THE EFFECT OF SURFACE MINING ON WATER QUALITY IN THE UPPER LEVISA SUB-BASIN OF CENTRAL APPALACHIA

GIS in Water Resources Term Project
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1.0 Introduction to Central Appalachia

Due to competing fuel sources, regulatory pressure, and the depletion of easy access coal reserves, the coal mining industry in Central Appalachia is declining (Plumer, 2013). Central Appalachia is located in the Appalachian Mountains region at the corner of Virginia, West Virginia, Kentucky, and Tennessee. An increased number of factories in the 20th century created a high demand for coal. In the 1990s, surface mining in the form of mountaintop removal became popular in the region, which has transformed topography and hydrology (McQuaid, 2009). However, since peaking in 2008, the total United States coal production has declined by almost 25%, with the Central Appalachia region experiencing the largest decline (Park, 2016). President-Elect Donald Trump promised to “save the coal industry” (2016), which could lead to an increase in mining operations around the region in the future.

Although rich in beauty and resources, the Central Appalachia region does not provide easy access to updated water and wastewater infrastructure for residents. Surface mine drainage can contaminate primary drinking water sources such as mountain springs and wells. The mountain streams eventually flow into larger waterbodies that provide drinking water for populations downstream.

1.1 Mountaintop-Removal Mining

The process of mountaintop-removal mining includes deforestation, altering the topography using explosives, and dumping excess debris and dirt over lower-lying lands, which is known as valley fill. These activities bury existing streams, increase sediment in waterways, and affect hydrology in the region. In 2009, the Environmental Protection Agency (EPA) tightened regulations regarding mountaintop-removal mining and the degradation of stream quality (EPA, 2009). However, continued studies on the long-term effects of mountaintop-removal mining on local water quality are needed.

1.2 Evaluating Stream Water Quality

Specific conductance and total suspended solids (TSS) were chosen as parameters to evaluate stream water quality in the region. Both water quality parameters are indicative of aquatic life health in the streams and affect drinking water quality. Streams may be considered impaired for specific conductivity or TSS under Sections 303(d) and 305(b) of the Clean Water Act if they do not meet state-specified water quality standards. For impaired streams identified in the Watershed Quality Assessment Report, states may be required to develop total maximum daily loads (TMDLs) under direction by the EPA.

Specific conductance is a measure of water's conductivity. Drainage from both active and abandoned mines can contain higher concentrations of metals, minerals, sediment, and other pollutants (Kleinmann et al., 1998). Hence, changes in conductivity within streams is an indirect measure of dissolved ions in the water and can be a pollutant indicator. Conductivity values are easily obtained using a sensor that measures electrical resistance using the following equation.

$$Specific\ Conductivity = \frac{1}{Resistance}$$

Waterways near mining regions will have some specific conductivity value due to naturally occurring minerals. In 2011, the EPA issued a guidance concluding that at 300 micro-Siemens/cm, there is a negative impact on aquatic life, and at 500 micro-Siemens/cm, the mine is in violation of water quality standards on their permits (Copeland, 2015; EPA, 2010). The benchmarks intend to protect approximately 95% of aquatic organisms in Central Appalachian streams that would not likely survive under high conductivity levels (EPA, 2010). Therefore, this project uses 500 μS/cm as the maximum allowable conductivity level before impairment.

Suspended solids are a major source of pollution in Kentucky (KWRI, 2000). TSS is associated with sediment levels in the water because suspended solids typically consist of more inorganic versus organic material. Higher levels of sediment contribute to the cloudiness and turbidity of water. As turbidity increases, the amount of light penetration decreases, affecting aquatic life. Higher sediment loads occur in areas with less dense vegetation to stabilize soils, or where soils are exposed, such as around surface mines.

There is no numeric water quality standard for TSS in either Virginia or Kentucky. The narrative water quality criteria for TSS in Kentucky "shall not be changed to the extent that the indigenous aquatic community is adversely affected" (EPA, 2015). According to Kentucky's River Assessment Monitoring Project, for TSS levels above 80 mg/L, benthic macroinvertebrate populations drop by 60%, which adversely affects the aquatic community (KWRI, 2000). For this project, streams with TSS concentrations above 80 mg/L are considered impaired.

1.3 Upper Levisa Sub-Basin

The Upper Levisa sub-basin (HUC 05070202) is located in the Central Appalachian region and straddles the state line between Kentucky and Virginia as shown in Figure 1.

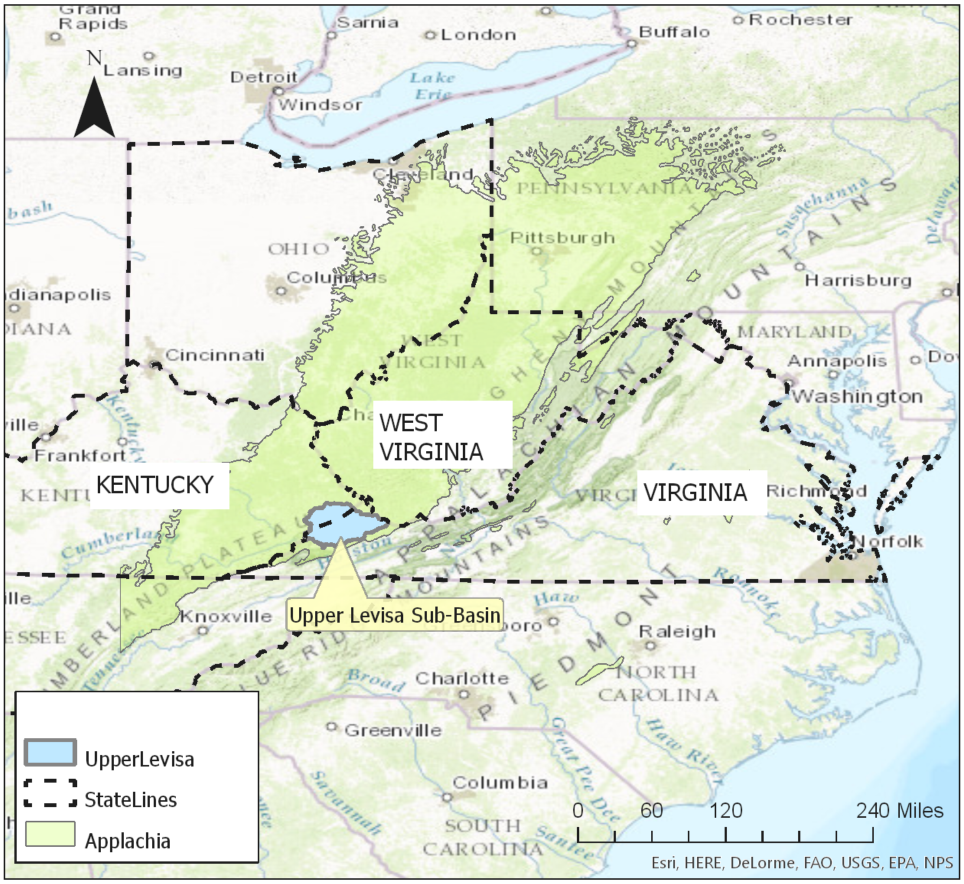
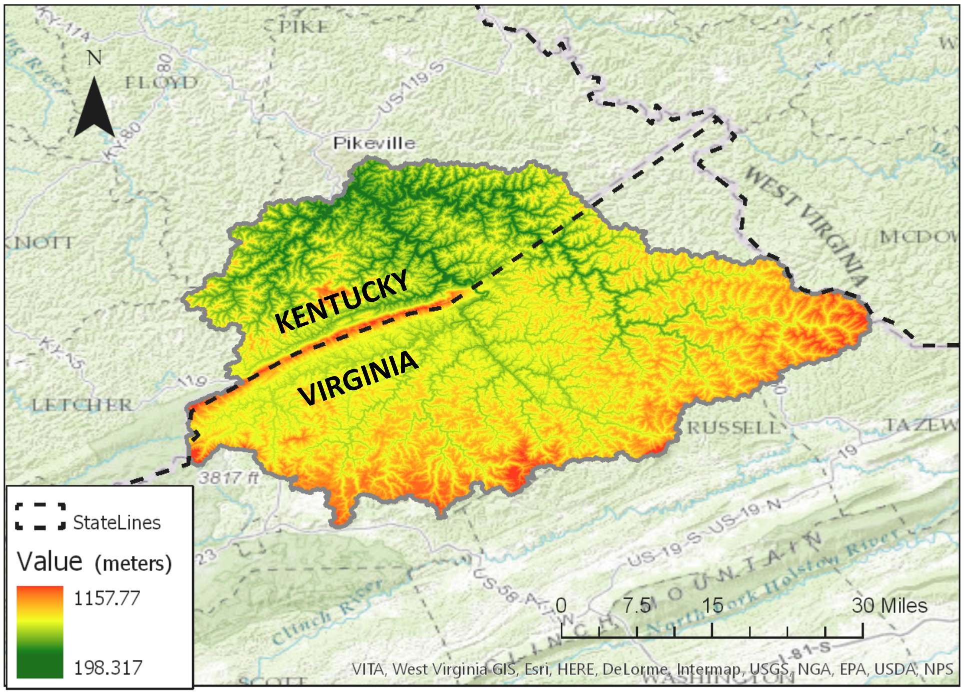


