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This research compares interpolation methods used to create digital elevation models (DEM) for mountainous regions where mountaintop removal coal mining takes place. The research focused on the Frozen Hollow Surface Mine located in Boone County, West VA as the case study.

Three interpolation methods were compared in order to create a DEM for pre-mining conditions at the Frozen Hollow Surface Mine. The methods compared were Inverse Distance Weighted, Ordinary Kriging, and Spline with Tension. Topographic maps were used as the source of data for the sample points. Four sets of sample points were created using centroids from two grid sizes, $20m^2$ and $30m^2$, and comparing the use of single value cells (SVC) and multi value cells (MVC). This resulted in 12 interpolation methods in the study.

The Spline with Tension method was statistically significant compared to the other methods in all four data sets. The interpolation method with the least amount of error was the Spline with Tension method using both the SVC & MVC from the $30m^2$ centroids.

A COMPARISON OF INTERPOLATION METHODS FOR

ESTIMATING MOUNTAINTOP REMOVAL

by

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CHAPTER I

INTRODUCTION

More than a billion tons of coal is produced in the United States each year (Coal Statistics, 2011). The world's consumption of coal is expected to increase dramatically from 139 quadrillion Btu in 2008 to 209 quadrillion Btu by 2035. In 2011, West Virginia led the nation in the extraction of bituminous coal, with 26,000 more short tons than the second leading state, Kentucky. (U.S. Department of Energy, 2013) With the rapidly growing demands for coal energy, cost effective and efficient mining practices have become a priority for many companies. Boone County leads all counties in the state of West Virginia by producing more than 12 million short tons of coal annually through surface mining (U.S. Department of Energy, 2013). Surface mining is a form of coal mining that is used to extract coal seams within several hundred feet of the Earth's surface. Surface mining has scarred a portion of the West Virginia landscape and there are over 766.83 square miles of land with permits for some form of surface mining (WVDEP, 2013). By April of 2011, 24% of the total area of Boone County had been permitted for some form of surface disturbance through mining (WVDEP, 2013).

Coal mining is one of the major reasons for land use change in the Appalachian region. Between the years of 1973 to 2000, the leading land cover change in the Central Appalachians was the conversion of forest to mining. In fact, two-thirds of all land cover changes in the Central Appalachians during this period were related to coal mining (Sayler, 2011).

Mountaintop removal, which includes the formation of valley fills, is a form of surface mining. The EPA defines this type of mining as "removal of mountaintops to expose coal seams, and disposing of the associated mining overburden in adjacent valleys" (U.S. EPA, 2013). Mountaintop removal and valley fill (MTR/VF) mining is very controversial due to the known negative impacts on the surrounding ecosystems and the environment. MTR/VF mining was introduced in the 1970's as a response to the oil crisis. MTR/VF is preferred over other techniques since it is a relatively efficient and inexpensive way to extract coal to meet high demands. The environmental concerns regarding MTR/VF led to the passage of the Surface Mining Control and Reclamation Act in 1977 (SMCRA). The purpose of the act is to establish a set of standards to mitigate the effects on the environment from surface mining. Although MTR/VF has become much more prevalent in the past two decades, the long-term effect of this technique is still largely unknown.

Studies that assess the impacts of mountaintop removal often rely on data that capture and monitor pre-mining to post-mining changes in the environment. Digital elevation models (DEMs) are often employed as foundational datasets for examining changes in landscapes over time. Several studies have been conducted on geomorphological changes to the coastal region of North Carolina using DEMs derived from Light Detection and Ranging (LiDAR) data (Gares, Wang, & White, 2006; Mitasova et al., 2009; Zhou & Xie, 2009), however, the inception of many mining sites often pre-dates the technology. As an alternative, researchers have relied on other sources of elevation data. These sources have included USGS DEMS, topographic maps, and data collected at the mining site. The dearth of temporally sensitive elevation data for examining mining regions and activities places great importance on the need to assess methods that can accurately derive elevation datasets from ancillary sources (e.g. USGS Topographic Maps).

The purpose of this study is to assess interpolation methods for deriving elevation data from topographic maps during time periods of mining activity where no other data sources exist. Traditional USGS DEMS, as well as data collected at the mining sites, are often not available at the needed temporal scale. The results of the study should be useful for aiding research that uses DEMS to examine the impacts of mining and the removal of mountaintops.

This research compares three methods for interpolating elevation data in the mountainous terrain of West Virginia. Elevation in mountainous terrain can be difficult to interpolate due to high variation of elevation within a short distance (Ren et al., 2009). The study site is the Frozen Hollow Surface Mine in the town of Prenter, West Virginia. Inverse Distance Weighting, Ordinary Kriging, and Spline with Tension were compared. Interpolating a DEM of pre-mining conditions, while reducing the amount of error, is a central focus of this study. Model residuals for each interpolation method were assessed using Root Mean Square Error (RMSE) and compared through statistical analysis.

As an additional assessment of model accuracy, the volume of land mass altered within the site boundary was calculated and compared to overburden information acquired in the permit request.

CHAPTER II

LITERATURE REVIEW

Mountaintop Removal

Site Preparation

The process of mountaintop removal requires several steps including site preparation. The site must be prepared by clear cutting the forests and removing the topsoil. Trees are often cut down and dumped in the valleys by bulldozers. The Appalachian region is known for being vastly biologically diverse. Cutting down trees and clearing land threatens the success of species in the region. The A horizon of the topsoil is to be removed prior to any blasting to prevent contamination, and stored separately for the final reclamation stage. The original topsoil is to be used to provide sufficient soil properties for regrowth in those areas. However, if it can be proven that the original topsoil is unacceptable for future vegetation growth, or that a topsoil substitute would provide better quality, it is common for the topsoil substitute to be used instead of saving the original soil. Topsoil substitute is made from selected overburden materials (Title 30 U.S.C. §715.16, 2013). Overburden is all the rock and soil above the coal seams being mined. Both deforestation and removal of topsoil affect the rate of transportation of sediment and water (Charlton, 2008; Sharma, 2010).

Blasting

Blasting is performed to remove the layers of overburden. The explosive used to perform this task is ammonium nitrate/fuel oil (ANFO). Approximately 70% of all ANFO used in the United States is by the mining industry (Goodell, 2006; Pike, 2011). Holes are drilled into the layers of parent material and the explosives are detonated. This process creates fragmented pieces of overburden which are subsequently relocated with large machinery called draglines. The coal companies are required to "restore the area to the approximate original contour (AOC)" using the overburden and creating islands with the lowest grade but not more than the angle of repose (Title 30 U.S.C. § 1265, 2012). The remainder of the overburden is dumped in the valleys to create what is known as valley fills. The creation of valley fills is one of the major concerns to the environment. The area of the valley fill is not the only area affected by that fill, and the true effects of this form of mining may well reach past the boundary of the mine site (Phillips, 2004).

Extraction of Coal

Once the overburden has been cleared away from the coal seam, the coal is extracted and removed from the site to be processed at a separate facility. The "cleaned" coal is then shipped, usually by train or barge, to be sold for consumption. The remaining slurry (the byproduct from cleaning coal) is stored in slurry ponds. The dams of these ponds can fail or they can spill over during heavy rain events. In October 2000, in Inez, Kentucky, a coal slurry pond failed which resulted in 250 million gallons of waste being sent into nearby rivers and the community below. According to the EPA, this was one of the worst environmental disasters to ever hit the Southern U.S. (U.S.

EPA, 2001). The central criticism of MTR/VF mining is that the effects of this form of mining reach beyond the site boundary.

Reclamation

Reclamation is the final step in the mountaintop removal process. It is an attempt to leave the mined area in a condition that can support uses that it was able to support prior to mining, or better uses if possible (Title 30 U.S.C. § 1265, 2012). Ferrari et al. (2009) found that areas of reclamation due to mining activity are more similar to an urban landscape rather than an area that has suffered deforestation alone. United States Code, Title 30, Section 1265, outlines a set of performance standards for environmental protection related to surface coal mining (Title 30 U.S.C. § 1265, 2012). Within the code, it states that the operation shall "minimize the disturbances to the prevailing hydrologic balance at the mine-site and in associated offsite areas and to the quality and quantity of water in surface and ground water systems both during and after surface coal mining operations and during reclamation".

Figure 2.1 is a visual representation of the process of mountaintop removal and valley fill creation as described above (U.S. EPA, 2013). The overburden and soil is shown in yellow and black, the coal seams in bold black, and the green area represents areas that have been re-vegetated.

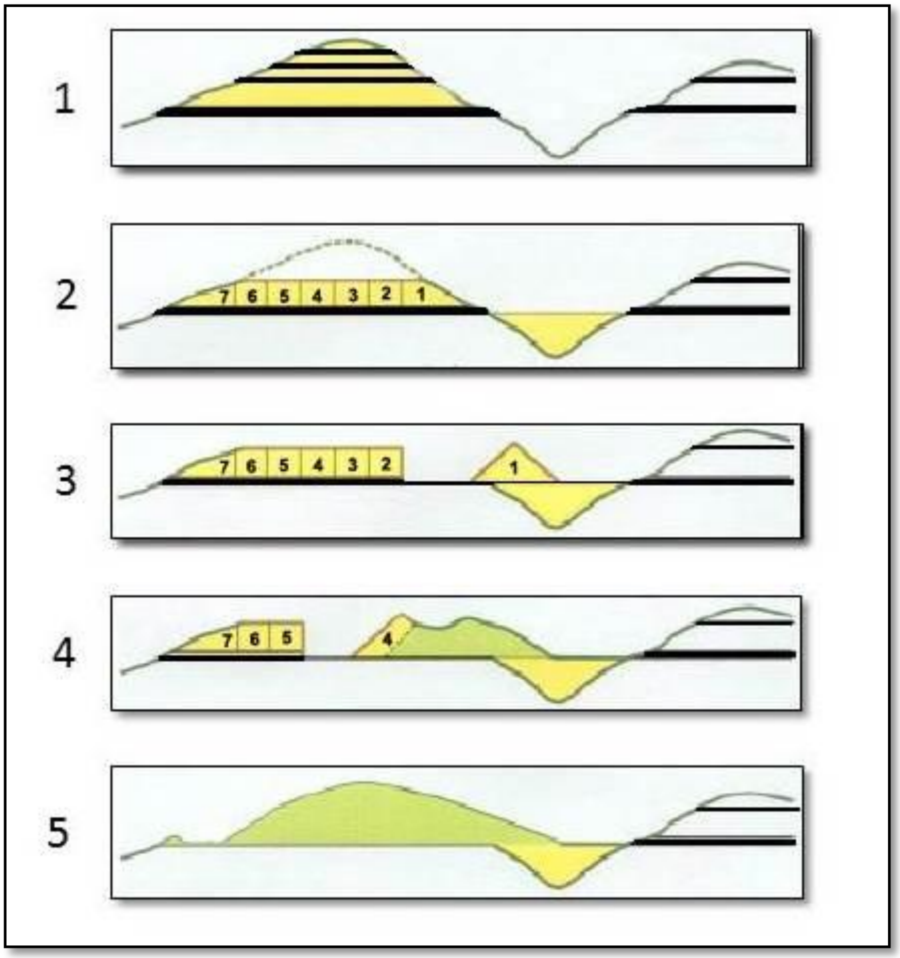

Figure 2.1. Diagram of Mountaintop Mining / Valley Fill Process (U.S. EPA, 2013)

Environmental Effects of Mountaintop Removal

Mountaintop removal affects the hydrologic balance of a watershed. It can alter many hydrologic processes, including, but not limited to, surface runoff, evapotranspiration, ground water flow, percolation, infiltration, and water quality (National Research Council, 1990). Mountaintop removal alters the shape of the surface as well as subsurface topography. During the mining process, unconsolidated overburden is used to create what is called *islands*, which is reference to the areas created post mining to attempt to recreate the "approximate original contour" of the land. The excess overburden is dumped in the adjacent valleys and is known as *valley fill*. Although an attempt is made to create approximate original contour, the bulk density of the material that makes up the contour changes, leaves the landscape and its ability to transport water in a different state than prior to mining. A combination of deforestation and the creation of valley fill, changes the flow of water, the rate of evapotranspiration is reduced, and the rate of weathering the parent materials increases (Dickens, Minear, & Tschantz, 1989). When explosives are used to expose the coal seam, the once consolidated parent material is fragmented into smaller pieces and dumped in the valley (Hartman, Kaller, Howell, & Sweka, 2005). Valley fills often bury headwater streams. The stream buffer zone rule of 1983 states that overburden cannot be placed within 100 feet of intermittent or perennial streams, however, the Environmental Protection Agency (EPA) estimated that over 1000 miles of headwater streams in the Appalachia had been buried by this type of mining; by 2010 that number had grown to over 2000 miles (EPA, 2010). In addition to being buried, water quality is affected by the harmful chemicals in the overburden. This previously un-weathered material is brought from well below the surface of the earth to the upper layers and causes exposure of the rock to increase the movement of sediment and oxidation (Dickens, Minear, & Tschantz, 1989). The fractured material which was once consolidated introduces pore space in the overburden and has much more of the surface exposed to air and water. Exposure to air and water activates weathering, and can alter the quality of the water passing through the fill (Dickens, Minear, & Tschantz, 1989). Several studies have shown that there is an increase in several toxic stream solutes downstream from MTR/VF activities (Lindberg, et al., 2011; Hopkins & Roush, 2013). MTR/VF process is believed to have many negative effects on the environment.

Digital elevation models play an important role in studies that investigate and predict changes in topography due to anthropogenic and natural impacts. Digital elevation models are used to calculate erosion and sediment transport rates to model drainage networks (Montgomery, 2003; Peckham, 2003), to map the risk of landslides (Kawabata & Bandibas, 2009), to model the amount of moisture in soil (Crave & Gascuel-Odoux, 1997), and to predict soil Ph (Castrignano et al., 2011). DEM differencing can be used to analyze change over a specific time period (James, Hodgson, Ghoshal, & Latiolais, 2011). Comparing DEM's created from measurements from different time frames allow scientists to explore impacts and analyze temporal changes in the landscape.

Interpolation Methods

In order to produce a continuous elevation surface from sample points and to calculate the volume of land mass altered, the creation of a digital elevation model is necessary to capture pre-mining landscape conditions. According to the United States Geological Survey (USGS), 4 methods of collecting data were used historically to create digital elevation models: (1) the Gestalt Photo Mapper II, (2) use of photogrammetric stereomodels, (3) interpolation of elevations from stereomodel digitized contours, and (4) interpolation from digital line graph (DLG) hypsographic and hydrographic data. The first 3 of the 4 methods have been retired and currently, only interpolation from DLG hypsographic and hydrographic data is used to collect DEM data. The method of interpolation that the USGS uses is called *Cubic Convulsion*. An interpolation method uses a mathematical algorithm to compute estimations of elevation between known points and their locations (Fisher & Tate, 2006).

Figure 2.2 is an example of how data are interpolated. The elevation value of the cell with the question mark is unknown. The value will be interpolated using some of the surrounding known elevation values highlighted in yellow. The interpolation process is a focal operation that uses a moving window and surrounding cell values to estimate the value of the focal cell. The selection and number of cells used in the interpolation process varies by method and parameters determined by the user.

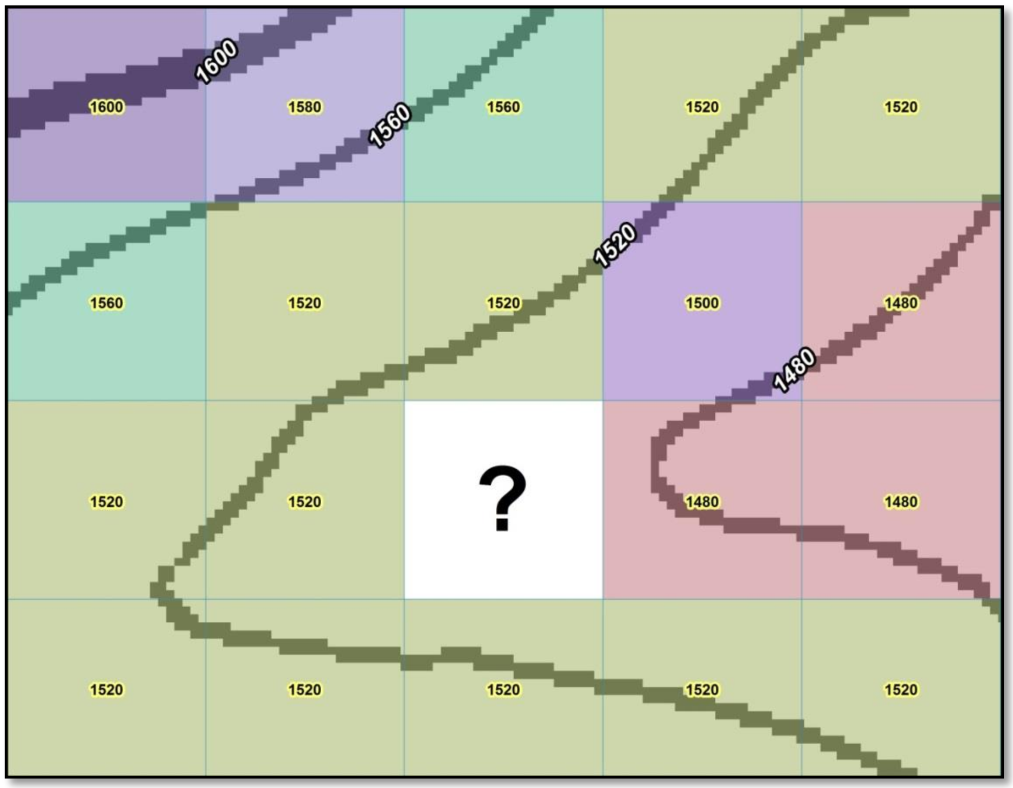

Figure 2.2. How Interpolation Works

Each interpolation method has its benefits and drawbacks. All interpolations results contain error since they are based on algorithmic estimations of unknown values from known values (Fischer, Scholten, & Unwin, 1996; Yue, Du, Song, & Gong, 2007; Chen & Yue, 2010). It is assumed that interpolation error will be lower in areas where the terrain is smoother and higher in areas characterized by steep and abrupt changes.

