Healthy soils for food system resiliency

BY

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Abstract

Urban gardens produce a growing portion of food consumed in U.S. cities and throughout the world. Spreading out food production means less reliance on centralized food industries, making the food system less vulnerable to external stresses brought about by climate change and other challenges. Yet, urban food production may occur in soils that need some revitalization before they produce safe, healthy food. Some urban soils contain a record of poor environmental practices in the form of accumulated toxins like heavy metals. Certain heavy metals can be toxic to plants, enter plant parts that people consume, or they can affect a person's health through direct ingestion, dermal contact, or breathing in contaminated dust or soil. Gardeners often seek solutions to problems proactively; the goal of this work is to provide the proactive gardener tools that can be used to assess the potential for toxins to be present, give suitable methods for detecting heavy metals, and provide guidance on making appropriate plans based on these findings.

This work investigates whether land use and environmental histories for a garden plot scaled up to a region can predict which heavy metals are present in the garden plot. Case studies are presented for Lawrence, Kansas including a broad environmental history of the town and site specific land use histories for ten urban gardens. Soil samples were collected and elemental analyses were performed using x-ray fluorescence. These results were used to demonstrate that predictions based on Lawrence land use and environmental histories were effective for arsenic, copper, lead, and zinc, but cadmium, chromium, mercury, and nickel were difficult to predict. Soil organic carbon was determined for a portion of the samples and a model for estimating organic carbon based on soil color is provided.

A discussion of the policy landscape for urban gardening in Lawrence, Kansas and Flint, Michigan provided material for a tool for determining what policy barriers may exist in any given city, and actions a gardener can take to address these barriers. Finally, a decision support tool was prepared based on lessons learned from the case study that will help gardeners gather relevant information, analyze the information, and make appropriate decisions in land management. Addition of organic matter is lauded as the simplest urban soil treatment that addresses many toxins as well as increasing soil tilth, nutrient status, and water holding capacity. Because urban gardening holds great potential for adding resiliency to the food system, urban soil health must be improved to protect public health.

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Contents

Chapter 1. Introduction

Food or hunger touches the lives of many people every day. Family food security refers to the idea that all individuals in a family receive sufficient food for health and vitality. Moving beyond the family to the community, national, and global scales add more complexity to the meaning of food security. Within these pages, the term "food security" will rarely appear, but the concept is inherent in the overarching goal of the work, i.e., to aid efforts that add resiliency to food systems at every scale.

Global socio-economic trends influence food system form and efficiency through population growth, rising incomes, changing levels and patterns of consumption, urbanization, and economic growth, which lead to increased demand (FAO 2009). At the same time, environmental challenges add difficulty to achieving a sustainable food supply (Figure 1) (FAO 2009). Climate change in human history has led to stressed agricultural systems and social unrest, at times even leading to war (Zhang et al. 2007, Burke et al. 2009, Büntgen et al. 2011). Climate change exacerbates existing challenges of biodiversity loss, water scarcity, and land degradation, all relevant to agriculture. These global challenges call for efforts to increase resiliency in all systems related to human and environmental health, starting with those providing food and water to people. A sustainable food system coupled with healthy soils equals a high level of resiliency, even when faced with challenges like climate change.

While the global socio-economic and environmental pictures of food security may appear bleak, small, expanding pockets of positive change appear throughout the world. In the U.S., local achievements in sustainable agriculture, soil rehabilitation, increased urban and peri-urban food production, along with efforts to consume less, have made gains toward a more sustainable food system. Yet, existing policy structures that favor a centralized, vertically integrated food industry hinder widespread change, leading to the supposition that significant change will likely sprout from the efforts of local farmers and gardeners.

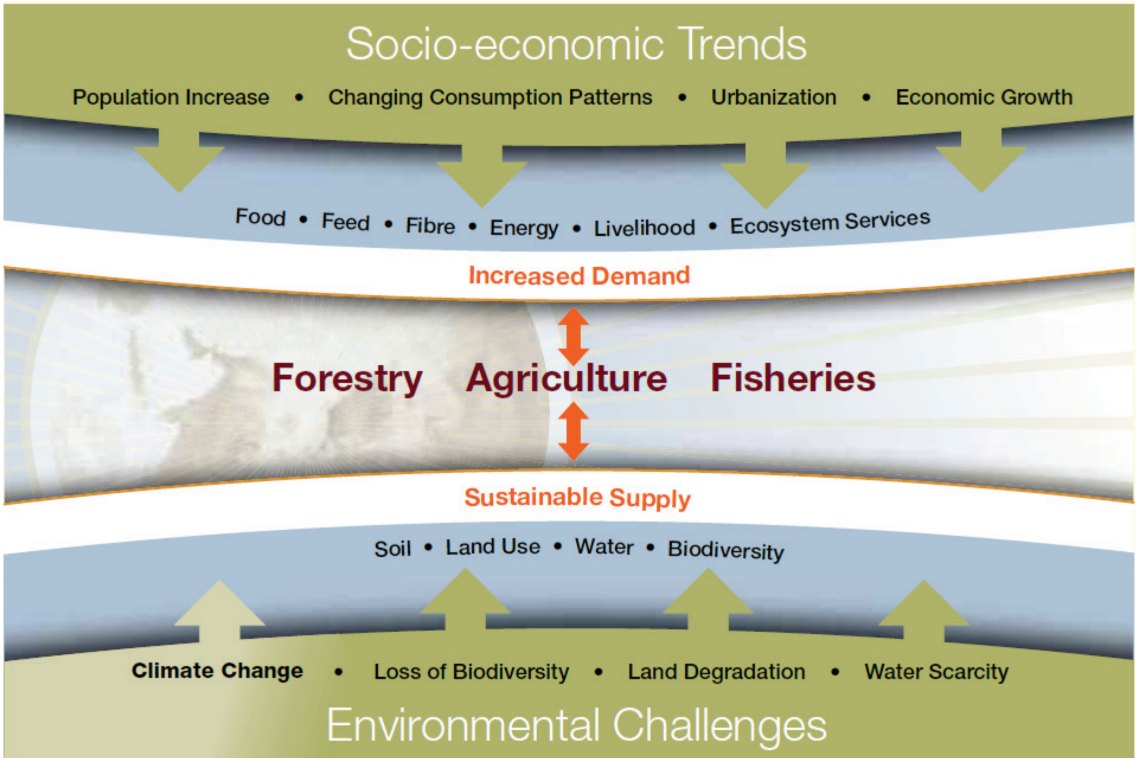


Figure 1. Socio-economic trends and environmental challenges result in a complex role for agriculture and a unique position to effect positive change. Source: FAO's *Profile for Climate Change* (FAO 2009).

The centralized form of the food production system causes it to be vulnerable to socio-economic shifts, natural forces, and other factors such as shrinking groundwater reserves. With less dependence on centralized nodes, a system gains resiliency and the ability to weather adversity. One city's sustainable food system adds resiliency to the broader food system by removing some pressure from centralized production, processing, and distribution nodes. Incremental decentralization of the food system through local food production and distribution is occurring now in many U.S. cities, indicating progress toward resiliency.

If a sustainable system feeds a city, a major portion of the food consumed must be produced, processed, and distributed from within or near the city. Serving as harbingers of sustainable cities is the growing popularity of urban gardening and more locavores, consumers of local foods (Martinez 2010). More urban gardens mean more locavores, even if the gardeners are only eating their own garden produce. Yet, since sustainability implies a continued source of food without harm to people or the environment, urban soil health must be part of the conversation.

Soils are not just a foundation for food production; soils provide protection for people, animals, microorganisms, and plants by filtering and storing a host of pollutants from water, air, and point sources like lead paint chips. This duality, emphasized in urban areas where more sources of pollution exist, means that urban gardeners must know their soils to participate effectively in sustainability. Gardeners must investigate and implement methods for promoting soil and plant health in order to ensure human health.

Soils rich with organic matter and free of toxins like heavy metals provide nutrient rich, bountiful yields of produce. These same soils continue filtering air and water contaminants, improving the microenvironment. If one shifts the effect from one garden to a multitude in a city, and a sustainable system is within reach. In this future vision of a city, a majority of fruits and vegetables eaten come from local gardens or peri-urban agriculture; gardens peppered throughout the urban landscape provide cool islands on hot days; air, water, and wildlife habitats are cleaner; even urban flooding has been diminished with more green spaces. These benefits are experienced locally, but the interconnectedness in the global food system means that the city's food system enjoys ramifications well beyond its limits.

Urban gardening will continue to play a major role in creating sustainable cities, triggering efforts to modernize local, state, and federal food policies, eventually leading to a higher level of resiliency for the U.S. Urban gardening is the focus of this work since it holds immeasurable potential for affecting change to the U.S. food system. Unfortunately, urban soils also hold immeasurable potential for contamination due to urban land use history.

Since individual gardeners and farmers will, in large part, catalyze food system change, these folk should be armed with information about how to detect soil toxins, increase soil health, and implement these strategies in land management. The following pages describe an effort to articulate how gardeners can gather enough information for making educated choices in sustainable land management. Links between past land uses and patterns of heavy metals in soils are explored for potential use as a predictive tool of soil health.

Garden case studies for one typical Midwestern city include the collection and analysis of the city's and each garden's land use histories and physical features (i.e. soil qualities, topography, proximity to flood zones and pollution sources, etc.). A series of Geographical Information System analyses provide insight into spatial and temporal patterns. Soil samples were collected from each garden and analyzed, providing insight into patterns of heavy metals and other soil characteristics relative to past and present land uses and landscape position. Results from these case studies provide evidence supporting some of the proposed heavy metal prediction and soil health monitoring procedures, but not others. In this way, physical and policy barriers for urban gardens, e.g., contaminated soils, land access, and food policy landscapes, are explored. The findings culminate in decision support tools for use by gardeners to help in synthesizing and applying gathered information. The tools provide straightforward advice to gardeners for planning next steps, both in the long-term and short-term.

Assessing food system form and resiliency, navigating policy obstacles for urban food production and distribution, and seeking linkages between land use and soil toxin patterns will take a life's work to grasp. The surface has now been tilled, seeds have been planted, and some concepts have sprouted.

Chapter 2. Global Change and U.S. Food Production

2.1. Food system science and sustainability

Food system science is the study of each arm of food production, processing, and distribution, as well as these parts in combination. The science looks at causes and effects of change in food systems from the perspectives of policy, economics, and natural systems such as climate change and soil degradation. The scale at which a problem is studied influences our grasp of the problem as well as which solutions can addressed. Food systems must be looked at from every scale or at least several scales to address problems as food production and distribution are simultaneously global and local (or "glocal") in practice. The interconnectedness of local systems to global systems creates unique problems; for example, a local weather phenomenon can affect a product's global trade network because of decreased availability and subsequently higher prices. An ample illustration of this point involves global wheat production. Drought in Russia, Ukraine, and parts of Europe in 2010 and in China in 2011, along with floods in Australia, have disrupted wheat production and reduced U.S. wheat reserves, leading to an 81% jump in wheat prices in one year (Wilson and McFerron 2011). Other local problems, particularly soil degradation, have gained global concern because of their ubiquity throughout the world's arable lands.

One way to study food system science is through the lens of sustainability (Tilman et al. 2002, Turner et al. 2003). Sustainability is defined in a number of ways, but here it is meant as the ability to maintain a system (e.g., food production and distribution) without negative impacts on people or the environment. A sustainable food system will provide an adequate food supply that is nutritious for people and not harmful to the environment, including people.

Sustainability science encompasses concepts of sustainable development, sustainability indicators, resilience theory, human-environment interactions, feedback loops, thresholds, and ecosystem services. Each of these concepts will be discussed in the context of food systems as they become relevant. The concepts of sustainability science provide a broader look at problems, avoiding traps of reductionism (i.e., avoiding complexities or oversimplifications at the finest scales), but they synthesize science discovered through reductionist methods to solve problems nonetheless. The concepts of sustainability science therefore provide tools for addressing the challenges of long-term survival of people along with Earth's other inhabitants, as well as how to flourish as interdependent communities. The crux of the challenge is at the surface of the planet, where human populations continue to swell while resources continue to dwindle.

As global population levels steadily rise, so does our understanding of how we have affected and continue to affect the Earth's surface. Continued success measured by the ability for everyone to survive and lead healthy, productive lives depends ultimately on our ability to provide an adequate supply of nutritious food for everyone on Earth. Stressors from war, shifts in climate, and natural disasters require attentive study for ways to achieve sustainability, with special attention toward adding resiliency in food systems to absorb these stressors without upsetting the system. Local and global attentiveness to these issues has increased in recent years, notably from grassroots efforts (SARE 2005). Achievement of food system resiliency and sustainability at all scales will need cooperation from producers to federal policymakers because the current food system is not sustainable. Proof of its unsustainability comes from degraded soils, chemical inputs at scales that cause harm to ecosystems, a decreasing number of farmers and increasing average farm sizes, and a slow motion avalanche of food safety and quality issues.

2.1.1. System form

At the most basic level, the form of a system dictates its function and functionality. The food system of the United States has shifted along a continuum of forms, a spectrum that has centralized production at one end and distributed production at the other (Figure 2). Reasons the U.S. food system has a centralized form stems from forces, e.g., the oligopolization of industrial agriculture, federal subsidies, and reliance on fossil fuels, among others (Feenstra 1992). System resiliency increases toward the distributed end, as stresses can be absorbed or contained at a small node, decreasing its negative effect on the entire system. By contrast, a minor disruption in a centralized system can cripple the system for an extended period, such as occurred during the U.S. egg recall of 2010, where a salmonella outbreak in one of the largest egg production facilities led to the recall of 380 million eggs (MyFoxNY.com 2010). The egg producer sent infected eggs to food wholesalers in eight states, who passed on the infected eggs to the entire nation. Generally, because most eggs consumed in the U.S. come from centralized production facilities (i.e., factory farms), a localized problem led to a nationwide outbreak of illnesses.

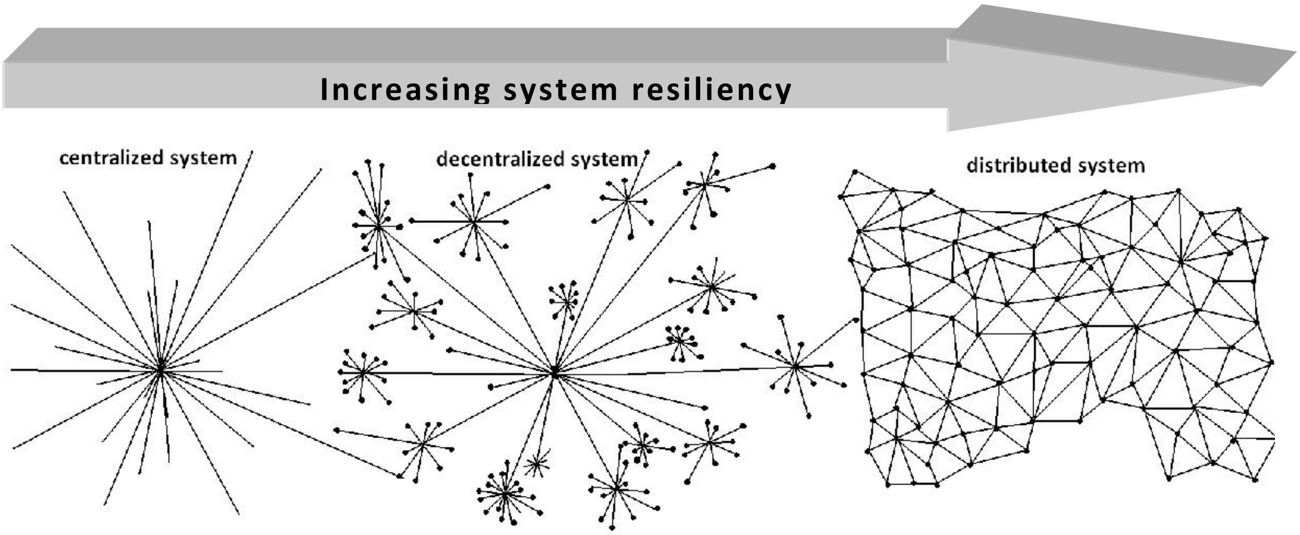


Figure 2. Illustration of continuum from centralized to distributed systems based on Baran's work (1964), with resiliency increasing as the system becomes less centralized.

The food systems of the first European settlers in America had a distributed form out of necessity and due to the absence of centralized government. Because of food scarcity, most families produced much of their own food for direct consumption or for trade for other consumables. Only when urban areas began to grow rapidly, i.e., in the nineteenth century, did food production become less distributed, as more people made a living in the city and could purchase food at local markets. Yet this system still had a decentralized form (Figure 2), as most production occurred in exurban locations or on nearby farms, and urbanites often knew the farmer who produced and handled their food (Lawson 2005).

The twentieth century witnessed many changes to the form of the U.S. food system. From 1890-1930, urban gardening was promoted in places like Detroit, where the mayor provided space to make Potato Patches to help people stave off hunger during difficult economic times (Lawson 2005). World Wars I and II led to a surge in backyard gardens, as the U.S. government campaigned for less consumption at home in order to provide more resources to Allied forces abroad. By 1942, the U.S. Department of Agriculture (USDA) estimated that almost half of the fresh vegetables consumed by Americans were produced in over 20 million garden plots (Basset 1981). This is an ideal example of a distributed food production system concentrated where the most people reside, i.e., in urban settings.

After World War II, the U.S. Congress commissioned two studies that helped evaluate the impact of increasing farm size (Goldschmidt 1946, Mills and Ulmer 1946). Both reports concluded that small farms are more beneficial to the community, the farmer, and food quality. Despite these findings, Congress took action to encourage industrialized agriculture, leading to centralized food production, processing, and distribution (Ikerd 2010). Mechanization in the form of heavy equipment for plowing, planting, harvesting, processing, and packaging led to a greater capital intensity of agricultural production and productivity (Cochrane 1979, Kislev and Peterson 1981). Furthermore, advances in agricultural chemicals and plant breeding enabled this system, leading to record crop yields (Cochrane 1979).

At the same time, the successes of centralized agriculture have their costs, not the least of which are decreasing food quality, stressed water supplies, and widespread soil loss and degradation (Pierce and Furuseth 1983). Today, however, more people are producing their own food in gardens or even in containers on apartment balconies (National Gardening Association 2001). Commercial urban agriculture operations are going a long way toward reviving food production in the most densely populated areas. These trends are shifting the U.S. food system, albeit slightly, toward a less centralized form, increasing the system's resiliency.

2.1.2. Resiliency

The concept of resiliency has been most commonly studied in the context of social work (DuPlessis VanBreda 2001). Applying the concept broadly to systems theory, particularly with environmental systems, has gained traction in recent years (Gunderson and Pritchard 2002). In general, the term "resilience" in systems theory refers to a system's capacity to manage stress without disrupting the functionality of the system (Gunderson and Pritchard 2002). In applying this concept to food systems, resilience retains this meaning of a system's relative capacity to absorb stresses, which varies among scales in the system, from soil health to food distribution patterns.

Consider the example of urban gardening. Once an initial level of sustainability is achieved (indicated by minimal degradation to Earth systems and sufficient food for everyone) through ecologically sound, distributed food production and trade, increasing resiliency is the next step in enhancing food security for urban residents. This goal can be achieved through more robust social networks (e.g., broader trade networks for access to a greater variety foods, sharing of gardening strategies) and through more robust ecological systems, such as permaculture, which maximizes productive capacity using primarily renewable resources and perennial crops.

At the foundation of ecological systems, particularly those utilized for food production, is the soil. To name a few factors, healthy soil has higher levels of organic matter and, therefore, more plant available nutrients; it has higher rates of infiltration and greater water holding capacity, which help crops survive floods and droughts; it produces higher yields of more nutritious crops, which feed more people and help fend off illness and disease (in both plants and people) (Culman et al. 2009). Increasing soil health serves to increase food system resilience in urban gardens and any agricultural system subject to stressors like climate change and market volatility. From a social perspective, higher quality, more copious food supplies coupled with a strong community and social network serve to increase resilience on an individual and household basis.

2.1.3. Natural constraints

Agriculture exists where there is arable land and a suitable climate or the ability to subsidize these factors to create an area utilizable for agriculture (e.g., with irrigation, soil amendment, using raised beds, etc.). When contemplating a shift toward a distributed system, constraints in the natural systems must be considered, including spatial distributions of arable land (determined as a function of soil quality, topography, accessibility, and climate), availability of water, weather patterns, and how all of these may shift or intensify with climate change, and the competition of these resources among people (e.g., municipal water needs) and between people and ecosystems (Blaikie and Brookfield 1987). The link between human health and ecosystem health, often described as “ecosystem services” has been increasingly recognized as an important consideration in sustainable development and economic development (Collins and Larry 2007). Further, since sustainability requires that there is no degradation of environmental health, ecosystem health (repair and) maintenance is considered a natural constraint to realizing a distributed food system.

2.1.4. Social constraints, economic drivers, and policy considerations

Agricultural change is driven and constrained through internal and external factors, both social and natural. It can be sparked or shaped by external forces, e.g., advances in technology or population growth (see Malthus 1798, Boserup 1965) or through external forces manifested through political economies. In Stone’s (2001, 329) discussion of Agricultural Change Theory, he states:

> *…most farmers have to contend with economic factors that affect the cost of inputs and value of output beyond local energetics … Few small farmers today grow crops exclusively for subsistence or sale; most do both, and they often favor crops that can be used for food or sale.*

While Stone's point is better applied to less developed countries, it raises a point that is increasingly becoming relevant for small farmers and urban agriculturalists in the United States, i.e., considering crops that can have dual value for subsistence and sales and recognizing a need to address their own family's food security. The economic framework of diversifying one's portfolio, or in this case, crops for home and market, will help farmers and their urban counterparts gain financial resilience. With rising energy and fuel costs, along with myriad other uncertainties, farmers and gardeners must find ways, such as crop diversification, to align their cultural beliefs with economic realities.

From the perspective of social change, an intensification of agriculture (i.e., gardening) in urban areas can be described as a form of agricultural involution (Geertz 1963). This idea states that external pressures (i.e., climate change, market forces, population growth) lead to an increase in agricultural labor (i.e., more gardeners) within a limited area (i.e., urban lots), leading to higher productivity per area, but not necessarily per person. As Turner and Brush point out, "The concept of involution seems particularly useful for understanding intensive subsistence agriculture that supports large and dense populations" (Turner II and Brush 1987, 20). They go on to say that when agricultural involution occurs, it often leads to a labor bottleneck, where there is insufficient labor at critical times in the crop cycle (Turner II and Brush 1987). From this perspective, the success of a start-up urban garden will hinge on the resourcefulness of the gardeners (i.e., reliance on tools, expert advice, etc.), and their access to family members and friends willing to share in the labor during more challenging phases of growing food crops.

The increasing incidence and popularity of gardening marks a shift in ethos, or a shift in cultural beliefs and attitudes surrounding gardens. This attitudinal shift is occurring despite how recent and rapid advances in technology (particularly in the ways people communicate over the last decades) have disrupted some of the continuity associated with passing ethos from one generation to the next. This change is also apparent in the U.S. food ethos, characterized by the way Americans prepare and consume food. As children, the Baby Boomer generation and earlier generations had a better understanding of food origins compared to today's children, whose experience with food may be limited to packaged, processed items (Schlosser 2002). An allegorical case in point is the children's movie *WALL-E* (Stanton 2008), where Americans had become so disconnected from food origins that they believed in pizza trees.

Consider the American ethos of farming. The majority of U.S. farmers are over the age of 55 (EPA 2009a), so the post-World War II belief in the superiority of industrial-scale agriculture is pervasive. These farmers witnessed the successes of the Green Revolution in the 1970s, where crop yields dramatically increased and agriculture expanded into lands that were previously thought to be unsuitable (Jain 2010). It follows that many of today's farmers work thousands of acres (much of this acreage leased from absentee land owners) and rely on chemical inputs and advances in seed varieties to maintain yields (EPA 2009a). Because farmers comprise less than one percent of the U.S. population (EPA 2009a), but manage about 41% of U.S. land (Economic Research Service 2010), they are a key group of actors in transforming the food system.

Yet the entrenched system form, both socially and systematically, is difficult to overcome. One way to overcome this entrenchment is by changing the demographics of the farming community by enticing young people into farming. While still limited, there is a growing interest among young Americans in returning to the land, running small farms (SARE 2009). They are faced with typical challenges of farm life, such as vulnerability to weather, and they have the added challenge of attempting to renew family farms in a system designed to favor large farms (section 2.1.1).

Another way to track changes in American agriculture is through tracking American soil ethos, i.e., the way people think about soil and the way land managers treat soil, which shift over time. For instance, starting with the Dust Bowl in the 1930s, soil enjoyed a period in which it was recognized as a valuable resource, something to be preserved and maintained, even treasured; while previously it was considered simply as a resource to be extracted (Berry 2010). While the idea of soil conservation remained important to farmers after the Dust Bowl, it was conceived primarily in terms of keeping topsoil in place, not necessarily preserving soil health (Berry 2010). The trends of resource extraction, measureable in nutrient depletion and loss of soil biodiversity have been masked by chemical inputs (Jain 2010). More farms are now utilizing no- or low-tillage management or are converting to organic farming practices (Clark 2010). These developments highlight a recent, albeit not widespread shift in soil ethos; an ethos that recognizes how healthy soil produces more nutritious foods and maintains ecosystem health – a win-win scenario for people, plants, and animals.

Unlike most farmers, urban gardeners are subject to municipal rules and regulations. Access to land for growing and selling in light of zoning restrictions and food safety regulations comprise two examples of complexities faced by urban food growers who intend to sell their products. Usually, backyard gardens for household consumption are not party to these limitations, unless gardens conflict with the restrictive covenants of a neighborhood association. Another difficulty has been when small food gardens have at times been considered as "eyesores" in the United States, leading to efforts to remove them. This attention to aesthetics in urban areas occurred during the City Beautiful Movement at the turn of the 20th century, where some upper and middle class people were disturbed by urban blight (Basset 1981). The movement led to destruction of some food gardens in favor of English-style formal gardens. The paternalistic thought was that lower class urbanites would take greater pride in their beautified neighborhoods, but in reality the removal of gardens relied upon for sustenance did more harm than good for the poor population (Williamson 2002).

