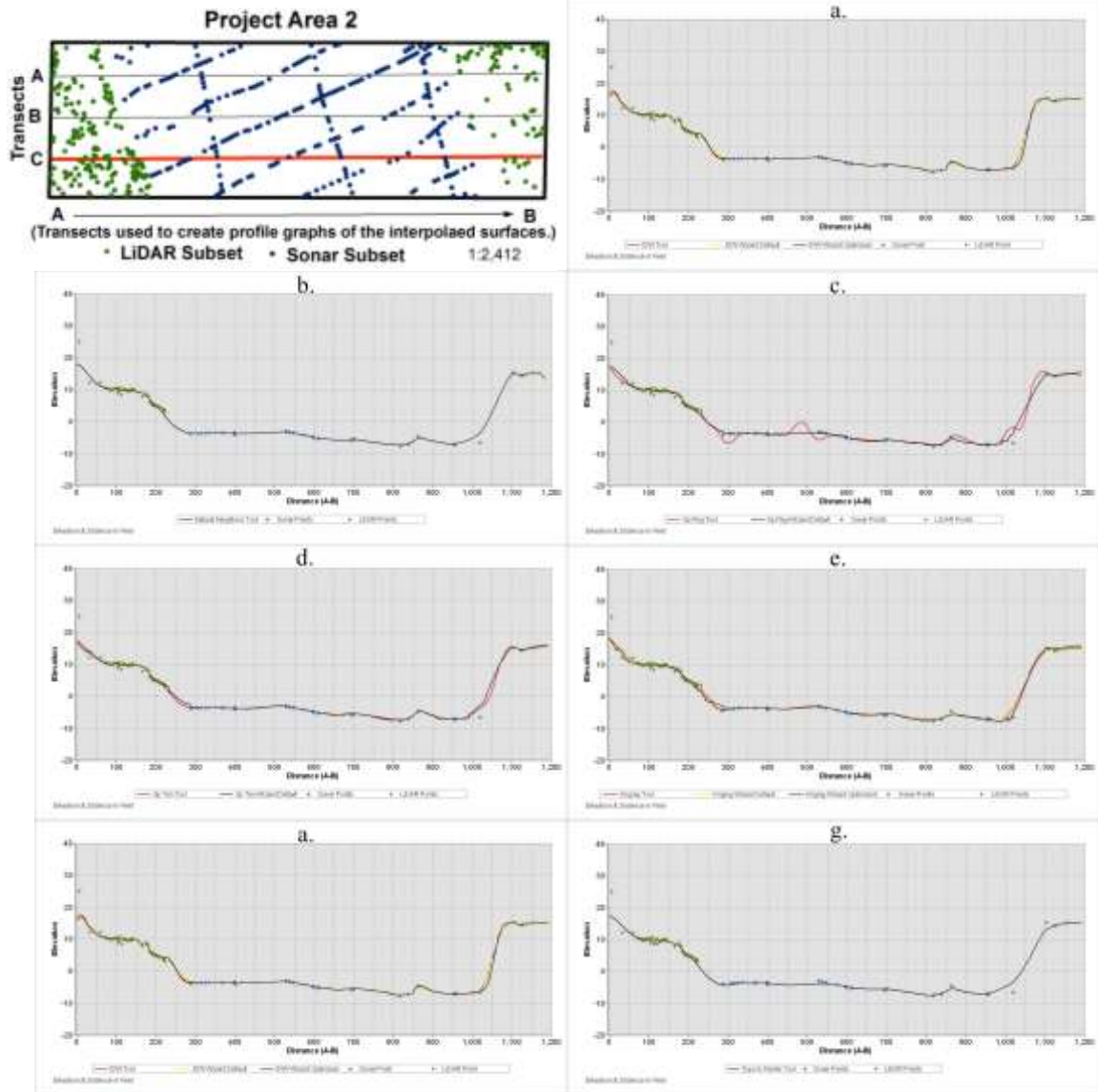
Figure 30: Profile graphs of transect C for Project Area 2. Each graph represents an interpolation algorithm, and all graphs represent the same transect within the Project Area: a. IDW, b. NN, c. Spline Regular, d. Spline Tension, e. Kriging, f. EBK, g. Topo to Raster.

Transect A has similar trends between the surfaces created within the Tool, Wizard

Default parameters and the Wizard optimized, except in the case of the Spline Regular as

seen in Figure 28. The Spline Regular tool interpolated surface contained great variation

of the below water surface, creating peaks of over 20 ft., where the Wizard Default

parameters created a smoother surface comparable to the other interpolated surfaces.

Spline Tension tool, created not so drastic anomalies as the Regular Spline tool method,

although the Wizard Default settings also minimized these variations. The Kriging

interpolation contained some variation within the various uses methods, but generally

followed the same path.

Transect B (Figure 29), has similar results between the tool, Wizard default or Wizard

optimized except in the case of the Spline Regular then using the tool. The slight

variation can be seen within the Kriging interpolated surfaces, where the Wizard Default

and optimized settings were slightly above the tool's surface at around 200ft, then at

1500ft shot above the tools estimation, this is caused by the distance between the known

points. The IDW interpolation methodology in created an interesting bench at around

1250ft where the Spline Regular Wizard default and the Topo to Raster tool also creates

some sort of benched feature. This benched feature is actually a retaining wall for an old

bridge and decommissioned road.

Transect C contain interesting variation of the interpolated surfaces at a distance on

the transect of 200 to 300 ft. illustrated in Figure 30. This area is about where the land

and water measured points join, although on the other end of transect at between 1000 to

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1100ft the variations can also be seen. Kriging compared to the IDW interpolation methods are most interesting between the 200 and 300ft area the Kriging Wizard default seems similar to the IDW interpolation, but the Kriging Wizard optimized setting the smooth surface disappears into sharp peaks where the only other interpolation method which dose this is the EBK Wizard default. The Spline Regular tool again produces undulating anomalies within the interpolate surfaces, but when using the Wizard default setting seem to produce respectable results.

The stark differences can be seen between the Spline Regular tool when compared to the Wizard default setting as seen in Figure 29. The Spline Regular default Wizard is comparable to the EBK Wizard outputs when compared visually, where the Kriging interpolation surfaces create a choppy representation of elevation for the Project Area. The Topo to Raster tool appears to encompass more of the morphological channelization of the stream channels entering the river. The differences between the interpolated tools and Wizards are moderately tame within this Project Area as seen in Figure 31, with the exception of the Spline Regular interpolation method, using the Wizard default setting, Spline Regular produces near similar results than other interpolation methodologies.
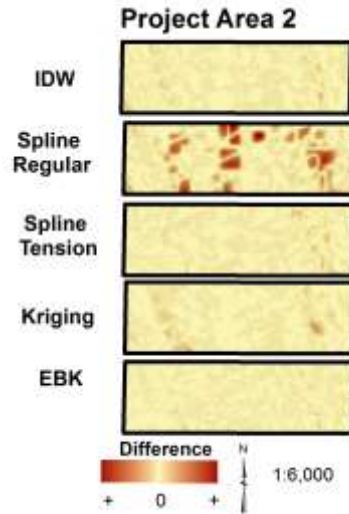
Figure 31: Maps illustrating the difference between the surfaces created by the Spatial Analyst tool and the Geostatistical Analyst Extensions.

Overall Project Area 2 several interpolated surfaces seem most appropriate to ascertain the smooth elevation surfaces of the Project Area, such as all the IDW interpolations, Kriging Wizard default, Spline Regular and Tension Wizard defaults, Natural Neighbor and Topo to Raster interpolation tools.

5.2.3 Project Area 3

Project Area 3 is the most complex, not with respect to river morphology, but with respect to having a peninsula within the Project Area. This causes slightly varying results then if the study was completed with the entire dataset and the interpolated surfaces were clipped to the Project Areas. Project Area 3 is a great representation of the data inconsistencies, which might occur when there is a time delay in LiDAR or Sonar data collections. The peninsula at the LiDAR collection was visible, but during the bathymetry

collection, either the river level was higher or the morphology changed to remove the sedimentation, which had created the spit.

Table 10: Table of the statistical distribution in Project Area 3.

Project Area 3

Entire Project Area Points							Subset Project Area Points					
Count	Min	Max	Mean	Median	Std. Dev		Count	Min	Max	Mean	Median	Std. Dev
10765.0	-19.7	42.4	11.2	4.7	14.1		500.0	-19.7	42.2	1.2	0.4	14.7

		Tool					Wizard Default					Wizard Optimized				
		Min	Max	Mean	Std Dev.	RMSE	Min	Max	Mean	Std Dev.	RMSE	Min	Max	Mean	Std Dev.	RMSE
IDW		-19.7	42.2	0.3	14.7		-19.7	42.2	0.4	14.5	1.3	-19.7	42.2	0.4	14.5	1.3
Natural Neighbor		-19.6	42.2	-0.8	13.2											
Spline	Regular	-67.5	123.0	0.7	18.6		-19.8	42.4	0.5	14.1	0.9					
	Tension	-22.6	46.7	0.0	14.8		-30.7	45.8	0.3	14.8	1.0					
Kriging		-21.2	42.8	0.4	14.4		-19.5	43.0	0.2	14.1	0.9	-50.8	47.1	-0.5	15.1	1.2
EBK		-29.6	45.5	0.1	14.7		-26.2	45.3	0.1	14.8	1.0					
TopoRaster		-19.6	46.8	0.0	14.0											

(Interpolation Method)

Project Area 3's statistics is summarized in Table 10. This Project Area had two interpolation methodologies with the smallest RMSE, which include Kriging and Spline Regular when using the Wizard optimized and default setting. Although a small RMSE is important, following the trends of the measured points is also a factor in determining suitability of a surfaces interpolation. The subset data for Project Area 3 has a man of 1.2 and a wide range of standard deviation with a value of 14.7. The interpolated surfaces followed similar trends away from the measured values, although natural neighbor and Spline Regular tools had results not following the other surfaces. The surfaces of Kriging produce statistically interesting results, the tool had a mean of 0.4 and an standard deviation of 14.4, but when utilizing the Geostatistical Wizard in the default parameters, the mean drops to -0.5 and a standard deviation of 15.1 and even further to the Wizard's optimized settings, where the mean is 0.2 and the standard deviation is at 14.1. These

statistical changes can also be seen within the map outputs (Figure 32) and the profiles