Figure 1. Location of Upper Levisa sub-basin within the Appalachian region.

As seen in the digital elevation model in Figure 2, the elevations are higher on the Virginia side. Farther downstream in the sub-basin, in Kentucky, the elevations are lower.



VITA, West Virginia GIS, Esri, HERE, DeLorme, Intermap, USGS, NGA, EPA, USDA, NPS

Figure 2. Digital Elevation Model of Upper Levisa sub-basin. Elevation data in meters.

Figure 3 shows the land cover within the sub-basin is composed mostly of forest and shrubbery. There is development along waterways, and some scattered agriculture. The grey spots for barren land cover show some evidence of abandoned mines.

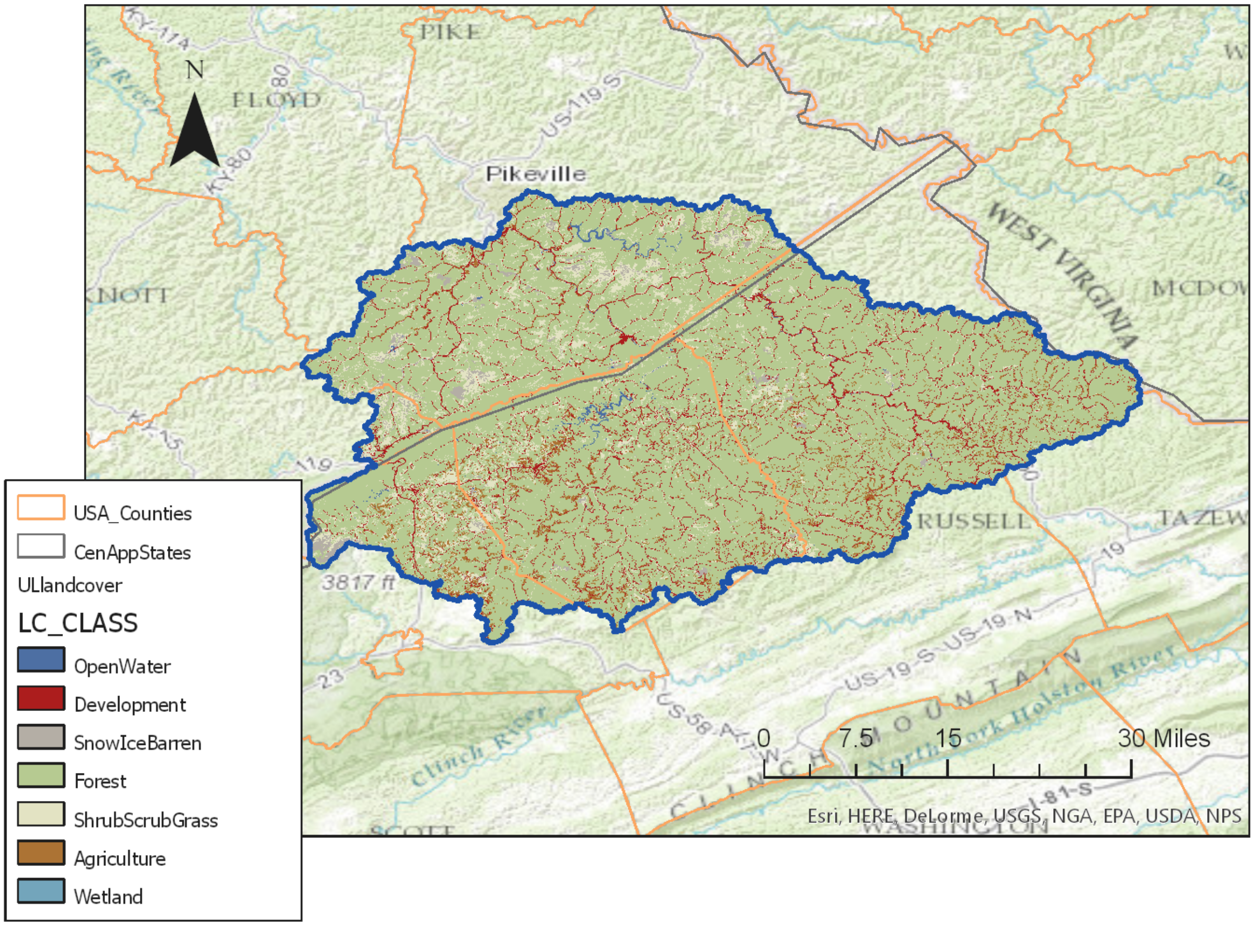


Figure 3. Land cover in Upper Levisa sub-basin.

The Kentucky, West Virginia, and Virginia counties within the sub-basin are Letcher, Pike, Floyd, Knott, Buchanan, Wise, Dickenson, Russell, Tazewell, and McDowell counties. The Upper Levisa is part of the Tennessee-Big Sandy River basin that eventually drains to the Mississippi River and into the Gulf of Mexico. This basin was chosen as the area of study within Central Appalachia because it includes several active surface mines, abandoned mine lands, and a sufficient number of nearby water sampling locations. According to the Kentucky Watershed Quality Assessment Report, 70% of all streams in the Upper Levisa are impaired by at least one water quality parameter, as shown in Figure 4 (EPA, 2012).