This study takes place in the mountains of West Virginia where the landscape is comprised of steep slopes making it difficult to interpolate elevation with accuracy. It is important to choose the best interpolation model for the terrain in the study to reduce the error in the DEM.   Robinson and Metternicht (2006) interpolated soil properties such as Ph, electric conductivity and organic matter, and found that the interpolation method that performed the best was dependent on the property being interpolated (Robinson & Metternicht, 2006). They found each of the three methods, Inverse Distance Weighting, Ordinary Kriging and Splines, outperformed each other for subsoil Ph, topsoil Ph, and organic matter respectively (Robinson & Metternicht, 2006). The input data, data density, the interpolation method, and an understanding of the nature of the phenomena all contribute to the accuracy of a DEM (Erdogan, 2009; Chaplot, et al., 2006). There have been several studies comparing different interpolation methods. Murphy, Curriero, & Ball (2010) compared IDW, Ordinary Kriging, and Universal Kriging in the Chesapeake Bay area to compare water quality data over time. Over a 9 year period from 1985 to 1994 they collected data such as water temperature, dissolved oxygen, and salinity and found that the Kriging methods were superior to IDW (Murphy, Curriero, & Ball, 2010). Zimmerman et al (1999) performed a comparison on synthetic data that included IDW, Ordinary Kriging, and Universal Kriging interpolation methods and found the Kriging methods performed better than IDW (Zimmerman, Pavlik, Ruggles, & Armstrong, 1999). In another study, Ordinary Kriging, Spline, and IDW were all compared for a study of sample elevation points on a hill in Turkey, the results showed that the DEM with the least amount of errors came from the Spline method (Erdogan, 2009). When studying soil moisture in difficult terrain, Yao et al found that both IDW and Ordinary Kriging performed poorly in comparison to a Regression Kriging model (Yao, Fu, Sun, Wang, & Liu, 2013). The focus of this study was to assess and identify the best method for interpolating mountainous topography. The goal was to minimize error and reduce the amount of error propagation in subsequent analysis.

Several interpolation methods can be used to create digital elevation models. For this study, three commonly used interpolations methods were considered; Inverse Distance Weighting (IDW), Ordinary Kriging (OK), and Spline with Tension.

IDW is the most widely known and commonly used method of interpolation (Shiode & Shiode, 2011; Achilleos, 2011). IDW is a deterministic method of interpolation that calculates the predicted values within the range of the minimum and maximum known values using the assumption that similarity among items are based on proximity to each other. The First Law of Geography states that things closer to each other are more alike than things further apart (Tobler, 2004) . IDW is based on this characteristic where the points closest to the point being predicted have more weight than those further away. IDW does not have the ability to estimate outside of the minimum and maximum known values (Chang, 2010). The weight of a sample point is directly related to their distance from the unknown point being interpolated.

The equation for IDW is:

$$z_0 = \frac{\sum_{i=1}^{s} z_i \frac{1}{d_i^k}}{\sum_{i=1}^{s} \frac{1}{d_i^k}}$$

Where $z_0$is the value being interpolated at point 0, z_i is the assigned z value at point i, d_i is the distance between point i and point 0, s is the number of known points used in the estimation, and k is the specified inverse-distance weighting power. The weight of a sample point is directly related to its distance from the unknown point.

Ordinary Kriging also uses the distance of the sample points to the prediction location, but uses the spatial connection between the measured values around the location to be predicted as well (GIS by ESRI, 2004). The assumption is that if points are close to each other they are similar but if they are far apart they would not necessarily have a correlation (Tao, Chocat, Liu, & Xin, 2009; Jones, Davis, & Sabbah, 2003). Kriging has the capacity to predict values outside the minimum and maximum elevation at known points, and it uses weighted averages. Weights of the sample points are derived through geostatistical analysis during the kriging process. A fitted semivariogram is assigned to the kriging interpolation, and the results of the prediction vary based on the chosen semivariogram (GIS by ESRI, 2004). Included in the Ordinary Kriging process is a prediction of the variance (Chang, 2010).

The equation for Ordinary Kriging is:

$$z_0 = \sum_{i=1}^{s} z_x W_x$$

Where $z_0$is the estimated value, z_x is the known value at point x, W_x is the weight associated with point x, and s is the number of sample points used in estimation. The weight of a sample point is derived using the distance from the unknown point as well as through geostatistical analysis of the spatial relationship of all other sample points in the surrounding area.

Spline is a method that passes through each of the known sample points but minimizes the curvature of the predicted surface. For this reason, spline can have problems interpolating areas with sudden changes in elevation (Chang, 2010). Splines have the ability to predict outside the range of known values.

The equation for Spline is:

$$Q(x.y) = \sum A_i d_i^2 \log d_i + a + bx + cy$$

Where x and y are the coordinates of the unknown point being interpolated, $d_i^2 = (x - x_i)^2 + (y - y_i)^2$ with d being distance, and x_i, and y_i are the x-, y-coordinates of the sample points i….A, a, b, and c are coefficients that are determined by a linear system of equations.

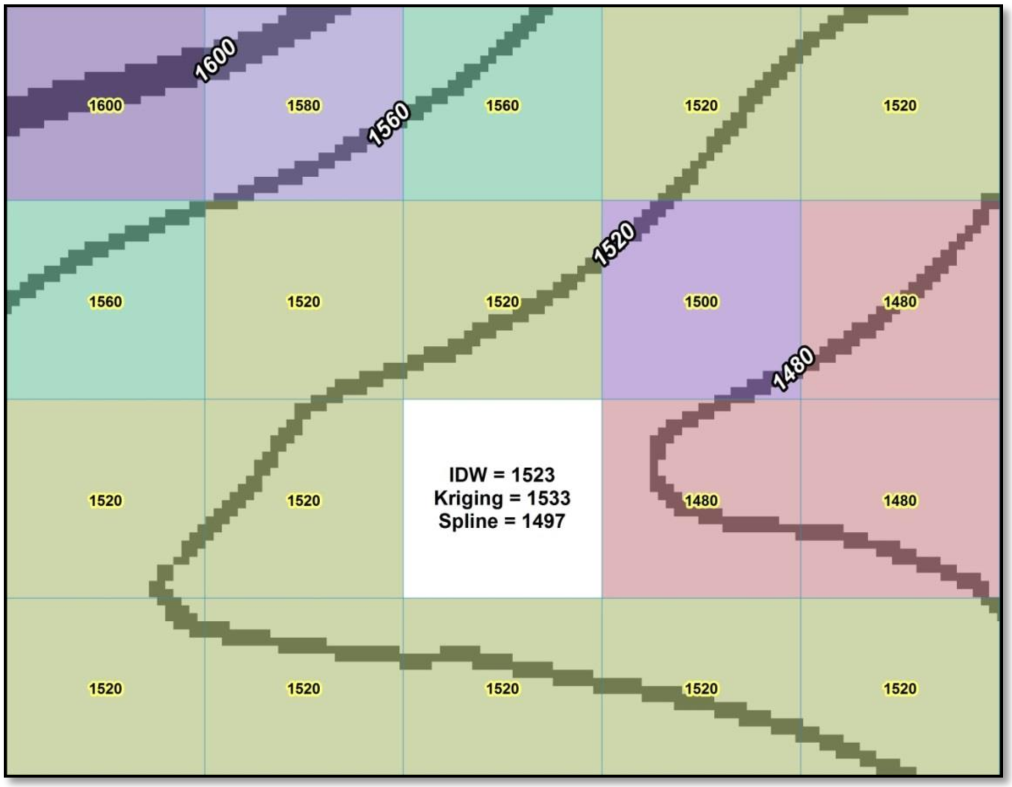

Figure 2.3. Interpolation Example Result

Figure 2.3 shows the result from the interpolation example shown in Figure 2.2. It is noted that the three interpolation methods used in this example all yielded a different result.

CHAPTER III

METHODS

Study Area

Site selection for this study was challenging. Most, if not all, surface mining sites are completely inaccessible to anyone outside the coal mining industry. Surface mining sites are also in remote areas with very difficult terrain. The Frozen Hollow Surface Mine was suggested by Rick Stevens, a landscape photographer working in the southern coal fields of West Virginia. West Virginia is one of the most heavily mined states in the United States. Boone County, West Virginia has a total area of 509.37 square miles, 123.54 of those are permitted areas of surface disturbance through mining (WVDEP, 2013).   Figure 3.1 shows the location of these areas. The mountaintop removal mining site chosen for this study is part of that 123.54 miles, it is named the Frozen Hollow Surface Mine (Figure 3.2).

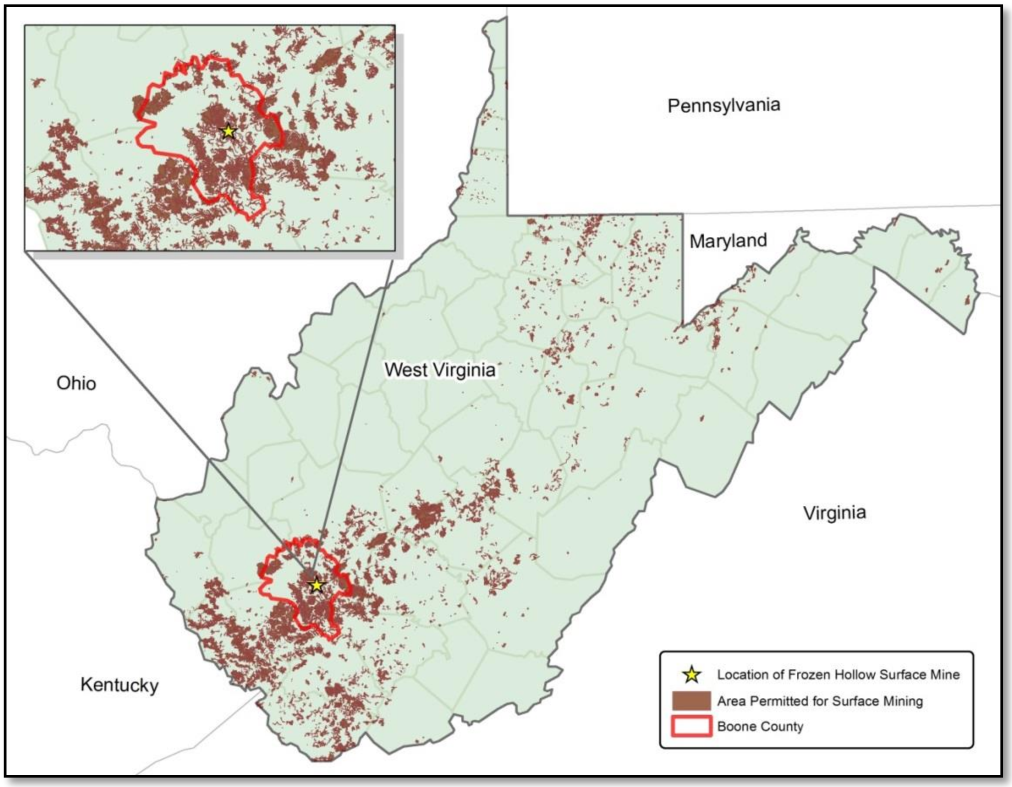

Figure 3.1. Boone County, West Virginia; Permitted Surface Mining Area

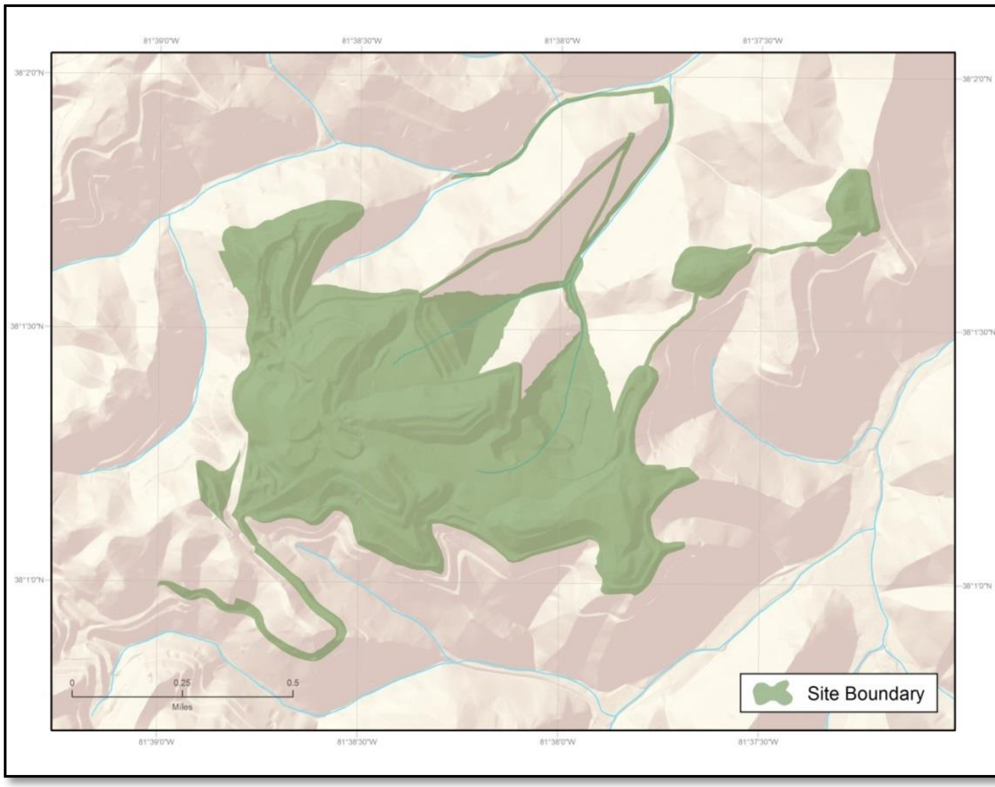

Figure 3.2. Frozen Hollow Surface Mine

The Frozen Hollow Surface Mine sits approximately 30 miles south of Charleston, in the community of Prenter, at geographic coordinates of 81°38’30” W 38°1’13” N. The Frozen Hollow Surface Mine has an area of only 378.30 acres; it accounts for less than half of one percent of the permitted mining area in Boone County.

According to the mining permit, this area was contour mined in the late 1960’s leaving some highwalls and flattened areas within the study area (WVDEP , 1996). Ideally, a site that was not previously mined would have been selected for this study. However, an alternatively suitable location with accessibility could not be found. Figure

3.3 is an orthophoto showing the conditions of the Frozen Hollow Surface Mine in 1996 prior to the start of mountaintop removal mining at this site.

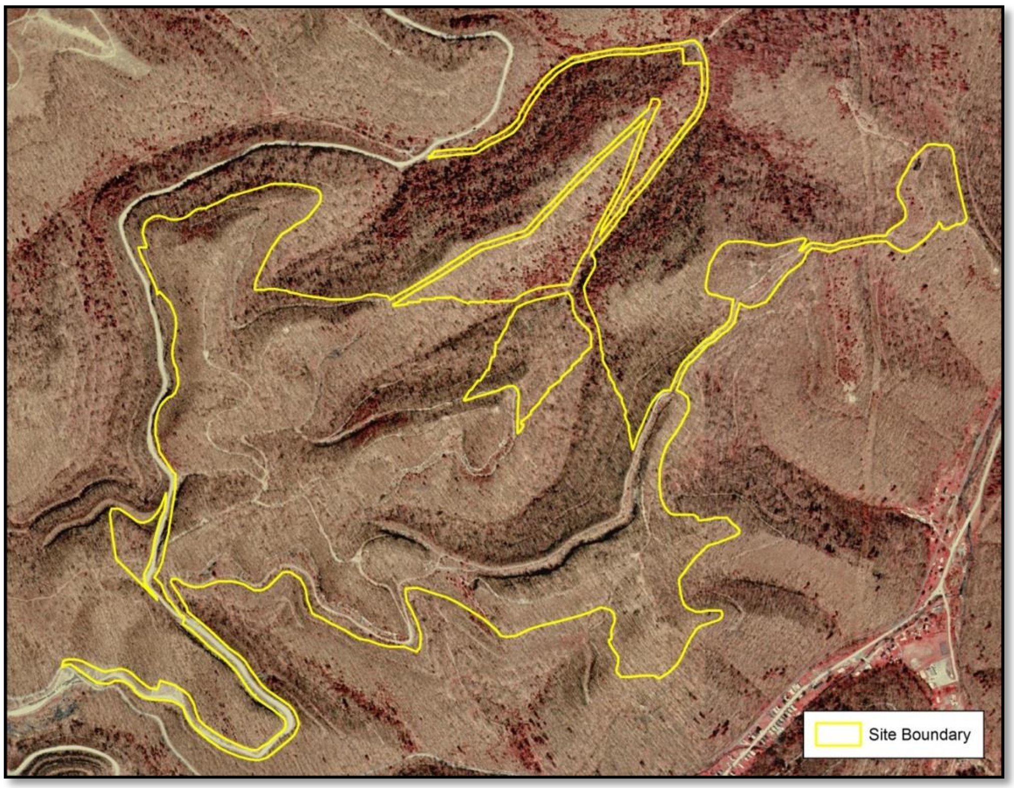

Figure 3.3. Pre-Mining Imagery of Frozen Hollow Surface Mine

The location of the site is in the Alleghany Plateau of the Appalachian mountain range. The climate is humid, with annual rainfall ranging from 75-125 cm annually. Sandstone and shale make up most of the geologic composition of this area. One of the controversies of MTR is that, in order to reach the coal seams, layers of sandstone and shale must be disturbed. Table 3.1 shows the depths of the coal seams found in the boreholes during overburden evaluation from the permit request for this site. Figures 3.4 and 3.5 show a portion of the geologic cross section included with the permit. Cross sections of boreholes BM 131, BM133, BM 130, and BM132 can be seen in Figure 3.4 and cross sections of boreholes B-301C and BM131 and part of B-302C and BM124 can be seen in Figure 3.5 (WVDEP , 1996). These figures are a qualitative representation of the amount of coal extracted compared to the amount of waste produced in order to mine the coal. Waste (i.e. overburden) is shown in grey above and between coal seams shown in red.