(Figures 33-35).
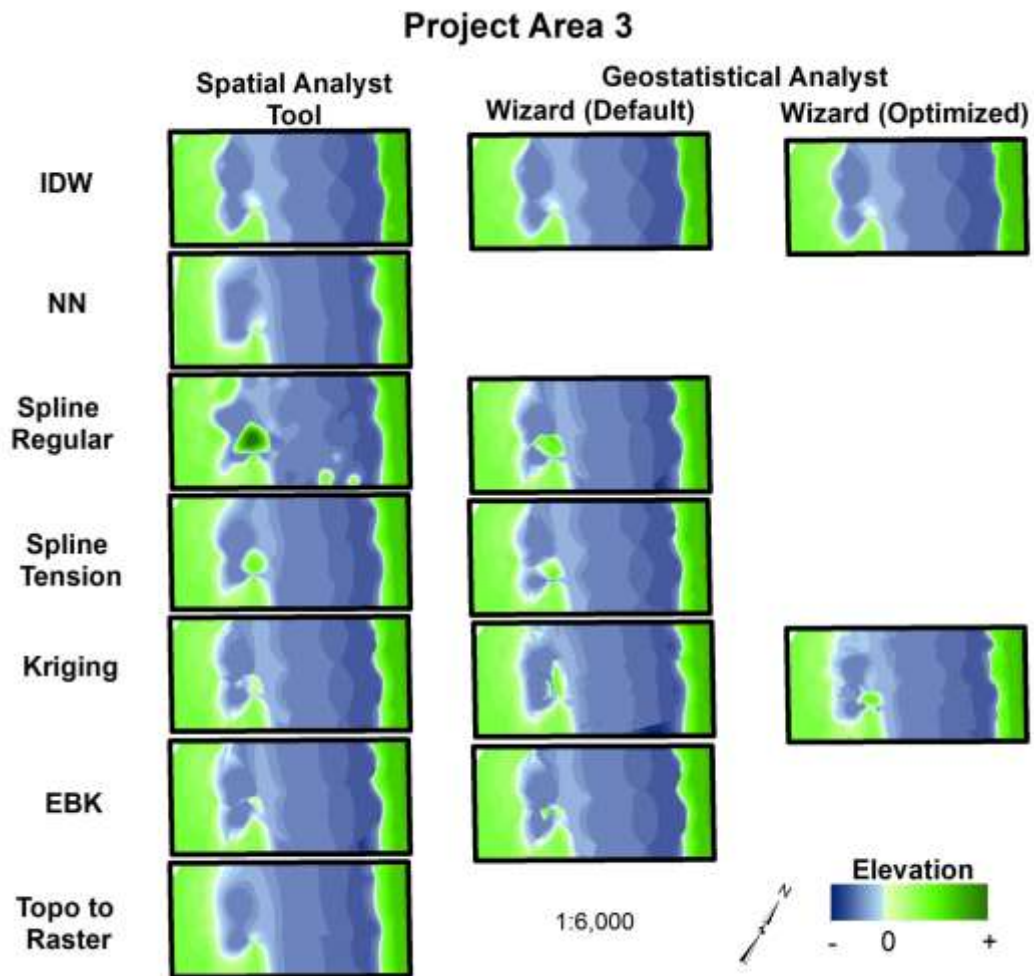
Figure 32: Surface raster maps of interpolation algorithms. Note the differences between the different interpolation algorithms.
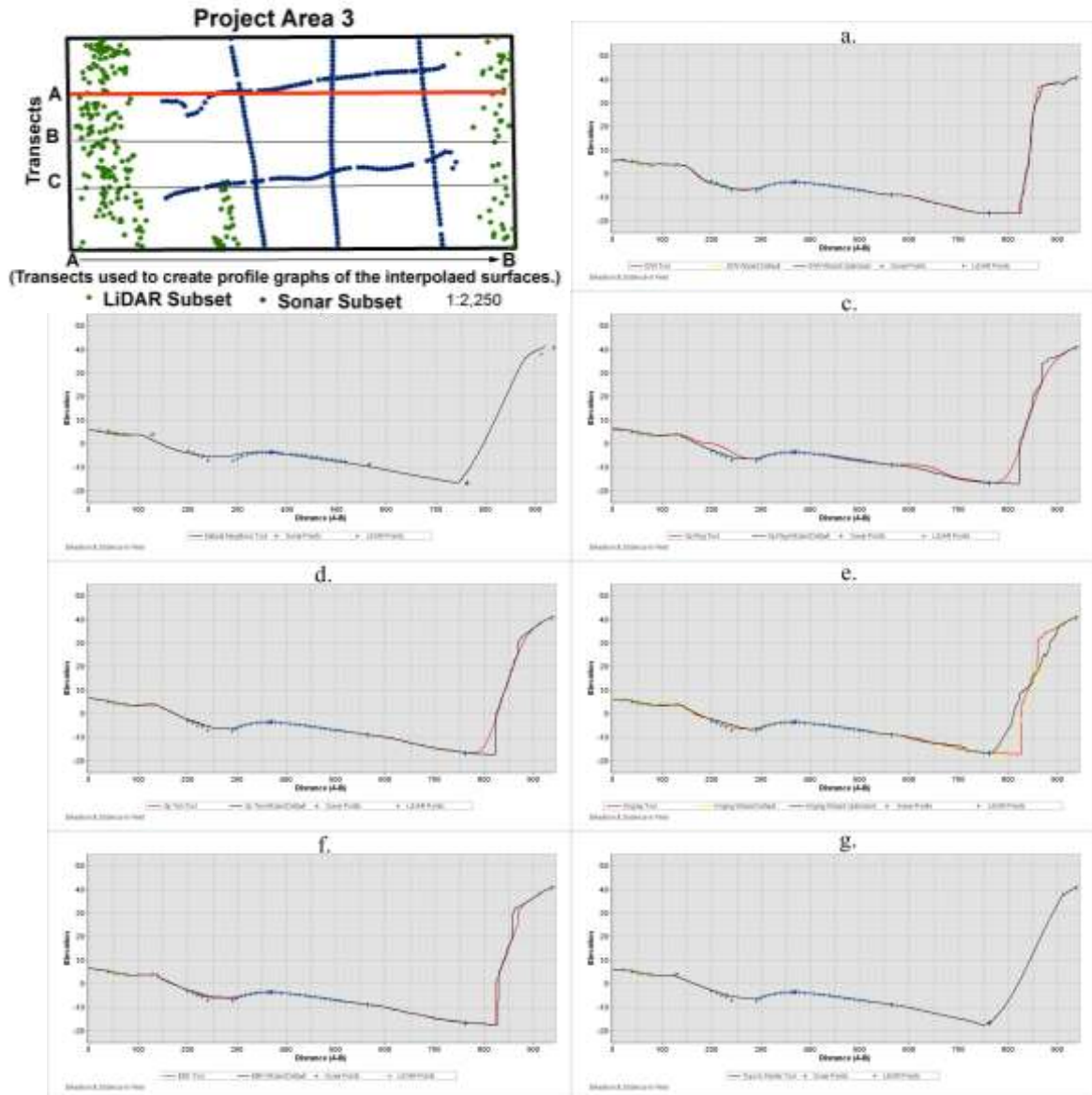
Figure 33: Profile graphs of transect A for Project Area 3. Each graph represents an interpolation algorithm, and all graphs represent the same transect within the Project Area: a. IDW, b. NN, c. Spline Regular, d. Spline Tension, e. Kriging, f. EBK, g. Topo to Raster.
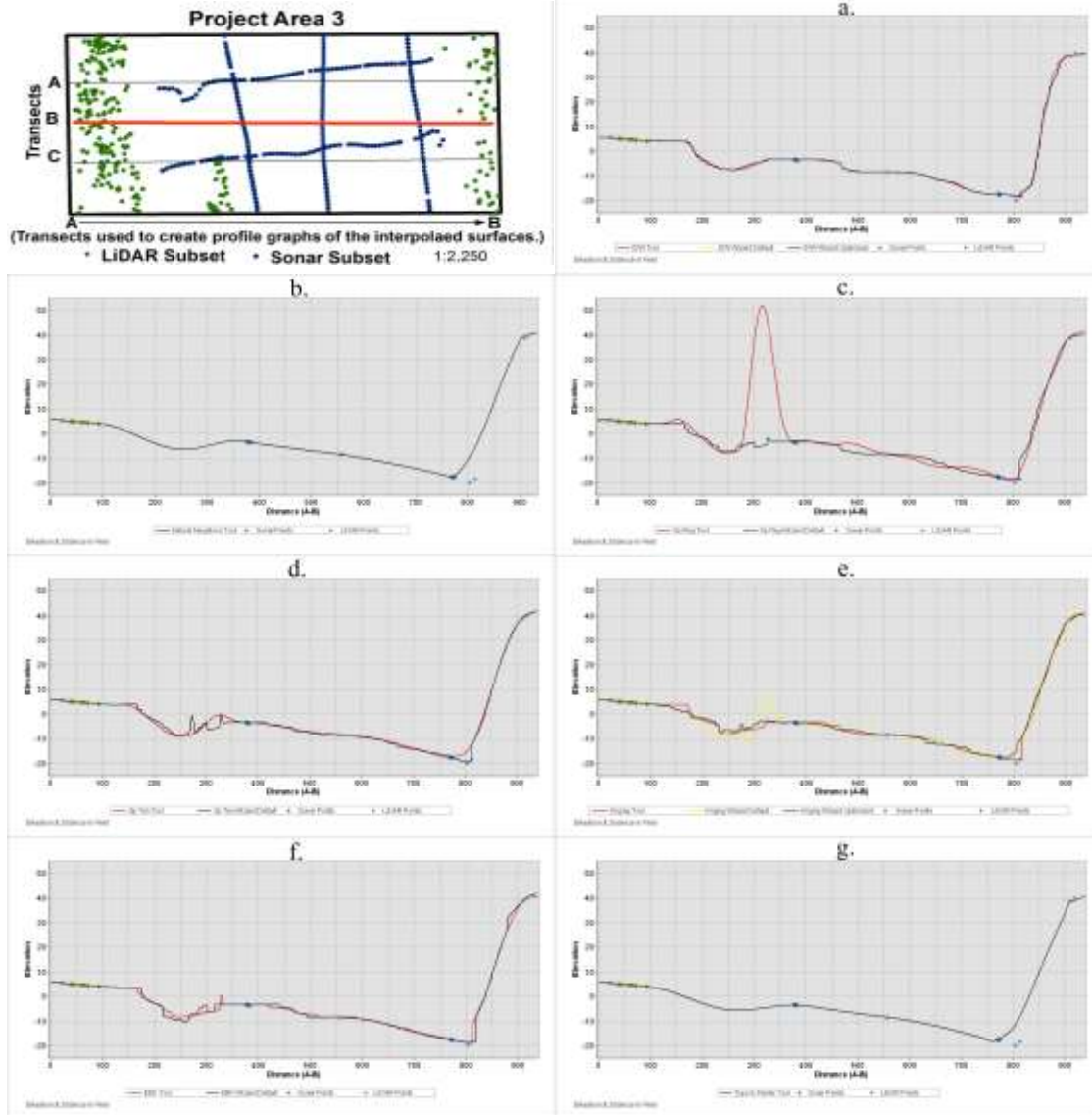
Figure 34: Profile graphs of transect B for Project Area 3. Each graph represents an interpolation algorithm, and all graphs represent the same transect within the Project Area: a. IDW, b. NN, c. Spline Regular, d. Spline Tension, e. Kriging, f. EBK, g. Topo to Raster.
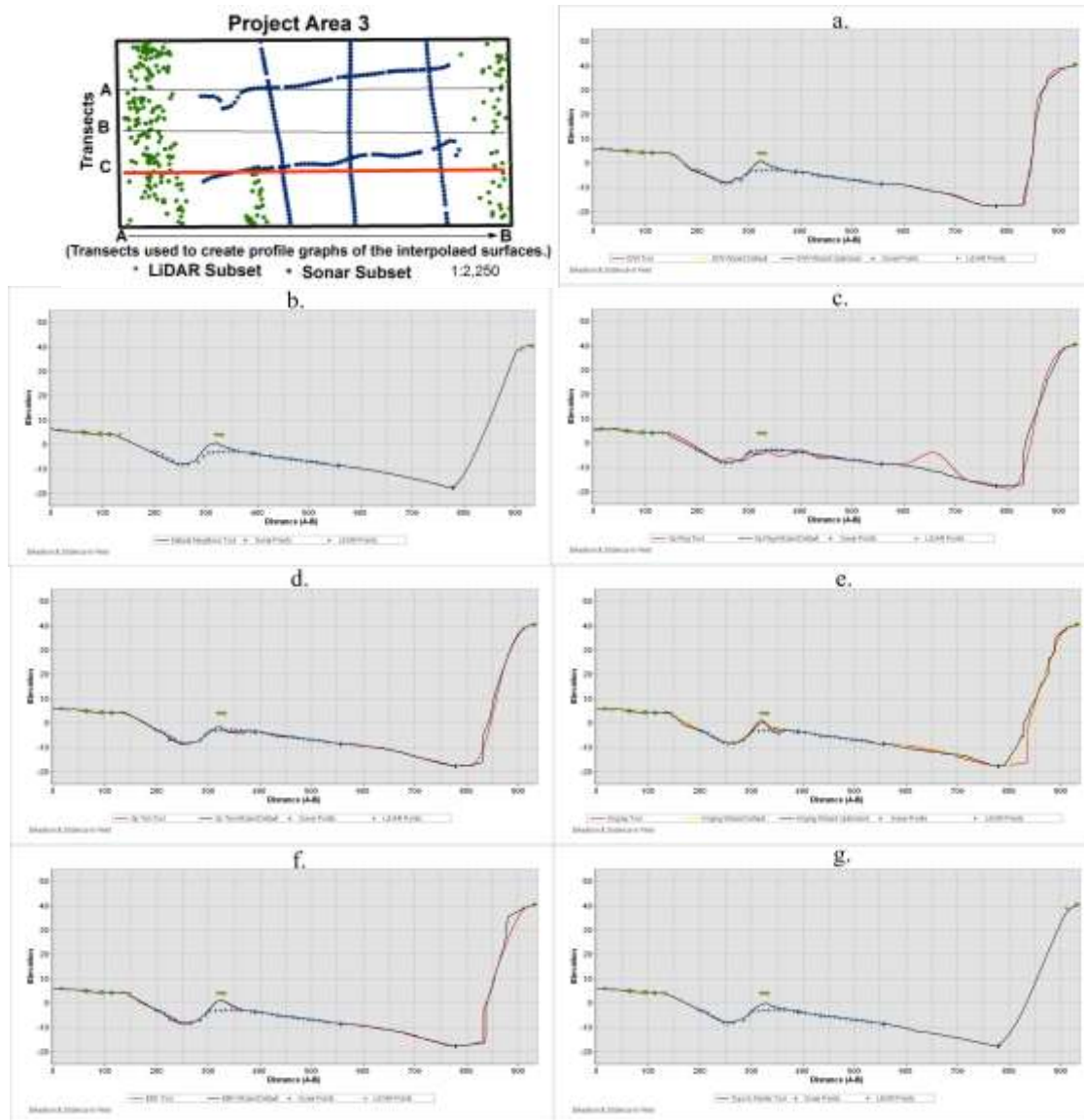
Figure 35: Profile graphs of transect C for Project Area 3. Each graph represents an interpolation algorithm, and all graphs represent the same transect within the Project Area: a. IDW, b. NN, c. Spline Regular, d. Spline Tension, e. Kriging, f. EBK, g. Topo to Raster.

