

Investigation of Elevated Childhood Blood Lead Levels for Spatiotemporal Clustering Patterns in Salt Lake County, Utah, 2008 - 2017

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EXECUTIVE SUMMARY

Elevated blood lead levels in children is a persistent public health concern (Hauptman et al. 2017). A function of epidemiology is to investigate the prevalence of elevated blood lead levels, starting with a statistical review of blood lead tests. The Environmental Epidemiology Program (EEP), a program within the UDOH, conducts statistical reviews of elevated blood lead levels in Utah.

This report presents a statistical review of the spatial and temporal distribution of blood lead tests among children from birth to age five in Salt Lake County, Utah, from 2008 to 2017 using a spatiotemporal scan methodology. The purpose of this review was to identify areas within Salt Lake County with a historical or ongoing excess prevalence of elevated blood lead levels.

One cluster of elevated blood lead levels was identified by the scanning tool (relative risk 2.54, 2.08 – 3.10). The cluster is situated in north-central Salt Lake County for all years in the study period. The location of this cluster confirms what are believed to be the high-risk areas for elevated blood lead levels in Salt Lake County. It also shows that the current EEP targeted screening recommendations effectively characterize the risk of elevated blood lead levels in children from birth to age five in the county. This report can be used to help focus blood lead-related health education and outreach efforts within Salt Lake County.

INTRODUCTION

Lead: Lead is a bluish-gray metal found naturally in the environment. It is typically found combined with other elements (called lead compounds) rather than in its elemental form (Agency for Toxic Substances and Disease Registry [ATSDR] 2007). The physical properties of lead have made it a popular choice for a wide range of uses. Lead is dense, resistant to corrosion, malleable, and has a low melting point (ATSDR 2007). Lead is used in a variety of products, including ammunition, shot, and bullets; brass and bronze billet and ingots; nuclear and medical radiation shielding; storage batteries; paint, glass, ceramics, and other pigments; solder; and type metal (ATSDR 2007; United States Geological Survey [USGS] 2017). In 2015, the total usage of lead in the United States was 86% storage batteries, 5% ammunition/shot, 2% type metal, and 2% in other metal products (e.g. foil, collapsible tubes, galvanizing, plating, fishing weights) (USGS 2017).

Exposure to Lead: In addition to the routes of exposure discussed in this section, differences in screening and detection practices may contribute to variations in observed blood lead levels across geographies and over time. Even though lead is a naturally occurring element, human activity is responsible for much of the proliferation of lead in the environment. Though there have been significant efforts to reduce the amount of lead released in the environment, it is easily absorbed into soil and does not degrade into other substances. This means that lead released from previous activities is still in the soil (ATSDR 2007).

Leaded Gasoline: The use of leaded gasoline was previously the largest source of lead released into the environment (ATSDR 2007). However, a phaseout process of lead additives in gasoline began in the 1980s, with a ban instituted on January 1, 1996. Even prior to the 1996 ban, the phaseout process largely contributed to a 77% decrease in the mean blood lead levels of children ages one to five (Pirkle et al. 1994).

Lead-Based Paint: Exposure to lead in older homes with lead-based paint is still a primary source of concern for childhood lead exposure (Jacobs et al 2002; Needleman 2004; Levallois 2014). Lead-based paint and contaminated dust is the most widespread and hazardous source of lead exposure for young children (CDC 2015a). Even though lead-based paint was banned for use in residential homes in 1978, many children live in or visit homes that contain lead-based paint (American Academy of Pediatrics Council of Environmental Health [AAPCEH] 2016; Jacobs et al. 2002) Homes built before 1978 may still have lead on the walls, floors, ceilings, window sills, or on the outside walls. Lead concentrations in the house can increase as the older paint peels, chips off, or is disturbed as part of a remodeling project. In 2018, approximately 13.2% of residential housing was built pre-1950 and 47.1% was built pre-1978 in Salt Lake County (Utah Automated Geographic Reference Center [AGRC] 2018a).

Occupational Exposure: Occupational exposure to lead occurs for workers in the lead smelting and refining industries; battery manufacturing plants; steel welding or cutting operations; construction; rubber products and plastics industries; printing industries; firing ranges; radiator repair shops; painters who sand or scrape old paint; and other industries requiring flame soldering of lead solder (ATSDR 2007). The major routes of exposure in these occupations are inhalation and ingestion of lead-containing dusts and fumes (ATSDR 2007). Families of

individuals in these types of occupations can also be exposed to higher levels of lead when workers bring home lead dust on their work clothes (ATSDR 2007).

Individuals who participate in certain types of hobbies may expose themselves or others to lead in a similar manner. These include working with stained glass; glassblowing; lead fishing weights; ammunition; leaded glazes and frits with pottery; and lead may be present in platinum printing and screen-printing materials (ATSDR 2007; Grabo 1997).

Drinking Water: The primary way lead enters drinking water is when plumbing materials that contain lead corrode and leach. The amount of corrosion can be influenced by water chemistry, water temperature, amount of lead in the plumbing materials, amount of wear on the plumbing materials, how long water stays in the pipes, and the presence of protective scales or coatings inside the plumbing materials (United States Environmental Protection Agency [EPA] 2018c). U.S. Environmental Protection Agency regulations require water systems to monitor lead levels in drinking water at customer taps. If lead concentrations exceed an action level of 15 parts per billion in more than 10% of customer taps sampled, the water system must undertake a number of additional actions to control corrosion (EPA 2018d, Electronic Code of Federal Regulations [eCFR] 2018).

Air Emissions: As a part of the phaseout of lead additives in gasoline, the level of lead in the air decreased nationally by 99% between 1980 and 2017 (EPA 2018a). The current National Ambient Air Quality Standard (NAAQS) for lead is $0.15 \mu\text{g}/\text{m}^3$ of air during a rolling three-month average (EPA 2016). Today, major sources of lead in the air come from ore and metals processing facilities; waste incinerators; utilities; lead-acid battery manufacturers; and piston-engine aircraft operating on leaded aviation fuel (EPA 2017). In 2014, more than half of lead released into the atmosphere in Utah came from mobile sources, nearly all of which was due to exhaust from aircraft using leaded aviation fuel; the second largest source of releases came from industrial processes, particularly metal smelting and processing (EEP 2018d, EPA 2018b).

Between 1982 and 2005, the Utah Division of Air Quality (UDAQ) monitored lead air levels along the Wasatch Front. During this time, no violations of the former NAAQS were measured. Lead monitoring was reinstated with the 2008 revision of the NAAQS. Due to a lack of current air monitoring data, all areas in the state of Utah are currently designated as unclassifiable for lead (UDAQ 2018). However, concentrations at the longest running lead monitor in Utah (located in Magna, Salt Lake County near the Kennecott smelter and refinery) have consistently been below the NAAQS (EEP 2018d).

Consumer Products: Lead may also be present in a number of consumer products. Older or antique toys may be painted with lead-based paint prior to the 1978 ban. Imported toys may also contain lead-based paint. Since the use of lead in plastics has not been banned, some plastic toys may use lead to make it softer or more flexible (CDC 2013a). Certain types of traditional (folk) medicines or remedies have been shown to contain high amounts of lead. Lead may be included purposefully as part of the intended remedy or by accident as part of preparation or packaging (CDC 2013b; Hauptman et al. 2017). Other products can include imported cookware, cosmetics, religious powders, dietary supplements, candy from Mexico, foodstuffs, spices, herbs, and toy jewelry (CDC 2015b, 2013c; Hauptman et al. 2017; AAPCEH 2016).

Health Effects: Lead plays no biological function in the human body (Hauptman et al. 2017). While lead affects many organs in the body, the most consequential system it impacts is the central nervous system (Needleman 2004). Lead imitates the function of calcium and impedes the entry of calcium into cells, thus affecting neuron signaling (Needleman 2004; Markovac & Goldstein 1988; Simons 1993). It can also impact blood vessels, which in turn has a negative effect on the blood-brain barrier (Krigman 1978). There is no safe level of lead exposure (AAPCEH 2016; ATSDR 2007; Gilbert & Weiss 2006).

Childhood lead exposure is of particular concern because children are more vulnerable to the effects of lead toxicity than adults; they are exposed during critical periods of physiological development that may result in lifelong health effects. Children can be exposed in utero and via breastmilk if their mothers are exposed as well (ATSDR 2007). Children absorb lead more easily than adults, and the developing central nervous system is more susceptible to lead than a fully developed one (Ziegler et al. 1978; Needleman 2004).