Table 3.1. Coal Seam Information from Geologic Boreholes

	BM-130	BM-131	BM-132	BM-133	BM-124	BM-300	B-301	B-302	B-305	B-306
Coal Seam 1 Start Depth	51.6	117.4	N/A	48.9	105.7	135.3	123.8	169.5	84	89.9
Coal Seam 1 End Depth	52.8	121.15	N/A	53.9	109.83	139.2	127.7	174.4	88.48	92.97
Height of Coal Seam 1 in Feet	**1.2**	**3.75**	**N/A**	**5**	**4.13**	**3.9**	**3.9**	**4.9**	**4.48**	**3.07**
Coal Seam 2 Start Depth	71.9	134.8	N/A	62.3	123.5	141.8	131.4	177.35	90.56	99.19
Coal Seam 2 End Depth	77.4	143.1	N/A	64.15	130.4	144.7	135.7	186.09	92.81	100.85
Height of Coal Seam 2 in Feet	**5.5**	**8.3**	**N/A**	**12.8**	**6.9**	**2.9**	**4.3**	**8.74**	**2.25**	**1.66**
Borehole Total Depth	81.8	150	N/A	92	143	181	155.5	216	105	113

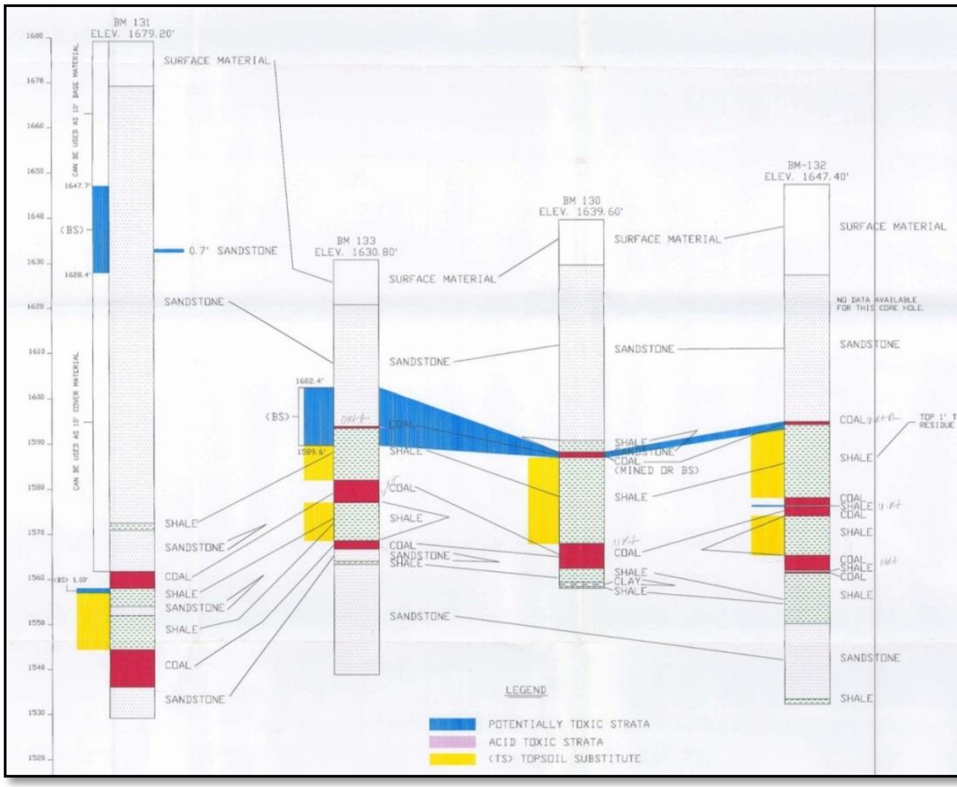

Figure 3.4. Portion of Geologic Section B-B

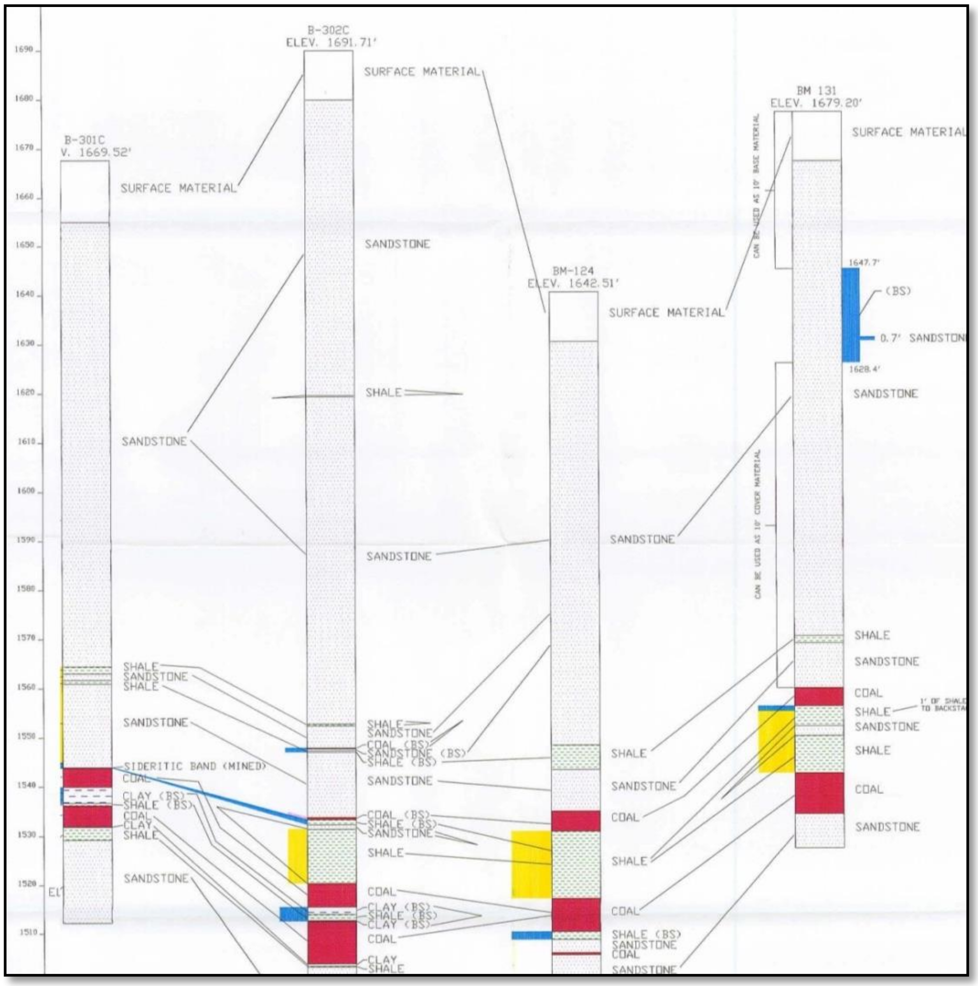

Figure 3.5. Portion of Geologic Section A-A

The coal mined at this site is bituminous and comes from the Pennsylvanian age (National Research Council, 1990). The coal mined at the Frozen Hollow Surface Mine was from four coal seams; Stockton, Stockton Rider, 5 Block and 5 Block Rider seams. The Pine Ridge Coal Company estimated that they would remove 3,534,435 tons of coal from this site over the 6 year mining period from 1996-2002 (WVDEP , 1996). The Frozen Hollow mine site covers 378.30 acres, and sits in the Coal watershed. The pre-mining use of this land was forestland and post mining is classified as Fish and Wildlife

Habitat/Recreation. According to the 1996 topographic map, the elevation within the site boundary varies from approximately 1160 feet at the base of the valley to 1702 feet at its highest point with a range of 542 feet.

Topographic maps show that the two areas which are now known as Valley Fill 1 and Valley Fill 2 were originally valleys that each had an intermittent headwater stream. These streams are identified through the National Hydrography Dataset by reach codes. They are RCH 05050009001656 for Valley Fill #1 and 05050009001636 for Valley Fill #2. The lengths of stream buried by each fill were .45 miles and .33 miles respectively (See Figure 3.6).

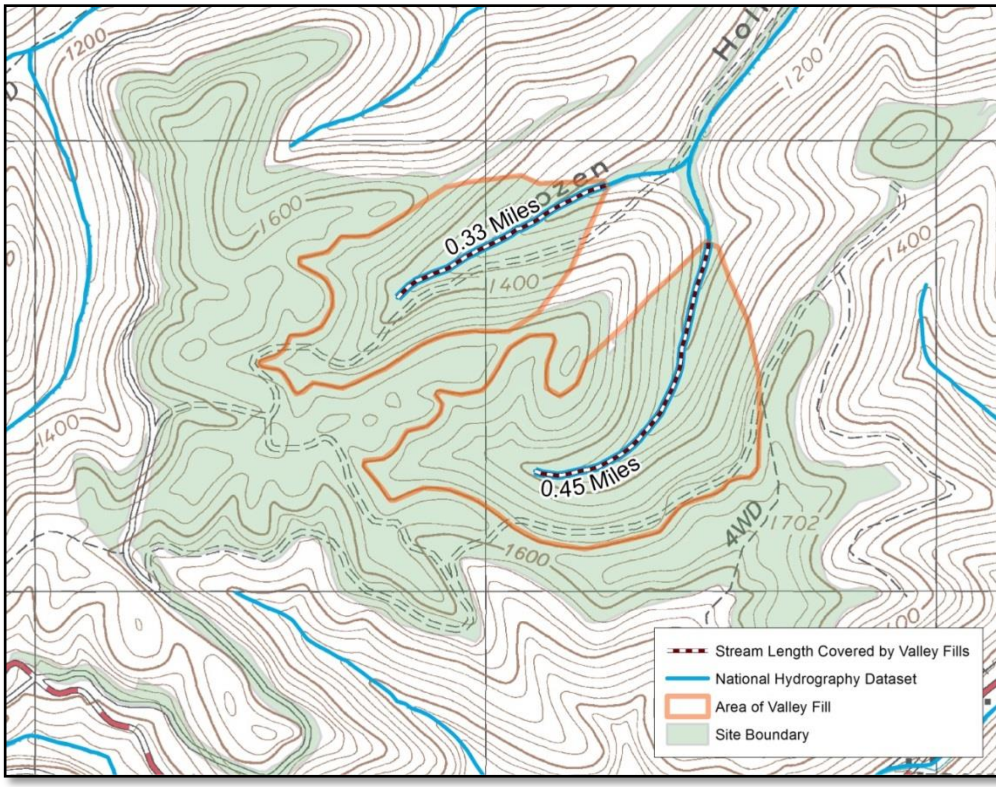

Figure 3.6. Intermittent Stream Headwaters Buried by Valley Fills

Mining Permit Application

Taking advantage of the U.S. Freedom of Information Act, a compact disc (CD) containing portable document format (pdf) versions of all Frozen Hollow Surface permit documents was acquired from the West Virginia Department of Environmental Protection. This CD contains all documents pertaining to the Frozen Hollow Surface permit application, beginning with the original permit request from 1996 and ending with an inspection report dated 2010. Estimates of the overburden generation and disposal are included in the permit request for Frozen Hollow Surface Mine (WVDEP , 1996). In order to explore the accuracy of the approach in this study, the calculated volume was compared to the estimates included with the permit application. Estimations of generation of overburden per the permit application are outlined in Table 3.2. As this overburden is removed from its original state, it becomes unconsolidated and according to the permit request this results in a swell estimate of 1.2738% for a total net overburden capacity of 36,667,366.18 cubic yards for disposal. Table 3.3 outlines how the overburden will be distributed and the capacity of each location.

Table 3.2. Estimation of Overburden Generation

	Cubic Yards	Cubic Yards Overburden (post swell of 1.2738%)
Island No. 1	23,415,729.91	29,8269,56.76
Island No. 2	4,711,314.59	6,001,272.52
Island No. 3	363,265.82	462,728.00
Island No. 4	295,500.78	376,408.89
Total	28,785,811.10	36,667,366.18

Table 3.3. Estimation of Planned Capacity of Overburden Disposal

	Cubic Yards
Valley Fill No. 1	10,077,448.78
Valley Fill No. 2	5,806,879.76
Island No. 1 - Backstack	17,474,125.09
Island No. 2 - Backstack	3,310,164.36
Total Gross Capacity	36,668,617.99

Site Visits

An introductory site visit took place on February 7, 2011. This visit took place to explore the community, meet Rick Stevens in person, and to see the Frozen Hollow Surface Mine. Figure 3.7 is an image looking down Valley Fill 1 during this introductory site visit. The site is monitored by random security visits. More than the threat of a trespassing charge, access to the site is limited simply by the terrain and condition of the road leading up to the top of the site. It was difficult even with the large four wheel drive truck. Figure 3.8 shows the condition and rugged terrain for a portion of the road at the base of the valley fills.

Figure 3.7. Site Visit Photo –Valley Fill 1

Figure 3.8. Site Visit Photo – Road at Base of Valley Fills

A second site visit took place on May 21, 2011. The purpose was to make an attempt to acquire ground truthing points within the one- tenth mile buffer outside the boundary of the Frozen Hollow Surface site. This area was unchanged during the mining process, so the plan was to use these points to assist in the accuracy in the interpolations. The difficulty of the steep terrain as well as weak GPS signals made it very difficult to acquire these points. The boundary edges border steep inclines, so in order to acquire the ground truthing points within the buffer it was necessary to climb up steeply graded and densely vegetated hillsides (see Figure 3.9). There were only 12 usable ground truthing points acquired during this visit. Due to the cost, and difficulty of obtaining access to the site, no further site visits took place.

Figure 3.9. Site Visit Photo - Steep Slopes and Densely Vegetated Hillsides

The presence, or lack, of vegetation changes the way water flows in a watershed. Mountaintop removal mining disturbs the natural distribution of vegetation. According to general standard 19 in the Environmental Performance Standards of US Code 30, the mining operation is required to:

> Establish on the regraded areas, and all other lands affected, a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area of land to be affected and capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area; except, that introduced species may be used in the revegetation process where desirable and necessary to achieve the approved postmining land use plan (Title 30 U.S.C. § 1265, 2012).

Figure 3.10 is a photo of Valley Fill 2 during the second site visit showing the actual vegetation growth approximately 8 years post mining at the Frozen Hollow Surface Mine.

Figure 3.10. Site Visit Photo – Revegetation of Valley Fill 2

Interpolation Preparation

To determine the volume of land mass altered, it was necessary to have a pre-mining DEM and a post-mining DEM. A pre-mining DEM was unavailable. A DEM of pre-mining elevations at this site was created in GIS using interpolation of a set of sample points. The sample points were created manually by assigning values from a pre-mining topographic map to a set of evenly spaced centroids. Error is greater around the edges of any interpolated surface. To reduce interpolation error at the margins of the study area, a one-tenth of a mile buffer was created and used to collect additional sample points. A vector grid reaching the extent of the buffer was the basis to create the sample points used to interpolate the DEM. One grid had $20m^2$ cells resulting in 10433 cells across the study area. Efficiency, as well as accuracy, is a goal of this study. To make this process more efficient, a second grid was created with a coarser resolution of $30m^2$ cells. The second set resulted in 4626 grid cells. A comparison of results will be performed to determine if the results are as accurate when using fewer points. The grid spans an area approximately 2.84 square miles. Figures 3.11 shows the grid for the $20m^2$ grid cells and Figure 3.12 shows the grid for the $30m^2$ grid cells. Centroids for all cells were created and then clipped to only the points within site and the one-tenth mile buffer around the site. Elevation was then assigned to the resulting 10433 points from the $20m^2$ grid (Figure 3.13) and to the 4626 points from the $30m^2$ grid (Figure 3.14).