Transect A for Project Area 3 has dramatic variation in the surfaces created from interpolated methods as well as the tool, Wizard default and Wizard optimized settings. (Figure 33) The IDW methods area extremely similar that only slight variations are visible in the wide measurements gaps within the surface. The surfaces created from the Kriging interpolations, particularly within the instance along the transect of 700 to 900ft are drastic, where the tool surface is similar to the interpolated surfaces such as IDW, EBK, and natural neighbors. Spline Regular using the tool seems to produce an uncharacteristic smooth result but in this case does not follow the data trends. The Topo to Raster tool seems to smooth some of the rapid variation in the surface when compared to the other interpolation methods.

Transect B has one feature which has in interesting influence on the surfaces created as seen in Figure 34. This transect has the least amount of measured points surrounding the profile which causes the surfaces to rely on point measurements further away, some of which are within the discrepancy areas. Both the Spline Regular and Tension tools return to the normal form of creating exaggerated mounds within the surface, which some might consider the Tension Spline tool to be favorable when compared to the erratic steps created by the Wizard default surface.

The peninsula creates interesting results within transect C as seen in Figure 35, although the transect does not exactly include the peninsula, the effects of the data variability can be visualized in the interpolated surfaces. The Kriging interpolation just as the rest of the Project Area 3 shows the variation with the tool, Wizard default and

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Wizard optimized settings. The peninsula influence can be visualized within the 300 and 350ft area. The influence can be seen as the Kriging, Spline Regular and Tension, with the Kriging creating different surfaces for the discrepancies. The variation in most surfaces can be seen as well in the distance range of 600 to 900ft, due to a large data gap. The influences of the surrounding measured points at a further distance creates manipulations within the interpolated surfaces, where most interpolated surfaces when using the Wizard default of optimized methodology follow a sharp curve at about a distance of 825ft.

The visualizations of the surfaces are starkly different then the visualized profiles or statistical overview of the surfaces. The representations of the peninsula vary, the surface created from the Spline Regular, Spline Tension and EBK all produce multiple island/peninsula visualization. Although the visualizations of this Project Area visually seem skewed, the representations made by the various interpolations represent the influencing factors of the interpolation methodology. Where the measured point values are densely spaced, the values are all within a reasonable variation and where discrepancies exist such as in Transect 3, the measured points directly on the raster grid cell prevails. The differences between the Tool, Wizard default or optimized settings can be seen within this Project Area more than others. Not only within the peninsula area, but with the bank on the right hand side of the page, the variations are distinct in all interpolation methodologies.

The lack of consistency within the overall Project Area might be attributed to the sparseness of the overall measured points. The timing of the data collections, the choice of LiDAR and Sonar point integration methodology and the lack of verification on the ground all attributed to the irregularities within Project Area 3. Although the data succeeded in illustrating the interpolated surfaces methods for either incorporating, the surrounding measured points to varying degrees.

5.2.4 Project Area 4

Project Area 4 is has a gradually sloping bankline with deep channelization of the river due to the force of the water upstream and has a sharp incline into the land once again via a levee feature and boat docks.

Table 11: Table of the statistical distribution in Project Area 4.

Project Area 4

	Entire Project Area Points							Subset Project Area Points					
	Count	Min	Max	Mean	Median	Std. Dev		Count	Min	Max	Mean	Median	Std. Dev
	9984.0	-31.6	72.0	9.5	10.3	11.4		500.0	-31.6	70.4	-0.2	0.3	13.8

		Tool					Wizard Default					Wizard Optimized				
		Min	Max	Mean	Std Dev.	RMSE	Min	Max	Mean	Std Dev.	RMSE	Min	Max	Mean	Std Dev.	RMSE
IDW		-31.6	70.4	-2.9	13.1		-31.6	70.4	-2.9	12.9	1.7	-31.6	70.4	-2.9	13.2	1.6
Natural Neighbor		-31.6	70.3	-3.1	12.3											
Spline	Regular	-49.4	73.3	-2.2	14.2		-32.1	70.9	-2.8	13.2	1.4					
	Tension	-32.4	71.7	-2.9	13.2		-32.2	71.2	-2.8	13.4	1.1					
Kriging		-28.6	65.5	-3.0	12.0		-32.0	71.6	-2.8	13.5	1.1	-32.8	72.0	-2.8	13.7	1.0
EBK		-31.4	72.1	-2.9	13.3		-31.5	71.6	-2.9	13.3	1.2					
TopoRaster		-31.6	69.2	-3.5	13.1											

(left margin label: Interpolation Method)

The statically comparison in Table 11 of Project Area 4 is not as large as other Project Areas, but the impact on the resulting interpolated surface raster is visible as seen in Figure 36. The variation in standard deviation from the Kriging tool and the Kriging Wizard optimized setting is drastic, as well as compared to the variation seen in the Spline Regular tool. The subset measured points for the area has a mean of -0.2, where

the interpolated surfaces caused reeducation in this value ranging from -2.2 to -3.5. The

Kriging Wizard optimized setting also produced the lowest RMSE, and the maximum

and minimum just fall outside the measured point's values.

Project Area 4
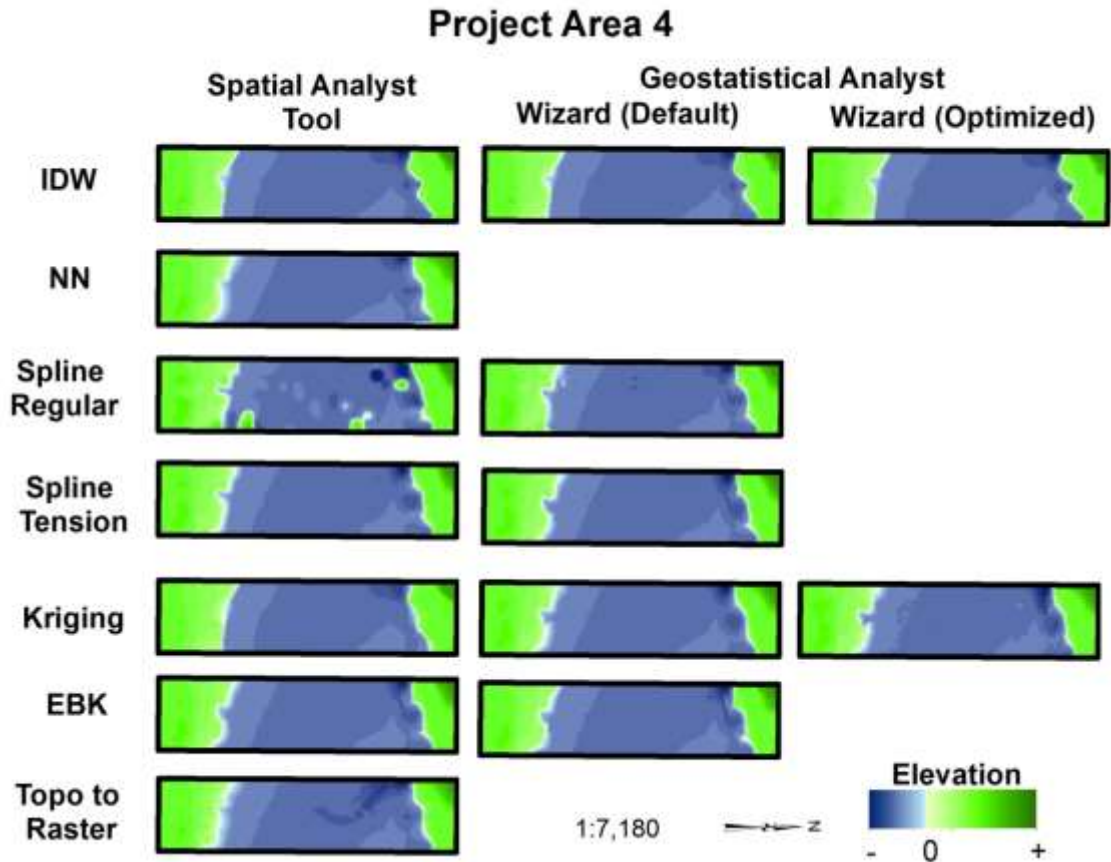
Figure 36: Surface raster maps of interpolation algorithms. Note the differences between the different interpolation algorithms.

Transect A majority of the variation can be seen at a profile distance of about 950 to

1350ft in Figure 37. This variation can be seen within the methodologies of the Kriging

tool, Wizard default and Wizard optimized. The Kriging Wizard optimized parameters

cause the depth to an exaggerated amount compared to the other interpolated surfaces,

another interesting note is that the tool for Kriging produces a bench at the end of the transect where none of the other interpolation methods do so. Within this Project Area, the topo to raster tool interpolates an interesting series of dips at a profile distance of 900 to 1500ft. where Spline Regular also has sever dip at this location, the influence of distant measurements on the surface profiles.

The variation with the Wizard default and the optimized setting is small within Transect B, but the differences in the tool parameters are visible within the profiles seen in Figure 38. Kriging interpolation using the tool creates a stair-step surface around the profile distance of 100 to 350ft and again at 1500 to 1250ft, this discrepancy within the surface of at one point nearly 15ft. Spline Regular and Tension tools create rolling hills within the surface to illustrate the value distribution, where a slight shelf follows the data values more functionally. The IDW interpolation between the Wizard and the tool, a slight peak is created where there is a lack of data values.

Transect C contains several sections of clustered data along the transect profile on Figure 39. This clusterization and sparse distribution of other data causes models such as Spline Regular tool to create steep peaks within the surface, where when using the Wizard default smooth these features. The Kriging tool creates a visual stair-step approach simulate to that of the IDW interpolated surfaces, but when using the optimized setting of Kriging is generally smoothed with the exception of rugged variation near a profile distance of 11000 to 1200ft. EBK tool created a seemingly smooth surface

compared to the optimized version, but within out complete visualization of the surface

the judgment cannot be made.

Figure 37: Profile graphs of transect A for Project Area 4. Each graph represents an interpolation algorithm, and all graphs represent the same transect within the Project Area: a. IDW, b. NN, c. Spline Regular, d. Spline Tension, e. Kriging, f. EBK, g. Topo to Raster.

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Figure 38: Profile graphs of transect B for Project Area 4. Each graph represents an interpolation algorithm, and all graphs represent the same transect within the Project Area: a. IDW, b. NN, c. Spline Regular, d. Spline Tension, e. Kriging, f. EBK, g. Topo to Raster.
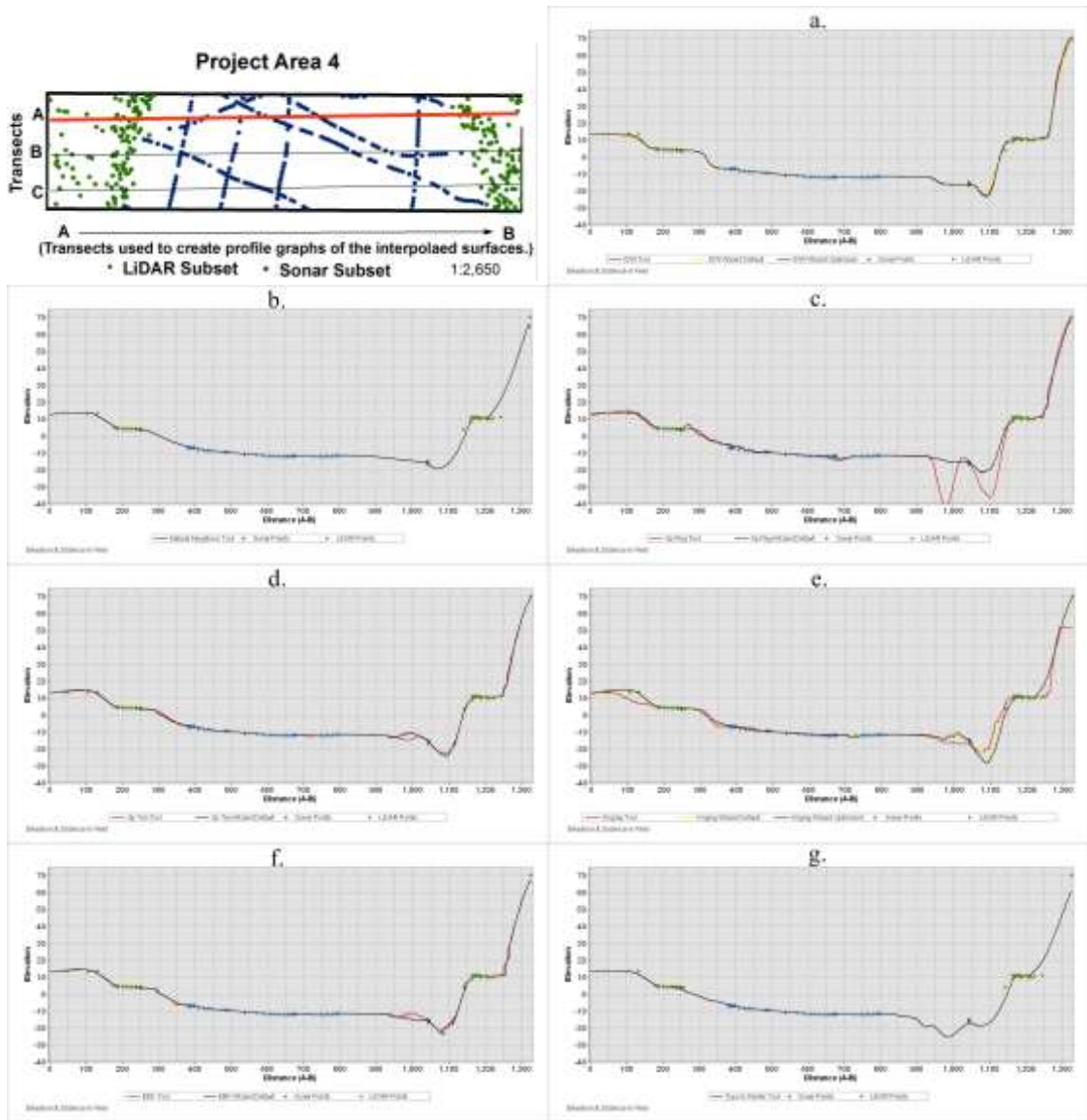
94

