

Geochemical Analysis of Surface Materials Surrounding the Bautsch-Gray Mine Superfund Site near Galena, Illinois

**A senior thesis written by
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ABSTRACT

The Bautsch-Gray zinc and lead mine, near Galena, IL, was in operation from the early 1900s until closing in 1975. The mine's tailings pile has documented elevated lead and zinc concentrations in the surface materials surrounding the site. Numerous floods have caused contaminated sediment to migrate off the mine tailings pile, across Blackjack Road and into an outwash basin, and towards Smallpox Creek. Since this site was designated an EPA priority list Superfund site in 2010, the EPA has conducted numerous remediation efforts. This study attempts to develop a better understanding of the contamination within the soils of the outwash basin down-gradient of the mine as well as within the sediment bedload and vegetation of Smallpox Creek. Thirty-eight samples (mine tailings, soil, stream bedload sediment and algae) were collected, using a shovel or garden trowel, throughout this area and analyzed for lead and zinc contamination using X-ray fluorescence spectrometry. Samples from both the outwash basin and Smallpox Creek had concentrations of lead and zinc in excess of EPA limits for soils near a Superfund site. Excluding six samples from the mine tailings that served as a baseline for contamination levels in mine tailing sediments, 17 samples exceeded the lead contamination limit of 400 ppm for soils near a Superfund site and 19 samples exceeded the zinc contamination limit of 7500 ppm for soils near a Superfund site. The highest concentrations of lead and zinc were 4,539 ppm and 94,537 ppm respectively. Though there have been mitigation efforts to remove contamination from the outwash area, these results indicate that there is still more work to be done. High concentrations of lead and zinc in the outwash basin indicate that Smallpox Creek is susceptible to continued contamination from this site.

INTRODUCTION

The Upper-Mississippi-Valley Zinc-Lead district of Illinois, Wisconsin and Iowa was an active mining region from the early 1800s until 1979 (Mining History Association, 2011). The Bausch-Gray mine was one of the major mines in this region. Mining and milling of the Galena dolomite and the Platteville limestone (middle Ordovician) at this site produced an approximately 55 acres mine tailings pile at the site when the mine was closed in 1975 (Peters, 2011). Heavy metal (lead, zinc, arsenic, copper and cadmium) contamination is present to varying degrees in the tailings pile, in nearby residential properties, in a nearby marshland and in Smallpox Creek. In 2000 the IEPA (Illinois Environmental Protection Agency) began sampling the area. After a request for federal assistance, the national EPA took over the site and designated it an EPA Superfund site in 2010 (United States Environmental Protection Agency, 2010). Since this time, the site has gone through multiple rounds of testing and mitigation efforts. The aim of this study is to test surface materials at and around the site to see how effective mitigation efforts have been and whether more mitigation efforts are necessary. A second goal of this study is to determine whether Smallpox Creek is contaminated and how prone it is to contamination from site runoff.

This study focuses on testing for lead and zinc within surficial materials. Lead can cause damage to the central nervous system, kidneys and reproductive system. Lead contamination in well water can cause anemia. Exposure to lead is especially harmful to children and the unborn children of expecting mothers (Agency for Toxic Substances and Disease Registry, 2015). Low levels of zinc in a diet contribute to good health, but exposure to high levels is harmful. Exposure to high levels of zinc can cause anemia, stomach cramps and changes in cholesterol levels. Nearby residents are susceptible to contamination through

surface materials, airborne materials and through well water. Besides human health risks, heavy metal contamination affects the local environment. The majority of the mine tailings site is not vegetated. Deer and other animals have been seen on the mine tailings and can be adversely affected (Colomb, 2010). According to the Illinois Department of Natural Resources there are endangered, threatened and rare species within this area that could potentially be affected by site contamination.

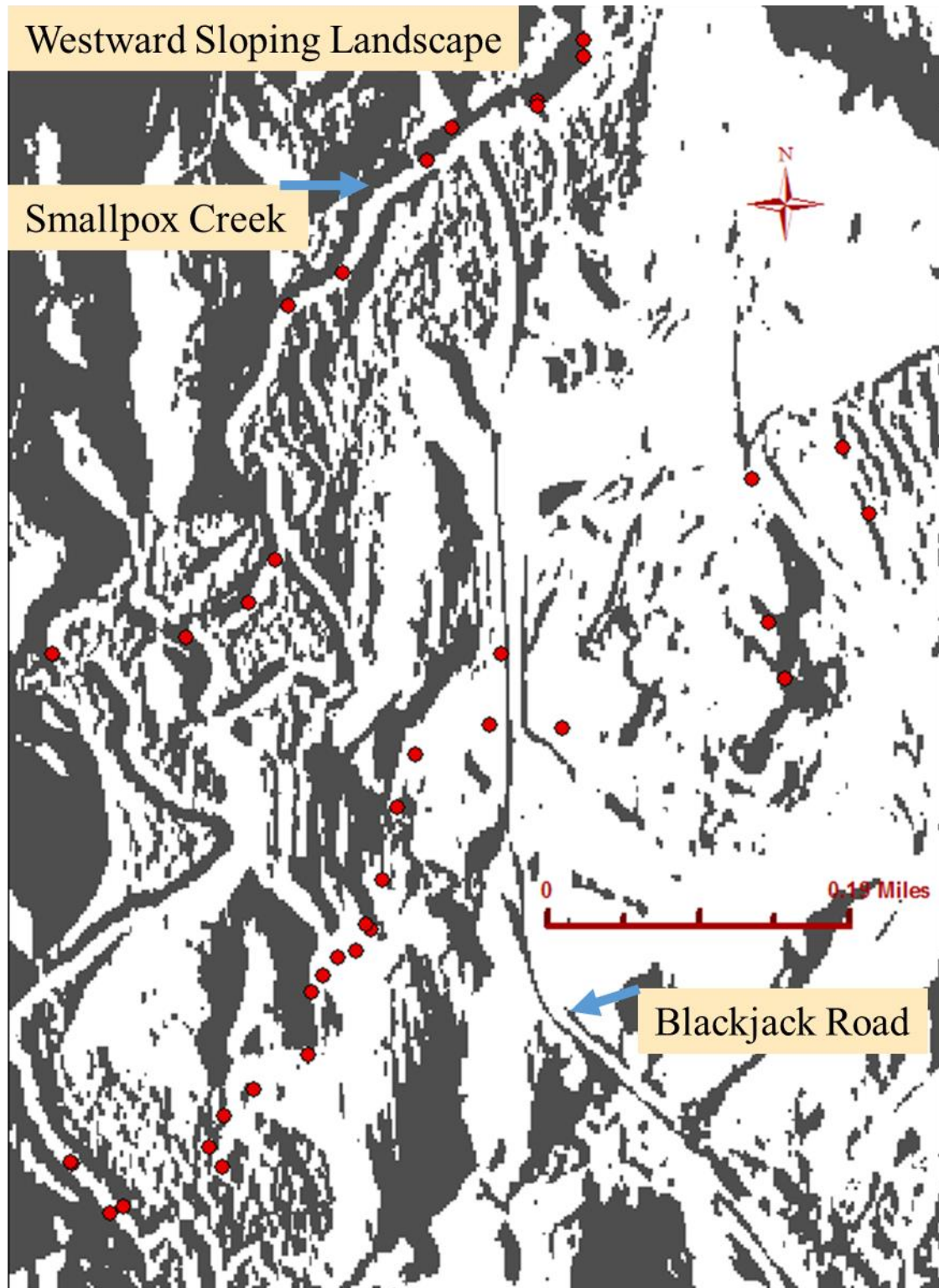
Site Location and Description

The Bautsh-Gray mine is located at 1000 South Blackjack Road in Jo Daviess County Illinois ($42^{\circ} 21' 26.72''$ N, $90^{\circ} 23' 54.85''$ W). This site is about 4 miles south of Galena, Illinois and within the driftless zone of northwestern Illinois (A region not subject to glaciation in recent geologic history) (Figure 1). The area is hilly and located in a rural agricultural and residential area. To the east of Blackjack Road is the 55 acre, approximately 50 foot high mine tailings pile. The pile is on a hillside which is sparsely vegetated and contains several retention ponds installed by the EPA. West of the retention ponds, a berm borders Blackjack Road. To the west of Blackjack Road is a residential property owned by the Hartness family. South of the Hartness property a marshland area borders Blackjack Road and extends westward towards Smallpox Creek. Smallpox Creek drains thirty square miles of land and feeds into the Mississippi River, which is approximately two miles west of the site. The general trend of the site is slopping east to west (Figure 2). The gradient on the mine tailings pile is greater than the gradient west of Blackjack Road.



Figure 1: Map showing general location of Bautsch-Gray Mine

Figure 2: This map shows all generally eastward sloping areas (0-180 degrees) in gray and all generally westward sloping areas (180-360 degrees) in white. This map shows that almost all sediment and overland flow from the mine tailings pile would be funneled through the outwash basin and towards Smallpox Creek.



