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Measuring Lead Concentrations of Vacant Lots in the Tree Street Neighborhood of Lewiston, ME

Final Report

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Executive Summary

High levels of lead contamination have detrimental health implications for communities, with the most profound impacts of lead poisoning affecting young children. The City of Lewiston, Maine, is home to a disproportionate amount of reported lead poisoning cases as compared to the rest of the state. Within Lewiston, the downtown “Tree Street” neighborhood contains 72% of all reported lead-poisoning cases in the city, signifying a need to identify the source(s) of lead exposure and minimize the impact of lead contamination on Tree Street residents.

In collaboration with Healthy Neighborhoods, we identified 19 vacant lots in the Tree Street neighborhood to test for soil lead contamination. With the aim of quantifying and contextualizing the distribution of lead across the vacant lots, we took 9 composite samples from each lot and tested them for lead using an X-Ray Fluorescence (XRF) gun. The XRF gun provided an elemental analysis of each sample in parts per million (ppm). Using this data, we created maps showing the geographic distribution of lead across the neighborhood and each site. We also created graphs showing the concentration distribution across and within sites. The most concerning site (site 17) had an average lead concentration of 634 ppm and a maximum value of 2370 ppm, which surpasses the Environmental Protection Agency (EPA) safety threshold of 400ppm for bare soil in play areas.

Along with identifying the extent and distribution of lead contamination in the vacant lots, we considered which types of lead remediation are best suitable for minimizing exposure to lead contamination in the Tree Street neighborhood. In this report, we examine the remediation strategies of phytoremediation, soil caps and raised beds, and soil amendments. After a comprehensive discussion of these three strategies in relation to the criteria of cost, feasibility, and effectiveness, we determine which strategies are most suitable for use in the lead-contaminated Tree Street neighborhood vacant lots. We recommend the use of sunflower phytoremediation as our primary remediation technique. We also recommend the use of certain soil amendments as a secondary remediation technique; the use of this strategy, however, is contingent on whether Healthy Neighborhoods and the City of Lewiston have access to the appropriate equipment necessary for the processing of these amendments. Finally, we end our report with recommendations for next steps for Healthy Neighborhoods and the City of Lewiston in continuing the project of creating a lead-free community.

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Background

The health implications of lead exposure are insidious, impacting almost every organ system, with particularly apparent effects on the central nervous system and the developing brain. Lead enters the brain as a calcium ion substitute, causing brain damage. Conditions stemming from this brain damage include intellectual disability, behavioral problems, nerve damage, and potentially Alzhemiers, Parkinsons, and Schizophrenia. (Sanders et al., 2010). In growing children, lead is also incorporated into the bones. This causes lead concentrations to be high in the blood of these children for years to come, as it takes many years for bones to breakdown and regenerate (Laidlaw and Filippelli, 2008). Although both leaded gasoline and paint have been banned in the United States, lead does not degrade in the environment and can remain in soil for years to come (Sanders et al., 2010). Lead contaminated soils are a health hazard of epidemic proportions in the United States, with children living in urban areas being the most vulnerable demographic. It is estimated that over 3.6 million American homes with significant lead paint contamination have at least one child living in them (Hauptman et al., 2017). The quantity of lead in the built environment is estimated at 10 million metric tons (Mielke and Reagan, 1998).

Vacant lots have high risks of lead contamination because of their potential demolition history in addition to their proximity to roads. Post-industrial cities have increasing levels of vacant and abandoned properties, including blighted residential, commercial, and industrial buildings (Schilling and Logan, 2008). An abundance of these vacant properties can lead to negative patterns of reduced property values and increased crime in affected areas, so many cities have undertaken initiatives to demolish or deconstruct vacant buildings (Beniston and Ratan, 2011).Heavy metal contamination in the soil of vacant lots can be attributed to an industrial past and contamination with wastes and stack fumes, vehicular exhaust and, metals in the exterior paint on houses (Sharma et al., 2014). Popular community solutions for dealing with these vacant and potentially contaminated plots have been community gardens and urban farms with their potential to provide numerous societal benefits (Smit et al., 2001). Community gardens provide access to low cost, local food resources some users might not have access to otherwise. At the same time, urban gardening on a contaminated lot can also increase exposure to lead-contaminated soil (Latimer et al., 2016).

Lead contamination is a prominent issue in Lewiston, Maine, where an aging housing stock containing high levels of lead paint (Skelton, 2016) is a leading contributor to the city’s status as having “the highest lead poisoning rate in the state” (Kittredge, 2018). In 2018, there were 210 cases of high blood-lead levels in children around the city (“Growing Our Tree Streets,” 2018, p. 42), accounting for over half of the most recent data reporting 310 cases of elevated blood-lead levels in the state of Maine (CDC, 2019). In addition to the health risks the current housing stock pose, buildings in downtown Lewiston continue to be condemned and demolished, creating vacant lots whose soil is contaminated with remnants of lead paint from the former structures. Many of these lots are located in the Tree Street neighborhood of downtown Lewiston, an area characterized by “concentrated poverty [and a] slow pace of revitalization and rehab” (“Growing Our Tree Streets,” 2018, p. 6).

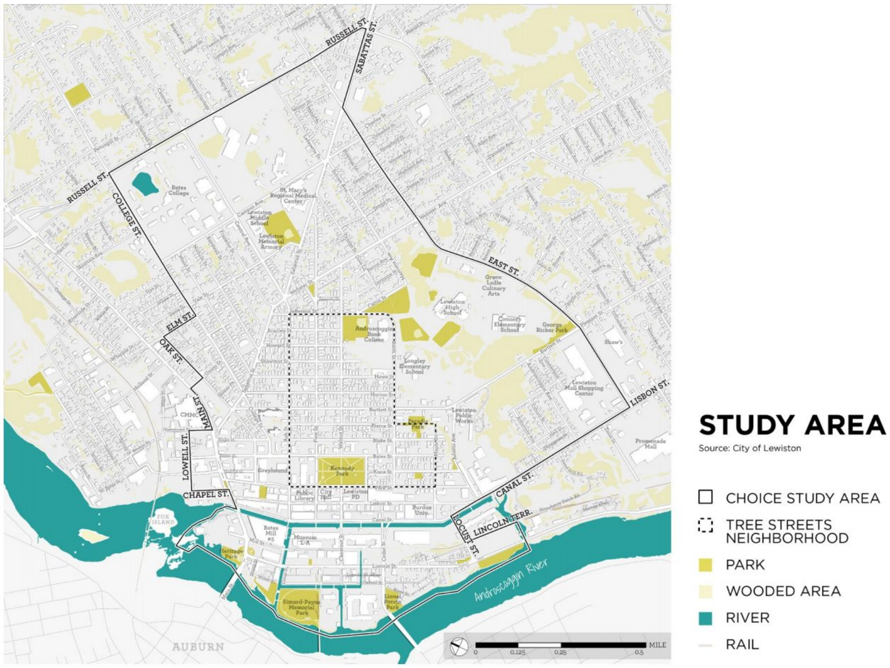

Figure 1. The Tree Street Neighborhood in the context of greater Lewiston, ME (“Growing Our Tree Streets,” 2018, pg. ii)

Since 2008, at least 142 housing units were demolished in the Tree Street neighborhood (“Growing Our Tree Streets,” 2018, p. 51). Of the 210 children who testing positive for elevated blood lead levels in Lewiston, 72% of them live(d) in the Tree Street neighborhood (“Growing Our Tree Streets,” 2018, p. 51) These high rates of demolition and concentration of children experiencing lead poisoning, in combination with other social demographic factors, makes the Tree Street neighborhood a particularly vulnerable area in Lewiston for exposure to lead in housing structures and the soil, along with the impacts that come from lead contamination.

Healthy Neighborhoods is an organization in downtown Lewiston whose transformation plan “Growing Our Tree Streets” is focused on “grow[ing] as a safe, healthy, welcoming, equitable, and vibrant community” (“Growing Our Tree Streets”, 2018, p. 3) through the completion of 9 goals. Their first goal, as outlined in their plan, is to “Grow a Healthy Future through a Holistic Lead-Free Lewiston Effort Rooted in the Tree Streets” (“Growing Our Tree Streets”, 2018, p. ix). This goal is threefold and encompasses steps including educating families on health risks and lead screening processes, ensuring current housing stock is fit to live in, and removing lead in general from the Tree Street Neighborhood (“Growing Our Tree Streets”, 2018).

In order to move toward the completion of Healthy Neighborhoods’ goal to create a lead-free Lewiston, our project aims to reduce health risks impacting Tree Street residents through two objectives:

Objective 1: Quantify the spatial extent and the level of lead contamination in the soil of 19 vacant lots in the Tree Street neighborhood.

Objective 2: Determine which remediation techniques are the most feasible and suitable for the contaminated Tree Street lots.

Methodology

Our methodology can be broken down into four sections: (1)sampling, (2)testing, (3)data analysis, and (4)remediation criteria and evaluation.

(1)Sampling Method:

Our sampling regime consisted of collecting and testing soil from 19 vacant lots identified by Healthy Neighborhoods and the City of Lewiston. These sites are located in the downtown Tree Street neighborhood of Lewiston, and were targeted for lead testing and remediation within the larger framework of the collaborative redevelopment efforts being conducted by the City of Lewiston, Healthy Neighborhoods, and the Department of Housing and Urban Development through a Choice Neighborhoods grant.

Using a measuring tape and colored flags, we divided each site into a grid made up of nine equidistant points. Each of the samples were composed of five subsamples, one of which was sourced from the center sample and four of which were sourced from a foot away from the center sample in four separate directions.[1] Ground cover was removed using a shovel, and soil samples were collected from just below the surface. The soil was mixed using a bowl and spoon, bagged, and labeled with the site and sample number. At each site, we collected GPS points to maintain spatial accuracy when constructing our GIS maps. We also created hand-drawn maps to correspond with our GPS points, allowing us to cross-reference the locations of the GPS points with the points drawn on the maps and therefore achieve accuracy in the location of the sample points plotted on our final maps.

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[1] Our inclusion of composite samples as opposed to samples taken from a singular location accounts for soil’s high variability; by taking a composite sample made up of five subsamples, we were able to better determine the average lead concentration found in the soil covering the sample area.

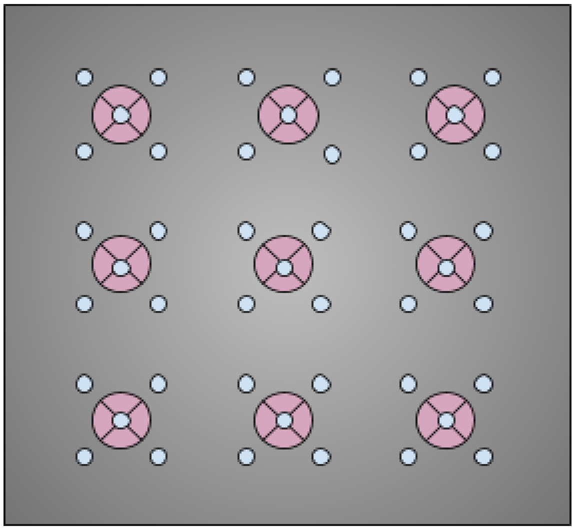

Figure 2. Composite sampling method

The blue dot in the middle of each quadrant represents the center sample point of each composite sample. The four blue dots outside of the pink circle represent the 4 other composite samples collected for each sample, while the pink circle represents the foot distance we compiled these 4 samples from.

(2)Testing Method:

After collecting our samples, we tested their heavy metal concentrations in a lab at Bates College. We labeled weighboats and filled each with soil from the corresponding site. Next, we dried the samples in a drying oven for 24 hours at 60 degrees Celsius. Then, we used an x-ray fluorescence (XRF) gun to measure heavy metal contamination levels of each sample.[2] In the interest of capturing all potentially dangerous heavy metal content in the soil (despite our project's focus on lead), we recorded data on the XRF gun's calculated lead, chromium, arsenic, thallium, mercury, and cadmium levels for each soil sample and compiled this data in a spreadsheet. For each data point we also recorded its standard error as determined by the XRF gun.

We determined that our threshold for concern for lead would be 100 ppm, based on the Minnesota state threshold for lead contamination which states that "bare soil on an affected property or on a play area is lead-contaminated if it contains lead in a concentration of at least 1/100 of one percent (100 parts per million) by weight" (Minnesota Department of Health, 2004). For growing crops, we determined that 400 ppm would be the threshold for concern, based on

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[2] We dried the soil samples before testing their heavy metals concentrations in accordance with protocol from Binstock et. al which specifies that drying soil samples before using the XRF gun yields more accurate results than simply testing the soil on site (Binstock et. al, 2009).

the EPA's threshold (U.S. Environmental Protection Agency, 2014). It should be noted that while higher thresholds for lead-contamination in soil exist— for instance the EPA's threshold for lead-contaminated soil in children's play areas is 400 ppm while their threshold for soil in non-play areas is 1200ppm (EPA, 2019)— we chose to follow the lowest threshold we could find (Minnesota's) in the interest of minimizing exposure to any potentially harmful levels of lead-contamination. Although our threshold value for concern (100ppm) is relatively low when compared to the general EPA threshold, we see our standard as taking precaution against any exposure to lead that could be viewed as potentially harmful for human health.

(3)Data Analysis

Mapping:

We created maps using a shapefile of the 19 Tree Street neighborhood vacant lots, provided by Carissa Aoki and Francis Eanes. The GPS points taken at the sites were imported to the map. Each point was cross checked with the hand drawn map we drew in the field in order to ensure accuracy. Once the location of the points was confirmed to be correct, they were classified according to their lead value (ppm). The first range, 0ppm to 99ppm, was the 'below threshold' (green) range, meaning that no lead value in that range crossed any of our researched thresholds. The second range, 100ppm to 400ppm, was the 'between thresholds' (yellow) range, meaning that any point in that range was between the lowest Minnesota threshold (100ppm) and the EPA's threshold (400 ppm). The final range,>400ppm, was the 'above threshold' (red) range and encompasses all points that cross the EPA's threshold and should be considered a problem. A map was created for each site to show the lots' surrounding environment as well as the distribution of lead across the site.

Two overview maps were created to show the average and maximum lead levels for each of the 19 lots (Appendix A). The average lead values were assigned to the original shape file and classified by the same ranges as in the individual site maps. The same was done for the maximum lead value for each site. All maps were compiled into a single document.

Graphs:

In order to better compare the data within and across sites, we made several bar charts. The first set displays the maximum and average lead level per lot in comparison to our lowest threshold (100ppm). The second set displays the lead level for each of the 9 sample points within each site in comparison to the site average (Appendix B). The first allows for comparison between sites while the second allows for the identification of potential hotspots within a particular site.

(4)Remediation Criteria and Evaluation:

We created a set of remediation criteria that we believe best reflects the interests of the community. These criteria include feasibility, cost, and effectiveness. In this report, we define feasibility as the ease in which the community can practice this remediation method given their access to the necessary equipment and materials. We define cost as the total cost it takes to purchase the supplies necessary for the remediation method, the cost of labor needed to implement the method, and other costs associated with the method's process (such as disposal of hazardous waste). We define effectiveness as the ability for the remediation method to prevent exposure to lead. As will be discussed later in the report, we examine the *in situ* methods of remediation including soil amendments, phytoremediation, and soil capping and raised beds.

Results:

Figure 3 shows the average lead contamination level across all 19 vacant lots in comparison to our lowest threshold (100 ppm). Sites 2, 5, 7, 8, 11, 12, 17, and 18 all cross the lowest threshold of 100 ppm. The only two sites that cross the EPA threshold (400 ppm) are sites 12 and 17. These two sites are the most concerning, given their extremely high levels of lead concentration.

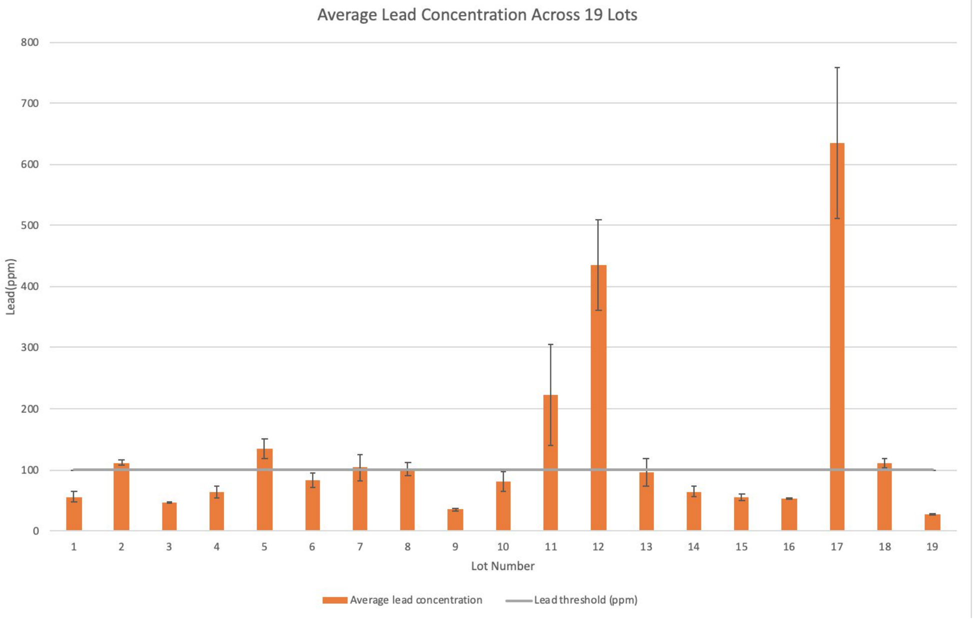

Figure 3. Graph of average lead concentration across the 19 lots

Figure 3 shows the spatial distribution of these 19 sites across the Tree Street Neighborhood and has marked sites according to their lead level. There are 12 lots below any threshold, 5 between thresholds, and 2 above the EPA threshold. The distribution of lead in sites 12 and 17 can be seen the individual maps for the sites in Appendix A. Site 12 has its highest levels of lead on the corner of Pine Street and Bartlett Street with only one point below any threshold in the opposite diagonal corner (Appendix A). Site 17 has its highest concentration of lead away from the street towards the back of the lot (Appendix A).

Figure 4 shows the maximum lead level for each of the 19 vacant lots in comparison to our lowest threshold (100ppm). Sites 1, 2, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14,15, 17, and 18 all crossed the lowest threshold of 100 ppm. Sites 12, 13, and 17 all crossed the EPA threshold of 400 ppm. If we look at the maximum lead values, then these three sites become the most concerning because they have the highest-valued hotspots.

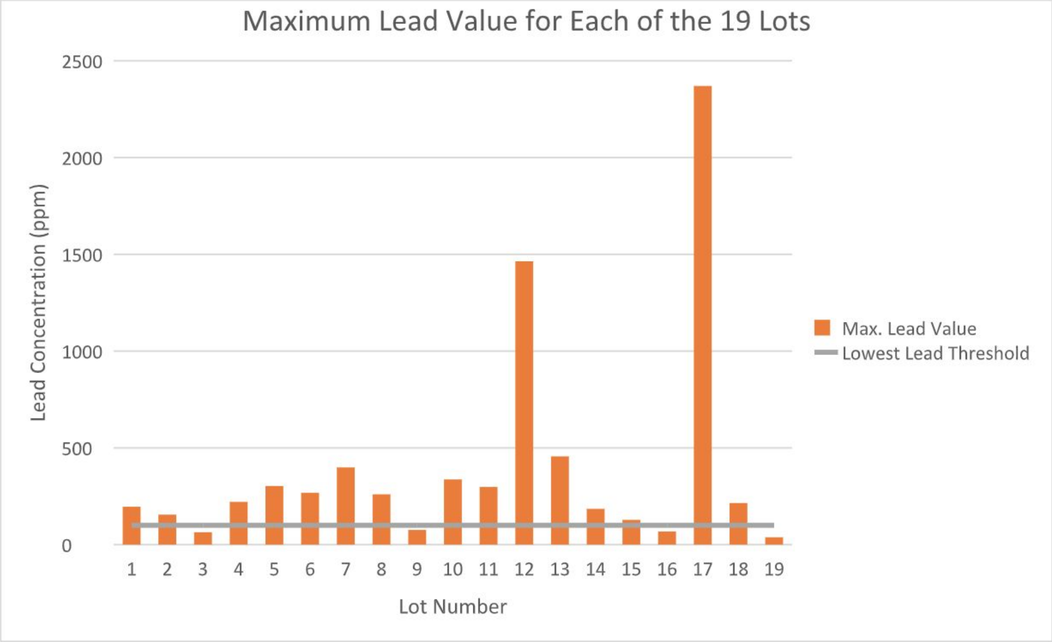

Figure 4 - Graph of maximum lead concentration for each of the 19 lots

When looking across all 19 lots there were 45 hotspots that exceeded the 100 ppm threshold (see maps in Appendix A). Concentrations of hotspots differ by site. Notably, the individual site maps in Appendix A and graphs in Appendix B show that site 2 had five hotspots, site 5 had four hotspots, site 8 had four hotspots, site 12 had eight hotspots, site 17 had six hotspots, and site 18 had five hotspots. Site 12 had the highest number of hotspots with eight, followed by site 17 with six, sites 2 and 18 with five, and finally sites 5 and 8 with four.