Figure 39: Profile graphs of transect C for Project Area 4. Each graph represents interpolation algorithms, and all graphs represent the same transect within the Project Area: a. IDW, b. NN, c. Spline Regular, d. Spline Tension, e. Kriging, f. EBK, g. Topo to Raster.
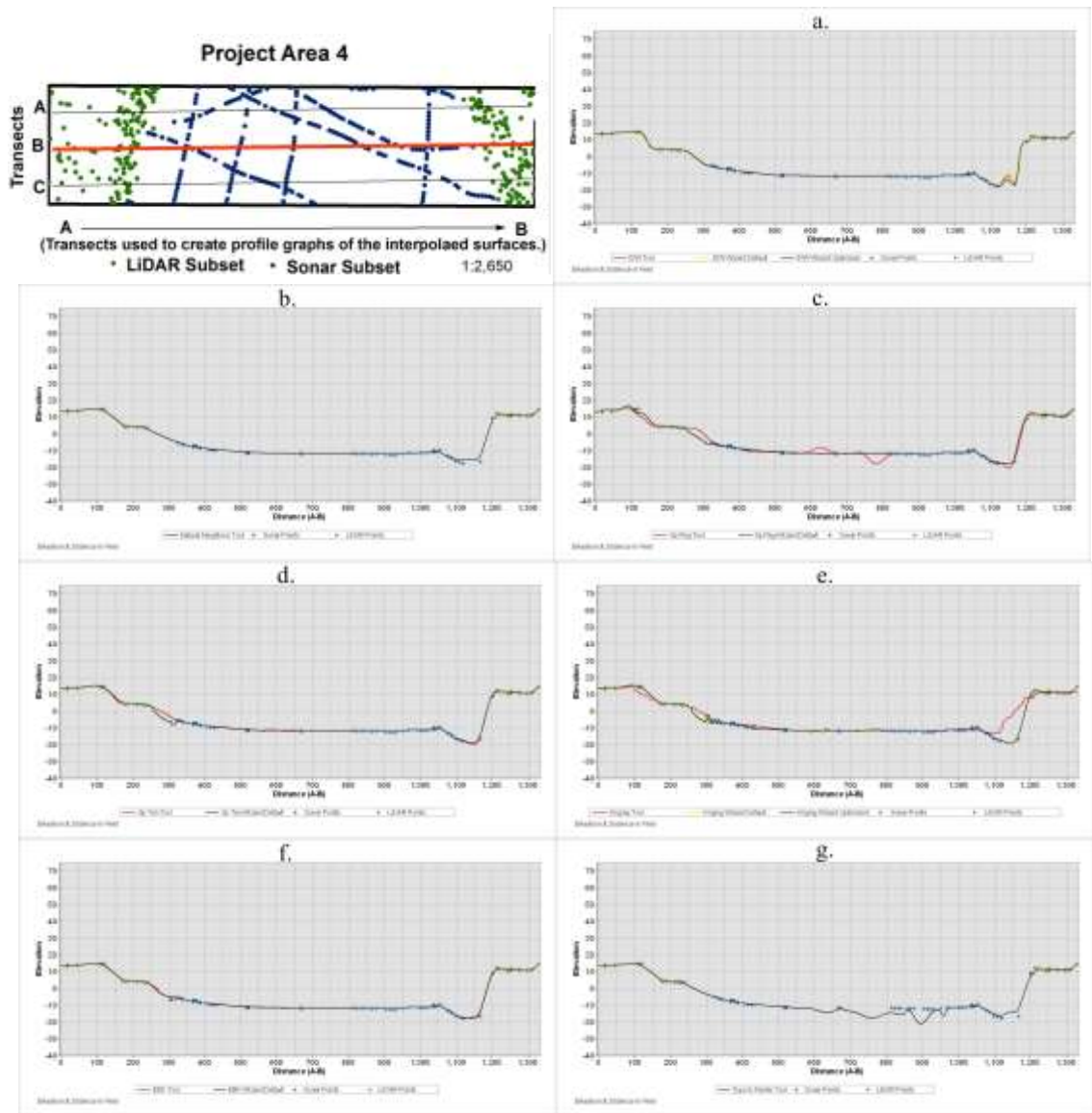
The visual representation of the elevation profiles all generally follow a seemingly

smooth transition from topography to the bathymetry and back, with the exception once

more with the Spline Regular tool seen in Figure 36 and 40. The Spline Regular tool

surface has islands and anomalies where there are no measured points. The Topo to

Raster tool produces a visually pleasing output of their surface concentrating on the

gradients of elevation. The Kriging interpolation and the Spline Regular tool have the

greatest differences between the tool and the Wizard default or optimized settings.

Although, all surfaces have some high degree of variation
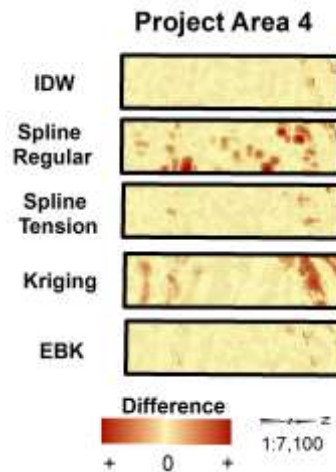
Figure 40: Difference maps comparing the surfaces created from the Spatial Analyst and the Geostatistical Analyst Extension.

Project Area 4, which is complicated by deep channelization of the river flow as well

as manmade features of a levee within close proximity, illustrates the need for

understanding the statistical variation of the dataset and the mathematical interpolation

the data is undergoing when interpolating the result. The small jitters of surfaces such as

those created by using the Wizard optimized setting in Kriging and EBK can affect the surface characteristics.

5.2.5 Project Area 5

This Project Area 5 contains a low elevation wetland island, with a deep channel river outlet as the water flows near the ocean to a manmade levee and boat ramp. This Project Area is most susceptible to tidal influence, although we are not accounting for tidal flow into the measurements.

Table 12: Table of the statistical distribution in Project Area 5.

Project Area 5

	Entire Project Area Points							Subset Project Area Points					
	Count	Min	Max	Mean	Median	Std. Dev		Count	Min	Max	Mean	Median	Std. Dev
	19072.0	-17.9	90.6	7.2	5.3	7.3		500.0	-17.7	51.4	-2.6	0.4	11.2

Interpolation Method		Tool					Wizard Default					Wizard Optimized				
		Min	Max	Mean	Std Dev.	RMSE	Min	Max	Mean	Std Dev.	RMSE	Min	Max	Mean	Std Dev.	RMSE
IDW		-17.7	51.3	-4.5	11.2		-17.7	51.3	-4.5	11.1	1.6	-17.7	51.4	-4.4	11.7	1.5
Natural Neighbor		-17.7	51.1	-5.0	10.5											
Spline	Regular	-96.8	252.3	-3.3	23.5		-17.7	51.4	-4.4	11.2	1.6					
	Tension	-18.0	54.6	-4.3	11.4		-18.3	55.4	-4.3	11.7	1.4					
Kriging		-17.2	42.1	-4.6	10.8		-18.3	57.5	-4.2	11.8	1.4	-21.1	59.3	-4.4	11.5	1.4
EBK		-18.1	53.3	-4.3	11.7		-17.8	53.2	-4.3	11.6	1.5					
TopoRaster		-17.7	50.2	-4.6	11.0											

Project Area 5 has a measured mean elevation value of -2.6 and standard deviation of 11.2, although all the interpolated surfaces underestimated the mean elevation at around -4.6, the standard deviation was just slightly off. (Table 12) The Spline Regular tool produces most variation of the surface with a standard deviation of 23.5, where the Spline Regular Wizard default is able to smooth the changes to an acceptable value of 11.2. The Kriging Wizard default properties did appear to both lower and increase the minimum and maximum value, the mean and standard deviation were within the normal variation, where the RMSE was one of the lowest within this Project Area. The maps illustrating the statistical variability can be seen in Figure 41.