Site History

Mining in the area surrounding Galena became significant in the early 1800s. In 1927 the Mineral Point Zinc company began mining in the current Bautsch-Gray mine site (Peters, 2011). In the 1940s another company bought out Mineral Point Zinc. From 1946 until 1969 Tri-State Zinc and a few other companies mined this site. In 1969 Eagle Picher bought the land and continued to mine the area until the mine was closed in 1975 (Peters, 2011). A subsequent settling lagoon was installed and a NPDES (National Pollutant Discharge Elimination System) permit was granted in 1975 and terminated by the IEPA in 1989 (Colomb, 2010).

In 1999 concern was raised regarding the site after it was discovered that a company was using mine tailings as fill for foundations of residential properties. In 2000 and 2001 a study by the IEPA found that there was heavy metal contamination within the mine tailings and that the tailings were migrating and contaminating neighboring residential properties, a marshland to the west and Smallpox Creek (Colomb, 2010). In 2009 a heavy rain event caused roughly 1-2 feet of mine tailings to migrate across Blackjack Road and into a marshland that flowed towards Smallpox Creek. This event and further testing prompted the IEPA to request federal assistance from the EPA (United States Environmental Protection Agency, 2010).

In 2010 the EPA designated the site a Superfund site and began mitigation efforts. The EPA removed roughly 2,600 yd² of contaminated soil and tailings that had migrated on a residential plot and resurfaced the area with new soil. This resident also had high levels of lead within his well water so a filtering device was installed (United States Environmental Protection Agency, 2012). To prevent tailing migration, multiple stormwater retention ponds

were installed on the mine tailings pile. A berm was created and vegetated to prevent further runoff from crossing Blackjack road. Finally efforts were taken to divert surrounding stormwater from entering the site and contributing to erosion of the mine tailings.

In 2012 the site was placed on the NPL (National Priorities List), which is a list of the nation's most hazardous waste sites. This allowed for additional funding which prompted another round of testing and mitigation efforts. Mitigation efforts included adding soil, biosolids and vegetation to the marshland that was contaminated with tailings from the heavy rain event in 2009 (United States Environmental Protection Agency, 2012). Sections of the mine tailings pile were graded and vegetated. Testing indicated that the primary mode of transportation of contaminants was through erosion and overland flow of mine tailings, and an air-monitoring experiment suggested that minimal materials were being transported through the air (Colomb, 2010).

A senior research project completed by Carl Peters in 2011 at Augustana College (Rock Island, Il.). Carl Peters took a number of soil depth samples through contaminated zones. His results show decreasing contamination with depth, which suggests that cations dissolving into solution are not readily being transported through the soil profile (Peters, 2011). In the spring and summer of 2014 another round of sampling was conducted by the EPA to see what efforts needed to be taken in the future at this site (United States Environmental Protection Agency, 2014).

Methodology

Collection

In order to achieve a better understanding of the contamination occurring at and around the Bautsch-Gray mine, thirty-eight surface material samples were taken from the mine tailings pile, from the marshland (outwash basin) to the west of the mine tailings and from the sediment bedload of Smallpox Creek. Six surface samples (0-6 inches) were taken from the mine tailings pile. These samples are useful as an indicator level of heavy metal concentrations from the contamination source (mine tailings pile) to compare to samples that were taken from the contamination source. These samples consisted exclusively of gravel-sized mine tailings material. Each sample was collected using a garden trowel and stored in a gallon-sized Ziploc bag. The location of the sample was marked with a GPS unit. Relevant information such as a physical description of the sediment, a physical description of the samples location and other relevant information were recorded in field notes. Between each sample, the garden trowel was cleaned and sterilized with de-ionized water to prevent cross contamination between samples.

Seventeen surface samples were taken from the outwash basin/marshland that drains off the mine tailings pile west of Blackjack road. This site was cleaned by the EPA in its second round of remediation in 2012. Samples were collected with the garden trowel or a shovel (dependent upon which was the most appropriate tool for the surface material being collected). These samples included gravel-sized sediments, soil sediments, clay sediments and one algae sample taken from an area of standing water. This algae sample was taken in order to gain insight into whether contamination was being incorporated into the tissue of

organisms in the area. Though many types of surface materials were collected, there was bias towards gravel-sized sediments that appeared to be mine tailings. As with the mine tailings samples, the locations were marked with GPS, field notes were recorded and the hand trowel/shovel was cleaned between each sample collection.

Sixteen samples were collected from Smallpox Creek, upstream of the confluence with the outwash basin. Thirteen of these samples were sediment bedload from Smallpox Creek, and three of these samples were algae from Smallpox Creek. These samples were collected with a shovel and had locations ranging throughout the width of the creek. As with the previous collection locations, sample locations were marked with GPS, field notes were recorded and the shovel was cleaned between each sampling. The sediments ranged from gravel-sized to fine grained clays.

Drying and Crushing

All of the samples were poured into beakers and allowed to dry in an oven at 120° C for at least twenty-four hours. No organic matter was removed from any of the samples because the data results from this procedure best represents the contamination levels that organisms would be subject to at the study site. After the samples were dried, they were placed in small Tupperware containers for storage until further analysis. Samples that were too large for analysis (primarily gravel-sized sediments) were crushed using the crusher in the XRF lab. The crusher was cleaned with water and isopropyl alcohol between each crushing event to prevent cross contamination between samples.

Pellet Preparation and XRF Analysis

The samples were then prepared into pellets for mineralogical analysis with a Rigaku Supermini X-Ray Fluorescence Spectrometer. For each sample, between 11 and 12 grams of sample were mixed with methanol (CH_3OH) in a ceramic container to create a slurry. The slurry was then then mixed in an electric shaker with a ceramic ball for five minutes to create a homogeneous mixture. Samples were then moved to a tin container and allowed to dry in an oven at 55°C for at least 24 hours.

From the dried slurry, 8.5 grams were then mixed with 1.5 grams of SPEX Sample Prep 3646 Paraffin Binder (particle size ≤ 30 microns) using a mortar and pedestal. Once a homogenous sample was created, the samples were then placed into a small tin within a casket apparatus. The sample was then crushed at two tons for two minutes and then at sixteen tons for two minutes. A homogenous pellet was produced through this process. Throughout the pellet creation process, care was taken to clean mixing utensils between each use with isopropyl alcohol to prevent cross contamination between samples. Each pellet sample was then run through the XRF to determine the ten most common rock forming minerals along with levels of trace elements in parts-per-million (ppm). Lead and zinc are included within the list of trace elements that the pellets were analyzed for.

Results and Discussion

Overall a total of 38 samples were analyzed (Data Tables). Without excluding the six samples from the mine tailings, thirteen samples had levels over the TCR (time critical removal) level for lead (1,200 ppm), while 23 samples had levels over the COL (cleanup objective level for soils near a Superfund site) (400 ppm) (figure 3). Six samples had levels

over the TCR for zinc (23,000 ppm), while 24 samples had levels over the COL for soils near a Superfund site (7500 ppm) (figure 4).

Sample Name	Pb (In PPM)	Zn (In PPM)
Mt-1	1010	20088
Mt-2	1609	17946
Mt-3	446	11445
Mt-4	1282	3502
Mt-5	1366	13778
Mt-6	1943	14356
Average	1276	13519
Maximum	1943	20088
Minimum	446	3502
EPA TCR	1200	23000
EPA COL	400	7500
EPA EMT	107	5100
EPA Background		
101	35.2	135
EPA		
Background102	44.5	255

Data Tables

EPA TCR= triggers a "time critical removal" by EPA

EPA COL= EPA Cleanup Objective Level for soils near Superfund site

EPA EMT= EPA regulatory limits for soils not near Superfund sites

EPA Background= An EPA background samples for the region

Sample Name	Pb (In PPM)	Zn (In PPM)
Ha-1	199	2939
Ha-2	4539	25821
Ha-3	194	1576
Ha-4	2401	6622
Ha-5 ALG	609	25437
Ha-6	4219	25677
Ha-7	1974	10125
Ha-8	815	10836
Ha-9	1727	12030
Ha-10	929	14134
Ha-11	915	14033
Ha-12	1427	16612
Ha-13	3167	20916
Ha-14	2034	6516
Ha-15	810	9293
Ha-16	166	11283
Ha-17	932	8987
Average	1592	13108
Maximum	4539	25821
Minimum	166	1576
EPA TCR	1200	23000
EPA COL	400	7500
EPA EMT	107	5100
EPA Background 101	35.2	135
EPA Background102	44.5	255

Sample Name	Pb (In PPM)	Zn (In PPM)
Rs-1	207	31565
Rs-2 ALG	135	6209
Rs-3	65	298
Rs-4	205	63118
Rs-5	173	8216
Rs-6	142	2131
Rs-7	460	4864
Rs-8 ALG	305	7038
Rs-10	122	1413
Rs-11	858	94537
Rs-12	134	1886
Rs-13	130	12164
Rs-14	210	3697
Rs-15	172	3314
Rs-16 ALG	1368	20554
Average	312	17400
Maximum	1368	94537
Minimum	65	298
EPA TCR	1200	23000
EPA COL	400	7500
EPA EMT	107	5100
EPA Background 101	35.2	135
EPA Background102	44.5	255