Furthermore, certain childhood behaviors increase the likelihood and frequency of lead exposure. It can be ingested or inhaled when children play on the ground, sand, dirt, or floor; lead-based paint chips are a concern due to increased “hand-to-mouth” behaviors exhibited by children (Hauptman et al. 2017; Needleman 2004; ATSDR 2007).

Clinical symptoms can begin to appear at exposure levels of ~45 micrograms per deciliter of blood ($\mu\text{g}/\text{dL}$). These include abdominal pain, constipation, colic, anorexia, staggering, and clumsiness (Needleman 2004; Hauptman et al. 2017). High levels of lead exposure ($> 70 \mu\text{g}/\text{dL}$) pose an immediate threat to life and well-being; symptoms include loss of voluntary muscle control, convulsions, vomiting, coma, encephalopathy, and death (AAPCEH 2016; Hauptman et al. 2017).

Even at exposure levels $< 5 \mu\text{g}/\text{dL}$, intellectual and cognitive capacity is reduced, with symptoms including hyperactivity, inattention, restlessness, antisocial behavior, decreased academic achievement, and lower IQ scores (AAPCEH 2016; Hauptman et al. 2017; Needleman 2004; Gilbert & Weiss 2006). While these neurobehavioral effects should resolve after the source of lead is removed, some long-term effects could still persist (ATSDR 2007).

Previous Studies of Lead Exposure in Salt Lake County: From 1986 to 2017, there were nine health hazard assessments in Salt Lake County involving lead (in which it was typically only one of many contaminants of concern) (EEP 2018a; EEP 2018b; EEP 2018c; EEP 2012; EEP 2005; ATSDR 2018a; ATSDR 1993; ATSDR 1990; ATSDR 1986). These investigations focused on remnant lead deposits in the soil, surface water, groundwater, and air from now-defunct mining, milling, and smelting facilities. Many of these sites were formerly on the National Priority List. The purpose of a health hazard assessment (also called a public health assessment) is to evaluate a hazardous waste site for hazardous substances, health outcomes, and community concerns, including if people could be harmed from the site-related substances (ATSDR 2018b). No actual biomonitoring assessment of individuals’ blood lead levels were included as part of these health hazard assessments. Other surveillance studies have conducted lead biomonitoring assessments

near previous milling sites (Danse et al. 1995), among adults in the workplace (Roscoe et al. 2002), and as part of a multi-state consortium (Chaudhuri et al. 2017).

The Utah Blood Lead Registry (UBLR) conducts ongoing surveillance of statewide blood lead test results. These data are provided on Utah's Indicator-Based Information System for Public Health (IBIS) and the Utah Environmental Public Health Tracking websites (UEPHTN) (IBIS 2018; UEPHTN 2018). Website users can query Utah's blood lead test result data using a variety of strata (i.e., year, age, sex, race, ethnicity, blood lead level, and geographic area). These data are updated annually after the previous year's data are validated.

Disease Incidence Statistical Reviews: A core function of epidemiology is to track and evaluate disease patterns. This function helps public health officials and policymakers identify and assess communities with public health challenges; define public health priorities; develop and implement informed public health policy; monitor and evaluate public health actions; discover knowledge about public health concerns; and guide public health outreach, education, and interventions activities (Dicker 2002; Lawson & Kulldorff 1999; Stanbury et al. 2012; Thacker 2000; Thacker et al. 2012). Lead exposure is an environmental public health concern- and one that can be entirely prevented (CDC 2015c, 1997). Both public health and health care professionals can work in tandem to provide accurate information, identify trends, mitigate sources of lead exposure, and deliver case management services. From the public health perspective, a statistical review is useful to help identify community needs regarding elevated blood lead levels, awareness, and prevention; public health screening services; and public health interventions. Results of this review and similar studies can empower communities to make improvement in governmental policymaking and health care services (Bell et al. 2006; Kingsley et al. 2007).

One of the outcomes of a statistical review is the identification of probable patterns of disease clustering. A spatial cluster (also called a "hot spot") is defined as a limited area within a general study area with a significant and meaningful increase in the incidence of disease. A temporal cluster is defined as a period of time within a larger range of time with a significant and meaningful increase of disease incidence. A spatiotemporal cluster is a cluster defined in both the geographic and temporal dimensions (Aamodt et al. 2006; Hinrichsen et al. 2009; Lawson & Kulldorff 1999; Wakefield et al. 2000; Wheeler 2007).

The discovery of a possible disease cluster usually warrants additional action, either as continued monitoring or a more aggressive investigation. However, disease clusters may not always be a public health concern. When evaluating a long period of time, historical clusters may be discovered that have since resolved themselves. Clustering may be the natural result of the distribution of residential or demographic population patterns or may be a function of wall-to-wall analytical units that do not properly accommodate disease patterns. For example, there are no areas within the boundaries of Utah that are not also part of a census tract geographic area. Thus, some census tracts include areas of geography (e.g., the Bonneville Salt Flats and the upper elevations of Utah's mountain ranges) where no people live. Clusters also may occur due to chance, or because of the presence of factors that are not measurable or are highly variable (Wakefield et al. 2000). Furthermore, clusters may be reported due to an improper application of statistical analytical methods (Tango 1999).

Public Statement of Concern: The Environmental Epidemiology Program (EEP), within the UDOH receives concerns from the public about potential sources of lead exposure that may lead to increased elevated blood lead among children.

Study Objectives: This report presents a statistical review of the spatial and temporal distribution of blood lead test results among children from birth to age five in Salt Lake County, Utah from 2008 through 2017 using a spatiotemporal scan methodology. The purpose of this review is to identify trends of elevated blood lead test results and regions of Salt Lake County with an excess incidence of elevated blood lead levels among children from birth to age five.

Authority and Funding: This study was conducted as part of the UDOH Executive Director's responsibility to investigate public health concerns within Utah. The executive director delegates responsibility for blood lead investigations to the EEP. Blood lead test results, population, and geographic data for this investigation are collected, maintained, and made available by the UBLR and the UEPHTN. The UEPHTN also funds the ArcGIS® geospatial analytical software licenses that were used to conduct this investigation. The UEPHTN is funded by a grant from the CDC (UEPHTN 2018). Personnel time used to conduct this investigation was charged against state-funded Environmental Health Administrative funds. No federal funds were directly used to conduct this investigation.

DATA AND METHODS

Study Design: This investigation is a retrospective statistical review of blood lead test results using spatiotemporal scanning methodology in the SaTScan (version 9.6) computer application to identify spatial clusters in the data. Statistical reviews are not cluster investigations and lack the power to link incidence to putative risk factors (Jekel et al. 1996; Kingsley et al. 2007; Mann 2003). A statistical review is a tool used by the EEP to evaluate the health status of a population, identify public health needs, and assess public health activities. A good study design includes determining the underlying spatiotemporal epidemiologic theory, selecting appropriate scales of analysis, selecting an appropriate analytical methodology, defining risk and exposure, and determining how to manage locational and attribution uncertainty (Meliker & Sloan 2011).

Since a child who receives a blood lead test either is or is not a case of elevated blood lead levels, the appropriate analytical model applies binomial statistics. The Bernoulli model was used since blood lead case data are independent of the underlying population and address data (point location) for cases and controls were available (Warden 2008). This investigation used the spatiotemporal scan statistic to look for current and historical clusters. The spatiotemporal scan method creates many different aggregations of spatial and temporal analytical units using the point location of cases and controls (e.g., northern Utah County from 2008 to 2012). Clusters are identified by comparing the distribution of cases to the distribution of controls (Kulldorff 1997; Kulldorff & Nargwalla 1995; Warden 2008).

Utah Childhood Blood Lead Screening Recommendations: Utah relies on what is known as a “targeted” blood lead screening approach. Under this model, blood lead testing is conducted on

the basis of risk (EEP 2003). A child's risk is typically determined during visits to a health care provider. Utah's screening recommendations consist of the following:

- All children in Utah who live in a ZIP code that has $\geq 27\%$ of pre-1950 housing (according to the 2000 U.S. Census) should have at least one venipuncture or capillary blood lead test at 12 and 24 months of age, and children at 36 to 72 months of age who have not been screened previously. For Salt Lake County, there are 10 identified ZIP codes that meet this criterion: 84006, 84101, 84102, 84103, 84104, 84105, 84106, 84108, 84111, and 84115. Figure 1 presents a map of these ZIP codes. Figure 2 presents a map that displays the percentage of pre-1950 housing at the census block group level using 2018 Salt Lake County Assessor parcel data.
- All children in Utah who live in a house built before 1978 should have at least one venipuncture or capillary blood lead test between the ages of 12 and 24 months, and children 25 to 72 months of age should have a blood lead test if they have not been previously screened.
- Additional questions for a basic risk assessment questionnaire are provided for healthcare providers. If a parent or guardian responds "yes" or "don't know" to any of the following questions, the child should be screened:
 1. Does your child live in or regularly visit a house that was built before 1950?
 2. Does your child live in or regularly visit a house built before 1978 with recent or ongoing renovations or remodeling (within the last 6 months)?
 3. Does your child have a sibling or playmate who has or did have lead poisoning?
 4. Does your child live near or play on tailings from mining or milling operations?