There are 7 hotspots that exceed our highest threshold of 400 ppm. These are the most concerning because they have the highest concentration. Individual site maps in Appendix A and graphs in Appendix B show that Site 17 had the highest number of hotspots that exceeded the 400ppm threshold, with 4 hotspots. Site 12 had two hotspots that exceeded this highest threshold, while Site 13 had one hotspot above the 400ppm threshold.

Discussion:

The variance in concentrations of lead across the 19 lots could be related to the ways in which lead enters the soil. Hotspots seemed to be more likely to occur when they were adjacent to a road or to another vacant lot where a demolition had previously occurred. For example, site 2 had hotspots adjacent to Pine Street and Webster street, two busy Lewiston roads. These hotspots could therefore be a result of lead contamination from gasoline runoff. Furthermore, site 17 had hotspots adjacent to vacant lots on the Northern and Eastern edges of the lot where we assumed buildings used to be located. These hotspots could therefore be a result of lead-contaminated paint entering the soil from building demolitions. Sites that were free of hotspots, like sites 3 and 9, generally were surrounded by other buildings. While these observations seem noteworthy, our hypothesis for why hotspots occurred in certain areas has not been tested with any kind of statistical analysis; they are just general observations. However, a future statistical analysis of a correlation between proximity to roads or vacant lots and lead concentration could yield important results. Results from such an analysis could help identify which lots have higher lead contamination risks as well as whether or not demolitions are being completed safely with minimal impact on surrounding lots.

The impact of impending demolition on lead levels in the soil of vacant lots across Lewiston should be another point of investigation. During our sampling of site 10 and 11, we noticed the buildings on the Northern and Southern end of the lots being stripped and prepared for demolition. These sites, at the time of our sampling, only had three points of concern between 100ppm and 400 ppm that were all located on the border of the lots adjacent to the road. We believe this lot will have a high possibility of lead contamination and that they should be tested again after the demolitions have been completed. These results could lead to an investigation of the current procedure of demolition in Lewiston.

The results of our sampling and testing of the soil in the 19 vacant lots exemplify the need for some sort of lead remediation in the majority of the lots. 8 out of the 19, or 42%, of the lots, exemplify average lead concentrations over the lowest threshold (100 ppm), while 14 out of 19, or 74%, of the lots contained at least one hotspot of lead contamination that exceeded the lowest threshold. In order to determine which forms of remediation are the most suitable for use in these lots, it is first important to define what types of remediation techniques exist and why we chose to focus only on three broad categories of remediation within our project.

Generally, remediation of lead-contaminated soil is focused on minimizing the impacts of lead exposure to the environment and people (Wuana and Okieimen, 2011). Within the broad scope of remediation, there are *in situ* and *ex situ* treatments. *In situ* treatments are focused on treating the contaminated soil onsite, while *ex situ* treatments entail the removal of soil from its original location to be treated or disposed of offsite (Wuana and Okieimen, 2011). In the context of our project, we focus on only *in situ* remediation techniques, as *ex situ* excavation and transportation of soil to another location generally requires more resources and is more costly than other *in situ* remediation methods (Wuana and Okieimen, 2011). Additionally, the Healthy Neighborhoods organization has voiced their desire for the use of *in situ* methods in this project. The drawbacks of *ex situ* methods and the requests from our community partner, therefore, has guided our research to focus on only remediation technology that can be applied to soil onsite.

In terms of *in situ* remediation techniques, “immobilization... and phytoremediation techniques are frequently listed among the best demonstrated available technologies for remediation of heavy metal-contaminated sites” (Wuana and Okieimen, 2011, p.2). Conversations with Healthy Neighborhoods member Shanna Cox revealed an interest in the research of both immobilization and phytoremediation techniques. In addition, Lewiston’s proximity to the Maine coast and some initial research done by Cox on the ability for crustacean shells to be used in remediation practices led us to focus on immobilization techniques using crustacean shells and other soil amendments.

Lastly, while not included in the realm of phytoremediation or immobilization techniques, we decided to research the use of soil caps and raised beds as a third possible strategy to reduce health impacts from lead contamination. The current use of raised beds in some Lewiston properties demonstrated a need for more research on their effectiveness and feasibility of reducing the human consumption of lead. Different forms of soil caps provide another possible way to contain lead-contamination and reduce lead-related health impacts in downtown Lewiston, leading us to research their effectiveness, cost, and feasibility.

The following sections describe each lead remediation strategy in depth, along with an evaluation of their cost, effectiveness, and feasibility in the context of our project. The three strategies are then compared against one another in order to offer guidance as to which remediation strategy(ies) may prove the most suitable for use in the contaminated Tree Street lots.

Phytoremediation:

Phytoremediation is the process by which plants “capable of extracting hazardous substances… from the environment” are used to uptake “heavy metals and turn them into safe compound metabolites” (Mahar et. al, 2016, p.112). In other words, phytoremediation uses plants to remove heavy metals, like lead, from the soil to prevent consumption and further contamination of these dangerous metals. Under the umbrella of phytoremediation are phytostabilization and phytoextraction. Phytostabilization uses plants’ root systems to “absorb and accumulate” heavy metals, making them less bioavailable to the surrounding environment (Mahar et. al, 2016, p.117). Phytoextraction, on the other hand, is not focused on simply reducing bioavailability of metal in soil, but actually extracting the metals, transferring them from the ground into the biomass of the plant (Mahar et. al, 2016). Because “phytostabilization is not tasked at the remediation of polluted soils but at the reduction of the contamination of nearby media” (Mahar et. al, 2016, p.117), our research is focused on phytoextraction as the desired form of phytoremediation. While we recognize that other remediation strategies we’ve researched, such as immobilization techniques, focus on the containment rather than extraction of heavy metals, given the option in phytoremediation to either contain or extract dangerous metals from contaminated soil we prefer the option of extraction. It is therefore noted that in further discussion of phytoremediation in this report, phytoextraction is the implied technique as opposed to phytostabilization.

While the field of phytoremediation is “relatively recent… with research studies conducted mostly in the last two decades” (Ali et. al, 2013,p. 871), its benefits have been recognized through numerous scientific studies and applications that point out its cost-effectiveness, environmental benefits and friendliness, aesthetic value, and ease of implementation. While other remediation methods often require “expensive and intrusive” measures to extract heavy metals from the soil (Purakayastha et. al, 2018, p.62), the “costs of growing a crop are minimal when compared to those of soil removal and replacement” (Adesodun et. al,2009,p.196). In addition to the economic benefits of phytoremediation, the technique not only provides an alternative to the degradation of soil structure that is consequential from soil washing and leaching processes, (Adesodun et. al, 2009), but actually provides the opportunity to “improve soil quality for the subsequent cultivation of crops” and “prevent erosion and metal leaching” (Ali et. al, 2013,p.871). In the context of the Tree Street lots, which may be used as sites of crop production and cultivation in the future, this prospect of strengthening soil quality is attractive in the prospects of future community gardening projects.

Besides the economic and environmental benefits of phytoremediation, it is a remediation strategy that is visually pleasing and relatively easy to implement and maintain. The planting, maintenance and cultivation of plants requires a low level of technical training and the aesthetics of covering vacant lots in vegetation is likely to draw “good community acceptance” (Mahar et. al, 2016, p.119) of the project. The ease of implementation in phytoremediation practices also provides a potential opportunity for community engagement. Community-centered events for planting and harvesting the plants used in phytoremediation, along with the potential for a shared responsibility of maintenance during the growing season, could serve as a way to build community and a shared investment in the project of creating a lead-free Tree Street Neighborhood.

In the realm of phytoremediation, the plants which are able to accumulate the greatest heavy metal contaminants from the soil are referred to as hyperaccumulators. Since the start of phytoremediation research in the 1990s, research in the lab and in the field have helped determine which plants can be classified as hyperaccumulators, as well as which of these plants are the most effective in removing lead and other heavy metals from contaminated soil. In researching which plants would be most effective and feasible to implement in the phytoremediation of the contaminated Tree Street lots, we considered which plants had the most literature written on their phytoremediation potential, along with which plants made sense climatically and aesthetically for implementation.

While there is literature on a variety of different hyperaccumulators, from ferns (Salido et. al, 2003) to legumes (Wang et. al, 2002) to hydrangea plants (Forte, 2017), the most has been written on the use of Indian Mustard (*Brassica juncea*) and sunflowers (*Helianthus annuus*) to uptake lead. Although these two species of plant both have the capacity to grow in Maine, research asserting that “the sunflower has a greater potential for HMs [heavy metals] uptake and tolerance than other crops” (Rizwan et. al, 2016, p.1499), along with the plant’s high biomass (Ангелова et al, 2016), the aesthetic value of the flower, and past endeavors with sunflower remediation in Lewiston properties lead us to pursue the sunflower as our main subject of phytoremediation research in this project[3].

In examining the phytoremediation potential of sunflowers, we investigated existing research to interrogate questions of the time period and extent to which the plant is able to uptake lead from the soil. While the studies show variability in the exact amounts of lead extracted by the sunflower plant, some notable studies demonstrate that one plant is able to remove as much as 700ppm lead from contaminated in soil in 4 weeks (Forte et. al, 2017). This research indicates that hazardous amounts of lead could be removed from many of the sampled Tree Street lots in only 4 weeks, meaning that the lots have the potential to be remediated to lead concentration levels below our lowest threshold in only one growing season.

In terms of maximizing the potential for sunflower phytoremediation in the Tree Street lots, there are additional agents one can use in conjunction with the plant in order to enhance lead uptake, including chelating agents. Chelating agents are chemicals used to help bind

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[3] It should be noted that while we chose to exclude Indian Mustard for our project due to a desire to minimize cost and maximize ease of implementation by recommending only one species of plant for phytoremediation, there have been many studies that indicate its effectiveness in phytoremediation processes and therefore it should not be discounted as a consideration in future remediation endeavors.

heavy metals together, therefore increasing their bioavailability and assisting in their uptake by hyperaccumulators (Mahar et. al, 2016). While the use of chelating agents seems appealing in their efficiency to speed up the process of phytoremediation, there are also significant economic and environmental costs that come with the use of such agents. Using fertilizer, acid, or other chemical compound chelating agents is expensive and comes with the risk of contaminating groundwater and soil structure (Mahar et. al, 2016). Some of the studies that test the ability of chelating agents to aid phytoremediation even recommend against the use of the agents outside of the lab setting because of these environmental hazards (Salido et. al, 2003; Rizwan et. al, 2016). In the interest of minimizing remediation costs and environmental degradation in our project, we are not currently recommending the use of chelating agents in the Tree Street lots.

An alternative to chelating agents, however, comes in the form of organic amendments such as compost and vermicompost (composting with worms). While there is not a significant amount of research on the specific effect that compost has on the uptake of lead in sunflower phytoremediation, a few studies have shown that “tested organic amendments significantly increased the uptake of Pb… by the sunflower plant,” (Ангелова et. al, 2016, p.261) in the compost’s ability to both increase the bioavailability of metals in the soil and strengthening the plant’s resistance to the toxicity of metals such as lead (Jadia et. al, 2008). Based on this research, along with the general trend of organic fertilizer as being beneficial to plant growth, we recommend the consideration of compost and other organic amendments in this project.

A major consideration within the process of phytoremediation is the safe disposal of the hyperaccumulator plants that are used to extract lead and other metals from the soil. Upon their harvest, plants contaminated with heavy metals from the phytoremediation process must be treated as hazardous waste (Ali et. al, 2013), with the appropriate precautions taken to ensure risk minimization of these plants spreading metal contamination.

One big limitation in the research of phytoremediation is that there is a lack of field implementation of phytoremediation practices. The limitation of most research to “laboratory and greenhouse scales and only a few studies… conducted to test the efficiency of phytoremediation in the actual field” (Ali et. al, 2013, p. 877) leaves a gap between the results of phytoremediation in scientifically controlled experimental situations and literature on real-life implementation of these techniques in communities similar to Lewiston. Reasons for this lack of implementation include a lack of interest for commercialization because of phytoremediation’s longer timeline as compared to some other remediation methods and a lack of understanding regarding phytoremediation and its science from remediation practitioners (Beans,2017).

Valuable insight can be drawn from past experiences in Lewiston with sunflower lead remediation. Raise-Op is a downtown Lewiston-based organization that has used sunflowers to remediate a lead-contaminated property they sought to turn from a driveway into a garden (Craig Saddlemire, personal communication, 11/25/19). Although Raise-Op does not have access to data related to the lead levels in the soil before and after remediation, their experience growing sunflowers on these properties speaks to the importance of ensuring the soil quality in vacant lots is suitable for plant growth in the first place. According to Craig Saddlemire, the cooperative manager at Raise-Op who was involved in their sunflower remediation process, their efforts to grow sunflowers in the lead-contaminated lot was first met with minimal success due to a lack of nutrient content and the compactness of the soil (Personal communication, 11/25/19). After adding more soil from a neighboring lot, along with other soil amendments like compost and manure, the sunflower growth progressed and Raise-Op was able to successfully remediate the soil to safe crop-growing conditions (Saddlemire, personal communication, 11/25/19). In addition to Saddlemire's account, Sherie Blumenthal, another person involved in Raise-Op's remediation process, recalls that the use of sunflowers in this project resulted in the transformation of the soil from having "moderate" contamination to "no recognizable levels of lead" (Blumenthal, 2012).

In addition to the Raise-Op remediation project, the use of sunflower phytoremediation has been implemented in Lewiston-based lead remediation projects performed by St. Mary's Nutrition Center. In the organization's Lots to Gardens urban community gardening program, sunflowers have been implemented as remediation agents in some of the lead-contaminated sites. While initial contact was made to gather information about this project, more information should be gathered from the Nutrition Center as to the success of their projects and data concerning pre and post remediation lead concentrations.

As evidenced in the circumstances where poor soil conditions yielded poor sunflower growth, the use of amendments that increase the nutrient content of soil are crucial in creating an environment to stimulate sunflower growth and therefore soil remediation. In other words, "soil needs to be reasonably good for growing in the first place in order for most bio-remediation efforts to work properly" (Saddlemire, personal communication, 11/25/19). In considering phytoremediation of downtown Lewiston lots of our project, it is important to note the importance of soil amendments in promoting growth and making remediation projects successful. As emphasized previously, we strongly recommend the use of compost as a way to maximize the potential for effectiveness of sunflower remediation.

We will now discuss sunflower phytoremediation in terms of the remediation criteria guiding this project: effectiveness, feasibility, and cost. First, the effectiveness of the sunflower to remediate lead from the soil is apparent in the various studies that were researched and examined for this project. While discrepancies between studies exist regarding the amount of lead able to be remediated from the soil using sunflowers, the amount of research classifying the sunflower as an effective hyperaccumulator demonstrates its effectiveness in preventing lead exposure by uptaking and containing large amounts of lead from the soil. The success of the plant as a hyperaccumulator in previous Lewiston lead remediation projects shows that sunflowers are effective phytoremediators not only in studies outside of our project, but also in the context of Lewiston's climatic, environmental, and soil conditions.

The feasibility of sunflower phytoremediation is demonstrated through its ease of implementation. There is a minimal amount of equipment and supplies needed to perform phytoremediation; implementing the remediation strategy would require only the necessary materials needed to plant, grow, and harvest sunflowers (seeds, compost, water, shovels etc.) and perhaps vehicles to transport sunflower waste to hazardous waste disposal sites. The low level of technical training needed to grow sunflowers them speaks not only to their feasibility regarding implementation, but also to the potential for the remediation project to generate community engagement and investment. The ability for community members to engage in implementing this remediation strategy through planting, growing, and harvesting sunflowers on the contaminated lots could create the potential for sunflower planting and harvesting events on the lots, as well as a shared responsibility for maintaining sunflower growth. The strategy is not only feasible for implementation by Healthy Neighborhood members, then, but also has the potential for involvement from the Tree Street neighborhood community as a whole.

In order to calculate the cost of sunflower phytoremediation, we considered the cost of sunflower seeds and compost, the labor required for the remediation method, and the cost of disposal. In calculating a per unit cost for sunflower seeds and compost, we used the company Paramount Seeds to estimate cost per seed and the Maine-based company We Compost It! to estimate compost cost. Assuming each sunflower is planted 1-2 feet apart, each square foot of remediated land would have one sunflower on it. The cost of one sunflower seed, if purchased in a 10,000 seed quantity, is $.025 (Paramount Seeds, 2019). Assuming compost is added to the soil on the remediated area at a 1 inch depth, the cost of We Compost It! compost to fill a square foot at one inch depth is $.18 ,according to calculation guidance from The Daily Gardener compost price calculation page (Weeks, 2019). In total, the unit cost of one square foot of sunflower remediation is around $.20 per square foot of remediation.[4]

Figure 5 breaks down cost estimates for a variety of different methods that could be used to remediate the hotspots and lead-contaminated lots we have identified. Using Census data from LandGrid.com to calculate the area of each of our sample sites, we were able to apply the $.20/sq ft cost of sunflower phytoremediation to estimate the cost of remediating both the total area of contaminated sites and the hotspots on these sites. In calculating the area needed to remediate identified hotspots, we assumed that the area required to remediate one hotspot and its surrounding soil would be about 1/9 of the total site's area, given that we collected 9 composite samples from each site. It should be noted that these costs are mere estimates and are meant to give a rough idea of the range of phytoremediation options and their costs.

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[4] It should be noted that this cost does not include the cost of equipment to till compost into the soil on a large-scale level, which may be applicable to sites on our project. More information regarding the cost of this equipment should be considered.

Figure 5 shows an overview of cost estimates for different approaches to sunflower phytoremediation on contaminated lots. According to this table, the most expensive option for sunflower remediation would be planting sunflowers on the total area of sites whose averages exceeded the lowest 100ppm threshold, while the cheapest option would be to plant sunflowers only around hotspot areas that exceeded the highest 400ppm threshold. The table also shows how different approaches to remediation will yield different costs. For example, focusing on remediating hotspots with relatively higher lead concentrations is cheaper than remediating the area of entire sites. In deciding which remediation strategies to implement, these approaches to either targeting entire sites or specific known hotspots in these sites should be considered, along with their corresponding costs.

Sunflower Phytoremediation Strategy	**Cost Estimate**
Planting sunflowers on all hotspot areas that exceeded 100 ppm	$7,914.76
Planting sunflowers on hotspot areas that exceeded 400 ppm	$1,001.01
Planting sunflowers the total area of sites whose averages exceeded 100ppm	$11,755.28
Planting sunflowers the total area of sites whose averages exceeded 400ppm	$3,446.64

Figure 5 - Cost estimates for various potential phytoremediation strategies

In terms of labor cost, we see the potential of volunteerism as minimizing the cost of the labor needed to plant, maintain, and harvest the plants. As previously discussed, the ability for community members to engage in sunflower remediation opens up the opportunity for a community-driven component to the project. If community members participated in volunteer events planting and harvesting the sunflowers, as well as dedicated part of their time watering and maintaining the plants as a collective, shared effort, the cost of labor for this project would be minimized or even eliminated.