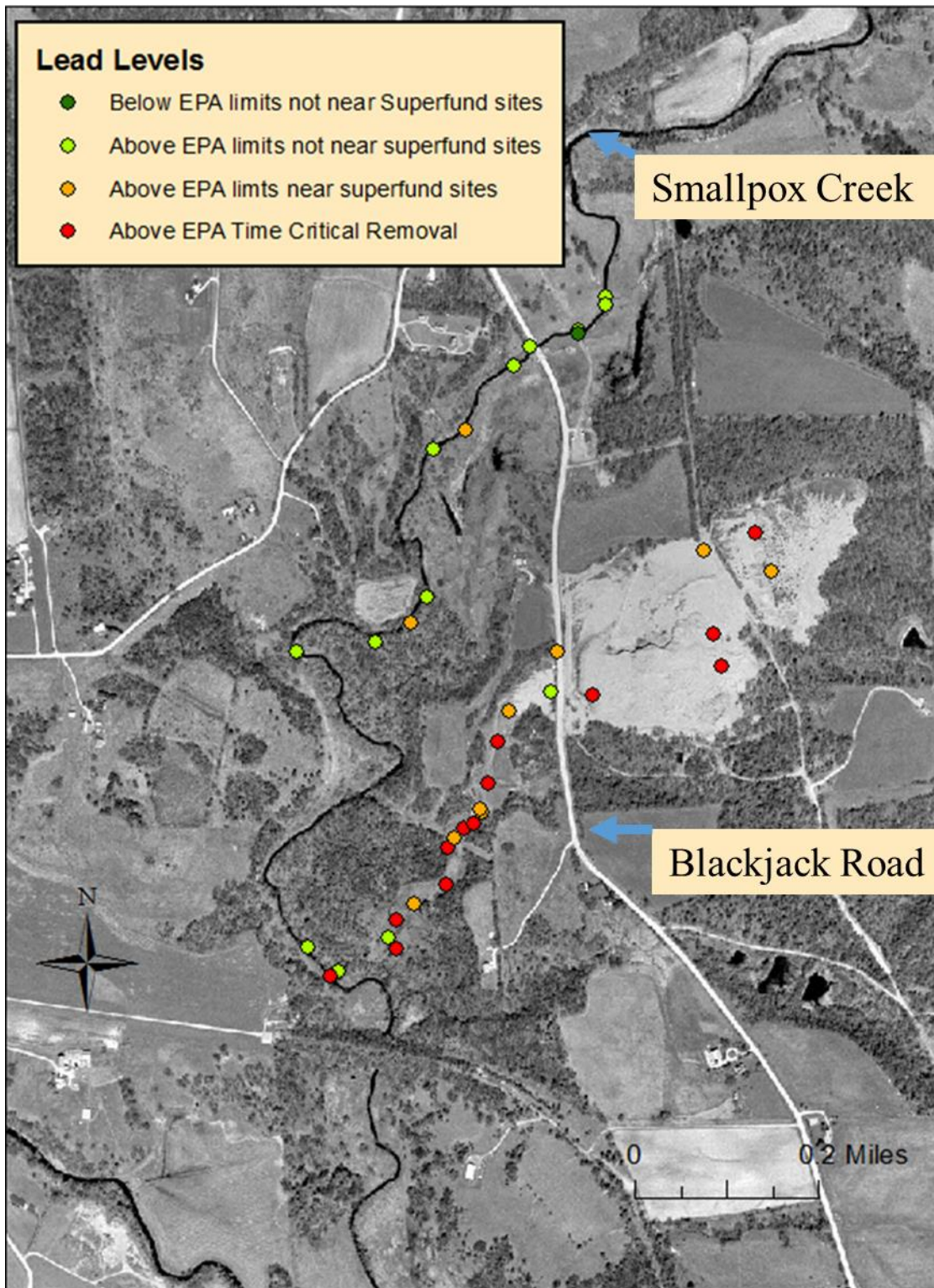


Figure 3: A map showing relative lead contamination levels based on the EPA's classification system. Time critical removal, limits near Superfund sites and limits not near Superfund sites are 1200 ppm, 400 ppm and 107 ppm, respectively

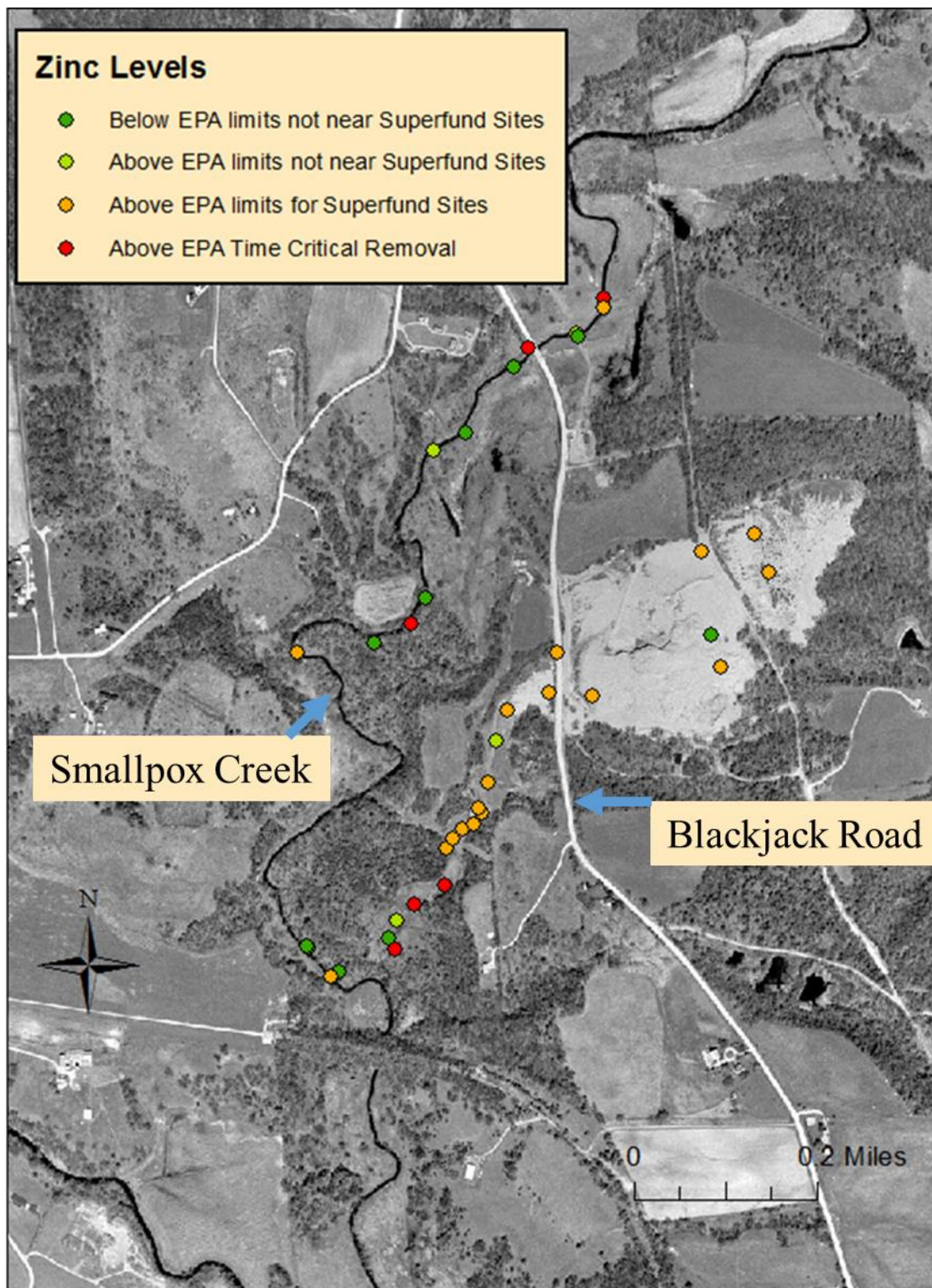


Figure 4: A map showing relative zinc contamination levels based on the EPA's classification system. Time critical removal, limits near Superfund sites and limits not near Superfund sites are 23000 ppm, 7500 ppm, and 5100 ppm, respectively

Mine Tailings

Six mine tailing samples were analyzed (Figure 5). Four of the samples were above the TCR level for lead and all six were above the COL for soils near a Superfund site. None of the samples were above the TCR level for zinc and 5 (all but one) were above the cleanup objective for soils near a Superfund site. It is not surprising that none of the samples were above the TCR for zinc because 23,000 ppm is a relatively high value as compared to many of the other thresholds. This is simply due to the fact that the EPA does not consider zinc to be an immediate concern unless it is at very high levels.

Sample MT-3 only has a lead value of 446 ppm. Though this does put it just above the COL, it is still a fairly low concentration compared to the other mine tailings samples. This low value is likely due to the fact that this sample was collected from the sidewall of a rill on the mine tailing pile. The sample seemed to have a higher soil content than other MT samples that were collected directly off the surface of the tailings pile. Though the lead level for this sample was low, it still had a higher zinc level of 11445 ppm. This could possibly be due to lead going into solution as water passed through this rill. There is a pattern of lower levels of lead associated with fluvial sampling locations (though the Zn levels aren't necessarily low in these locations) that I will discuss in further detail later in this paper.