All children in Utah who are enrolled in Medicaid are also screened as part of federal policy (Centers for Medicare and Medicaid Services [CMS] 2018). However, Medicaid status is not a risk factor in Utah for elevated blood lead levels. The study "Prevalence of Elevated Blood Lead Levels in Utah Medicaid Children," found that elevated blood lead levels in Utah children ages 12 to 36 months old who were enrolled in Medicaid, were not higher than the prevalence in non-Medicaid Utah children (EEP 2003). This is in contrast to Medicaid-eligible children in other parts of the country, who had a higher prevalence rate of elevated blood lead.

While other methods for statewide blood lead screening have been evaluated, they have not been found to be effective. The EEP conducted a study in 2014 to assess the efficiency and reliability of a screening method using newborn blood spots, but it was found to not accurately describe the overall burden of elevated blood lead levels in Utah (EEP 2014). See Appendix A for additional questions and answers about childhood blood lead screening in Utah.

Blood Lead Data: Blood lead test results were identified as cases if the result met the reference level of ≥ 5 $\mu\text{g/dL}$, which corresponds to the CDC-recommended "blood lead level of concern" (Utah Administrative Code 2017; CDC 2017). This standard was applied to all blood lead test results.

Data on blood lead test results for children from birth to age five in Salt Lake County from 2008 to 2017 were obtained from the UBLR. The UBLR completed a thorough data review for

completion and quality before data are released to the EEP. All statewide blood lead test results are reported and collected by the UBLR under authority of the Utah Administrative Code Injury Reporting Rule R386-703 (Utah Administrative Code 2017). When an elevated blood lead test result is identified ($\geq 5 \mu\text{g/dL}$), case management is conducted by the respective local health department where the child resides (EEP 2016; Utah Administrative Code 2017).

The blood sample for a lead test may either be drawn from a vein (venipuncture) or a capillary (typically a fingerstick test); both methods have been shown to be appropriate methods for blood lead level screening (Schlenker et al. 1994; Parsons et al. 1997). Venipuncture tests are the preferred method due to a lower probability of contamination due to the smaller area of entry and the direct collection of blood from the vein. Capillary tests have a higher probability of contamination, as the finger may be insufficiently clean, pooling blood on the finger may contaminate the specimen, and using a capillary tube to collect the specimen. If a capillary test shows an elevated blood lead level, a second test is needed to confirm the level. While venipuncture is the preferred method, a second capillary test, called a “confirmatory pair,” may also be used. A confirmatory pair is two consecutive capillary tests performed between one and 84 days apart. The second test is considered the “confirming” test to classify the test result. If there is more than one test as part of a confirmatory pair, the highest result is used.

It is not uncommon for a child to receive multiple blood lead tests within a given year (especially if undergoing case management). In order to select the test results that most accurately reflect the true blood lead level, the hierarchy of test result classification was used. This hierarchy informs how blood lead test results should be chosen when there are multiple test results available:

1. Venous tests $\geq 5 \mu\text{g/dL}$
2. Confirmed capillary or unknown results $\geq 5 \mu\text{g/dL}$
3. Venous result $< 5 \mu\text{g/dL}$
4. Unconfirmed capillary or unknown results $\geq 5 \mu\text{g/dL}$
5. All other results $< 5 \mu\text{g/dL}$

All tests were categorized as “confirmed” if the sample was taken by venipuncture or a second capillary confirmatory pair was available within the aforementioned timeframe. For a logic chart of how blood lead test results were classified, please see Appendix B.

Between 2008 and 2017, there were 17,860 unique blood lead test results among children from birth to age five in Salt Lake County that were reported to the UBLR. The residential address information provided by the UBLR includes the patient’s street address, city, and ZIP Code at the time in which the blood lead test was taken. The EEP geocoded the residential address provided with each record to obtain an x- and y-coordinate for that individual. Most addresses automatically geocoded using address locator data obtained from the AGRC (AGRC 2018b). Addresses not found due to land reutilization, street name changes, address realignment, or are newer than the address locator file, were researched using historic street maps, online street maps, integrated aerial photographs, and other references to locate the address and manually geocode it. The EEP was able to geocode 15,960 (89.4%) of the blood lead test records.

An additional 74 (0.41%) of records were removed after being identified as being duplicate tests. Finally, 71 (0.40%) records were removed after being identified as being associated with a refugee initial health assessment after arrival to Utah. The Utah Refugee Health Program provides a comprehensive health screening within the first 30 days of arrival; blood lead testing is part of the screening (Refugee Health 2018). These refugee test results were removed under the assumption that the individual's lead exposure occurred prior to arrival to Utah and does not represent lead exposure risks in Salt Lake County. The final count for blood lead test results included in this statistical review was 15,815. For additional data on the study population, please see Table 1.

SaTScan: The SaTScan application features a number of models. For this study, the Bernoulli model for space-time cluster detection was used (Kulldorff 1997; Warden 2008). The model used an elliptic spatial window shape with medium noncompactness penalty. In most cases, the choice of the penalty does not dramatically change the findings (Goujon-Bellec et al. 2011). The maximum cluster size for the spatial component was identified by a cluster information criterion statistic to be 25% of the population (Han et al. 2011). No geographic overlapping of clusters was allowed. Scans were run with other model parameters (e.g., more or less compactness, population size limits, with or without stationarity adjustment, etc.) with little difference in the findings. For this investigation, a more liberal p-value of ≤ 0.10 was used (instead of the typical 0.05 threshold) to determine statistical significance. This decision was allowed because of the small case count ("the rarity") of the clusters (Dietz et al. 2011; Hsu et al. 2004; Park 2010; Wagner et al. 2013; Wheeler 2007).

The SaTScan application implements this methodology as part of the likelihood calculation to control for the many calculations. Only areas with higher-than-expected rates were considered during the scan. Cluster data was output as a data file that was joined to the attribution table of a geographic data file (shapefile) for symbolization and visualization. For a further discussion of the spatiotemporal scanning methodology in SaTScan, please see Appendix C.

Cluster Homogeneity and Cluster Confirmation: Several discrete and noncontiguous areas with slightly elevated rates that individually are not statistically powerful enough to be distinguished from random variation may, when combined within an aggregated area, result in the delineation of a cluster area. This kind of false-cluster would be represented visually by a heterogeneous presentation of small area rates. True clusters would have a homogenous presentation of high rates compared to the surrounding small areas (Chen et al. 2008).

FINDINGS

Descriptive Assessment: Between 2008 and 2017, there were 15,815 non-duplicate, geocodeable blood lead tests performed in Salt Lake County, as reported to the UBLR. Fifty-three percent of cases were male with a median age of 1.5 years. Table 1 displays study population demographics. Using the current blood lead level of concern, 386 cases were identified (2.44%). The median blood lead test result for cases was 7.10 $\mu\text{g/dL}$; for controls the median test result was 1.0 $\mu\text{g/dL}$ (range < 0.15 $\mu\text{g/dL}$ to 29.0 $\mu\text{g/dL}$). Table 2 displays the blood lead test results. The majority of tests were performed by venipuncture (69.70%) and an average of 1,581 tests were conducted each year. Table 3 displays additional characteristics of the blood lead tests.

SaTScan Results: One cluster of elevated blood lead test results was found in Salt Lake County from 2008 – 2017. The relative risk was 2.54 (with 95% confidence limits of 2.08 – 3.10), meaning, this is the measure of the magnitude of increased risk. The cluster was found to be significantly likely ($p < 0.00001$); this is the probability that the cluster is due to random chance (the probability of this being a true cluster is $1 - p$).

The cluster covers approximately 31.9 square miles and is almost exclusively situated in Salt Lake City; the southern portion of the cluster extends into the northernmost portion of South Salt Lake. Figure 3 shows the cluster location relative to Salt Lake County. Figure 4 displays a detailed view of the cluster.