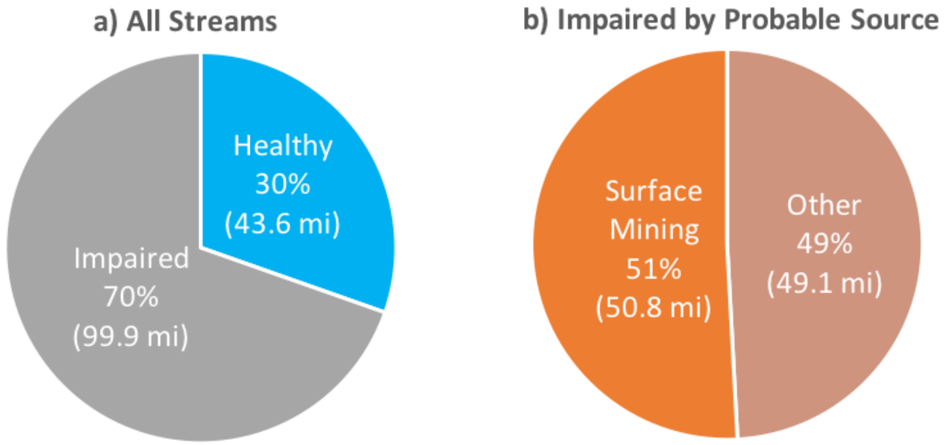


Figure 4. Pie chart of health of all streams in Upper Levisa in (a) and of streams impaired as a result of surface mining in Upper Levisa in (b). Data from 2012 Watershed Quality Assessment Report for Upper Levisa in Kentucky (EPA, 2012).

TMDLs for the impaired streams are needed, but have not yet been developed. This paper explores the relationship between surface mining and stream water quality in the Upper Levisa sub-basin using spatial analysis in order to make recommendations on remediating impaired streams.

2.0 Materials and Methods

Open data for mines, water quality, streams, and land characteristics was downloaded to support this analysis. The data was then fed into ArcGIS Pro to investigate the relationship between surface mining and water quality. The spatial analysis process is outlined in this section.

2.1 Data Sources

Land and stream data were taken from various sources. Elevation data was taken from the National Elevation Dataset (NED) at a 30-meter resolution to create a digital elevation model (DEM) for the area of interest as shown in Figure 2 in Section 1.3. Stream flowlines and values were extracted from the National Hydrography Dataset Plus (NHDPlus V2). The National Land Cover Database (NLCD) provides land use data at a 30-meter resolution as extracted and shown in Figure 3 in Section 1.3. Hydrologic unit code 10 (HUC 10) divides were extracted from the Watershed Boundary Dataset to provide an idea of the size of the Upper Levisa sub-basin as shown in Figure 6 in Section 2.2. State and county boundaries were taken from the ESRI Living Atlas. The outline for the Central Appalachian region shown in Figure 1 in Section 1.3 was downloaded as a shapefile from the *2000 Resource Assessment of Selected Coal Beds and Zones in the Northern and Central Appalachia Basin Coal Regions* published by the United States Geological Survey (USGS).

The data source for active mines is the USGS Energy Data Finder. From the USGS active mines feature class, only points classified as surface mines were selected and mapped. Abandoned mine lands (AML) feature classes containing polygons are available from the Kentucky Mine Mapping Information System (MMIS) and Virginia Department of Mines, Minerals, and Energy (DMME). All downloaded mine feature classes were in geographic coordinates corresponding with NAD 1983.

Stream water quality data provided by USGS and EPA gages is available from the Storage and Retrieval and Water Quality Exchange Database (STORET). The Water Quality Portal can be used to query STORET data by year, location such as states, counties, or HUC codes, and water quality parameters such as TSS and specific conductivity. Gage information and water quality results are downloaded separately in Excel spreadsheet format. A total of eight spreadsheets for specific conductivity and TSS values in time periods 2000-2009 and 2010-2016 were downloaded. Gage coordinates correspond with NAD 1983. Specific conductance measurements are taken in μS/cm corrected to 25 degree Celsius temperatures via grab samples. TSS samples are taken at a depth of 0.3 meters and typically have a minimum detection value of 1 mg/L.

2.2 Data Management and Spatial Analysis

To determine which data points were relevant, the area of interest, the Upper Levisa sub-basin, was first delineated. A buffer was created around the counties within the sub-basin. Using the buffer, a DEM was extracted from NED 30m as shown in Figure 2 in Section 1.3. ArcGIS Pro spatial analyst tools use this DEM to fill sinks to create flow direction and flow accumulation raster layers. Figure 5 shows the flow direction raster used to create the flow accumulation raster.

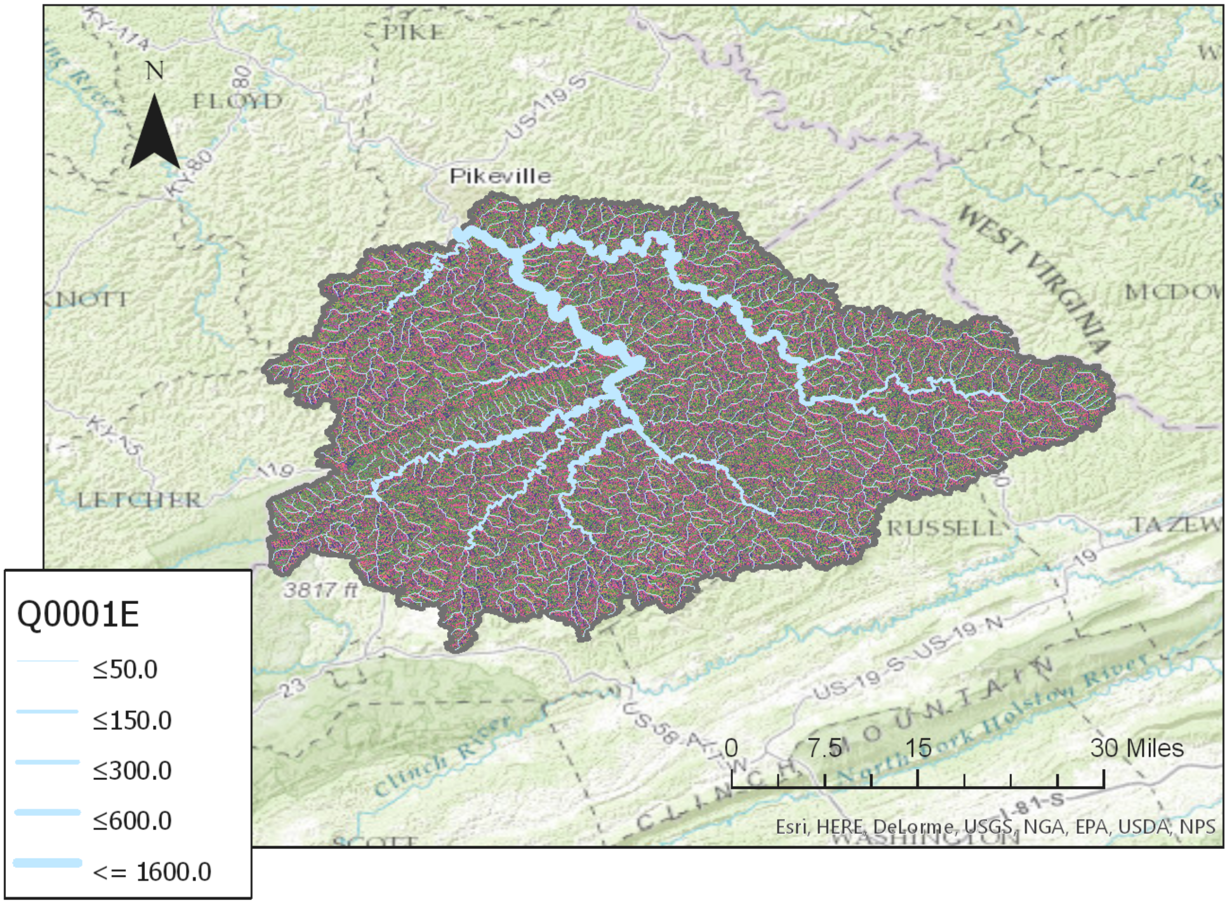


Figure 5. Flow direction raster for Upper Levisa sub-basin based on the DEM with NHDPlus V2 flowlines. Flow values are in cfs.