Some cities in the United States have made gardening part of their future vision, expressed in plans such as climate change adaptation strategies (City of Kansas City 2009). Other municipal involvement comes in the form of financial donations to existent urban garden non-profit entities (e.g., Denver Urban Gardens), progressive zoning laws (e.g., Cleveland), or regulations that are seen as a hindrance to existent gardening efforts (e.g., Chicago) (Denver Urban Gardens 2010, FindLaw 2011, Eng 2011, respectively). What is not clear from these efforts is how cities will handle liability issues, e.g., those that may arise due to soil toxins on public property. In Lawrence, produce from one garden has been avoided by some consumers that suspect contaminated garden soil (Grimes 2009), but the municipal government has not intervened or established soil testing requirements in response to these concerns. Urban soils' relatively higher potential for contamination based on past and present land use, while rarely considered by municipal governments (e.g., not including designated polluted sites, e.g., brownfields), is an issue worth considering for protection of local growers and consumers alike.

Part of the difficulty for municipal governments is how to define contamination since thresholds vary depending on the medium (i.e., soil, water, air) and rules governing required actions, if any, can vary from state to state. Furthermore, remediation measures are typically expensive and/or time consuming. An attempt to detect and then trace a contaminant through the food system requires skilled workers with broad knowledge of physical systems and food networks. In addition, each case of potential contamination is significantly influenced by local factors including physical (i.e., weather, climate, soils, water, topography), economic (i.e., access to and willingness to fund clean-up activities), and social (i.e., value placed on the contaminated resource by the community). Within this document, the term "contaminated" in the context of heavy metals is meant as any level above normal background levels from weathering of geologic strata, which varies widely from place to place. Furthermore, a soil is considered to be contaminated when the natural background level exceeds safe levels as determined by the EPA, where applicable. With state and federal agencies establishing definitions of "safe levels" of certain contaminants appears a first example at how policy affects soil management and therefore, gardening activities.

Social factors and dynamics of the local economy play large roles in setting the tone for the local policy environment. From this account it is clear that the local policy environment has the greatest impact on how local food is produced and sold in urban areas, including food safety nets that are present or absent. The policy framework for any place dictates the ease with which urban food production can successfully expand to become an important part of the local economy. As urban gardening seems to be a grassroots movement that is gaining traction, in most cases it seems to be garnering support from local governments due to its positive impacts in education (e.g., through schoolyard gardens), environmental and human health (e.g., fewer food miles, less packaging, exercise and fresher produce for consumption), and local economies (burgeoning small businesses, farmers markets, community supported agriculture). These trends indicate a shift in the American ethos surrounding food production and consumption.

2.2. Development of urban landscapes related to food production

Once people starting living in one place for extended periods, two events followed: they realized a need to manage their waste and they became gardeners. Human waste, either by design or by chance, typically enriched the soil during these early times (Woods 2008). The growth and success of ancient civilizations was highly dependent on the ability to capture the nutrients in waste and reapply them on agricultural fields (Denevan 1998). For instance, ancient Amazonian cultures converted poor soils into rich agricultural soils by using wastes effectively (Woods and McCann 1999). Early farmers eventually shifted to a system of exporting nutrients from their fields to nearby urban centers, where soils became enriched from daily activities (McNeill and Winiwarter 2006). This trend has continued and farmers have tried to alleviate the nutrient extraction with soil amendment (Jain 2010).

Another prevalent land management technique both then and now has been burning, either to clear woody vegetation or to keep out unwanted species in an agricultural landscape (Pyne 1998). Intentional burning perhaps marks the onset of intensive resource management to maximize the landscape potential for food production (Woods 2008). As ancient societies improved landscapes year after year, they became more productive and therefore more valuable, a concept known as “landesque capital" (Widgren 1997). A modern farmer's ability to improve landesque capital is typically limited by what technology is available and affordable within his operation. Either way, the historic land management has resulted in anthropogenic soils in both urban and rural areas with a vast variety of characteristics due to their different anthropogenic landscape histories (Woods 2008).

Two central differences exist between ancient and modern agricultural techniques: (1) the capital-intensity and labor-intensity of the work, and, (2) soil management. By reviving some ancient techniques of soil and land management, coupled with the productivity of highly mechanized work, modern farmers can boost production in a sustainable fashion. By contrast, urban gardeners typically rely on human labor rather than machines; thus the concept of landesque capital in the ancient sense, i.e., gained through human labor, is more applicable in this context. Additionally, urban gardeners can more easily implement ancient strategies involving nutrient management, building productive soils, as well as water management and other techniques. Worth noting is that while ancient societies tended to enrich urban soils with nutrients, modern urban soils have experienced a multitude of land use histories, either harmful or beneficial, resulting in a heterogeneous anthropogenic soil at even the finest scale (Woods 2008, NRCS 2008).

2.2.1. Urban and agricultural revolutions

Vernacular gardens became common when people became sedentary (Doolittle 2000, Doolittle 2004, Kimber 2004). The same ingenuity and resourcefulness that permitted a sedentary lifestyle lent its cleverness to creating kitchen or dooryard gardens filled with useful and favorite plants. These gardens supplemented diets and provided a ready source of medicinal herbs (Doolittle 2004). Gardens for food and medicine were commonplace beginning with early settlements, and became urban gardens as our settlements became cities (Doolittle 2000, Doolittle 2004, Kimber 2004).

Ancient civilizations known for sophisticated agriculture developed in most parts of the world, including Asia, New Guinea, Europe, Africa, and The Americas (UNDP 1996). The agricultural practices of these societies can be characterized by their innovative methods of utilizing waste to increase soil productivity, water management practices (e.g., terracing, irrigation, aqua-terra farming), and use of urban space (UNDP 1996). Also notable, and a common factor among these societies, is where they located their cities and their agricultural sectors within naturally favorable landscapes. The Nile River delta, Amazon River bluffs and floodplain, or the western slopes of the Andes, for instance, all have distinctive advantages for agriculture. Each landscape in these success stories, although unique in availability and quality of resources, was improved to enhance its long-term natural productivity, increasing its landesque capital (Woods 2008).

2.2.2. "Landesque capital" and palimpsests in urban settings

The term, "landesque capital" was introduced by Amartya Sen in 1960, and was later refined by Australian geographer Harold Brookfield (1984) to describe a type of land improvement that "once created persists with the need of only maintenance." Prior to Sen, Marx had described the idea of *la-terre capital* or land-capital as capital that "was fixed in the land, incorporated in it" (Marx 1959). Brookfield expanded the definition of landesque capital to include more innovations, including more types of lasting land improvement, but limited the definition to include only investments with lasting benefits "well beyond that of the present crop, or crop cycle" (Blaikie and Brookfield 1987). This definition excludes short-term management techniques, e.g., spraying crops for pest control (Widgren 1997). So, it is Brookfield's definition that is most widely used today (Widgren 1997), encompassing items like irrigation structures, agroforestry, and anthropogenic soils that demonstrate improved, lasting quality (Brookfield 2001).

Widgren (1997) makes the point that although soil and climate comprise the most obvious factors in current agricultural productivity, landesque capital, i.e., land use history, is the next most important factor explaining global disparities in land productivity. Widgren goes on to say that landesque capital is best understood by looking at its spatial rather than economic aspects:

> *Unlike monetary capital, which is fluid in space but fixed in time, landesque capital is fixed in space but "fluid" in time. The chronological and social contexts of its use, management and further development, can differ significantly from the contexts that once shaped it* (1997, 8).

Important to understanding landesque capital, especially in urban settings, is the idea of adding layers over time, layers of value and/or layers of differing land uses. This notion is akin to the law of superposition, where layers of sediments are deposited in a temporal sequence, meaning that older layers are positioned below younger layers (Hamblin 1978). Generally speaking, this concept may be applied to urban settings, where new structures are built upon old. Here the concept of palimpsest becomes helpful, as often a shadow of the old structure is reflected in the new structure (Whittlesey 1929, Bailey 2007). If not recorded in structures, changes in land use are often recorded in the physical or chemical structure of a soil (Brady and Weil 2002). It follows that land inhabited or otherwise used by people over generations can be thought of as a palimpsest, whereby different uses and histories are recorded in layers of soil (Bailey 2007), each layer potentially reflecting qualities of other layers. Regular improvements of a landscape result in a layers of landesque capital improvements. On the other hand, urban soils by their very nature are often disturbed, e.g., from urban flash flooding and consequent erosion, construction, or bringing in new material. With digging or mixing, the law of superposition is nullified, and the palimpsest concept may only apply in specific cases.

The idea of landesque capital, applied to modern urban settings, encounters some problems as well. Brookfield's treatment of the term implies an agricultural land use. Setting aside this implication, modern urban land use satisfies the general idea: "once created persists with the need of only maintenance" (Blaikie and Brookfield 1987), because urban infrastructure provides a wide range of long-term benefits to society. Increasing urban landesque capital by implementing, intensifying, and maintaining agricultural land use would expand opportunities for landesque capital investments in urban settings. Accordingly, by studying successful ancient urban societies, who were experts at melding agriculture with urban land use, we can evaluate past methods of generating landesque capital and their appropriateness for the present.

2.2.3. Ancient agricultural techniques

Many examples exist of societies that were able to build empires around successful land management technologies (Castillo 2003). Archaeologists and aerial imagery have helped uncover massive earth and waterworks at the edges and within urban areas of ancient civilizations. This infrastructure provided food for people and animals, wood for fuel, buildings, shade, windbreaks, and fences. It provided plants for ornamental, medicinal, and ceremonial uses and land for livestock, transport, and trade (Mougeot 1994, Castillo 2003). The ingenuity and consequent effectiveness of these infrastructures and systems demonstrate how the success of the ancient cities was reliant on urban agriculture (Mougeot 1994). Some illustrations of the ingenuity and practice of building landesque capital in ancient civilizations throughout the world follow.

Uruk, with an estimated population of possibly 50,000 in fourth-millennium Mesopotamia, extended over 1100 acres, a third of which was in palm groves (Adams 1994). In addition to their primary occupation, most of the working adults in Uruk practiced agriculture, either on their own land, their allotted land, or as dependent retainers on large estates (Adams 1994). Knossos, the Neolithic Minoan settlement, developed mixed farming of wheat, barley, lentils, sheep, goats, pigs, and a few cattle (Rodenbeck 1991). Spread over 75 acres, the population of 12,000 was organized into a central court surrounded by grouped storage and production areas. Just outside the city, about 2,500 acres were in production, likely controlled by the Minoan ruling class (Rodenbeck 1991). In 1500 BC, Thebes was covered with walled gardens for the flourishing Egyptians, hence fresh pomegranates, apples, almonds, dates, and other fresh produce was common (Jellicoe 1989). The Egyptian city of Akhenaton was also covered in gardens with additional space designated for food storage, breweries, and animal keeping (Courtlandt and Kocybala 1990).

Urban agriculture was probably limited by water shortages in ancient Greece, but ingenious water management, e.g., the use of aqueducts, cisterns, and terraces with irrigation allowed for agricultural production in a typically arid climate (Rodenbeck 1991). Greek city-states supplied their own olive oil fuel for house lighting and their own goat milk (Rodenbeck 1991). The Romans also innovated to maximize their landscapes. In the ancient port of Ostia, near the mouth of the Tiber River, archaeologists discovered a planned complex of garden houses, erected in approximately AD 128 (Watts and Watts 1994). Housing around 400-700 people in 40 to 100 apartments, the complex was likely constructed for the lower and middle classes. Water was supplied from six fountains in the complex (Watts and Watts 1994). Other examples where imperial Romans influenced the landscape can be found in Timgad in Algeria and Volubilis in Morocco, where extensive agricultural drainage schemes were built (Watts and Watts 1994). Later, at its height around 100 BC, the Roman city of Cosa included a fish farm that was linked to the harbor through artificial and natural channels (McCann 1994).

Medieval European food issues, including quantity, freshness, and price were a source of constant anxiety (Reynolds 1984). Tapestries from the era depict castle gardens with raised beds and rabbitries (Jellicoe 1989). In addition, crop rotation systems were tested and improved in and around many of the larger building compounds, e.g., monasteries, walled cities, and castles. Sometimes buildings were erected encompassing a garden, with orchards nearby, such as the 15th century College of the Vicars Choral in York, England (Hall et al. 1988). The medieval Russian city of Novgorod was built with well-spaced housing, gardens, and orchards inside the city and outside its walls (Yanin 1994).

There are also examples of ancient societies developing landesque capital in the Americas. North America's Mississippian culture, at its peak in AD 1050-1250, inhabited rich alluvial valleys of several large rivers and their tributaries including the Mississippi, Arkansas, Tennessee, Ohio, and Red Rivers (Coe, Snow and Benson 1986). The rich soils allowed for productive horticulture, defined by growing a variety of cultigens in a relatively small area (Woods 1986). The largest pre-Columbian urban settlement north of Mexico was Cahokia, in southern Illinois. With a population estimated to be at its peak 10,000 to 15,000 (Coe et al. 1986, Fowler 1997, Milner 1998, Dalan et al. 2003), the success of Cahokia relied on its ability to feed its citizenry. While Cahokians employed a number of adaptive agricultural techniques, e.g., raised beds and ridging, the particular genius of this urban settlement had to do with choosing its strategic location with sufficient resources, which in this case included good surface drainage, arable soils, access to water, and availability of fuel wood (Woods 1986). Cahokia's central location along a major river system also means that it likely served as a hub for trade and possibly as a center of ceremony (Woods 2008). Later, mismanagement of these resources was part of the stress that led to eventual failure of the city (Woods 2004).

South of Cahokia, the Moundville site in Alabama utilized pits for storing live fish (Coe et al. 1986). The American Southwest is dotted with earthworks such as terraces and irrigation systems to maximize agricultural production (Doolittle 2000). Further south, in Central America, steep hills were terraced, and swamps drained into fields at the edge of Nohmul, a late Pre-Classic city near the Belize-Mexico border (Hammond 1994). The nearby city of Edzna (in the present day state of Campeche, Mexico), waterworks were built capable of storing 2.25 million m^3 of water. These waterworks were needed to support a highly organized agricultural economy (Hammond 1994). In the Valley of Mexico, four thousand years ago, small towns, e.g., Tlatilco and Ticomán were constructed atop stone-faced terraces, where people grew vegetables and raised dogs and turkeys (Burland 1976).

Also in Central America the Aztecs developed a variety of techniques to build landesque capital depending on the character of the place. They constructed an artificial island of over 20 square miles on Lake Mexico, where their capital city of Tenochtitlán was located (Anton 1993). Equally impressive was the Aztec metropolis of Teotihuacán, at its height in 500 BC (Millon 1994), which was larger than imperial Rome and had a population five times that of Henry VII's London at the time (Redclift 1987). While both cities relied at least partially on food production within and at the edge of the urban settings, Tenochtitlán's unique location led to invention of *chinampas,* a unique form of wetland agriculture (Coe 1964, Armillas 1971, Deneven 2001). Artificial islands were created within shallow lakes; then nutrient-rich sediments from the lake bottom were regularly placed atop these plots (Coe 1964, Armillas 1971). Because of the rich nutrients and the microclimate created by this aqua-terra system, the farmers of the *chinampas* were able to produce three harvests per year (Coe 1964, Armillas 1971). Also, a system of artificial canals allowed easy distribution of the foods to the inner parts of the city of Tenochtitlan (Coe 1964, Armillas 1971). Today, a few of the *chinampas* are still in operation in the shallow waters of Lakes Chalco and Xochimilco and in most of the island of Tenochtitlan-Tlateloco (Deneven 2001). To protect Lake Texcoco *chinampas* from inundation with saltwater in the rainy season, the society constructed a 15 km long dike (Coe et al. 1986). Northeast of Tenochtitlan, an aqueduct brought water to a hilltop orchard (Haas 1993). Burland notes that the well-spaced layout of the city likely meant that each home had its own garden (Burland 1976). A nineteenth-century painting of Mexico City, reprinted in Haas' *Gardens of Mexico* portrays a woman and her attendants in her rooftop garden, with a water seller nearing the group (Haas 1993). Haas observes that rooftop container gardening is a lasting trend in many parts of Mexico.

Figure 3. Stone terraces near these homes in the ancient Inka city of Choquequirao took advantage of the nearby water source while protecting soils (Calvert 2008).

To the south, in the Colombian Sierra Nevada, the Tairona people built a sophisticated landscape of retention walls, canals, and drainage systems to employ urban agriculture at the Buritaca site (Burland 1976, Coe et al. 1986). The ingenuity of this system brings to mind the famous terraces of Machu Picchu located in the Peruvian Andes. Origins of terracing in the Andes are pre-Incan, and there may be a connection between the Spanish word for bench terraces, *andenes,* and the name of the mountain range (Deneven 2001). The terraces served and continue to serve many purposes, including reduction of soil erosion on the steep slopes (**Error! Reference source not found.**). Depending on the form of the landscape and the need for irrigation, ancient farmers made a variety of improvements, including retention walls, terrace gravel beds, stone-lined drainage and other earth works (Francisco, Clay and Smeltekop 2010). Less obviously, Incans were able to use irrigation with some terrace systems (Deneven 2001) to control the microclimate, which extended the growing season in the higher latitudes by fending off frost (Francisco et al. 2010). Incans also understood effects of latitude on plants, and would select crops that fared best in different latitudes (Francisco et al. 2010).

A final example involves the *terra preta do Indio,* or “black soil from the Indians” of the Brazilian Amazon (e.g., Sombroek 1966, Woods and McCann 1999, Glaser and Woods 2004). Faced with extremely poor soils, the indigenous tribes learned over centuries which land management practices led to soil enrichment. These black soils contain high concentrations of nutrients and a high quantity of archaeological remains (i.e., pottery, lithics, fauna bones, human burial remains, and charcoal). The pH tends to be neutral (around 6-7) and the high cation exchange capacity and richness of organic materials provides excellent conditions for crops (Sombroek 1966, Woods and McCann 1999, Glaser and Woods 2004). Unintentional soil enrichment led to an intentional soil building method. Remarkably, the soils built hundreds to thousands of years ago (Erickson 2003) have maintained their structure and high nutrient status (Sombroek 1966, Woods and McCann 1999, Glaser and Woods 2004, Lehmann and Joseph 2009).

From these examples, two points become clear. First, that some ancient societies were successful because their cities were planned with urban and peri-urban food production in mind. “Being more vulnerable to supply disruption or insufficiency, malnutrition or famine, food provision throughout history has been a pervasive concern of city populations" (Mougeot 1994). It is clear that throughout human history, urbanites have been directly involved in food production to varying extents. It is also clear that this food production typically occurred nearby personal residences, and/or in or near the city boundary. These nucleated populations needed a reasonably reliable source of food and nonfood items to ensure continued subsistence and trade, a possible explanation for the complex earth- and waterworks (Mougeot 1994), which are forms of landesque capital, sound investments in food security. The second point is that many ancient landesque capital investments have continued to pay off; for instance, the *chinampas* of Mexico, the terraces of the Peruvian Andes, and *terra preta do Indio* have continued to be productive and have intrigued farmers, earth scientists, and archaeologists into learning from these technologies.

A counter perspective, i.e., that not all landesque capital has value for modern agricultural production, reveals two more points. First, some areas have likely been abandoned due to social or natural factors (e.g., war, shortage of labor, soil degradation, climate change, etc.). Second, there has been a breakdown in knowledge transfer from older societies to modern times. In places that seeded ancient populations, knowledge and practices from the past often shape how urban agricultural systems perform today (UNDP 1996). The continuation of historical practices in concert with the industrial agricultural revolution and rapid urbanization during the post-World War II era have molded urban agricultural systems throughout much of the world (UNDP 1996). The United States, by contrast, has generally not benefited from ancient knowledge of the climate and landscape from native peoples of the continent. Since the hemisphere was virtually emptied of indigenous people before European colonization was well established, there were few people left to transfer such knowledge (Dobyns 1966, Denevan 1976). The first European settlers brought some skill sets with them, e.g., pläggen cultivation (Conry 1974), but very little knowledge transfer from indigenous American societies is apparent in the current urban agricultural system present in the U.S. Evidence for advanced Native American land management techniques including terracing, irrigation, site selection, soil enrichment, among others has received little attention or study outside archaeological circles (Doolittle 2000).

2.2.4. Modern agriculture techniques

Unlike ancient techniques, modern agriculture typically places little value in landscape-scale modifications for the enhancement of productive capacity and resiliency at one site. There are some exceptions, but generally, the U.S. agricultural landscape looks very similar from state to state, even in fields thousands of miles apart. This modern landscape of U.S. agriculture is filled with rows of monoculture, harvested with intensive mechanization. Modernity in agriculture here is defined by mechanization, advances in plant breeding and genetics, and extensive application of chemicals for fertilizer, pest control, and weed control. Mechanization began with the plow, and has progressed through history to entail enormous motorized equipment, capable of plowing, planting, and harvesting hundreds of acres per day (Paarlberg and Paarlberg 2000). Modernization in agriculture also means that fewer people are needed for daily or seasonal farm operations; weeding by hand has been replaced by chemicals, harvesting has become a widely mechanized instead of a human endeavor, and computers in tractors have raised efficiency in fertilizer application and time management enough to allow one farmer to perform more tasks (Oden 2010).

Yet at what cost has agriculture made these gains? Advances in genetically engineered crops, for instance, have enabled these landscapes of monocultures, where yields may be high, but soil nutrient levels must be subsidized to account for the extractive nature of these engineered crops. Additionally, monocultures are often more susceptible to disease (Zhu et al. 2000) or pest issues (Conway and Pretty 1991). Crops engineered for gains in one aspect such as pest resistance are often less favorable in another aspect, e.g., damage to beneficial insect populations (Losey, Rayor and Carter 1999). Increases in crop yields over the past several decades may be attributable to advances in plant sciences, but some experts argue that improved land management may account for a large part of yield increases (Gurian-Sherman 2009). Plant engineers have advanced perennial crop yields, lauding the benefits of planting a crop and enjoying many years of harvests while reducing fuel, water, chemical, and electricity costs and increasing overall soil and ecosystem health (Glover et al. 2010).

Soil and ecosystem health in concert with agriculture rely on proper land management. Modern agriculture also means advances in how land is managed, paying attention to soil type and landscape position, for instance. The USDA's Conservation Reserve Program (CRP) for decades has paid farmers not to crop acreage that was most susceptible to erosion (NRCS 2009). This program is being phased out (Farm Service Agency 2010); consequently, many marginal lands are returning to production (Roberts and Lubowski 2007). With proper planning and management, e.g., implementation of no-till practices, some experts claim that even marginal lands can enjoy some productive capacity while maintaining soil and ecosystem health (Loomis and Connor 1991). Yet this point has been contentious, including how to define "marginal land" (Dale et al. 2010).

In comparing ancient to modern agricultural techniques, one can ask, "Which has more resiliency?" Is it the enhanced landscape, improved over decades to millennia of use and climate shifts, or is it the monocultured landscape, gradually sapped of its topsoil and nutrients and inundated with chemicals? More farmers are beginning to acknowledge and address these issues. As a result, many improvements are being made in land management techniques, including awareness of soil health, and efforts to improve it.

Along these lines, one aspect of the modernization of agriculture involves advances in soil science. While soil science has come a long way toward understanding and quantifying soil characteristics (e.g., factors of soil genesis, which qualities constitute a healthy soil, carbon fluxes to and from a soil, and biogeochemical processes), modern soil building practices are no better than those used by ancient societies. Scientists are uncovering ancient soil building methods that are being revived by modern farmers, and evaluating their efficacy with modern soil science techniques. For example, in many countries scientists are uncovering how biochar was used by past societies in a variety of ways to increase soil health (International Biochar Initiative 2011). Farmers in northeastern Spain appreciated several benefits of charring soil, including its weed-killing properties, soil fertilization, and interestingly, the disinfecting benefits helping control or eliminate diseases or infections (e.g., fungi) that could harm crops (Masip 2003). Amazonians mixed biochar and manure into soils to change hard, nutrient-poor rainforest soils to organic-rich soils ideal for agriculture (Sombroek 1966). As a result of these and other technological rediscoveries, an international effort to study biochar for use in modern and provincial settings is underway (i.e., International Biochar Initiative).

With mechanization of agriculture, engineered perennial grains, and a broader understanding of what makes a soil healthy, scientists and farmers are working together to simultaneously increase farm efficiency while maintaining yields and increasing soil and ecosystem health (SARE 2005). Modern agriculture increasingly means embracing sophisticated technology combined with knowledge from the past, and intensifying less traditional locations for food production such as urban rooftops and vacant lots. Urbanites are making gains in using space and resources more wisely with rooftop gardens, rainwater capture, vertical gardens, and more. In this way, modern cities are revealing a shadow of ancient urban functionality, a sort of palimpsest of distributed urban food production, and an investment in landesque capital. Investments in landesque capital demonstrate ways that people can effect positive change by creatively managing and improving land. The next section explores how people influence climate through land use change in urban settings.

2.3. Urban climatology

Urbanization is one of the most dramatic types of land cover change. Not only does it influence climate directly through temperature changes (i.e., urban heat island), but it also modifies the hydrology, vegetation, wildlife habitat, and biogeochemical exchanges of a location (Svirejeva-Hopkins 2008). With a swath of mostly impermeable surfaces, flooding in urban areas is comparably more intense than in rural areas. Likewise, heat-storing building materials mean that hot days are even hotter in urban areas (Landsberg 1981), leading to higher urban death tolls during heat waves (Luber and McGeehin 2008).

Anthropogenic influences on climate have been observed for some time. For instance, scientists now attribute the Little Ice Age to tropical forest regrowth after the introduction of disease in the Americas led to the death of 90-95% of the population (Dull et al. 2010). On a city scale in urban environments, scientists first acknowledged how changing from rural to urban land cover influenced climate in 1820 London. Luke Howard observed that the city was 2.1°C warmer in the daytime than the adjacent rural areas, a phenomenon later described as the urban heat island. Howard also noted that the effect is more dramatic at night, as buildings and pavement release stored heat (Landsberg 1981).

Perhaps the urban heat island affect was first noted in London because the extent of an urban heat island is related to population size (Oke 1982, Viterito 1989). Specifically, the difference in temperatures of urban and adjoining rural areas increases as a logarithmic function of population size (Bonan 2002). City size and population largely dictate heat island extent as people tend to create environments that store and release heat. For instance, since impervious surfaces, e.g., roads, buildings, and sidewalks cover soil, a source of water vapor, there is a reduced latent heat flux. Additionally, the materials that make up the impervious surfaces (e.g., asphalt) store heat, thereby storing, redistributing and typically increasing sensible heat flux to the atmosphere (Grimmond and Oke 1995).