Thirteen ZIP codes were found to be at least partially included in the identified cluster. The following are completely contained within the cluster area: 84101, 84102, 84111, 84112, and 84150; the following are partially contained within the cluster area: 84103, 84104, 84105, 84106, 84108, 84113, 84115, and 84116. Of the 10 aforementioned ZIP codes in the EEP screening recommendations listed as having $\geq 27\%$ of pre-1950 housing, three are completely within the cluster area (84101, 84102, 84111), six are partially within the cluster area (84103, 84104, 84105, 84106, 84108, 84115). The only one not included was 84006 in Copperton (south of Magna and west of West Valley City).

DISCUSSION

Salt Lake County Elevated Blood Lead Cluster: One cluster was identified by the spatiotemporal scan method. The ZIP Codes included in the cluster align with nine of the 10 aforementioned ZIP Codes with $\geq 27\%$ of housing built before 1950 that are part of Utah's targeted screening recommendations (see Figure 1). The other included ZIP code, 84116, contains residential housing but is not part of the list of ZIP codes containing $\geq 27\%$ of housing built before 1950. The final three ZIP Codes that were included (84112, 84113, and 84150), do not contain residential housing and were only included due to the shape of the spatial window that was used in the Bernoulli model.

In essence, the location of the cluster is primarily situated in the area of Salt Lake County that has the highest ratios of pre-1950 housing, and thus, lead-based paint in residential housing (see Figure 2). This result is to be expected based on the current knowledge of elevated blood lead risks. It also shows that the current EEP targeted screening recommendations effectively characterize the risk of elevated blood lead levels in children from birth to age five in Salt Lake County.

The overall number of blood lead tests increased from 1,377 tests in 2008 to 3,004 tests in 2017 (see Table 3). This is in contrast to a 2.6% decrease in the population of children from birth to age five in Salt Lake County over the same time period (despite a 13.6% increase in the overall population) (Population Estimates 2019). This increase in the number of blood lead tests was likely due to efforts by the UBLR to improve blood lead test reporting, rather than an increase in children who are considered “at risk” according to the EEP targeted screening recommendations.

Performance of the SaTScan Application: SaTScan is widely used and well-accepted as a tool for discovering spatiotemporal clusters of health outcomes (Aamodt et al. 2011; Almeida et al. 2011; Cromley & McLafferty 2012; Oliveira et al. 2011; Robertson & Nelson 2010). The Bernoulli model performs well over a wide range of disease burden levels and geographic or temporal scales and is the preferred model (Warden 2008). Because the tool is easy to use and the results are easy to interpret, SaTScan is particularly popular for use by state and local public health agencies with the responsibility to do public health surveillance and cluster assessment. However, the SaTScan tool and its application in this study are not without limitations.

- SaTScan uses simple circular or elliptical shaped geographic windows to identify study areas that might be clusters. In this investigation, these study areas consist of aggregations of point locations of individuals' residential address. SaTScan is most able to detect circular or elliptical shaped clusters and may not be able to detect very irregularly (e.g., "S" or "U") shaped clusters (Aamodt et al. 2006; Goujon-Bellec et al. 2011; Oliveira et al. 2011; Wheeler 2007).
- Because of the use of simple circular or elliptical filters to identify clusters, consideration of the potential shape of the cluster in the study area is an important concern (Cromley & McLafferty 2012; Wheeler 2007). For this study, elliptical filters were used.
- Related to the above limitations, is the tendency of SaTScan to merge several small, strong, irregularly shaped clusters that do not fit well in a circular or elliptical filter into one larger, less significant cluster that fits better (Oliveira et al. 2011; Van Meter et al. 2008). This may be the situation for the cluster identified in this study.
- Additionally, the SaTScan tool is not capable of considering geographical features other than the patient address points. As a result, the aggregating process may result in the combining of distinct communities that may have natural barriers (e.g., lakes, mountain ranges, etc.) that tend to isolate them from each other.

Methodology Limitations: The public often wants public health investigations to determine if elevated blood lead levels can be linked to specific environmental concerns. The methods (the indirect standardized incidence ratio and the spatiotemporal scanning for clusters) used in this investigation do not have the capability to definitively link the findings of elevated blood lead level risk to any inherent or external risk factors, including environmental exposures. There are a number of limitations that impede this linkage. These kinds of statistical reviews are based on annual incidence data reported to the UBLR, and the incidence of elevated blood lead test results is dependent on targeted screening practices and successful reporting by health care providers. There is seldom any knowledge about the frequency, duration, or intensity of individuals' exposure to a putative environmental concern. Chance also plays a role in the distribution of elevated blood lead levels and is often the dominating causal factor in small populations or for diseases that occur rarely. Overcoming these limitations usually requires a comprehensive assessment of individual risk supported by a clear and consistent trend of elevated rates for a population.

This investigation used data from the UBLR. In Utah, all blood lead test results are reportable to the UBLR. When a Utah resident seeks a blood lead test, a report is generated and the UBLR follows up on the report to confirm information, collect additional factors about the case, and notify the pertinent local health district (if needed). This process occurs when cases are diagnosed in Utah but may not occur if a case is diagnosed outside of the state. The UBLR may contain records of blood lead test results on individuals who lived outside the study areas but moved into the study area prior to seeking diagnosis and treatment. These situations are ascertainment biases. For the purposes of diagnosis, the EEP assumes that the ascertainment bias is non-systematic, meaning that “move-in” and “move-out” situations balance each other. It is highly unlikely that this assumption is true in all cases and can be a significant limitation when the study population is small.

Due to the nature of targeted blood lead testing in Utah, testing typically only occurs among high-risk groups (EEP 2016, 2003). Thus, the cluster location corresponds with targeted testing protocol, given what is known about elevated blood lead level risk factors in Utah (i.e., housing age and lead-based paint). Figure 5 presents the number of tests performed in each ZIP Code during the study period. There was also no individual assessment of housing age or environmental lead levels. Other potential sources of lead exposure (e.g., lead dust brought home from parental occupation or hobby) were not considered. This investigation used all confirmed and unconfirmed elevated blood lead results, as opposed to using only confirmed. While this does introduce a degree of uncertainty in the results, they were included to represent the range of test results that were found.

CONCLUSIONS AND RECOMMENDATIONS

This study identified the spatiotemporal location of a possible cluster of elevated blood lead results. The cluster was recent or active at the end of the study period (2017) and is likely to be real and meaningful.

The location of this cluster confirms what are believed to be the high-risk areas for elevated blood lead levels in Salt Lake County. It also shows that the current EEP targeted screening recommendations effectively characterize the risk of elevated blood lead levels in children from birth to age five in the county. This report can be used to help focus blood lead-related health education and outreach efforts within Salt Lake County.

Potential causal factors identified by literature review were presented, but not investigated as part of this investigation. Random variation (chance) is an important element in any investigation involving cluster detection and can play a dominant role when the investigation involves rare diseases or small population counts.

Children who are afflicted with elevated blood lead levels are best served by their health care team. Individuals who are concerned about lead exposure should be referred to their health care provider. This report can be used to help formulate a response for individuals concerned about elevated blood lead levels in their communities.

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Web links for citations of government or organization websites may wrap onto multiple lines.

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FIGURES AND TABLES

Figure 1. ZIP Codes with $\geq 27\%$ of housing built pre-1950, based on 2000 U.S. Census, Salt Lake County, Utah