The cost of disposal for sunflower remediation in this project is dependent on which hazardous waste removal option is utilized. According to the Maine Department of Environmental Protection, any “waste generated as a result of lead-based paint activities in residential settings is household waste” and is “exempt from hazardous waste regulation (Maine DEP, 2019). In the instances of disposal of this waste, the Maine DEP states that “all debris from lead abatement activities, including all lead-contaminated debris that will be disposed of as household hazardous waste, must be wrapped in a protective covering with all seams taped, or placed in closed durable containers resistant to puncture" (Maine DEP, 2019). In Raise-Op's project, sunflower waste was disposed of by placing the sunflowers in trash bags before disposing of them and labeling them as hazardous waste upon bringing them to the dump (Blumenthal, 2012). It follows, then, that in this similar remediation project, the process and cost of disposal would follow the cost of disposing of any other type of waste.

Soil Caps and Raised Beds

Soil caps and raised beds are a form of remediation that involves containing the lead as opposed to immobilizing the lead of absorbing it through phytoremediation. The first capping in place method involves covering the lead contaminated soil with asphalt or concrete layer that will most likely be used as a parking lot. The result of this method is a high strength, low permeability cover that reduces surface water infiltration and stabilizes contaminated soils (EPA, 2010). This cap allows lowers the mobility of the lead in the soil, keeping groundwater protected.

While in the field, we were approached by a neighbor who expressed a high level of interest in building a lot on site 7. She expressed interest on behalf of both her and one of her neighbors who has to walk particularly far in the winter.

This is one of the costliest methods of lead remediation. According to the EPA, the cost of clearing the site varies from $5,000 to $7,000 per acre. Then adding a 1" sub base will cost $2.50 to $7 per square yard. Then the asphalt surface will cost $12 to $20 per square yard. A swale should also be built for water runoff and that will cost $15 to $25 per linear foot. Finally, the EPA expects a $1000 annual maintenance cost which account for repairs, long term inspections, and site supervision. These cost estimates are all from the EPA's Engineering Controls on Brownfields Information Guide(EPA, 2010).

The materials required for the installation of this method are accessible to the city of Lewiston. They involve simple road building equipment but they are expensive to employ. In terms of weather, this method has risk of damages. For example, rapidly decreasing temperatures in the winter could cause the asphalt or cement to contract quicker and build tension faster, leading to an increased chance of cracking (Bitumonious Roadways, 2017). These cracks are concerning, given that the lead would still be beneath that layer.

This method is effective in eliminating the pathway of lead inhalation and ingestion because it will contain the contaminated soil. However, the lead still remains below the asphalt or concrete so there is a risk of re-emergence if the layer were to fail to uphold.

Capping in place with a clean fill as opposed to asphalt or concrete is a remediation process that involves the removal of a varying thickness of contaminated soil and replacing it with clean and uncontaminated soil. The EPA recommends 2-3 feet of soil for non-residential uses, and 10 feet for residential uses to eliminate any potential contact with contaminated soil (EPA 2016). The new soil then becomes covered with a vegetative layer that is not only aesthetically pleasing but also adds a stabilizing component to the soil. The vegetative layer usually consists of soil sufficient for development of good root support and moisture storage and a vegetative layer consisting of growth media and soil amendments with the micro- and macro-nutrients necessary to sustain growth(ITRC, 2010).

This method, like the other capping in place technique is costly. According to the EPA the cost of excavating contaminated soil is $15 to $30 per cubic yard then the placement of clean soil costs $50 to $75 per cubic yard. The seeding of grass or other vegetation on top of the clean soil varies from $100 to $200 per 1,000 square feet. Finally, the EPA expect an annual maintenance cost of $5,000 which is much greater than an asphalt or concrete cap. The vegetative layer requires high levels of maintenance. Overall, this method is the costliest of the capping in place strategies. Regardless of cost, this method is very feasible. The materials required for installation include excavators, dump trucks and manual labor.

This method is very effective at lowering lead concentration given that it clears the lead contaminated soil and replaces it with a new layer of clean soil and on top of that adds a stabilizing layer of vegetation. The vegetative cover protects against gullying and scouring by surface water and wind, thereby minimizing erosion (ITRC, 2010).

Covering contaminated soil with a polypropylene geotextile and adding a soil cap and a vegetative layer on top is another method of lead pathway intervention that has been used in New Orleans, Vietnam, and Zambia. The vegetative layer serves the same purpose as in the previous method. The geotextile serves as a membrane where water can pass through but soil cannot, so the contaminated soil is contained safely.

The cost of this method is cheaper than the previous method because it does not call for the excavation and disposal of contaminated soil. The geotextile costs about $2.36 per square foot (~$22 per square meter). The placement and seeding will be around the same as the last method, so around $50 to $75 for clean soil and an additional $100 to $200 for seeding.
This method requires similar equipment to the last two examples. The geotextile is also available online and there are also several geotextile manufacturers and suppliers in Maine that can be found, such as Contech Engineered Solutions LLC located in Portland, ME.

In Zambia, this method was employed in teams of 30-40 people for 78 households showing the possibility of community organizing to complete this project. The project reduced lead concentration from 2,000-4,000 ppm all the way down to around 25ppm (Ericson and Dowling, 2016). The same overall method was used in New Orleans to a similar effect. The initial 558 ppm median soil lead level (range 14-2692ppm) decreased to median 4.1 ppm (range 2.2-26.1ppm). These two practical implementations were immediate success stories and very effective at reducing the lead concentration to safe levels. The only pushback on these studies is the longevity of the containment as well as a lack of large scale studies. The geotextile has a service life of 100 years (Laidlaw, 2017) but that does not account for any outside factors that could cause rips or tears.

Raised beds are some of the most commonly used forms of lead protection for homes. A raised bed is a boxed in plot of soil above ground that is often used for growing produce. The soil in it is lead free and there is usually a barrier at the bottom of the bed protecting it from any lead contaminated soil below.

The cost of raised beds is fairly with estimates for 8’x4’ bed being around $35 which comes out to ~$1.10 per square foot. The tools are accessible too and the construction can even be done by individuals on a small scale.

Despite their feasibility in accessing the necessary materials and actual construction, raised beds are considered a limited exposure method for two reasons. Firstly, they do not cover the whole lot so patches of lead contaminated soil are left exposed and the pathway is still present. Secondly, because they do not cover the whole lot they only reduce the produce consumption pathway which according to a model developed by Clark et al. (2008) accounts for only 2-3% while ingestion of soil accounts for 72-91% of the total body burden. There is also a risk of recontamination if the whole lot is not contained. Clark et al. also found that lead concentration in raised increased from 150ppm to 336 ppm over 4 years. They deduced that wind-transported fine grain soil is the mechanism of recontamination but offer methods to avoid recontamination. Removing the top 3-5cm of soil and replacing it with compost would keep Pb concentration low (Clark et al., 2008). Overall, this method, while cheap, is not the most effective at eliminating health risk for children because it is only a limited reduction of exposure.

Soil Amendments

Soil amendments are a remediation method that relies on the addition of compounds to the soil in order to reduce the bioavailability and/or bioaccessibility of heavy metals. Bioavailability and bioaccessibility are the two most important measurements of success when adding soil amendments, with bioavailability signifying the amount of metal present for uptake by organisms and bioaccessibility signifying the amount of metal that is released upon digestion within the organism. A number of studies have determined that soil amendments are effective in reducing these two factors, thereby mitigating the health hazards presented by lead contaminated soil (Mahtab et al., 2012; Ok et al., 2010). The mechanism of reducing this hazard is through immobilization, which can occur in two ways. The first is by raising the pH of the soil, which binds the metals in place within the soil. The second is through absorption properties of the amendment. In the case of biochar amendments, absorption proves to be an effective mechanism for reducing available lead. However, the presence of other metals such as cadmium and aluminum can reduce effectiveness as these metals compete for absorption (Han et al., 2017). Although the addition of soil amendments is effective in immobilizing heavy metals and reducing risk of lead poisoning, it is important to recognize that this remediation method does not physically remove the contaminants from the soil. The four amendment types we examined were as follows: crustacean shells, Class C fly ash, cow bone, and biochar. We analyzed these four types of amendments through three criteria: feasibility, cost, and effectiveness.

The three crustacean amendments we examined were natural oyster shells, calcined oyster sells, and mussel shells. Both oyster and mussel shells are waste products from the food industry. Therefore, sourcing this amendment would be extremely cheap, if not free. However, prices were not readily available online. Suppliers would need to be contacted in order to determine price and feasibility of this remediation strategy, but we anticipate neither to be an issue. Crustacean shell amendments have proven to be some of the most effective in immobilizing lead (Ok et al., 2010; Mahtab et al., 2012). Out of the three types, calcined oyster shell powder (COSP) was the most effective addition. It is important to recognize that natural and calcined oyster shells require specific equipment in order to transform them into soil amendments. For preparation, both types of oyster shells require a forced air oven and a mechanical crusher (*ibid.*). Calcined oyster shells require further preparation and need to undergo a calcination process in order to be effective as a soil amendment. Calcination requires a furnace that reaches temperatures of 900 degrees celsius, such as a Carbolite furnace. Next, both types of oyster shells need to be analyzed for proper chemical properties, using a Thermogravimetric Analyzer and an X-Ray Fluorescence gun (*ibid.*). Mussel shells also require a forced air oven and mechanical crusher. Bates College currently has some of this equipment including the X-Ray Fluorescence gun, but equipment limitations may prove to be a barrier in using crustacean shells as a remediation option. However, we believe that crustacean shell amendments are one of the most promising remediation strategies given their cost and effectiveness. If the community wants to explore this option further, more research should be done on overcoming the equipment barriers.

Class C fly ash is a byproduct of coal-powered energy generation. There are few productive uses for this compound, and roughly 40 million tons of it were sent to landfills in 2008 (Moon et al., 2013). A number of companies supply Class C fly ash for prices as low as $30/ton (Pennsylvania State University, 2019). This amendment was found to be optimal in coordination with calcined oyster shells. The most effective combination was determined to be 10% shell and 5% ash (Moon et al., 2013). Therefore, fly ash's feasibility relies on the ability to be able to process oyster shells. If the community sources the proper equipment for this, we recommend using a combination of calcined oyster shells and Class C fly ash, given the cost and effectiveness.

Cow bone was found to be an effective amendment in reducing lead bioavailability (Mahtab et al., 2012). This amendment is a waste product of the food industry, and can be purchased from local restaurants or meatpacking plants. We were unable to find prices for cow bone online, and the community would need to reach out to sources to inquire about price and availability. Cow bone requires preparation, and is optimal at particle sizes < 1-mm, known as homogenized cow bone powder (CBP) (*ibid.*). To prepare CPB, the bone needs to be washed, dried, and ground to a fine particle size. This amendment type is less effective than crustacean shells at immobilizing lead, however fewer equipment constraints exist in preparing the compound (*ibid.*).

Biochar is a type of charcoal created using a controlled burning process known as pyrolysis. Historically, biochar has been used as an agricultural amendment to improve the quality of the soil. Recently, it has gained more acceptance as a means of remediating lead contaminated soils. A number of companies produce the compound. Wakefield Biochar sells 2 cubic yard quantities online for $375 (Wakefield Biochar, 2019). This remediation method is feasible for the community as the compound is easily available for purchase and does not require further processing. However, it proves to be the least effective amendment method that we examined (Mahtab et al., 2012).

Remediation Recommendations:

We are choosing to recommend sunflower remediation as our primary recommendation for this project. As noted in Appendix C, sunflower phytoremediation has a relatively low cost in comparison to the other researched remediation strategies, is effective in its removal of significant amounts of lead in one growing season, and displays feasibility in its success in past Lewiston lead remediation projects. The low technical skills required for sunflower phytoremediation also allows for community involvement in the project of remediation, creating the potential for greater shared investment in the goal of creating a lead-free Lewiston.

Our second recommendation is the use of crustacean shells in combination with Class C fly ash. Appendix C shows that of all the soil amendment options we researched, the combination of these two amendments yields the highest effectiveness. While both amendments are derived from waste products and are therefore fairly inexpensive, the feasibility of the use of these two amendments depends on the availability of necessary processing equipment. Further research should be done to determine the availability of the necessary equipment, which will then determine whether the use of these two amendments for lead immobilization is feasible in the context of the Tree Street vacant lots.

We are choosing not to recommend soil cap remediation strategies due to their relatively high costs in comparison to the other remediation strategies, the high level of technical skill needed to implement them, and the fact that while the other remediation strategies are effective in eliminating lead from the soil or immobilizing lead particles to prevent bioavailability, soil capping only suspends the issue of lead exposure by isolating contaminated soil (Appendix C). In the interest of meeting the “Growing Our Tree Streets” goal of creating a lead-free Lewiston, we are interested in recommending strategies that will actively rid the vacant lots of lead contamination, as opposed to containing the contaminated soil.

Recommendations for Next Steps:

In order to continue on the path toward removing all hazardous levels of lead contamination from the 19 Tree Street Neighborhood vacant lots, we recommend the following actions:

1) **Distribute** a flyer (Appendix D) detailing the scope of lead contamination and potential remediation strategies

We believe that the distribution of a synthesized version of our findings would greatly benefit residents, community-based organizations, and local government in becoming more knowledgeable on the impact of soil lead contamination, the scope of the problem in the Tree Street Neighborhood, and possible remediation strategies that can be implemented on these vacant lots

2) **Gather** community input on remediation preferences

Receiving community input is essential in decision-making that benefits all residents. We recommend that following the distribution of an informational flyer, efforts should be made to collect community input on their opinions and preferences on what type of remediation strategies they'd like to see implemented in the community.

3) **Determine** which remediation option is most feasible for the community given resource availability

More research should be done to determine which types of equipment and resources the city of Lewiston and neighboring communities have in the context of necessary equipment for remediation strategies. Especially in the context of soil amendments, more research should be conducted on the feasibility of acquiring and using the necessary tools for processing certain amendments to be used for soil remediation. In this research, it should also be determined whether the use of this equipment and resources is cost effective in terms of Healthy Neighborhoods and the city's budget for remediation.

4) **Begin** remediation

Upon prioritizing which vacant lots or hotspots on these lots will be targeted first for remediation and determining which remediation method(s) will be used, remediation efforts can begin.

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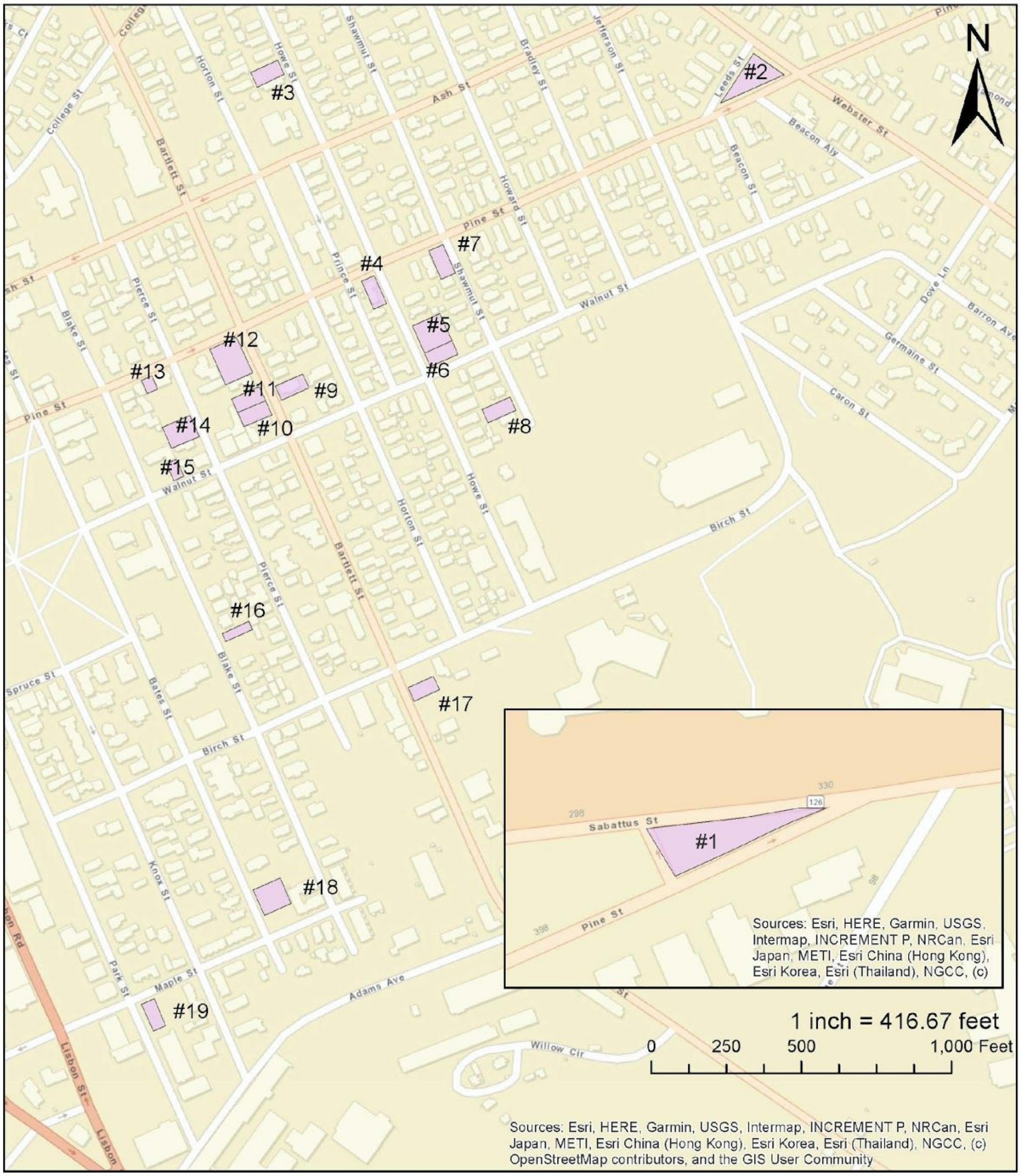
Appendix A- Maps

Site Locations of Vacant Lots in Tree Street Neighborhood



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c)

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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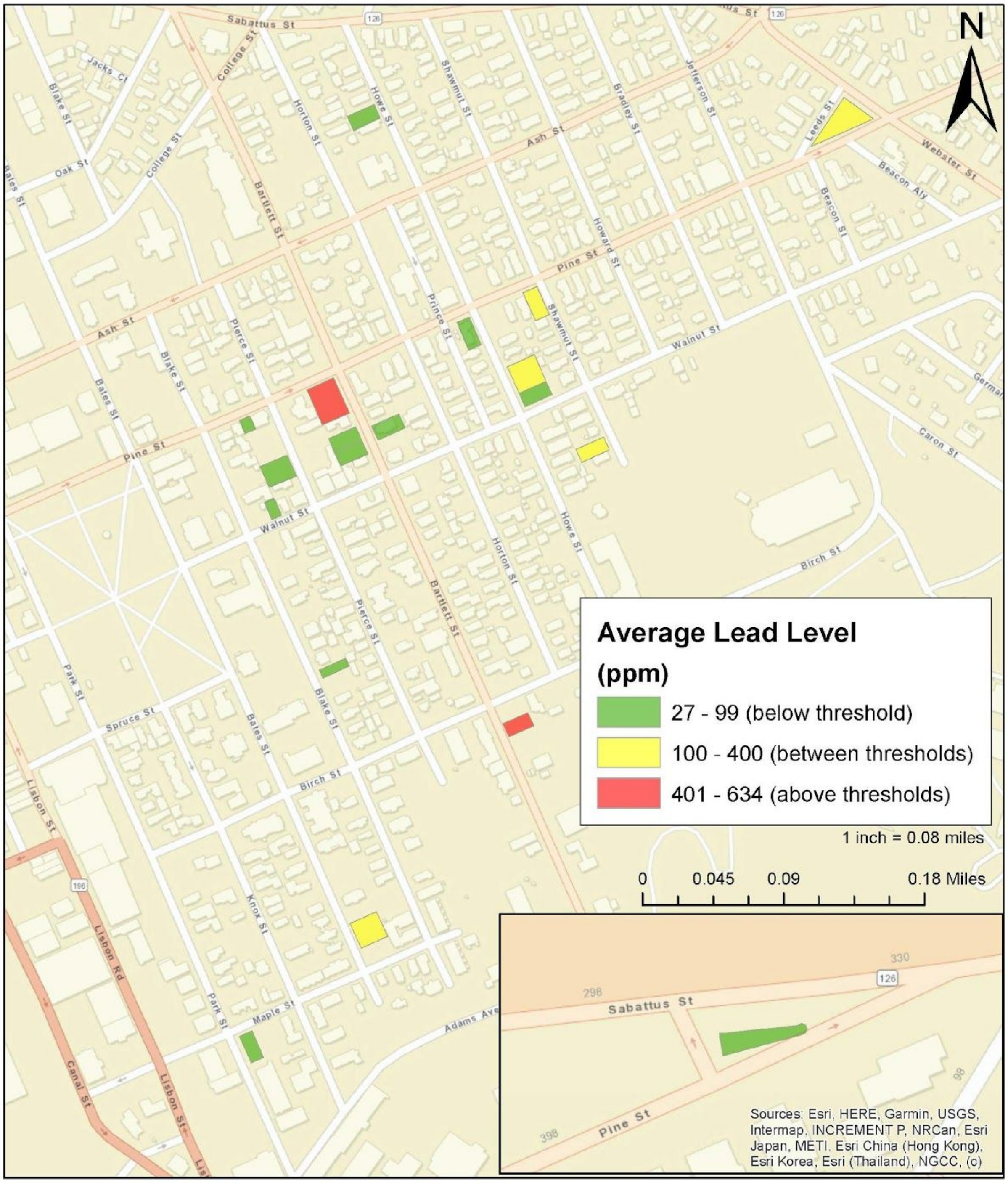
Lead Average per Vacant Lot in Tree Street Neighbourhood