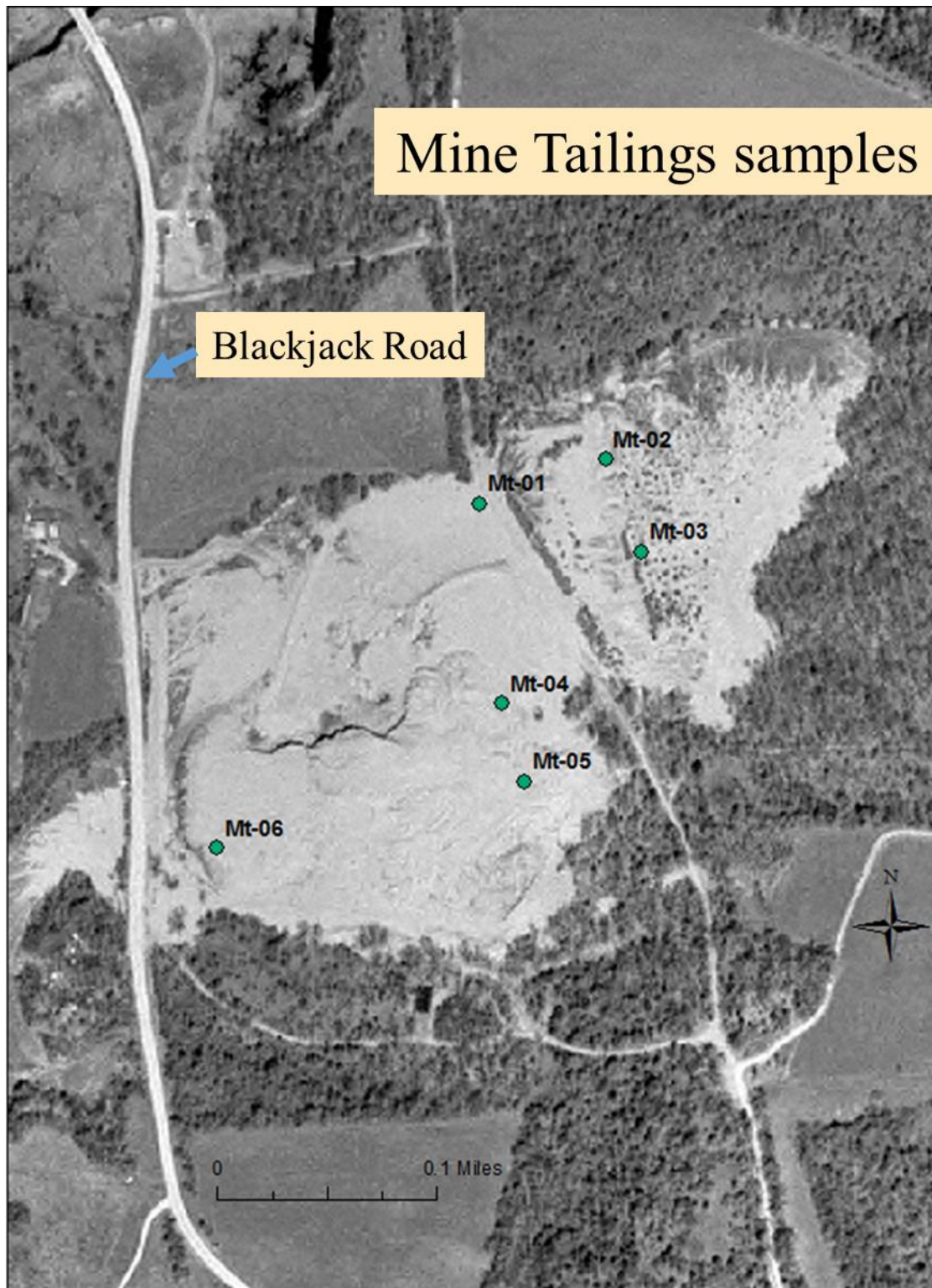


Figure 5: A Map showing the location of samples taken from the mine tailings pile

Outwash Basin

There were 17 samples collected from the outwash basin. Eight of the samples were above the TCR for lead and 14 were above the COL for soils near a Superfund site. Three of the samples were above the TCR for zinc and 13 were above the cleanup objective level for soils near a Superfund site. These samples were not collected randomly. There was a bias towards a cluster of samples (samples 7-14) near the middle stretch of the outwash (Figure 6). This was because there was an approximately twenty foot steep slope of mine tailings at this location. This seemed like a very probable area for contamination, so it was important to get multiple samples from this area. Furthermore, there was a visible wetland just downslope from the mine tailings with cattails, sedges and other wetland plants. These two features made this area a highly desirable sampling area.

Though this area certainly had high values of contamination, most of the other areas within the outwash basin also had high values. Therefore this central area does not skew or misrepresent the type of contamination that is occurring throughout the outwash basin. For example, sample Ha-02 has very high levels of lead and zinc despite the fact that it is approximately 900 feet downgradient from the central area. This sample had 25821 ppm of zinc and 4539 ppm of lead, which is the highest concentration of lead for all of the samples taken throughout the whole entire study. The fact that there are such high concentrations of heavy metals near the end of the outwash basin suggests that Smallpox Creek has the potential to be prone to runoff contamination from the mine site.

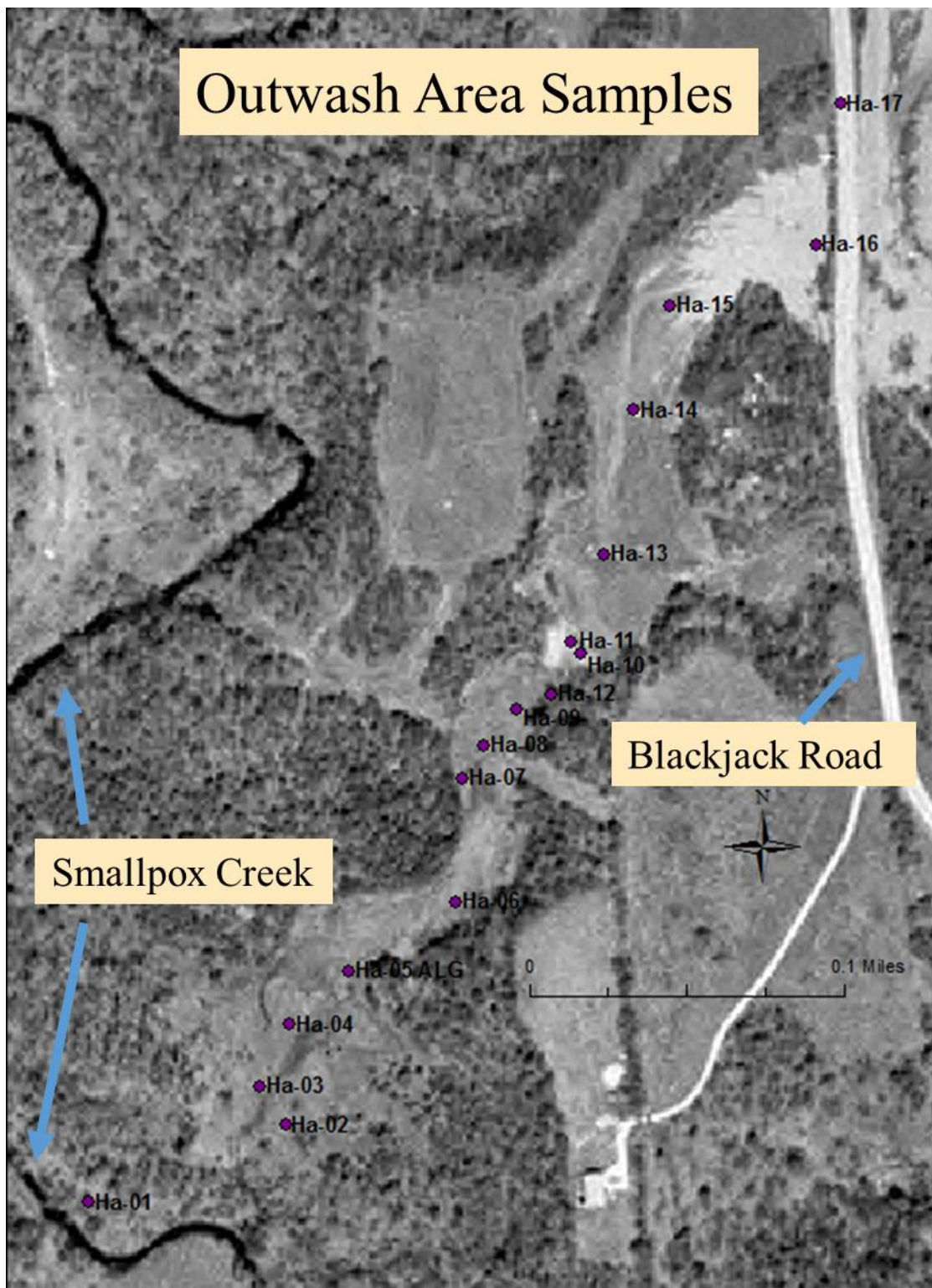


Figure 6: A map showing the locations of samples taken from Marshland / Outwash Basin

Despite sample Ha-02 having such high concentrations of heavy metals, sample Ha-3 had surprisingly low levels of heavy metals for being in such close proximity to sample Ha-02. Sample Ha-03 was actually a sample taken from a removed clay core near a marked flag (Figure 7). This clay was likely a depth sample that the EPA had removed from the beneath the surface during recent testing. The fact that this sample was so low in heavy metals yet sample Ha-2 was so elevated suggests that contamination is primarily occurring at the surface and is not penetrating far beneath the surface through dissolving into solution or through other processes. Figure 6 shows that there is a small forested gap between the unforested outwash basin and Smallpox Creek. Sample Ha-1 is within this forested zone and located very close to Smallpox Creek. This sample had low levels of contamination. This is not particularly surprising due to the low gradient between Ha-2 and Ha-1 and the fact that the forest area could potentially have a buffering effect towards contamination transport.