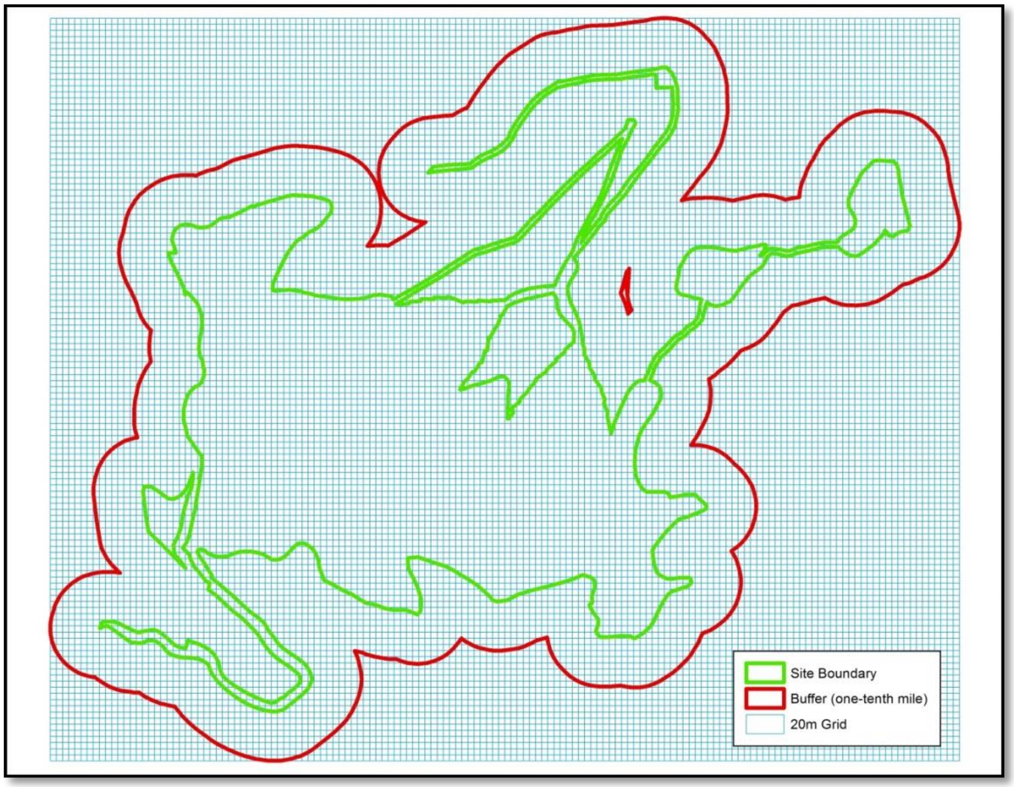

Figure 3.11. 20m^2 Grid

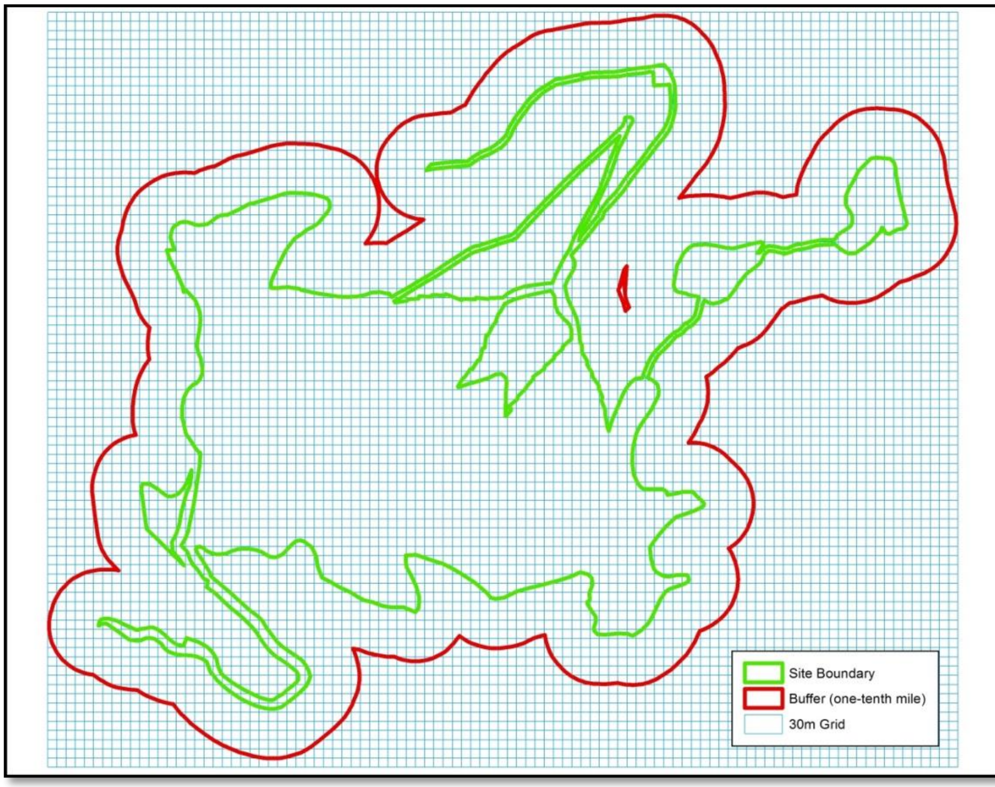

Figure 3.12. 30m^2 Grid

Figure 3.13. 20m^2 Centroids

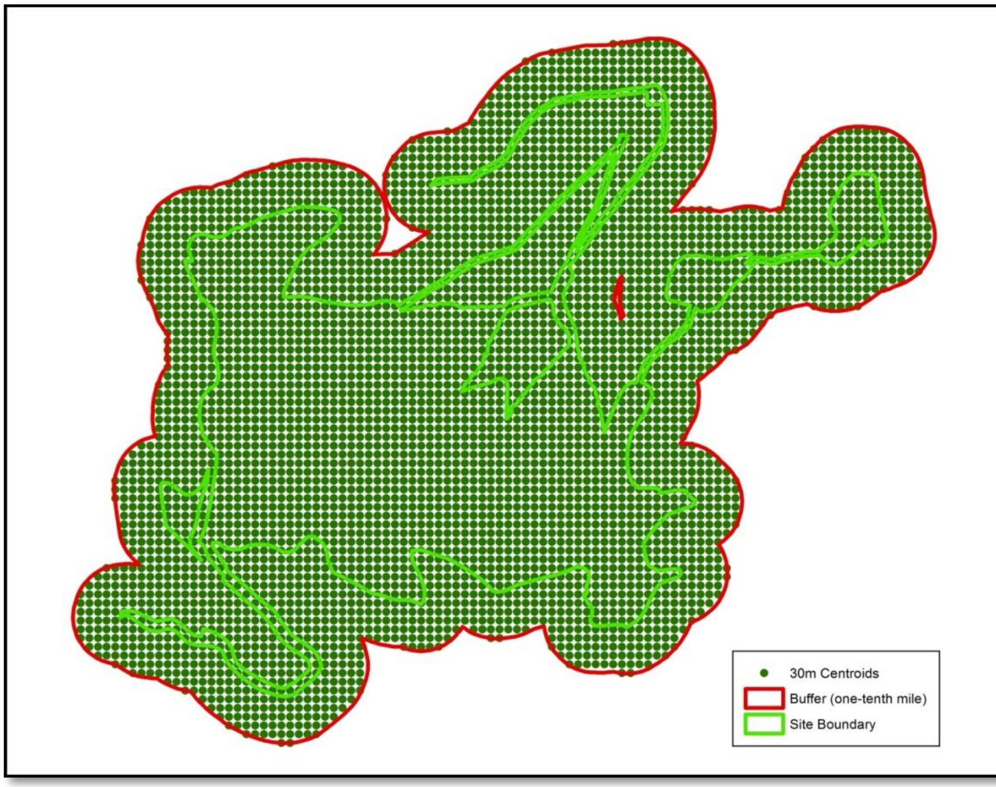

Figure 3.14. 30m^2 Centroids

The centroids of the grid cells were used as the sampling points. United States Geological Survey (USGS) 7.5 minute topographic maps with 40 foot contour intervals in digital raster graphic (DRG) format was used as a base layer to assign elevation (z) values to each of the sampling points. The Williams Mountain Quad and Sylvester Quad (West Virginia GIS Technical Center, 2011) both contain part of the study area. These topographic maps were updated in 1996. Cells with a single contour line (SVC) were assigned the value of that contour line, cells with no contours (NVC) were coded as such and removed from the interpolation data, and cells with multiple contour lines (MVC) were given a value of the average of all contours that fell within that cell. Cells with multiple contour lines (MVC) can create a problem with interpolation because only one value can be stored for each cell (Xie, et al., 2003). To determine whether the cells with multiple contour lines negatively affected accuracy, interpolations were performed using both MVCs and SVCs as well as only SVCs to compare results for accuracy. In all cases, the cells with no values (NVC) were left out of the interpolation process. Figure 3.15 represents a sample of the attribute data added to each cell.

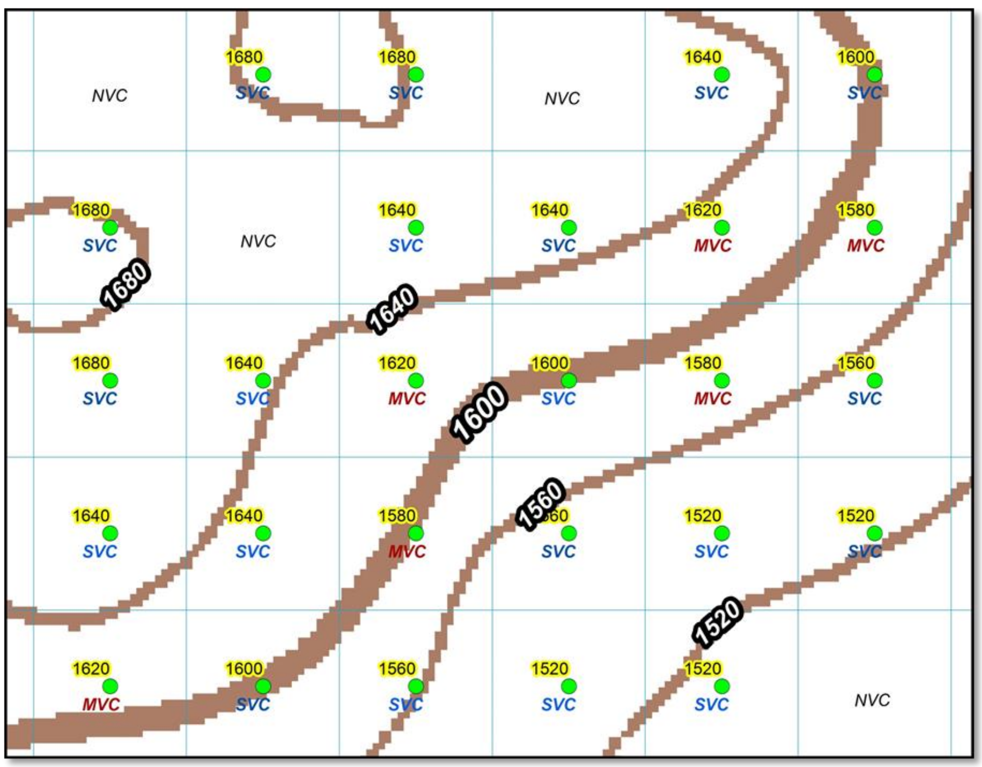

Figure 3.15. Sample of Attributes Assigned to Points

The centroids from the 20m^2 grid cells resulted in 6834 SVCs, 1255 MVCs, and 2344 NVC. Figure 3.16 shows the MVCs and SVCs for the 20m^2 grid. The centroids from the 30m^2 grid cells resulted in 2297 SVCs, 1928 MVC, and 411 NVCs. Figure 3.17 shows the MVCs and SVCs for the 30m^2 grid. NVCs are represented by void space.

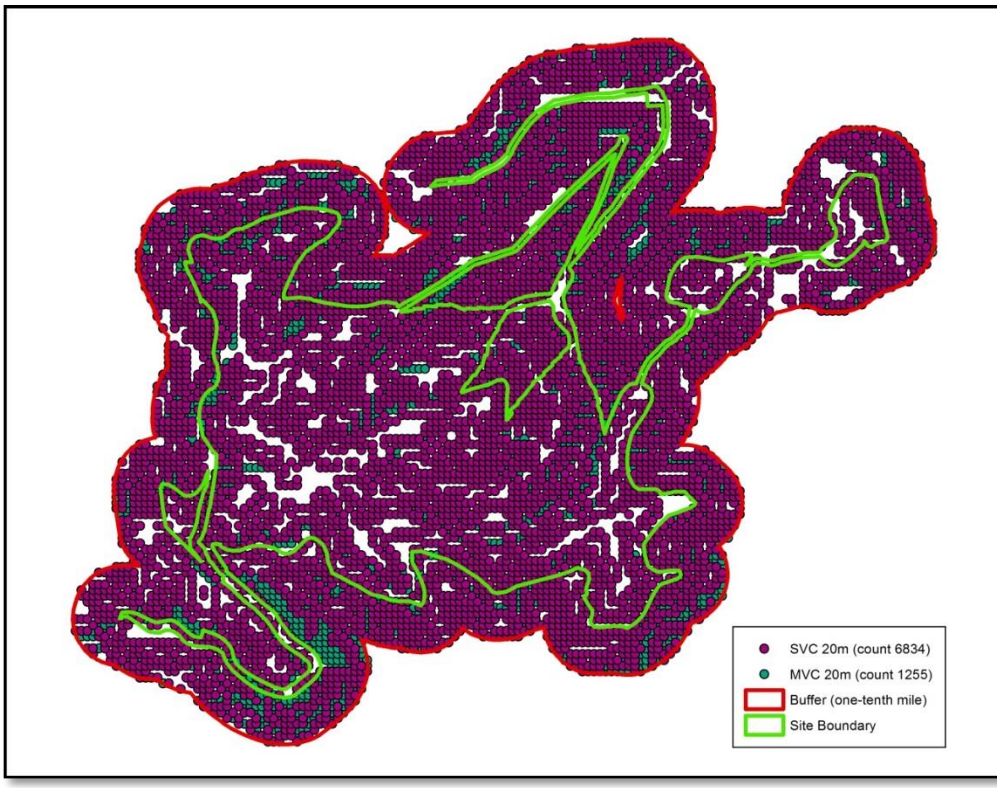

Figure 3.16. MVC & SVC for 20m^2 Grid Cells

Figure 3.17. MVC & SVC for $30m^2$ Grid Cells

Interpolation Comparison and Examining Residuals

In order to evaluate the impact of grid size and sample points, 4 data sets were created to use with each of the 3 interpolation methods; 1) SVCs only using the $20m^2$ grid points 2) SVCs and MVCs using the $20m^2$ grid points, 3) SVCs using the $30m^2$ grid points, and 4)SVCs and MVCs using the $30m^2$ grid points. Approximately fifty percent of each set of points were randomly chosen to be used for interpolations. The remaining points were used as testing points to calculate the error of the interpolation methods. Split Sample Validation was used to analyze the performance of each interpolation method. In order to evaluate the error of the interpolation within the mine site, the interpolated DEM was clipped to the mine boundary prior to error assessment.

In order to determine the best interpolation method for mountainous terrain with the least amount of error, a comparison of three methods was performed. Inverse Distance Weighting (IDW), Ordinary Kriging (OK), and Spline with Tension were all used to create DEMs for the area using the same input points from the 4 data sets. A preliminary study was conducted on the use of both Regularized and Tension versions of the Spline method. The error was assessed in order to determine which method was the most accurate.

The USGS uses the Root Mean Square Error (RMSE) to evaluate the accuracy of the DEM (National Mapping Division USGS, 1998). RMSE is the difference between the original value at a particular point and the interpolated value of that point. The equation for RMSE is:

$$RMSEz = sqrt[\Sigma(zdata\ i - zcheck\ i)2 /n]$$

Where z data i is the vertical coordinate of the i th check point in the dataset. z check i is the vertical coordinate of the i th check point in the independent source of higher accuracy, n = the number of points being checked, i is an integer from 1 to n (Federal Geographic Data Committee, 2012).

This method was used for producing the error for each interpolation method that was analyzed using a statistical model.

The results of the preliminary comparison of Regularized and Tension Spline revealed that the Spline with Tension version was more accurate based on RMSE values. In all four data sets Spline with Tension had lower RMSE values than Regularized Spline, therefore Spline with Tension was chosen for the Spline method in this study.

Table 3.4. RMSE Values for Spline Comparison (Regularized and Tension)

	$20m^2$ SVC	**$20m^2$ MVC&SVC**	**$30m^2$ SVC**	**$30m^2$ MVC&SVC**
Regularized	18.64	18.64	16.07	14.08
Tension	17.25	17.54	15.68	12.78

DEM Differencing

In order to calculate the volume of change between pre-mining conditions and post-mining conditions, a DEM of Difference was created. DEM differencing is performed by subtracting one DEM from another. A DEM created from 2003 data was the most recent elevation data available for this area. According to the phase map in the mining permit application, the mining process was to be completed in 2001 and the final reclamation phase was to be finished by March of 2002. Based on 2-ft color orthophotos from 2003, it is believed that final re-grading and reclamation was not complete at that time, however based on the imagery and the phase schedule in the permit documents, it is believed that the majority of the mining and valley fill work was finished in 2003 (See Figure 3.18). There is some expected variation in the volume calculated in this study compared to the amounts in the permit due to the work not being totally complete at the time of the creation of the 2003 DEM. Raw LiDAR data that was acquired in late 2009 and early 2010 is currently available for the Southern Coal Fields of West Virginia which include Boone County (WVDEP, 2013). However, the most recent available DEM is from 2003. Future work could include additional volume calculations with a more recent DEM to quantify the amount of variation.

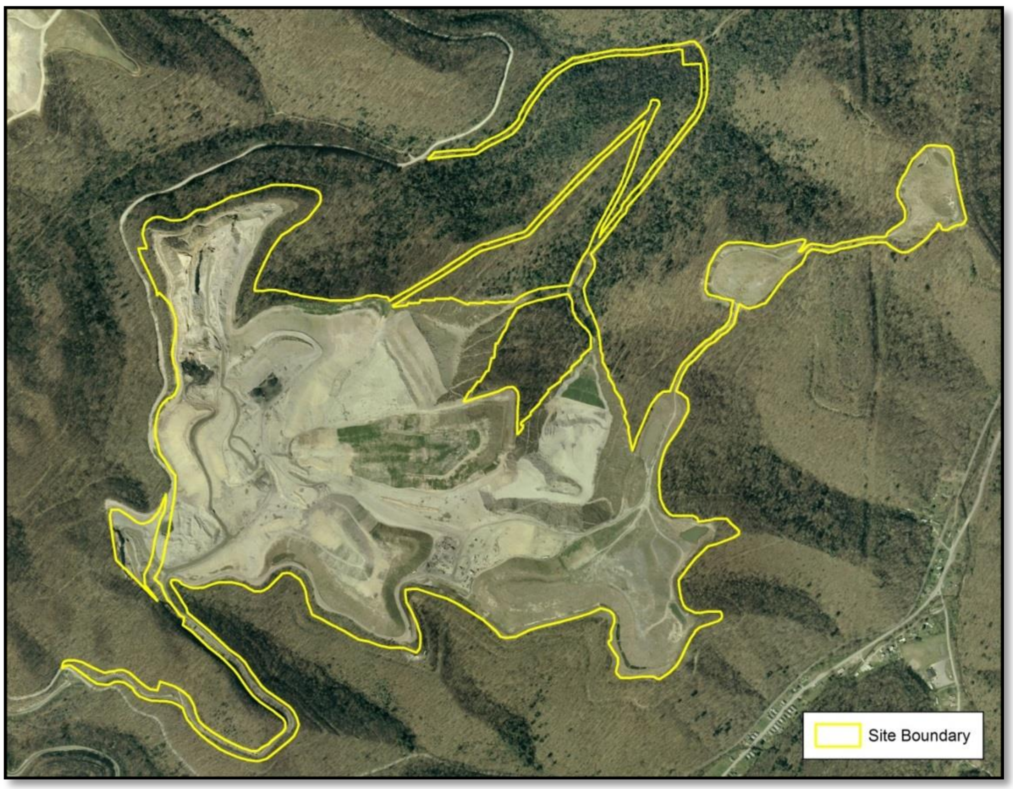

Figure 3.18. Post Mining Imagery 2003

CHAPTER IV

ANALYSIS AND RESULTS

This section explains in detail the interpolation residuals. Descriptive statistics, a T-Test and a Univariate Analysis of Variance (ANOVA) to identify the amount of variance explained by the main effects were used to examine the residuals. A comparison of means test was used to identify significant differences among category means for the factors in the main effects. The residuals were mapped to visually examine geographic patterns in error in relation to physical characteristics of the underlying mining region.