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c)

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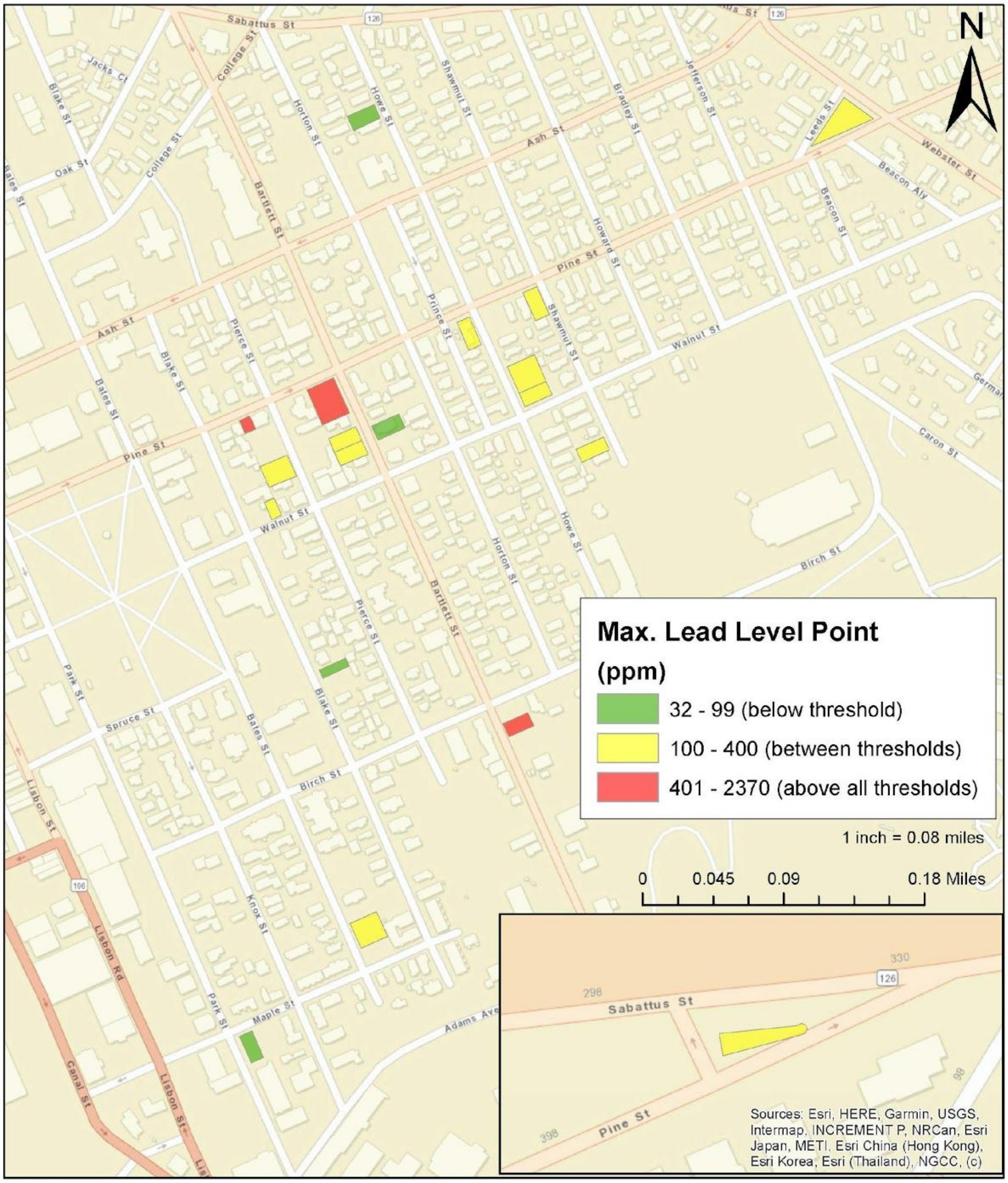
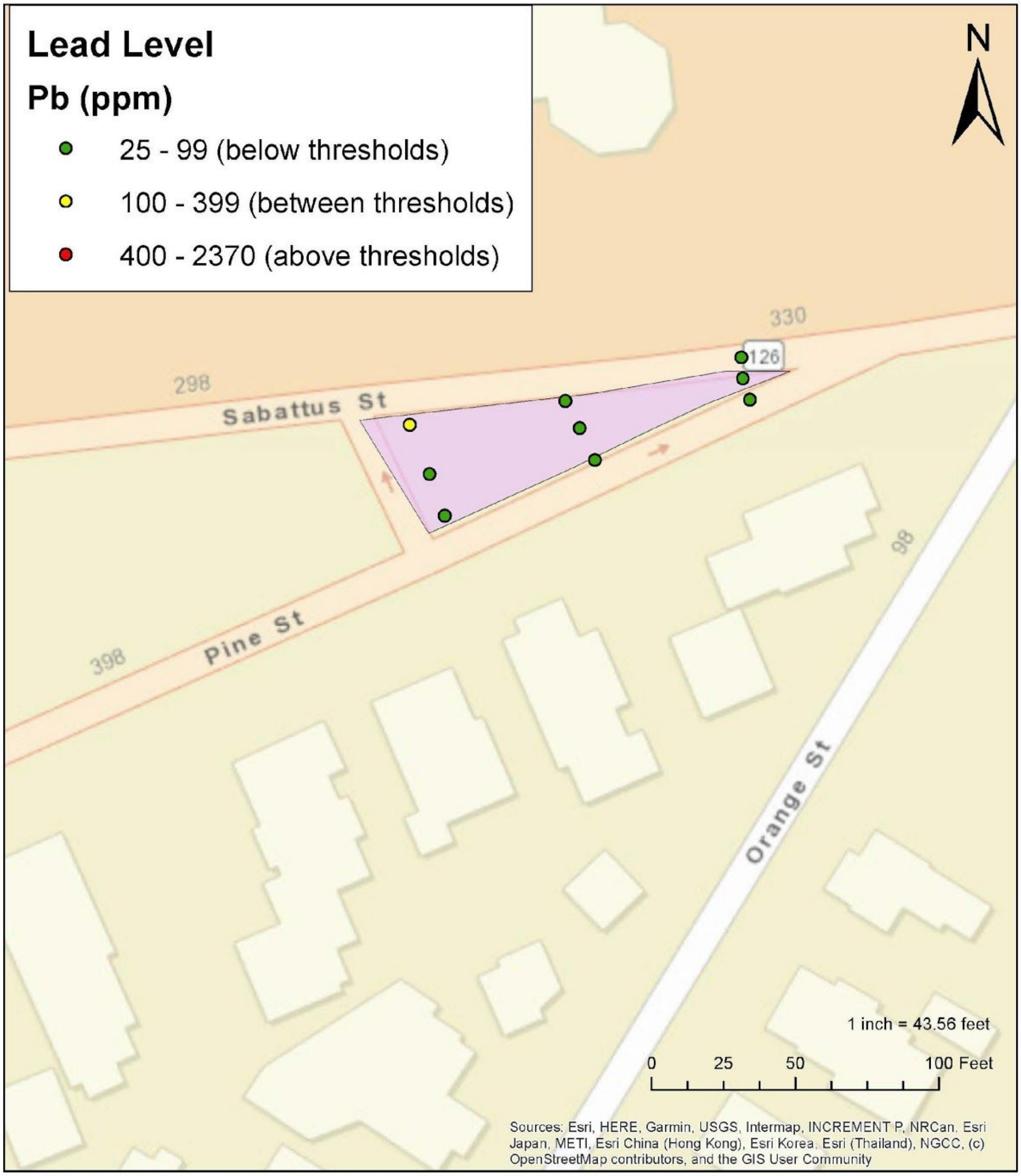
Lead Maximum per Vacant Lot in Tree Street Neighbourhood



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c)

Lead Levels at 348 Pine Street, Lewiston, ME (Site 1)



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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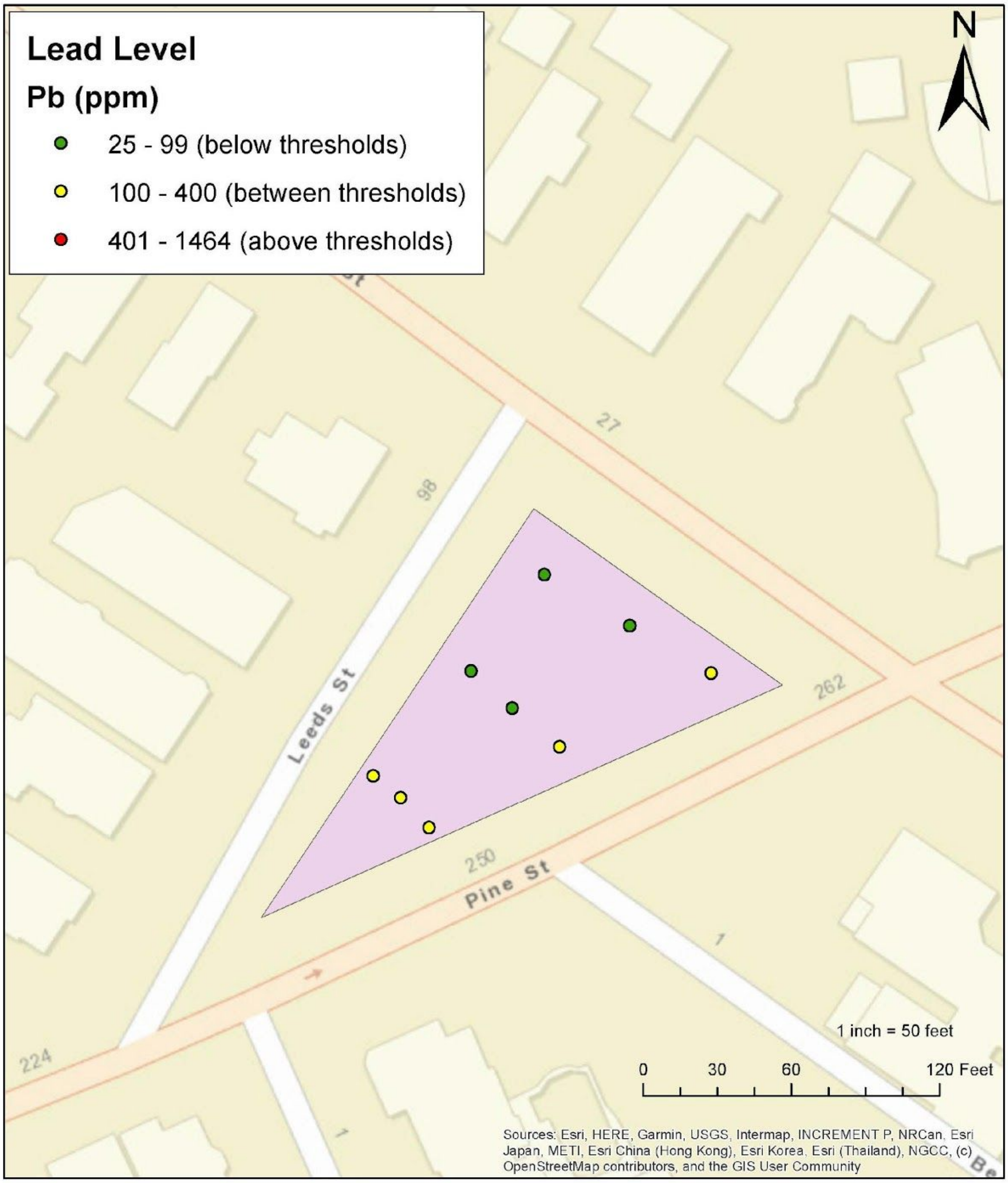
Lead Levels at 236 Pine Street, Lewiston, ME (Site 2)



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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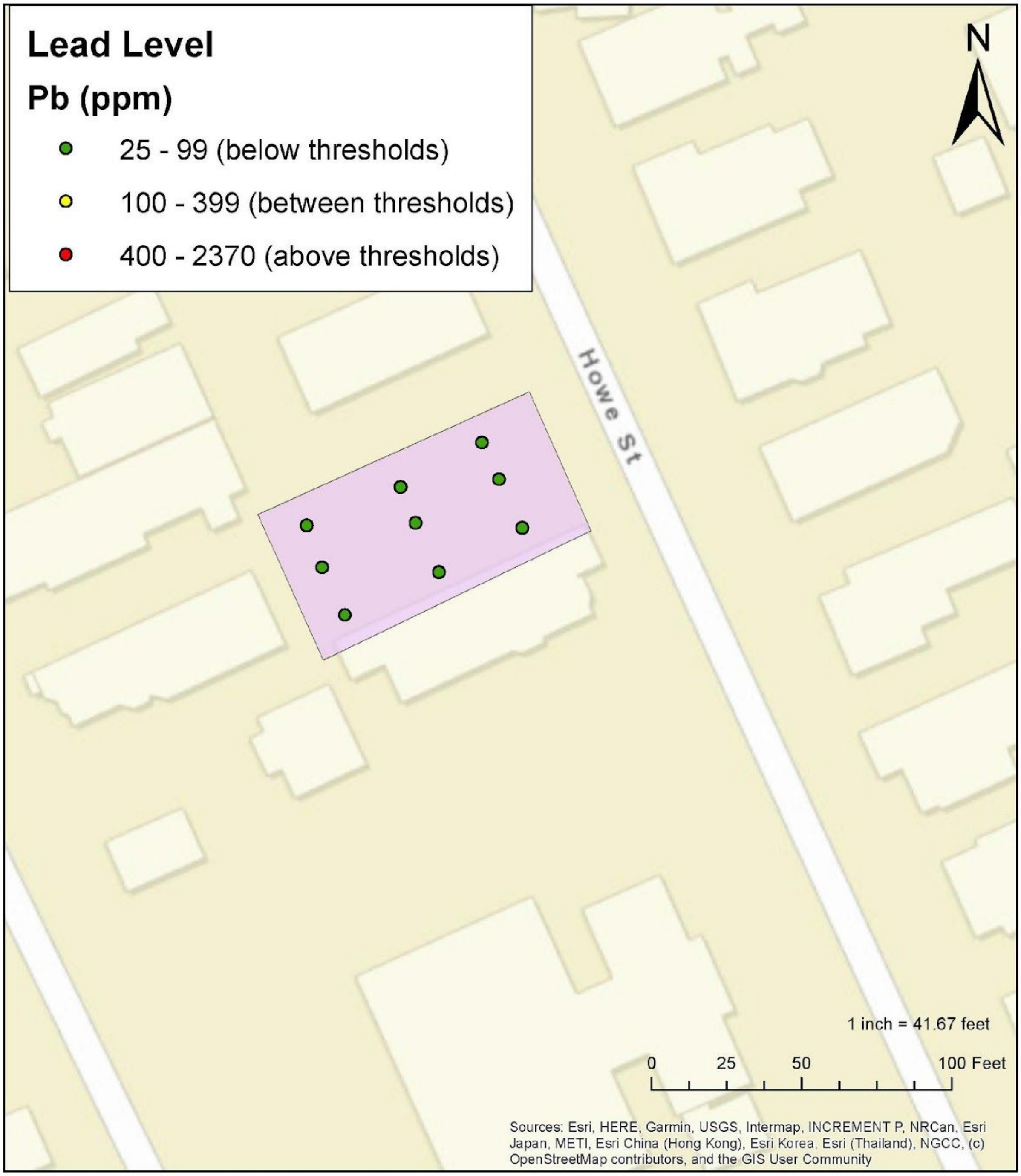
Lead Levels at 23 Howe Street, Lewiston, ME (Site 3)



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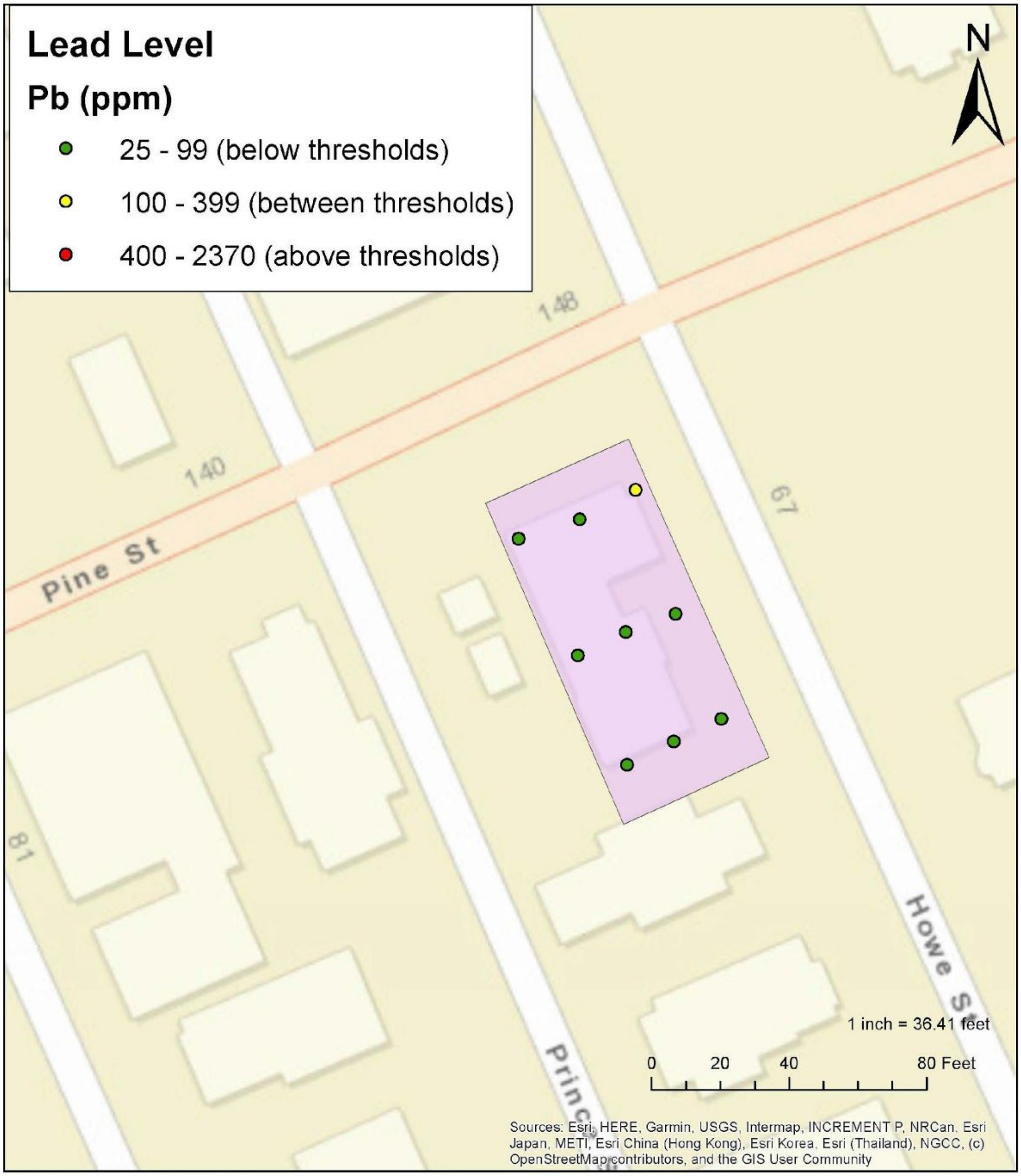
Lead Levels at 143 Pine Street, Lewiston, ME (Site 4)