Figure 7: Sample location of Ha-3

Sample Ha-5 was an algae sample taken from standing water in the outwash basin. Ha-5 has levels of lead above COL and levels of zinc above the time TCR level for zinc. This suggest that heavy metals are being incorporated into biota in areas where the soil has high levels of contamination.

River Sediment

There were 15 samples collected from the outwash basin (Figure 8). There were originally 16 river sediment samples, but one had to be discarded because a GPS location was not collected for that location. One sample was above the TCR level for lead and 3 samples were above the COL. Three samples had levels above the TCR level for zinc and 6 samples had levels above COL for soils near a Superfund site. Overall the levels of lead and zinc within these soils were low (Figures 9 and 10). This is not surprising because all these samples are upstream of the confluence of the outwash basin with Smallpox Creek. Though there are certainly other potential sources of heavy metal pollution to Smallpox Creek, the outwash basin is the most likely and obvious source. Sample RS-16 is from the sediment bedload of Smallpox Creek and lies directly at the confluence of Smallpox Creek and the outwash basin. This sample has the highest level of lead for all of the river sediment samples as well as an elevated zinc level. Though this sample alone cannot verify that contamination from the outwash basin is entering Smallpox Creek, it certainly supports this hypothesis. More samples downstream of the confluence of the outwash area with Smallpox would need to be taken to make a more definitive claim on whether the outwash area was contaminating Smallpox Creek.

River Sediment Samples

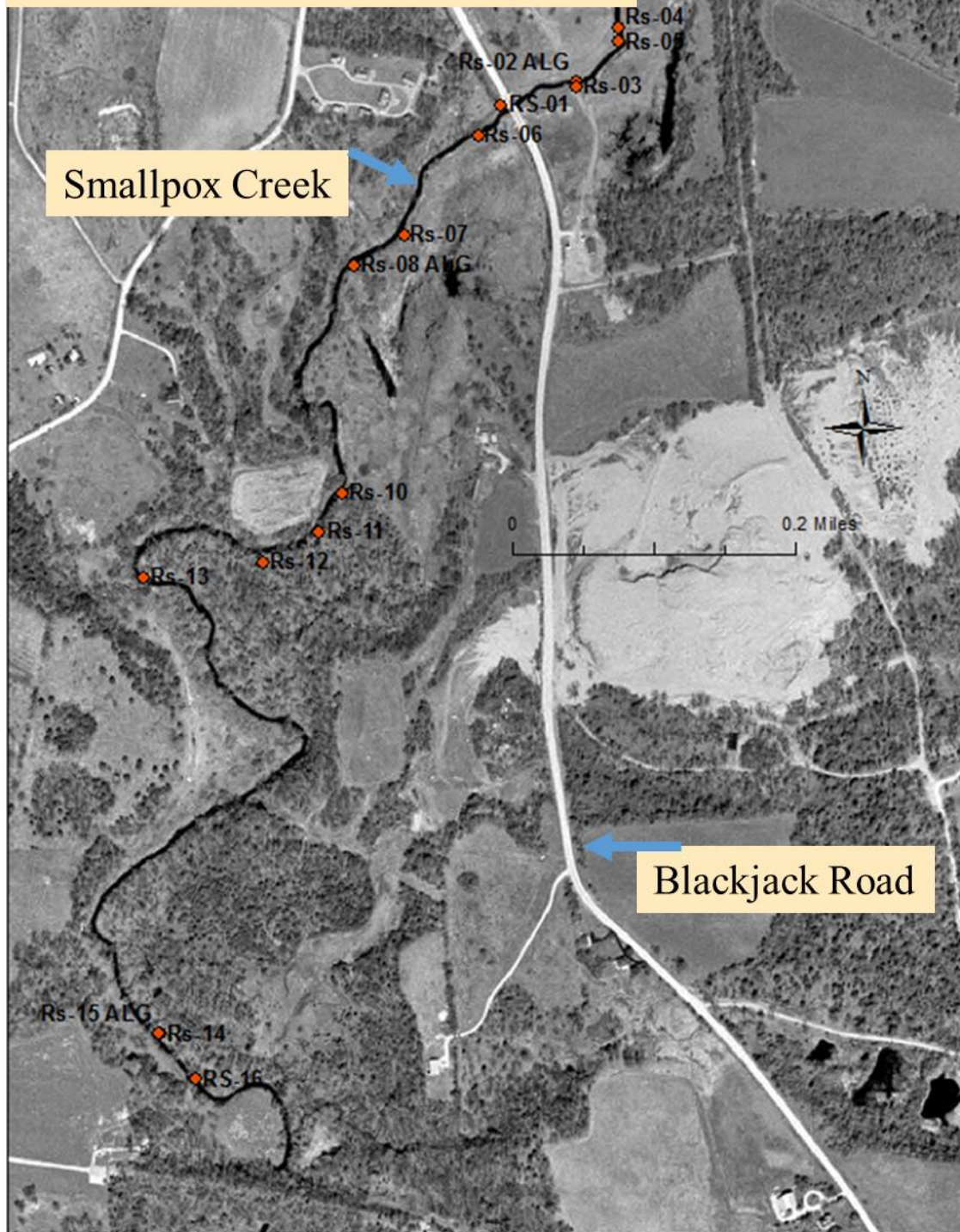


Figure 8: A map showing the locations of samples taken from the River Sediment bedload of Smallpox Creek