From the flow accumulation raster, a pour point at the confluence of two streams, depicted in Figure 6, was selected. The Upper Levisa sub-basin can then be delineated using the flow accumulation raster and the pour point. This sub-basin matches the divides from the Watershed Boundary Dataset. The seven HUC 10 watersheds within the delineated sub-basin are also shown in Figure 6.

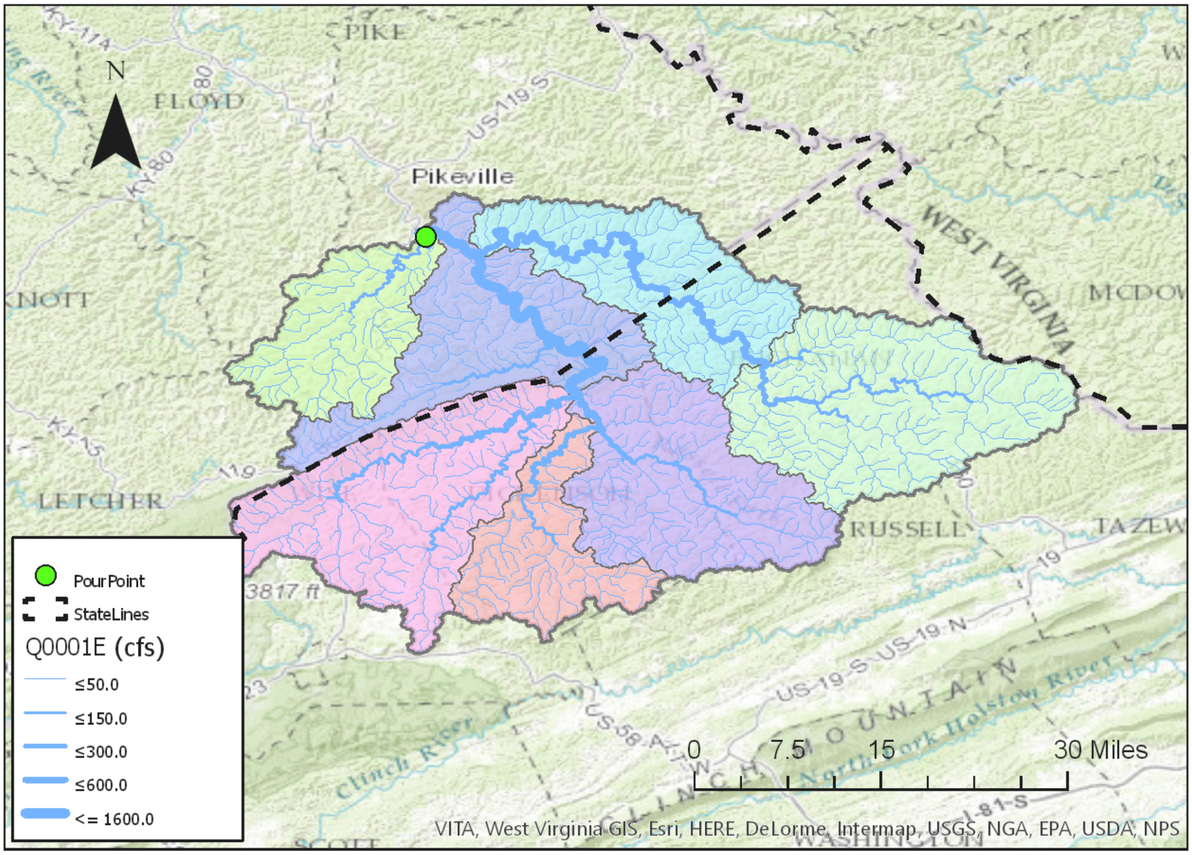


Figure 6. The delineated Upper Levisa sub-basin (HUC 8) with HUC 10 watersheds, NHDPlus V2 flowlines, and pour point.

Next, the feature classes containing active surface mine points and AML shapes within the Upper Levisa sub-basin are clipped and plotted in Figure 7.

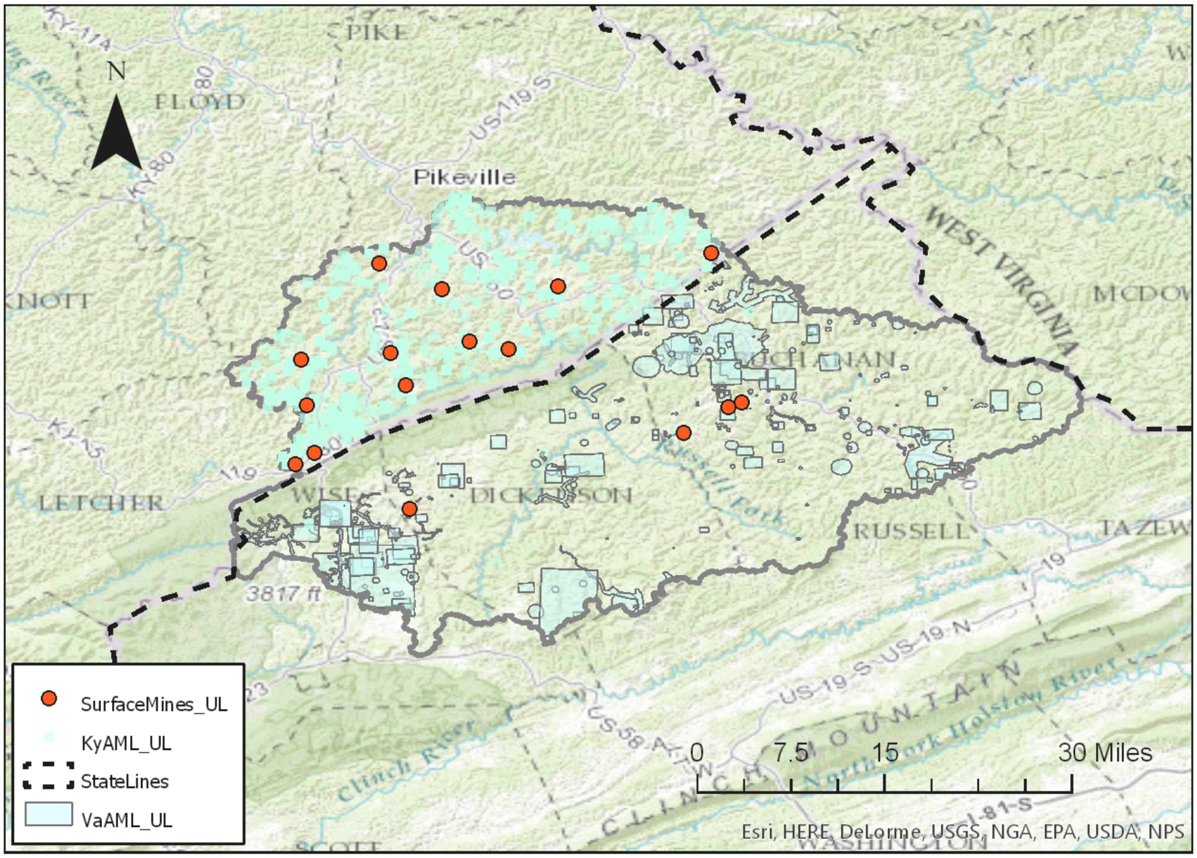
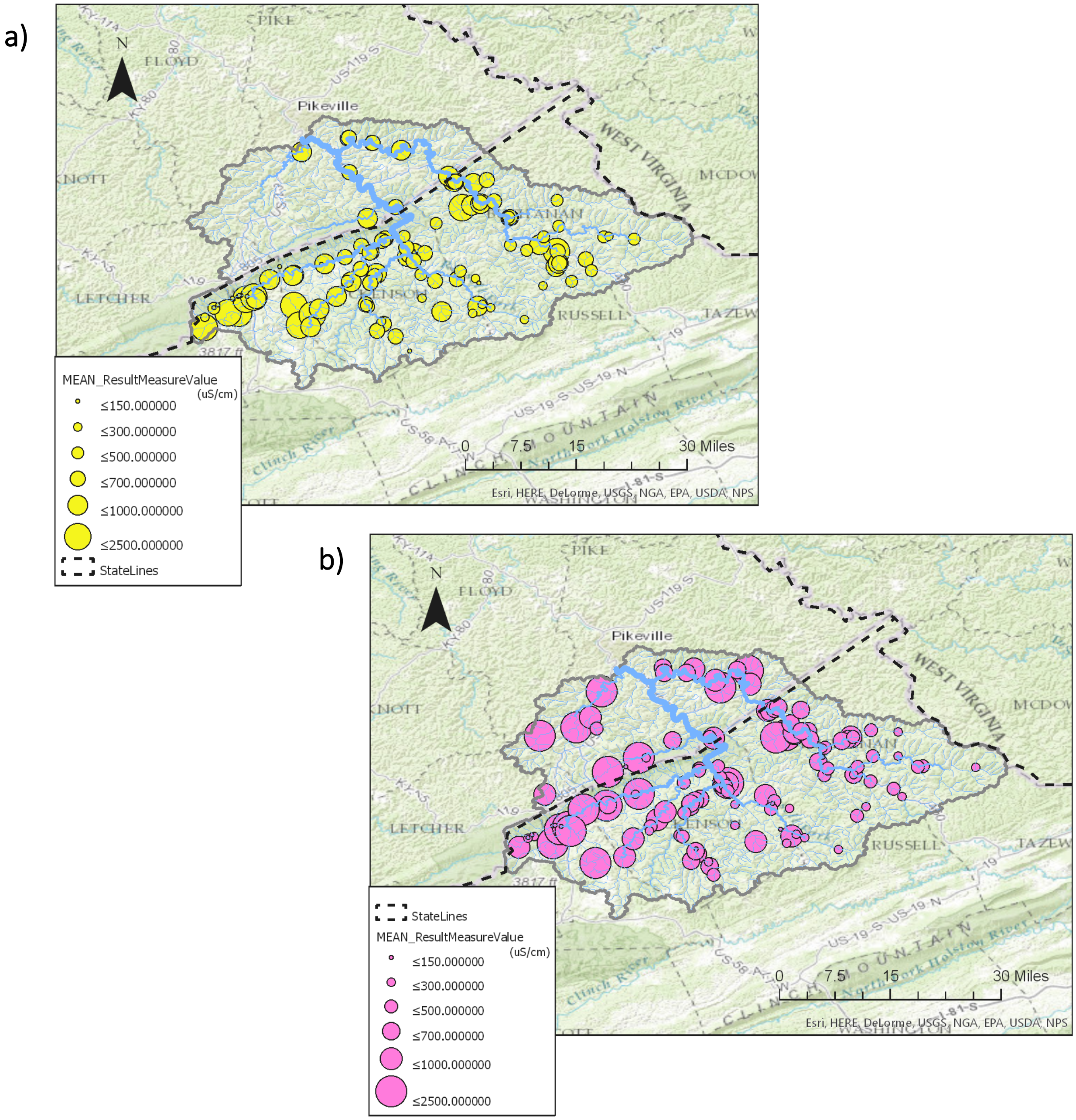