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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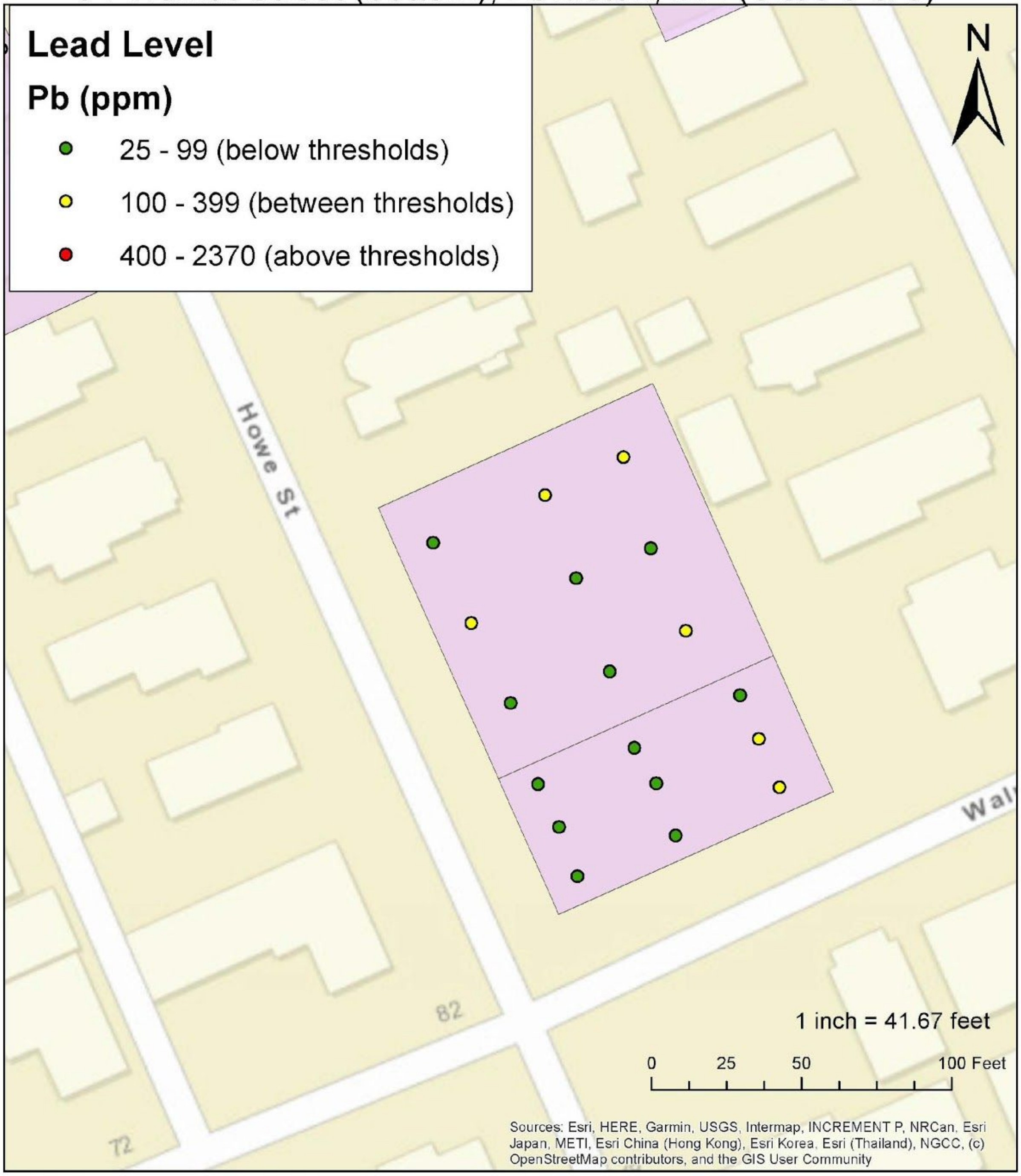
Lead Levels at 94 Howe Street (top) and 84 Walnut Street (bottom), Lewiston, ME (Sites 5 & 6)



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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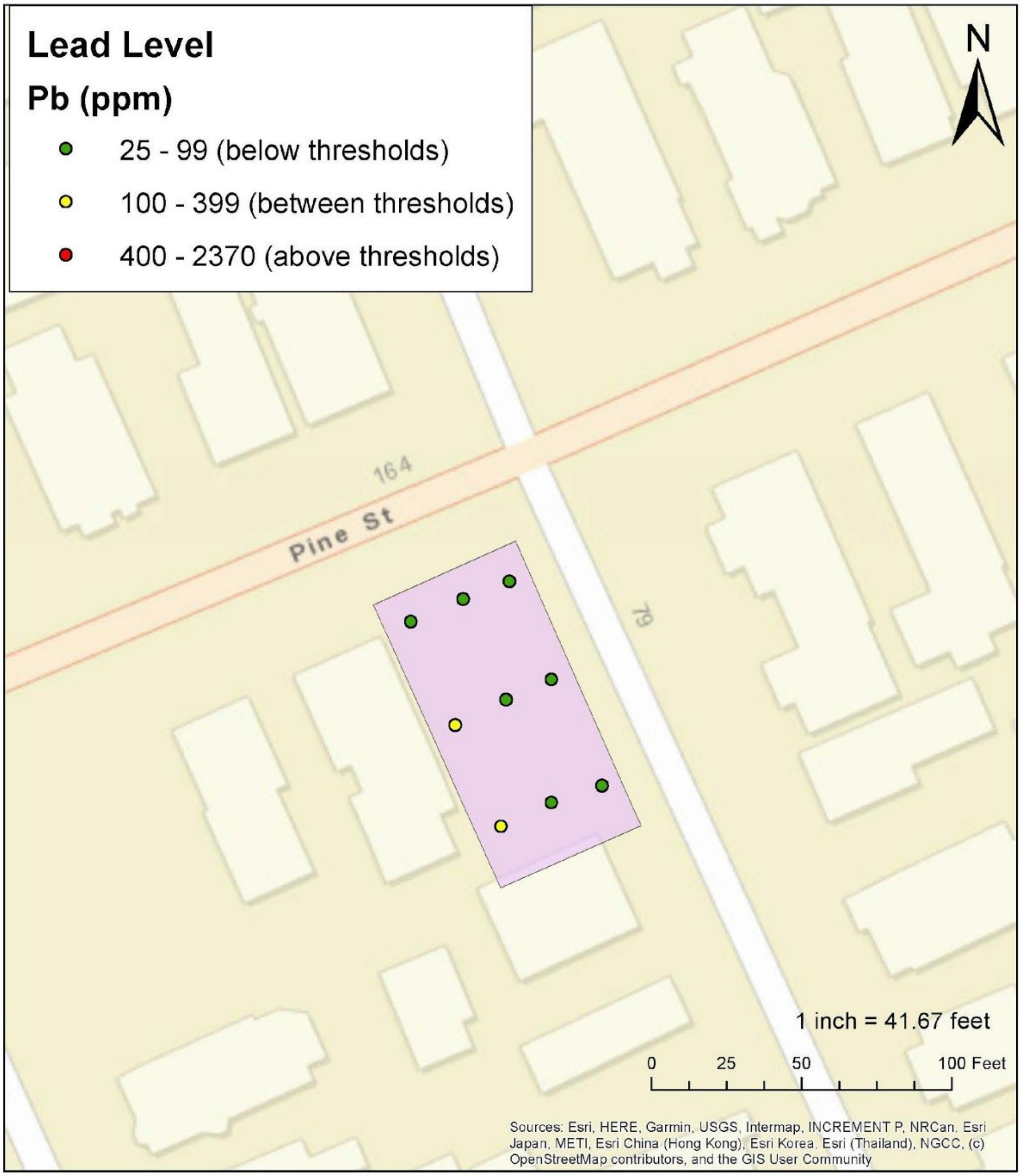
Lead Levels at 159 Pine Street, Lewiston, ME (Site 7)
Cross street: Shawmut St



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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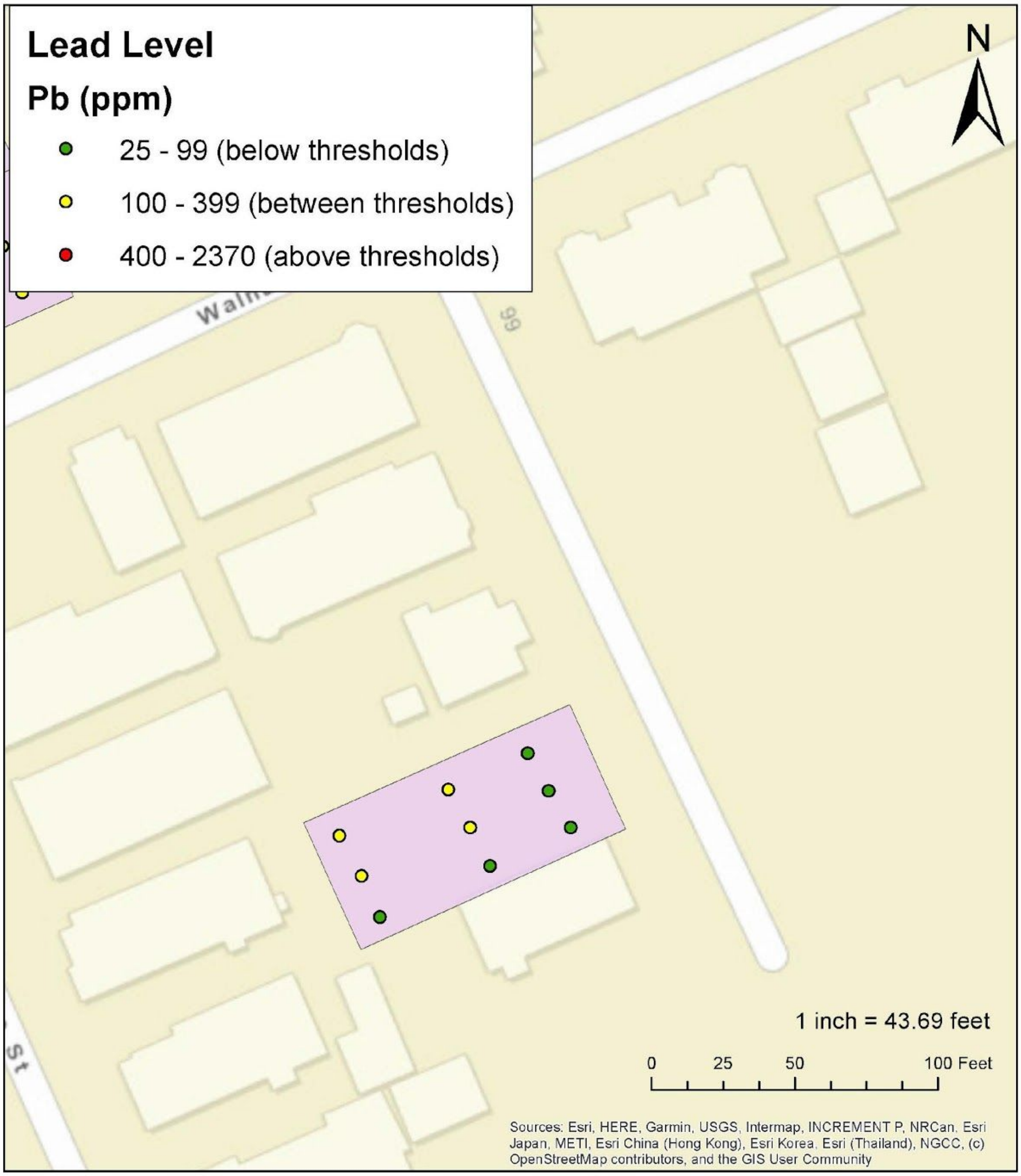
Lead Levels at 115 Shawmut Street, Lewiston, ME (Site 8)
Cross Street: Walnut St



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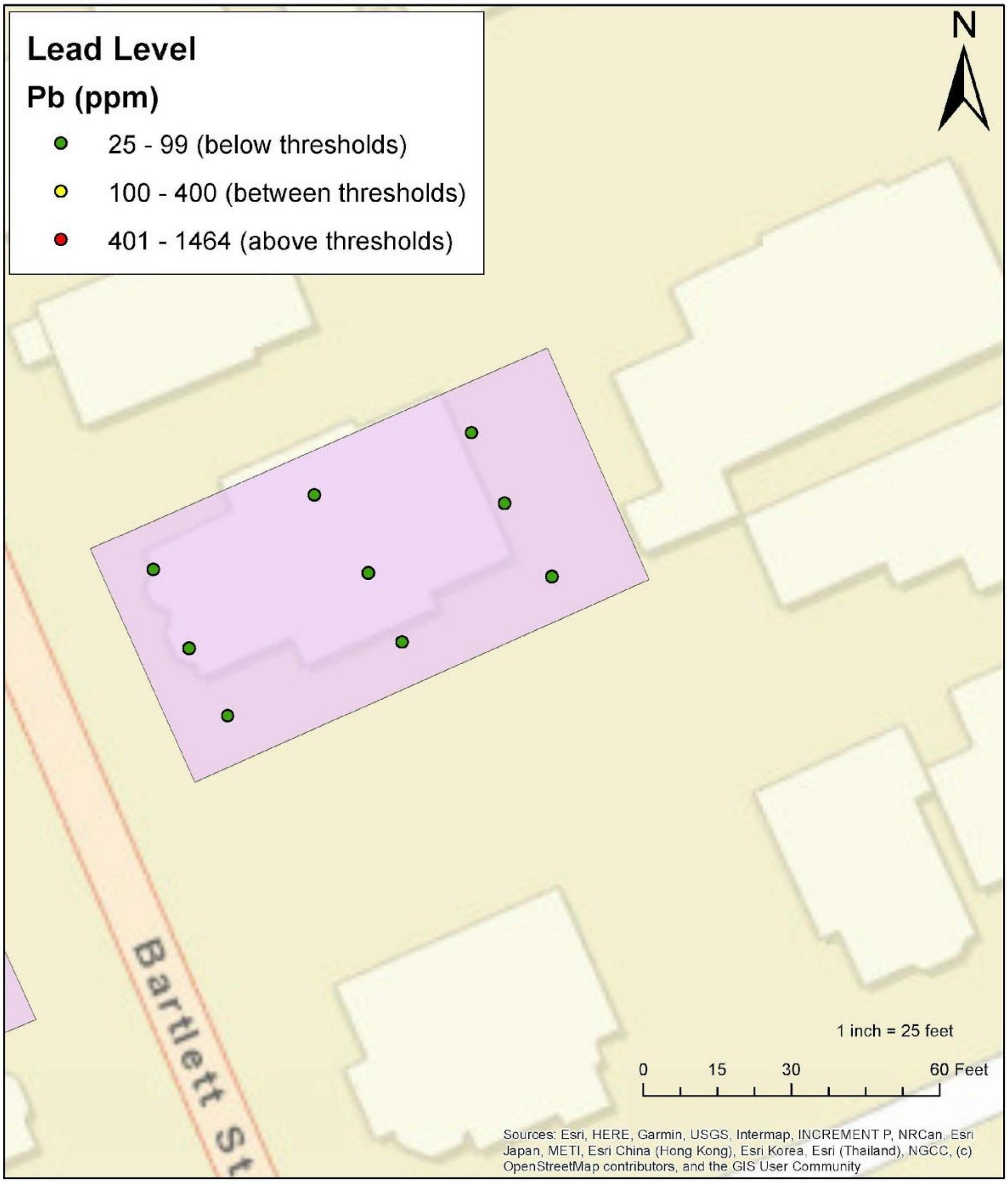
Lead Levels at 114 Bartlett Street, Lewiston, ME (Site 9)



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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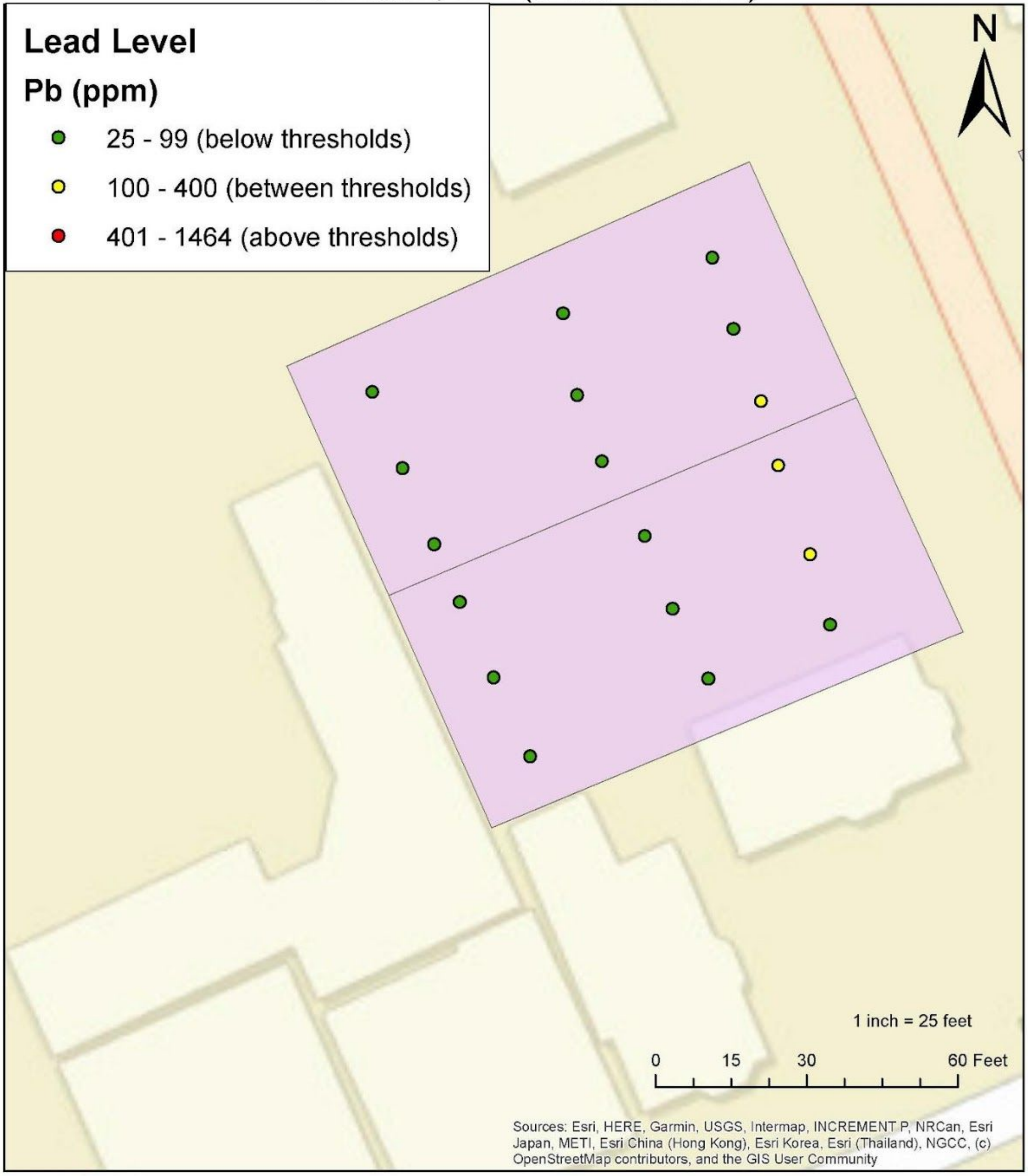
Lead Levels at 111 (top) & 115 (bottom) Bartlett Street, Lewiston, ME (Sites 10 & 11)