Relative Lead Levels

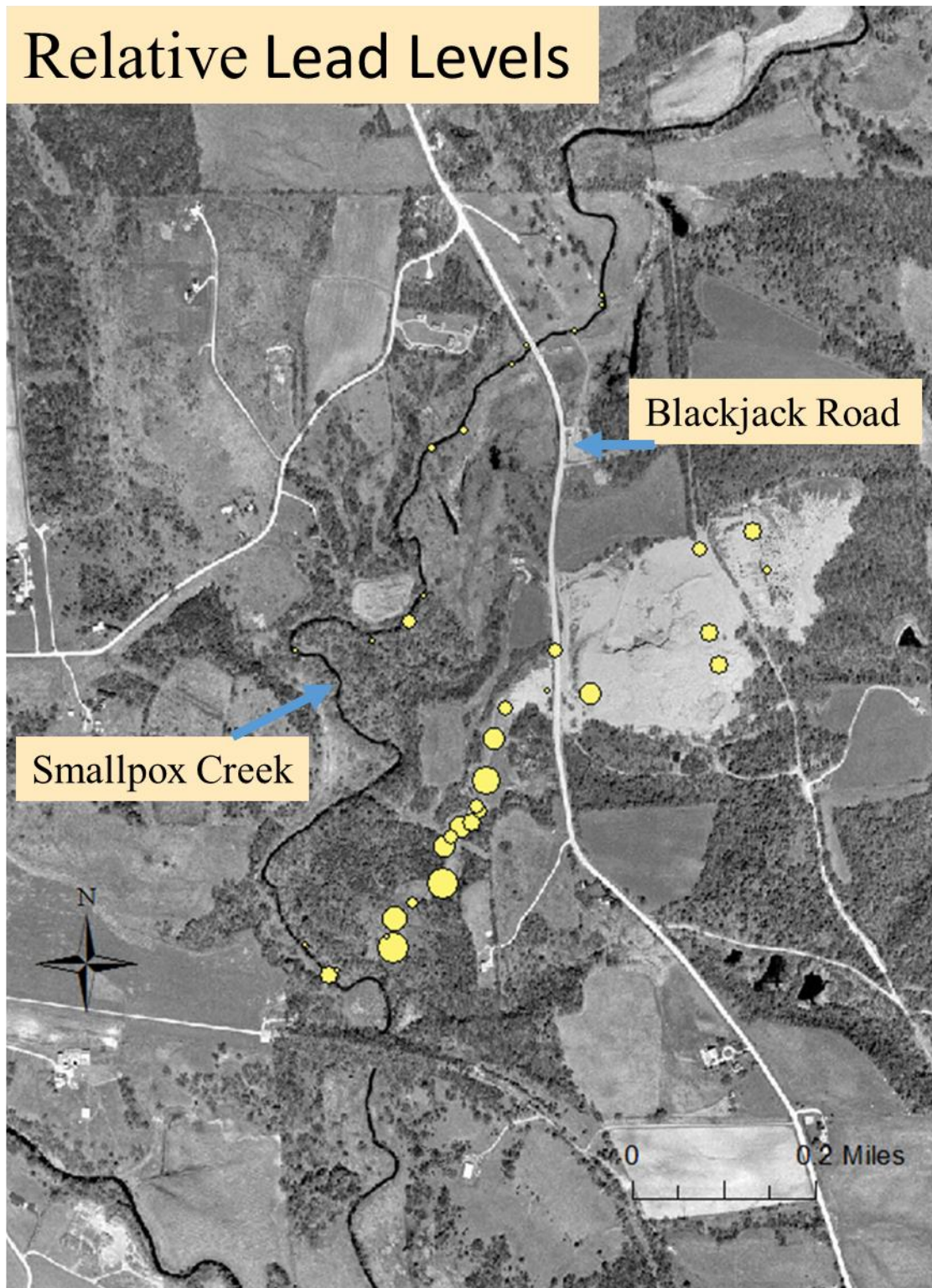


Figure 9: A proportional symbol map showing lead levels based on the circle's volume

Relative Zinc Levels

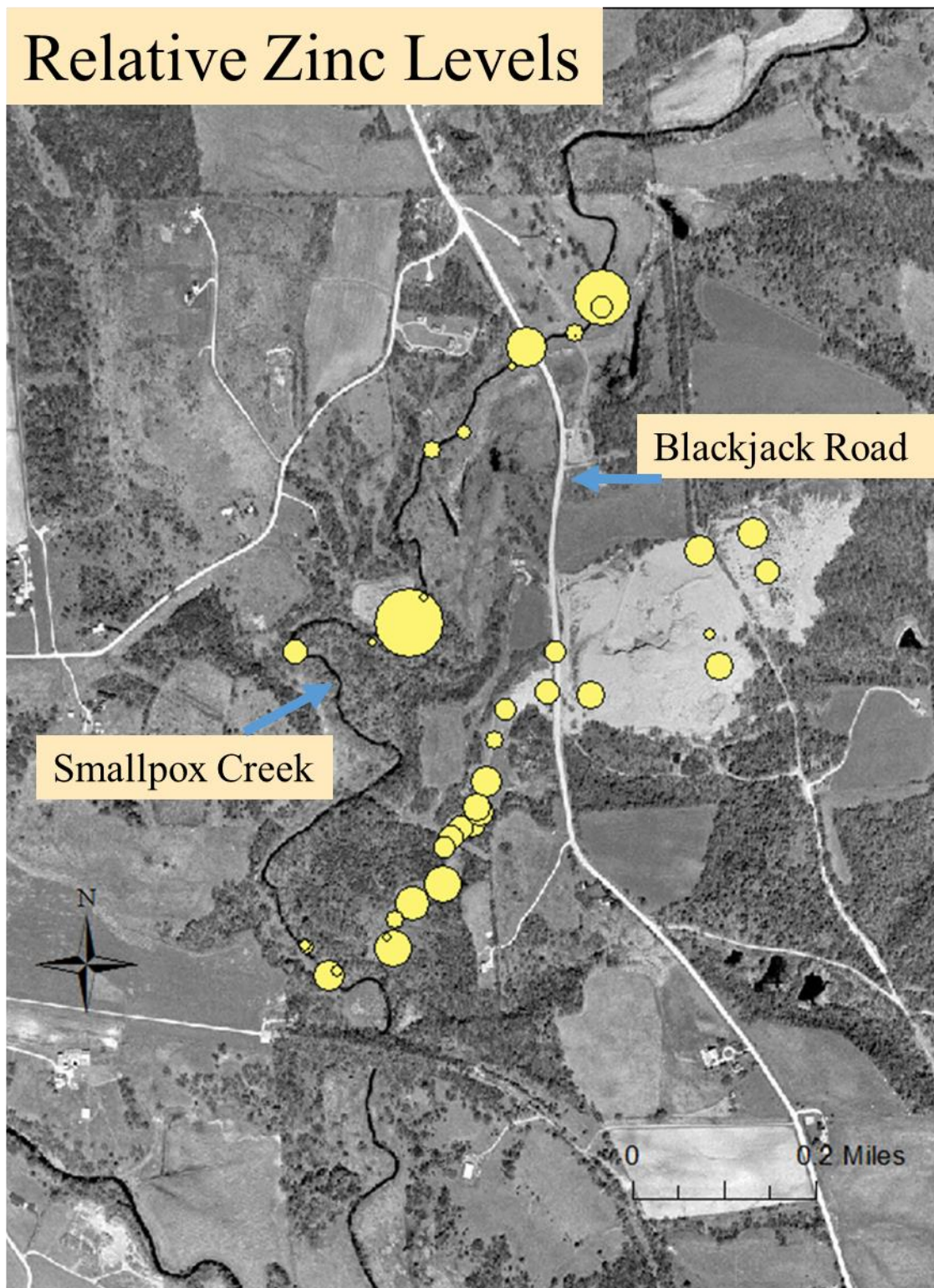


Figure 10: A proportional symbol map showing zinc levels based on the circle's volume

Despite the fact the many of the river sediment samples had low values of heavy metal contamination compared to the outwash basin and mine tailings pile, there were a few samples (Rs-1, Rs-4 and Rs-11) that had exceptionally high levels of zinc. Such high levels of zinc suggest that a chunk of pure sphalerite was within the collected sample sediment. This raises the question of what source could cause such high levels of zinc. One hypothesis is that the source is the Bautsch-Gray mine tailings. This hypothesis unlikely due to the fact that none of the samples taken from the mine tailings pile had levels of zinc as high as these three samples found in Smallpox Creek. It seems unlikely that the destination of a contaminant would have a higher level of contamination than the source since generally, contaminants tend to be diluted with distance. Another possibility is that the high levels of zinc are from other mining activities. The high zinc levels could be coming from the Blackjack mine tailings pile, which is a much smaller tailings pile located just north of Smallpox Creek. The high zinc levels could also be from mine tailings dumped into the creek sometime in the past (remember this region has hundreds of years of mining history).

A third, and most likely, hypothesis is that Smallpox Creek is cutting into and eroding bedrock from either the Platteville limestone or Galena dolomite. These are the same source rocks layers that were mined at Bautsch-Gray, the source of the mine tailings. These layers certainly have an abundance of sphalerite which could account for such high levels of zinc. Furthermore from looking at my field notes samples Rs-1, Rs-4 and Rs-11 all are described as gravel-sized sediment. These could very likely be sediment from the limestone and dolomite layers which are a source for sphalerite. Many of the river sediment samples that were described as clays had much lower heavy metal contamination. The slope map (Figure

11) is a GIS map that shows relatively flat areas in green while progressively steeper gradients shade from yellow into reds. This map shows a number of steep gradients located on or just upslope of the stream bank that could be sources of bedrock due to erosion or stream bank cutting. Once this rock is mass wasted into Smallpox Creek, fluvial and geomorphic dynamics likely cause gravel-sized sediments to congregate in certain particular areas while clays are segregated into other, likely slower flow, areas. This was observed in Smallpox Creek. For example, sample Rs-1, with 31,565 ppm of zinc was collected from a thick gravel-bar that rose above the surface of Smallpox Creek. Figures 12 and 13 are other types of GIS surficial maps which can provide insight into erosion and stream bank cutting.