Figure 7. Active surface mines and abandoned mine lands in the Upper Levisa.

To plot water quality points, the gage information spreadsheet was converted to a table and locations were mapped using the latitude and longitude. These gage location points do not initially contain water quality data. The water quality results spreadsheet was also converted to a table and contains multiple values at each monitoring location over each time period. Since sampling was not consistent in duration or time of study, or at regular intervals across all locations, a summary statistics table averaging all values at each monitoring location over the entire time period was created. The summary statistics table was joined to the gage layer using the 'MonitoringLocationIdentifier' field. The results of this process for specific conductivity in 2000-2009 and 2010-2016, as well as TSS in 2000-2009 and 2010-2016 are shown in Figure 8 and 9, respectively.



Esri, HERE, DeLorme, USGS, NGA, EPA, USDA, NPS

Figure 8. Average specific conductivity values at each gage station from 2000-2009 in (a) and from 2010-2016 in (b).

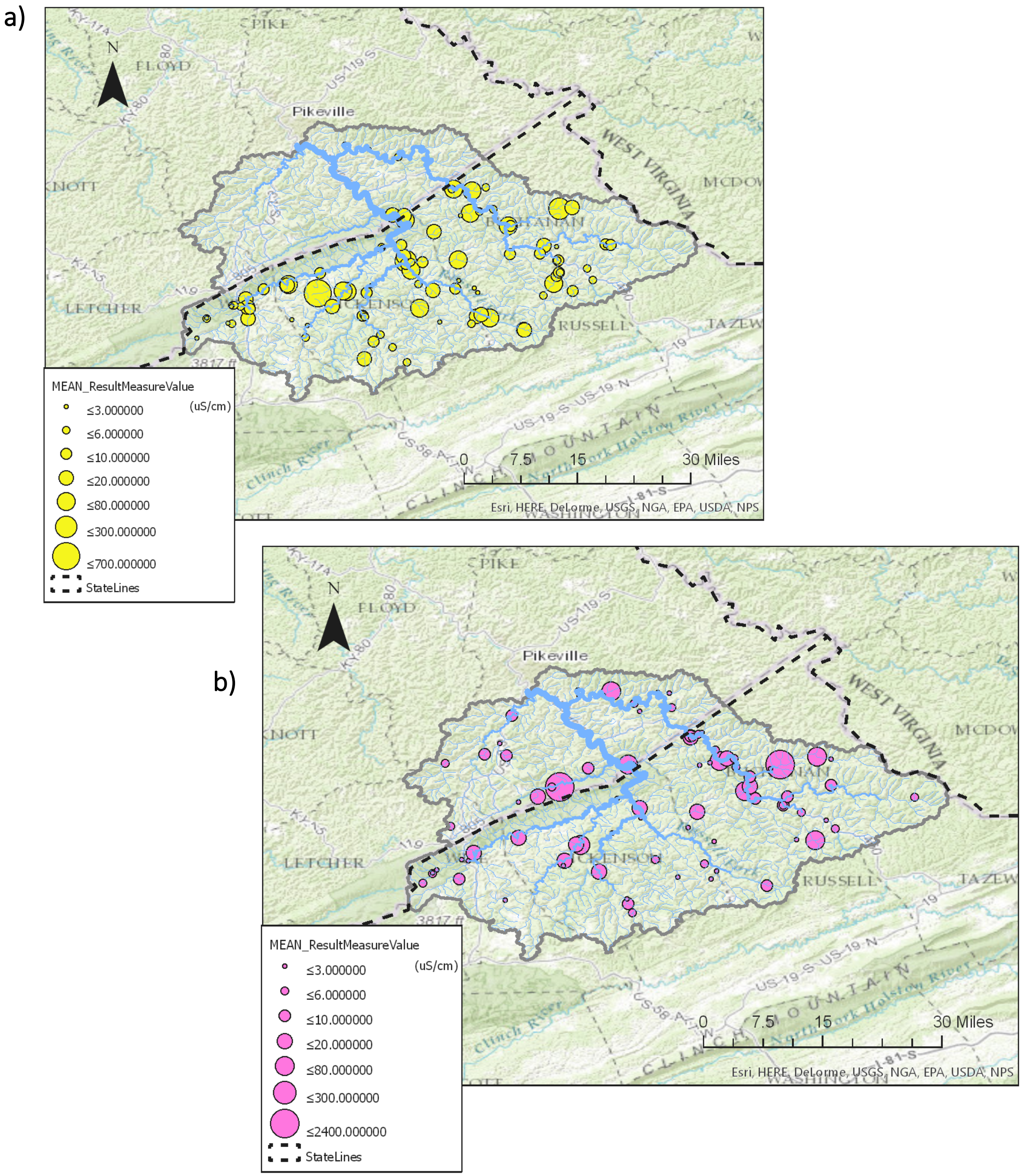


Figure 9. Average total suspended solids values at each gage station from 2000-2009 in (a) and from 2010-2016 in (b).