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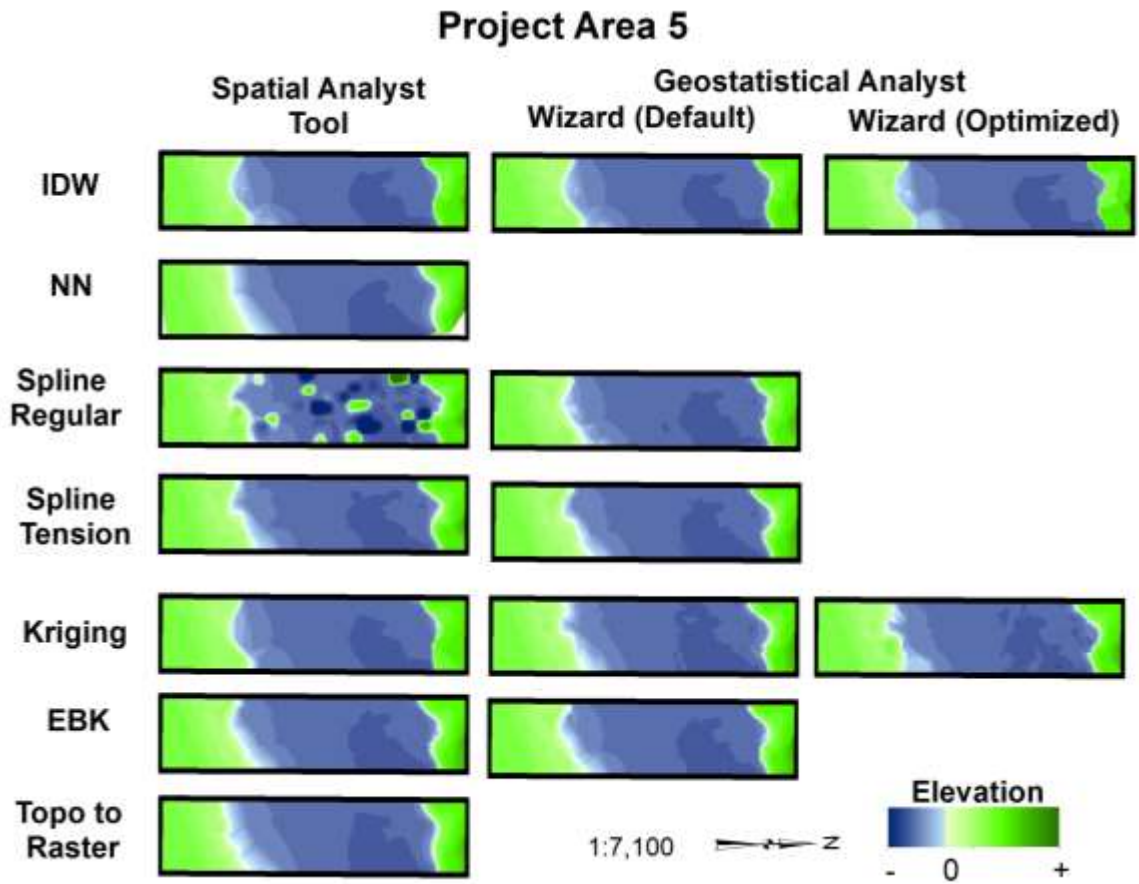
Figure 41: Surface raster maps of interpolation algorithms. Note the differences between the different interpolation algorithms.
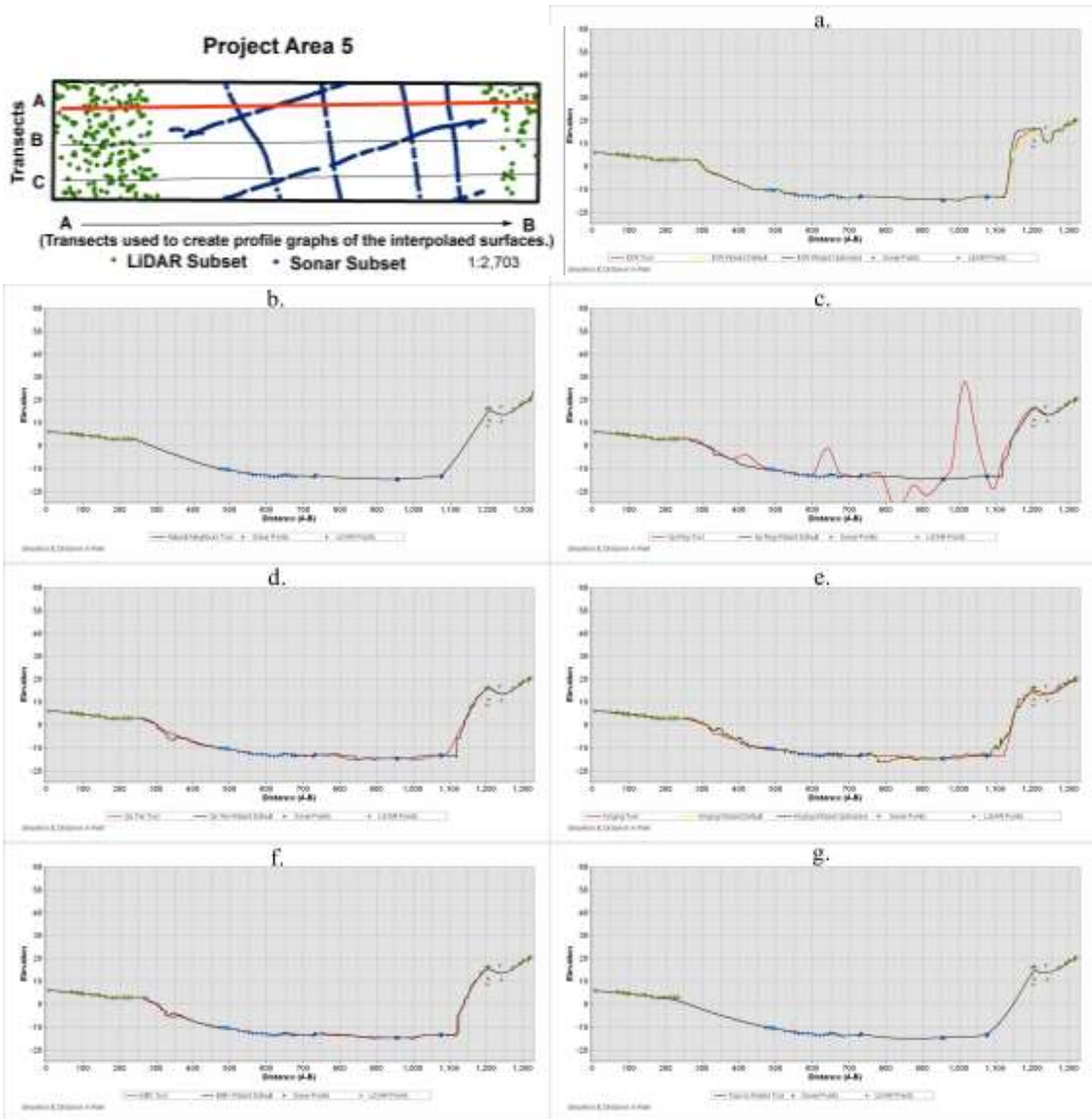
Figure 42: Profile graphs of transect A for Project Area 5. Each graph represents an interpolation algorithm, and all graphs represent the same transect within the Project Area: a. IDW, b. NN, c. Spline Regular, d. Spline Tension, e. Kriging, f. EBK, g. Topo to Raster.
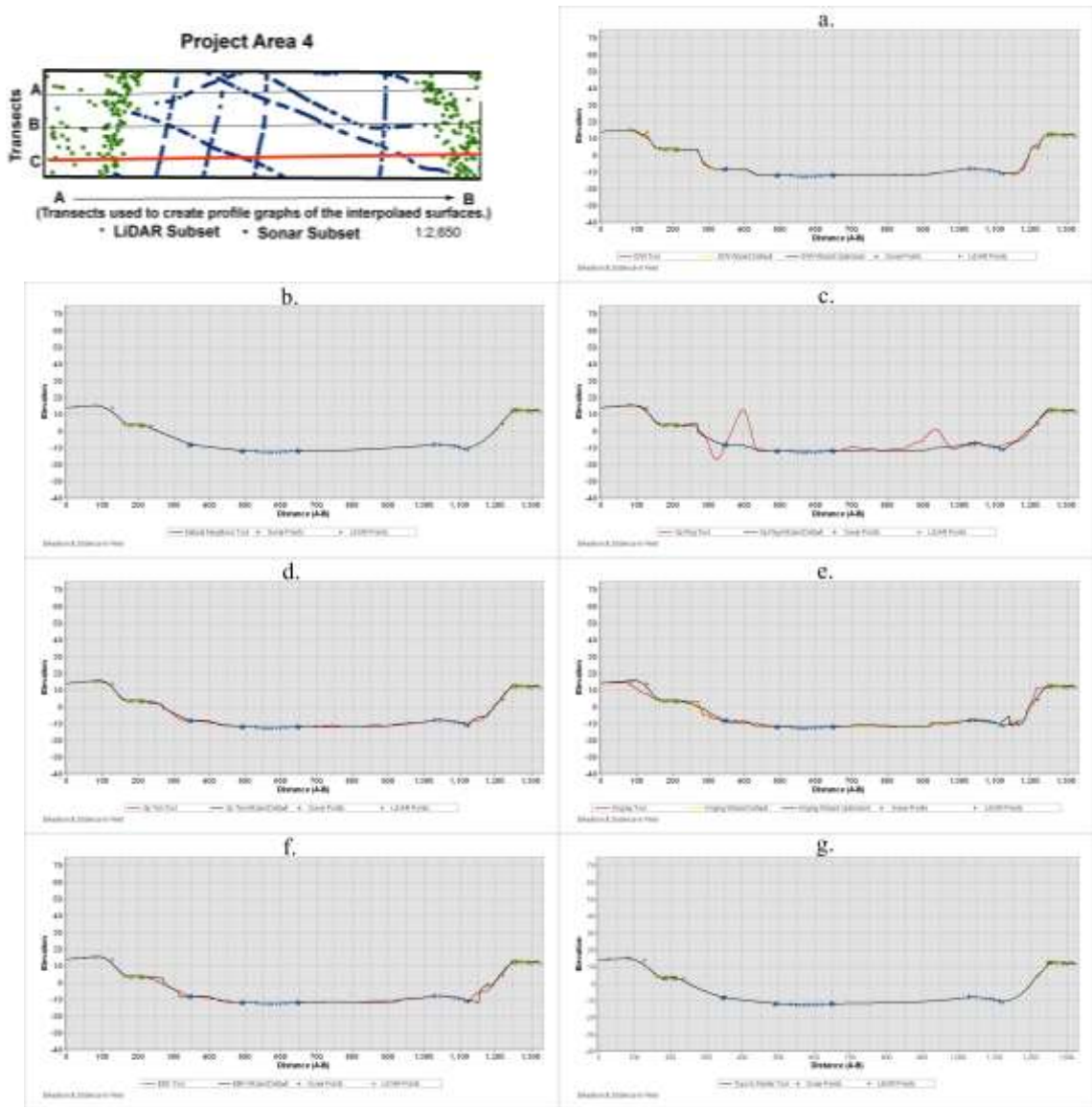
99
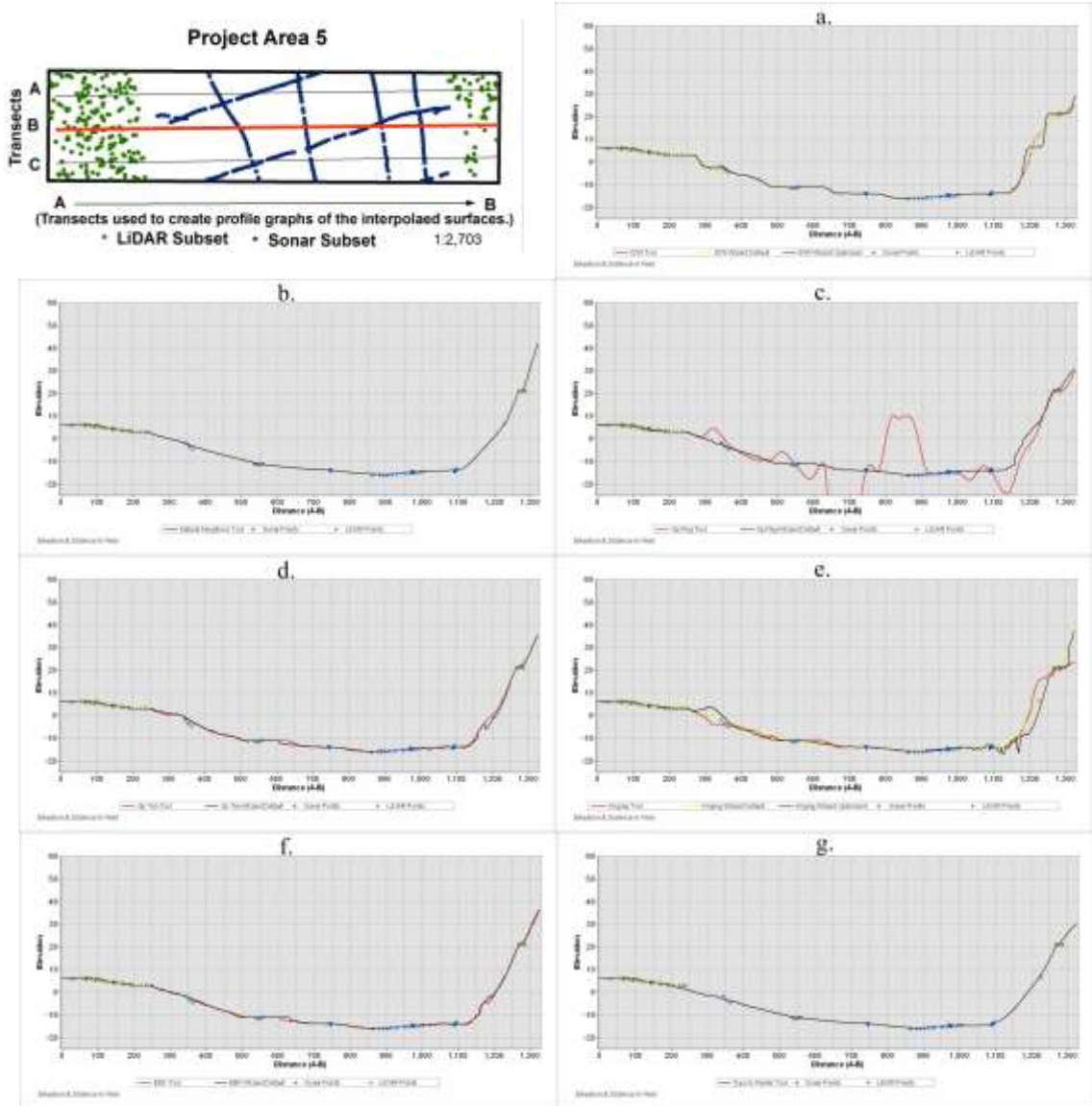
Figure 43: Profile graphs of transect B for Project Area 5. Each graph represents an interpolation algorithm, and all graphs represent the same transect within the Project Area: a. IDW, b. NN, c. Spline Regular, d. Spline Tension, e. Kriging, f. EBK, g. Topo to Raster.