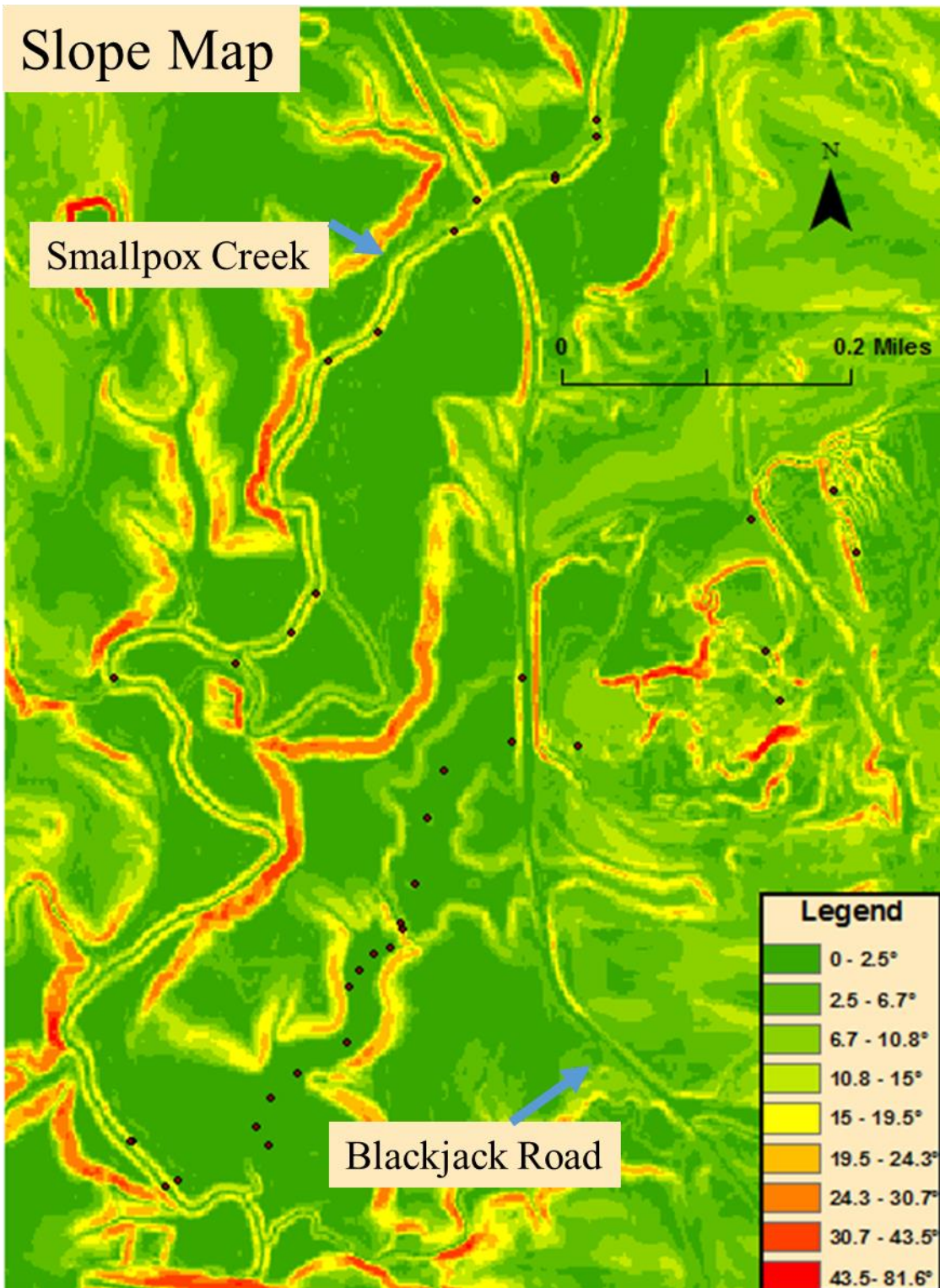


Figure 11: A slope map that shows the slope steepness of the site and surrounding landscape. Areas shaded green have the lowest slope while red areas have the steepest slope

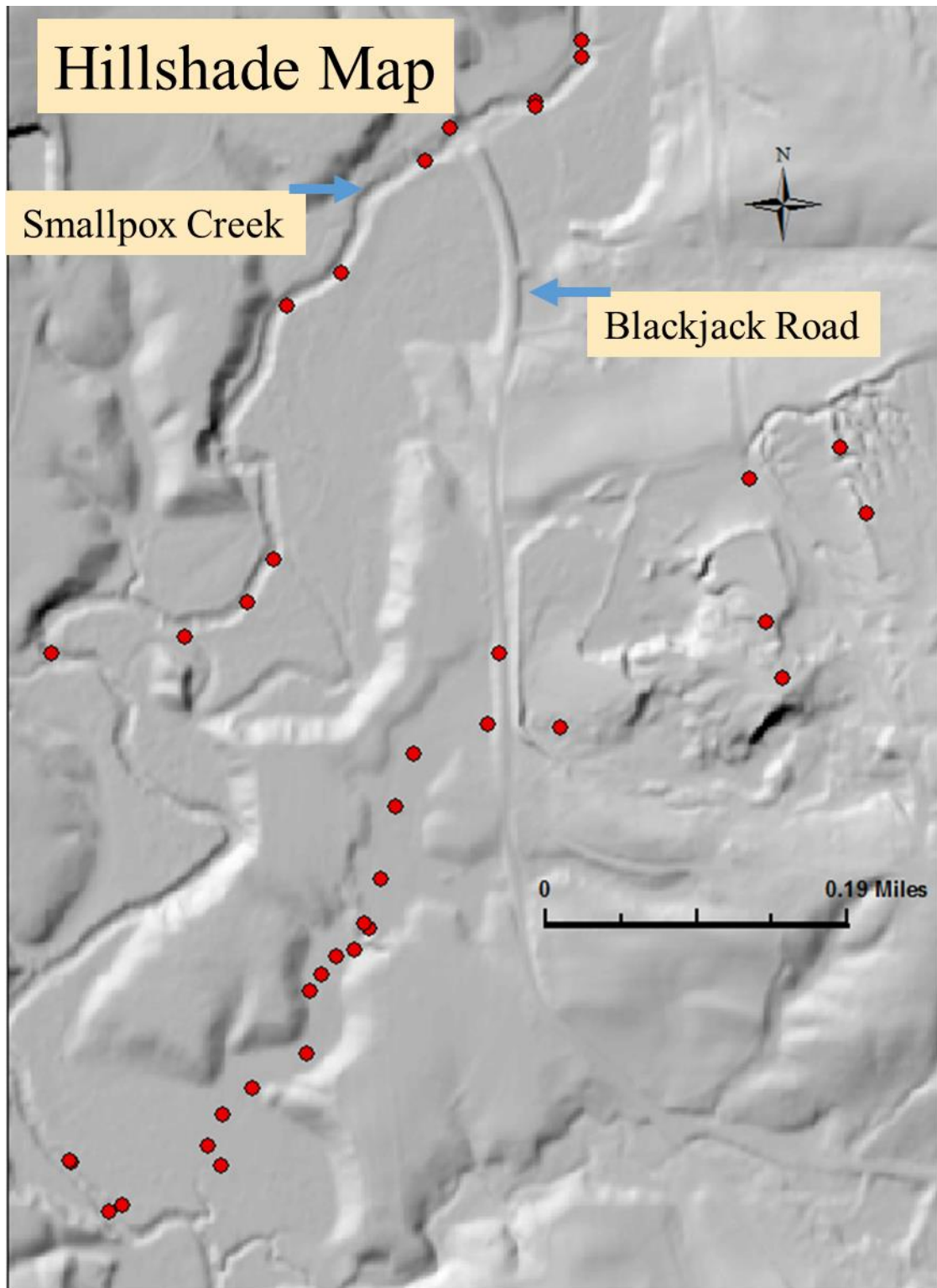


Figure 12: shows the study area's land surface as though an illumination source were shining on it. Similar to what would be seen from an aerial view if no vegetation were present.