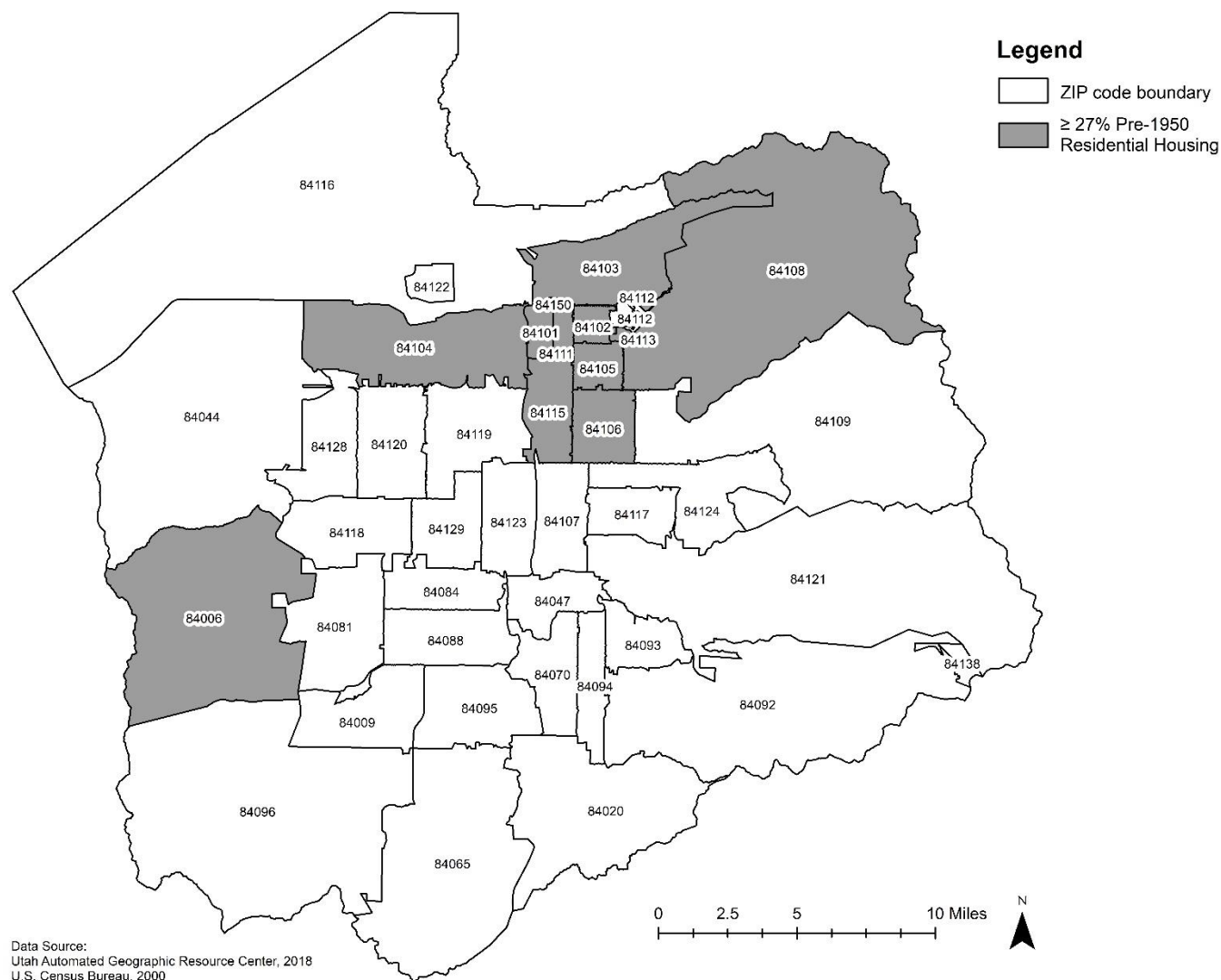


Figure 2. Percent of pre-1950 total residential housing, by 2010 Census Block Group, Salt Lake County, Utah, 2018

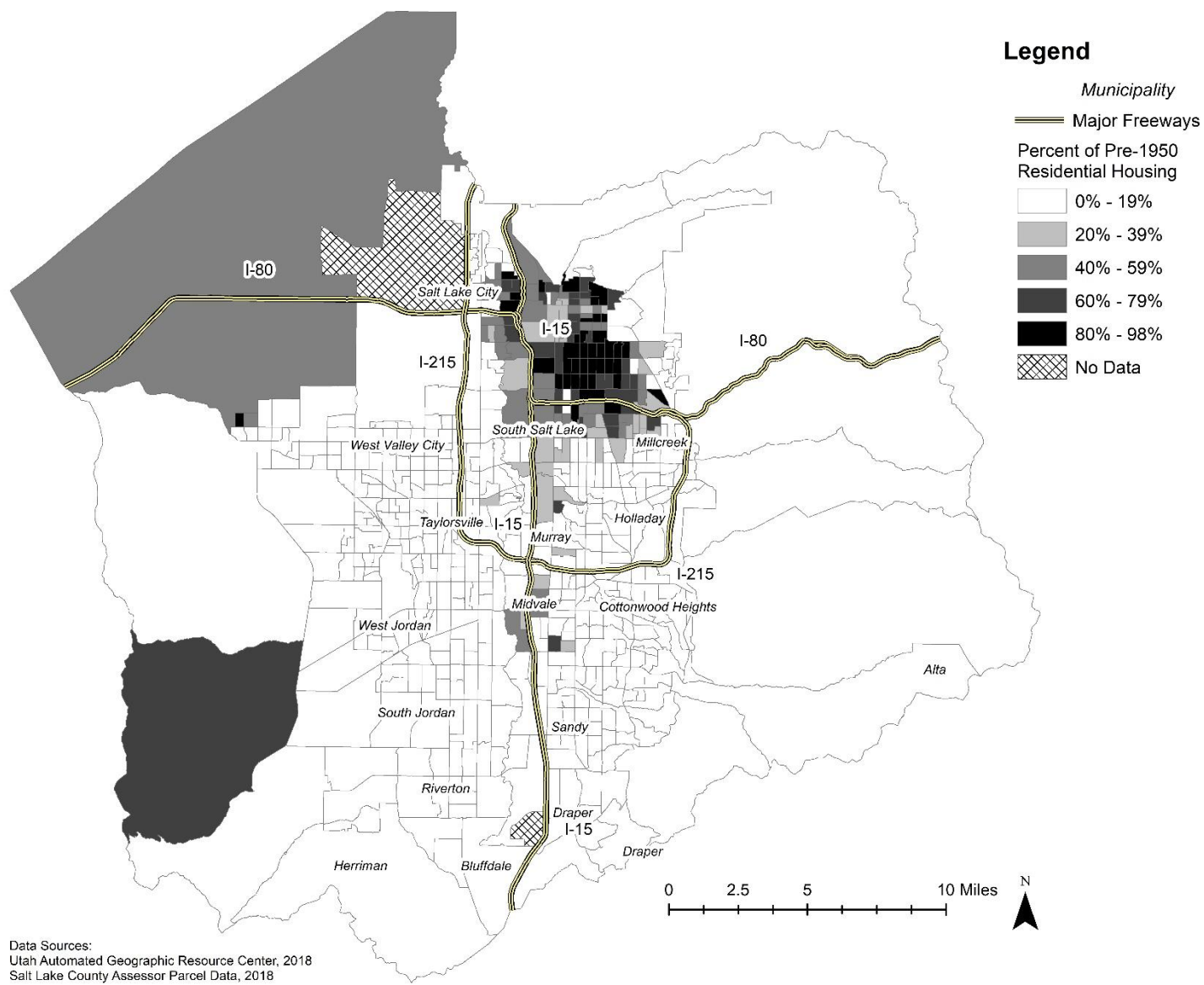


Figure 3. Identified cluster of elevated blood lead levels, among children ages 0-5 years, Salt Lake County, Utah, 2008-2017