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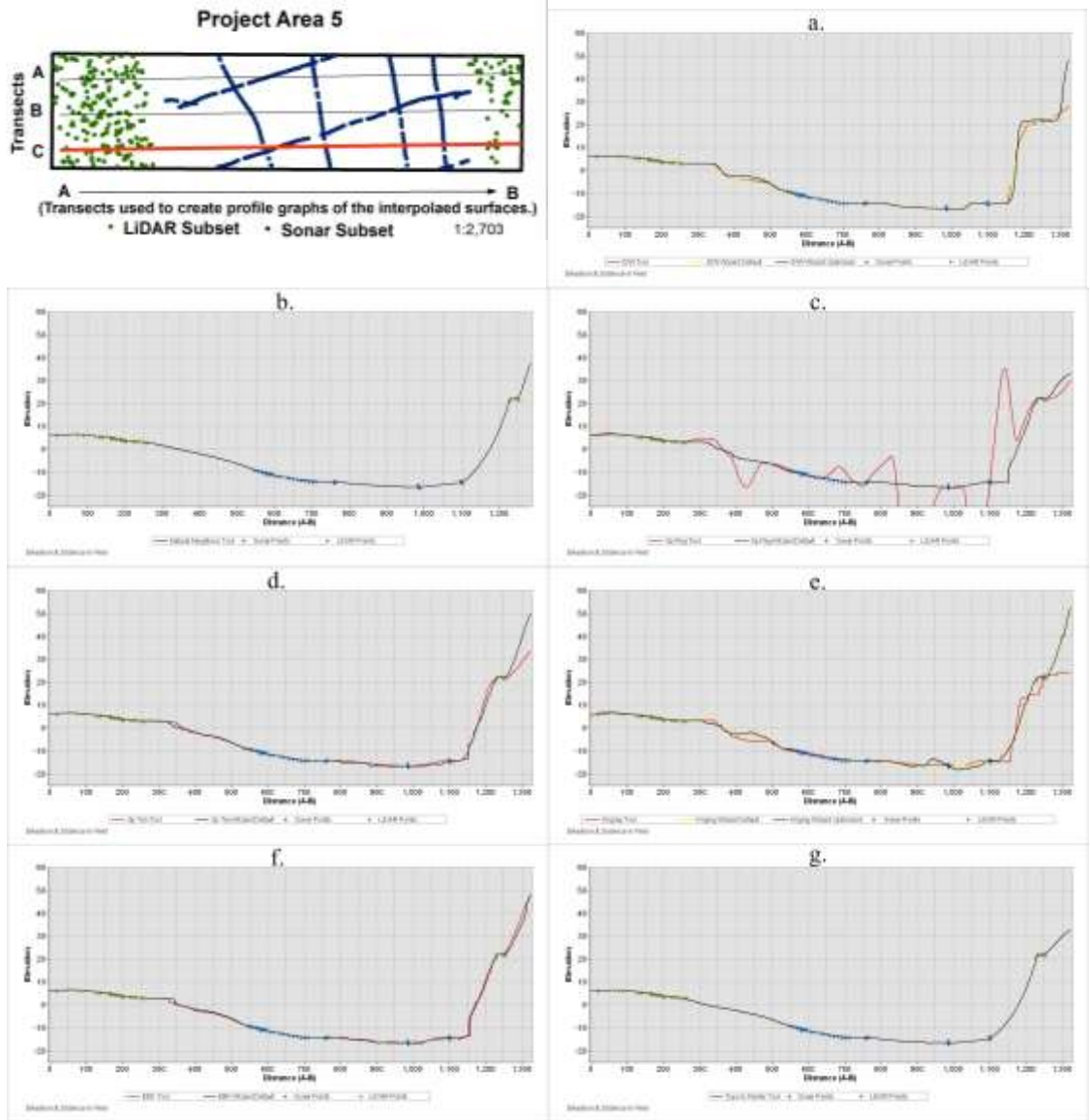
Figure 44: Profile graphs of transect C for Project Area 5. Each graph represents an interpolation algorithm, and all graphs represent the same transect within the Project Area: a. IDW, b. NN, c. Spline Regular, d. Spline Tension, e. Kriging, f. EBK, g. Topo to Raster.

Transect A has several large discrepancies within the transect profile see Figure 42. The variations between the tool and the Wizard default or optimized can be visualized in nearly all the interpolated surfaces. The IDW surface, although the surfaces created seems irrational along the profile distance between 1100 to 1300ft the elevation behind the levee actually dips to a certain degree, where other interpolation methods attempted to smooth or reduce this on-the-ground data anomaly. The Kriging and spline tension Wizard surfaces created sharp transitions of the bathymetric surface, where topo to raster, EBK and natural neighbor seem to adjust these variations into a smooth surface.

A road features is contained within profile B, which should result in a bench representation of the data in Figure 43. Topo to raster, EBK and natural neighbor do not seem to account for the temporally consistent drop of elevation from the hillside below and above the road as seen on the profile distance 1250 to 1325ft. Other variation noticeable particularly within the Kriging surfaces occur within the profile distance of 250 and 400ft. where the variation between the tool the Wizard default and the Wizard optimized have a gap of at least 3 feet between the surfaces. At the other end of the Kriging profile at distance of 1100 to 1325 ft. the variations are also erratic.

Transect C has the similar features as transect B with the levee and road, but the distribution of the clustered measured pointes is further, causing smoother but still different interpolations within that area. (Figure 44) The spline tension interpolated surfaces at a distance of 1250ft can be seen diverging, with the tool having a less gradual slope increase than the Wizard default. The surfaces of IDW the variations between the

tool, Wizard default and Wizard optimized can be seen, where the tool and Wizard default follow the similar pattern, but when the surface has the Wizards optimized setting accounting for the Spatial Statistics of the measured points the surface changes greatly to encompass the slight slopes and bank features.
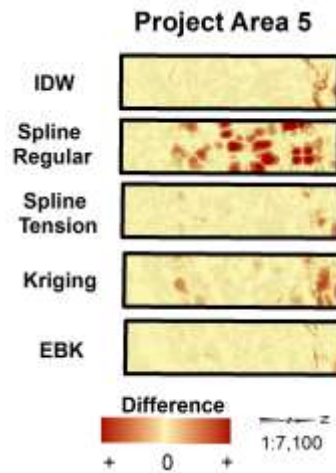
Figure 45: Difference maps of the Interpolation algorithms comparing the surfaces created by the Spatial Analyst and Geostatistical analyst.

When visualizing the elevation of these surfaces, a smooth transition of gradient is necessary when looking in the surface maps in Figure 41. When viewing the surfaces created by the Kriging interpolation methods both the default and optimized Wizard create jittery appearance. IDW, Natural Neighbor and Topo to Raster produce smooth results, where EBK Wizard's surface has some disjointed colorization, the overall effect is correct of incorporating the levee and road features. The differences are visible within all surface profiles, with EBK tool and Wizard optimized having the least amount of variation, which only occur near the manmade features as seen in Figure 45.

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Project Area 5 has the most varying interpolated surface of any of the previous

Project Areas, not only between interpolations, but when comparing the tool to the

Wizard default or optimized settings. As expected from the previous interpolations,

Spline Regular tool created outrageously varied results. The clustered data and the

sparseness of some of the dataset areas cause such erratic variation within the

interpolated surfaces.

5.3 Results Summary

The anticipated result of comparing the parameters from the Spatial Analyst and the

Geostatistical Analyst Extensions was that there was some slight variance, but the degree

of discrepancy illustrated in the results was not anticipated. The largely held concept of

tools ArcGIS having multiple ways to access an interpolation algorithm cannot be held,

the parameter differences make any of these algorithms preform drastically different. The

change of the parameters had a great impact in all the resulting surfaces.

When analyzing the tables exclusively, one raster surface has noticeable different

results than the rest. The Spline Regular tool surface contains values greatly exaggerated

from any other surface or the measured points. Although when the Spline Regular

method of interpolation is utilized within the Geostatistical Analyst, the values return to a

reasonable degree of variation. The interpolation method of the Geostatistical Analyst

Wizard Spline Tension, Kriging and EBK, shows generally a lower overall value of

RMSE. These methods follow closely the measured points for both the subset surface in

which they were created from as well as the entire Project Area. This phenomenon is visualized in the transect profiles of the Project Areas.

The profile view provides the comparison of the various interpolated surfaces to make a determination judgment on the suitability and continuity of the dataset for the topography and bathymetric datasets integration. The surface profiles when utilizing the Spatial Analyst tools, provided variation compared to the Geostatistical Analyst Wizard, when the optimization setting was utilized. The variation of the surfaces between the tool and the Wizard are overall greater than expected.

The raster surfaced visualized as a map output, then classified in a color schema exaggerating the land/water integrations provided overall characteristics of the surface created by the various interpolation methods that cannot be ascertained by the transects alone.

Chapter 6: Discussion and Conclusions

Providing information is the not the same as providing an understanding. The developing

field of GIS is tasked with not only collecting and illustrating information; it has to

provide an understanding of the world in a narrative. The challenge of bridging the gap

between the information collection and the storyline is usually lost in translation by a

data-rich GIS community. GIS professionals rely heavily on the derived datasets from the

nation's leading government agencies such as the USGS, without consideration for the

background development of the information. Elevation, which is the most fundamental

geospatial dataset available from the USGS in the form of DEMs, lacks the attention and

scrutiny it deserves. The measurement of elevation is currently set by industry standards

for LiDAR collections, but there is no standard on how to convert the LiDAR

measurements into a raster surface for use in geospatial analysis. ArcGIS, the world's

leading geospatial software company that is used by all US government agencies,

provides multiple pathways (extensions) for the interpolation of points into a raster

surface this allows for uncertainty. Documenting the exact software, version, extension,

and parameter selections can help the users to become scientists and better storytellers by

building the platform to develop the geospatial story.

Creating a representative surface of the Earth's elevation, interpolating from point

datasets to a raster, is taught in most introductory GIS courses with the latest Esri ArcGIS

software but attempting to create the most reliable and accurate surface is more

complicated than relying on the default parameters of the Spatial Analysis Extension's

interpolation algorithms. Esri provides a Geostatistical approach to point to raster surface creation in the Geostatistical Analyst Extension, which has many of the same interpolation algorithms as the Spatial Analyst Extension, yet it produces different results. The variation, usually unbeknownst to the GIS professional, can have implications on the resulting analysis. The variation can be seen in the selection of which points to use as the cornerstones of the interpolation, also known as the search neighborhood. The power functions in many of the weighted interpolation algorithms can also differ between the Spatial Analyst Extension and the Geostatistical Analyst Extension, with the Geostatistical Wizard providing optimization (sometimes by default). The Geostatistical Wizard takes the statistical variability of the point dataset into consideration when interpolating, this influences the Wizard's parameter choices and provides an illustrative level of confidence in the elevation surface created from the parameters in the forms of a RMSE. The change in parameters when using the Geostatistical Wizard optimized parameter values creates a more reliable interpolated surface than using the Spatial Analyst interpolation tools' parameters alone.

The incorporation of two diverse datasets in density, distribution and accuracy, such as Topographic/Bathymetric measurements, provide an illustration of the need to statistically understand the dataset prior to and during interpolation. The use of the interpolation algorithms: Inverse Distance Weighting, Natural Neighbor, Spline Regular, Spline Tension, Kriging, Empirical Bayesian Kriging, and Topo to Raster,- can be accessed through Spatial Analyst and/or Geostatistical Analyst. The interpolation

algorithms have their own requirements of Normal Distribution, Data Stationarity, Trends, and spatial auto-correlation, can and should influence the choice of interpolation based on the statistical distribution of the point dataset. Although each interpolation algorithm's method is essentially correct based on the parameters selected, their reliability fluctuates. With Topographic/Bathymetric surface field validation, the interpolated surface is not feasible due to the high rate of surface variability. The ability to validate the surface is attempted by three methods; comparing the interpolated surfaces to an existing DEM, comparing the differences between the measured points and the interpolated surfaces, and using a type of cross validation across all surfaces. These attempts to determine a reliable measure of implied correctness of a surface is performed on Project Area 1 and is achieved with both visual inspection and statistical checking.