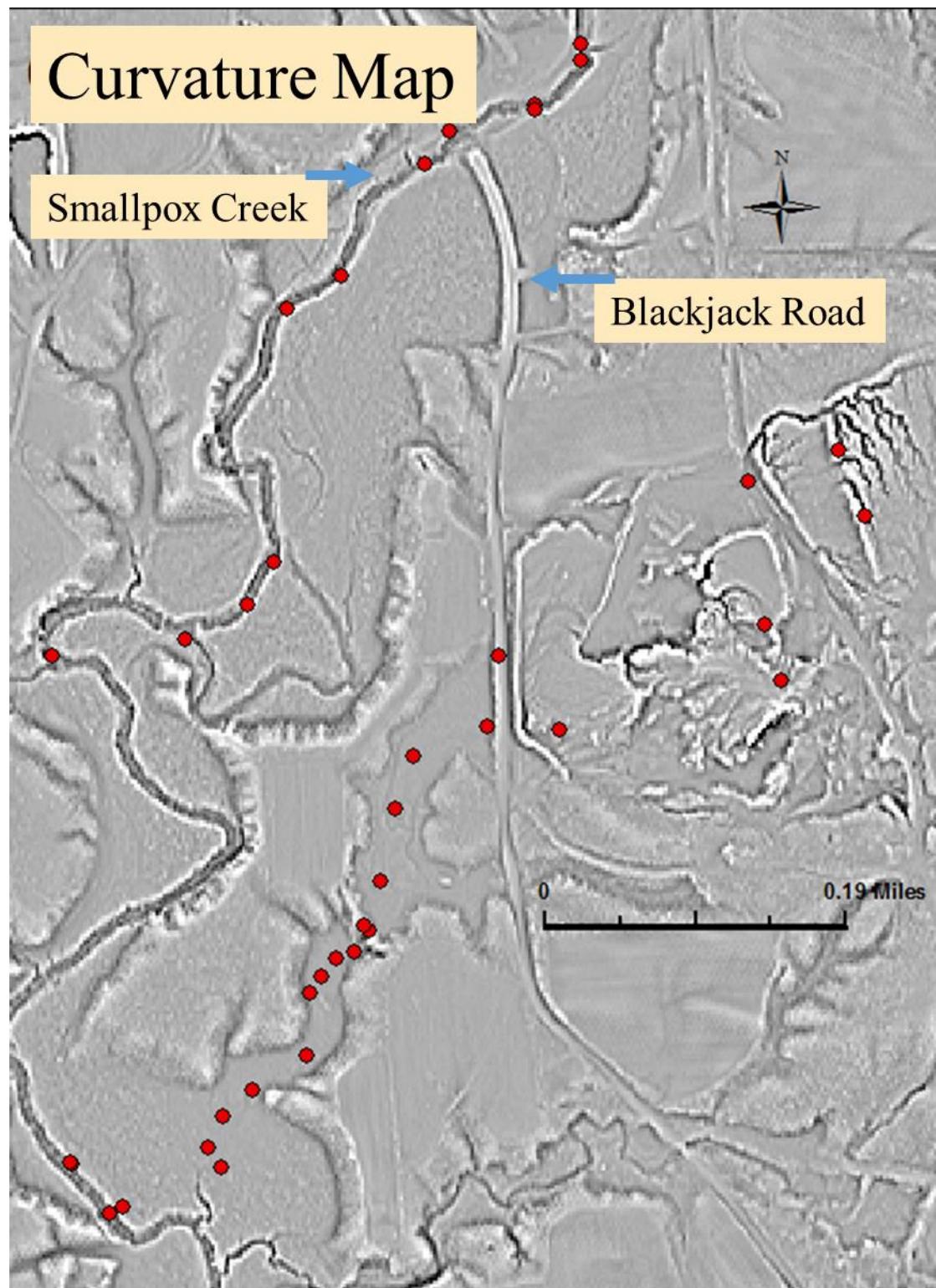


Figure 13: A curvature map which shows the slope over distance of the study area. This map can be thought of as the derivative of the slope map. This map shows fine details (such as rills) that often are not displayed on surface or hillshade maps.

Further examination of the data reveals that despite the fact that samples Rs-1, Rs-4 and Rs-11 had very high levels of zinc these samples had disproportionately low levels of lead. How could these samples have such high levels of zinc, yet such low levels of lead? In general, most other samples that had high levels of zinc would also have high levels of lead. This makes sense because the bedrock as well as the mine tailings have high concentrations of zinc and lead. Figure 15 is a GIS map of the samples with the level of zinc normalized to lead. Though all samples have much greater zinc than lead content, five samples showed ratios of more than 54 times the amount of zinc than lead. Four of these five samples are river sediment samples (Rs-1, Rs-4, Rs-11 and Rs-13). The fifth sample that has a ratio of greater than 54:1 zinc to lead is sample Ha-16. All five of these samples are from fluvial sampling locations. The river sediment samples are from sediment bedload in Smallpox Creek which are subject to fluvial processes, and sample Ha-16 is just below a drainage pipe that carries overflow water from the east to west side of Blackjack Road (Figure 14).



Figure 14:
Sample
location of
Ha-16

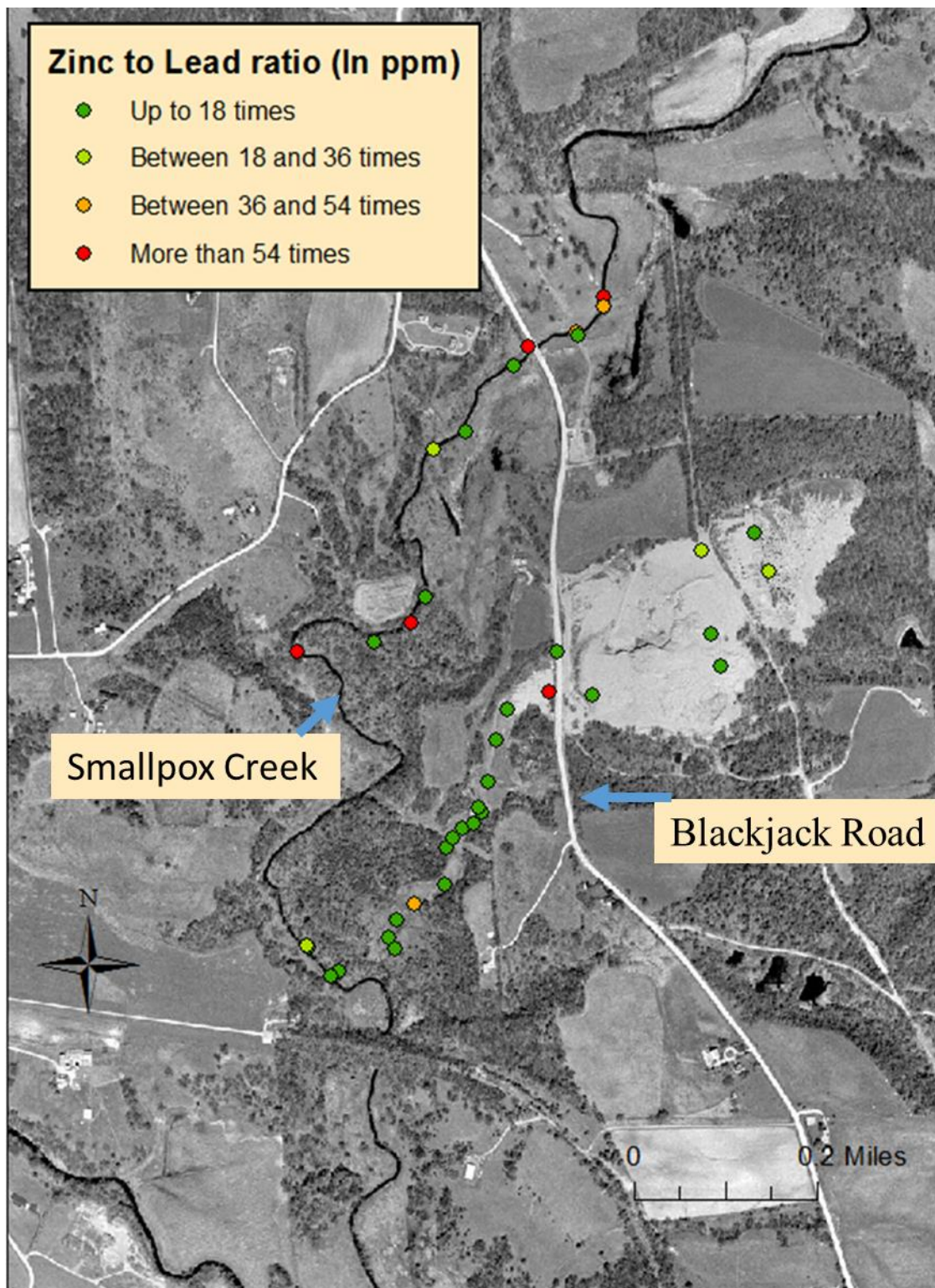


Figure 15: A map showing the zinc to lead ratio of samples (values are arbitrary)

The fact that these samples are all in fluvial environments and have such large Zn:Pb ratios leads to the hypothesis that lead is more readily to going into solution from the host rock or sediment than zinc. Almost all of the other Ha samples had less than 18 times the amount of zinc to lead (which is considered low in these arbitrary defined intervals). The only other outwash area sample that had greater than 18 times the ratio of zinc to lead is Ha-05, which is the algae sample that was located in standing water. I do not think it is coincidence that the only Ha samples that had a Zn:Pb ratio of greater than 1:18 also happen to be the only two Ha samples located in fluvial environments. Furthermore, every single sample that had Zn:Pb ratio greater than 36:1 is located in a fluvial environment. This supports the hypothesis that lead more easily dissolves into solution, when subject to water, than zinc. Another interesting correlation that I noticed was that all 5 samples with a zinc to lead ratio greater than 54:1 were gravel-sized sediments. This gravel-sized sediment is likely the same material that is eroded from the carbonate bedrock and suggests that zinc is not readily dissolving into solution from the parent material.

Conclusion

Mine tailings from historic mining operations at the Bautsch-Gray Mine site have impacted the areas surrounding the mine site. The contamination seems to migrate westward due to the natural gradient of the land and an installed drainage system on the mine tailings constructed by the EPA. Samples taken from the outwash area show that this area still has elevated levels of heavy metals and that there is certainly potential for this outwash area to contaminate Smallpox Creek. One sample taken at the confluence of the outwash area and Smallpox Creek suggests that contamination has already occurred, but more samples would need to be collected to say this with greater confidence. Samples of algae taken suggest that

biological material is incorporating heavy metals into its structure near areas with high levels of surface contamination. This study shows a strong correlation between gravel sediments and high levels of heavy metal contamination. Smaller sized particles such as clays tended to have lower levels of contamination. Finally, data suggest that fluvial processes tend to dissolve lead into solution and concentrate sediment with high levels of zinc into gravel-bars.

A future project on this site could look at contamination above and below the confluence of the outwash area with Smallpox Creek to determine whether the outwash area is contaminating Smallpox Creek. Approximately 20 samples could be taken upstream of the confluence and 20 below and analyzed for trace elements (heavy metals). If contamination is occurring near the confluence, this study could also provide insight into the distance downstream that contamination is affecting sediment in Smallpox Creek (contamination would likely decrease downstream).

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