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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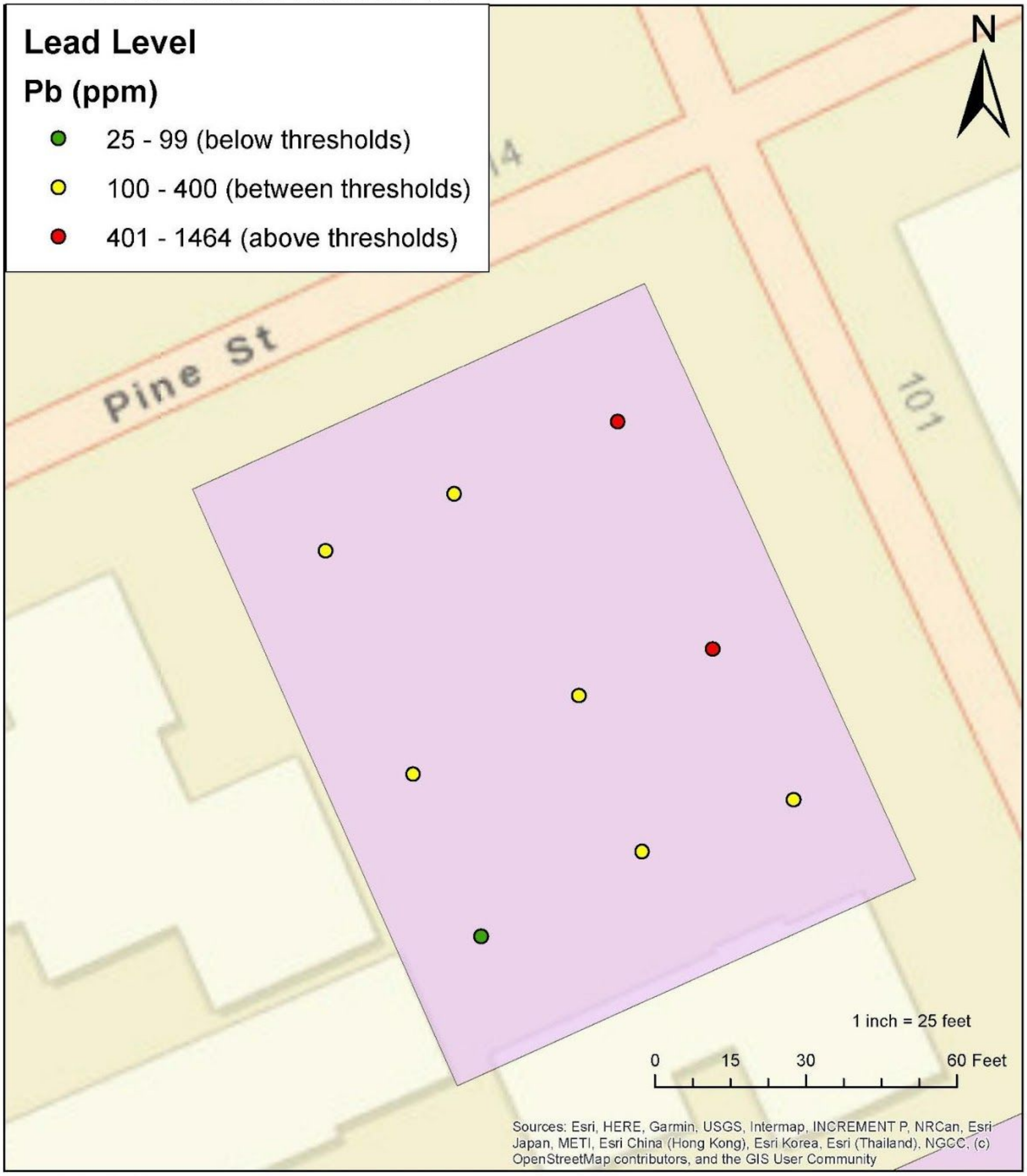
Lead Levels at 111 Pine Street, Lewiston, ME (Site 12)
Cross Street: Bartlett St



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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Lead Levels at 91 Pine Street, Lewiston, ME (Site 13)
Cross Street: Pierce St

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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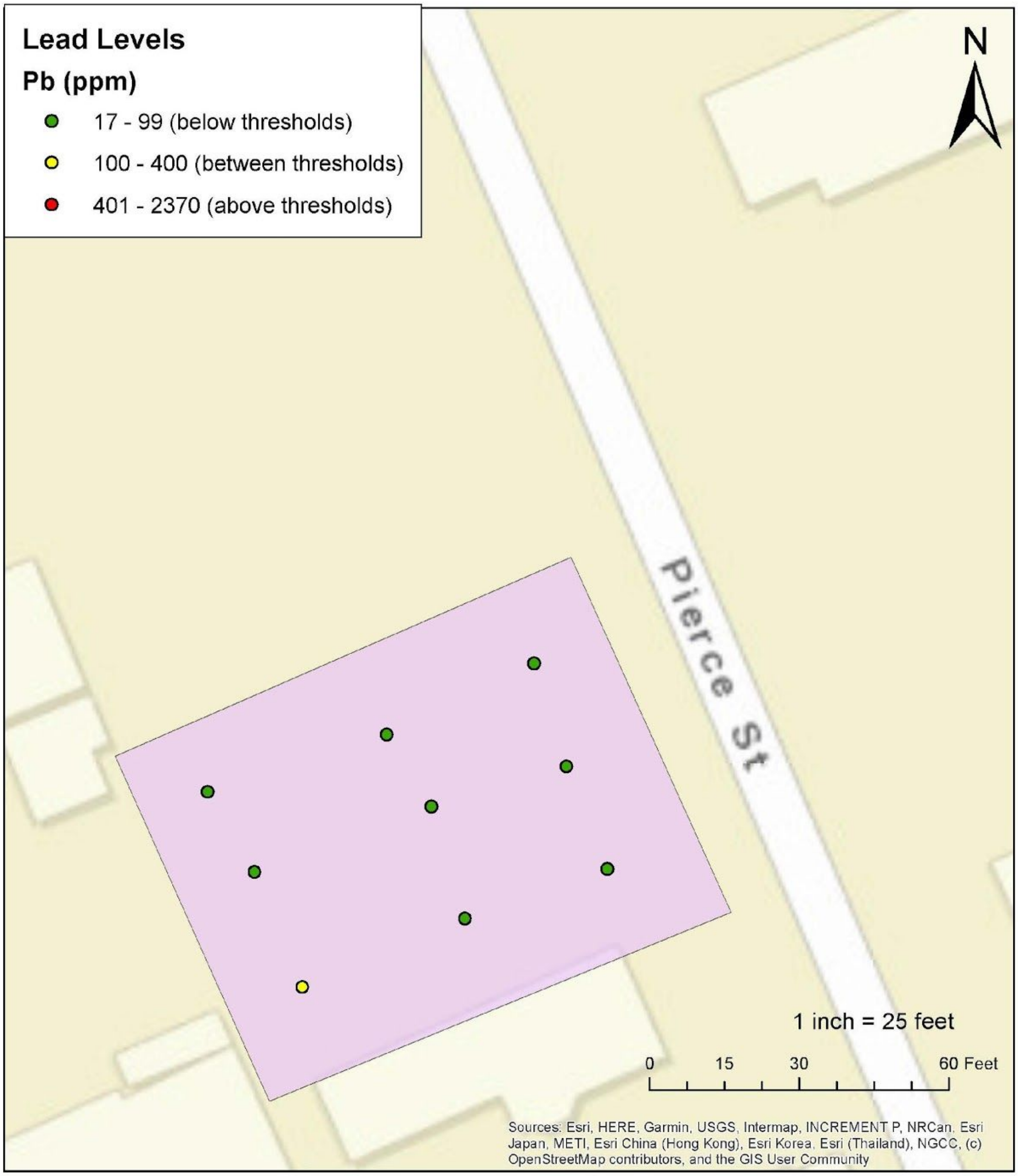
Lead Levels at 79 Pierce Street, Lewiston, ME (Site 14)



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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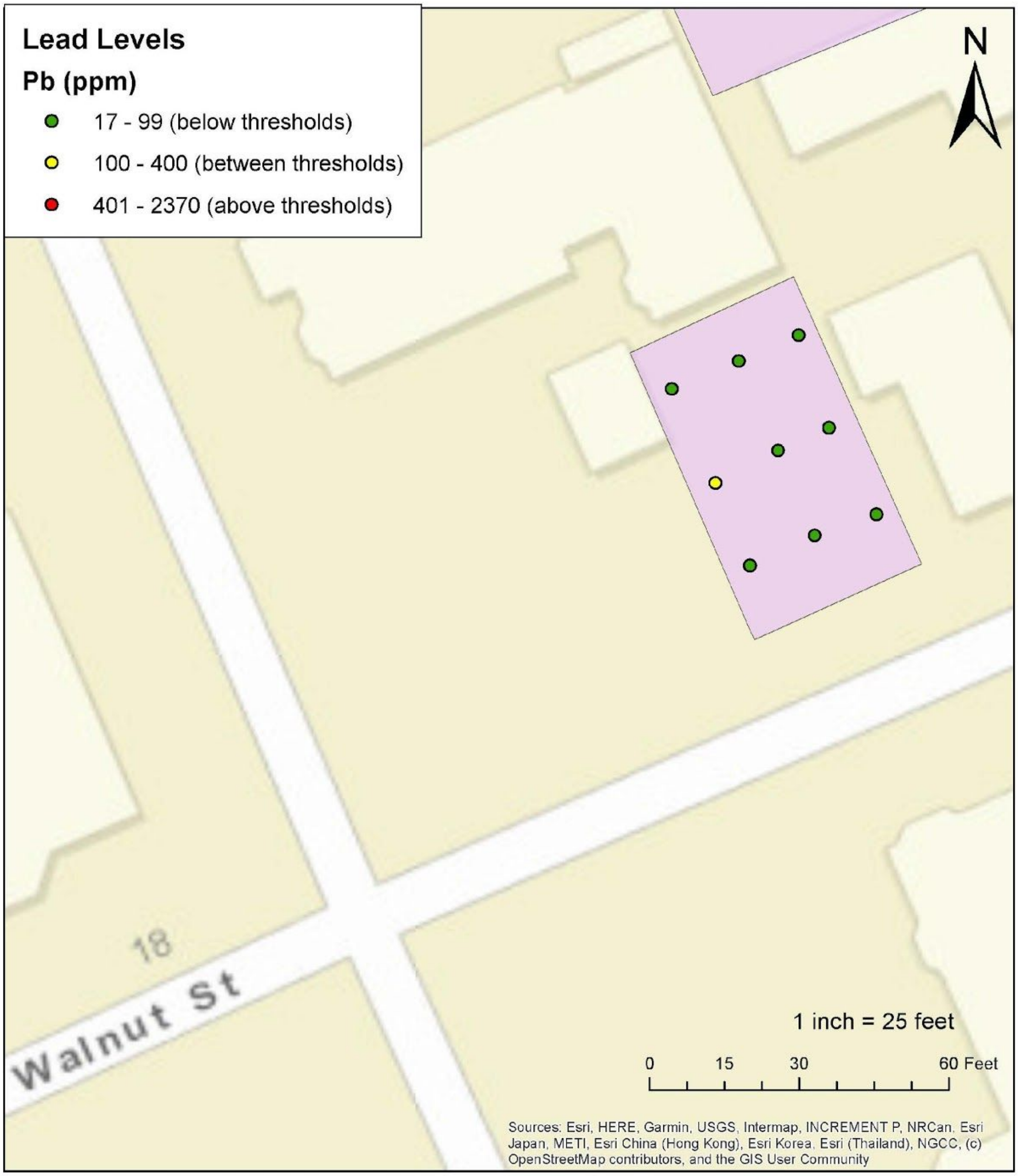
Lead Levels at 24 Walnut Street, Lewiston, ME (Site 15)
Cross Street: Blake St



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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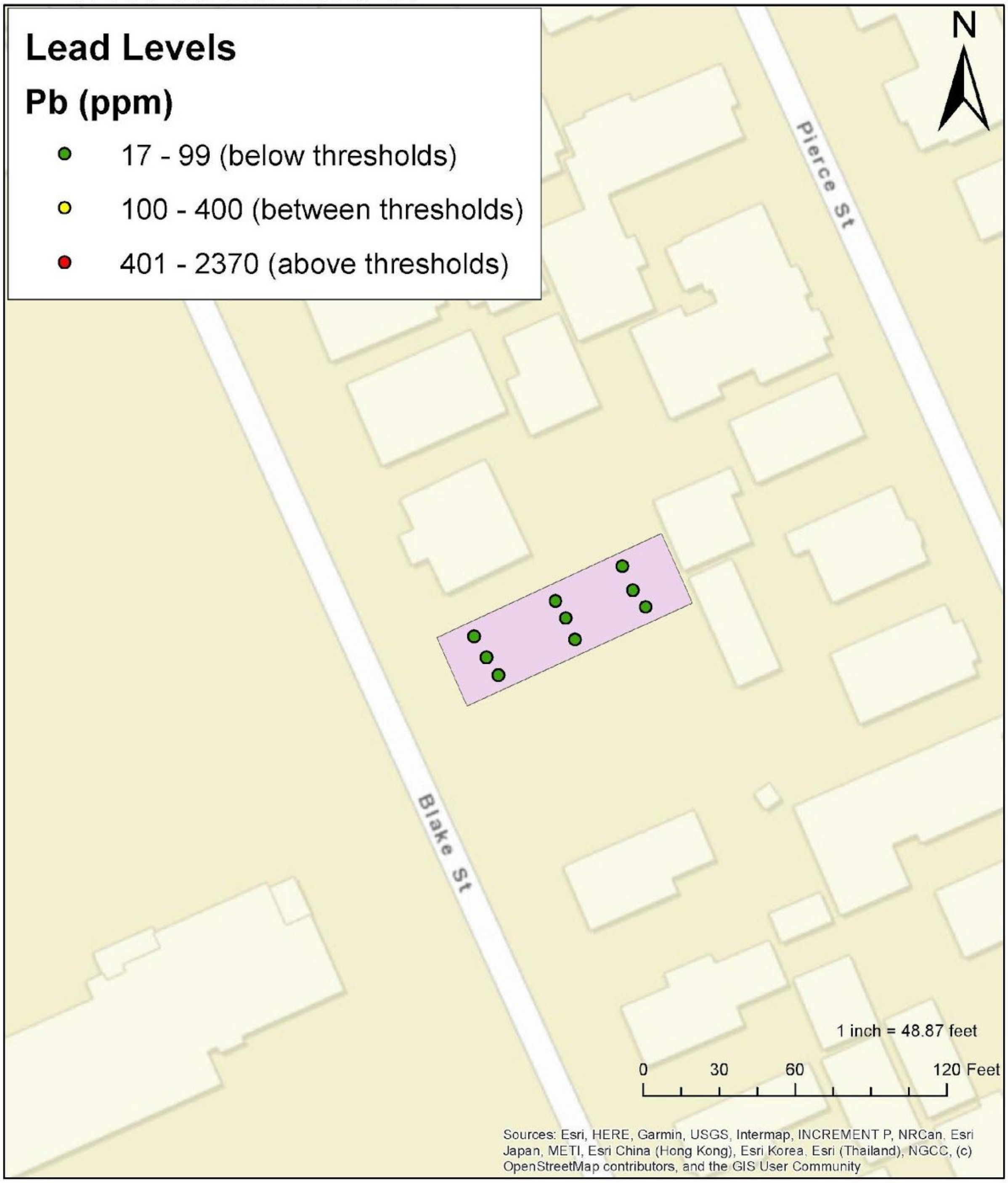
Lead Levels at 186 Blake Street, Lewiston, ME (Site 16)
Cross Street: Blake St



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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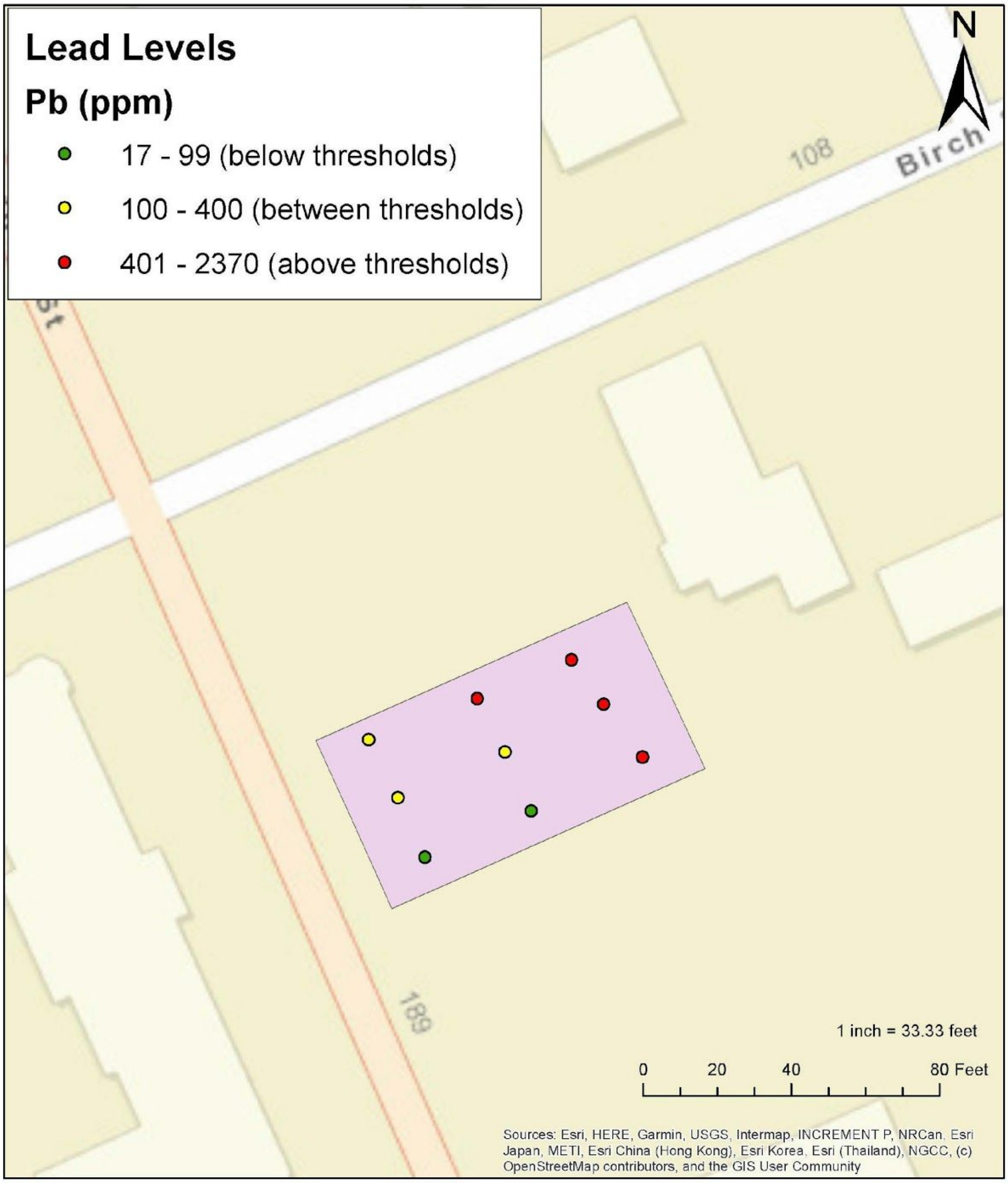
Lead Levels at 192 Bartlett Street, Lewiston, ME (Site 17)