Impervious surfaces are a main driver of heat islands, but heat island development and intensity are subject to weather conditions (Kidder and Essenwanger 1995a). The greatest temperature differences between urban and nearby rural areas generally occur on clear, calm evenings while minimum heat islands occur under cloudy and windy conditions (Kidder and Essenwanger 1995b). Wind helps mix adjoining air masses and reduces the thickness of the urban boundary layer, thereby diminishing the urban heat island effect (Kidder and Essenwanger 1995b).

Within-city temperature variations can be attributed to topography, proximity to bodies of water, types of building materials, and differences in land use including density of development and the amount and types of vegetation present. For example, land use accounted for 17-25% of air temperature variations within Lawrence (Henry, Dicks and Marotz 1985, Henry and Dicks 1987). Similar studies using high-resolution satellites confirm these findings by determining that commercial-industrial areas are warmer while parks have cooler temperatures (Carlson et al. 1981, Vukovich 1983, Roth, Oke and Emery 1989, Nichol 1996). Now city planners are using this information to mitigate increasingly hotter urban heat islands due to warmer temperatures (MacDonald 2010), often by adding "green spaces" or areas of vegetation.

Like parks, urban gardens cool surrounding temperatures, creating a more pleasant microclimate. Gardens are usually irrigated, elevating cooling effects from evapotranspiration and related heat fluxes. Container gardens and rooftop gardens cover materials that would normally absorb and store solar radiation. Instead of adding to the city's heat, these operate as cooling islands within city boundaries.

2.4. Climate change and soils

Soil scientists use soils to study past climate change, so it follows that modern soils are influenced by climate and its fluctuations. Conversely, soils affect climate through factors, e.g., albedo, soil moisture and related heat fluxes, and fluxes of greenhouse gases between soil and the atmosphere. Because of these relationships, soils can potentially act as a positive or negative feedback to climate change by adding or subtracting from the balance of greenhouse gases. For example, as melting permafrost releases greenhouse gases, more warming leads to more melting of permafrost, an example of a positive feedback mechanism. An example of a negative feedback mechanism is soil management that leads to gains in soil organic matter, which sequesters atmospheric carbon in the soil and plants, leading to richer soils and healthier plants that store even more carbon. Scientists are struggling to understand the intricacies of these and other mechanisms in order to discover ways to mitigate greenhouse gas levels in the atmosphere with soil management.

2.5. Soil formation processes and land use

Jenny's (1941) state factors of soil formation determine rates and pathways of soil genesis. These factors include climate, organisms, relief (i.e., topography), parent material, and time (i.e., ClORPT). When considering how land use may influence these factors, it is clear that some are more easily tweaked (e.g., topography via terracing, local climate via irrigation) than others (e.g., time, parent material). One way to measure soil change is by monitoring soil carbon stocks (Post et al. 2004) (**Error! Reference source not found.**). Primary factors influencing the soil carbon cycle include climate, soil physical and chemical properties, vegetation, and land use.

Table 1. Jenny's (1941) state factors of soil formation describe soils genesis. Elements that influence soils genesis coupled with land use impact soil characteristics, including how soils capture and store carbon. Adapted from Post, Izaurralde et al. (2004).

State Factor	Influences of state factors and land use activities on soil carbon stocks and overall soil characteristics
Climate	Temperature and precipitation constrain plant production, decomposer activity, and weathering of soil minerals. Irrigation, addition/removal of shade plants, or aeration, for instance, can affect these soil processes.
Organisms	Vegetation controls input rates, depths, timing, and form of carbon (surface litter versus belowground input), affects decomposition through the inputs' decomposability, and competes with decomposers for water and nutrients. Soil biota control decomposition and the cycling and availability of nutrients. Activities affecting soil biota health and composition, e.g., addition of pesticides and fertilizers, or tillage, influences soil characteristics.
Topography	Topography affects erosion, deposition, infiltration, moisture, and temperature, influencing soil and vegetation type at the landscape scale; it affects temperature, moisture availability, and soil texture at finer spatial scales. Terraforming the landscape (e.g., terracing, mound building, construction) affects these physical parameters, and therefore, will change soil characteristics over time.
Parent Material	Soil type, degree of weathering, mineralogy, texture, and structure influence pH, water and nutrient supply, aeration, organo-mineral complexation, and the habitat for soil biota, affecting both plant production and decomposition. Addition of material, e.g., gypsum to clayey soils or biochar and organic wastes to rainforest soils, affects the biogeochemical structure of the soil, which can dramatically change soil character (e.g., change a latosol to a mollisol).
Time	The temporal scale influences the relative importance of other state factors, which affect productivity and decomposition and the balance of carbon input and loss. Land use is important at all temporal scales, from seasonal (e.g., crop type and tillage system) to millennial (e.g., continuously inhabited soils as a sort of palimpsest of anthropogenic influence).

Land use affects soil genesis and characteristics, for example its capacity to sequester and store carbon. A disturbed soil loses soil organic matter mainly through mineralization, but a beneficial change in land management can reverse this trend (Figure 4). The more degraded a soil becomes, the less capacity it has to support plant life. Once plants die or are removed, soil often becomes eroded, losing organic-rich top layers. For these reasons, no-till or low-till agriculture has become more commonplace, allowing soil to maintain its structure and, consequently, more of its organic matter (Johnson 1995). This process, in turn, provides higher levels of productivity, water holding capacity, and pest and disease resistance, furnishing more ideal conditions for soil decomposers and other biota, which builds soil organic matter, comprising a beneficial negative feedback mechanism (Culman et al. 2009). A contrasting example is slash and burn practices common in tropical forest settings, which implement a detrimental positive feedback. Removal of plant cover and subsequent mining of minimal soil nutrients often results in clay pan conditions, where the soil surface becomes hardened, leading to marginal levels of productivity (Alegrea and Cassel 1996). Once a tropical soil reaches this state, it is very difficult to reverse; subsequently, farmers move on to another plot where they start the cycle again by clearing the area with slash and burn (Alegrea and Cassel 1996).

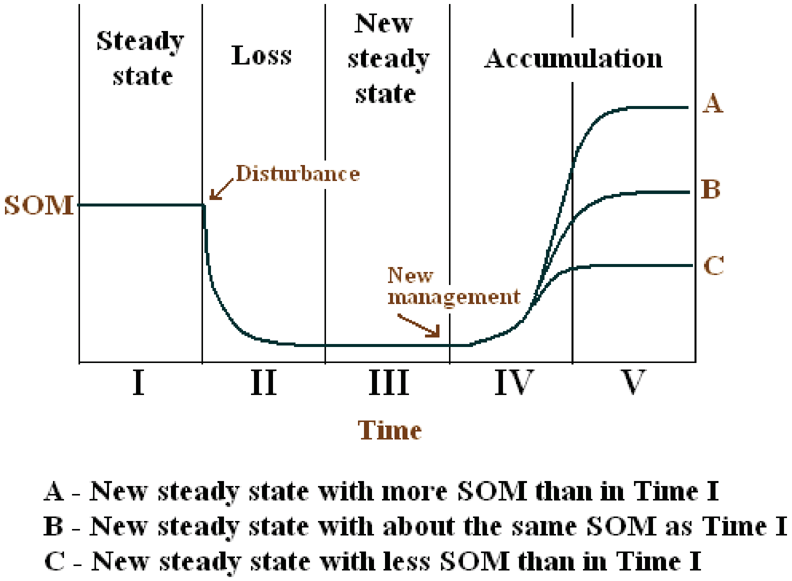


Figure 4. Changes in soil organic matter levels with disturbance and change in land management practices. Levels of soil organic matter reach a new steady state after disturbance or new management. With beneficial management, soil may either reach the same level of organic content as in Time I (B), or organic content may be increased above the levels in Time I (A). Adapted from Johnson (1995).

Historically, the spectrum of agricultural land use has resulted in an equally wide spectrum of consequent soil quality. Landesque capital, added by many successful past societies, gives examples of how people have maximized a landscape's productivity potential. At the opposite end of the spectrum are those areas that are deforested with slashing and burning, farmed for a short period, and then abandoned after a rapid decline in productivity. But many examples exist of societies that have overcome environmental difficulties through innovative adaptation strategies, like the Amazonian cultures that created *terra preta* (i.e., dark earth) out of latosols (i.e., highly leached tropical soils). The existence of *terra preta* provides an ideal illustration of how people can intentionally modify soil genesis pathways and, consequently, dramatically influence soil quality.

By increasing agricultural land managers' awareness of relationships between soil organic matter and crop yields, for instance, gains in resiliency for all or part of the food system are possible. Stresses stemming from climate change, for instance, are more readily absorbed in areas with land management practices designed to build and protect soil health. For example, a recent drought in the Amazon led to a large tree mortality event (Lewis et al. 2011). Likely, where *terra preta* is present, trees did not die since the organic-rich soil could maintain higher levels of available moisture compared to the predominant soils of the region, latosols. Where latosols are exposed because shade trees have died, there will likely be carbon fluxes to the atmosphere as material decomposes and organic matter mineralizes. The Amazon is a net carbon source in drought years, and a sink otherwise; estimates of carbon loss are difficult because of differences in soils and the vegetation they support (Lewis et al. 2011). This example provides evidence of how healthy soils can shift the balance in favor of plants, helping reduce plant mortality due to extreme weather events.

2.6. Adaptive capacity, resiliency, and soil health

From observing how human activities influence soils, vegetation, and climate, and how the environment provides limitations on human activities, an understanding takes shape of humankind's capacity to influence these systems. In climate change language, the term "adaptive capacity" has been used to describe a society's or species' ability to adapt to change, and the speed at which it might adapt. From this framework, resiliency takes a central role, as any action that increases a system's or species' resiliency will increase its adaptive capacity. Soil health, being central to the success of many Earth and social systems, is a starting point for working toward gains in resilience.

One area of soil health intersects directly with human health and, as a result, concerns food system resiliency. It is the prevalence of heavy metals such as arsenic, lead, and mercury that have been released into the environment through mainly human activities, and are subsequently found at detectable levels in most soils. While levels of heavy metals in most soils are not phytotoxic (i.e., plants can still grow normally), the soil serves as an exposure pathway, allowing heavy metals to enter a person's body through direct ingestion, through the skin or lungs, or through eating plant parts that have concentrated the metal. Heavy metal toxin exposure is more likely in an urban environment, where more activities (e.g. metal smelting, chemical manufacturing, coal burning), past and present, have led to the release of heavy metals. Urban centers are defined by denser populations, so incidence of exposure to heavy metals is higher. For urban agriculturalists to be involved in improving soil health while adding resiliency to the food system, heavy metals in soils is an issue that must be addressed.

Although media coverage of urban soil health seems to be increasing (Murphy 2009), few viable solutions, if any, have been offered. Gardeners must have certain qualities to be successful, including patience, determination, and the ability to solve problems. Add to this list the idea that many gardeners (in urban settings especially) have an interest in changing the food system, or at the very least, their personal relationship with food. These are people that are engaged in at least one issue concerning food and they regularly work at finding solutions to gardening issues. Furthermore, gardening knowledge and practical advice is readily shared within the local gardening community. Because of these characteristics, educating urban gardeners about soil health, particularly how to detect and manage heavy metals, should be well-received by a thoughtful audience. Providing gardeners with information in a way that encourages continued participation in the food system will ensure that knowledge about heavy metals in soils will not detract from anyone's desire to garden. Some suggested first steps include:

- *Increase public awareness of the issues in concert with potential solutions.*
- *Educate urban gardeners (and other land managers) about how to protect their health by detecting and managing environmental toxins such as heavy metals.*

- *Provide resources through local organizations including policy support and access to services (e.g., offer advice, and/or equipment for soil sampling, analysis, and building soil health).*

Potential solutions can be specific, e.g., selecting crops that do not concentrate a detected metal, or solutions can be universal, e.g., composting. The most basic metric for soil health in agricultural settings is how much organic matter it contains. Addition of organic matter increases a soil's ability to support plant life, but it also dilutes any toxins that are present, helps maintain a neutral pH, and it promotes formation of soil microaggregates and a chemical environment that keep metal cations in the soil, physically and chemically. From this it can be argued that composting has many benefits for soil health, as it adds organic matter to the soil. Beyond soil health, composting helps gardeners take a step toward a circular resource usage pattern, recycling nutrients much like the successful societies of the past. Addition of organic matter to increase soil health and circular resource usage adds resiliency to the food system, increasing our society's adaptive capacity.

The agricultural techniques of past societies illustrate our potential resourcefulness and innovation in managing modern challenges. Not only must we overcome food, water, and energy scarcity, but we must do this in an increasingly toxic world. Changing from a linear to circular resource usage is a step in the right direction, yet true solutions will demonstrate efficiency as well the capacity to avoid additional environmental and human exposure to toxins. Only then will agriculture make gains toward greater resiliency.

Chapter 3. U.S. Land Use History, Urban Soils, and Urban Gardening

Environmental and human health are directly linked to soil health, as soils serve the dual purposes of a geochemical sink and a buffer for many toxic substances. A soil acting as a geochemical sink means that polluting land uses coupled with persistence of toxins have recorded a legacy of poor waste management practices, inadvertent point sources (e.g., lead paint chips), pollution arriving via aerial and/or hydrological sources, or a combination of these factors. Soils containing toxins (i.e., substances harmful to biota, including humans) often act as a buffer by protecting people, plants, and animals from exposure to toxins by chemically or physically "holding" it in the soil (Kabata-Pendias and Pendias 1984).

With about 15% of the world's food supply grown in urban areas (USDA 2007), an awareness of how to detect soil toxins and then properly manage urban soils for food production is a matter of public health. A first step is the study of land use history; a plot's history provides clues as to what environmental issues are of greatest concern (i.e., potential toxin sources). In this chapter the focus is on human activities that have historically been linked to heavy metal pollution, as heavy metals collectively make up the group of toxins that are most common and dangerous to people, plants, and animals (ATSDR 2009). Next, the focus shifts to properties of heavy metals and their behavior in soils, especially regarding soil properties that affect plant uptake of heavy metals. The chapter ends with a history of urban gardening and the importance of understanding and managing urban soil health from a public health perspective.

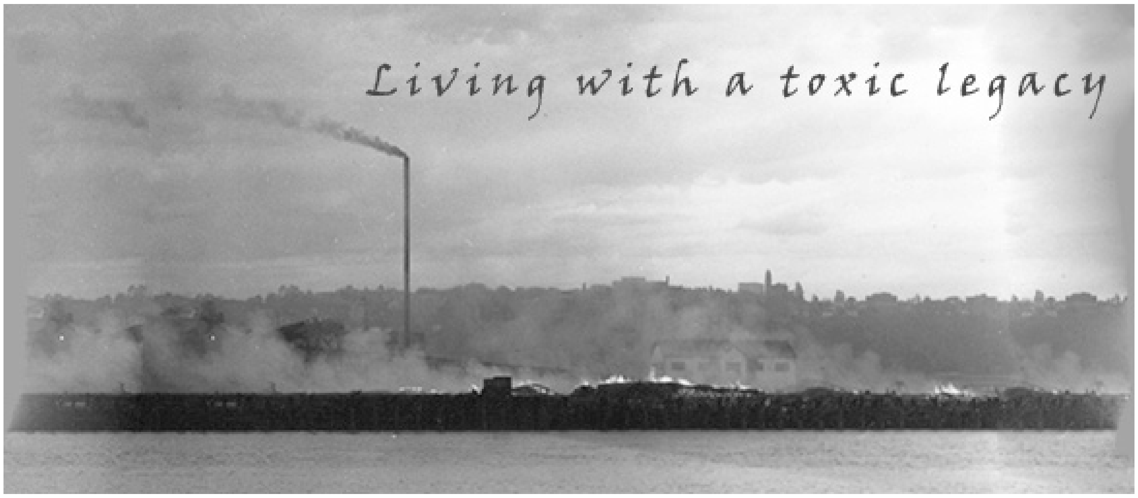


Figure 5. Image of Asarca copper smelter that once operated near Tacoma, Washington. This image appears of the Department of Ecology's website for the State of Washington, entitled "Dirt Alert." The website provides information, including maps, on levels of arsenic and lead in soils in relation to children's play areas and schools, for instance (State of Washington Department of Ecology 2011).

3.1. History of mining and metallurgy

As civilization expanded industrial activities through time, so did the human capacity to pollute the environment. It was the mining of ores and the processing of these ores that marked the onset of human-induced environmental toxification. Metal mining began around 7000 B.C. and processing of metals commenced soon after (Aitchison 1960). Human innovation in the use of copper and gold helped society's transition out of the Paleolithic. Many ancient civilizations succeeded in large part due to their expert metallurgy, e.g., the Inka and their bronze tools, jewelry and other art pieces (Bingham 1922). The primary metals of antiquity, i.e., gold, silver, lead, tin, iron (smelted), and mercury, were all discovered by 750 B.C. (Aitchison 1960). Metal discovery and use accelerated dramatically during the Industrial Revolution. Before the 19th century humans had knowledge of only 24 metals, 12 of which were discovered in the 18th century (Aitchison 1960). With 9,000 years of metal mining, the quality of ores remaining today has declined (Buck and Gerard 2001). Because of this decreased quality, processing ores creates more byproducts even though smelting and other ore processing techniques along with byproduct management have improved with time (Buck and Gerard 2001).

Even with improved metal-related operations, abandoned operations of the past have left persistent problems. Abandoned mines continue to pollute, often because of the heavy metals that are present and discharges of acids end up in water supplies, with deleterious effects on residential usage and wildlife, especially fish populations (Buck and Gerard 2001). A specific example of this phenomenon concerns the Asarco copper smelter in Tacoma, Washington (Figure 5). Operating for over 100 years, the smelter left a plume of high levels of arsenic and lead in the soils that extends over 1,000 square miles (State of Washington Department of Ecology 2011). The communities that live there are struggling to manage exposure levels of children and other sensitive populations and to find ways to clean up the contaminated soils (State of Washington Department of Ecology 2011). As we gain an understanding of past mistakes such as this, technology for managing waste and pollution improves. Nonetheless, many toxins persist in the environment; hence the history of waste management is very relevant to the current status of soils, air, and water.

3.2. History of waste management

Throughout most of U.S. history, the country was focused on survival and building a government rather than environmental health. Like the European cities from which they originated, people in urban settings usually managed waste by throwing refuse into the streets and alleyways or by burying it (Melosi 2005). The first refuse management system in New York City included 200,000 horses, each of which produced 24 pounds of manure daily (Figure 6) (ASTC and SITES 1998). By the mid-1800s, American city streets were littered with animal carcasses, human refuse, and pigs rooting through the garbage, conditions that encouraged diseases e.g., cholera, yellow fever, and malaria (Melosi 2005). In 1874, a waste incinerator was first built in Europe, and the U.S. soon followed suit, constructing 180 incinerators between 1885 and 1908 (ASTC and SITES 1998). Thus began the American version of linear resource consumption; a lack of recycling organic wastes (e.g., for agricultural use) combined with wider acceptance of the germ theory around 1900, promoted the “out of sight, out of mind” mentality (ASTC and SITES 1998, Melosi 2005).

Figure 6. Nineteenth century waste management in New York City (artist unknown).

The linear resource trend, consumerism, and an “out of sight, out of mind” mentality are reflected on today’s American landscape of municipal waste centers. One example is one of the largest waste facilities in the world, Puente Hills Landfill, commonly referred to as “Garbage Mountain.” Covering 1,365 acres, the facility accepts and processes 12,000 tons of garbage per day from Los Angeles County, California (Los Angeles County 2006). Garbage Mountain is only atypical because of its size, but this designation is diminishing; municipal waste facilities in the U.S. are decreasing in number, but they are increasing in size (EPA 2009b).

Most important perhaps, is what is being thrown away, how much of it, and its fate in the environment. Americans disposed of 243 million tons of solid waste in 2009, with about one third of this total being offset through recycling or other means of recovery (EPA 2009b). Over half of what is discarded is organic, most of which is compostable (EPA 2009b) (Figure 7). While gains in recycling have reduced the overall volume of waste generated since its peak in 2007, there are still difficulties in recovering some more harmful wastes such as metals. For instance, only 34.5% of metals discarded are recovered, including 69% of lead, mostly from lead-acid car batteries (EPA 2009b). While car batteries have the highest rate of recycling (96%), an unacceptable portion of lead is remaining in waste facilities, where it can potentially leach into soils and the water supply or become airborne through incineration (EPA 2009b).

The potential of waste to pollute depends on its source and how it is managed after it is discarded. Human excreta, even after treatment, can be a source of biological and chemical contamination (e.g., from pharmaceuticals) in the environment (Jones, Voulvoulis and Lester 2001); oil and paint dumping has led to release of heavy metals and volatile organic carbons in soil, air, and water (Yan et al. 2007); wood rubbish removed during renovation projects releases large amounts of carcinogenic formaldehyde when burned (Gamlin and Price 1988); a combination of waste material, when incinerated, can be transformed into dioxins, eventually settling on soil (Shibamoto, Yasuhara and Katami 2007). Another potent example comes from crematoria. In addition to toxins that may be stored in a person's tissues, dental fillings and other

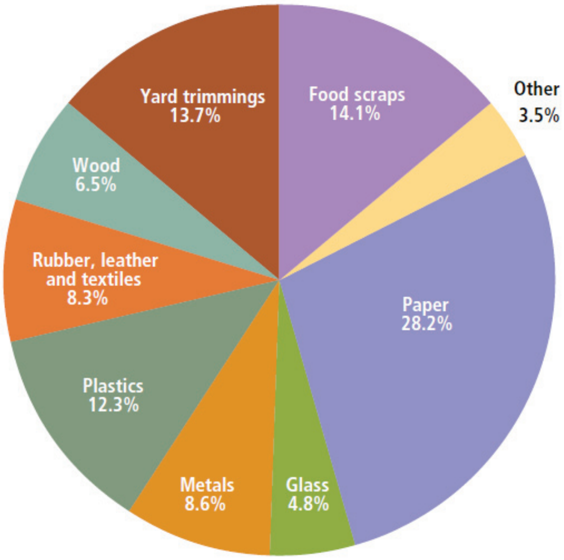


Figure 7. Depiction of what comprises municipal solid waste in the U.S. before recycling (EPA 2009b).

metallic components are volatilized during the cremation process, typically resulting in a plume of contamination downwind of the crematory (Ottesen and Langedal 2001). The history of waste management is filled with such examples of toxin release into the environment, an effect concentrated in urban areas.

Even with the bulk of waste from municipal sources, it seems trivial in comparison to other sources. Agricultural, industrial, and mining wastes make up 95% of the solid waste produced annually in the United States (Net Industries 2011). Solid waste is only one component of industrial and agricultural waste, which can also take on the forms of liquid, gas, or even waste heat. Its many forms add to the complexities of managing it presently and cleaning up areas polluted in the past.

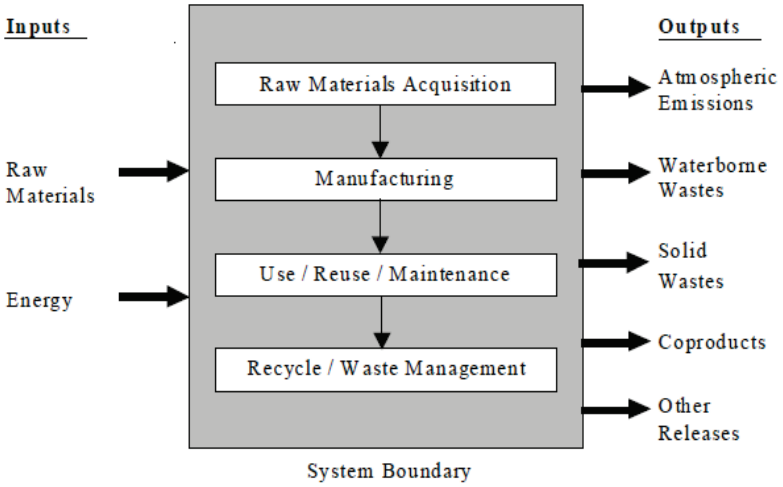


Figure 8. Life cycle of industrial contaminants in the environment (EPA 2006b).

3.3. History of industrial and agricultural pollution

3.3.1. Industrial pollution

Pre-dating the Industrial Revolution were cottage industries, an effort to fill farmers' free time during winters with profitable activities like cloth making, tanning hides, and metal working, each with varying levels of environmental consequences (Mendels 1972). These activities mark the onset of pollution from manufacturing and industry near or in human settlements. Like these small operations, larger scale industry works toward conversion of raw materials into usable products. This process requires many steps, most of which are energy intensive and result in byproducts, wastes, and atmospheric emissions (Figure 8) (EPA 2006b). All industrial sectors, including extraction, refining, production, distribution, transport, storage, and consumption pollute the environment (Shen 1999). Of course, different industries and their sectors pollute in different ways and at different rates, but chemical plants are among the worst polluters (Shen 1999).

United States history shows a progression in attempts to control pollutants during the manufacturing process, but little effort towards reducing or eliminating production of environmentally damaging products, often due to high costs of changing or altering established manufacturing practices (Shen 1999). Products such as asbestos, DDT, leaded gasoline, certain plastics, and some pesticides and herbicides are all known to harm the health of the environment and people by contaminating air, water, soil, and food with detrimental substances (Shen 1999). Although production of some of these products has ended in the U.S. (e.g., leaded gasoline), their damaging effects often persist in the environment regardless (Shen 1999). Lead from gasoline, for instance, is quite immobile in soils, so it can be constantly re-introduced to the air in the form of dust from contaminated soil (ATSDR 2007).

3.3.2. Spatial patterns of pollution

Historically, industrial facilities were built at the edges of urban settlements, where the expanding cities eventually encompassed them (Von Eckardt and Gottman 1964). In some cases, industrial operations near rail lines attracted skilled workers; accordingly, urban areas were centered on the industrial campus, typically extending along railroad routes (Brush 1994). This pattern of settlement means that some of the densest populations of the past and present were and are exposed to pollution from industrial activities in urban or peri-urban environments. Railroads, roadways, and rivers provide corridors for dispersing pollutants.

One example of a pollution corridor spawned the Greenway Program of Oregon, implemented in 1968 (Penn 2001). Waste from pulp and paper mills, untreated industrial effluents, and raw sewage were causing increasing levels of toxins, including trace metals in the Willamette River. As more fish began to die, the issue became visually alarming, activating people to call for change (Penn 2001). In this case, the river carried toxins away from the industrial sites, distributing them downstream. At the same time, environmental consequences allowed people to trace the pollution back to the source. Industrial pollution can be released into waterways, such as in this instance, or into the air, creating a more dispersed pattern of contaminants, depending on local conditions. Either way, air and water serve as media for the transfer of contaminants to soils.