Interpolation Residuals

The 12 variation of interpolation methods were processed and analyzed using the computed RMSE for each. Table 4.1 shows the resulting RMSE comparison. The Spline with Tension method performed better than both IDW and Kriging in all 4 categories. The interpolation method with the lowest overall RMSE of 12.78 was the Spline with Tension method using both SVCs and MVCs and was from the $30m^2$ grid points. IDW and Kriging had similar results in all 4 data sets, though IDW performed slightly better than Kriging in each. IDW and Kriging both performed better when using the $20m^2$ grid points as opposed to the $30m^2$ grid points. Spline performed better with the $30m^2$ grid points rather than the $20m^2$ grid points.

Table 4.1. RMSE Results. Range of elevation values in testing area were from a low of 1160 ft to a high of 1702 ft, for a total range of 542 ft.

	20SVC	**20MVCSVC**	**30SVC**	**30MVCSVC**
IDW	22.91	23.21	28.31	26.39
KRIGING	24.03	23.85	30.94	27.19
SPLINE	17.25	17.54	15.69	12.78

Figure 4.1 through figure 4.12 show the mapped residuals for all 12 interpolations. IDW and Ordinary Kriging consistently show a pattern in all 4 data sets of overprediction in the valleys and underprediction everywhere else. The Spline with Tension interpolations for all four data sets show a more equal distribution of error across the site.