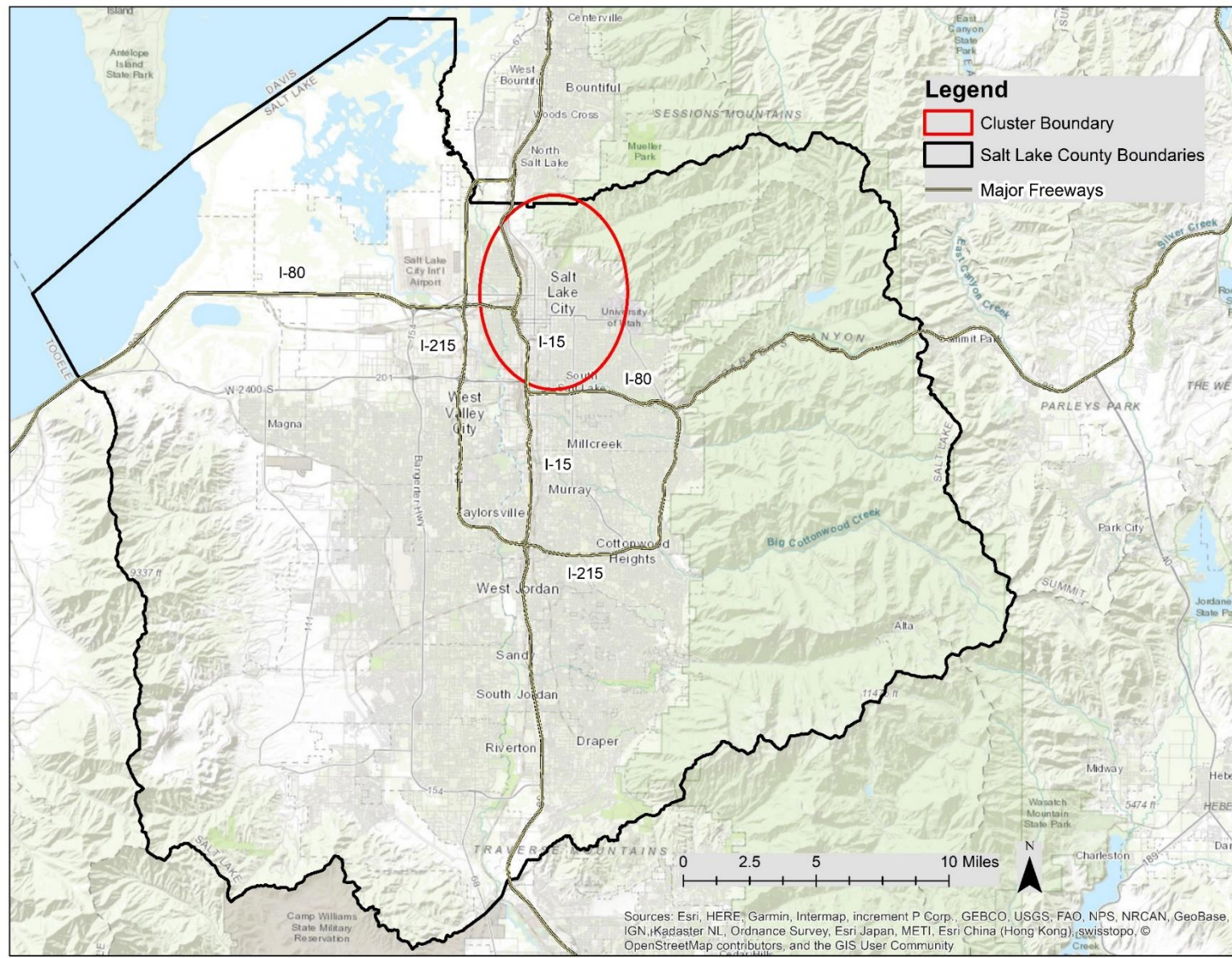


Figure 4. Identified cluster of elevated blood lead levels (detail), among children ages 0-5 years, Salt Lake County, Utah, 2008-2017

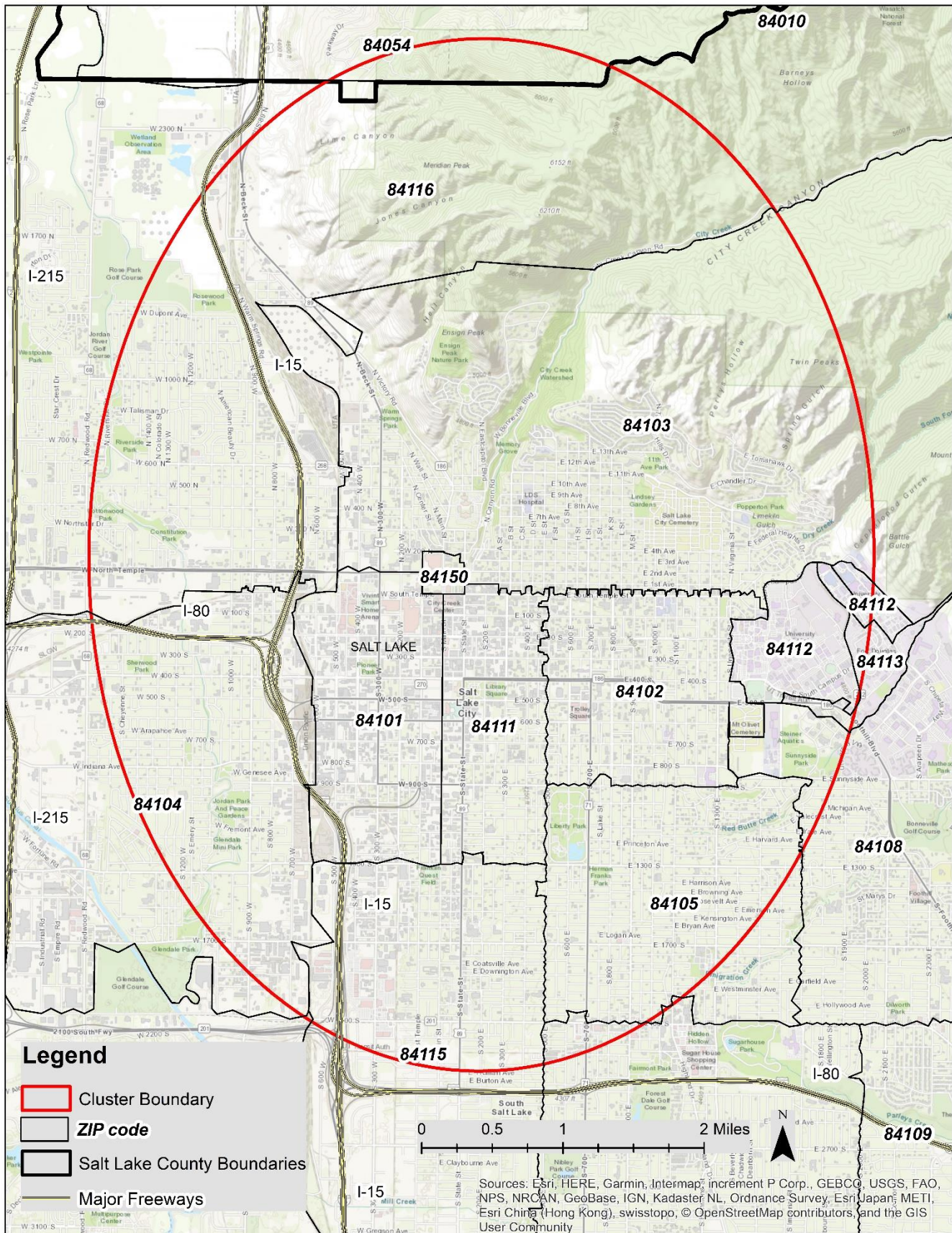
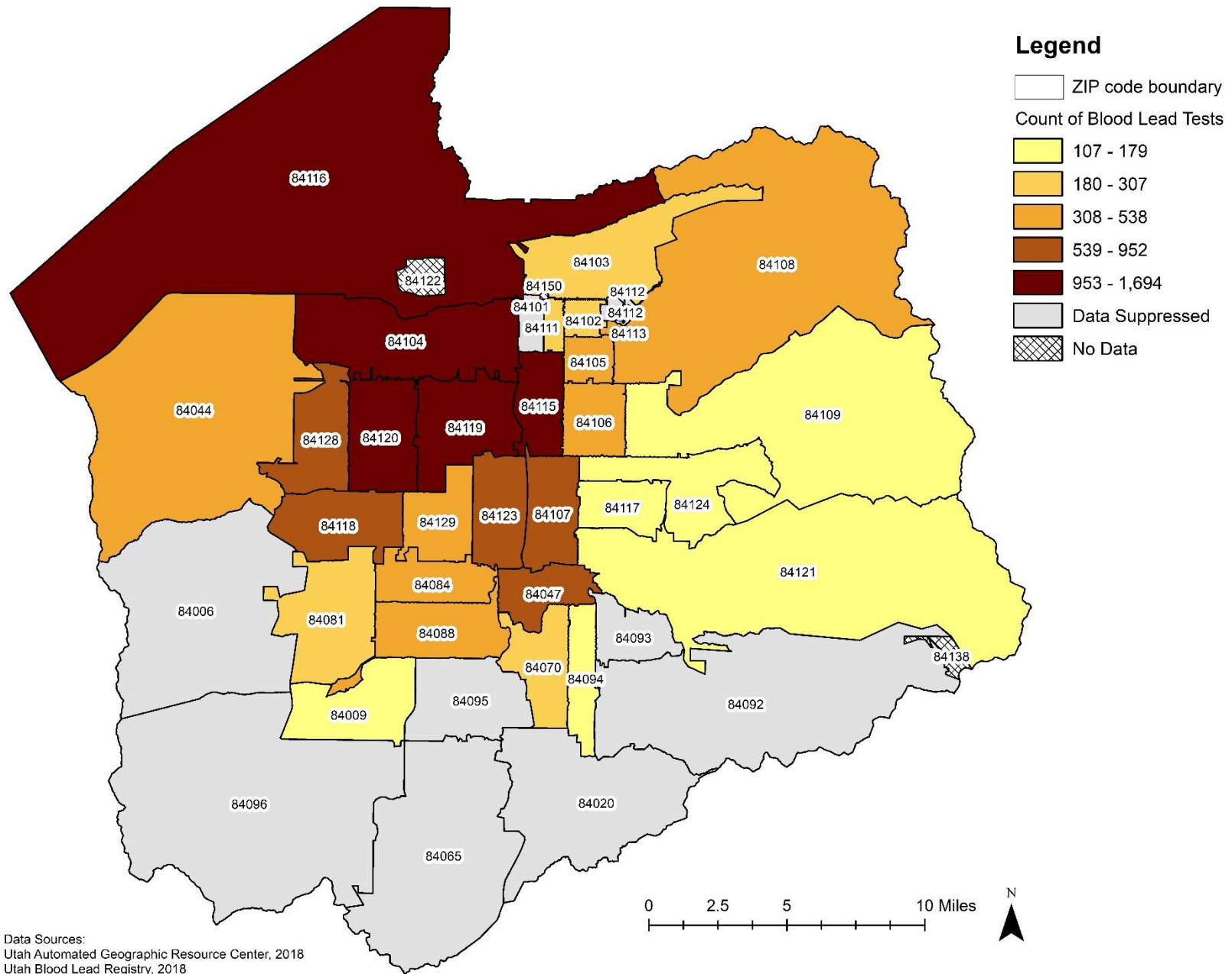