While industry is one of the largest polluters, it differs from agriculture in its proximity to urban environments. Pollution from agriculture can be either concentrated or dispersed in the environment. Consider feedlots. Some large feedlot operations that are involved with animal agriculture produce the equivalent waste of a town or city (USGAO 1999). This is mainly because animals associated with U.S. agriculture produce 130 times more waste than one person (USGAO 1999). Besides manure, many agricultural practices use intensive chemical applications of fertilizers and pesticides, which affect the environment and food supply, often detrimentally. Use of agricultural chemicals typically takes on a more dispersed spatial pattern, although transport of chemicals via runoff, groundwater, airborne particles, etc. can concentrate pollutants in certain forms and locations (e.g., river sediments).

3.3.3. Pollution from agriculture

Like industry, agricultural practices have improved with time, but not before making some environmentally devastating mistakes. For instance, arsenic and lead were major components of pesticides and herbicides commonly used in orchards in the past (Kenyon et al. 1979). Because of their ability to tolerate arsenic, potatoes are often planted where orchard trees have been removed (Benson 1968). Potatoes may tolerate arsenic, but they also accumulate available arsenic in their leaves and peel

(MacLean and Langille 1981). In cases like this, where even a slight change in land use is made, heavy metals residing in the soil can become plant available, soils can erode into waterways, or people can be exposed to toxins simply by coming into contact with contaminated soils.

Arsenic compounds were also popular insecticides during the 1930s Dust Bowl years, when a scourge of locusts covered the Great Plains (Egan 2006). Aided by the National Guard and the Civilian Conservation Corps (CCC), farmers would use a seeding machine to dust a mixture of arsenic, bran, and molasses on fields to kill locusts. With as much as 175 tons of toxins spread per acre (Egan 2006), there are likely many areas in the Great Plains where the soils contain a record of this activity. Although arsenic-containing pesticides are no longer available for use in the United States, commercial use of arsenic is still high, with the U.S. being the largest global consumer of arsenic as recently as 2003 (ATSDR 2010). Most of the commercial arsenic is used for weatherizing wood products in the form of chromated copper arsenate (CCA), so urban environments with wooden decks, fences, poles, and some children’s play equipment often are a source of arsenic, copper, and chromium in urban soils (Chirenjea et al. 2003).

Fertilizers used by farmers often contain traces of heavy metals (Al-Shawi and Dahl 1999), primarily due to the characteristically higher levels of these metals in the phosphate rocks that fertilizers are made from (Hodge and Popovici 1994). Cadmium is one of these metals and industry professionals have worked to remove some cadmium during the process of generating fertilizer (Hodge and Popovici 1994). Even at trace levels, continued use of fertilizers leads to accumulation of heavy metals in soils with time. Urban agriculture is not immune to this problem, as many gardeners rely on some form of commercially produced fertilizer to feed their crops. Herein lies another argument for composting; it will simultaneously fertilize a garden, not add significant (if any) toxins to the soil, and generally help keep heavy metals in the soil, reducing human exposure and limiting plant uptake.

3.4. Heavy metals in soils

The term “heavy metal” can be misleading since elements included under this term may be light or heavy (atomic density > 6 g cm^{-3}), and may or may not be a metal (Alloway 1995). Because no consensus on an alternative term has been reached, “heavy metal” is used here and includes the following elements (listed alphabetically by chemical symbol):

silver (Ag)
arsenic (As)
gold (Au)
cadmium (Cd)
cobalt (Co)
chromium (Cr)
copper (Cu)
mercury (Hg)
manganese (Mn)
molybdenum (Mo)
nickel (Ni)
lead (Pb)
antimony (Sb)
selenium (Se)
tin (Sn)
thallium (Tl)
uranium (U)
vanadium (V)
tungsten (W)
zinc (Zn)

3.4.1. Soils as a geochemical sink for heavy metals

Metals occur naturally in the earth’s crust, thus they are constituents of soils, natural waters, and living matter. On the other hand, heavy metals are persistent and common environmental pollutants, mainly due to their mining and use in industrially and technologically advanced countries (Alloway 1995). The primary anthropogenic origins of heavy metals in soils are:

1. Atmospheric pollution from motor vehicles, lawn mowers, and other machines powered by petrol (especially leaded petrol).
2. Combustion of fossil fuels, including both the dispersion of many elements into the atmosphere and the disposal of coal ash.
3. Agricultural fertilizers and pesticides, either as active ingredients or impurities.
4. Organic manures, e.g., pig and poultry manures and sewage sludge.
5. Disposal of urban and industrial wastes, including deposition of aerosol particles from incinerators, dumping or disposal of metal-containing items (e.g., dry cell batteries, abandoned cars or car components), and burning or burial of waste in domestic settings.
6. Metallurgical industrial activities, e.g. emissions of contaminated fumes and dusts, release of effluents into waterways, and through creation of waste dumps and scrap yards where metals may leach into underlying soils.
7. Mining and smelting of non-ferrous metals, which can disperse metals through dusts, effluents, and seepage water (Alloway 1995).

The seven categories detailed above are mainly associated with agriculture, industry, transportation, and urban waste management, all of which have been practiced over time spans ranging from decades to millennia. As mentioned, heavy metal accumulation in soils is predicted to continue globally as current industrial and agricultural practices continue (Purves 1977). Pollutants migrate through the environment via several pathways, and soils serve as a sort of geochemical sink for many pollutants (Kabata-Pendias and Pendias 1984). Soils become polluted via atmospheric deposition, from contaminated water percolating through the soil column, or through direct dumping of toxic materials onto (or into) the soil. The top layers of soil have been accumulating heavy metal pollutants throughout human history; consequently, management and remediation of toxic soils is required for continued support of human and environmental health, particularly when considering food and water safety. Recent efforts to further understanding of soil biogeochemistry and soil-plant interactions highlight this need.

Soil and sediment surveys conducted in the past decades indicate anomalously high heavy metal concentrations, especially in urban and industrial areas (Bowen 1979, Kabata-Pendias and Pendias 1984, Adriano 1986, Nriagu 1978, 1979a, 1979b, 1980a, 1980b, 1980c). Global estimates of primary production of metals and the rate at which these metals reaches the soils were estimated by Nriagu, who states that we may be experiencing a "silent epidemic of environmental metal poisoning" because of the increasing levels of metals reaching the biosphere (Table 2) (1988). Past efforts to measure heavy metal levels in soils focused on total concentrations instead of levels available under conditions that create an environmental hazard (e.g., crop uptake) (McLaughlin et al. 2000).

Table 2. Changes in primary production of selected metals and the rate of heavy metal emissions reaching the soil in the 1980s (10^3 t/yr) (Nriagu 1988).

Metal	Year				Global emissions rate
	1930	1950	1980	1985	1980s
Al	120	1,500	15,396	13,690	—
Cd	1	6	15	19	22
Cr	560	2,270	11,248	9,940	896
Cu	1,611	2,650	7,660	8,114	954
Fe	80,180	189,000	714,490	715,440	—
Pb	1,696	1,670	3,096	3,077	796
Mn	3,491	5,800	26,720	—	1,670
Hg	3.8	4.9	7.1	6.8	8.3
Ni	22	144	759	778	325
Sn	179	172	251	194	—
V	—	2	35	134	132
Zn	1,394	1,970	5,229	6,024	1,372

Public awareness of the accumulation of heavy metals in soils gained traction in the 1970s because combustion of leaded gasoline was leading to air, water, and soil pollution. A fuel additive since the 1920s to reduce engine wear, billions of tons of lead were released into the environment before the EPA eventually phased it out between 1973 and 1996 (EPA 1996). Because of this deposition, soil lead levels are especially high near highly traveled roadways, such as any urban area. Automobiles are a source for other heavy metals, primarily from wearing parts, e.g., tires and brakes. In one representative study, roadside agricultural soils were found to have elevated levels of Pb, Cu, Zn, and Cd compared to background levels, which were attributed to automobile traffic (Wu et al. 2010). Still, lead is the main culprit, the heavy metal that has been most prevalent, persistent, and toxic to human health. Once lead was largely removed from gasoline, paint, and food cans, the percentage of U.S. children 1 to 5 years of age with higher than acceptable blood lead levels decreased from 88.2% to 4.4% within a few years (Mahaffey et al. 1982). Despite this dramatic decrease, the American Association of Pediatrics estimates that 25% of U.S. children are at risk for exposure to lead in their environment (American

Association of Pediatrics 2005) and even more exposure occurs in summer months when children play outside (Yiin, Rhoads and Lioy 2000). This example demonstrates how a long history of poor environmental management has led to long-term ramifications for environmental and public health.

Arsenic also seems to have received an increasing level of attention from the public, as measured by the frequent mention of arsenic in conjunction with lead, especially in the gardening literature, since these metals bioaccumulate in food plants. Anthropogenic sources of arsenic indicate that the likelihood that urban areas contain elevated levels of arsenic is great. As previously stated, wood products such as decks, posts, and children's play structures commonly have been treated with chromated copper arsenate (CCA), which makes up 70% of world arsenic production (Ng et al. 2001). Another 22% is and has been used in agricultural chemicals, e.g., herbicides and pesticides (Ng et al. 2001). Lawrence harbors its fair share of privacy fences, posts, and other wooden structures, and its history of agriculture in the area leads to the supposition that arsenic will be a common component of both urban and rural soils in the region. Since wood products treated with CCA may also leach copper and chromium into soils, these components are more likely to be found in elevated levels in urban rather than rural soils. The exception to this pattern is rural roadsides that have telephone or power lines mounted on CCA-treated poles, or even fences with CCA-treated posts. Because of the prevalence of these items in the human landscape, and their potential as a continuing source of metals, scientists seek ways to effectively monitor their behavior, as discussed in the next section.

3.4.2. Measurement and behavior of heavy metals in soil

Each metal behaves differently in soils, complicating detection and remediation procedures (Table 3). Earliest analytical techniques of soils, stream sediments, and natural vegetation were developed for mineral exploration, but were subsequently applied to agricultural and regional patterns of soil pollution (Alloway 1995). Traditionally, soil chemists had focused on plant macronutrients (i.e., nitrogen (N), phosphorus (P), and potassium (K)), but a shift occurred with enhanced public concern of environmental toxins. Analytical techniques, e.g., atomic absorption spectrophotometery and other leaps forward in technology developed in the 1970s allowed for rapid analysis of large numbers of samples (Lepp 1981, Alloway 1995). This trend continued into the 1980s along with greater concern and study of toxic effects of heavy metals on animals and plants (Alloway 1995). More on analytical techniques used in this study can be found in section 4.6.

Table 3. Natural and anthropogenic sources, chemical properties, and interactions within the soil column for select metals. Summarized based on Alloway (1995) and Berkowitz, Dror and Yaron (2008) unless otherwise noted.

Select Metals	Sources, Properties, and Interactions	
Arsenic, As	Sources	Arsenic occurs throughout Earth's crust, and trace quantities can be found in all rock, soil, water, and air. More concentrated, natural sources of As in soils mainly come from oxysalts and S containing minerals. As-compounds have been widely used as pesticides, desiccants, and wood preservatives (i.e., CCA) although this trend has declined. Coal combustion, waste from oil shales, smelting, and irrigation with As-rich water are other sources. Anthropogenic activities can lead to high levels of As in sewage sludge and dredged material from waterways.
	Properties	Arsenic does not display all the typical chemical behaviors of a metal so it is considered a metalloid. It is often found in the +5 (in oxygenated environments) or +3 (in reducing environments) oxidation states in soils. Research suggests that because of the similar chemistry of As(V) with phosphate, plants and people can accumulate As in their tissues(Obinaju 2009), potentially leading to serious health problems (see Table 5 for effects on human health). Uptake and toxicity of As for plants depends on the species of As present, thus "available" As content in soil is better indicator of toxicity rather than total As concentration.
	Interactions	Clay minerals of Fe and Al oxides and organic matter can influence As solubility and rate of oxidation. Levels of As in edible plant parts are typically low, although higher levels occur in sands or sandy loams because these soils have weaker sorption capability for As. In general, roots take up more arsenic than the stems, leaves, or fruits, indicating a barrier in the root for further uptake. Toxic effects of As on plants increases with decreasing pH, noted by decrease in water mobility and arrested seed germination. Average As soil level = 5-10 ppm

Select Metals	Sources, Properties, and Interactions	
Cadmium, Cd	Sources	Cd is typically found in higher concentrations at the surface horizon of soils because of the usual sources of atmospheric deposition (from volcanic activity, metal production, fossil fuel combustion, refuse incineration, smelting), phosphate fertilizers, manure, sewage sludge, and through mining zinc, lead, and copper ores. Human exposure usually occurs through topsoil, via uptake into tobacco leaves and food plants.
	Properties	Cd is more mobile than Pb and Cu, making it more available for plant uptake. pH strongly controls Cd sorption in soil and bioavailability, with more basic conditions favoring both sorption and plant uptake. Cd content of plants is inversely proportional to the cation exchange capacity (CEC) in the soil. Total Cd in soil is one of the major factors affecting how much Cd enters plants. The origin of Cd also affects its bioavailability. Cd from inorganic sources (e.g., mining and smelting) compared to organic sources (e.g., sewage sludge) tend to be more available for plant uptake because of adsorption of Cd with organic matter.
	Interactions	Cd competes with other metal ions for adsorption in a soil, especially Zn and Ca, and excesses of Cu, Ni, Se, Mn, and P can reduce plant uptake of Cd. In other words, Cd found with carbonate minerals, coprecipitated with hydrous iron oxides, or precipitated as stable solid compounds is likely to remain in place, and is therefore less likely to be bioaccumulated or released in a dissolved state. The opposite is true with Cd is sorbed to mineral surfaces or organic materials.
Chromium, Cr	Sources	Cr(III) is an essential nutrient and is found in trace amounts throughout the environment. Cr(IV) and Cr(0) are created generally as byproducts of industrial processes. Cr is released through mining of certain ores. In its metal form, Cr(0) is used in steel making while Cr (VI) and Cr(III) are used for chrome plating, wood preservatives, tanning leather, and making dyes and pigments.
	Properties	Chromium toxicity varies widely depending on the species, therefore it is regulated differently depending on its oxidation state. It is most commonly found in the environment as Cr^{+3}(Cr(III)) or Cr^{+6}(Cr(IV)), or hexavalent Cr, the most toxic form. Cr can strongly sorb to soil, yet even the smallest quantity can be dissolved in water, mobilizing it in the soil column and eventually entering the water table. Cr(IV) are the most common form of dissolved Cr found in alkaline waters.
	Interactions	Cr(III) is the most stable form found in the environment as it occurs under typical environmental and biological conditions of redox potential and pH. Cr(III) has low solubility and reactivity, meaning that it is not very mobile or toxic to living organisms. But Cr(III) can be transformed into CrO_4 and Cr_2O_7 through oxidation (especially where pH>5), which are both mobile and toxic. Cr(IV) has vastly different chemical behavior because it exists as an anion and is a strongly oxidizing species. In the presence of soil organic matter, Cr(IV) is reduced to Cr(III); this reaction occurs more readily in soils of lower pH.

Select Metals	Sources, Properties, and Interactions	
Lead, Pb	Sources	Lead is one of the earliest metals used by humans, used widely since 5000 BC. Pb is seldom found in elemental form in nature, yet Pb-containing compounds are common worldwide. It is found in the ores galena, cerussite, and anglesite; the smelting of these ores is a source of Pb in air, soils, and water. The most common use of lead has been in lead-acid batteries. A large percentage of these batteries are recycled (EPA 2006a). The most environmentally important use of Pb in the 20th century was as a gasoline additive, leading to widespread contamination of soils near roadways. Lead paint was phased out in the 1970s, but it remains on many buildings, and is a source of Pb in soils and water (Clark, Brabander and Erdil 2006).
	Properties	Pb in soil is generally in the form of hydroxide complexes and carbonates. Pb has a long residence time compared to most other pollutants, as it strongly sorbs to soil minerals and forms complexes with humus. This in concert with its low solubility and lack of appeal for microbes (for degradation) means that Pb accumulates in soil, where it increasingly becomes available to the food chain and to human metabolism. Human blood lead levels correlate directly to soil lead levels near people's homes (Mielke et al. 1997). Topsoil contains an average Pb content of 10 ppm, and ranges from 7 to 12.5 ppm in sedimentary rock. Soil lead levels in U.S. urban areas have been reported up to 5300 ppm; the EPA safe level for soil lead is below 400 ppm in bare soils where children play.
	Interactions, Pb	CEC and pH are the primary controllers of Pb bioavailability and mobility. In a soil of lower pH, Pb acts primarily as a cation and forms some complexes with organic molecules. In calcareous soils, those with a higher pH, organic complexes are dominant with some cationic activity. High soil Pb inhibits soil microbial activities, slowing organic matter breakdown and decomposition, resulting in lower productivity. Pb can enter a plant through foliar or root uptake, and the rate at which this occurs depends on the physiological status of the plant the season. It is generally not very bioavailable due to its low solubility and mobility, but it can pose a potential health risk near lead-using industries and in cities, where Pb levels are high.
Mercury, Hg	Sources	Mercury has been used by people for at least 3500 years, many with pharmaceutical applications until 1643 with Torricelli's invention of the barometer and with Fahrenheit's invention of the Hg thermometer in 1720. Throughout the past century, the use of Hg has changed rapidly, and its use has declined substantially in the past 30 years. Main sources of Hg in the environment are mining and smelting of ores, burning fossil fuels (mainly coal), industry, agricultural applications, and waste incineration.
	Properties	Hg has no known biologic function; it is one of the most toxic elements to humans and other higher organisms. All Hg-containing compounds are toxic to humans, but Hg does not cause any toxic symptoms to plants. Hg in plants is typically concentrated in the roots, perhaps demonstrating that the roots provide a barrier to transporting it to the shoots. However, Hg^0 can volatilize from the soil, leading to foliar uptake. Hg may occur in three valence states, Hg^0, Hg^{2+}, and Hg_2^{2+}, the former two normally occurring in soil.
	Interactions	Hg^{2+} readily forms complexes with hydroxides, chlorides, and humic matter so under natural conditions it rarely occurs in free ionic form. The primary controllers of Hg speciation and chemical behavior in soils are redox potential, pH, Cl^- concentration, and microbial activity. In acid soils, Hg^{2+} is mainly attached to organic matter. Adsorption is the primary process that retains Hg in soil, and the level of adsorption is determined by the chemical form of Hg, grain size distribution of the soil, character of the soil colloidal fraction, pH, and redox potential. Below pH 5.5, organic matter sorbs $HgCl_2$; in more neutral soils (pH 5.5 to 7), iron oxides and clay minerals adsorb Hg^{2+}.

Select Metals	Sources, Properties, and Interactions	
Nickel, Ni	Sources	Nickel is primarily comes from sulfide and oxide ores, and it is released into the environment during the mining and smelting of these ores. Ni is used in stainless steel production, and nickel alloys and platings in vehicles, machinery, armaments, tools, electrical equipment, appliances, and coins. Ni-containing compounds are also used in catalysts, pigments, and in Ni-Cd batteries, but the largest anthropogenic source of Ni is released through burning fossil fuels, which becomes concentrated in the organic residue (sewage sludge) of treatment plants. Ni concentrations in soil vary widely, mainly dependant on whether the parent material contains Ni; this also determines whether the topsoil (anthropogenic source) or the subsoil is more enriched with Ni.
	Properties	Nickel occurs in five forms in air, water, soil, and plants: elemental nickel and its alloys, inorganic soluble and insoluble compounds, organic water-insoluble compounds, and nickel carbonyl ($Ni(CO)_4$), the most toxic form to humans. Acid rain can mobilize Ni from soil, leading to water contamination, enhanced uptake by plant roots, and possible toxicity to animals, plants, and microorganisms. Ni(II) is the most stable form over a wide range of pH and redox conditions. Its ionic radius is similar to those of Fe, Mg, Cu, and Zn, hence it can replace essential metals in certain enzymes, disrupting metabolic pathways.
	Interactions, Ni	Ni is taken up by plants through their root systems in amounts determined by soil pH and humidity, organic matter content, clay content, amount of hydrous Fe and Mn oxides, and extractable Ni concentration. Mobility of Ni increases with decreasing pH and CEC. Under oxic conditions in acid soils, Ni will most likely be present as Ni^{2+}, $NiSO_4$, $NiHCO^{3+}$, and organic complexes. In alkaline soils Ni will most likely be as $NiCO_3$, $NiHCO^{3+}$, $NiHCO^{3+}$, Ni^{2+}, and $NiB(OH)^{4+}$. High Ni content in soils leads to diminished soil microbial activity, and deleterious effects on seed germination and plant growth.

Key soil properties involving or affecting heavy metals in soils include soil pH, soil organic matter, clay minerals, and oxidation and reduction chemical reactions (i.e., redox reactions) in soils (Alloway 1995). These factors are discussed in general, but *in vivo*, because soils are heterogeneous at even the finest scale, precise interactions between these elements is difficult to generalize. The heterogeneity of urban soils is further pronounced, offering additional complexity to the study of urban soil properties.

How soil properties influence the soil solution has been studied extensively (Barrow 1987, McBride 1989, Schindler and Sposito 1991, McBride 1991). The soil solution determines a soil's pH, which is a primary controller of bioavailability of heavy metals in soils (McLaughlin et al. 2000, Clark et al. 2006). Bioavailability of heavy metals, or the amount of a metal that a plant can take up from the soil, is a complex topic. Bioavailability depends upon the metal species, its interaction with soil colloids present, soil physical and chemical characteristics, and the time the metal has been in contact with the soil (Naidu, Oliver and McConnell 2003).

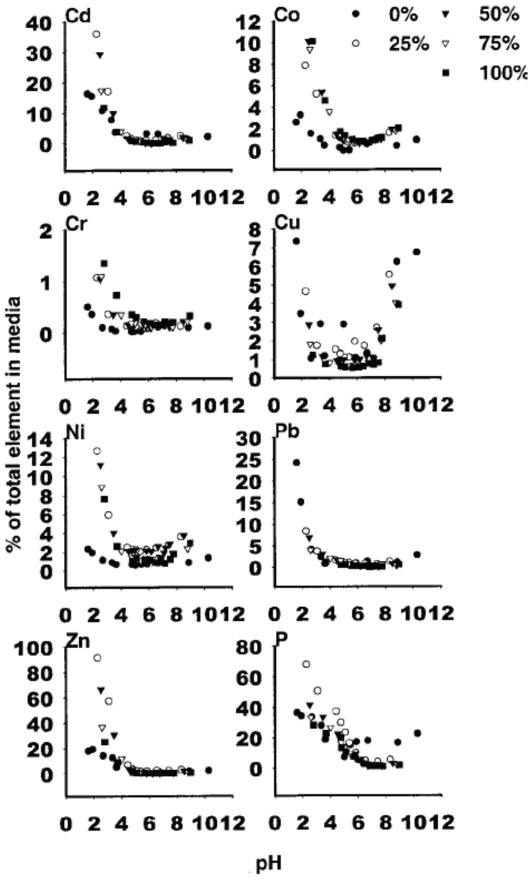


Figure 9. Chart by Zhang et al. on solubility of heavy metals and P in soil amended with differing proportions of compost in relation to pH (Zhang et al. 2004). Note that in the neutral pH zone, most heavy metals have limited solubility and therefore limited mobility and bioavailability, but solubility increases under more acidic conditions.

The pH of a soil describes the hydrogen ion (H^+) concentration of soil solution in dynamic equilibrium with the predominantly negatively charged surfaces of soil particles (Bache 1979, Wild 1988). These negative surfaces strongly attract hydrogen ions, which have the power to replace most other cations. Several mechanisms can buffer soil pH with varying success such as hydroxyaluminum ions, CO_2, carbonates and cation exchange capacity (CEC) (Alloway 1995). Heavy metal cations generally become most mobile under acid conditions (McLaughlin et al. 2000). Under certain specialized conditions the opposite relationship can be true (i.e., for CrO_4^{2-} and AsO_4^{3-}) (McLaughlin et al. 2000). Raising the pH (e.g., by adding lime) usually reduces the bioavailability of most heavy metals (Alloway 1995) (Figure 9).

One way to stabilize soil pH to help control bioavailability of most heavy metals is through promoting soil organic matter (SOM). The definition of soil that distinguishes it from rock fragments is the presence of living organisms, organic debris, and humus, which comprise SOM (Alloway 1995). Initially, organic matter enters the soil as plant and animal litter. Organic compounds released through decomposition include sugars, starches, proteins, carbohydrates, cellulose, fats, lignins, waxes, resins, and organic acids (Brady and Weil 2002, Ponge 2003). The most resistant of these organic compounds make up humus: cellulose, fats, waxes, resins, lignins, and some organic acids (Brady and Weil 2002, Ponge 2003). As decomposition continues, the relative content of humus increases (Schlesinger 1997). The precise composition of humus remains elusive, largely because the organic inputs and dominant soil processes determine its composition. It is characterized as the amorphous, colloidal material of complex organic substances (Brady and Weil 2002).

Colloidal soil organic material significantly influences chemical properties of the soil (Alloway 1995). Once SOM takes the form of humus, it is stabilized via three primary processes: adsorption, complexation, and physical protection. Adsorption of humus to clay minerals occurs due to their attraction to electrostatic sites on the clays. Many clay minerals (e.g., 2:1 and 1:1 layer silicates) hold a permanent negative charge from isomorphous substitution for ions of lesser valence (e.g., Al^{3+} for Si^{4+}, Mg^{2+} for Al^{3+}) (Verburg et al. 1995, Brady and Weil 2002). This negative charge attracts soil colloids, e.g., humus. Also, cations (e.g., heavy metals) may provide the venue of interaction of polar molecules and the presence of oxygen at the mineral surface may lead to hydrogen bonding with humus (Verburg et al. 1995). A purely chemical method of holding humus and associated metal cations in soil involves incorporating organic molecules as ligands to metal ions present on the clay mineral surface. This reaction is pH-dependent and typically more stable than adsorption reactions. It often occurs on metal oxides (Al and Fe) and amorphous minerals (Verburg et al. 1995).

These primary mechanisms for humus adsorption provide physicochemical means for protection of humus and subsequently, heavy metals, within the soil profile (Table 3). Generally speaking, metals in solution bind to soil colloids (or other charged particles), therefore the physico-chemical factors associated with this soil component directly affect concentrations of metals in soil solution and subsequently, bioavailability (Alloway 1995, McLaughlin et al. 2000).