Finally, the values are analyzed with spatial interpolation. Several methods of spatial interpolation were tested. This project uses natural neighbor interpolation because this method gives and displays the most reasonable values. This technique is a reasonable selection given the relatively local distribution of gages. To see values across the entire basin, values from gages surrounding the basin were included in the analysis. All gage points were projected onto the North America Albers Equal Area Conic coordinate system for the interpolation. Natural neighbor interpolation for specific conductivity and TSS is discussed and shown in Sections 3.1 and 3.2, respectively. Using the natural neighbor rasters, the total length of impaired streams was determined by summing reach lengths within critical zones. Critical zones are areas where specific conductivity or TSS exceed maximum acceptable values previously defined in Section 1.2.

3.0 Results and Discussion

Natural neighbor spatial interpolation estimates values across an area and along stream lengths where sampled field measurements are unavailable, thus painting a better picture of water quality throughout the sub-basin. These values are classified by different color shading as described in each map legend. For specific conductivity, areas shaded in green are within a healthy range (≤ 300 μS/cm) according to the EPA guidance, areas shaded yellow are within a warning range (≤ 500 μS/cm) that is not yet considered impaired. Orange, red, dark and light pink shaded areas indicate values that exceed the maximum allowable value, and are impaired. For TSS, areas shaded in dark and light pinks exceed 80 mg/L, the chosen water quality standard to define impairment for this project.

3.1 Specific Conductivity Results

Figure 10a shows natural neighbor interpolation for specific conductivity values during 2000-2009 in relation to active and abandoned mines. The map indicates that in areas where levels exceed the maximum allowable, there is a greater concentration of AMLs as indicated by the blue polygons. In general, surrounding and downstream of active mine sites, the conductivity values are greater. AMLs continue to affect stream water quality because they are not immediately rehabilitated and may be left as barren lands. Stormwater runoff has decreased opportunities to infiltrate, and carries sediment and pollutants into nearby waters. AMLs are generally transformed into recreational use areas. Even following transformation, years may pass before vegetation takes root and matures.

For the time period from 2010-2016, a similar spatial relationship between active mines and interpolated conductivity values can be seen in Figure 10b, where there are higher values surrounding mine sites. An overall increase in conductivity across the sub-basin is evidenced by a change in colors between the two maps from majority yellow and orange (500 - 700 μS/cm) to red and pinks (≥ 700 μS/cm). Potential causes of this change include increased development or agriculture in the area.

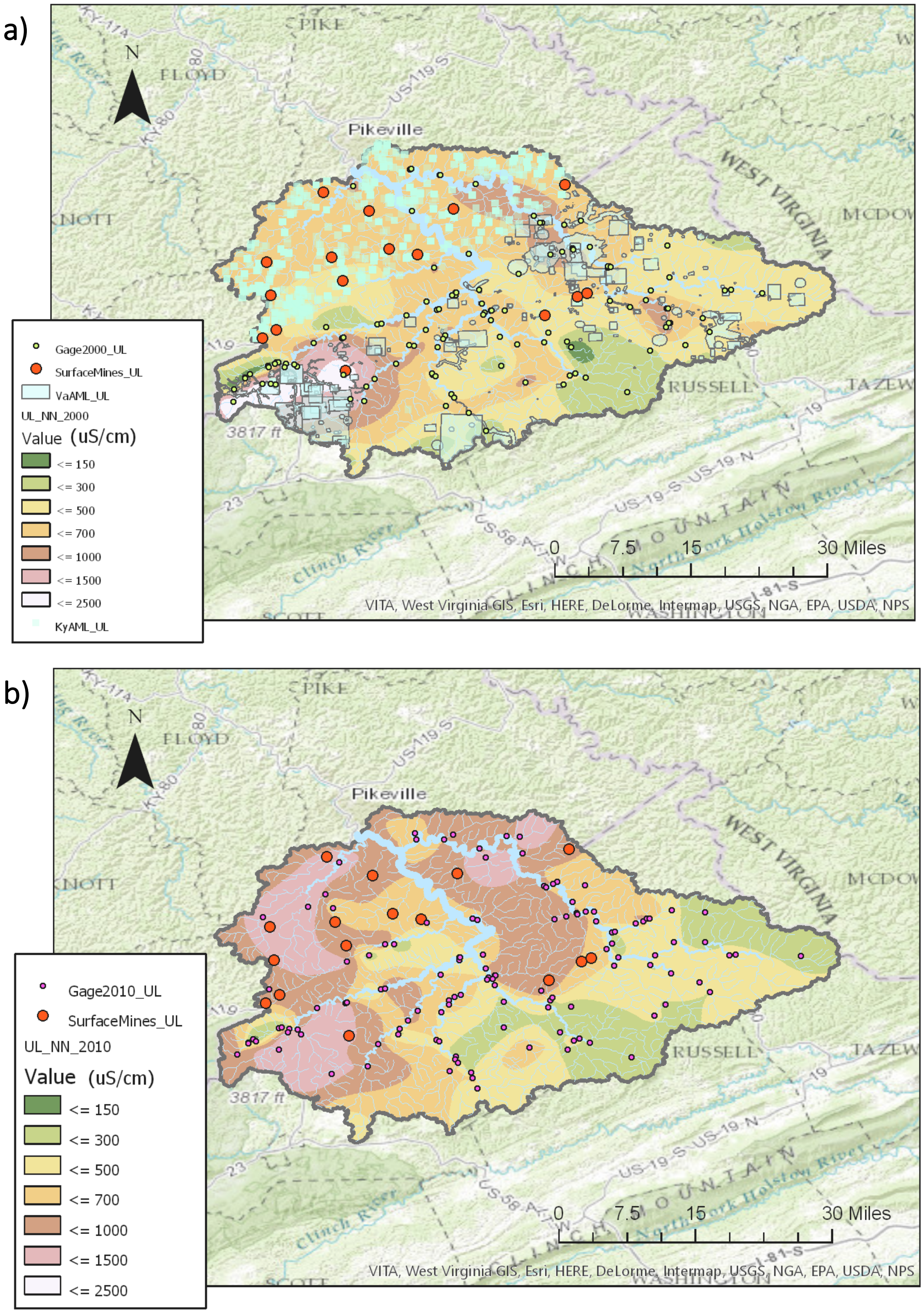


Figure 10. Natural Neighbor interpolation of averaged specific conductivity values from 2000-2009 shown with red active surface mine points, blue abandoned mine lands shapes, green relevant gage station points, and NHDPlus V2 flowlines shown in (a). Natural Neighbor interpolation of averaged specific conductivity values from 2010-2016 shown with red active surface mine points, magenta relevant gage station points, and NHDPlus V2 flowlines in (b).