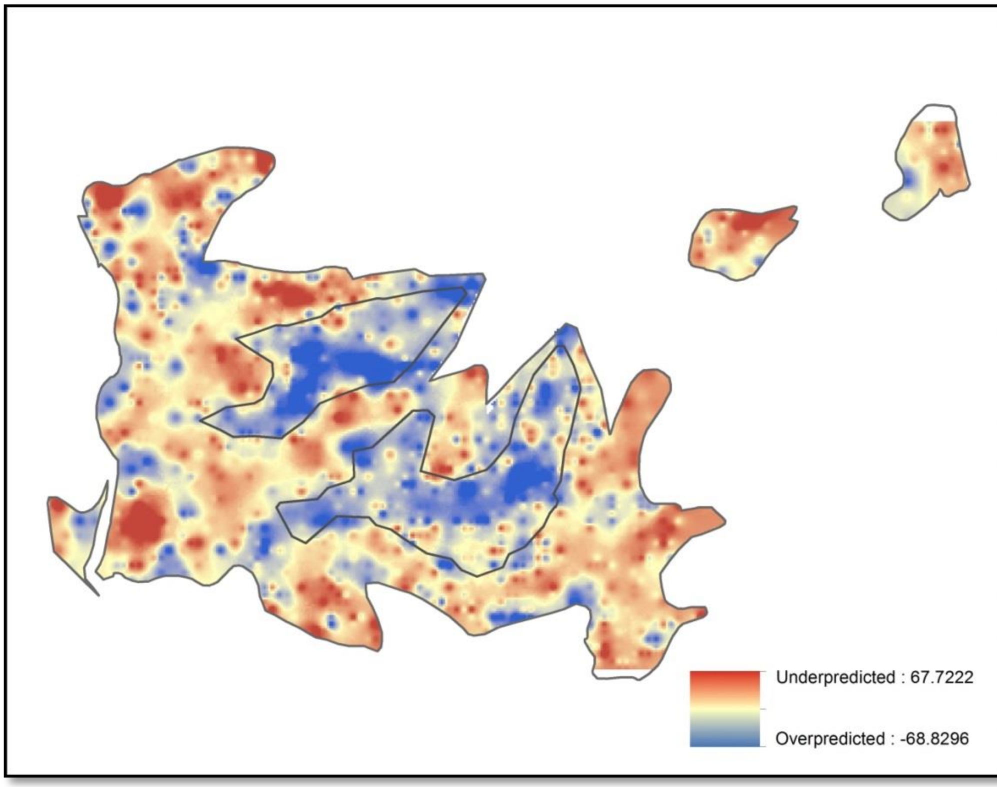

Figure 4.1. Map of Residuals - IDW 20m^2 SVC

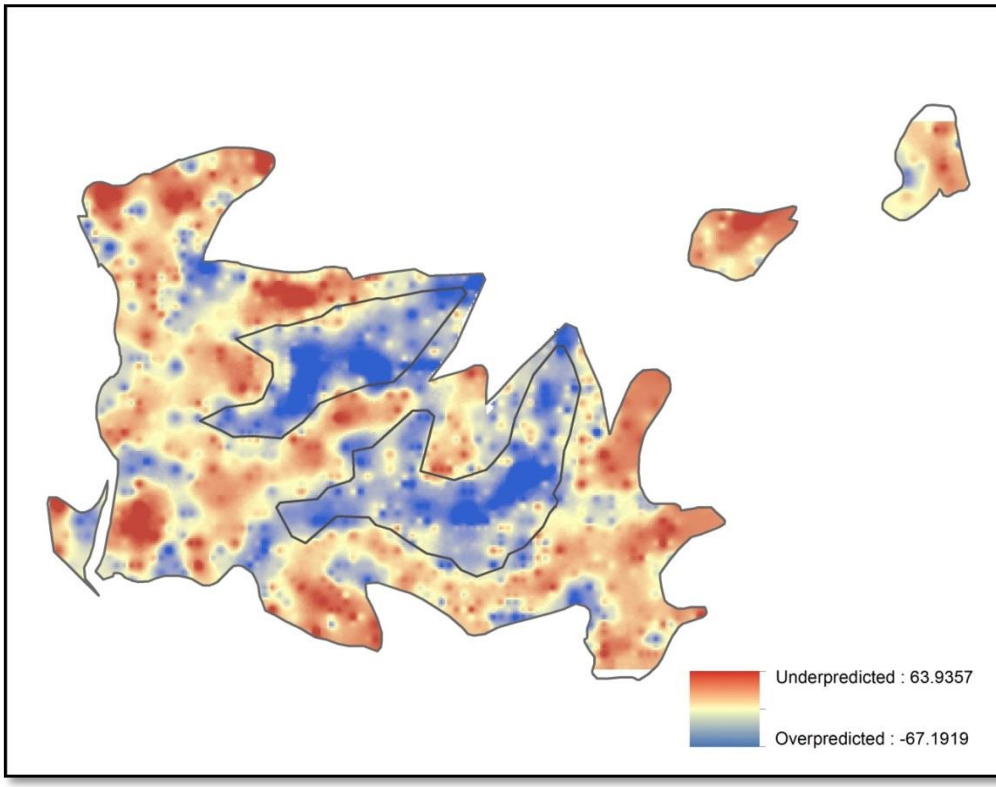

Figure 4.2. Map of Residuals - Ordinary Kriging $20m^2$ SVC

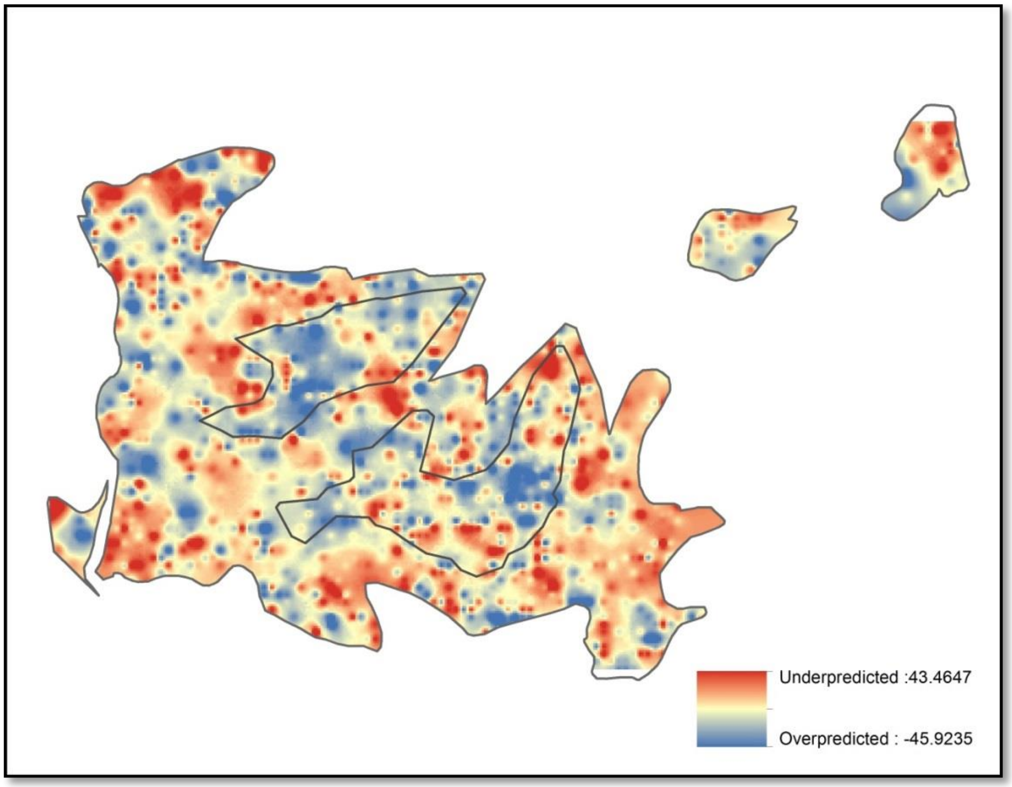

Figure 4.3. Map of Residuals - Tension Spline $20m^2$ SVC

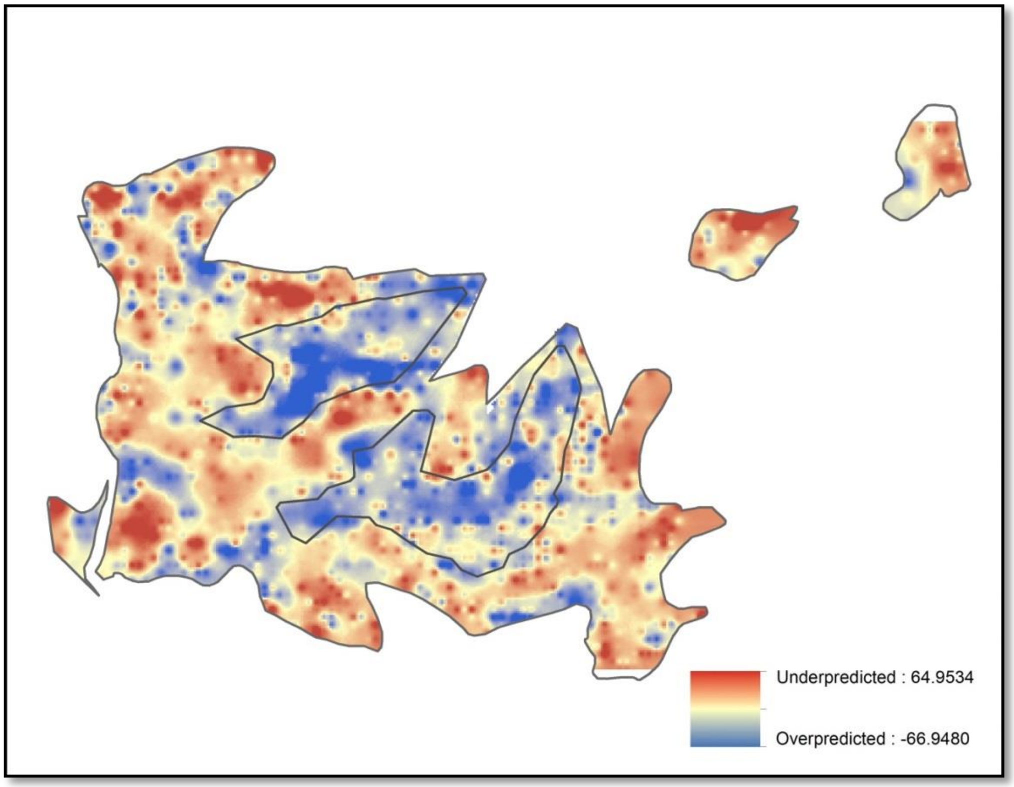

Figure 4.4. Map of Residuals - IDW $20m^2$ MVC & SVC

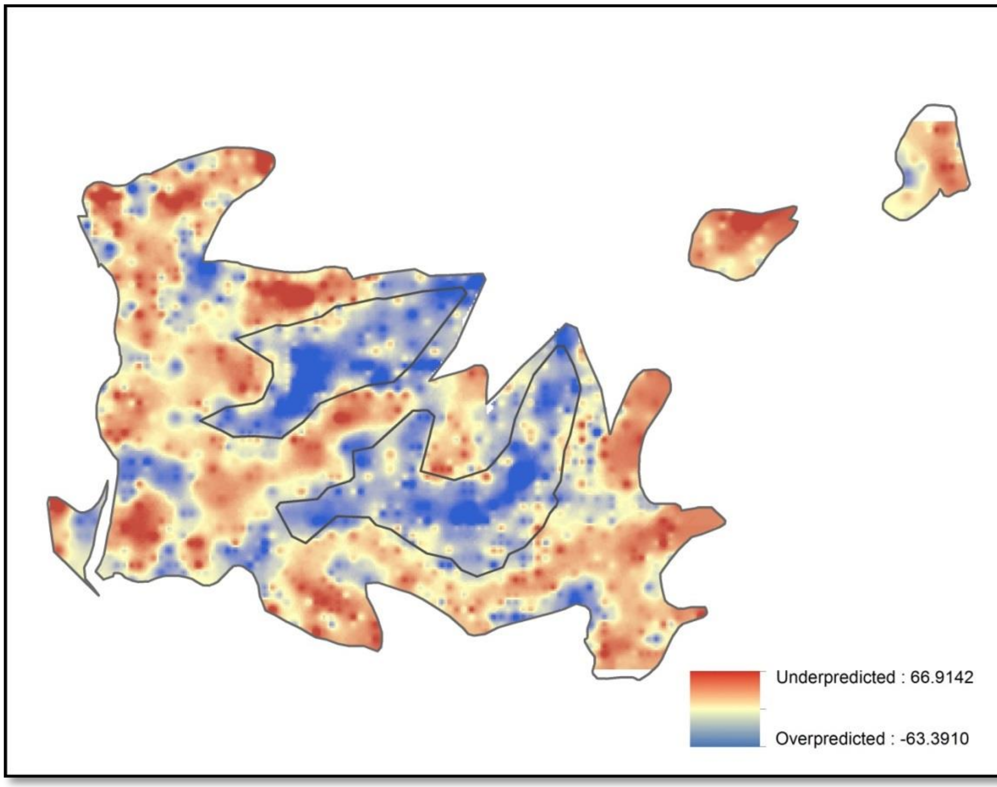

Figure 4.5. Map of Residuals - Ordinary Kriging 20m^2 MVC & SVC

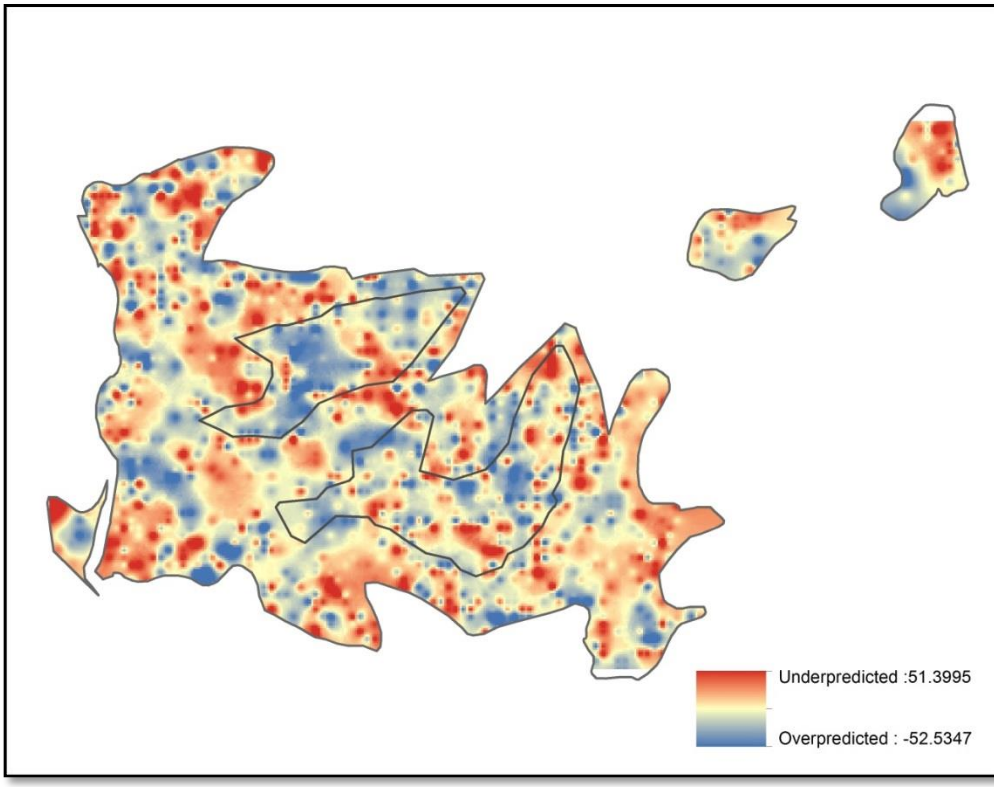

Figure 4.6. Map of Residuals - Tension Spline 20m^2 MVC & SVC

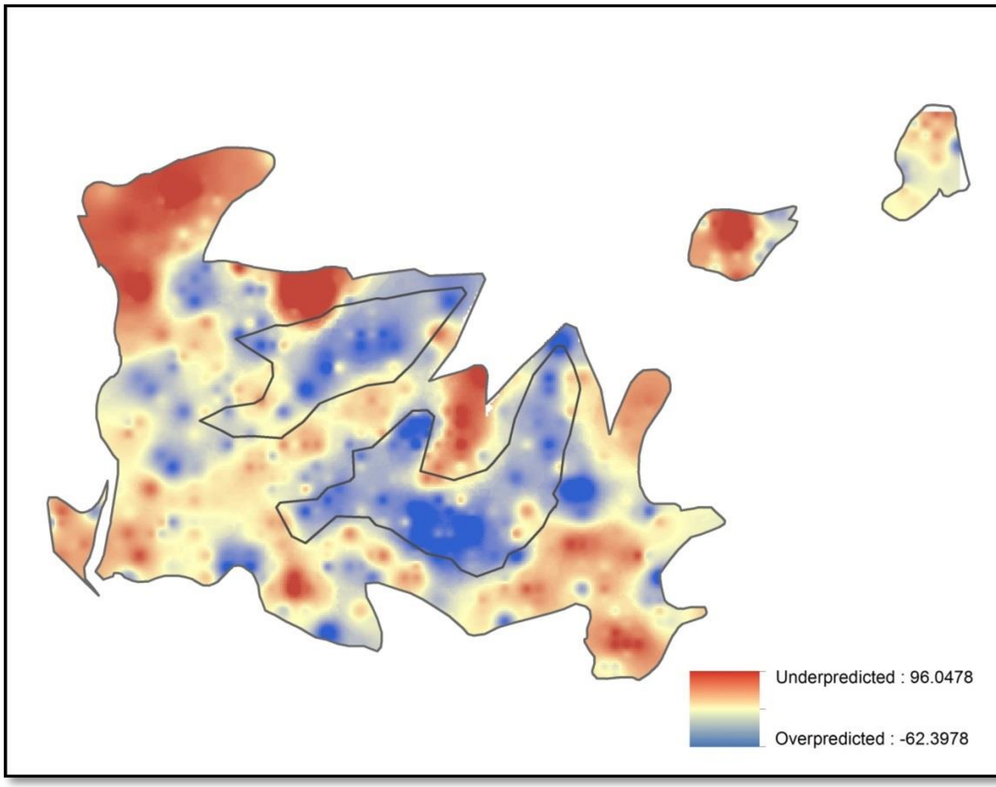

Figure 4.7. Map of Residuals - IDW 30m^2 SVC

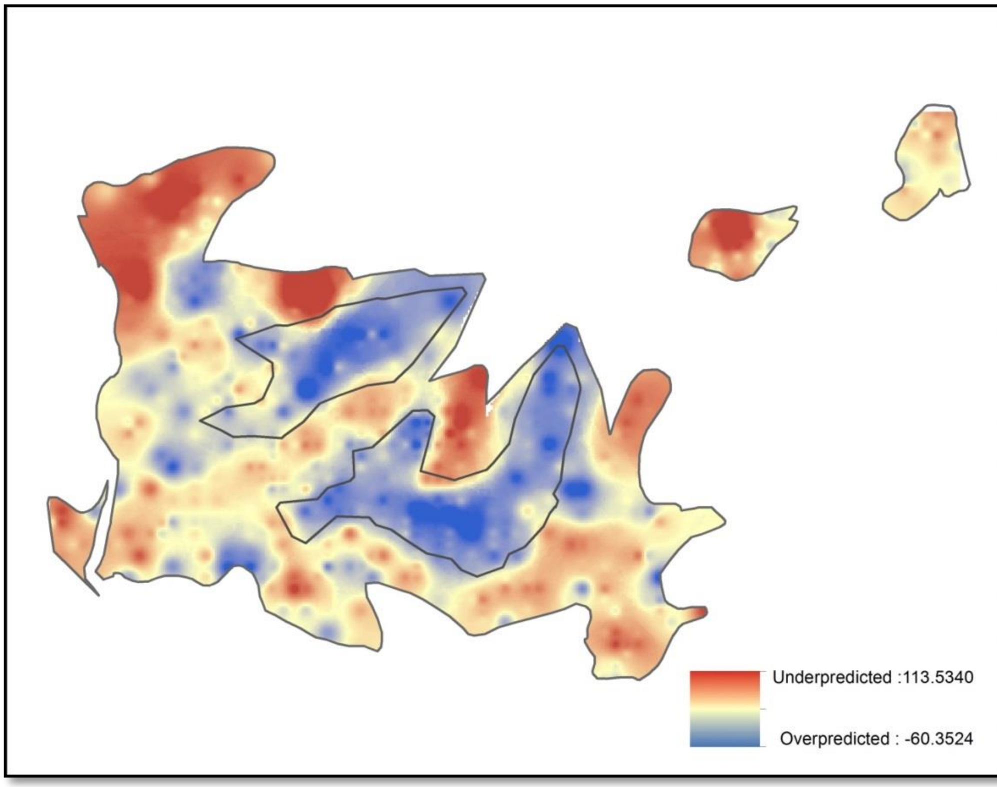

Figure 4.8. Map of Residuals - Ordinary Kriging 30m^2 SVC

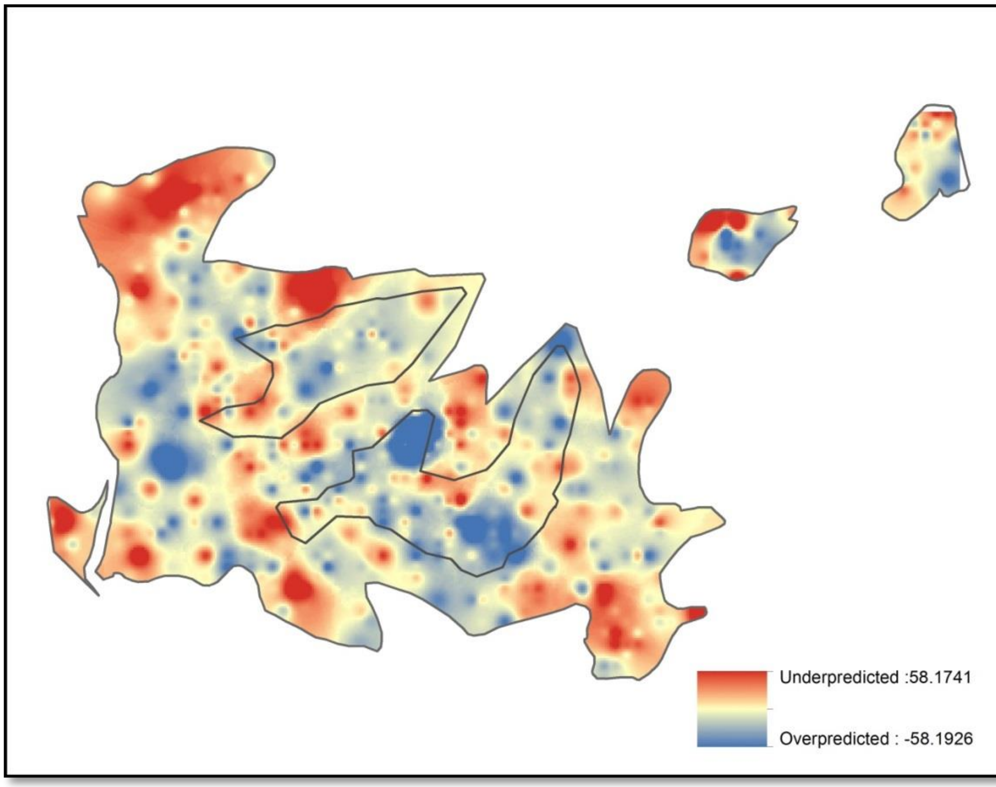

Figure 4.9. Map of Residuals - Tension Spline $30m^2$ SVC

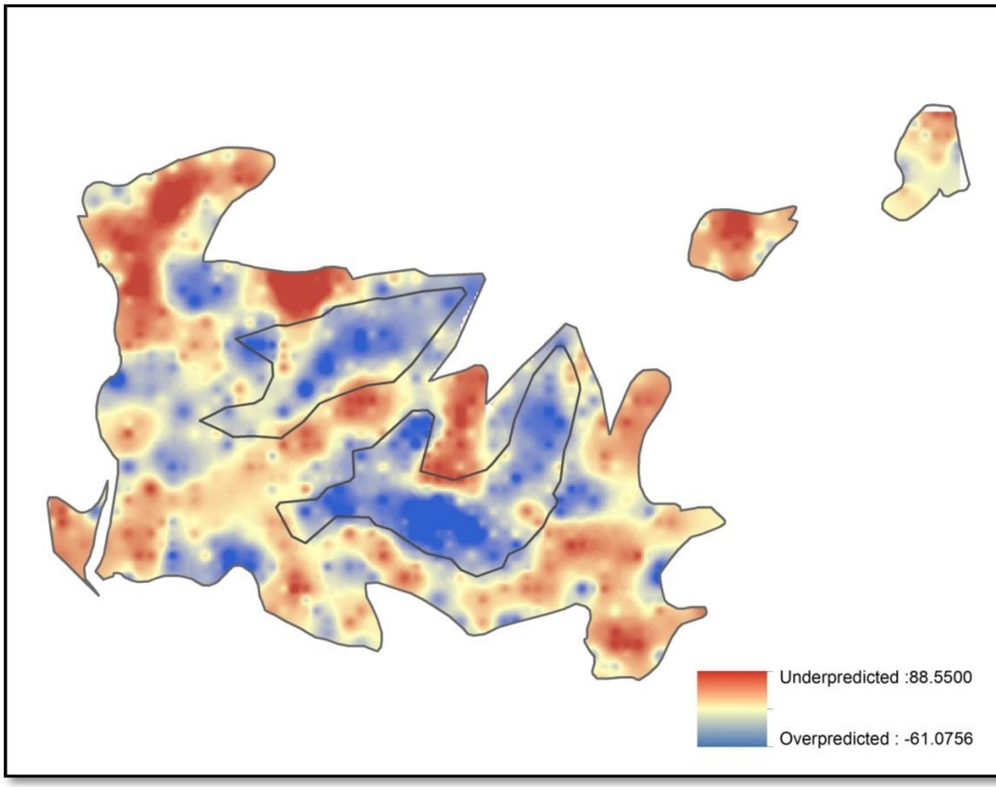

Figure 4.10. Map of Residuals - IDW 30m^2 MVC & SVC

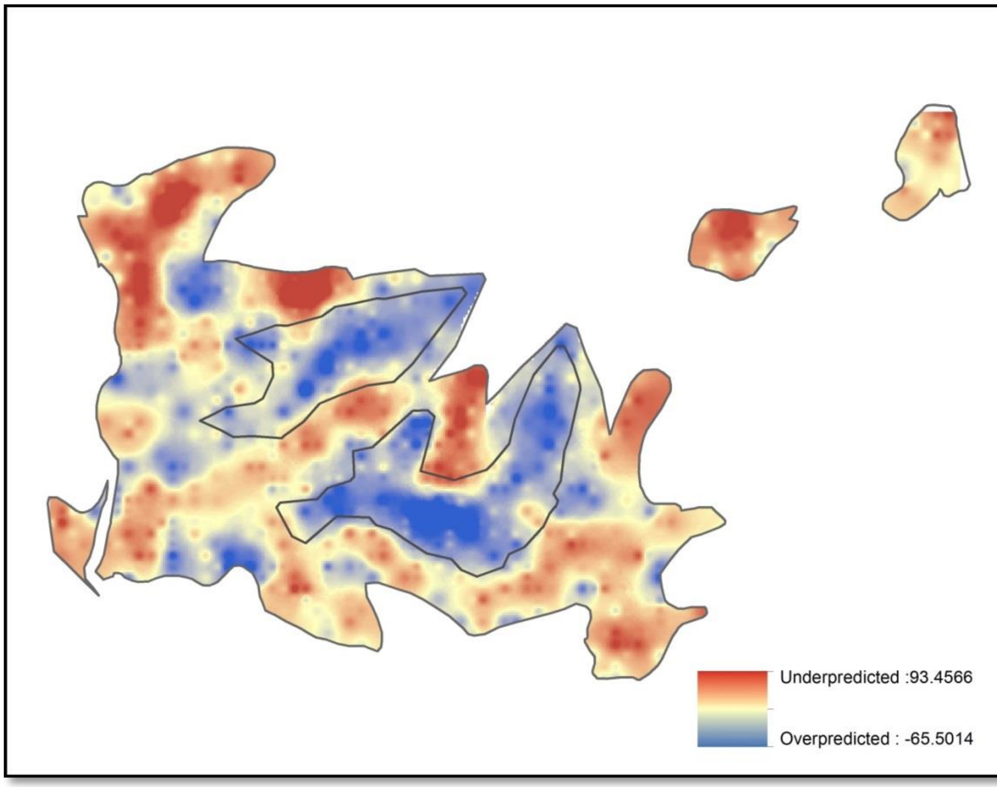

Figure 4.11. Map of Residuals - Ordinary Kriging 30m^2 MVC & SVC.

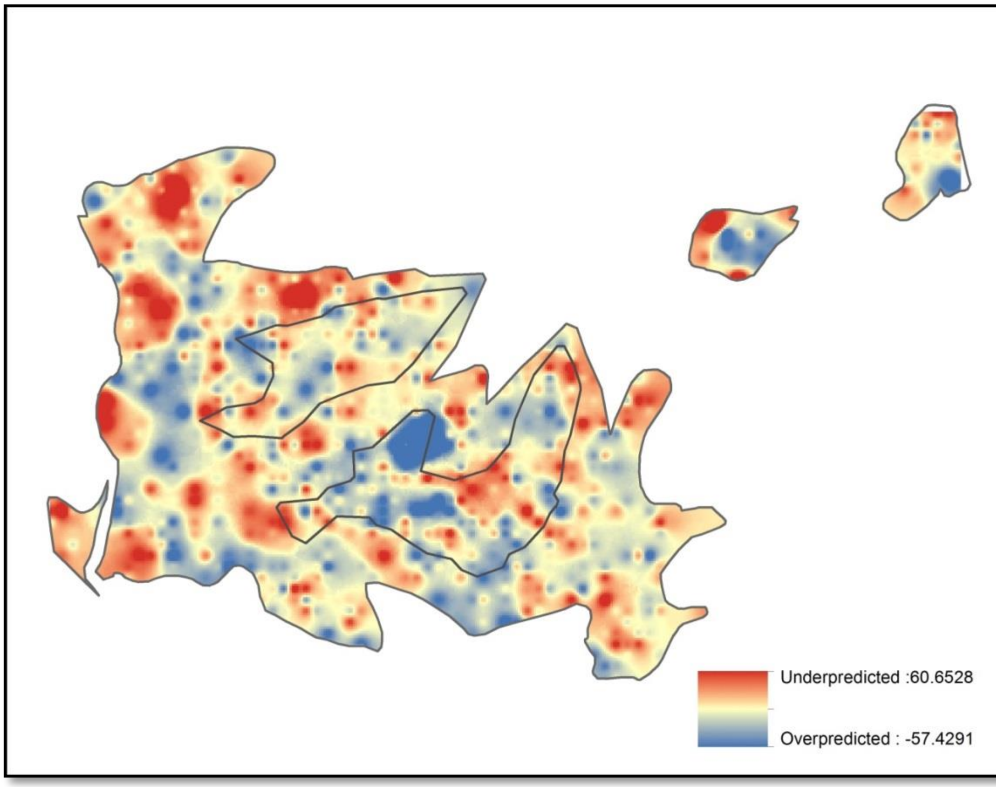

Figure 4.12. Map of Residuals - Tension Spline 30m^2 MVC & SVC.

Statistical Model

In order to explain the variance between the topo contour value and predicted elevation, an ANOVA test was performed using the residual (error) as the dependent variable along with 3 independent factors; slope, interpolation method, and valley or non-valley. A post hoc T-Test was also used to compare the residual means for the factors named valley (V) and non-valley (NV). Slope was categorized into 4 classes based on quartiles of the dataset. Points which have a slope value ≤ 34° were ranked as class 1, points with slope value 34° > 51° were ranked as class 2, points with slope value 51° > 59° were ranked as class 3, and any point with a slope value ≥ 59° was ranked as class 4. Points were also classed as being in a valley (V) or in an area of non-valley (NV). The second factor in the ANOVA is interpolation method. Three interpolation methods were tested using 4 sets of points for each method, resulting in a total of 12 interpolation models. The twelve categories were as follows: IDW using $30m^2$ grid cells of both single contour cells and multi contour cells (IDW30MVCSVC), IDW using $20m^2$ grid cells of both single contour cells and multi contour cells (IDW20MVCSVC), IDW using $30m^2$ grid cells of single contour cells only (IDW30SVC), and IDW using $20m^2$ grid centroids using only cells with a single contour falling through them (IDW20SVC), Kriging using $30m^2$ grid cells of both single contour cells and multi contour cells (KRIG30MVCSVC), Kriging using $20m^2$ grid cells of both single contour cells and multi contour cells (KRIG20MVCSVC), Kriging using $30m^2$ grid cells of single contour cells only (KRIG30SVC), and Kriging using $20m^2$ grid centroids using only cells with a single contour falling through them (KRIG20SVC), Spline using $30m^2$ grid cells of both single contour cells and multi contour cells (TS_30MVCSVC), Spline using 20m^2 grid cells of both single contour cells and multi contour cells (TS_20MVCSVC), Spline using 30m^2 grid cells of single contour cells only (TS_30SVC), and Spline using 20m^2 grid centroids using only cells with a single contour falling through them (TS_20SVC). Descriptive statistics for all 12 interpolations are shown below in Table 4.2.

Table 4.2. Descriptive Statistics of Absolute Residual by Interpolation Method**.**

Interpolation Method	Number of Samples	Mean	Median	Std Deviation	Lower Bound	Upper Bound
IDW20SVC	1145	18.80	16.00	13.08	18.04	19.56
KRIG20SV	1145	19.90	18.00	13.46	19.12	20.68
TS_20SVC	1145	13.89	12.00	10.26	13.29	14.48
IDW20MVCSVC	1293	19.08	17.00	13.20	18.36	19.80
KRIG20MVCSVC	1293	19.66	18.00	13.51	18.92	20.39
TS_20MVCSVC	1293	14.04	12.00	10.50	13.47	14.62
IDW30SVC	457	22.87	20.00	16.65	21.34	24.40
KRIG30SVC	457	25.06	22.00	18.11	23.39	26.72
TS_30SVC	457	12.03	9.00	10.07	11.10	12.95
IDW30MVCSVC	696	21.34	18.00	15.51	20.19	22.49
KRIG30MVCSVC	696	21.88	19.00	16.11	20.68	23.08
TS_30MVCSVC	696	9.91	8.00	8.10	9.31	10.51

Results of the Statistical Model

The main effects for the ANOVA were *Slope* and *Interp_Method* and the dependent variable was the residual or estimation error (ABS_RES). The model also included a two-way interaction effect using SLOPE*INTERP. The dependent variable (ABS_RES) was significant for the overall model (F = 231.26, p = .0001). The r-squared was .675, indicating that the majority of the variance was explained by the variables used the statistical model. A post-hoc range of mean test was conducted to examine the categories for each of the main effects.