Many of the chemical reactions described above fall under the broad category of redox chemistry or the gain (reduction) or loss (oxidation) of electrons. The redox status of soils mainly concerns the elements C, N, O, S, Fe, and Mn, but some heavy metals can be affected including Ag, As, Cr, Cu, Hg, and Pb (Alloway 1995). Redox chemistry in soils typically occurs at a slow rate, and is catalyzed by soil microorganism activities, e.g., respiration and decomposition of organic materials, either in the presence or absence of oxygen. If oxygen becomes exhausted (e.g., due to waterlogging, compaction, consumption via respiration of soil organisms) anaerobic respiring microorganisms predominate. Anaerobic conditions favor a reducing environment, hence susceptible elements (Mn, Cr, Hg, Fe, Cu, and Mo) are gradually reduced (Sposito and Page 1985, Rowell 1981). Reducing conditions can drastically change soil physical and chemical properties through dissolution or precipitation of Fe oxides or production of sulfate ions, which may lead to precipitation of metal sulfides, e.g., FeS_2, HgS, CdS, CuS, MnS, and ZnS (Sposito and Page 1985).

3.4.3. Soil-plant interactions and heavy metals

Heavy metal pollution is a complex problem that requires an understanding of the origin and nature of the pollutants, the substrate being polluted, and knowledge about the conditions where these items interact. Soil-plant interactions become the next area of study, as this is where the pedosphere, atmosphere, and biosphere converge. Thus far heavy metals have been broadly discussed as pollutants, but certain metals are essential for plant growth (i.e., Cu, Mn, and Zn). In this way, heavy metal deficiencies and/or pollution are intrinsically linked to crop yield and crop composition (Alloway 1995).

Anthropogenic sources of heavy metals are typically concentrated on the upper soil horizon, mainly because pedogenic processes have not been acting long enough to redistribute the metals through the soil profile (Alloway 1995). As a result of cycling through vegetation, atmospheric deposition, and adsorption by SOM, certain elements are concentrated in surface horizons, including Ag, As, Cd, Cu, Hg, Pb, Sb, and Zn (Bowen 1979). In cultivated soil, this upper horizon that is worked is called the A_p horizon, or plow layer. The A_p horizon contains the majority of the root mass and so is where plants typically uptake bioavailable heavy metals. By contrast, Al, Fe, Ga, Mg, Ni, Sc, Ti, V, and Zr are located in lower soil horizons and tend to be associated with accumulations of translocated clays and hydrous oxides (Bowen 1979).

Plants can concentrate heavy metals in their tissues through root uptake and foliar absorption. For root uptake, factors that control the amount of metals absorbed into a plant's tissues have to do with (1) concentration and speciation of the metal in the soil solution, (2) the ability to the metal to move from soil to the root surface, (3) the ability of the plant to move the metal from the root surface to its interior, and (4) the plant's ability to move the metal from the root to the shoot (Wild 1988, Chaney and Giordano 1977). Some plants can prevent movement of metals from roots to shoots, hence foliar absorption becomes the dominant pathway of heavy metal concentrations of stems and leaves (Table 3).

Plant uptake has much to do with the amount of metal ions present in the soil solution, but this can be mediated by the surface area of the plant's roots (Wild 1988). Mechanisms by which absorption occurs can vary for different metal ions, but metal ions that use the same absorption pathway compete with each other. For instance, Zn absorption is diminished by Cu and H^+, but not by Fe and Mn, which use a different pathway (Barber 1984, Graham 1981). Microbiological and chemical activity occurring in the rhizosphere due to exudates from the roots, mucilage, sloughed-off cells and their lysates can liberate metals from soil, increasing absorption into plant tissue (Marschner 1986). Foliar absorption of heavy metals uses the same pathway that agriculturalists use when spraying plant foliage with micronutrients (Hovmand, Tjell and Mossbaek 1983). Levels of absorption depends on the plant species, its nutritional status, cuticle thickness, leaf age, presence or absence of stomata guard cells, humidity of the leaf surface, and the nature of the solutes (Marschner 1986, Chamel 1986).

Table 4. A selection of studies investigating food crop bioaccumulation of heavy metals.

Metal	Metal accumulating food crops			
	(Davis and Calton-Smith 1980)	(Samsøe-Petersen et al. 2002)	(Mattina et al. 2003)	(Food Standards Agency of the United Kingdom 2007)
Cd	Lettuce, spinach, celery, cabbage	Hazelnut, blackberries, carrots (more in peel), lettuce	Zucchini, spinach, lettuce, tomato, thistle	Pine nuts, mushrooms
Pb	Kale, ryegrass, celery	Hazelnuts, black and red currants, carrots (more in peel), potatoes (mostly in peel), radish	No significant bioaccumulation	Carrots, licorice, mushrooms, honey, root vegetables, nuts,
Cu	Sugar beets, certain barleys	Not analyzed	Spinach	Root vegetables, dried fruit, mushrooms
Ni	Sugar beets, ryegrass, mangold, turnips	Hazelnut, blackberry, beans	Not analyzed	Not analyzed
Zn	Sugar bees, mangold, spinach, beetroot	Not analyzed	Zucchini, spinach, tomato, pumpkin (leaves), cucumber (leaves), thistle (leaves)	Mushrooms, nuts

All in all, bioavailability is a complex relationship between the soil and mainly the roots of the plant, although metal-containing detritus can provide a new or recycled source of heavy metals to the soil (McLaughlin et al. 2000). Thus, different plant species bioaccumulate heavy metals at different rates under different conditions. Because of this complexity, there is no comprehensive list of crop bioaccumulation rates, although there are many studies that look at this topic using various approaches in different soil types and levels of contamination (Table 4).

3.4.4. Heavy metals and climate change

Heavy metal bioavailability may also be influenced by global climate change. For instance, with higher levels of atmospheric CO_2, precipitation becomes more acidic as water combines with CO_2 to form carbonic acid. More acidic rain falling on soils can increase metal mobility and therefore its availability to plants (Alloway 1995) (**Error! Reference source not found.**). Whether considering contaminated soils, urban garden soils, or soil parent material containing heavy metals, shifting precipitation regimes and more acidic rainfall can liberate heavy metals from soils, resulting in higher toxicity to plants, animals, microorganisms, and ecosystems in general.

Current research in soil remediation focuses on removal and control techniques, e.g., phytoremediation (i.e., use of plants and fungi that hyperaccumulate heavy metals in their tissues) (Meagher 2000, Mendez and Maier 2008) and pH control (e.g., Stevens, Dise and Gowing 2009) to limit bioavailability of heavy metals. But even with remediation technology, the heavy metals are simply displaced, not removed from our environment. Proper waste management in this case requires long-term containment of harmful constituents. Global pollution levels coupled with climate change require an interdisciplinary approach to identify adaptive strategies in urban food production that protect human and environmental health.

Figure 10. Layers of urban land use are apparent in this trench on the University of Kansas campus in Lawrence, KS. Pipes shown are approximately four inches in diameter. Photograph by T. Jackson.

3.5. Urban soils as anthrosols

After centuries of polluting Earth's air, water, and soils, humankind today is reaping the consequences. Urban soils (Figure 10), which have been altered by human activities, differ from their rural counterparts in several ways, including greater heterogeneity within a small area and typically higher pH (Kabata-Pendias and Pendias 1984, Marcotullio, Braimoh and Onishi 2008). Anthrosols, soils formed or profoundly modified by humans over long periods and Technosols, soils of recent deposits of artificial origin or mixed with alien products (Spaargaren 2006), are new classes of soils according to the International Union of Soil Scientists (IUSS) (2007). Urban soils often fall under one of these definitions, as they are typically characterized by accelerated erosion, land filling, land leveling, surface removal, contamination, sedimentation, severe compaction, and/or artificial saturation (NRCS 2008). These urban soil characteristics complicate toxin detection and management, as any physical or chemical soil characteristic has the potential to influence the behavior of contaminants in a soil.

Figure 11. Intensive urban agriculture of Caracas, Venezuela, where the city depends on urban food production for a significant portion of its food supply (UNDP 2007).

Urban soils are particularly susceptible to contamination due to their past and present proximity to polluting industries, automobile exhaust, and poor waste management practices. Many contaminants persist in the system; subsequently, surface soils have become progressively more polluted throughout human history (Kabata-Pendias and Pendias 1984). Besides heavy metals, other toxins introduced through human agency include pharmaceuticals, MTBE (methyl tert-butyl ether), benzene, and chlorinated hydrocarbons (CFH), e.g., solvents, pesticides (e.g., DDT), and PCBs (polychlorinated biphenyls) (Alloway 1995). The U.S., along with the rest of the world, has a long, complicated history of polluting practices that differs from place to place on the microscale, a history that should be considered when planning land uses, e.g., a children's play area or urban garden.

3.6. History of urban gardening in the U.S.

A notable contrast between the United States and much of the rest of the world is the differing conceptual frameworks for urban food production. In some circles, the terms "urban gardening" and "urban agriculture" are used interchangeably. Yet the distinction seems to be in the primary motivation behind the activity and not the activity itself that differs. The United States typically refers to food production in cities as "urban gardening," which implies a relatively low level of production (i.e., less dependence on it for subsistence) compared to the intensive "urban agriculture" of Taiwan, China, or

Caracas, Venezuela (Figure 11), for instance. While urban *gardeners* usually garden for pleasure or perhaps for environmental reasons (such as in the United States), urban *agriculturalists* usually work toward intensive food production to fend off hunger or to make a living. It seems that the distinction often can be drawn based on income or class, although certain exceptions exist. Still, history tells us that American have not always fit easily in to this generalization.

Americans of the 18th and 19th centuries certainly relied on gardens for subsistence, and they differed substantially from modern Americans in their enthusiasm for using human and animal wastes as fertilizer (Melosi 2005). Gardens were ideally located in suburban or exurban locations where there was available space as well as ready access to wastes (Lawson 2005). From 1890 to 1930, gardening was promoted by municipal governments such as the aforementioned example of Detroit, where the mayor provided space for Potato Patches to help people help themselves during difficult economic times (Lawson 2005).

Figure 12. "Every Garden a Munitions Plant." 1918 war garden promotional poster by James Montgomery Flagg (Pack 1919).

Despite hard economic times around the turn of the 20th century, the U.S. population surged, and almost half of the population lived in cities (Lawson 2005). Inner cities became destitute and crime-ridden as poverty created desperation for food and housing. Railways constructed around this period facilitated the migration of the upper and upper middle classes to suburban and exurban locations (Lawson 2005). The state of U.S. cities, including poor sanitation, crime, and over-population, spurred the upper and middle classes to lead the City Beautiful Movement from 1890 to 1910 (Basset 1981). The thinking behind the movement was that creating beauty would inspire “civic loyalty” and “moral rectitude,” leading to lower crime rates (Basset 1981). As previously noted, in some cases elegant parks or promenades replaced kitchen gardens that were nourishing the poor (Williamson 2002). The plan for the National Mall of Washington, D.C. was passed by Congress in 1901 as a part of this movement (Basset 1981).

Civic loyalty and moral rectitude were replaced by patriotic duty as an impetus for urban gardening during World Wars I and II. In 1914, as European farmers left to fight in the war, much of the burden of providing for 120,000,000 Europeans living in Allied countries fell on the United States (Heimer 2008). In response, Americans reduced consumption, or at the very least, shifted consumption patterns. Prices were elevated for products like butter, eggs, and coffee, and many Americans started small kitchen gardens to subsidize their meager food supply (Pack 1919). Anticipating that the United States would join the war, the National War Garden Commission was established by Charles Lathrop Pack in 1917. Pack produced propaganda to enlist citizens to help Allied forces by growing Liberty Gardens (Figure 12) (Pack 1919).

The federal government of the time also promoted gardening. President Woodrow Wilson proclaimed “Everyone who creates or cultivates a garden helps…This is the time for America to correct her unpardonable fault of wastefulness and extravagance” (Krochmal 2005). The response of the American public was enormous. Nationally, there were three million garden plots in 1917 and well over five million in 1918 (Pack 1919). As gardeners increased their knowledge of and enthusiasm for gardening, the harvests became more abundant. In 1918, over half a billion tons of produce were harvested, along with the birth of the “city farmer” (Pack 1919).

It must have been helpful to have established spaces and knowledge of gardening when the economic and environmental hardships of the 1930s came about. The period 1930 to 1938 marks the era of Depression Relief Gardens. Unlike Liberty Gardens, this movement was led by city governments to fend off hunger, poverty, and emotional stress (Williamson 2002). Gardens lifted spirits and increased health much like the Potato Patches of the 1890s by offering participants opportunities for food and work, giving them feelings of usefulness and productivity (Tucker 1993).

The groundwork laid by Liberty Gardens and Depression Relief Gardens helped kick start the next gardening trend at the beginning of World War II. This time the War Food Administration, a federal government agency, created the Victory Garden Program (Basset 1981). During this era in American gardening, it was an activity for almost everyone, not just for the poor (Figure 13). It became a popular activity to promote mental and physical health and to garner a sense of community (Basset 1981). Under wartime duress, gardening provided an outlet for the fears, anxieties, and stresses and served as an expression of patriotism (Basset 1981). In 1942, approximately 5.5 million Americans grew Victory Gardens, increasing seed sales by 300% and producing 44% of the fresh vegetables consumed in the United States (Basset 1981).

Figure 13. A resident of Washington, D.C. stands beside her Victory Garden in 1943 (left). More affluent Americans also participated in the movement; gardeners work the grounds of the Charles Schwab estate in New York, NY, 1944 (right) (Library of Congress 1943 and 1944).

Liberty Gardens of World War I and Victory Gardens of World War II meant that many Americans were learning to garden in any available plot (Lawson 2005). The five main goals for Victory Gardens concerned:

- Vegetable supply: Reduce demand for commercial supplies to increase availability to Armed Forces and lend-lease programs.
- Strategic materials: Lessen demand for materials used in food processing and canning.
- Transport: Free up railroads to carry war munitions rather than produce.
- Vitality and morale: Produce nutritious vegetables; provide outdoor activity.
- Food stockpiling: Preserve fruits and vegetables for use when food shortages might worsen (Figure 14) (Basset 1981).

With the end of World War II came the end of the patriotic view of gardening. It was the beginning of the Baby Boomer era in America, when consumption and the suburban lifestyle became the norm (Roberts 2006). Some Victory Gardens were located on borrowed land that needed to be returned to owners (Lawson 2005).

Gardening in the United States dramatically changed along with American culture in the post-war era (Lawson 2005). The Baby Boomer years following the war reshaped the American countryside and its culture. The U.S. Interstate Highway System was constructed starting in 1956, marking the onset of trends in fast food,

Figure 14. Jeffersontown, Kentucky had a community cannery, shown here in June, 1943. The cannery was started by the Works Projects Administration (WPA) to handle the large amounts of Victory Garden produce (Hollem 1944).

shopping malls, and the decline of urban retail centers (Roberts 2006). Already in 1930 over half of American families owned automobiles, so after World War II ended and the GI bill was passed (allowing many families to buy their first homes), the American dream was intimately connected with cars and the suburban lifestyle (Roberts 2006). Instead of gardens, a beautiful lawn became fashionable (Fort 2000).

A desire to connect with the Earth, protect the environment, and connect with one's neighbors promoted a surge in community gardening in the 1970s, which continues today (Lawson 2005). Cities throughout the United States started urban renewal gardening projects and in 1978 they banded together to establish the American Community Gardening Association (ACGA) (Lawson 2005). By 1973, garden hobbyists numbered about 80 million (2005). It once again became a trend in healthy living to tend a garden. Gardeners had long sung the praises of gardening as a way to relax and soothe the tensions of daily life. A 1973 study quantified this effect, showing that gardening and viewing green spaces produces a restorative effect on one's health (Kaplan 1973).

Besides community spirit, stress relief, and physical activity, other motivations drew Americans to gardening in the 1970s. Economic benefits of gardening arose since food prices had risen, partly due to the oil embargo (Lawson 2005). There was an activist mentality in the 1970s, and gardening provided one way of exercising control over one's daily life. In 1976, 51% of American families had vegetable gardens, 10% of these in community gardens (Gallup 1976). By 1982, gardening was listed as America's top leisure activity (Francis, Cashdan and Paxson 1984). The same poll noted that 18 million households would have gardens if they had space suitable for gardening (Francis et al. 1984).

Gardening as a form of social activism was especially prevalent in America's inner cities, which were continuing the decline that commenced following World War II, particularly in the aftermath of deindustrialization (Lawson 2005). While many buildings had become vacant, run-down, and vandalized, the plight of inner city urban communities continued as poverty increased. In response, select city dwellers chose to convert vacant lots into community gardens. By enlisting the disenfranchised youth who were primarily responsible for crime and vandalism, urban communities were able to restore a sense of neighborhood pride. This pride translated into crime reduction, a source of nourishment, physical activity, socialization, and an overall beautification of the immediate and surrounding areas (Lawson 2005).

Gardening as activism has recently evolved into a new vein. Widespread concerns over climate change and environmental degradation have provided new strength to ideas sprouted in the 1970s. History shows that more people gardened during difficult times, both through economic hardship and wartime, to experience a sense of purpose, productivity, and control over their immediate environment (Lawson 2005). Many contemporary urban gardeners in the United States have propagated the 1970s activist mentality, evoking the same sense of empowerment by fighting against the heavy resource consumption promoted by large-scale commercial food producers and even tackling the local and global issue of climate change.

Recently, concern about climate change has inspired some U.S. citizens to grow “New Victory Gardens,” borrowing the terminology of the World War II Victory Gardens (ReviveTheVictoryGarden.org 2009). Like their predecessors, the benefits of contemporary gardens include reducing dependence on commercial foods, decreasing energy needs, increasing individual health through physical activity, and garnering a sense of family and community (Basset 1981, ReviveTheVictoryGarden.org 2009). Today’s gardening activists also seek to “fight global warming” through reducing (or eliminating) one’s carbon footprint via carbon sequestration and waste reduction (2009). At the heart of these efforts is the idea that personal and community health is related to environmental health. Although the idea is not new, recent concerns over food quality and climate change have reignited this discussion.

3.7. Urban food production and public health

Connections between food quality and personal health have gained wider attention in science and policy in recent years, driven largely by concerns over the U.S. obesity epidemic (Mokdad et al.

1999). Evolving out of this public discussion is the realization that a key to personal health relies on sound food policies that support quality food in an environmentally sustainable system.

3.7.1. Fusion of environmental and public health issues

First Lady Michelle Obama has taken on the issue of childhood obesity as her mission, hailing the importance of daily exercise and healthy eating (Lee 2009). A first step was to implement a White House spring vegetable garden, promoting gardening as physical activity and as a way to renew children's connection with food (White House staff 2010). Mrs. Obama's effort to renew interest in gardening may be working, with a 19% increase in the number of gardens in the U.S. and a 30% increase in seed sales in 2009 (White House staff 2010). Interestingly, although Mrs. Obama hails the healthful benefits of gardening, she has not taken the opportunity to educate people about soil testing for heavy metals. This failure is despite the fact that the White House soils were tested, and lead was found above normal levels before the garden was implemented (Swarns 2009). A White House spokesman defended the health of the soils, simply stating that they were completely safe (Swarns 2009). Fortunately, the first mention of lead in the White House garden in the press appeared in a *New York Times* article about lead in urban gardens, and how gardeners should be aware of the ubiquity of lead in urban areas and have their soil tested (Murphy 2009). The reluctance of Michelle Obama to mention soil health in connection with healthful eating through gardening is an opportunity lost. Nonetheless, her successful promotion of gardening has brought up soil health as a side issue, where it was rarely mentioned in the past.

As another illustration of the national conversation about personal and ecosystem health as it relates to food, consider the debate about the 2012 Farm Bill. Scheduled to move through Congress in 2012, debates over fresh, local food for schools, sustainable agriculture, and food stamps started escalating in 2010. The Slow Food USA website discusses opportunities to change the current food system with the 2012 Farm Bill:

Figure 15. The Love Canal disaster of the late 1970s added rigor to the environmental movement (EPA 1978).

- *Could there be more incentives for farmers to grow fruits and vegetables, and not just commodity crops?*
- *Could accepting food stamps at farmers' markets help to combat obesity?*
- *Should sodas be banned from the food stamp program, similar to the program's existing bans on tobacco and alcohol?*
- *Could a "whole-farm revenue" concept for crop insurance replace the present system that encourages production of a single crop, and instead encourage more diverse crops?*
- *Could an expansion of the green payments program incentivize sustainable farming rather than overproduction?* (Slow Food USA 2010)

Based on these suggestions from Slow Food USA, a sustainable food system proponent, there appears to be an emerging awareness of the connection between the public health (i.e., obesity), environmental health (i.e., sustainable farming through crop diversity, for instance), economic health (i.e., farmers growing subsistence crops in addition to commodity crops), and local food production.

3.7.2. Environmental activism and policy

Perhaps the growing awareness of how food systems and ecosystems relate stems from a recent resurgence in environmental concerns that has its roots in the 1960s. Although some notable environmentally progressive events occurred prior to the 1960s (e.g., the establishment of the Audubon Society, Wilderness Society, and the National Park Service), it was the publication *Silent Spring* by Rachel Carson (1962) that triggered a national conversation, further awakening Americans' interest in the environment (Weiss 2005). The movement gained strength in the 1960s and 1970s as the U.S. Environmental Protection Agency was established, environmental disasters brought more anger and fear from the public (Figure 15), and organizations like the Sierra Club took on the powerful corporations who sought to exploit our country's national resources (Weiss 2005).

Figure 16. A Depression Relief Garden located in Youngstown, OH, 1932 before federal or state policies were passed protecting public health and the environment. Note the proximity of the gardens to polluting industries in the background (artist unknown 1932).

Like today, Americans in the 1970s displayed increasing concerns about the wasteful nature of the food system, as well as negative environmental impacts of agricultural practices, especially pesticides and herbicides (Weiss 2005). Americans had become more aware of the health risks associated with chemical residues on commercially produced foods (Weiss 2005), which prompted amendments to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) in 1972 (Conner et al. 1987). The 1972 FIFRA amendments empowered the EPA to classify pesticides and regulate pesticide residues on raw agricultural commodities (Conner et al. 1987). These changes along with coincident amendments to the Food, Drug, and Cosmetic Act (FDCA) led to development of the EPA's toxicity testing strategy (Gad and Chengelis 2001).

Regulation of industrial chemicals has followed a different path. In 1976, Congress passed the Toxic Substances Control Act (TSCA) to regulate new and existing industrial chemicals that were not addressed by other statutes (Kraska 2001). Unfortunately, while TSCA requires reporting of chemical information, no specific toxicity testing is required, nullifying much of the EPA's ability to protect public and environmental health from industrial chemicals (Kraska 2001).

3.7.3. Heavy metals and public health

Before the world gained a better understanding of environmental health and its relationship to public health, there was little thought about how pollution might affect air, water, and food quality (Figure 16). With a grasp on environmental science and a desire to protect public health, the U.S. government began to regulate pollution, efforts eventually leading to the formation of the U.S. Environmental Protection Agency (EPA). The EPA's charge, "to protect human health and to safeguard the natural environment – air, water, and land – upon which life depends" (EPA 2005) involves many complicated facets. An advisory agency to the EPA on whether people will suffer harmful health effects from their exposure to hazardous substances, the Agency for Toxic Substances and Disease Registry (ATSDR), was established as part of the Superfund Law of 1980 (EPA 1998). One service of this agency is to compile a list of substances most hazardous to human health in the U.S., called the Completed Exposure Pathway (CEP) (ATSDR 2009). The items are prioritized based on risk to human health and incidence of exposure. Topping the list are arsenic, lead, and mercury (ATSDR 2009), all of which are heavy metals commonly found in urban soil. Ten of the top 18 most hazardous substances to human health in the environment are heavy metals (ATSDR 2009).

Any activity that disturbs soil contaminated with heavy metals, e.g., gardening or construction, can release these toxins, in effect allowing them to harm people, animals, and plants. Heavy metals in soil can enter people and animals via direct ingestion, breathing contaminated dust, and through skin contact (ATSDR 2007). Urban gardeners are at risk even when using known strategies to avoid plant uptake, e.g., pH control. This method limits the toxins entering plant tissue, while disregarding other exposure pathways, which can be exceedingly toxic to the human body (Table 5). When working with soil during gardening or any similar activity on bare soil, all three routes of exposure are possible, including inhalation, skin or eye contact, and ingestion (ATSDR 2007). Because of this possibility, "safe" levels of lead are lower for bare soil compared to soil covered by vegetation or a sidewalk (EPA 2010b).

Adding further complexity to the issue are stricter state policies in some cases. For example, Minnesota established safe levels of bare soil below 100 parts per million (ppm) of lead compared to the federal bare soil maximum of 400 ppm (State of Minnesota 1993, EPA 2010b). In light of these regulatory complexities, together with heterogeneous soil characteristics, the safest policy for a gardener is soil testing and site-appropriate management strategies.

3.7.4. Best practices in urban gardening

With significant urban populations in the United States, a growing trend towards using local produce and its significance as a cultural tradition, urban gardening has become a symbol of community, individual worth, and survival. These meanings in American gardening are repeated from past in times of war or economic strife. The different theme occurring this time is the desire to address moral issues regarding consumption and stewardship, personal health, and environmental concerns including global climate change, one garden at a time. The gardening community strives to do this by resisting the degenerate food system to create a sustainable food system based on intensified local food production.

To accomplish this goal, Americans must learn some lessons from history. First, they should accept the country's history of flawed resource management, environmental deterioration, and poor waste management, especially in urban systems, due to the presence of environmental toxins. Then, they should look to the past for ways to reinvent circular resource usage, while keeping in mind the present situation (i.e., potential for contaminated soils). The growth and success of ancient civilizations was often dependent on their ability to capture nutrients in waste to reapply them on their agricultural fields (Denevan 1998). By emulating the more innovative of ancient civilizations in their ability to create an efficient, circular system of resource usage for sustainable food systems, while emphasizing soil health and quality, U.S. urban gardeners will be able to effect change at the global level.

Table 5. Heavy metals, anthropogenic exposure, and health effects of chronic exposure. CEP stands for Completed Exposure Pathway, which is based on how hazardous the substance is to human health and incidence of exposure, which is higher for substances more ubiquitous in the environment. Compiled from Naidu et al. (2003) and ATSDR ToxFAQs (2011).