The California Coastal Conservancy Coastal LiDAR project developed a digital elevation model from the bare earth LiDAR. This attempt to validate the raster surfaces will compare the bare earth DEM to the Interpolated surfaces created from that same LiDAR point dataset and the single beam sonar dataset. One would expect that the differences would only show within the Bathymetric area, but variation can be visualized throughout the surfaces as seen in Figure 46.
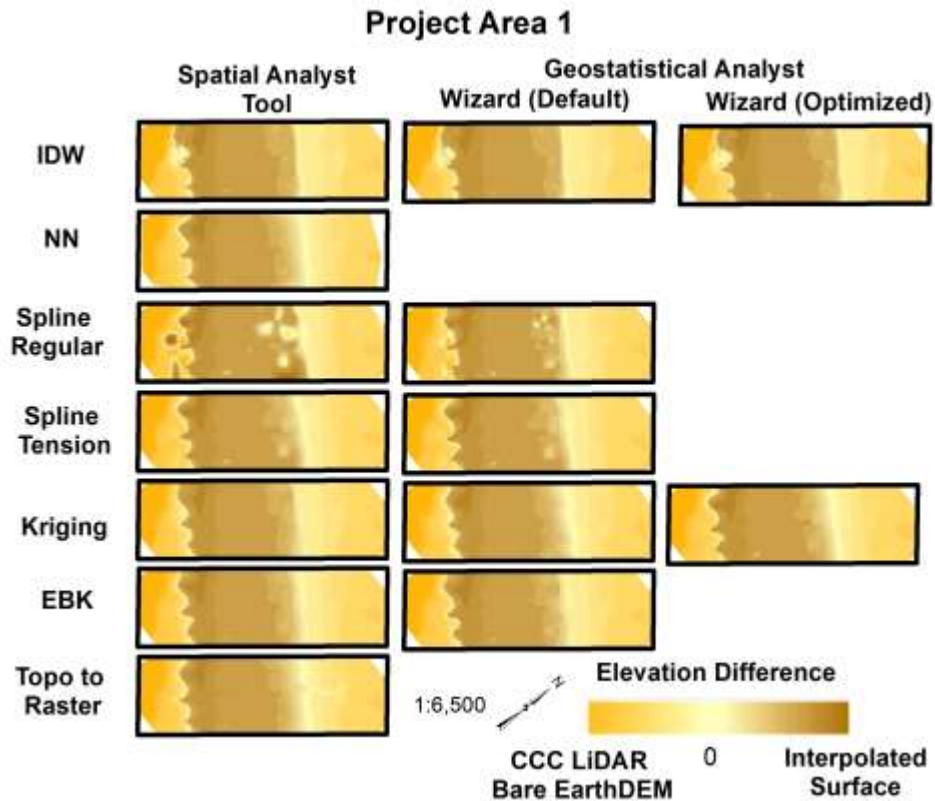
Figure 46: California Coastal Conservancy (CCC) LiDAR Bare Earth DEM subtracted from the interpolated surface. The differences are repersented by the color differences.

Within the results section, spatial comparison of the Tool and the Geostatistical

Wizard within the same interpolation algorithm but the overall comparison between

interpolation algorithms did not occur. This complete comparison visible within appendix

a., provides a general overview of the differences between the surfaces. Taking each

interpolation algorithm created from each Esri extension, using raster calculator to

compare it to every other interpolation algorithm and extension. An example of the cross

comparison can be seen in figure 47, gives a better understanding of the how the various

interpolation algorithms create different results.
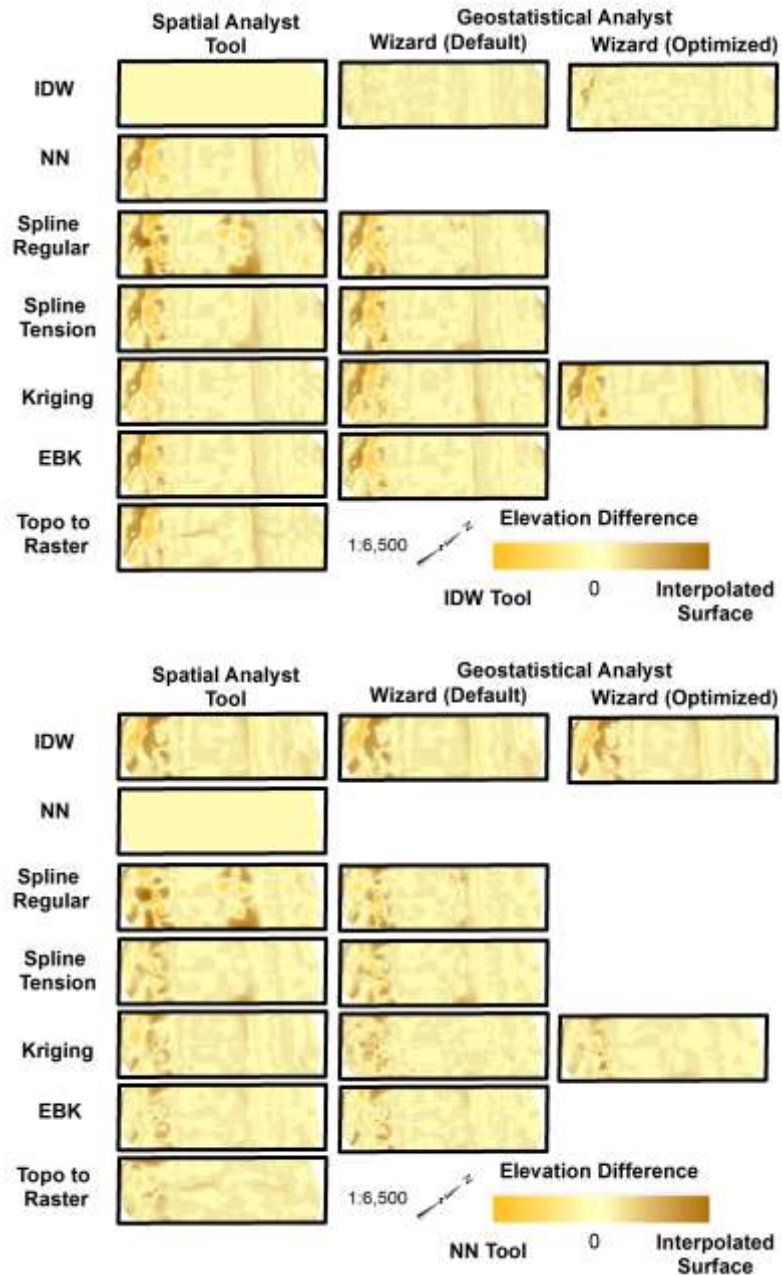
Figure 47: Two examples of the resulting Cross comparison. Taking the interpolation method/extension combination and subtracting it to each interpolation - extension interpolated raster surface created for Project Area 1 within the Study Area. Top image shows the cross comparison of the IDW interpolation used with the Spatial Analyst extension. Bottom image shows the cross comparison of the Natural NN interpolation methodology.

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As both the LiDAR and Sonar datasets have undergone post processioning and additional quality assessments, this data is considered the true values of the elevation and depth. Using the 500 subset points used to create the interpolated surfaces is then compared to the raster value of the interpolated surfaces. This illustrates two concepts, first if the interpolation is an exact or inexact interpolator and that when comparing the surfaces, using the Wizard's optimized settings improves the overall measured accuracy. This is visualized by the histograms in Figure 48. The difference between the measured points and the interpolated surfaces should be near zero an example of this is IDW. IDW is an exact interpolator, where when using the Spatial Analyst tool surface 98% falls within 0.1 foot difference, with the Geostatistical Wizard surface it is also 98%, but with the optimized Wizard interpolated surface 100% of the points fall on the surface exactly. Another example using the Kriging interpolation, where in Esri help documentation states that if the Kriging Parameter is set to zero then Kriging is an exact interpolator, but within the Spatial Analyst there is no parameter setting for this, and for the Geostatistical Analyst is default set to 100, therefor the kriging is assumed to not be an exact interpolator. When using the Spatial Analyst tool surface 25% falls within 0.1 foot difference, with the Geostatistical Wizard surface it is 21%, but with the optimized Wizard interpolated surface 88% of the points fall on the surface exactly. This is an interesting concept for the overall justification for using the Geostatistical Wizard's optimized setting.
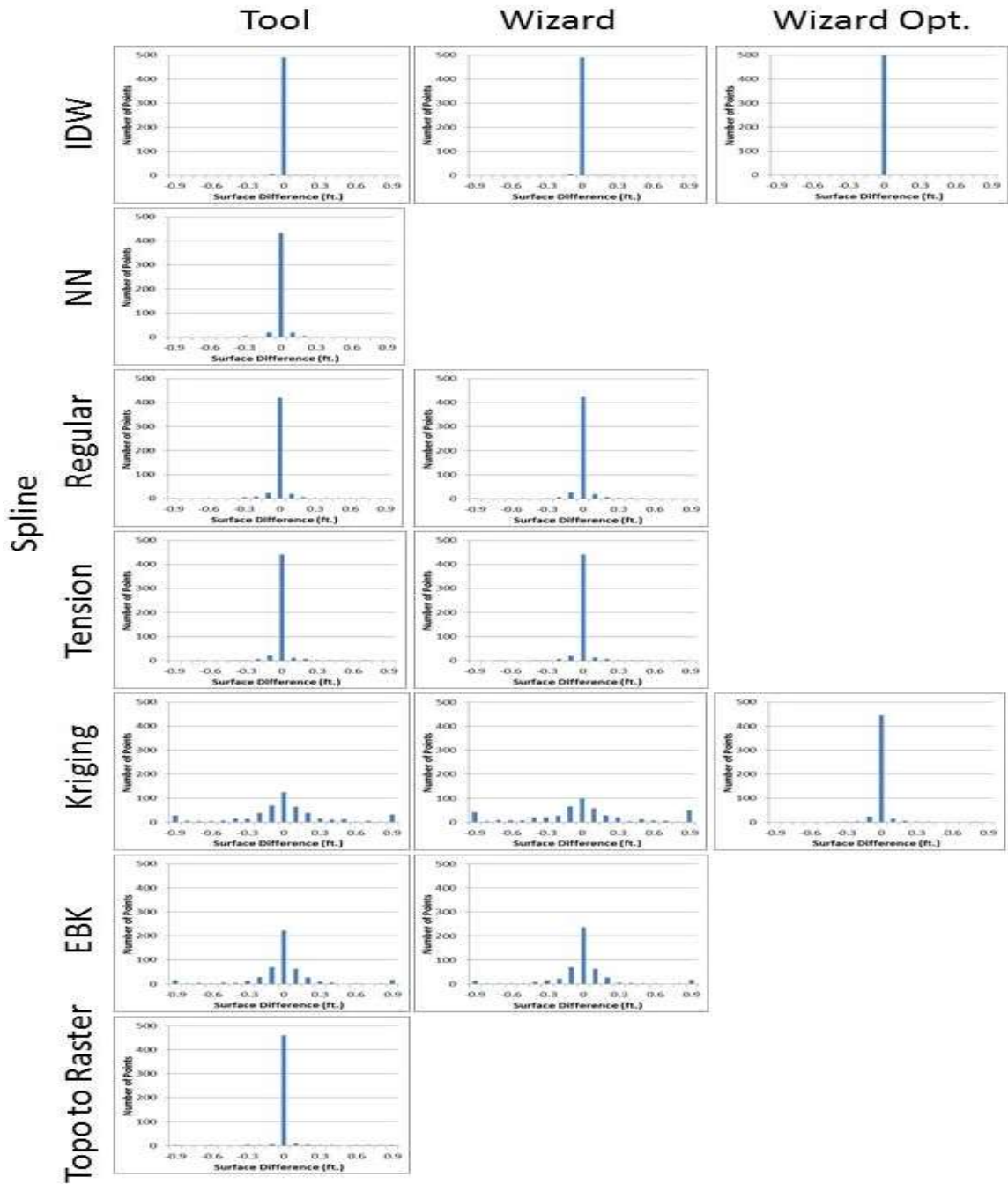
Figure 48: Elevation difference between the Measured points LiDAR and Sonar Dataset to the Esri interpolated surfaces. As the difference illustrated by the X-Axis, is closer to 0, the more similar the overall interpolated datasets fit the measured points.

For the entire study area's interpolated surfaces, the measures discussed can only provide an implied correctness, but some interpolation algorithms require special note; Regularized Spline and EBK.

The surface generated by the Completely Regularized Spline interpolation algorithm has several very different results when comparing the usage of the Spatial Analyst and the Geostatistical Analyst Extension. This interpolation method attempts to ensure a smooth surface by finding a function that minimizes the tradeoff between fitting the points and the smoothness of the surface. When using the Spatial Analyst default parameters, this function is static and cannot vary based on the statistical variation of the dataset. This results in erratic undulations of the raster surface. The Geostatistical Analyst Extension accomplished a slight reduction in the drastic variations, but when the Geostatistical Wizard is set to optimize the dataset the parameters of the variation, the surface produces both statistically and visually becomes an expected result.

Empirical Bayesian Kriging (EBK) model is the newest interpolation methodology incorporated into ArcGIS Desktop. EBK is "a particularly robust method of data interpolation because it accounts for the error introduced by estimating the Semivariogram model" (Krivoruchko 2012, b). EBK is only available in Esri's Geostatistical Analyst Extension, although when investigating the Geostatistical Analyst Extension and the Geostatistical Analyst toolbox, a change in search radius does occur. This variation between two seemingly exact interpolation algorithms modifies the surface

elevations and is important to note for usage of the Geostatistical Analyst with automated geospatial processes such as Esri's ModelBuilder, which requires the usage of toolboxes rather than Wizards.