Slope Effect

Slope Effect was significant at alpha = 0.05 (F = 10.44, p = .0001). The range of means test indicated that slope class 1 2, and 3, were not significantly different from each other but are all significantly different from class 4 which had the lowest mean of 17.01 (See Figure 4.13). This indicates that areas with lesser slope had greater error. Research indicates that areas with greater variation in slope over a given distance would have more error. The results from this model were the opposite. Areas with the greatest slope had the lowest error. This could possibly be explained by areas of less slope having cells that were labeled as no value when there was no contour line falling through it, those cells were not included in the interpolation, therefore there was less input data to interpolate in areas of the least slope.

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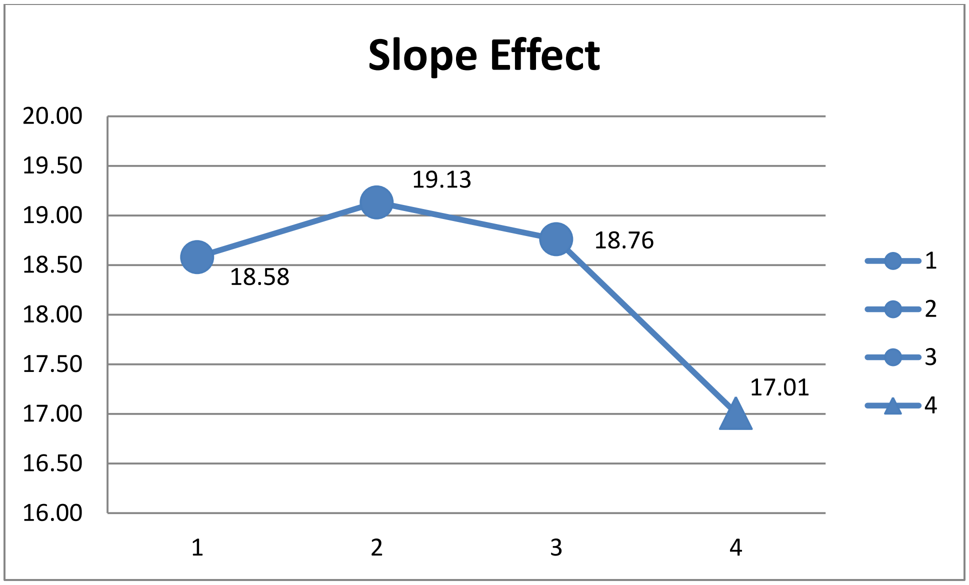

Figure 4.13. Slope Effect. *Slope* as the main effect for the mean residual. The different symbols indicate statistical significance. (Class 1 = Slope ≤ 34°, Class 2 = Slope 34° > 51°, Class 3 = Slope 51° > 59°, and Class 4 = Slope ≥ 59°)

Interp Method Effect

Interp Method Effect was significant at alpha = 0.05 (F = 75.04, p = .0001). The range of means test results are displayed in figures 4.14 through 4.17 . Figure 4.14 shows that for the 20m^{2}grid SVC set IDW20SVC and KRIG20SVC were not significantly different with mean residuals of 19.01 and 20.09 respectively. They were both were significantly different from TS_20SVC which had a mean residual of 13.80. Figure 4.15 shows that for the 20m^2 grid MVC & SVC point set IDW20MVCSVC yielded a mean residual of 19.17 and KRIG20MVCSVC yielded a mean residual of 19.98 and are not significantly different from each other, but both are significantly different from TS_20MVCSVC which yielded a mean residual of 13.82. Figure 4.16 shows that all three interpolation methods using the 30m^2 grid SVC point set are significantly different from each other with mean residuals of 22.87 for IDW30SVC, 25.05 for KRIG30SVC, and 12.20 for TS_30SVC. Figure 4.17 shows that for the 30m^2 grid MVC & SVC point set, IDW30MVCSVC yielded a mean residual of 21.73 and KRIG30MVCSVC yielded a mean residual of 22.68, both are not significantly different from each other but they are significantly different from TS_30MVCSVC with a mean residual of 10.00, which is the lowest mean residual of all twelve interpolations. A summary of mean residuals for all twelve interpolations can be seen in Table 4.3. This shows that the Spline with Tension methods had the lowest mean residual in all four data sets.

Table 4.3. Summary of Interp Method Effect. Mean residuals are in ascending order.

Interpolation Method	**Mean Residual**
TS_30MVCSVC	10.00
TS_30SVC	12.20
TS_20SVC	13.80
TS_20MVCSVC	13.82
IDW20SVC	19.01
IDW20MVCSVC	19.17
KRIG20MVCSVC	19.98
KRIG20SVC	20.09
IDW30MVCSVC	21.73
KRIG30MVCSVC	22.68
IDW30SVC	22.87
KRIG30SVC	25.05

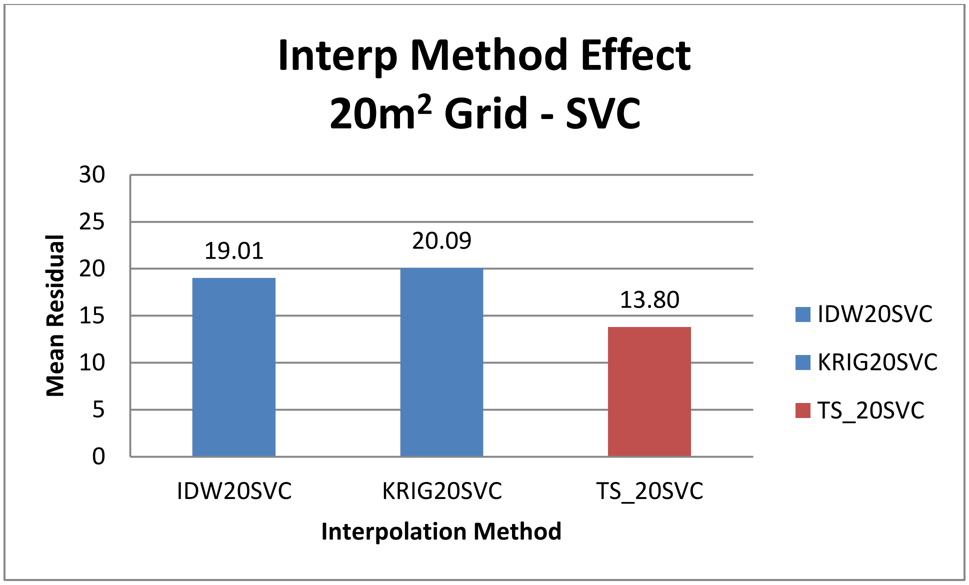

Figure 4.14. 20m^2 Grid SVC - Interp Method Effect. *Interp Method* as the main effect for mean residual from the 20m^2 grid SVC point set. The different colors indicate statistical significance.

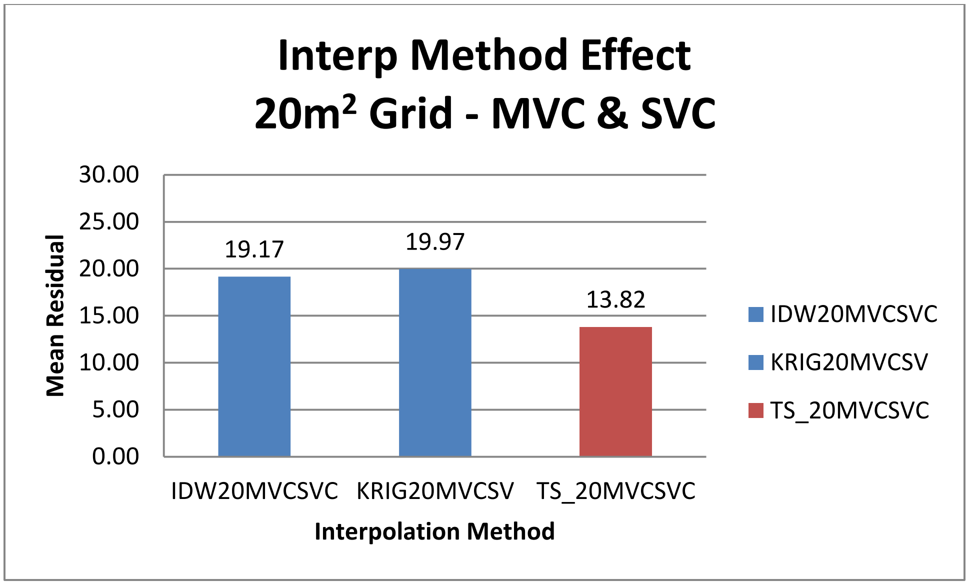

Figure 4.15. 20m^2 Grid MVC & SVC - Interp Method Effect. *Interp Method* as the main effect for mean residual from the 20m^2 grid MVC & SVC point set. The different colors indicate statistical significance.

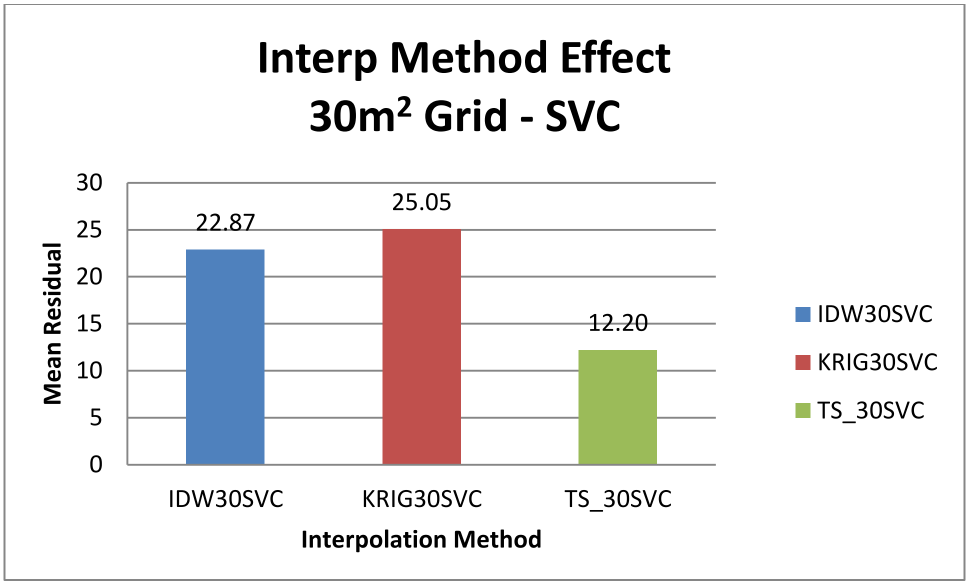

Figure 4.16. 30m^2 Grid SVC - Interp Method Effect. Interp Method as the main effect for mean residual from the 30m^2 grid SVC point set. The different colors indicate statistical significance.

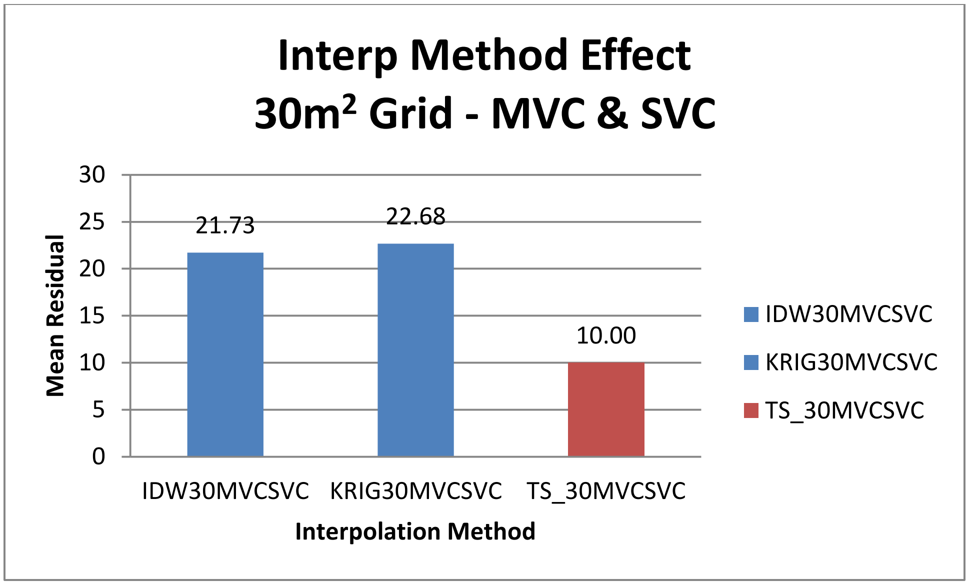

Figure 4.17. 30m^2 Grid MVC & SVC - Interp Method Effect. *Interp Method* as the main effect for mean residual from the 30m^2 grid MVC & SVC point set. The different colors indicate statistical significance.

Valley or Non-Valley Effect

Valley or Non-Valley Effect was significant at alpha = 0.05 (F = 17.70, p = .0001). A T-Test was used to determine statistical significance between the means for the categories of valley and non-valley. The results of the test indicated statistical significance between the two means (p-value = .0001, alpha = 0.05). The mean for Valley was 17.19 while the mean for Non-Valley was 18.33 (See Figure 4.18). This suggests that areas of valley have less error than non-valley areas. This aligns with the results from the ANOVA which indicated areas of greatest slope had the least error.

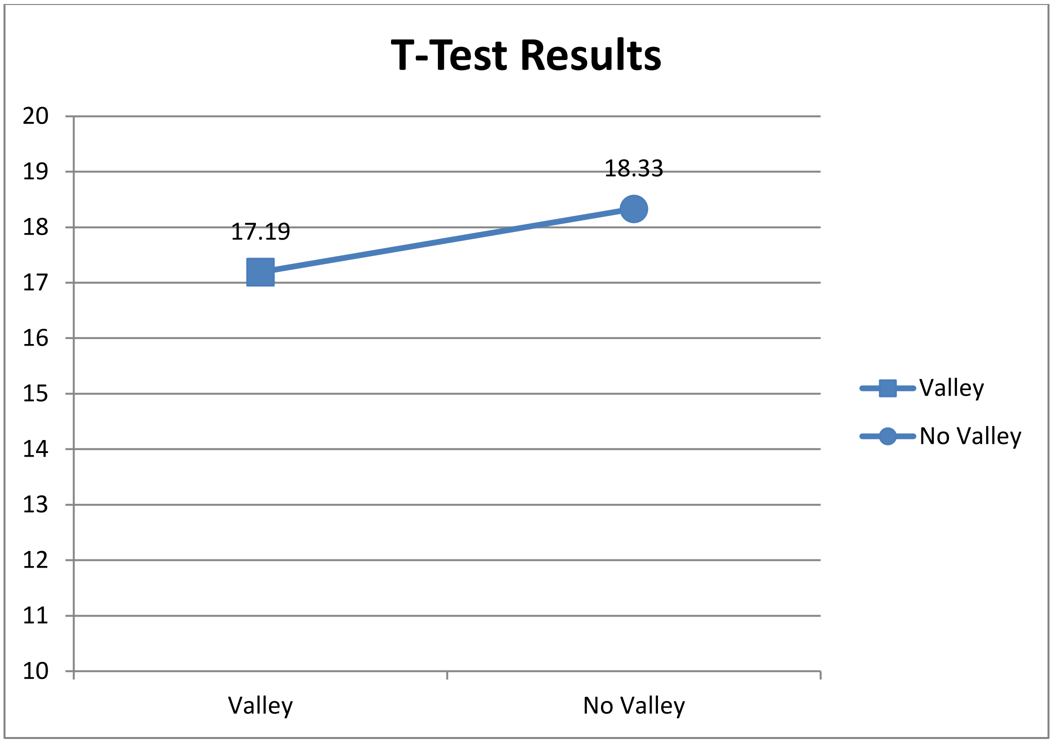

Figure 4.18. Valley / Non Valley T-Test Results. The different symbols indicate statistical significance.

Interaction Effects

The two-way interaction effect SLOPE*INTERP was also significant at alpha = 0.05 (F = 6.02, p = .0001). This suggests that the degree of slope and the type of method partially explained the variance in error. Class slope 1 had the lowest mean error (9.17) when the Spline with Tension interpolation using 30m^2 MVC & SVC was used and the highest mean error (27.90) when the Kriging interpolation using 30m^2 MVC & SVC was used. Slope class 2 had the lowest mean error (10.84) when the Spline with Tension interpolation using 30m^2 MVC & SVC was used and the highest mean error (26.83) when the Kriging interpolation using 30m^2 SVC was used. Slope class 3 had the lowest mean error (10.15) when the Spline with Tension interpolation using 30m^2 MVC & SVC was used and the highest mean error (25.10) when the Kriging interpolation using $30m^2$ SVC was used. Slopes class 4 had the lowest mean error (9.86) when the Spline with Tension interpolation using $30m^2$ MVC & SVC was used and the highest mean error (21.68) when the IDW interpolation using $30m^2$ SVC was used.

Discussion

Overall, Spline with Tension using $30m^2$ MVC & SVC had the lowest RMSE value of 12.78 and the results from the Main Effects show that it also had the lowest mean residual of 10.00. The elevation range within the boundary of the site is 542 feet, so a 95% confidence interval would be 27.10 ft. The DEM from TS_30MVCSVC had a RMSE value of 12.78, multiplied by a standard deviation of 1.96 = 25.05. Since $25.05 < 27.10$, the accuracy of this model is within the 95% confidence interval.