Element	CEP Rank	Primary anthropogenic sources	Human health effects
Arsenic, As	2	Pesticides, fertilizers, copper smelting, sewage sludge, coal combustion, detergents, treated wood	Ingesting high levels of As can result in death. Lower exposure causes nausea and vomiting, decreased red and white blood cells, abnormal heart rhythm, and damage to blood vessels. Long-term, low-level exposure by breathing or ingesting can cause a hyperpigmentation and excessive skin growth. Ingestion of certain As compounds can cause diarrhea and damage to the kidneys. As is carcinogenic**.**
Cadmium, Cd	6	Fertilizers, industry, fossil fuel burning, sewage sludge, Pb & Zn smelting, mine tailings	Breathing Cd severely damages the lungs and can cause death. Long-term exposure to lower levels of cadmium in air, food, or water leads to a buildup of cadmium in the kidneys and possible kidney disease, high blood pressure, iron-poor blood, liver disease, and nerve or brain damage. Cd is carcinogenic**.**
Chromium, Cr	7	Fertilizers, metallurgic industries, iron & steel production, cement, sewage sludge	Breathing Cr can cause nosebleeds, ulcers and holes in the nasal septum. Ingesting large amounts can cause stomach upsets and ulcers, convulsions, kidney and liver damage, and even death. Skin contact can cause skin ulcers or allergic reactions consisting of severe redness and swelling of the skin. Cr is carcinogenic**.**
Copper, Cu	13	Fertilizers, fungicides, sewage sludge, industry, mine tailings, copper dust	Cu is essential to human health, but too much is toxic. Breathing high levels of copper can cause nose and throat irritation. Ingesting high levels of copper can cause nausea, vomiting, and diarrhea. Very-high doses of copper can cause damage to your liver and kidneys, and can even cause death.
Lead, Pb	1	Mining, smelting, sewage sludge, fossil fuel combustion, pesticides, batteries, paint, solder in water pipes	Pb can affect almost every organ in the human body, but the main target is the nervous system. Chronic exposure may result in birth defects, mental retardation, autism, psychosis, allergies, dyslexia, hyperactivity, weight loss, shaky hands, muscular weakness, arthritis, colic, hyperactivity, mood swings, nausea, numbness, lack of concentration, seizures, weight loss, and paralysis. Pb is a probable carcinogen**.**
Nickel, Ni	17	Fertilizers, fuel & residual oil burning, alloy manufacture, nickel mining and smelting, sewage sludge, batteries	The most common harmful health effect of nickel in humans is an allergic reaction after skin contact or asthma attack after breathing it. Chronic exposure leads to chronic bronchitis and reduced lung function. Ingesting it causes stomach ache and suffered adverse effects to their blood and kidneys. Likely affects the blood, liver, kidneys, immune and reproductive systems. Ni is carcinogenic**.**
Zinc, Zn	12	Fertilizers, pesticides, fossil fuel combustion, nonferrous metal smelting, alloys, brass, sewage sludge, batteries.	Zn is essential to human health, but too much is toxic. Swallowing large doses can cause stomach cramps, nausea, and vomiting. Over longer periods it can cause anemia and decrease the levels of your good cholesterol. May cause infertility. Inhaling large amounts of Zn can cause metal fume fever. Causes skin irritation.

Chapter 4. Lawrence Gardens Case Studies

A case study of Lawrence is presented for the purpose of exploring issues, environmental, social, and policy-related; to help illuminate what is being done locally to improve the national food system. By looking at a sample of gardens from the community scale to backyard gardens, both land use and soil properties can be examined to evaluate methods of detecting and managing soil health in a variety of settings. The purpose of the case study is to guide the development of a process that helps local producers make informed decisions to ensure healthy soil, food, and gardening practices. The ultimate aim is to improve the U.S. food system one garden at a time.

4.1. Project description and purpose

In the spring of 2009, ten urban gardens were systematically sampled in the Lawrence, KS area, totaling 500 soil samples. The goals for this field-based case study are twofold. The first goal is to investigate the discrete and broad patterns of heavy metal contamination, if any, (and other soil characteristics, e.g., organic matter content) on the Lawrence garden landscape. This process requires a fine-scale grid sampling approach for gardens at two depths, a much higher resolution sampling scheme than currently recommended by most entities offering soil analyses for heavy metals. Then, by comparing heavy metal levels to site-specific and city-wide land use histories, two questions can be answered: (1) what is an appropriate resolution for soil sampling to effectively capture both broad and discrete sources of heavy metal contamination? And, (2) is land use history a good predictor of which heavy metals are present? Another part of the soils analysis evaluates soil color as a proxy for organic matter content of a garden soil. Generally speaking, organic matter forms complexes with heavy metal cations, helping to immobilize contaminants in the soil, reducing their plant availability. By encouraging soil health through adding organic matter (amounts roughly estimated via soil color), gardeners can reap multiple benefits of improved yields, lower water needs, and especially important, lower their potential for exposure to heavy metals from their soil.

The second goal of this case study is to use the lessons learned from the soils analyses and land use histories to develop decision support tools for urban gardeners and policy makers. This will be described in Chapter 5. Both groups, broadly speaking, are seeking ways to encourage local food production while maintaining health and safety. By providing simple methods for detection, management, and remediation of heavy metals in urban soils, this barrier can be removed and urban gardening can become a larger contributor toward distributed food production.

4.2. Research design

Gardens included in the study were selected using opportunistic sampling, guided by the desire of gardeners to be a part of the study usually due to soil contamination concerns. Some gardens were sought out due to their interesting land use history (i.e., Vermont Street garden) or community garden status (i.e., North Lawrence Community Garden), or both (i.e., Eastside Community Garden). Soil samples were collected in March and April of 2009 with the goal of retrieving samples before gardens were planted. Where garden plots had been planted, every effort was made to avoid disturbing garden plants. Soil cores about 2.5cm in diameter at a length of about 35-40cm were collected using a T-handled soil sample device a fine spatial scale (i.e., a minimum of one core per five square meters). Subsamples were collected from the cores to account for variation in soil characteristics and metal concentrations in different soil layers. A more detailed description of soil sample preparation and analyses is provided in 4.6.

Garden plot histories were investigated at two scales (plot and city) and from two perspectives (environmental and human factors) affecting soils at each plot. A variety of Geographical Information System layers (i.e., soils, land use, water features, pollution sources) overlaid with historic maps provided a spatial and temporal tool for understanding, predicting, and characterizing risk of soil contamination. Predictions from this process were tested against qualitative and quantitative soils analyses with the goal of evaluating the approach for use by a gardener. Finally, during the sampling process and again when sharing results, interactions with gardeners provided insight into general perceptions about soil health, contamination sources and levels, and remediation processes. While formal interviews were not performed, these conversations guided the design process of the items in section 5.3, which were created to convey information on addressing soil health issues to a general audience.

4.3. General study area description

Figure 17. Location of Lawrence, KS (red star) in the U.S. Midwest.

Lawrence provided an ideal study area for examining the relationship between land use history and heavy metals in soils. It has a long history of human occupation and is characterized by differential land uses and variable terrain. For instance, Lawrence has a rich history of industrial activities, sits near a U.S. Interstate highway and railroad system, and is intersected by the Kansas River. These factors, in addition to Lawrence's mid-range size (population and areal extent) among U.S. cities and vibrant history of agriculture and gardening, provide a superior setting for understanding how a typical Midwestern city may be influenced by past and present land uses.

Lawrence is located in the central Midwest of the United States at 38˚58'N, 95˚16'W (Figure 17) at an elevation of approximately 980 feet (299m). In the Köppen climate classification system, Lawrence fits within the *Dfa* category, characterized by hot summers in a continental locale where winters are drier than summers. Lawrence has a mean annual temperature of about 56 ˚F (13 ˚C), ranging from a daily average of 80 ˚F (27 ˚C) in the hottest month to 30 ˚F (-1 ˚C) in the coldest month. In a typical year, precipitation totals dramatically increase in the spring, peaking in the warmest months, with an annual average of about 40 inches (102 cm) (Figure 18). The climatic profile of the area provides superior conditions for development of mollic epipedons, ideal topsoil for agriculture. Nearly all of the soils in Douglas County (in which Lawrence is located) are Mollisols, soils naturally rich in organic matter, typically having a loamy texture, low bulk density, and high cation exchange capacity. These soils were formed under prairie vegetation.

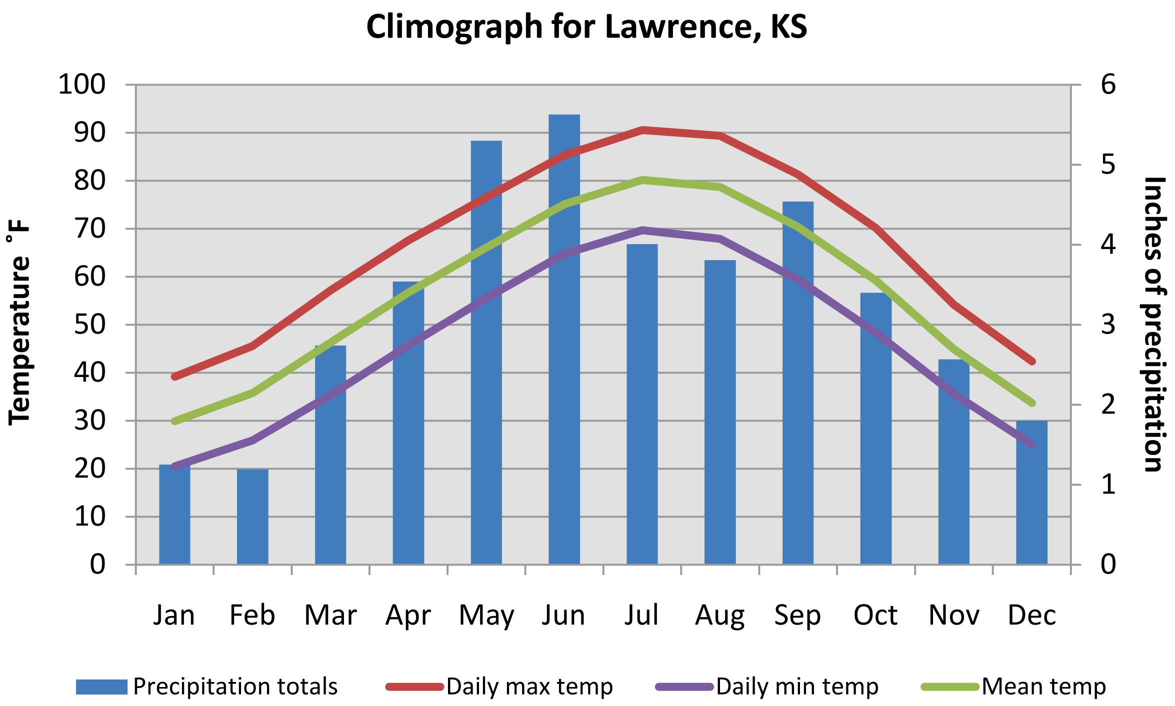


Figure 18. The climate of Lawrence, KS shows higher precipitation totals at the beginning of the growing season, a helpful feature for the success of agriculture in the region. Data (1971-2000) is from the National Climatic Data Center (2006).

Lawrence is situated between and just north of two rivers, the Kansas (Kaw) River to the north, and the Wakarusa River to the south. Lawrence sits at the southernmost extent of North American glaciation (Lyle 2009). The two rivers vary extensively in character, primarily due to the differing underlying geology. The Kansas River has a more meandering form with a much wider basin, as it moves through more sandy substrates including sandstone. The Wakarusa River travels through an area less affected by continental glaciation, consisting mostly of shale, silt, and limestone. Because of this geology, it has steep, muddy banks and thus its channel is more resistant to movement.

The differing qualities of these two rivers illustrate differing character of soils between north Lawrence (north of the Kansas River) and the rest of Lawrence. Soils north of the Kansas River are rich, deep soils formed on glacial till or river terraces. Soils to the south of the Kansas River contain significantly more clays, although most contain enough organic matter to provide a reasonable level of tilth to allow mixing in of soil amendments for improved texture.

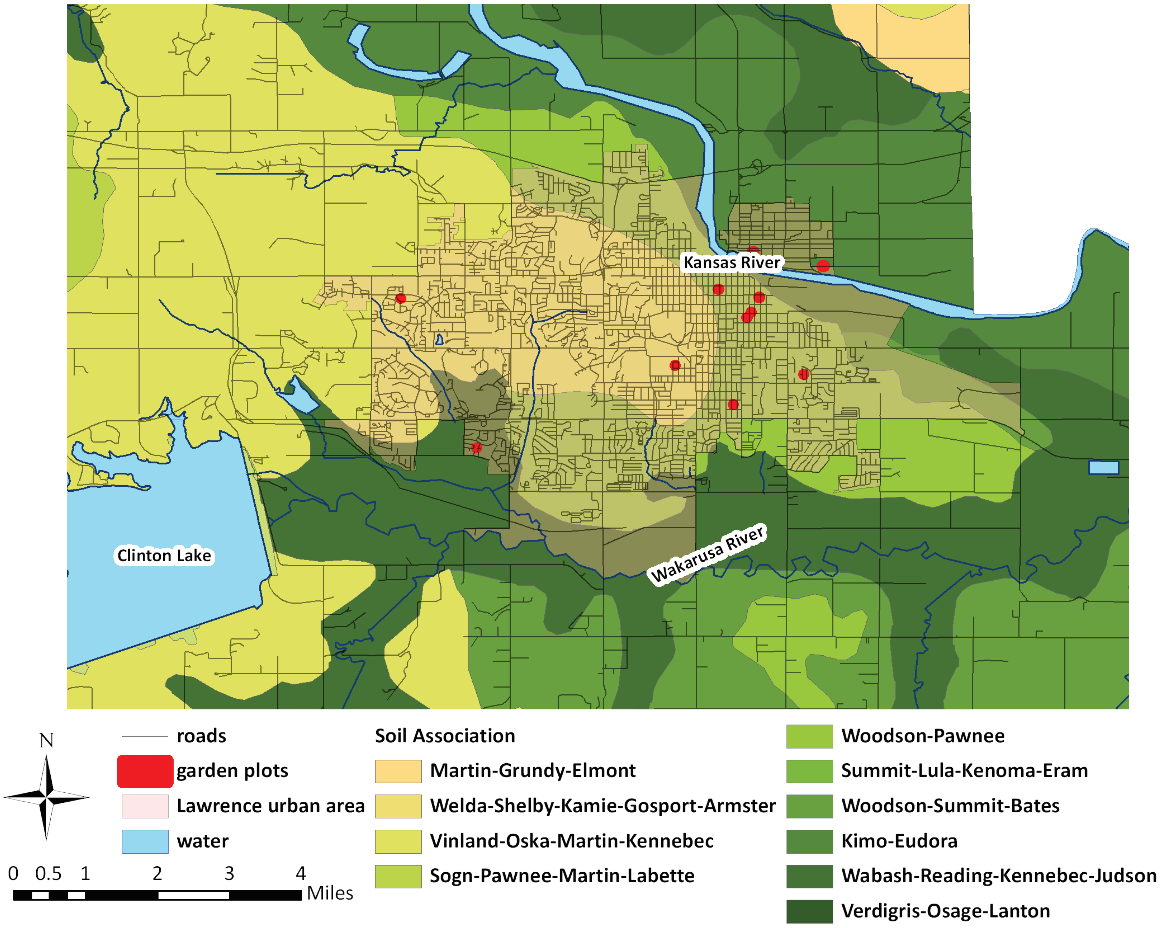


Figure 19. The city of Lawrence is situated between and just north of the Kansas and Wakarusa rivers in northeast Douglas County. The soil associations are characterized primarily by landscape position and effects from glaciation for the soils in the northeastern portion of the county. Soil layer from USDA NRCS (SSURGO version 2.1) (2010). Urban areas, water, and road layers from USGS and ESRI (2002).

The city occurs within or near the tall grass prairie-hardwood forest ecotone, but this is difficult to discern since the vegetative cover of the area has mostly been replaced by urban or suburban land uses surrounded by industry (e.g., concrete production and distribution) and agriculture (e.g., soybean and corn production) (Figure 19). Lawrence flourished and expanded in the 1860s and 1870s as a town brimming with various industries surrounded by agriculture (Middleton 1937). This heritage has continued, as various industries have continued to thrive in the area, the mix of industries changing through time. Industry is now less central to the town's success, as it houses a major university, the University of Kansas, among other vibrant organizations and businesses. The population of 87,600 is supplemented by the influx of about 26,000 college students annually (U.S. Census 2010, University of Kansas 2010, respectively).

Lawrence's electricity comes from an adjacent coal burning power plant, and its emissions along with those from the nitrogen fertilizer plant, interstate highway, and railroad activities have settled on surrounding soils for decades (Figure 20). The Kansas River that intersects the town is one of the most polluted waterways in the state, downstream from farms and ranches where pesticides, fertilizers, herbicides, animal wastes, and possibly leachate from an abandoned Lawrence landfill drain into the river (Stover 2010). Douglas County falls within the 80-90th percentile rank in the U.S. for number of

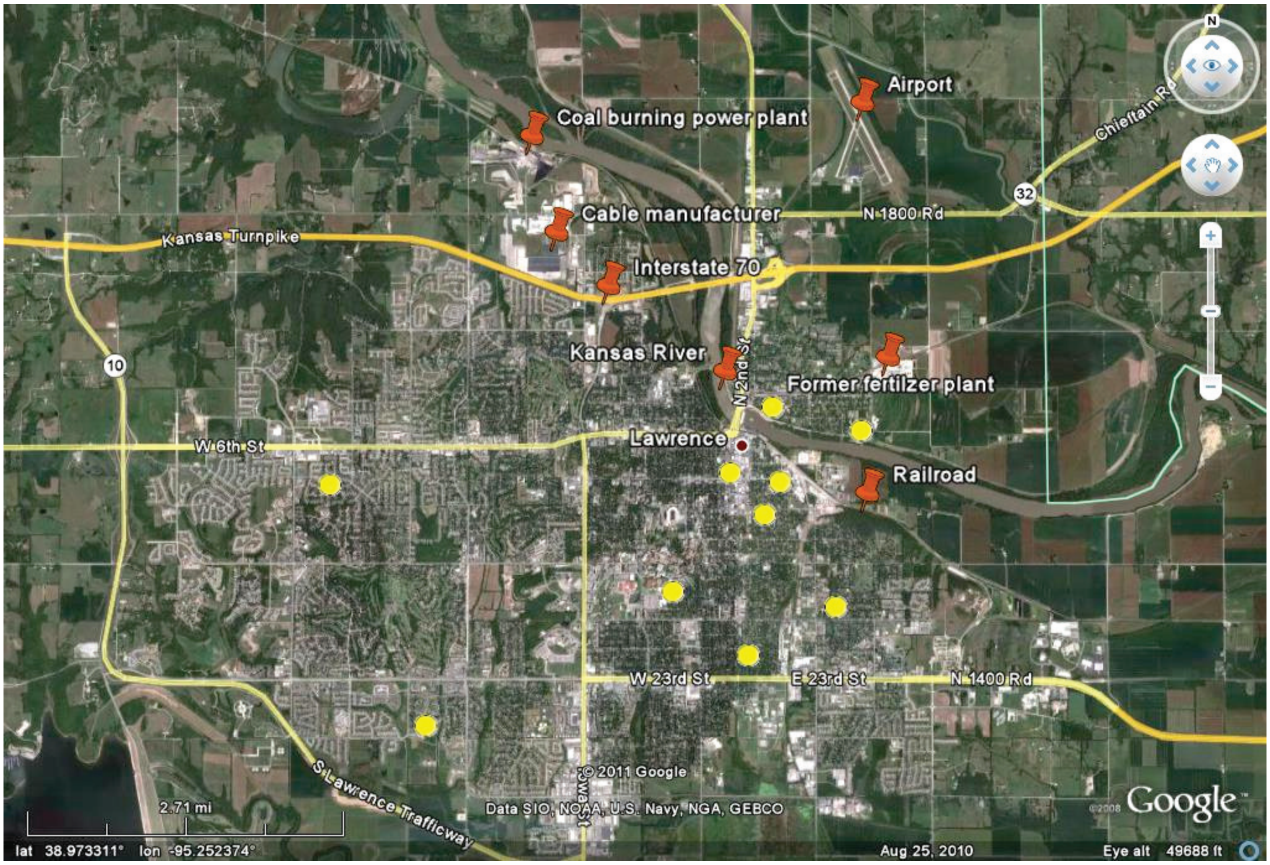


Figure 20. Google Earth image with locations of urban gardens in the case study (yellow dots) and some potential pollution sources (red tacks). Gardens plots are concentrated near the oldest parts of the Lawrence, where soil contaminants are more likely to be present. Image created on March 28, 2011.

housing units with high risk of having lead paint (Scorecard 2005). This sampling of regional factors combined with the specific land uses of each garden site give a variety of potential heavy metal contamination sources and patterns. More detailed environmental and land use histories of the city and each plot follow.

Figure 21. Ruins of the Free State Hotel after an attack by Sheriff Jones, May 21, 1856 (Robinson 1856).

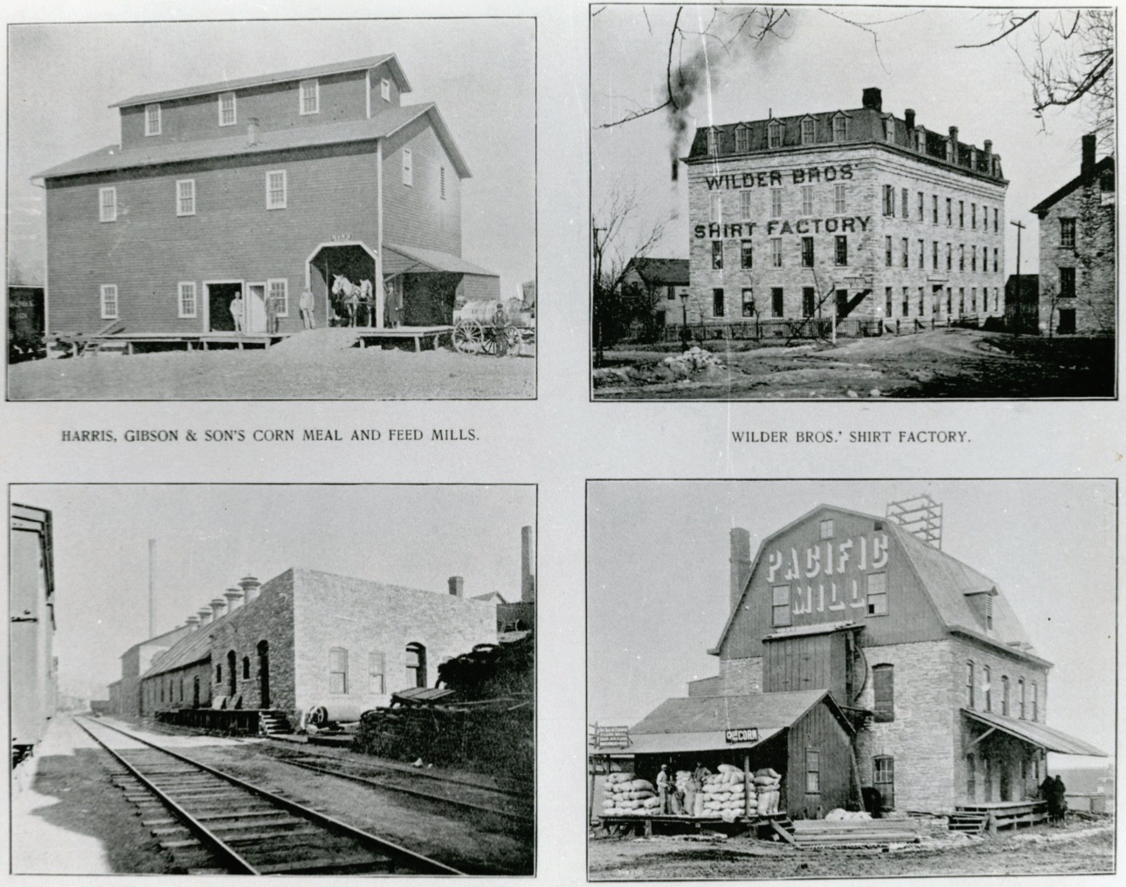
4.4. Land use histories

4.4.1. Environmental history of Lawrence

Lawrence's history is uniquely tied to national history because it was platted as an abolitionist town site in 1854 despite its proximity to pro-slavery settlements and the slave state of Missouri (Caviness 1988). Original settlers, many associated with the New England Emigrant Aid Society, hoped that by populating the area with abolitionists, Kansas would be admitted to the Union as a free state (i.e., one in which slavery was illegal) (Caviness 1988). Multiple raids damaged the growing city, such as the 1856 raid where Sheriff Sam Jones burned the main hotel on Massachusetts Street (Figure 21). Abolitionist efforts were rewarded when Kansas gained statehood in 1861 as a free state (Caviness 1988). Several current Lawrence businesses reflect this heritage, containing “Free State” in their business names. Yet, with statehood, the violence only escalated, as the U.S. Civil War began just three months later. In 1863, William C. Quantrill raided Lawrence, resulting in the burning of a large proportion of homes and businesses, including part of the Lawrence House, where the Vermont Street garden plot is now located (see Figure 31), and the killing of most of the male population (Caviness 1988).

By the end of the Civil War in 1865, a railroad had already been constructed through Lawrence, expanding in every direction during the decade from 1864-1874 (Middleton 1937). In 1874, Bowersock Dam construction was completed, harnessing the hydraulic power of the Kansas River (Caviness 1988). These two features of Lawrence provided shipping services and access to inexpensive power, an ideal environment for manufacturing businesses to blossom (Middleton 1937).

By the turn of the 20th century, Lawrence had become a major agricultural and manufacturing force in northeastern Kansas (Middleton 1937). Factories produced wire, boxes, agricultural equipment, musical instruments, metal castings, nails, pottery, paint, patent medicines, steam donkey-engines (steam-powered winches for logging and mining), textiles, paper products, canned and processed foods, clothing, shoes, beer, leather, wagons, and carriages. There were also sawmills, icehouses, grist mills, and brickyards (Caviness 1988) (Figure 22).



HARRIS, GIBSON & SON'S CORN MEAL AND FEED MILLS.

WILDER BROS.' SHIRT FACTORY.

THE LAWRENCE PAPER MILLS.

BOWERSOCK MILLING CO.'S PACIFIC MILLS.

LAWRENCE MANUFACTURING INDUSTRIES.