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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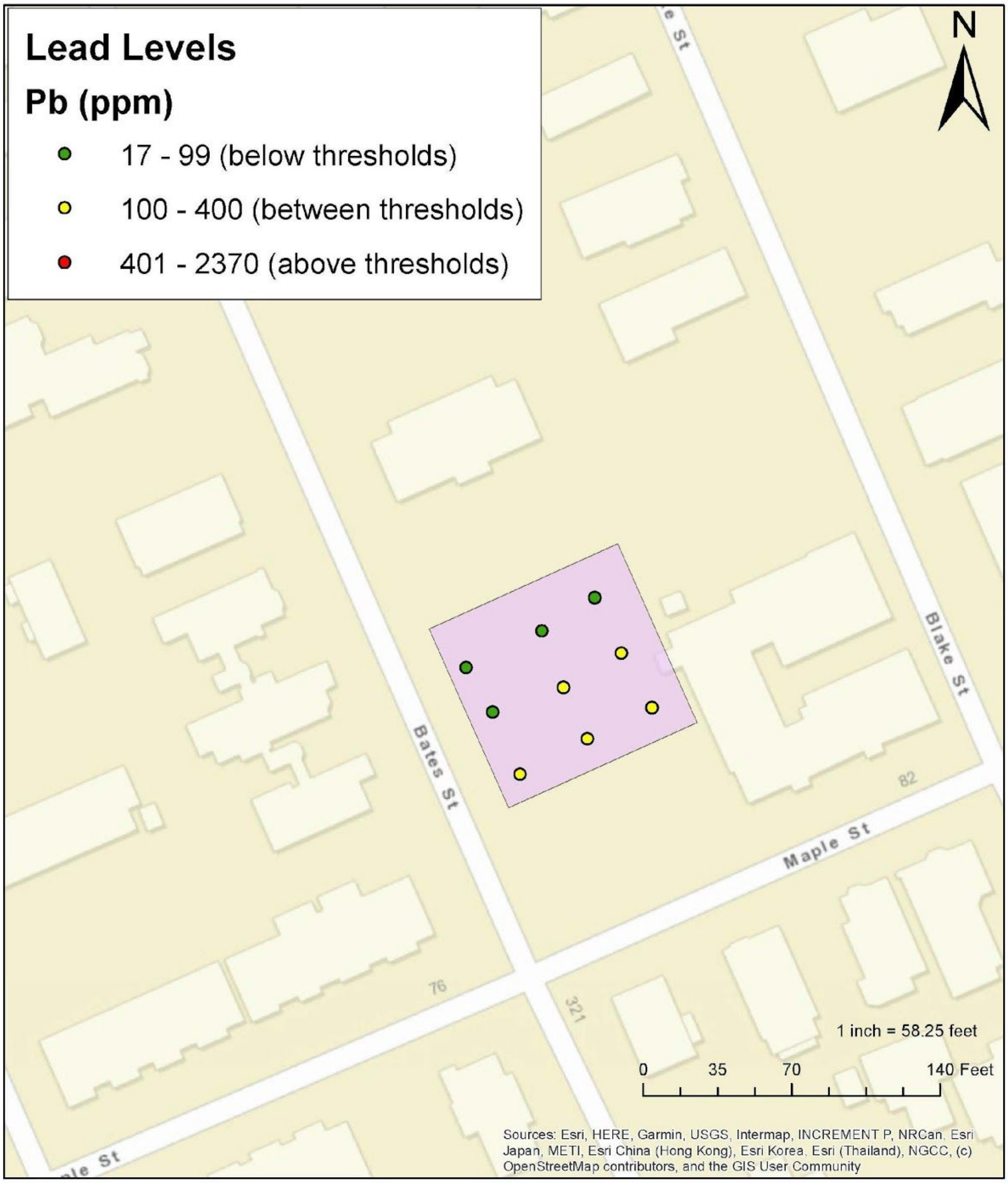
Lead Levels at 320 Bates Street, Lewiston, ME (Site 18)



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

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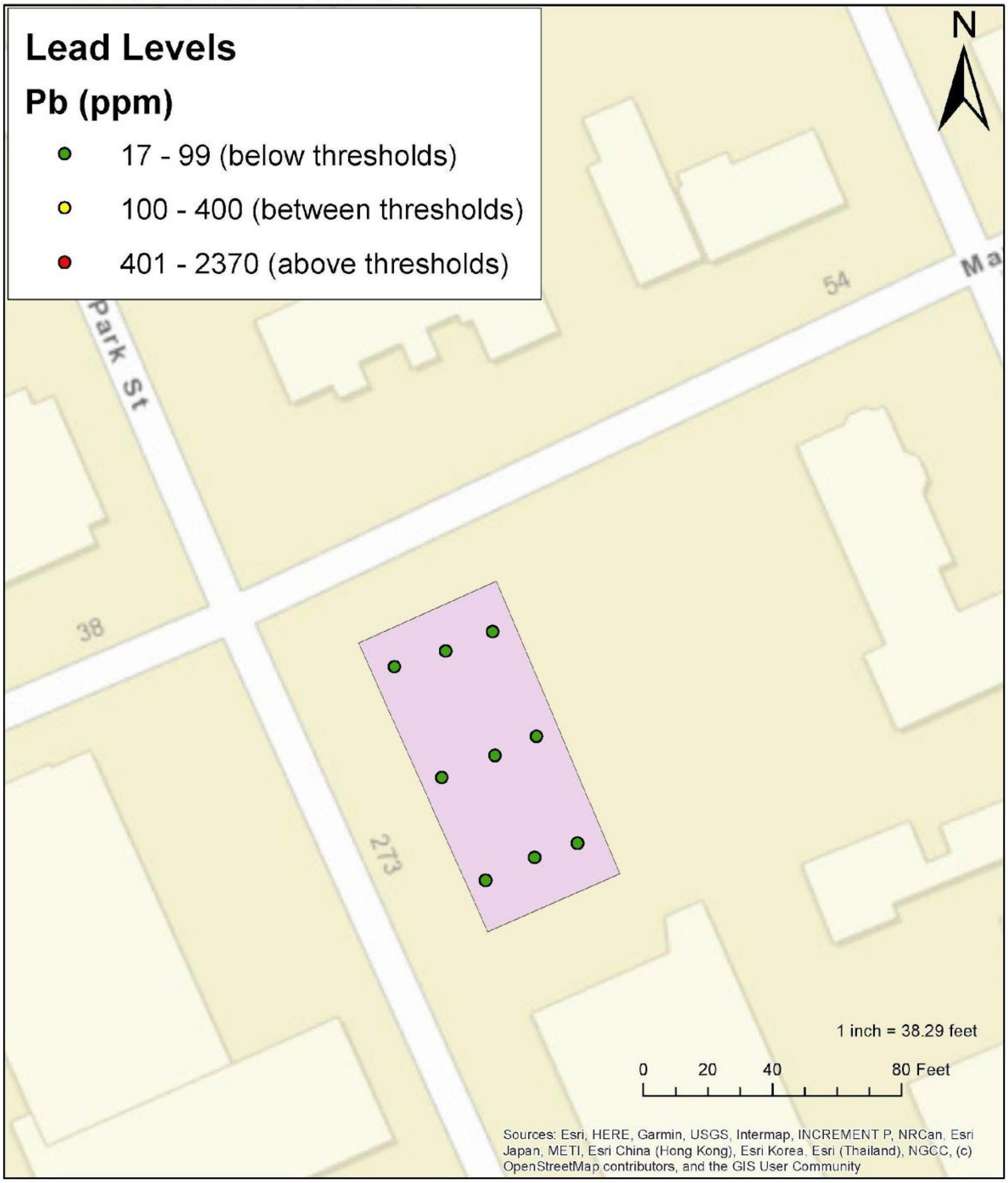
Lead Levels at 39 Maple Street, Lewiston, ME (Site 19)
Cross Street: Park St



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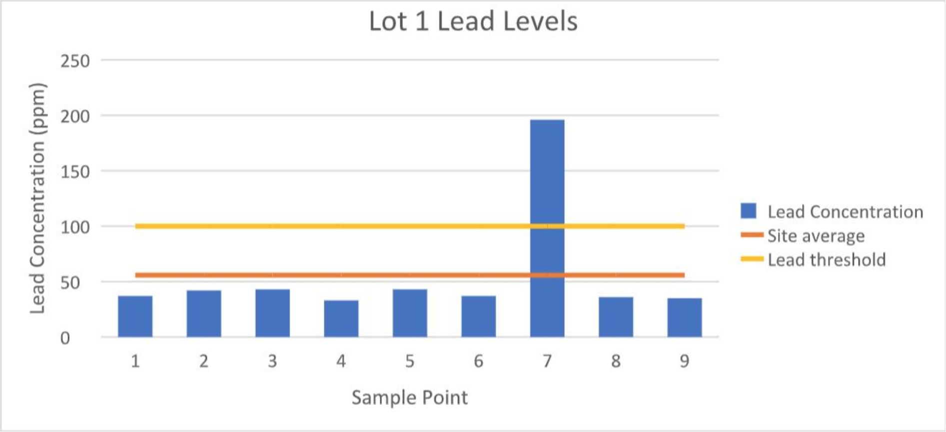
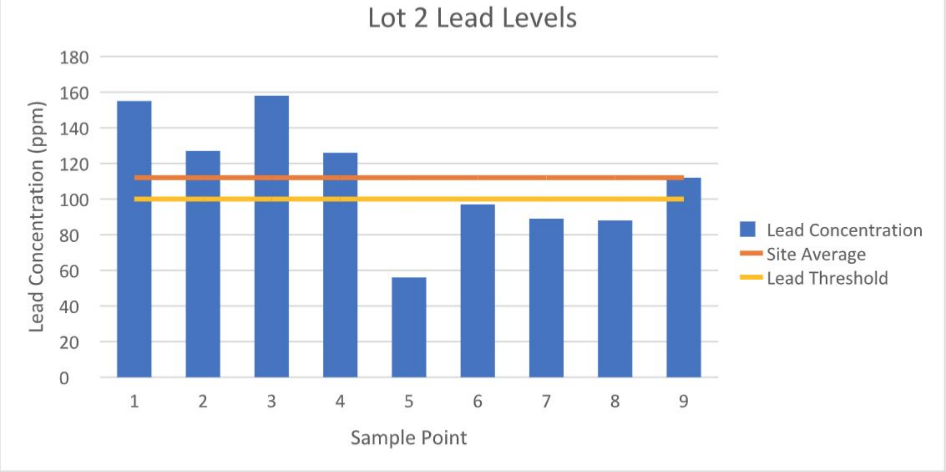
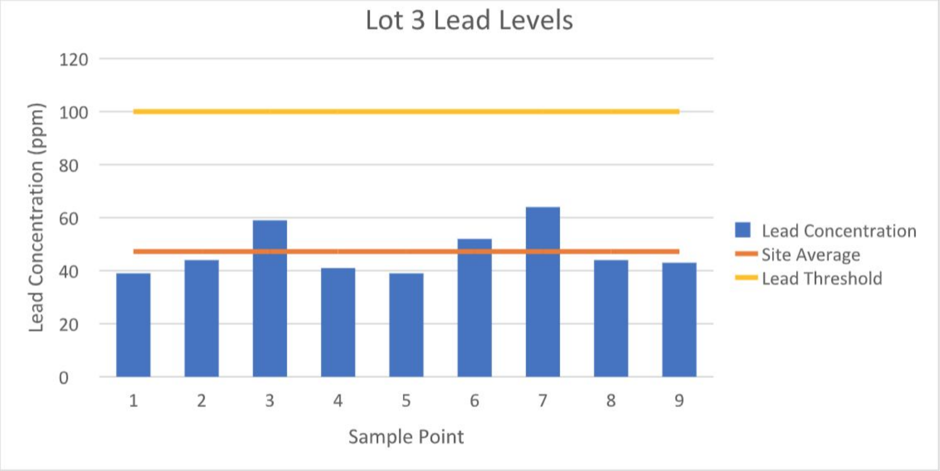
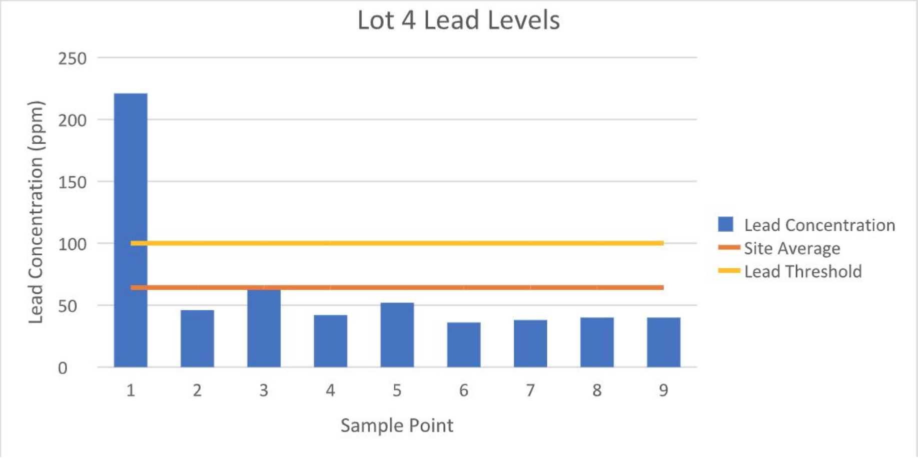
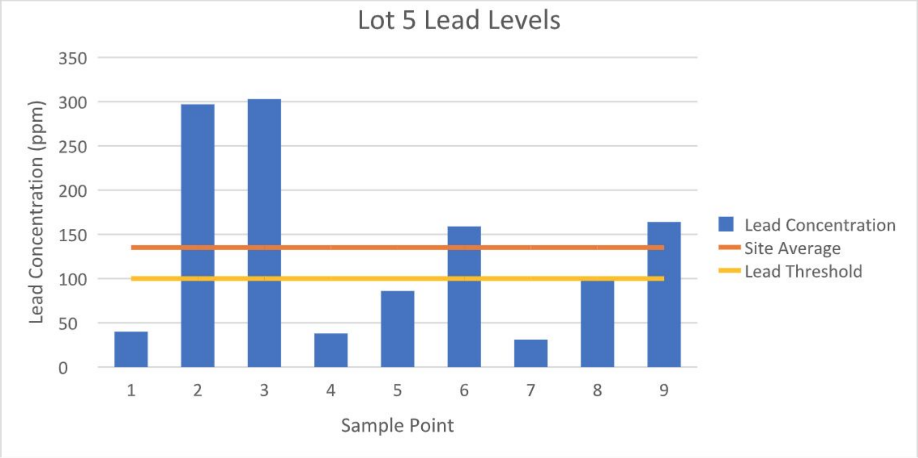
Appendix B- Individual Site Graphs

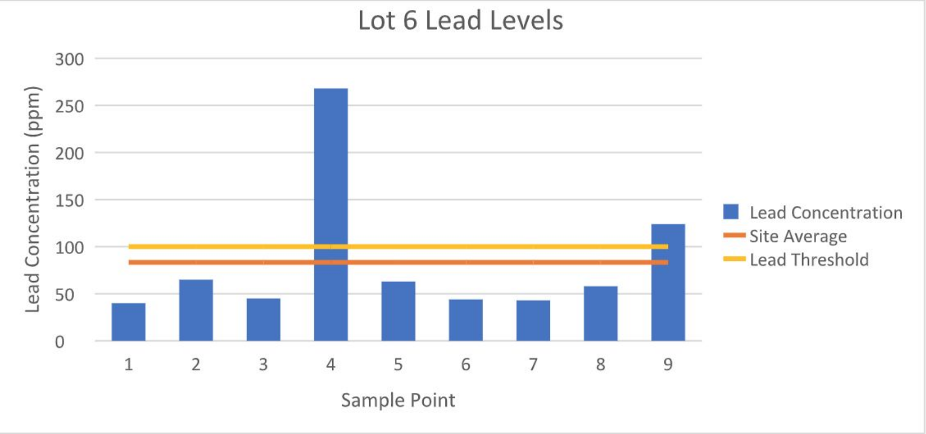


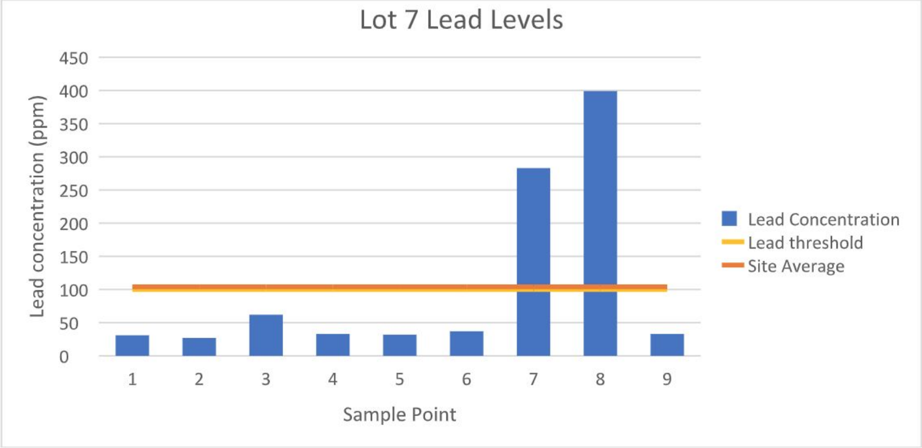


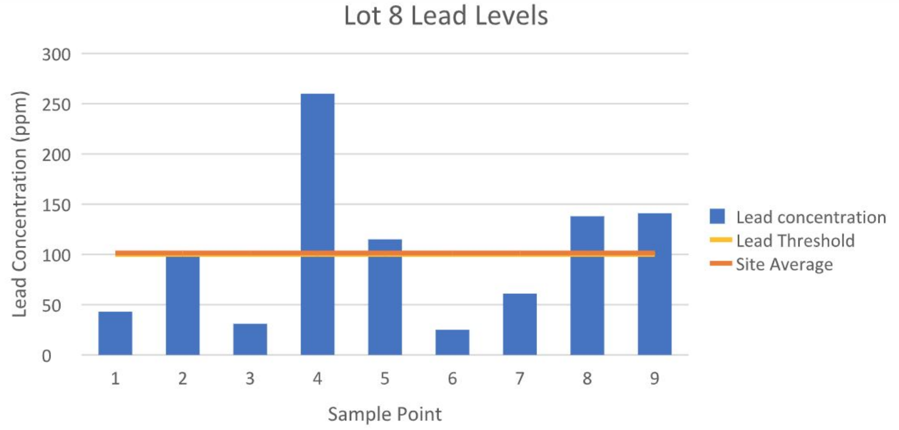



Lot 4 Lead Levels
Lead Concentration (ppm)
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
Sample Point
Lead Concentration
Site Average
Lead Threshold

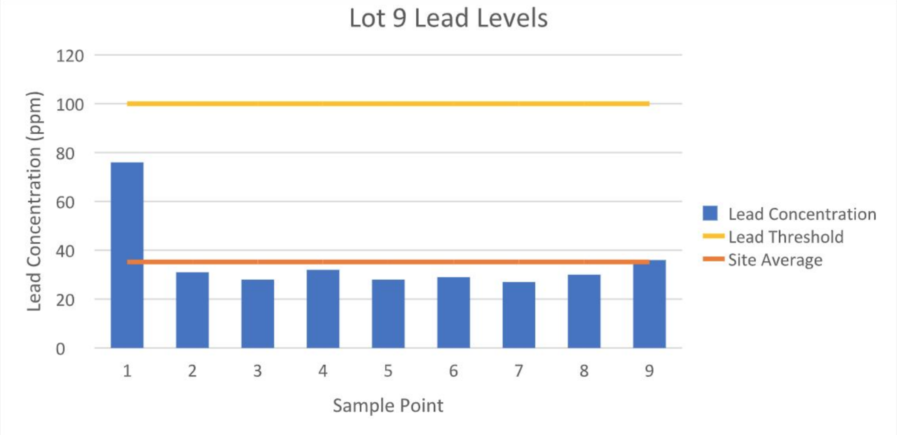

Lot 5 Lead Levels
Lead Concentration (ppm)
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
Sample Point
Lead Concentration
Site Average
Lead Threshold


Lot 6 Lead Levels
Lead Concentration (ppm)
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
Sample Point
Lead Concentration
Site Average
Lead Threshold

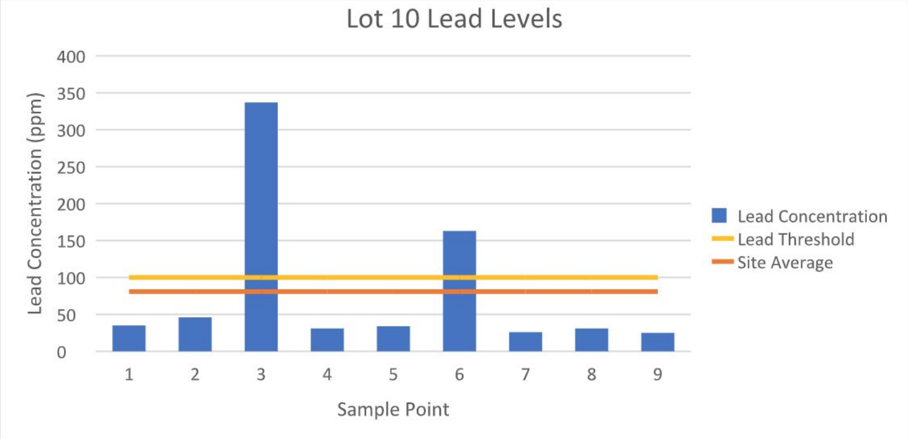

Lot 7 Lead Levels
Lead concentration (ppm)
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
Sample Point
Lead Concentration
Lead threshold
Site Average