Despite the EPA guidance, a rise in conductivity values is reasonable because the guidance is not an enforceable regulation, and doesn’t require mines to change their discharge or pollution control practices. Furthermore, stronger pollution control measures can take time to implement. Interpolated values are also affected by the number of data points as well as the method and time period over which field samples were collected. Generally, there are higher specific conductivity values as flow moves downstream in the sub-basin. This is due to increased mining, development, and agriculture affecting downstream reaches.

3.2 Total Suspended Solids (TSS) Results

There are higher values of TSS surrounding and downstream of abandoned mine lands in Figure 11a. This is expected since runoff carries sediment downstream from mine lands, and loose material from valley fill greatly increases sediment loading. In addition, runoff from impervious surfaces in developed areas add to sediment loads. Increased agricultural operations can increase TSS levels as well. Generally, TSS values increase as flow moves downstream.

For the time period from 2010-2016, there does not seem to be a relationship between mines and interpolated TSS values that can be determined visually in Figure 11b. Between 2000-2009 and 2010-2016, there is no overall increase in TSS levels across the entire sub-basin, however, previously existing critical zones increased in size.

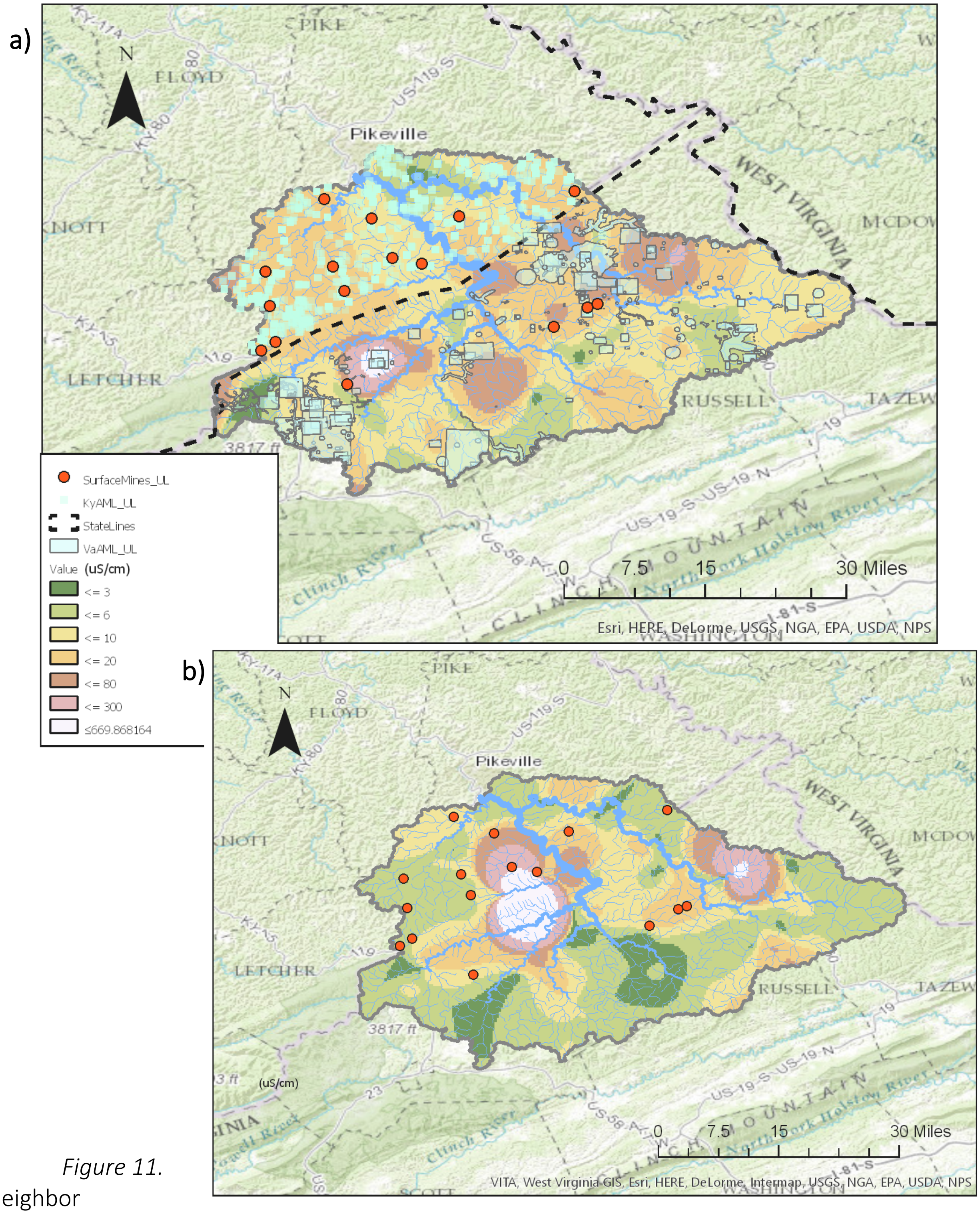


Figure 11. Neighbor interpolation of averaged total suspended solids values from 2000-2009 shown with red active surface mine points, blue abandoned mine lands shapes, and NHDPlus V2 flowlines in (a). Values from 2010-2016 shown with red active surface mine points, and NHDPlus V2 flowlines in (b).

3.3 Impaired Streams

From 2010 through 2016, results from spatial interpolation indicate 147.6 miles of streams are impaired by specific conductivity within this sub-basin, and 31.9 miles are impaired by TSS. The most recent Kentucky Watershed Quality Assessment Report identifies a total of 57.6 miles (58%), within the Upper Levisa as impaired by specific conductivity, and 45 miles (45%) as impaired by TSS (EPA, 2012). The percent differences between the impaired length provided by the EPA and the length obtained from spatial interpolation is shown in Table 1. When measuring impaired stream length, only stream reaches with flows greater than 50 cfs were considered due to a lack of data, and because the EPA watershed assessment does not evaluate the smaller tributaries.

A summary of impaired stream lengths determined through spatial interpolation and identified by the 2012 Kentucky Watershed Quality Assessment Report is displayed in Table 1. A visual depiction of the streams identified as impaired by the EPA and the spatially interpolated data is shown in Figure 12.

Table 1. Impaired Stream Lengths from Spatial Interpolation vs. Kentucky Watershed Quality Assessment Report (EPA, 2012)

	Measured Total Length of Streams Impaired (km)	**Measured Total Length of Streams Impaired (mi)**	**EPA Total Length of Impaired Streams (mi)**	**Percent Difference (%)**
Specific Conductivity	237.485	147.6	57.6	156
Total Suspended Solids	51.298	31.9	45	29