Figure 22. Early Lawrence industries that helped the town prosper in the late 1800s. The Lawrence Paper Mills (bottom, right) previously housed the Consolidated Barbed Wire Company until 1898. It was placed on the Kansas Register of Historic Places in 1990 (Brack 1991). Photograph courtesy of the Watkins Community Museum in Lawrence.

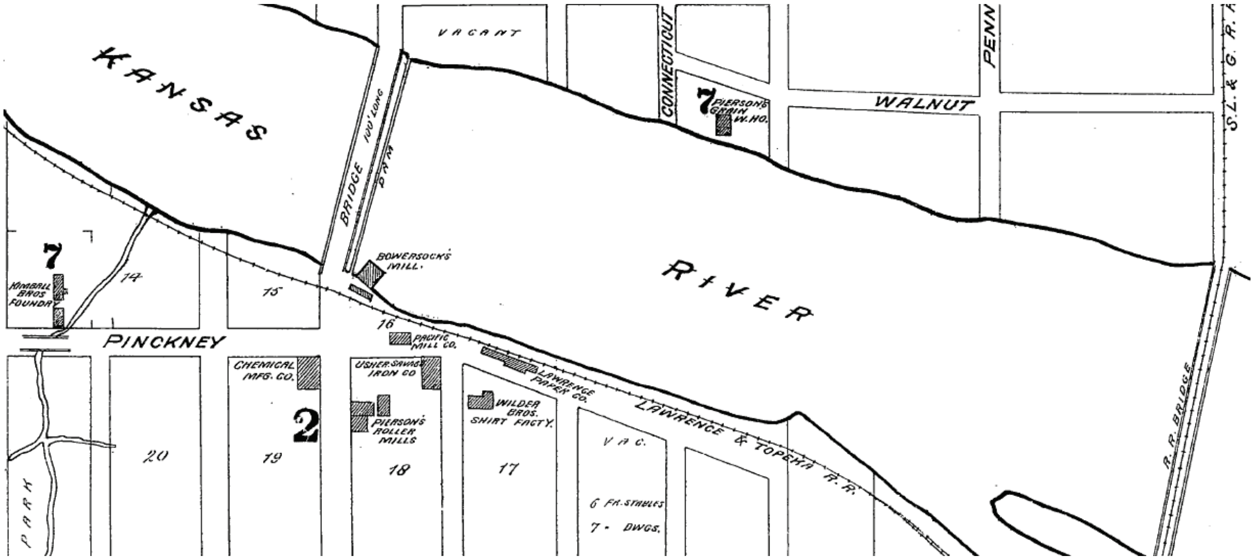


Figure 23. This portion of an Sanborn map (1883) shows the beginnings of industry in Lawrence. Note the presence of potential sources of heavy metals, including the Kimball Brothers Foundry (far left), the chemical manufacturing company and iron company (near "2").

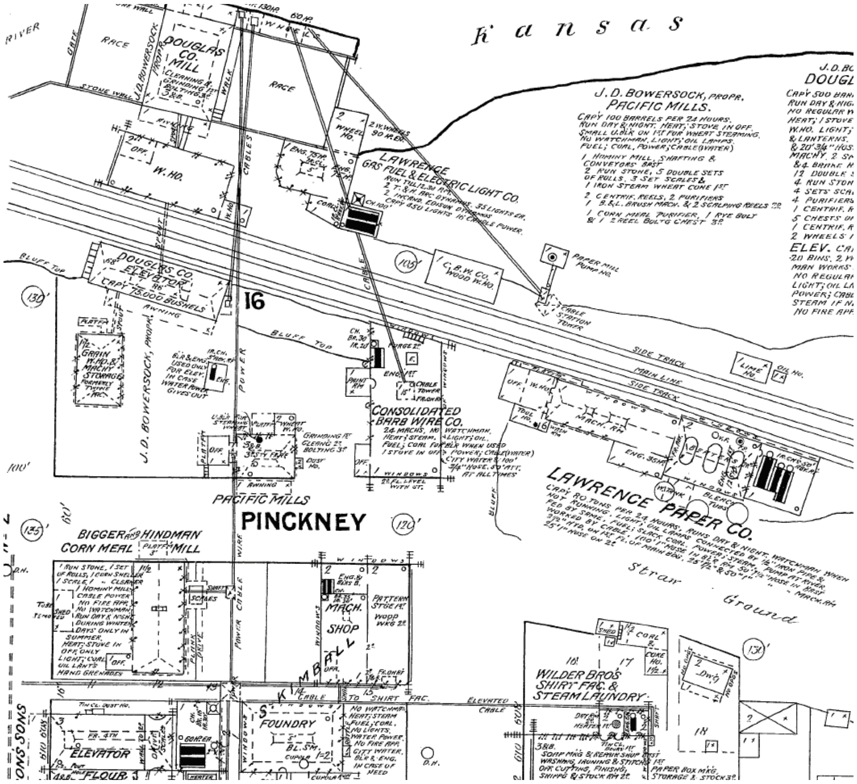


Figure 24. This portion of an 1889 Sanborn map near Pinckney (6th) and New Hampshire shows that in only six years industry had expanded significantly in Lawrence. See map references of building sizes for scale.

The more energy intensive businesses that also needed ready access to freight services, e.g., the Consolidated Barbed Wire Company, Jenny Wren Flour Mill, and the Lawrence Paper Mill, were located on the south side of the Kansas River, near the ready sources of power and freight (Figure 23) (Caviness 1988). Industry expanded eastward along the river and rail, so that area became more industrialized, while many businesses began populating Massachusetts and nearby streets to the south (Figure 24). The growth and success of Lawrence industry was interrupted by a flood in 1903 that caused major damage to Bowersock hydropower infrastructure and buildings on the river banks (Figure 25). Underground tunnels in the 600 block of Massachusetts Street had transmitted inexpensive mechanical power to businesses, but this changed when the dam was rebuilt in 1903-1905 (Retzlaff 1987). After repairs were completed, the dam provided power to Bowersock's factory and then sold electricity (rather than mechanical power) to the other businesses. As a result, the underground tunnels were sealed (Retzlaff 1987).

Figure 25. The flood of 1903 caused extensive damage to infrastructure along the Kansas River, including the Bowersock Dam. Many houses in North Lawrence were flooded, and some were swept away (left). In the right image (looking southeast), an onlooker watches debris pile up against the Massachusetts Street bridge, which eventually led to the destruction on its northern span (USGS 1903, Kansas Water Science Center 2009).

Within a short period, industrial activities blossomed, and the areal extent of Lawrence and its population also expanded (Caviness 1988). A comparison of the 1883 and 1889 maps (Figure 23 and Figure 24) illustrates some of these changes. Over the decades, the central infrastructure of Lawrence business and industry kept a similar form, while the building uses may have changed. For instance, in 1912 Bowersock mills added grain elevators, but then ceased operations at the beginning of World War II (*The Outlook* 1954). After the war, the building "was leased for the manufacture of alcohol, which was used for synthetic rubber products" (*The Outlook* 1954). By 1954, the main building stood vacant, while the grain elevator had been expanded with additional plans to add new access for semi-trailers. Other notable industries in Lawrence at this time included popcorn and seeds, canning (lima beans), industrial chemicals, fertilizer, metal fabrication, printing, ammonia nitrate products, pipe organs, alfalfa dehydrating and processing, milk processing, beverage bottling, and corrugated boxes (*The Outlook* 1954).

Change continued in Lawrence business and industry, as many followed a national trend where industry moved to the edges of town, partly because urban areas in the U.S. were shifting from manufacturing industries to more services-based economies (Bradbury, Downs and Small 1982). This change is apparent in the dilapidated state of the Lawrence river front buildings, spurring public outcry in the 1970s. A 1977 headline that appeared in the local newspaper captures this attitude: "Bowersock area gets a 'Yecch!' (Peterson 1977). Legal disputes, changes of ownership, and the eventual transfer of most the riverfront property to the City of Lawrence led to the eventual demolition or refurbishing of the historic area. City offices are now at the site of the old Bowersock Mill at 6th St. and Massachusetts St., the grain elevators have been demolished, and a "Riverfront Plaza" houses adjacent businesses to the east (Brack 1991).

Changes occurring at Lawrence's river front were not isolated, as the rest of the city was growing and changing as well. The population of the city increased dramatically in the height of the manufacturing boom from 11,500 in 1897 to 16,000 in 1918 (Sanborn Perris Map Company Ltd. 1897, Sanborn Map Company 1918). The areal extent of Lawrence has expanded from about four square miles in 1940 to about 33 square miles today (City of Lawrence 2007). Other major floods on the Kansas

River in 1951 and 1993 led to extensive damage to river front areas, especially in North Lawrence. The 1951 event exceeded levels of the 1903 flood, and the 1993 flood levels were less than this. However, because of extensive development over time, property damages from the 1993 flood were much greater (Juracek, Perry and Putnam 2008).

From an environmental perspective, the expansion of industrial activities, especially the manufacture of dangerous items, e.g., hand grenades at the foundry, or the manufacture with potentially toxic materials, such as processing various metals to make wire and nails, can lead to contamination of air, water, and soils. While air and water serve mainly as temporary conduits for pollutants, soils likely still contain some record of these activities. Major floods, e.g., those in 1903, 1951, and 1993 stir up contaminants that have settled in soils and sediments, reintroducing them to the built and natural environments. Because of this, the spatial extent of flood waters can be a predictor of soil contaminants from past and present industrial land uses and other polluting activities.

Other notable industries that may have broadly impacted the Lawrence area include the Lawrence Iron Works (1855-1922), which operated at several locations (*Lawrence Journal-World* 1950), the TRW Industrial Operations group that manufactured steel armor for petroleum pump cables (starting in 1975) (*Lawrence Journal World* 1975), and the nitrogen fertilizer plant in East Lawrence, with a daily capacity of 3,700 tons of fertilizer, in operation from 1954 to 20 (*Tele-Shopper* 1979, *Lawrence Daily Journal-World* 1951, *Biofuels Journal* 2001). The fertilizer plant was lauded at the time as a key national industry, captured in this quote from Howard Cowden, the President of the company building the plant:

> *The demands of our defense program and our steadily growing population are straining the productive capacity of our farms. We cannot continue to take more away from our land without putting more and more back to maintain its fertility (Lawrence Daily Journal-World* 1951).

In 2010, the City of Lawrence purchased the now polluted 375 acre tract with an $8.5 million fund from the seller for environmental cleanup of contaminated water and soil (Lawhorn 2010). Part of the cleanup involves pumping contaminated groundwater through existing pipes to agricultural land in North Lawrence (Lawhorn 2010). This is disquieting news for gardeners considering the possible presence of trace metals in the groundwater from the fertilizers (Rui, Shen and Zhang 2008). Copper, zinc, and nickel releases achieved reportable levels at the fertilizer plant from 1990-2000 (EPA 2011b).

The cable manufacturer has expanded significantly since 1975 and is now one of the largest polluters in Lawrence. In 2009, the manufacturer (now Schlumberger) reported releases of 700 pounds of copper, lead, and zinc (and compounds containing the metals), 92% of which is lead and lead compounds, of which 103 pounds (16%) are released into Lawrence air (EPA 2011b). Just south of the

Figure 26. Google maps image of Penny's Concrete in Lawrence, KS. Note the sand harvesting to the east of the plant and the effluent being discharged into the Kansas River (retrieved 7 March 2011).

Lawrence Energy Center near U.S. Interstate 70 and within a mile of the Kansas River (Figure 20), the location means that lead particles likely reach the river and the nearby soils, especially those downwind (typically) in the western part of North Lawrence.

Several other potentially large sources of soil contamination include the railroads, in continuous operation since 1864 (Caviness 1988), and the coal burning power plant, opened in 1955 and expanded in 1960 and 1961 (Westar Energy 2008). The power plant burns sub-bituminous coal (Energy Information Administration 2008), which is one of the less efficient types of coal, but attractive because of its low sulfur content (Hong and Slatick 1994). The power plant also must dispose of byproducts, including fly ash, bottom ash, boiler slag, and flue gas emission control residues. Liquids are evaporated and solid wastes are stored in an on-site landfill (Bridson 2008). Solid wastes from these types of operations commonly contain trace metals, e.g., antimony, arsenic, barium, boron, cadmium, cobalt, lead, mercury, molybdenum, and selenium (RTI International 2007). Reported air emissions from the Lawrence Energy Center indicate that the coal burning plant emits about 77% of the county's mercury, reaching 172 pounds in 2009 (EPA 2011b). Mercury accumulates in water bodies, soils, the organisms that inhabit them, and in people and animals that eat these organisms (EPA 2010a).

Mercury is also a source of concern in the manufacture of cement. Lawrence houses a major concrete company, which uses cement to make concrete (Figure 26). The cement industry has been in the national news lately for releases of mercury during production (often from using byproducts from coal burning, e.g., fly ash). The EPA attempted to put in place regulation on mercury emissions from concrete manufacturers, but the U.S. House of Representatives passed an amendment on February 17, 2011 that suspended EPA funding for enforcing the regulation (Thompson 2011). With the Senate's approval of this amendment, cement manufacturers will likely maintain the option of continuing to emit mercury. Fortunately, there are no reportable levels of toxic releases by Penny's Concrete of Lawrence (EPA 2011b).

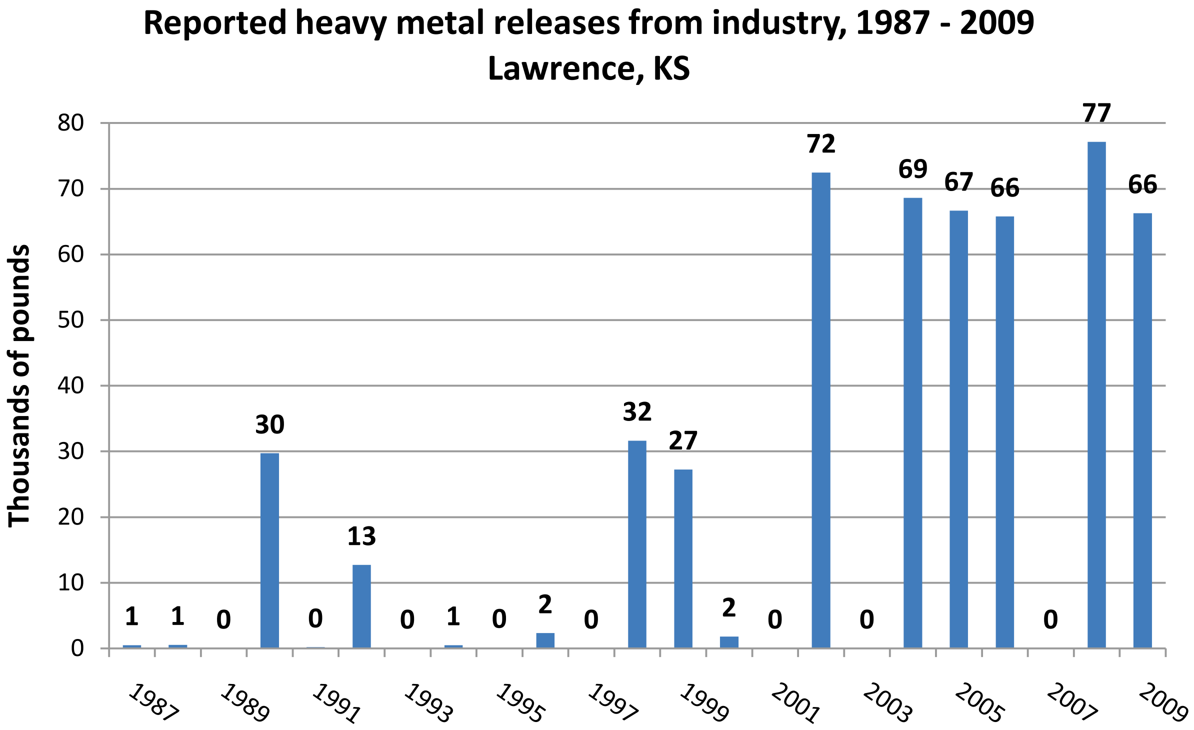


Figure 27. Frequently changing reporting requirements for the EPA's Toxic Release Inventory (TRI) has led to sporadic data, as shown here with no heavy metals reported for the same businesses that report releases in adjacent years. This can be due to alternate year reporting (after 2005) or changing minimum levels at which reporting becomes required (EPA 2011b). Totals include arsenic, copper, lead, mercury, nickel and zinc.

The public has been given access to data on industrial release of toxic substances for the past 25 years with the passage of the Emergency Planning and Community Right-to-Know Act (EPCRA), enacted in 1986 (EPA 2011b). Now available online, the compilation of these data is called the Toxic Release Inventory (TRI). While annual reporting has been constant, rules governing who is required to report, how often they report, and minimum release levels to be reported have changed frequently (EPA 2011b). As cited, the EPA's Toxic Release Inventory provides access to toxic releases from Lawrence industries (EPA 2011b) (Figure 27), as well as the fate of the contaminants (Figure 28).

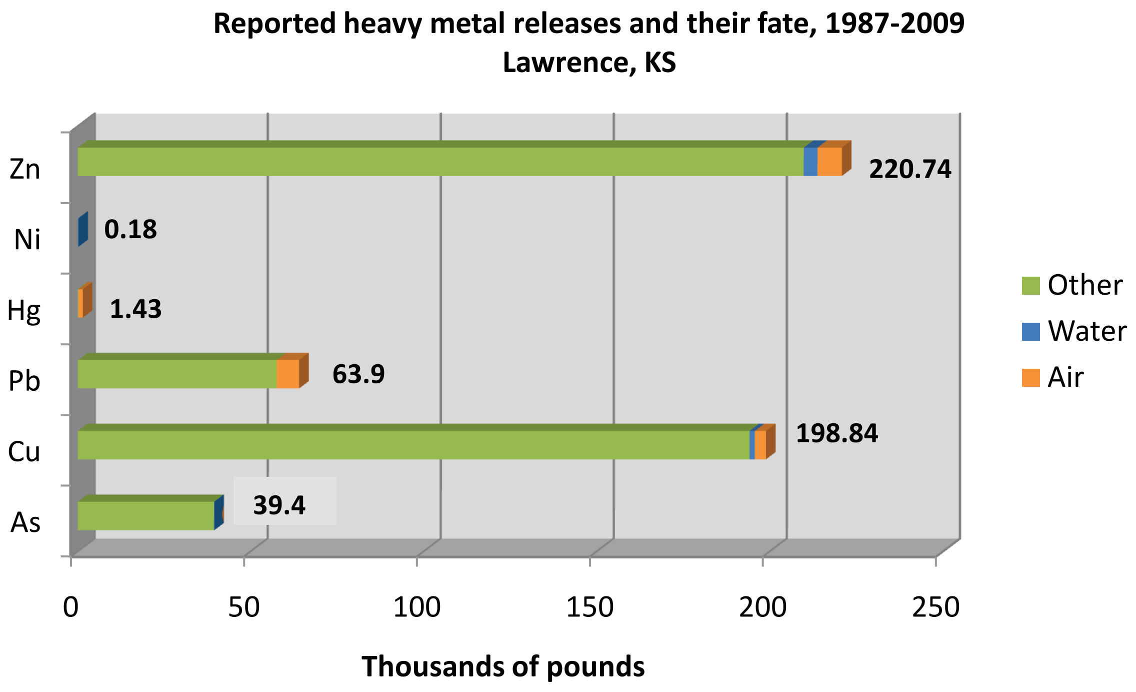


Figure 28. Out of the 10 metals of interest in this study, six have been reported as toxic releases in Lawrence. Here they are partitioned into air releases, water releases, or "other," which indicates transport to another site for disposal or storage. Totals also include compounds that contain these metals, in addition to metals in elemental form (EPA 2011b).

The fate of contaminants illustrated in Figure 28 emphasizes how a significant portion of industrial waste is either stored or transported elsewhere for management and disposal. Nonetheless, a portion of the thousands of pounds of metals released annually into the air and water accumulate in Lawrence soils over time. Additionally, waste from past activities adds to the contaminant burden of Lawrence soils.

As pointed out in the history of U.S. waste management (section 3.2), solid waste management is environmentally relevant, especially since industrial and waste management practices of the past did not sufficiently hinder contaminants from entering the ecosystem. Lawrence has two active solid waste facilities, one of which handles household hazardous waste (Figure 29). Another nine facilities in the Lawrence area have been closed, one of which was an illegal dump site in East Lawrence.

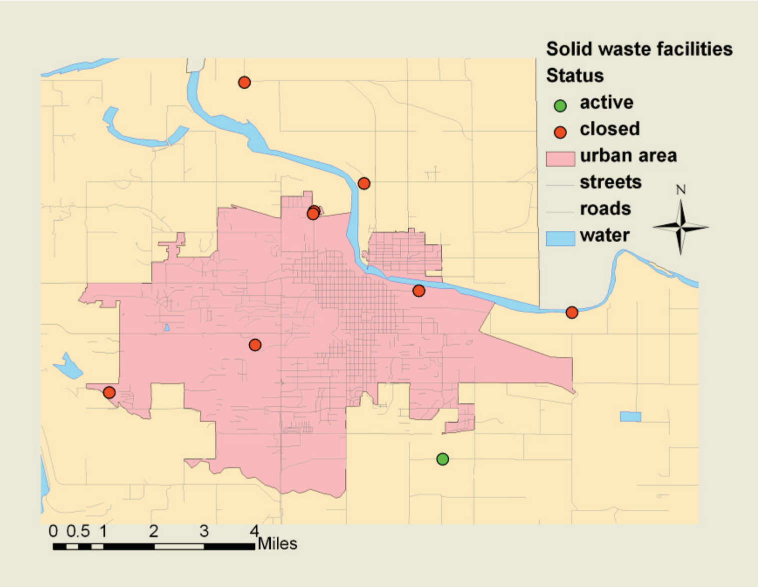


Figure 29. Solid waste facilities associated with the City of Lawrence, KS. The active municipal landfill for the city is located about 25 miles south of the city (not shown). Also, a previous city landfill that closed in 1999 is located about 45 miles to the north (not shown). The easternmost site was an illegal dump near the Kansas River. The only closed waste site that is under "post closure care" is the northernmost facility shown on the map. It was a Lawrence city landfill that closed in 1976 (Kansas Department of Health and Environment 2011). Note its upstream location relative to Lawrence.

Finally, environmental pollution can take on more subversive forms, such as via leaky underground fuel tanks. Locations of leaking underground storage tanks (LUSTs), spills of hazardous substances, superfund sites, and a list of major polluters by city, among other data are available from Homefacts.com with environmental data mined from the EPA and state websites, which for Kansas is housed at the Kansas Department of Health and Environment (KDHE). Lawrence has five superfund sites (three in residential areas), 220 leaking underground storage tanks, and reports of 18 spills of hazardous substances on the city's soils (Homefacts.com 2011). While it is unlikely that LUSTs will directly affect topsoil quality in gardens, the superfund sites (all reporting mercury contamination) and the spills certainly hold significance for current and future land use at these sites. On the other hand, LUSTs contaminate groundwater sources; hence water treatment policies and practices come into play for protection of public and environmental health. Water sources for Lawrence come from the Clinton Lake reservoir, the Kansas River, and occasionally from Kansas River sediments (City of Lawrence 2009). Lawrence has a solid record of adhering to EPA water quality guidelines, but trace metals and other contaminants occur at measureable levels due to anthropogenic activities, e.g., LUSTs (City of Lawrence 2009).

Considering the predominant south-southwesterly to north-northwesterly wind direction (AWS Truewind LLC 2008), and west-to-east flow of both rivers, both downstream areas to the east and downwind areas to the north are likely more influenced by major polluters, e.g., the coal burning power plant and Schlumberger manufacturing activities. Nonetheless, Kansas experiences frequent storms with high winds, especially in the spring and summer months, along with associated floods and tornadoes, which stir up contaminants and their typical patterns (e.g., plume), further dispersing them into other parts of the landscape. For instance, a 1911 tornado caused heavy damages to the Lawrence Paper Mill, sending parts of the building and its heavy machinery down the Kansas River (Associated Press 1954). High winds combined with loading the river with large debris provide two physical mechanisms for stirring up contaminants. Add to this the potential of chemical mobilization through flood waters, and contaminant transport can be even more significant.

As mentioned earlier, Lawrence experienced several major floods after its inception, including the floods of 1903, 1951, and 1993 (Kansas Water Science Center 2009), which certainly mixed up contaminated sediments and redeposited them. Sediments of the Kansas River contain a record of these flood events, both in its natural erosion-deposition cycle, as well as chemical traces of anthropogenic activities. Contaminants deposited in the Lawrence area likely include a mix of local and upstream sources. In fact, a study conducted by the United States Geological Survey (USGS) of contaminants in sediments from the 1993 flood of the Missouri and Upper Mississippi river basins quantified the levels of pollution, including pesticides and trace metals, among other components, many of which were from upstream sources of agricultural chemical (Schalk, Holmes and Johnson 1998) Therefore, it would be relevant for a gardener to learn if his or her plot was inundated with past flood waters, as flooding increases likelihood of contaminants in soils.

In summary, Lawrence's history of successful industries (especially those involving metals), the coal burning power plant, the city's close proximity to major transportation corridors, the frequency of hazardous substance spills and leaky underground fuel tanks, the high potential for homes to contain lead paint, and the presence of several closed solid waste facilities means that Lawrence soils have the potential to harbor contaminants from these and other sources. The metals of greatest concern based on this history include arsenic, copper, mercury, lead, and zinc. Furthermore, Lawrence's physical location between two rivers lends a higher potential of flood related mobilization and redeposition of local and upstream sourced contaminants. The additional threat of high winds and tornadoes adds to this mixing effect. A GIS-based analysis (section 4.5) of these risks aids decision making, especially in estimating risk from contaminants to determine subsequent action levels, for both gardener and policymaker.

4.4.2. Garden plot histories

Each Lawrence garden plot harbors a unique history. Certainly those located in the older parts of the city will also have longer, more significant histories of human impact. This section focuses on three gardens with longer histories and in closer proximity to potential pollution sources through time. The history of Garden Plot #1 (GP-1), on the 800 block of Vermont Street, is perhaps the most interesting, as it clearly reflects the national and local history. Garden Plot #2 (GP-2), at 9th and Pennsylvania is situated in a historically and currently industrial area of Lawrence. Finally, Garden Plot #3 (GP-3), located in North Lawrence just a few hundred feet from the Kansas River, sits in the floodplain and is near the fertilizer plant, railroad, major roadways, cable manufacturer (Schlumberger), and power plant. A brief history for the remaining seven gardens will be presented, focusing on proximity to broad pollutant sources, presence of treated wood, and the date of construction of buildings at each site, especially relevant for predicting lead levels and potential for continuing contamination.