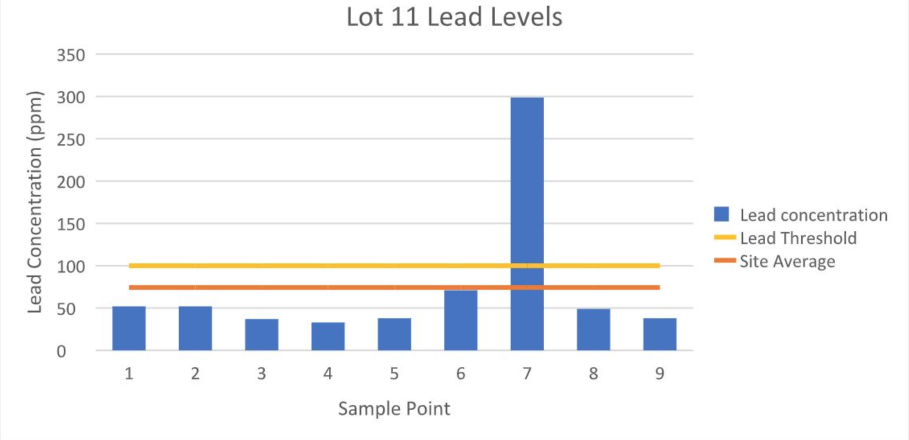
Lot 8 Lead Levels



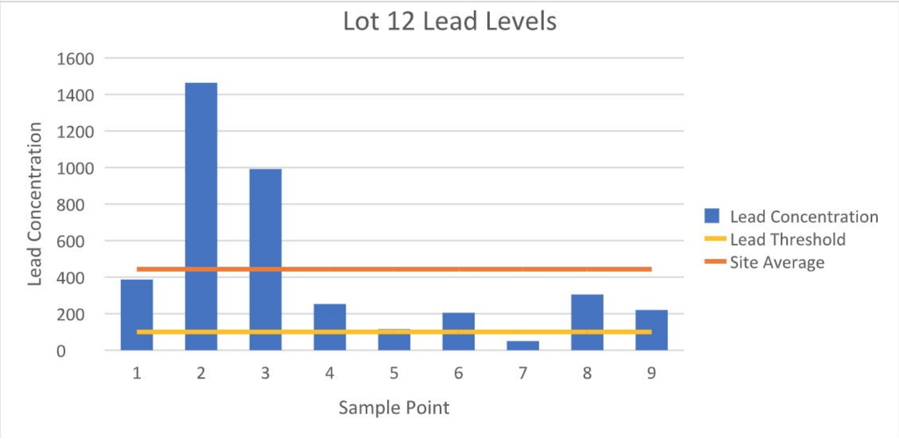
Lot 9 Lead Levels

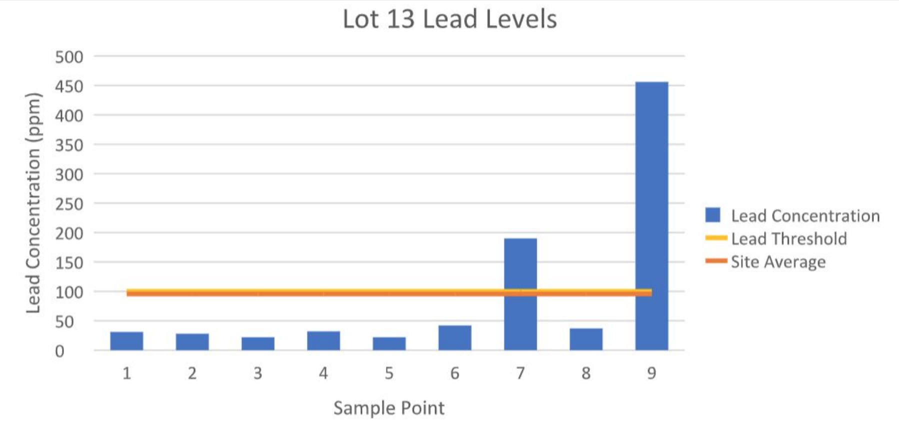


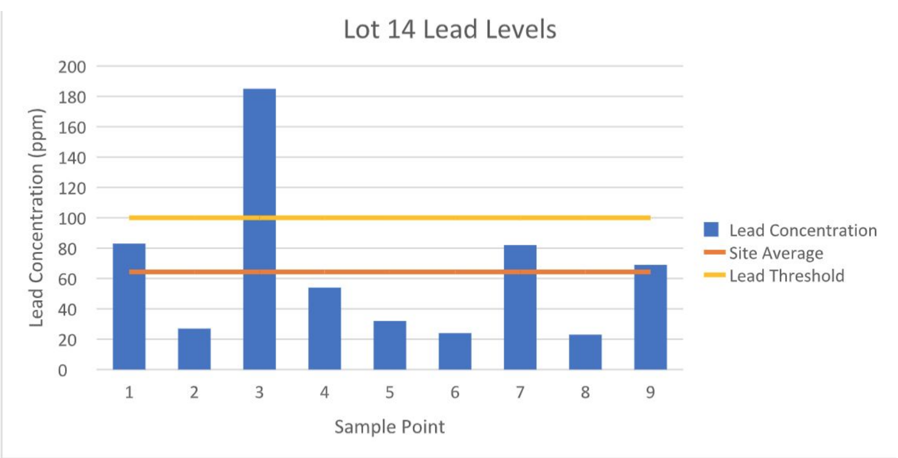
Lot 10 Lead Levels

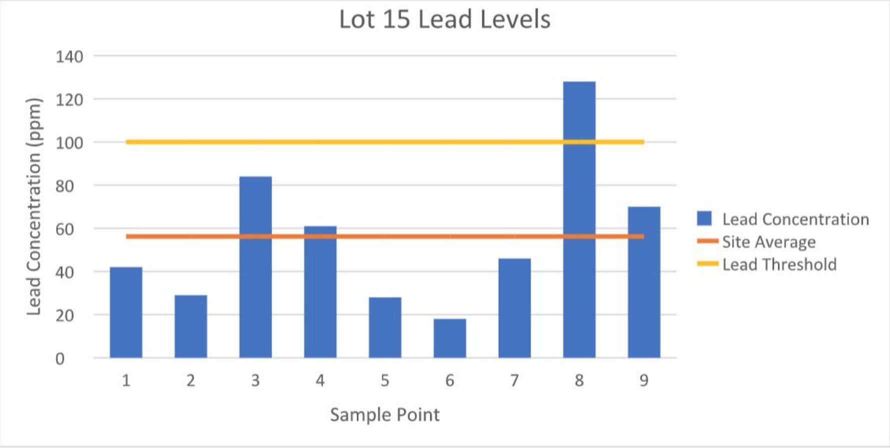


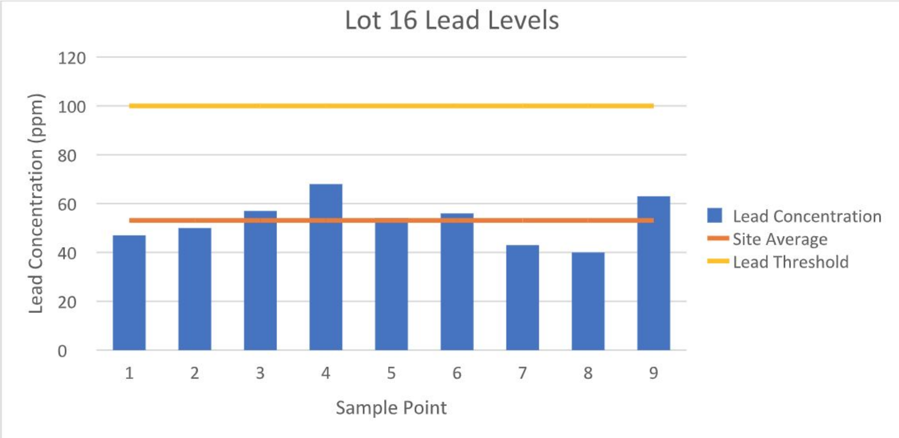
Lot 11 Lead Levels

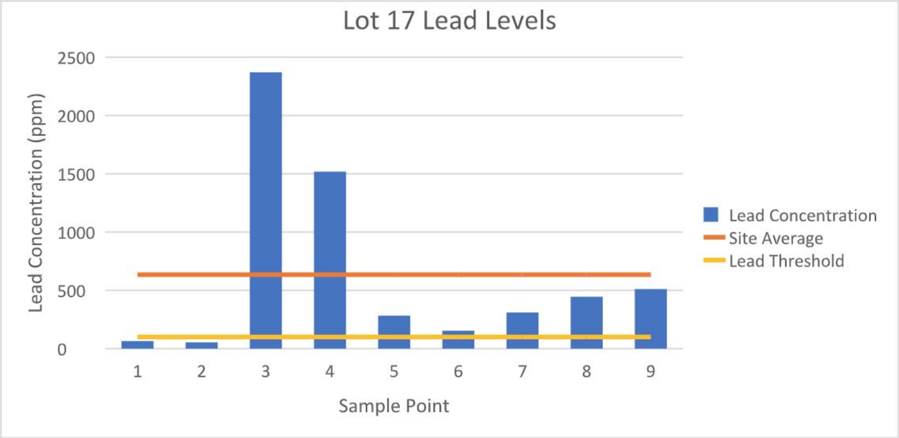

Lot 12 Lead Levels

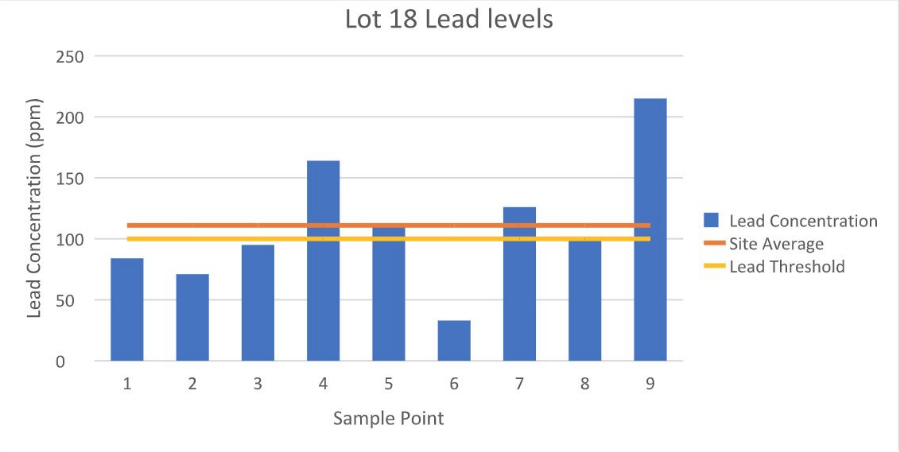

Lot 13 Lead Levels

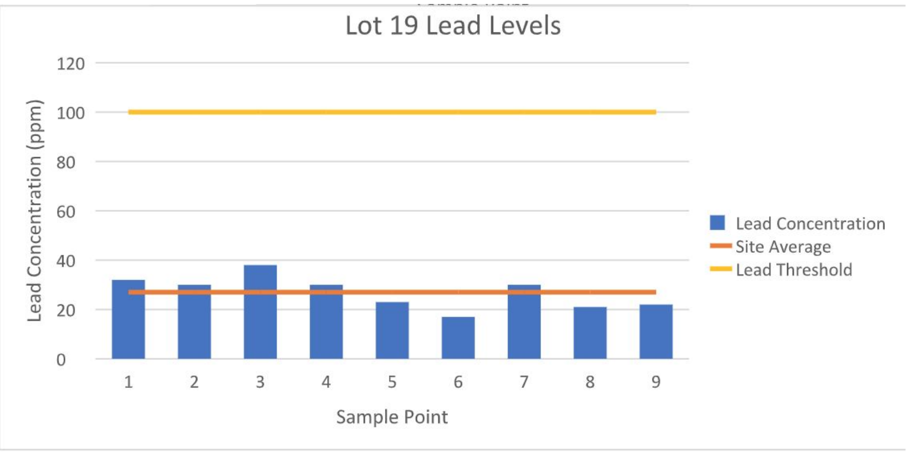

Lot 14 Lead Levels


Lot 15 Lead Levels


Lot 16 Lead Levels
Lead Concentration (ppm)
0
20
40
60
80
100
120
1
2
3
4
5
6
7
8
9
Sample Point
Lead Concentration
Site Average
Lead Threshold


Lot 17 Lead Levels
Lead Concentration (ppm)
0
500
1000
1500
2000
2500
1
2
3
4
5
6
7
8
9
Sample Point
Lead Concentration
Site Average
Lead Threshold


Lot 18 Lead levels
Lead Concentration (ppm)
0
50
100
150
200
250
1
2
3
4
5
6
7
8
9
Sample Point
Lead Concentration
Site Average
Lead Threshold


Lot 19 Lead Levels
Lead Concentration (ppm)
0
20
40
60
80
100
120
1
2
3
4
5
6
7
8
9
Sample Point
Lead Concentration
Site Average
Lead Threshold

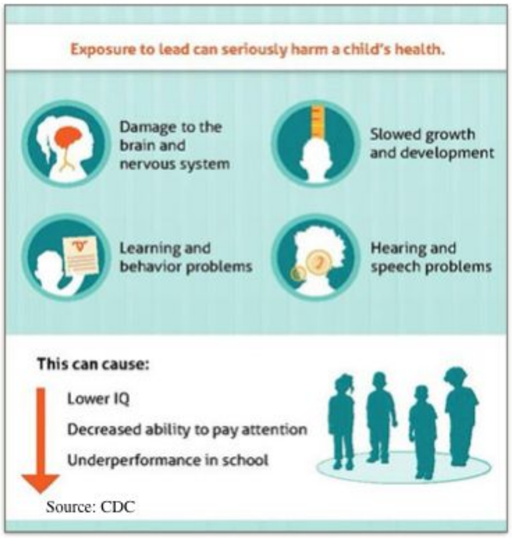
Appendix C- Evaluation of Remediation Strategies in Relation to Criteria

	Cost	**Feasibility**	**Effectiveness**
Sunflower Phytoremediation	$.20/sq ft plus potential tilling equipment and household rate for waste disposal	- Successful in past Lewiston projects - Little technical training needed	- One plant can remediate up to 700 ppm over 4 week period (Forte et. al) - More effective when used with compost and other amendments
Asphalt/Concrete Capping	clearing : $5,000/acre 1” sub base:~$5/yd^2 1.5” Surface:~$16/yd^2 Maintenance: $1000 annual	- Feasible - Requires accessible equipment	- Does not rid soil of lead - Limits lot use to parking
Clean Fill Capping	Exc. + place: $65-$105/yd^3 Seeding:~$150/1,000 ft^2 Maintenance: $5,000 annual	- Feasible - Requires accessible equipment	- Effective in removing most lead and covering any potential remaining lead - Open to more uses
Polypropylene Geotextile and Soil Cap	Textile: $2.36/sq ft Cheaper than clean fill	- Feasible, quick deployment - Low maintenance - Requires accessible equipment	- Contains lead while also providing top layer - Playgrounds have been built on top - No long term or large scale studies
Crustacean Shells	Cheap (waste product)	- Requires expensive equipment to process	- One of the most effective amendment options
Class C Fly Ash	$30/lb (waste product)	- Feasible but isn’t as effective without the addition of crustacean shells	- Most effective combination: 10% Calcined Oyster, 5% Fly Ash
Cow Bone	Cheap (waste product)	- Requires preparation, but less equipment compared to shells	- Less effective than shells, but more effective than biochar
Biochar	$150/cubic yard	- Feasible	- Less effective at reducing bioavailability, but improves soil health

Appendix D- Informational Flyer

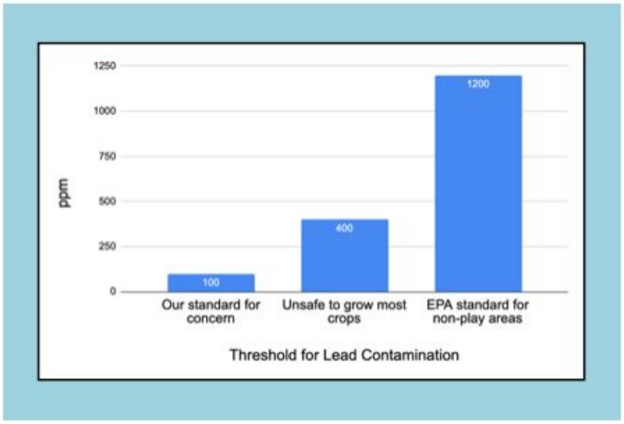
Soil Lead Concentrations in the Tree Street Neighborhood's Vacant Lots

Why is lead so bad?



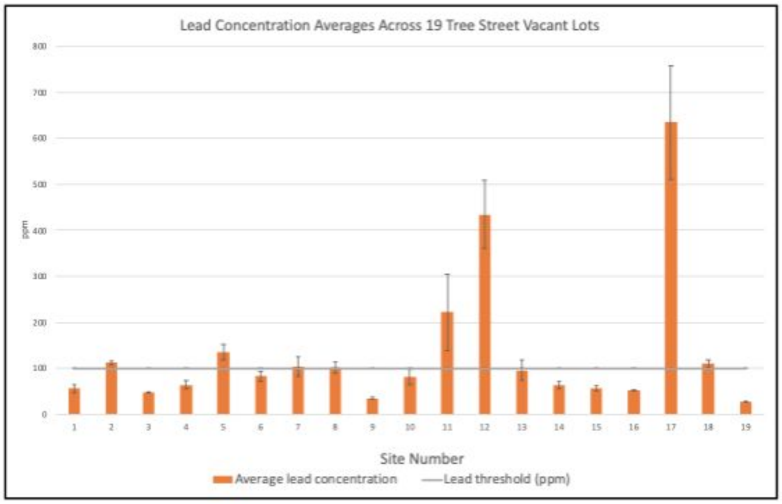
Source: CDC

How much lead is too much lead?



Did you know...

- **Lewiston has the highest rate of lead poisoning in the state of Maine**
- **Lead enters the soil from the demolition of old buildings with lead paint and from leftover runoff from gasoline that contained lead**
- **Lead contamination is a problem in the soil of many vacant lots located in downtown Lewiston**



What can we do about lead contamination?

Phytoremediation

- Uses plants to remove lead and other heavy metals from the soil
- Eco-friendly and pretty!
- Little technical skills or training involved
- Successfully implemented in past Lewiston remediation projects

Soil Capping and Raised Beds

- Contains contaminated soil to prevent lead exposure
- Growing field of new technology
- Raised beds already implemented in many Lewiston community gardens

Example of a cover with several layers

Source: EPA

Soil Amendments

- Immobilizes lead particles in soil to prevent exposure
- Many different forms of amendment options
- Potential to use Maine lobster and oyster shells as amendment
- Can improve soil structure and health

	Cost effective?	Feasible?	Effective?
Phytoremediation	Cheaper than most remediation strategies	Yes, already implemented in Lewiston projects	Yes, successful in past Lewiston projects
Soil Capping	Depends on type of technology used	More research needed	Successful in previous case studies, more research needed on new tech
Raised Beds	Cheaper than most remediation strategies	Yes, already implemented in Lewiston projects	Yes, but risk of soil contamination from wind
Soil Amendments	Depends on type of amendment used/equipment needed to process amendment	Depends on which type of amendment is used	Some amendments more effective than others

What remediation strategies would you like to see implemented in the Tree Street Neighborhood?

Stay tuned for more information about this project by keeping up to date with Healthy Neighborhoods' "Growing Our Tree Streets" Transformation Plan: https://www.growingourtreestreets.com/projects

A project by Bates College Environmental Studies Capstone course in collaboration with Healthy Neighborhoods

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Learn more at www.GrowingOurTreeStreets.com