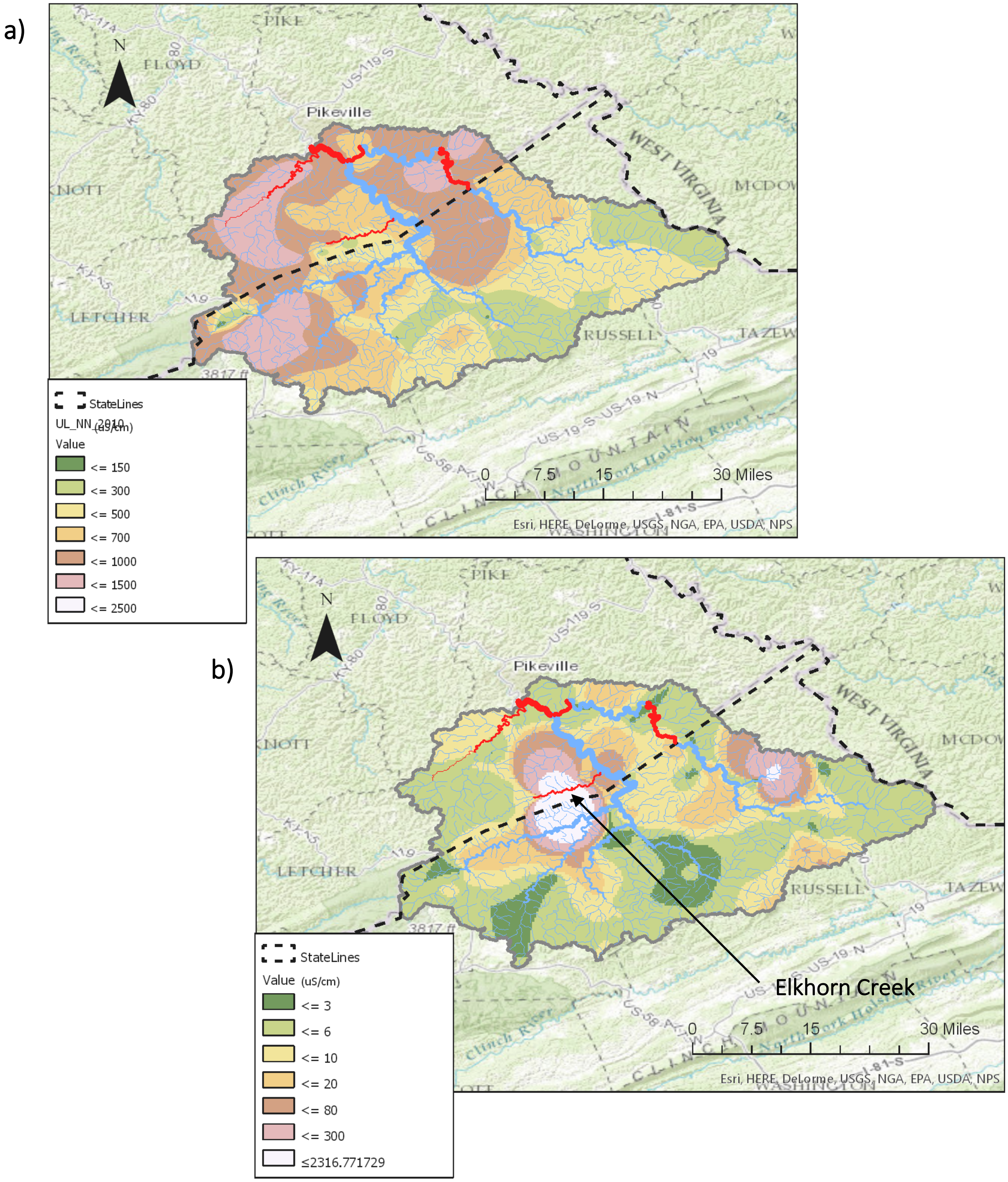


Figure 12. Impaired streams identified by EPA, colored red, overlay spatially interpolated values for specific conductivity from 2010-2016 in (a) and TSS from 2010-2016 in (b).

Although the total lengths of impaired streams differ, the streams established as impaired by the EPA agree with the spatial interpolation. EPA-identified impaired streams for both specific conductivity and TSS fall within the critical zones on the natural neighbor maps. In Figure 12a, the sections of Levisa Fork, Elkhorn Creek, Long Fork, and Shelby Creek impaired by specific conductivity according to the EPA are within critical zones and were also determined to be impaired based on the spatial interpolation data. In Figure 12b, Elkhorn Creek, which is also impaired by TSS according to the EPA, falls within the TSS critical zone and agrees with the impairment determined by spatial interpolation. The other streams are not impaired by TSS according to the report. In conclusion, spatial interpolation provides an overestimate of impaired streams, potentially due to data available, but agrees with those streams identified by the EPA. Only spatially interpolated data from 2010-2016 was evaluated for impaired streams because the Watershed Quality Assessment Report was from 2012.

3.4 Discussion

Differences in impaired lengths measured using GIS and lengths specified by the EPA can be attributed to variations in data sources and methods used to determine these lengths. The gage data used in this project is limited by what is provided by the USGS and EPA. This data can be inconsistent through the time period. For example, data collected at two separate stations may have been sampled at different intervals, or may have been measured over different periods of time. The number of data points from each station also varied. In addition, spatial interpolation only provides estimates in areas where field data is unavailable, but may not reflect true conditions. Based on distance to pollutant sources, land cover, and stream characteristics, actual values may deviate from interpolated values.

4.0 Conclusions and Future Work

From the spatial interpolation of data, it can be seen that specific conductivity and total suspended solids values increase as flow moves downstream as expected due to increased pollution sources. Specific conductivity is greater immediately downstream of active mines and areas with high concentration of abandoned mine lands. Specific conductivity values in these areas frequently exceed the recommended maximum value of 500 μS/cm. TSS values generally do not exceed the recommended maximum value of 80 mg/L. However, there is not enough data to determine if these high values can be attributed to surface mining. Likely, a number of different sources such as agriculture, development along water bodies, and various types of mining contribute to impairment in the region. Nevertheless, the high values adversely affect aquatic life and demonstrate the need for improved pollution control from probable pollution sources such as surface mines. Spatial interpolation seemed to overestimate lengths and number of impaired streams, but did include those identified by the EPA.

4.1 Future Work

Recommended future work includes analysis of additional water quality parameters such as benthic macroinvertebrate population, incorporating duration of activity for abandoned mines, and taking into account other sources of pollution. Additional data would aid in quantifying how much surface mining affects water quality as opposed to pollution sources. Aquatic life is a strong indicator of overall stream health, therefore more biological data in the Upper Levisa sub-basin is needed to conduct a spatial analysis. The lack of consistent data across the sub-basin in combination with high measured conductivity and TSS values shows a need for long-term stream monitoring.

4.2 Remediation

Since the Upper Levisa sub-basin crosses state lines between Kentucky, Virginia, and West Virginia, plans to remediate each state's respective stream reaches may differ. Each state has different requirements and procedures for TMDL development. The portion of the Upper Levisa in West Virginia is small, and West Virginia does not have a Watershed Quality Assessment Report for those tributaries. Virginia does not evaluate impairment for specific conductivity or total suspended solids in the Upper Levisa. Kentucky does identify streams impaired by conductivity or TSS, and require TMDLs for each. However, these TMDLs have not yet been developed. Generally, the results of this project agree with the assessment report that TMDLs are needed.

Improved erosion and sediment control (ESC) measures and maintenance at active mines can reduce the amount of pollutants entering nearby waterways. Although there are many rules regarding erosion and sediment control, measures are not always installed correctly or adequately maintained. Even with simple ESC measures such as the silt fence, proper maintenance, which includes replacing torn fencing, changing out fencing on a regular basis, and regular inspections may improve sediment control. Often, once silt fence is installed, it is not inspected or maintained, allowing dirty water to drain freely away from sites. Furthermore, stronger pollution discharge controls and source reduction best management practices (BMPs) for mines may be implemented to improve water quality. In addition to proper clean up, maintenance, and spill control, examples of BMPs for active mines include stormwater reuse, proprietary filtration devices, retention measures, swales, treating acid mine drainage, and sedimentation ponds (EPA, 2006). Some examples of BMPs for abandoned mine lands include industrial waste and wastewater treatment, vegetation, regrading, wet ponds, creating wetlands, and diverting streams (Colorado, 2002)

As mountaintop removal alters the landscape, further studies are needed to see the long-term hydrologic and environmental effects. The project demonstrates that spatial interpolation can visualize areas of need and impairment, as well as estimate values for reaches without sampling data. Results from further spatial analysis can help advise those involved with cleanup efforts, policy making, and identify drinking water risk for residents.

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