Although the general finding within this study concludes that the Geostatistical Wizard's optimized settings will produce greater reliability, and a mathematical explanation for the parameters selected, this can also be achieved manually within the Spatial Analyst Extension, but requires a more advanced mathematical background than that provided by most University bachelor's programs (D. Watson 1992). The Geostatistical Wizard provides the flexibility to walk the user through the parameters selection with the opportunity to on-the-fly modify the parameters and see the effect on the resulting surface without committing to the changes, while providing the ability to use advanced statistical modeling to select the parameters with a click of the optimization setting.

As GIS continues to advance as a field, the creation of additional data models will need to be developed, as the data models of Vector, TIN, and Raster cannot adequately describe all conditions of the earth's surface, which GIS professionals need to model. GIS Professionals can move towards to not only provide information but provide an understanding, remembering that not everything that counts can be counted, not everything that can be counted should be and never forget the Metadata.

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Appendix A:

Comparing surfaces visually is an important component to understanding the variation between interpolation method's and extensions. Taking each interpolation algorithm created from Spatial Analyst and Geostatistical Analyst extension, using raster calculator to compare it to every other interpolation algorithm and extension. This cross comparison gives a better understanding of the how the various interpolation algorithms create different results.
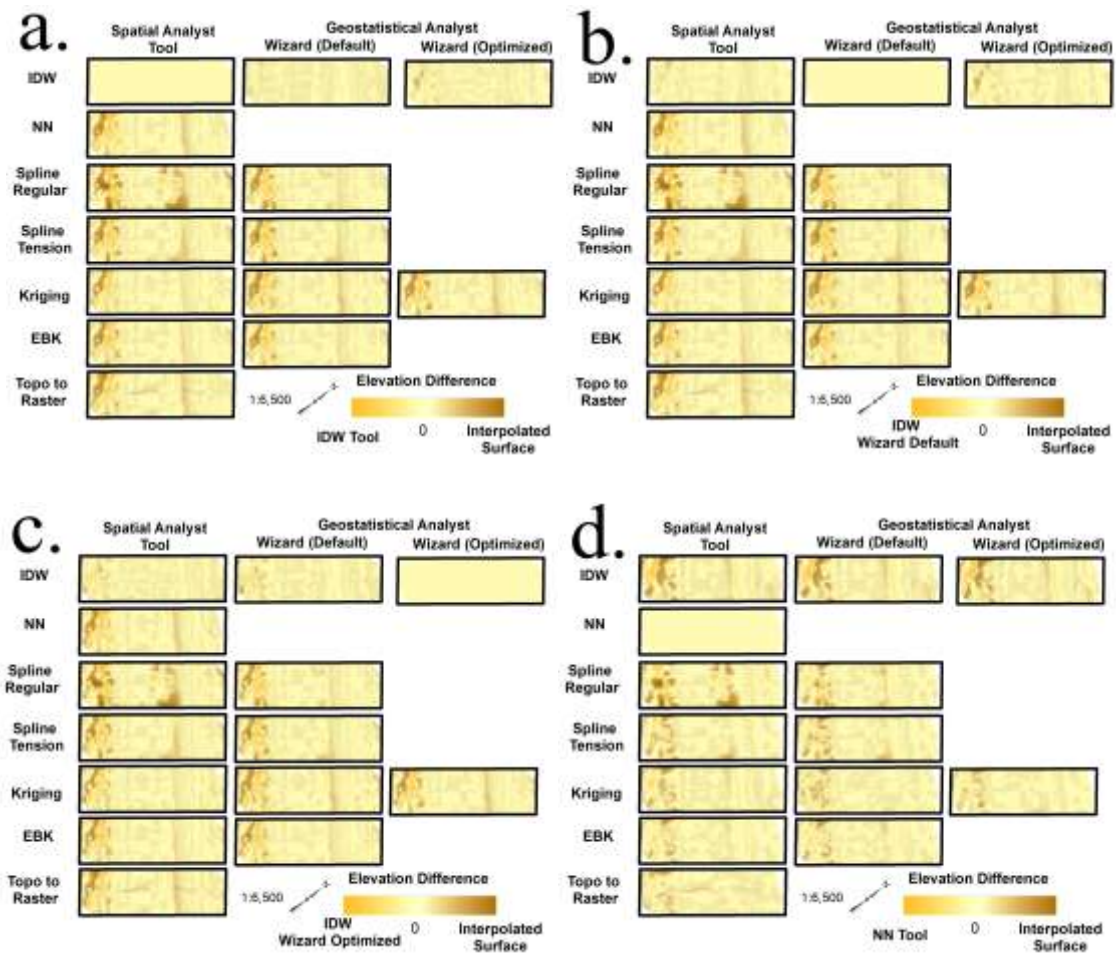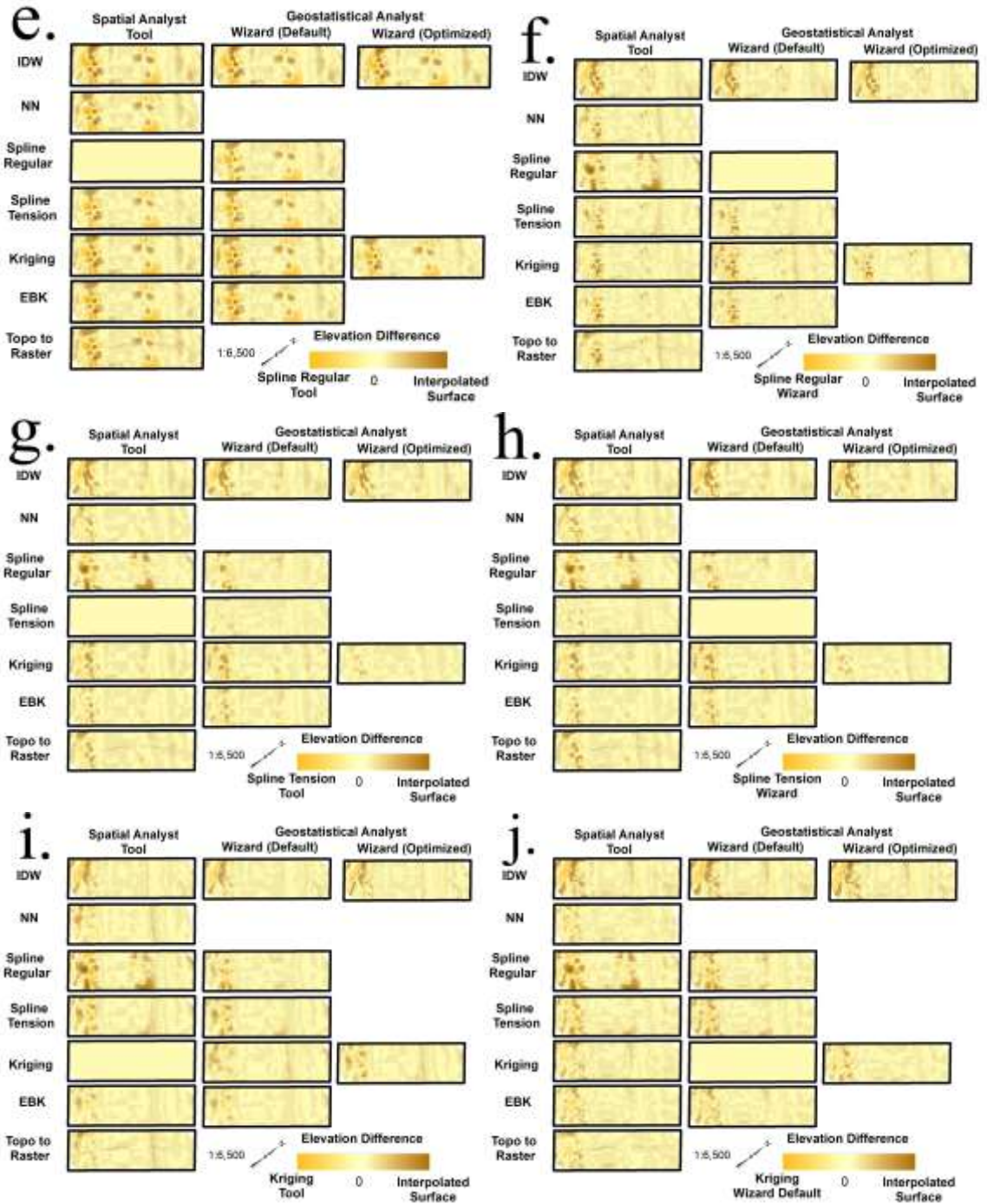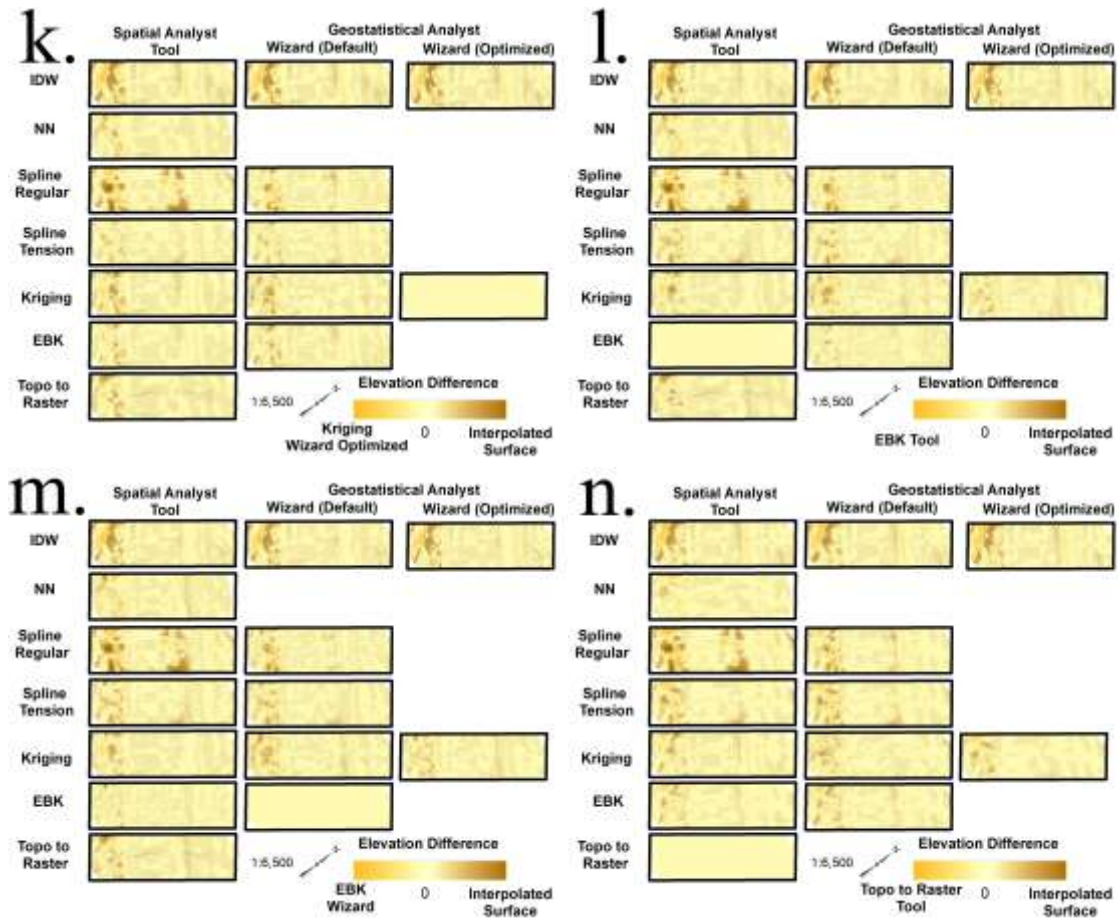
Figure 49: Cross comparison. Taking the interpolation method/extension combination and subtracting it to each interpolation - extension interpolated raster surface created for Project Area 1 within the Study Area. a) IDW interpolation algorithm using the Spatial Analyst extension is used as the base for comparison. b) IDW interpolation algorithm using the Geostatistical Analyst extension default parameters is used as the base for comparison. c) IDW interpolation algorithm using the Geostatistical Analyst extension optimized parameters is used as the base for comparison. d) Natural Neighbor interpolation algorithm using the Spatial Analyst extension. e) Spline Regular interpolation algorithm using the Spatial Analyst extension. f) Spline Regular interpolation algorithm using the Geostatistical Analyst extension. g) Spline Tension interpolation algorithm using the Spatial Analyst extension. h) Spline Tension interpolation algorithm using the Geostatistical Analyst extension. i) Kriging interpolation algorithm using the Spatial Analyst extension. j) Kriging interpolation algorithm using the Geostatistical Analyst extension default parameters. k) Kriging interpolation algorithm using the Geostatistical Analyst extension optimized parameters. l) EBK interpolation algorithm using the Geostatistical Analyst toolset. m) EBK interpolation algorithm using the Geostatistical Analyst wizard default parameters. n) EBK interpolation algorithm using the Spatial Analyst extension.

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