Figure 5. Number of blood lead tests, by ZIP Code, Salt Lake County, Utah, 2008-2017



Study population and blood lead test result descriptive statistics

Table 1. Study population demographics

	<i>Cases</i>	<i>Non-Cases</i>	<i>Total</i>
Age			
< 1 year	29	1,385	1,414
1 year	176	7,427	7,603
2 years	83	3,429	3,512
3 years	48	1,478	1,526
4 years	33	1,274	1,307
5 years	17	436	435
Gender			
Male	207	7,843	8,050
Female	171	7,499	7,760
Unknown	8	87	95
Race			
Asian	10	372	382
Black	18	622	640
White	67	3,677	3,744
Other	27	1,960	1,987
Unknown	264	8,798	9,062
Ethnicity			
Hispanic	21	1,393	1,414
Non-Hispanic	17	318	335
Unknown	348	13,718	14,066

Table 2. Blood lead test results

	<i>Count</i>	<i>Percent</i>
Case Status		
Case	386	2.4%
Non-Case	15,429	97.6%
Total	15,815	100.0%
Test Result		
< 5 µg/dL	15,429	97.6%
5 - 9.9 µg/dL	292	1.8%
10 - 14.9 µg/dL	54	0.3%
15 - 19.9 µg/dL	21	0.1%
20 - 24.9 µg/dL	13	0.1%
25 - 44.9 µg/dL	6	0.04%

Table 3. Blood lead test characteristics

	<i>Cases</i>	<i>Non-Cases</i>	<i>Total</i>
Test Type			
Capillary	124	4,470	4,594
Venous	224	10,799	11,023
Unknown	38	160	198
Test Status			
Confirmed	224	10,935	11,159
Non-Confirmed	162	4,494	4,656
Annual Counts			
2008	61	1,316	1,377
2009	68	1,313	1,381
2010	46	1,532	1,578
2011	48	1,362	1,410
2012	20	1,113	1,133
2013	22	1,246	1,268
2014	11	1,003	1,014
2015	14	1,096	1,110
2016	41	2,499	2,540
2017	55	2,949	3,004

APPENDICES

Appendix A: Frequently asked questions about childhood blood lead screening in Utah

Question #1: When and where is a child's blood lead exposure risk assessed?

Answer: All children in Utah who live in a ZIP code that has $\geq 27\%$ of pre-1950 housing should have at least one venous or capillary blood lead test at 12 and 24 months of age, and children 36 to 72 months of age who have not been screened previously (EEP 2003).

Childhood blood lead tests are typically only conducted under the age of 6 (72 months). This is because the risk of lead exposure significantly drops after that age, mostly due to behavioral changes (e.g., reduction in hand-to-mouth activity, not crawling on the floor). Risk increases again in late adolescence into young adulthood due to occupational exposures (i.e., by entering the work force), and involvement in other hobbies and activities (e.g., using all-terrain vehicles on mine tailings, bullet reloading, shooting activities, stained glass work).

The EEP provides childhood blood lead screening recommendations to physicians, who are then responsible for assessing risk. If a parent becomes concerned that their child may have been exposed to lead, then the child should be tested.

Children who are enrolled in Medicaid should have at least one venous or capillary blood lead test at 12 and 24 months of age, and children 36 to 72 months of age who have not been screened previously. Blood lead screening is included in the Medicaid providers manual and is assessed at the health care provider's setting. This manual includes its own risk factors the physician should consider when evaluating risk.

Question #2: How often are children screened for elevated blood lead levels?

Answer: The frequency of screening depends on the result of the initial blood lead test. If the test result is elevated ($\geq 5 \mu\text{g/dL}$), re-testing occurs. Depending on the result of the test, additional interventions may be taken (see Question #4). Multiple tests should be administered every two to three months to make sure blood lead levels are decreasing. This occurs until two consecutive tests report levels $< 5 \mu\text{g/dL}$, at which point subsequent tests are administered annually. Furthermore, if a parent becomes concerned that their child may have been exposed to lead, then the child should be tested.

Question #3: How do we know that all children who are at-risk for elevated blood lead levels are being screened?

Answer: Based on the recommendations, it is probable that more children should be screened than currently are being screened. However, there is currently no enforcement of the EEP childhood blood lead screening recommendations.

The UDOH works with state and local partners and stakeholders to assess and reduce elevated blood lead levels in children. These efforts include increasing awareness of the importance of blood lead screening; providing education on the risks of elevated blood lead levels; disseminating screening recommendations; facilitating test result reporting; and, identifying and mitigating potential sources of lead exposure.

Question #4: What is the role of the local health departments?

Answer: Currently, local health departments assist in notifying the child's parent(s) or guardian(s) of an elevated blood lead test. The specific response and action is contingent upon the reported test result. A table that explains the Utah blood lead follow-up guidelines based on the test result is shown on page 33.

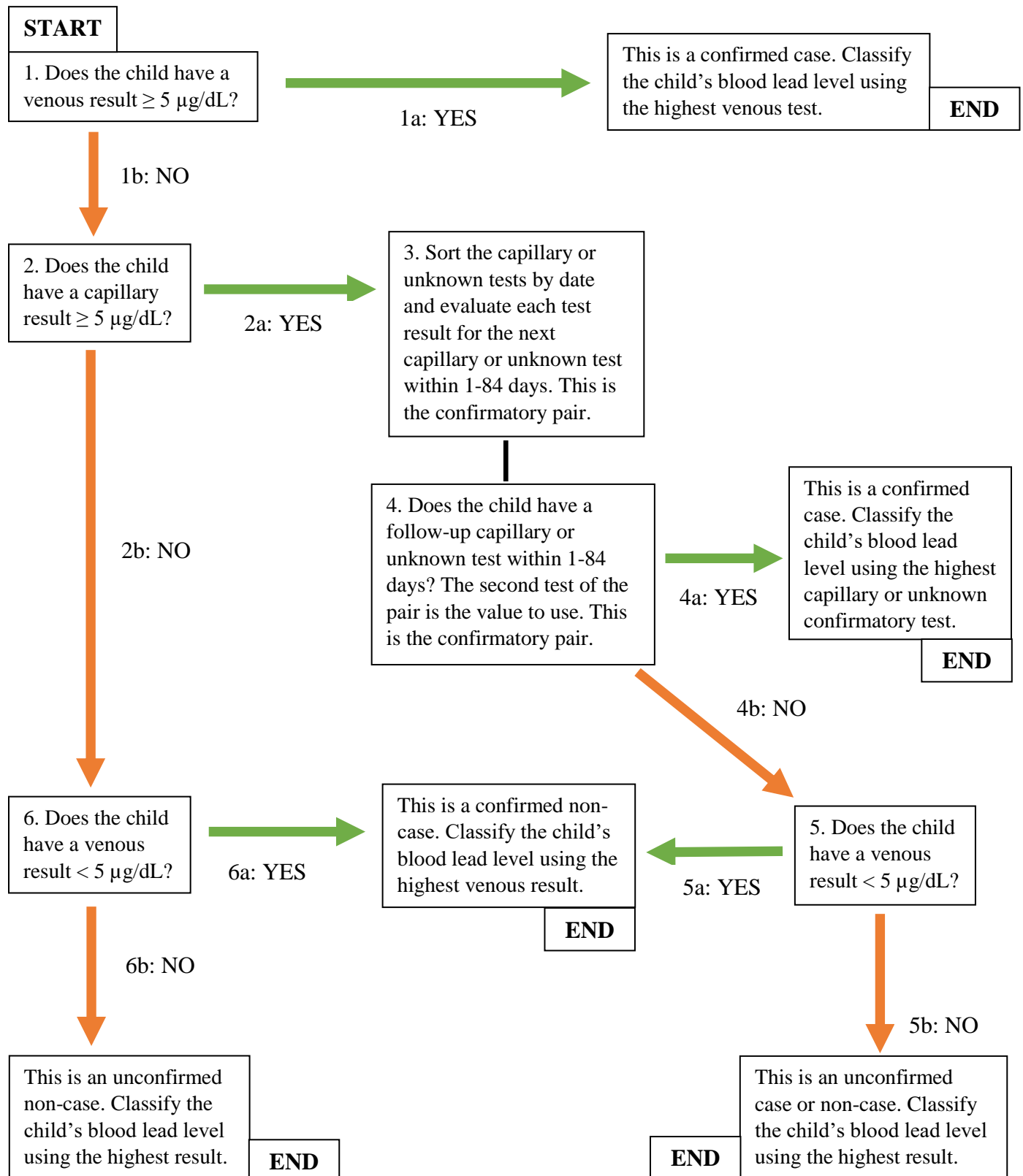
Additional action may be taken if a blood lead test result is ≥ 10 $\mu\text{g/dL}$. For test results ≥ 10 $\mu\text{g/dL}$, a Risk Assessment (RA) questionnaire is administered to the parent(s) or guardian(s). This is used to help determine the source of lead exposure. For test results ≥ 20 $\mu\text{g/dL}$, an environmental assessment is conducted. The assessment consists of testing and sampling paint, soil, water, and other products to determine if lead is present at or above action levels for remediation.