Calculation of Volume

DEM Differencing was performed to calculate the volume of land altered at the Frozen Hollow Surface Mine. Figure 4.20 shows a 3D representation of the pre-mining surface from the TS_30MVCSVC interpolation and figure 4.21 shows a 3D representation of the post-mining surface created from the 2003 DEM acquired from the USGS. The DEM from 2003 was subtracted from the DEM from the TS_30MVCSVC interpolation to create the DEM of Difference (see Figure 4.22). The DEM of Difference is the volume of land that has been altered at the Frozen Hollow Surface Mine. The calculation for volume of change includes an account of the 3,534,435 tons of coal that were expected to be removed per the permit (WVDEP , 1996), converted at a rate of 40 cubic feet per ton. The net changes were categorized in loss from mountaintops and gain in valley fill.   It was expected that the amount of elevation gain will exceed the amount of loss, even with the removal of the coal due to the amount of unconsolidated material in the valley fills and the creation of backstacked islands in an effort to keep “approximate original contour”.

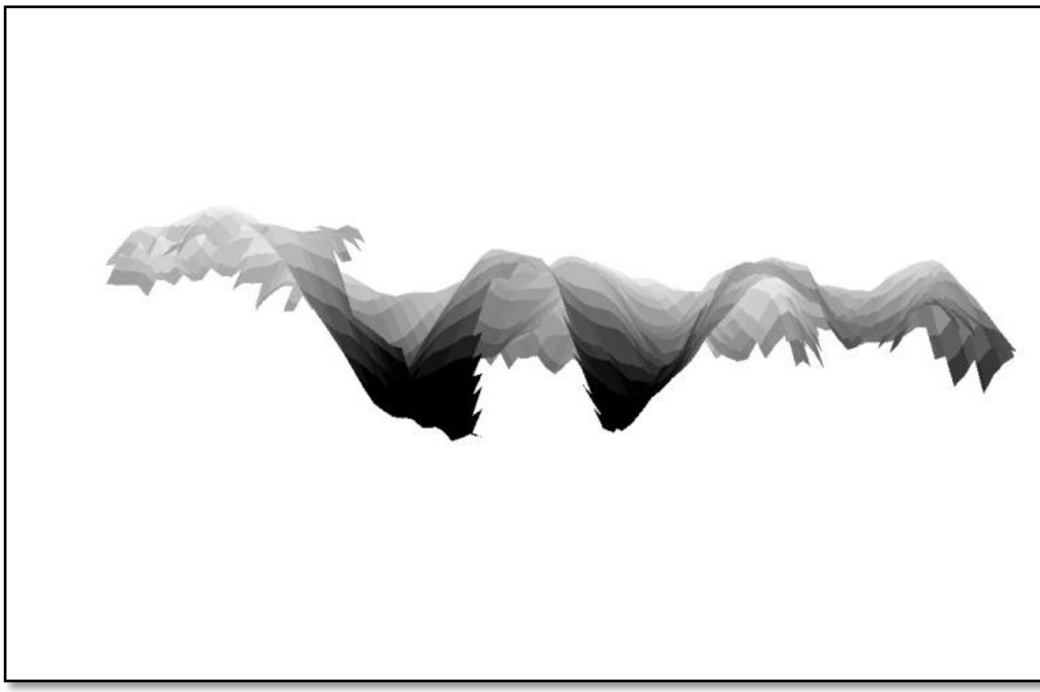

Figure 4.19. 3D Representation of Pre-Mining Surface

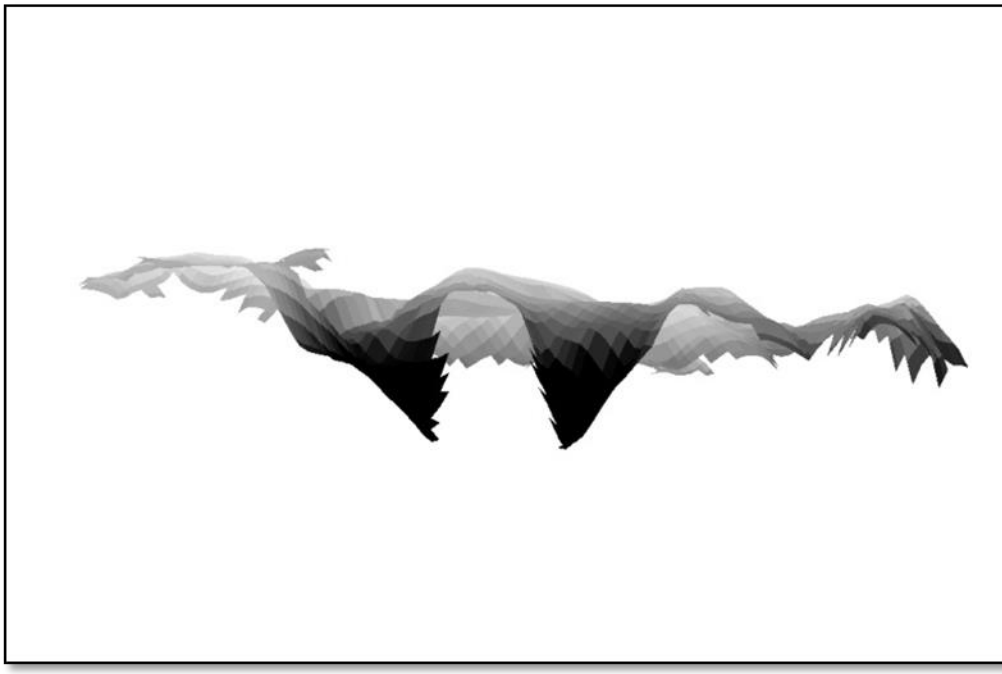

Figure 4.20. 3D Representation of Post-Mining Surface.

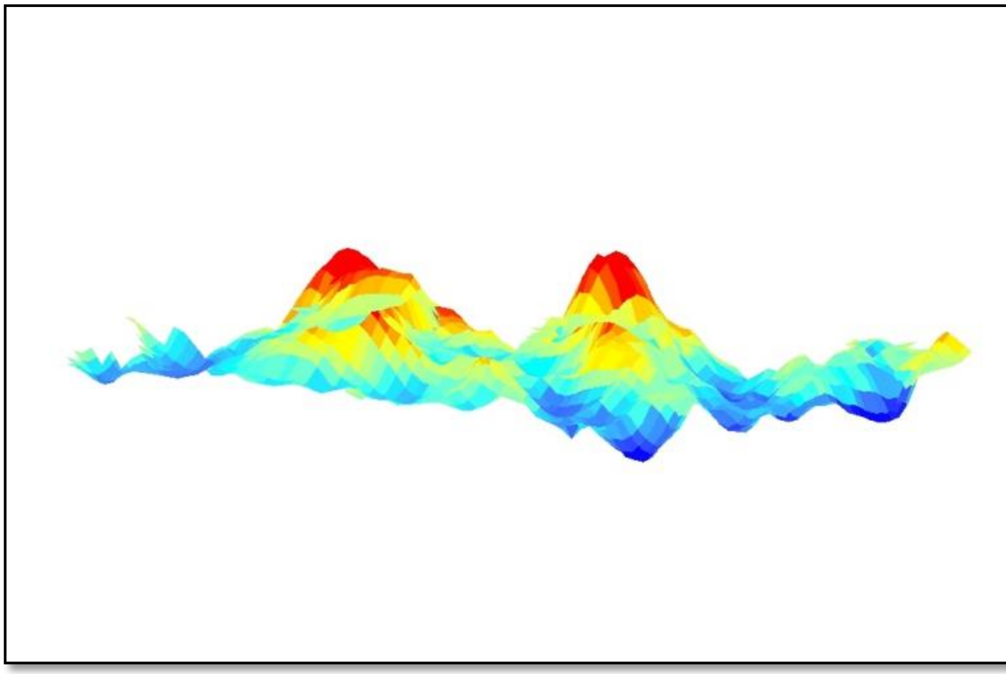

Figure 4.21. 3D Representation of DEM of Difference. (Areas with the most gain shown in red, areas with the most loss shown in dark blue.)

In order to quantify the amount of land that has been altered, volume calculations were performed based on area of each valley fill and then all non-valley areas. Based on the 2003 imagery it is noted that the original valleys extend past the boundaries of the valley fills supplied by the WVDEP (see Figure 4.23). For this reason, the boundaries of the valleys were digitized from the DRG and the digitized valley boundaries were used when reporting the net volume of change in each area (See Figure 4.24).

Figure 4.22. Valley Fill Boundaries - WVDEP

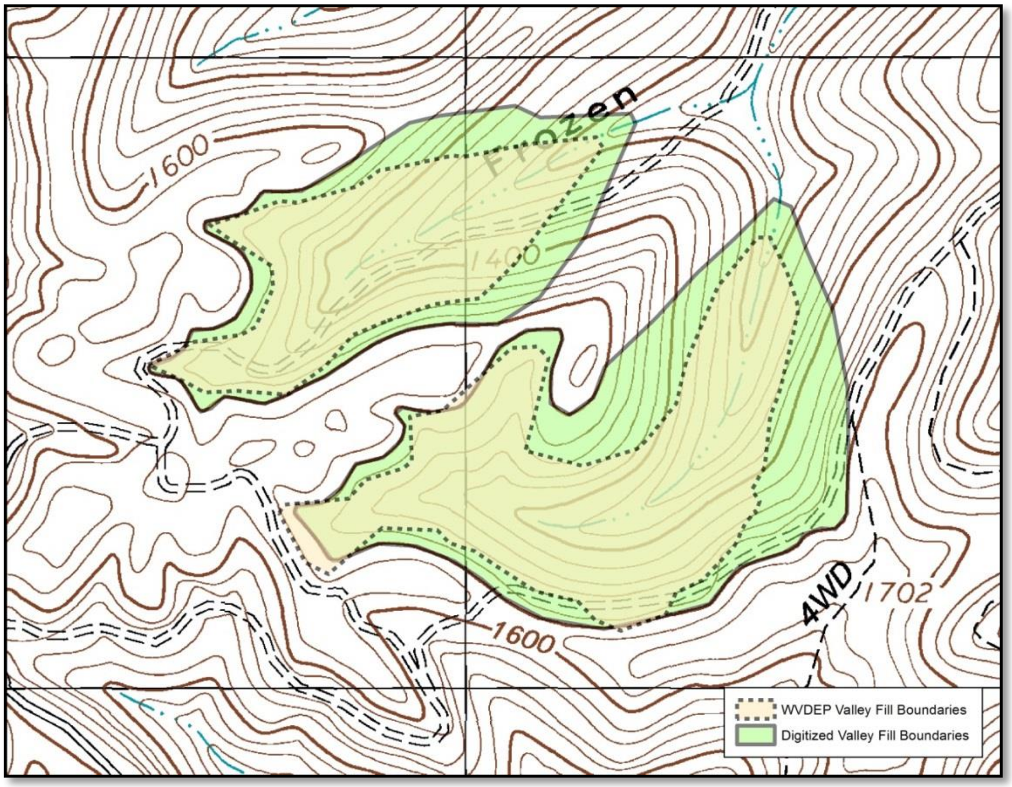

Figure 4.23. Valley Fill Boundaries -WVDEP and Digitized

Results show a net gain in Valley Fill 1 of 8,450,746 cubic yards, a net gain in Valley Fill 2 of 5,207,939 cubic yards and a net loss in the Non-Valley areas of 9,320,829 cubic yards. Figure 4.25 shows how these gains and losses were distributed across the site. The net difference for the overall boundary of the site was a gain of 4,337,856 cubic yards. According to the permit request 3,534,435 tons of coal were expected to be extracted. At 40 cubic feet per ton, there were 141,377,400 cubic feet, or 5,236,200 cubic yards of coal expected to be removed. Added to the net increase of 4,337,856 cubic yards represents a total of 9,574,056 cubic yards of elevation increase across the site due to the process of mountaintop removal mining. This amount represents the amount of pore space introduced below the surface due to the breaking up consolidated rock into unconsolidated rock.

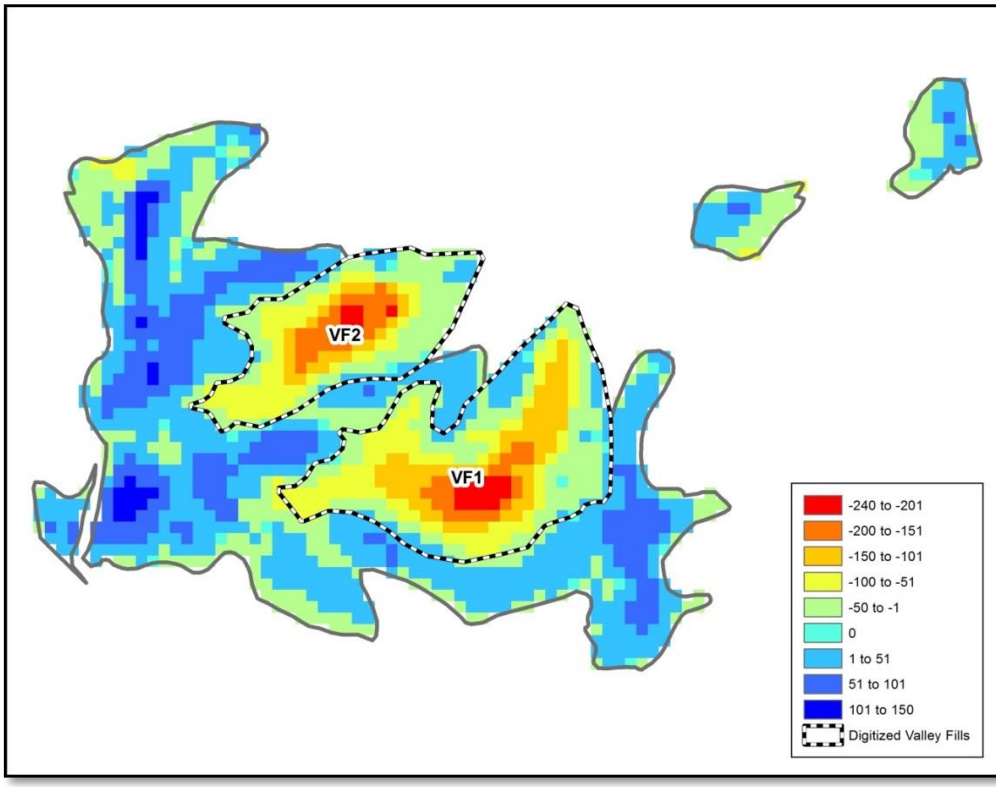

Figure 4.24. Change in Elevation. Increase in elevation shown as negative numbers and decrease in elevation shown as positive number.

In an effort to check the accuracy of the model, the results were compared to figures listed in the permit request. According to the permit request submitted by Asset Mining Company to the WVDEP Valley Fill 1 had an expected storage volume of 10,077,449 cubic yards of spoil, and Valley Fill 2 had an expected storage volume of 5,806,880 cubic yards of spoil. The results showed 1,626,703 cubic yards less than the expected capacity of Valley Fill 1, and 598,941 cubic yards less than the expected capacity of Valley Fill 2.

CHAPTER V

CONCLUSION

Mountaintop removal is a controversial form of coal mining due to the negative effect it has on the surrounding environment. Streams are buried, forests are cleared, hydrologic movement changes, and water quality is affected (Palmer, et al., 2010). Temporal elevation data may be required for scientists to study the wide array of environmental changes associated with the change in landscape due to mining. The difficulty finding historical digital elevation data makes it necessary to derive digital data from other sources.

This study focused on comparing interpolation methods in GIS to determine the best method in mountainous regions for creating a historical DEM from ancillary sources. Elevation data was limited to topographic maps for the area chosen. Finding a site with accessibility was extremely difficult, and the Frozen Hollow Surface Mine had been previously strip mined leaving some flattened areas and high walls. A site that had not been previously mined would have been preferable, as it is unclear how those flattened areas with no value cells and the high walls with great variation in elevation affected the interpolation methods. Future work could include an area untouched by mining. Elevation data was extracted based on contour lines to point sets in order to create a DEM of pre-mining conditions. It is assumed that there is some inherent error in the volume calculation because topographic maps contain some error because they are created by predictions through interpolations (Ziadat, 2007). However, the interpolations and the error analysis were performed with the same source as a way to increase the validity of the study.

Data sets were created by assigning the elevation data from topographic maps to centroids of $20m^2$ and $30m^2$ gridded areas over the study area. The sets were then divided into centroids with only one contour line passing through the cell and another for centroids with both single contour and multi-contour attributes for each of the grid sizes. Three interpolation methods were compared to determine the best method for mountainous regions. The three methods were Inverse Distance Weighting (IDW), Ordinary Kriging (OK), and Spline with Tension (TS). The results indicated that there was little difference between the results of IDW and OK but that TS was significantly different from the other two methods. The $30m^2$ set with both multiple contours and single contours using the Spline with Tension method had the lowest overall error.

The results revealed that when comparing Inverse Distance Weighting, Ordinary Kriging, and Spline with Tension, the optimal interpolation method for use in creating historical DEMs in mountainous areas is the Spline with Tension method. The accuracy of the Spline with Tension was within the 95% confidence interval. Using this method, the volume of land mass altered was quantified at the Frozen Hollow Surface Mine in Prenter, WV. Using the resulting DEM from the Spline with Tension method, and a 2003 DEM from the USGS, DEM differencing was performed to calculate the volume of land mass altered at the study site. The results showed that there was net gain in the valley fill areas of 13,658,685 cubic yards and a net loss in the Non-Valley areas of 9,320,829 cubic yards. The net difference for the overall boundary of the site was a gain of 4,337,856 cubic yards. When adding in the 5,236,200 cubic yards of coal that was removed, there was an overall increase in elevation of 9,574,056 cubic yards due to the process of MTR at this site.

This study used $20m^2$ and $30m^2$ grids to create point sets. Further work could be done to determine if other size grid cells produce better results. Future studies could also include adjustments to the parameters to further examine accuracy results. It would also be interesting to examine the Frozen Hollow Surface Mine site using a more recent DEM. More recent elevation data may provide better accuracy when calculating the volume of altered land mass. This would also help to determine whether mining activity was complete at the time of the 2003 DEM. For purposes of calculating the volume of land mass altered due to mountaintop removal, a site with more recent mining activity could be analyzed since the introduction of Lidar data increased elevation accuracy in DEMs.

Research focusing on the negative impacts of mountaintop removal mining on the surrounding environment could benefit greatly from creating accurate DEMs for pre-mining conditions. Timely DEM data and accurate interpolation are key to determining change in the terrain due to the mining activity. Monitoring and examining the impacts of mountaintop removal is very important to understanding the negative changes and their implications to the environment.

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