Utah Blood Lead Follow-up Guidelines

- For lab reports of blood lead tests performed on children from birth to age 15, follow the guidelines below at the various blood lead level ranges.
- If aged 16 years or older, no follow-up is needed at any blood lead level. However, if the blood lead level is $\geq 5 \mu\text{g/dL}$, it may be recommended that any child and/or pregnant woman (or who may become pregnant) who is living in the home receive a blood lead test.

5 – 9.9 $\mu\text{g/dL}$	10 – 14.9 $\mu\text{g/dL}$	15 – 19.9 $\mu\text{g/dL}$		20 – 44.9 $\mu\text{g/dL}$	45 – 69.9 $\mu\text{g/dL}$	$\geq 70 \mu\text{g/dL}$
Notify parent(s) or guardian(s) and provide test results	Contact parent(s) or guardian(s) and provide test results	Contact parent(s) or guardian(s), provide test results, and conduct RA questionnaire of child		Contact parent(s) or guardian(s), provide test results, and conduct RA of child	Contact parent(s) or guardian(s), provide test results, and conduct RA of child	Contact child's physician and coordinate for follow-up testing, and for emergency medical intervention
Contact child's physician for confirmatory test (venous-preferred or capillary) within one month of initial test, unless the initial test was a venous test	Contact child's physician for confirmatory test (venous-preferred or capillary) within one month of initial test, unless the initial test was a venous test	Contact child's physician for confirmatory test (venous-preferred or capillary) within one month of initial test, unless the initial test was a venous test		Contact child's physician for confirmatory test (venous-preferred or capillary) within one month of initial test, unless the initial test was a venous test	Contact child's physician for confirmatory test (venous-preferred or capillary) within one month of initial test, unless the initial test was a venous test	Contact parent(s) or guardian(s) and conduct RA of child
Provide educational materials to parent(s) or guardian(s)	Provide educational materials to parent(s) or guardian(s)	Provide educational materials to parent(s) or guardian(s)		Provide educational materials to parent(s) or guardian(s)	Provide educational materials to parent(s) or guardian(s)	Provide educational materials to parent(s) or guardian(s)
		If blood lead level drops to $< 5 \mu\text{g/dL}$: Continue to monitor and test annually	If blood lead level persists: Coordinate for an environmental investigation	Coordinate for an environmental investigation within 10 days	Coordinate for an environmental investigation within 5 days	Coordinate for an environmental investigation within 5 days
Send reminders to notify physician's office to conduct follow-up testing every two to three months until two consecutive tests are $< 5 \mu\text{g/dL}$	Send reminders to notify physician's office to conduct follow-up testing every two to three months until two consecutive tests are $< 5 \mu\text{g/dL}$	Send reminders to notify physician's office to conduct follow-up testing every two to three months until two consecutive tests are $< 5 \mu\text{g/dL}$		Continue to monitor blood lead level until two consecutive tests are $< 5 \mu\text{g/dL}$	Continue to monitor blood lead level until two consecutive tests are $< 5 \mu\text{g/dL}$	Continue to monitor blood lead level until two consecutive tests are $< 5 \mu\text{g/dL}$

Appendix B: Blood lead test result classification flowchart



Appendix C: SaTScan methodology description

The SaTScan (version 9.6) computer application applies spatiotemporal scanning methodology (Kulldorff 2018; SaTScan 2018; Kulldorff & IMS 2009). SaTScan implements a class of statistics known as “scan statistics” originally developed to scan through the spatial and temporal dimensions of interest, looking for anomalies in the incidence of an event(s) of interest (Wakefield et al. 2000). SaTScan scans data using all possible permutations of contiguous geography and time up to the maximum limits set by the user to identify likely spatiotemporal clusters. The tool quantifies the burden of these likely clusters with a relative risk measure and the significance of the clusters with a probability or p-value (Kulldorff & IMS 2018).

Cases and the underlying population are represented by a three-dimensional space-time point. This study uses the individual patient address as the geographic component coordinates. The scan method creates many cylindrical windows, where the base represents geography and the height represents time. These cylindrical windows are centered on each patient point and unit of time. Each cylinder is expanded incrementally to include multiple contiguous patient points and units of time. The incidence of elevated blood lead levels represented inside each cylinder is compared to the incidence outside the cylinder to identify areas and time periods of statistically elevated incidence. Many thousands of overlapping cylinders are evaluated and ranked for the likelihood of a cluster. For this evaluation, both circular shaped and elliptical shaped geography bases were used. The elliptical-based scan included all orientations and shapes of ellipses (Jones & Kulldorff 2012; Kulldorff 1997, 2018; Kulldorff & Nagarwalla 1995; Kulldorff et al. 2006).

Model parameters are decisions or limitations applied within the application to “tune” the model. Examples of model parameters include limits on the shape and size of the windows and the inclusions of various adjustments for spatial non-stationarity. The population is presented in the person-years units. To understand this unit, a cluster in a community of 1,000 persons lasting 10 years represents 10,000 person-years (1,000 persons x 10 years = 10,000 person-years).

Relative risk is one of the measures SaTScan generates to quantify the disease burden for a likely cluster. SaTScan only reports cluster areas that have a statistically elevated relative level. Relative risk is a ratio of the risk of elevated blood lead levels in the cluster area population, compared to the area outside of the cluster area (in this case, the rest of the county). If the cluster area’s level of risk equals the county’s level of risk, the relative risk ratio will equal one, which is interpreted as no increased burden of disease. Values greater than one are interpreted as a higher risk than expected. Conversely, values lower than one are interpreted as lower risk than expected.

SaTScan only reports likely clusters when the relative risk ratio is statistically elevated. However, for convenience of interpretation, the 95% confidence intervals (95% CIs) are included. The 95% CI ranges that almost include 1.0 (e.g. an interval range of 1.1 – 1.5) are less meaningful than those that do not (e.g., an interval range of 2.0 – 2.5). However, in these scenarios, both possible cluster areas had meaningfully increased relative risk values.

SaTScan generates an estimate of the likelihood of the cluster being a real spatiotemporal cluster and not just an artifact of the variability in the data. The likelihood is presented as a measure (probability) of randomness (or p-value). High p-values indicate a high degree of probability that the pattern is a result of the random variability in the data and not a real cluster. Low p-values indicate a low degree of probability that the pattern is a result of the random variability, hence, a higher likelihood of a real cluster.

Appendix D: Acronyms

µg/dL – Micrograms per deciliter (of blood)

AAPCEH – American Academy of Pediatrics Council of Environmental Health

AGRC – Utah Automated Geographic Reference Center

ATSDR – Agency for Toxic Substances and Disease Registry

CDC – Centers for Disease Control and Prevention

CMS – Centers for Medicare and Medicaid Services

eCFR – Electronic Code of Federal Regulations

EEP – Environmental Epidemiology Program

EPA – United States Environmental Protection Agency

IBIS – Utah's Indicator-Based Information System for Public Health

NAAQS – National Ambient Air Quality Standards

RA – Risk assessment

UBLR – Utah Blood Lead Registry

UDAQ – Utah Division of Air Quality

UDOH – Utah Department of Health

UEPHTN – Utah Environmental Public Health Tracking Network

USGS – United States Geological Survey