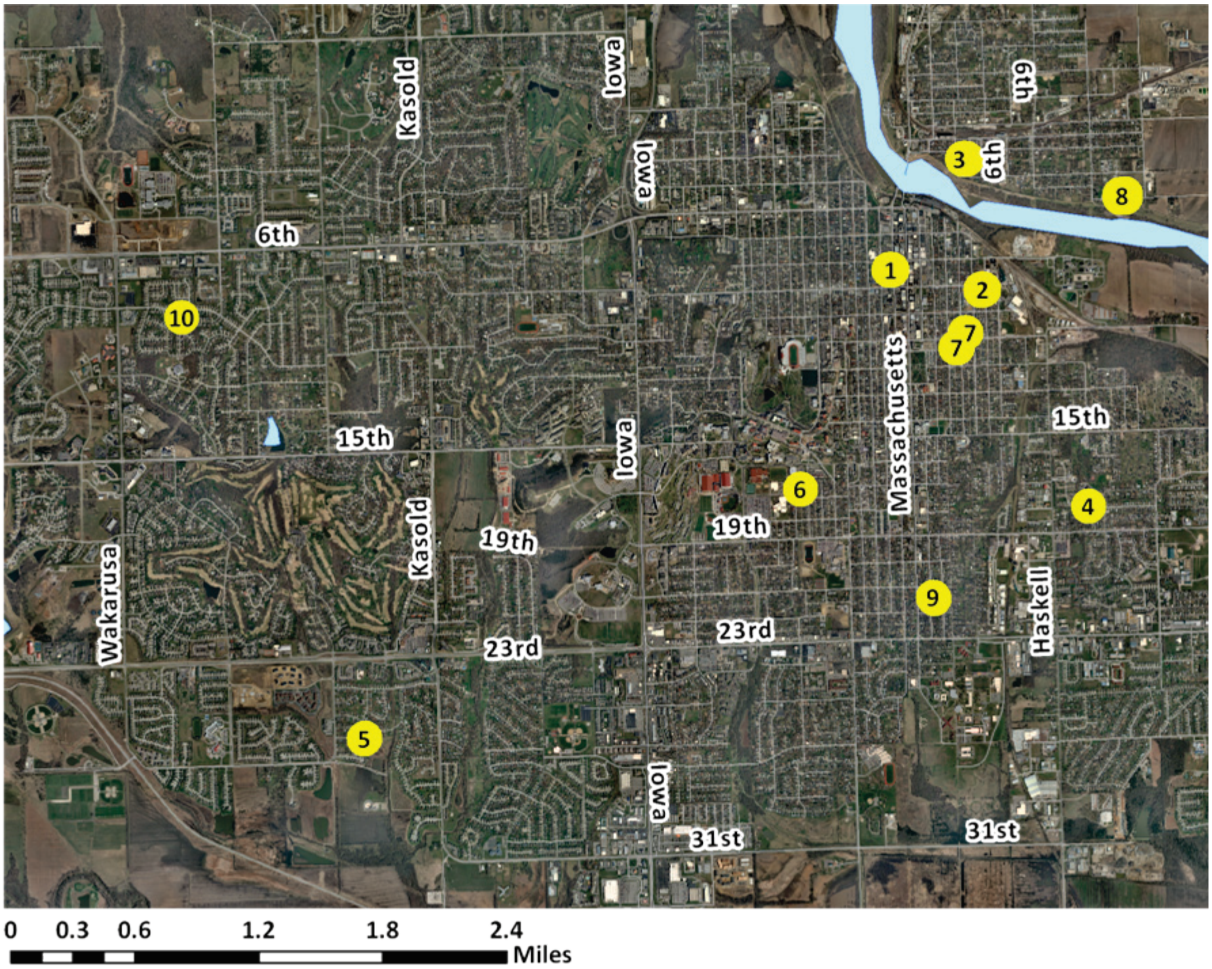


Figure 30. Locations of Lawrence, KS garden plots (GPs) in study. Satellite imagery (2009) courtesy of Douglas County.

The notable history of GP-1 (Figure 30), the Vermont Street garden, begins in 1863 when construction of a three-story brick building commenced on the west side of the street. Originally conceived to be a retail store, it soon became the Lawrence House (Figure 31), advertised to be among the fanciest hotels in Lawrence (author unknown, Watkins Community Archives). The 50- by 75-foot hotel contained 35 rooms, and was advertised to be “refurnished in the best style, and no pains will be spared to make guests comfortable” (author unknown, Watkins Community Archives). It was known as the “Women’s Rest Room” in 1919, and became vacant in 1929-1930 (author unknown, Watkins Community Archives). Redecorated and re-plumbed in 1931, half of the building was converted into a roofing company. At the time of this remodel, "rust eaten bayonets" were discovered in the back of the building (*Lawrence Daily Journal World* 1931).

Figure 31. The Lawrence House, where the Vermont Street garden is now located, is pictured here in the late 19th century. It was close to the main street, Massachusetts Street, but not on it, "so that visitors could avoid the noise, dust, and discomforts of the crowded business area" (Caldwell 1898).

History derived from the Sanborn Maps shows a fast-changing suite of neighborhood businesses over the years. In 1883, the Lawrence House was situated on the west side of Vermont Street (between 8th and 9th Streets) between small dwellings and an abandoned livery a few lots south (Sanborn Map & Publishing Company Ltd. 1883). To the north at the end of the block at 8th and Vermont Streets was a grocer and shops selling meat, upholstery, and paint. On the corner of 9th and Vermont Streets sat another hotel, and north of it along Vermont were a few dwellings interspersed with businesses included the Turkish Bath Hotel, a grain warehouse, and a furniture varnishing business. By 1889, the first building to the north of the Lawrence House housed a dentist, and the first building to the south was a “negro school.” Across the street, the corner hotel, named the “Central Hotel” had expanded to take up several lots with buggy storage, a feed yard, and sheds (Sanborn Map & Publishing Company Ltd. 1889). Also, new businesses appeared along that east side of Vermont Street, including the A.F.C. Wiedemann Pop Bottling & Mineral Water Works, the Kansas Dehorning Company, a wagon shop, a carriage house, furniture store, feed shop, and a “hearse house” (Sanborn Map & Publishing Company Ltd. 1889). Not much changed in the businesses along 8th Street at Vermont until 1897, when the map shows that a bowling alley had opened two lots north of the Lawrence House and the “negro school” was again labeled as a dwelling (Sanborn Perris Map Company Ltd. 1897). The Central Hotel, bottling company, wagon shop, carriage house, and furniture store were still present, but the Turkish Bath House was now labeled “tenements” and the dehorning company was gone (Sanborn Perris Map Company Ltd. 1897).

After the turn of the century, and perhaps partly due to the flood of 1903, many changes are noted in the subsequent Sanborn maps (1905). The Lawrence Hotel still had the dentist as a neighbor to the north, but the bowling alley building was gone, replaced by a paint shop (Sanborn Map Company 1905). The furniture store and mattress maker on 9th had become a tin shop, and the paint shop and grocer were still present. On the east side of Vermont Street, the Central Hotel and bottling company remained and at the corner of 8th and Vermont Streets. The map displays that a suite of offices and auditorium (the Fraternal Aid Building) had been added and a previous building interestingly was now labeled “geologist lodge room” (Sanborn Map Company 1905). Seven years later, the Central Hotel was gone and a new hotel had appeared just to the south of the Lawrence Hotel, labeled “King Hotel (negro)” (Sanborn Map Company 1912). The dentist to the north was gone, while the building was now used for rooming. On the southwest corner of 9th and Vermont Streets, the Lawrence City Library had been constructed (Sanborn Map Company 1912).

The next Sanborn Map for Lawrence (1918) reflects the then-recent inception of mass-produced automobiles. On the east side of Vermont Street, the 1918 map notes taxi stations, a delivery company, an auto repair shop, and an auto paint shop. Not much changed in the near vicinity of the Lawrence Hotel, other than a plumber and a cobbler starting businesses just to the south. One more significant change occurred just across the street, where a new plumbing and tin works business was added. Almost a decade later, the auto flavor to businesses had strengthened, as the long vacant area a few lots to the south of the Lawrence House had become a lot for auto storage next to a large filling station, complete with "vulcanizing & tire service," washing, and greasing (Sanborn Map Company 1927). Across the street the map notes a new ice cream factory next to an auto junk storage and near the rug manufacturer and cleaner. Numerous auto-related businesses peppered the east side of the street in 1927 along with a feed and produce company. By 1949, the Lawrence Hotel had been closed for many years; the back half of the old hotel was being used as a warehouse and the front half for rooming (Sanborn Map Company 1927, rev. 1949). Connected buildings to the south were used for selling produce and printing. The neighboring building to the north, which housed the dentist for many years, was now listed as "veterinary" (Sanborn Map Company 1927, rev. 1949).

The building that once housed the Lawrence Hotel burned down in the Christmas Eve fire of 1990, which also gutted two neighboring buildings (Taylor and Brack 1990). The buildings housed several businesses, including a printing shop, record shop, and antique and collectibles shop (Taylor and Brack 1990). In 2005, long after the rubbish from the fire was removed, the Vermont Street lot became a community garden (Oldridge 2006). Named the Kansas Mutual Aid Community Garden, it was manned by volunteers to grow fresh produce for the needy (Oldridge 2006). When the community garden effort faltered, a local gardener asked the owner for permission to continue the garden. Today, that same gardener works the plot (Figure 32), making extensive efforts to compost on-site and to add manure from a friend's goat farm early every spring (Grimes 2009).

Figure 32. Vermont Street garden in March 2009. Photo by T. Jackson.

As a result of the age of the buildings and the contents of the buildings that once sat on the garden plot, there is a relatively high potential for heavy metals to be present in the soil, including lead (from paint and pipes), copper (from pipes, printing equipment), and nickel (from Ni-alloys, e.g., antique cutlery). While neighboring land uses may be relevant, it is more likely that the building that once housed the Lawrence House protected the soil while it stood. Ironically, it later became a likely source of heavy metals when it burned down. An adjacent printing business that burned in the 1990 fire could have been a source of lead, arsenic, selenium, mercury, cadmium, and hexavalent chromium, all metals once common in printing inks (Fuchs 2008). Modern printers use different ink compositions and drying processes that make contain cobalt, copper, aluminum, barium, and manganese (Fuchs 2008).

If the building had not covered the soil for about a century, the garden plot may have been exposed to silver, gold, platinum, copper, and zinc from the neighboring dentist (Ferracane 2001), although any waste released from the dentist's activities would likely have traveled downslope toward the Kansas River, away from the plot. Upslope activities would be more likely sources of soil contamination via storm runoff. The auto storage and fuel station would have been an upslope source of pollutants for the plot, especially lead. Coal burning from neighboring businesses: the hotels, factories, and processing facilities would have been a source of mercury in the soils. The paint and tin shops were downslope, but there was one period when a plumber was located just uphill to the south of the lot. Metals from plumbing activities around 1918 would likely have contained ample lead and some zinc (Dunn 2008).

Based on the site-specific land use history, especially considering the building as a protector from then source of contamination, metals of concern that are most likely to be present in GP-1 are lead, zinc, and copper. However, because the current land use involves adding large amounts of organic matter, contaminants will have been diluted, especially in the upper 10 cm, where tilling and mixing in of organic matter occurs.

Garden Plot #2 (GP-2) (Figure 30) also got its start in gardening as a community garden, and now maintains that status as the Eastside Community Garden (Figure 33). Once a gravel parking lot for boats in disrepair, the City of Lawrence granted use to the neighborhood for a community garden along with a load of topsoil, spread over the gravel (Swift 2008). Established in 2003, the garden is comprised of 19 individual plots, separated by railroad ties or other scrap wood with grassy walkways and a central communal herb garden (Mortinger 2009). The back of the lot houses a shed for tools, picnic tables, and a compost area, including one slot for hauled in City compost (Swift 2008).

Figure 33. Eastside Community Garden on Pennsylvania Street in the early spring of 2011. Photo by T. Jackson.

A land use history based on the Sanborn maps reveals that the garden may be influenced by a rich history of industry in Lawrence's East Side, especially because of its proximity to the railroad. In 1883 the garden lot was empty. One and one half blocks northeast was the railroad passenger depot and one block north sat the Kansas Fruit Vinegar Company (Sanborn Map & Publishing Company Ltd. 1883). The adjacent lot to the north gained a building by 1889 and a half block to the north was the Hauber Brothers Cooperage (barrel making) near the fruit vinegar company (Sanborn Map & Publishing Company Ltd. 1889). The "gas works" had been built near the river and railroad at 8th and Pennsylvania Streets, with large storage areas for coal and some sizeable areas marked "coke." The neighborhood also included McFarland's Planing Mill and the Reedy Brothers Feed and Cider Mill. At this time the New York School had been built as well as several churches and homes in the surrounding area, especially toward the west, closer to the center of town. By 1905 a building was noted on the

Sanborn map near the location of the current community garden. More homes had been built, especially toward the south on Pennsylvania Street. To the southeast, near McFarland's Planing Mill, there was now the Kaw Valley Canning Company. To the north, the fruit vinegar company had changed to W.H. Pendleton, Elevator, & Vinegar Works next to an ammunition and fireworks business (Figure 34). The gas works label changed to Lawrence Gas, Fuel, & Electric Light Company and a grocery store at 8th and Pennsylvania Streets housed a fire proof banana room. To its south sat a "wooden ware, matches, and barbed wire" store (Figure 34).

From 1912-1918, the garden plot area still showed that the same building and the businesses of 1905 were still present, although some had changed owners or, at least, names. The gas plant was no longer operational in 1912, and the large coal shed was now labeled as a repair shop. The coal shed had been vacated and by 1918 and the area labeled as the Citizens' Light Heat & Power Company. Closer to the garden plot, across 9th Street on Pennsylvania was the Standard Oil Company, and just east of this was a junk yard. Notable changes shown on the 1927 map include addition of new businesses, e.g., a poultry and egg shipping facility, poultry warehouse (with cold storage), and a "candling" facility (for quality checks on eggs). Just to the east, near 9th and Delaware Streets, another bulk oil station had been added with 50,000 gallons of on-site oil storage capacity. The oil company and junk yard just across 9th Street on Pennsylvania expanded operations and were now called the Standard Oil Company Bulk Oil Station (including an area for oil and gas storage) and "auto wrecking and junk yard." The 1935 map updates indicate that the auto wrecking and junk yard facility performed radiator repairs and included a pipe shop. The corner of 9th and Delaware Streets still included the bulk oil station and to the south there was a lumber storage yard.

Of all the fossil fuel related industries in the area, perhaps those of greatest concern are near 10th and Delaware Streets, just two blocks away. According to the 1927 map last updated in 1935, a coal yard next to a canning facility, a National Refining Company, and Richardson Oil Company sat near the railroad tracks to the east. The junk yard had expanded significantly, taking up much of the available space toward the railroad tracks. Throughout the decades for which Sanborn maps exist, coal storage near the railroad within a few blocks of the site may indicate a historic and ongoing source of coal dust, a source of trace metals.

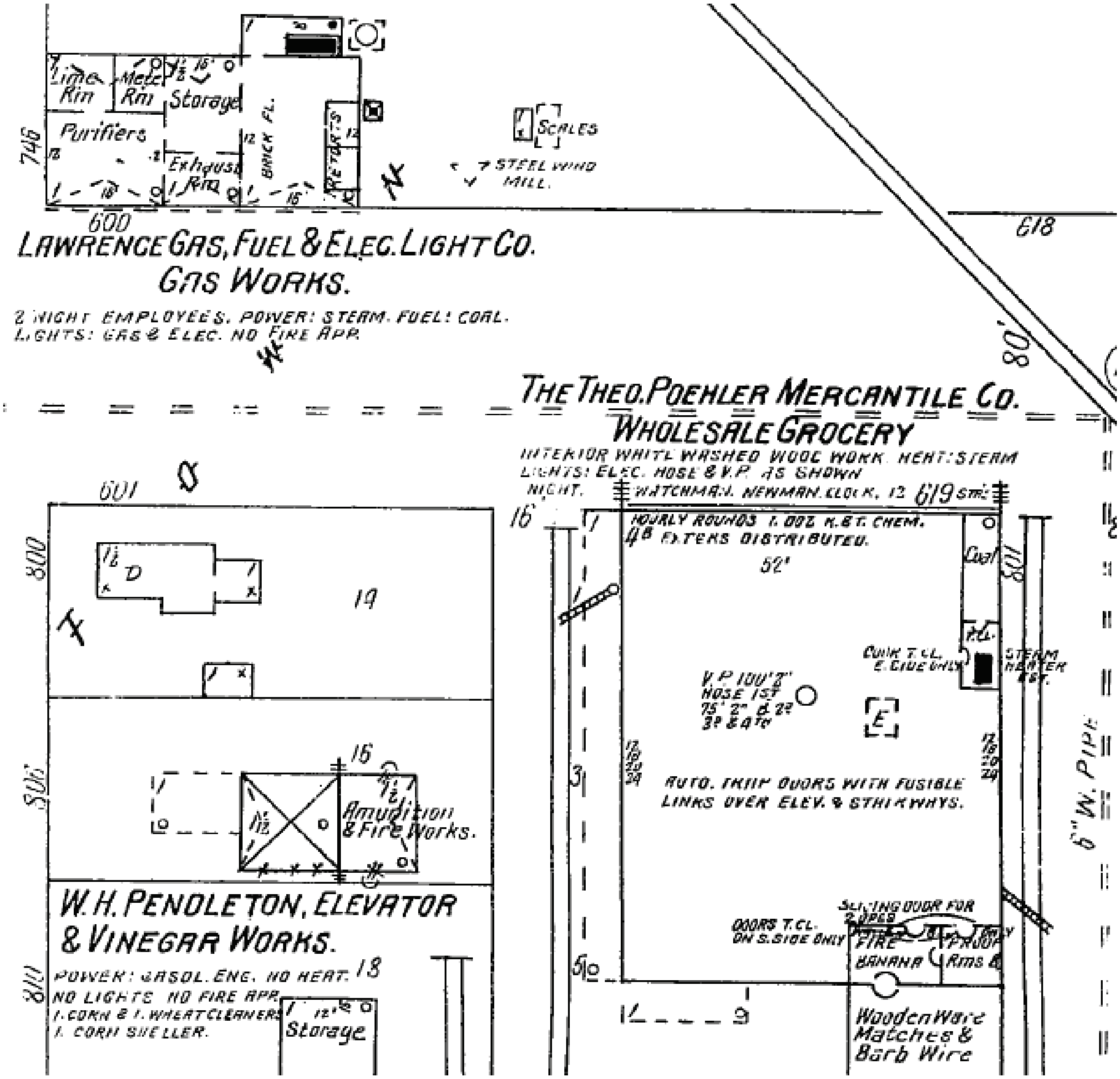


Figure 34. A portion of a Sanborn map from 1905 near 8th and Pennsylvania in Lawrence, KS. The parallel lines at the top right corner of the map mark the location of the railroad (Sanborn Map Company 1905).

The likelihood of metals or other toxins being present in this garden plot's soils also reflects its on-site history, much like the Vermont Street garden. The Sanborn maps show a building located adjacent to the garden lot, but no permanent structure is located there now. One of the current gardeners reports that the building had been demolished in recent years (Swift 2008). Also significant for this lot is the potential for deposited contaminants from past flood events, storm runoff, and aerial sources for past and present industrial and transportation corridors. Its recent land use as a boat parking lot means that there is a high likelihood that fuel, paint, and other toxic materials entered the soils there. Mr. Swift, a community garden member who requested soil testing, knew of the recent history, but was unsure whether the City of Lawrence removed the gravel from the boat parking lot before adding the layer of soil (Swift 2008). Soil testing revealed a layer of gravel at a shallow depth, as shallow as 5 cm in some beds. Boat fuel, oil, batteries, and antifouling bottom paints may contain toxic metals, especially lead, zinc, and copper. Considering the boat parking, destruction of a building at the site, proximity to fossil fuels and the junk yard and auto salvage, metals that are most likely present include lead, copper, and zinc. It is possible that cadmium, chromium, and arsenic will also be detected due to treated wood at the site and fossil fuel combustion, coal dust, and industrial processes near the site. Each bed within the community garden has undergone differing gardening techniques: some gardeners have added compost; others have used commercial fertilizers, etc. It is expected that there will not be continuity in results from plot to plot, both in basic their physical characteristics and in heavy metals detected.

Garden plot 3 (GP-3) differs considerably from the first two sites because of its soil type, history of flooding, no history of a building on or near the garden site, and close proximity to some of the highest polluters in Lawrence. Named the North Lawrence Community Garden, it is the largest of the ten gardens in the study. It is nestled in a residential neighborhood just north of the Kansas River. For this low lying area, both upslope and upstream land uses can be significant contributors to soil contamination, so these will be the focus of the Sanborn map study.

Starting with the 1883 Sanborn map, the area was vaguely labeled with four dwellings and three stables. Just upslope, on the block to the north (5th and Locust Streets), three hotels dominated the landscape. On the nearby river bank to the south sat a grain warehouse. The railroad runs on a north-south axis just about a block and a half to the east, then makes a quick turn to the west, so it is also within two blocks of the garden plot to the north. By 1889, the largest of the hotels at 5th and Locust Streets had gone out of business; consequently, the main building was vacant and some of the other areas had been filled with a billiards room, meat seller, and grocer (it was a barber in 1897). This area also housed a coal shed with scales, presumably for selling coal to homes and businesses. More homes appear on both the 1889 and 1897 maps, many on Elm Street, which is just to the north of the plot; alley access to Elm Street homes comes within a few feet of the plot. Upstream businesses include a vinegar and cider works, broom factory, and ice houses. By 1905, the status of North Lawrence buildings showed the detrimental effects of the 1903 flood. Only one business remained on the once busy strip on Locust. One building was labeled “tenement, old and very dilapidated;” the remainder of buildings were vacant. Upstream, the vinegar works and broom factory had persisted. Remarkably, the 1905 and 1912 Sanborn maps display the extent of the 1903 flood, which extended into North Lawrence much farther in the western portion, sparing the homes on Elm Street just north of the garden plot (Figure 35). Fortunately, a sizeable coal yard between Bridge and Rhode Island streets on the north side of Elm Street just barely escaped inundation with flood waters (Sanborn Map Company 1912).

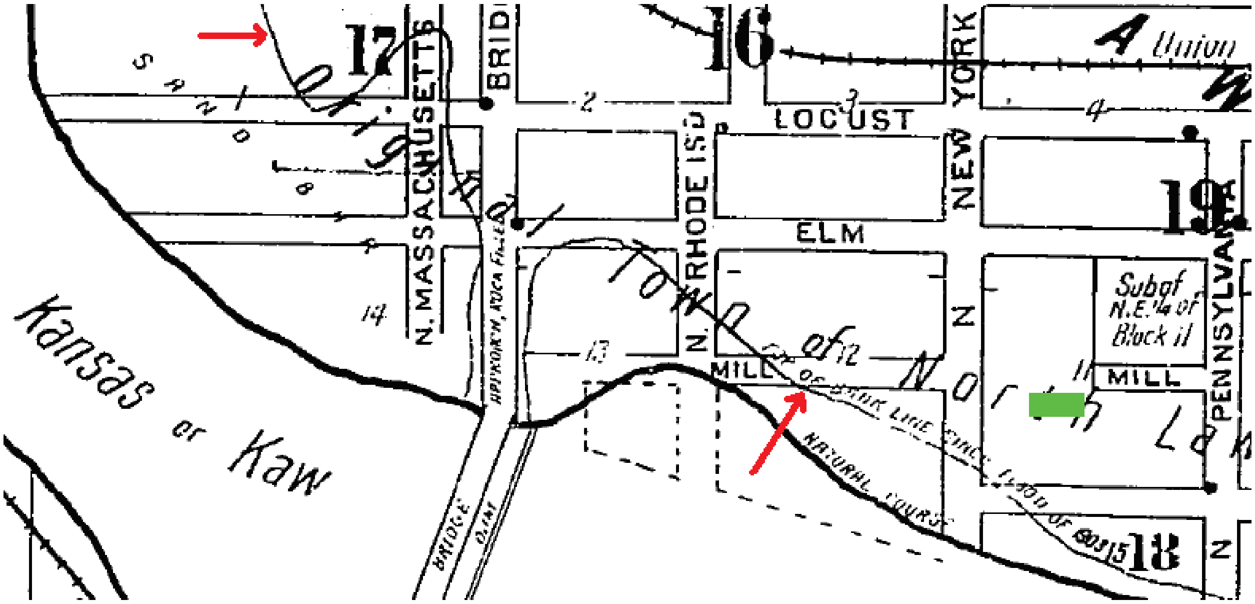


Figure 35. Portion of a 1905 Sanborn map depicting North Lawrence (1905). The green area approximates the current location of the North Lawrence Community Garden. Red arrows point to the line depicting the extent of the 1903 flood. Based on the scale of the map, flood waters came within 20-25 linear feet of the garden plot.

By 1918, the house on the west end of the lot with the community garden had been constructed, but few other notable changes were marked. Most of the nearby buildings, including those on Locust Street, were now dwellings. The 1927 map, by contrast, illustrates more emphasis on freight and coal in near-railroad infrastructure, whereas before the landscape had been dominated by a passenger depot and grain elevator (built in 1912). The most notable map update for 1935 includes addition of one more coal company near the railroad (Sanborn Map Company 1927, rev. 1949). No flooding occurred at GP-3 in the 1903 event (Sanborn Map Company 1905) or during the 1993 event (Hanson 2011), but it may have flooded in 1951, the most extensive of the three floods (Juracek et al. 2008).

The site specific history of this plot reveals less potential for discrete sources of heavy metal contaminants or from deposition of contaminated sediments. Its relative position to the coal burning plant, interstate highway, and Schlumberger, and downslope and proximate location to the railroad and old coal yards add up to more potential from storm water runoff than aerial sources of related contaminants. Considering that the garden sits outside of the main contaminant plume (Figure 41), it likely has escaped aerial contaminants from the coal burning power plant and the Schlumberger company, including lead, copper, mercury, and zinc (EPA 2011b). However, runoff from coal yards would likely contain trace amounts of cadmium, chromium, lead, and nickel, therefore these metals are expected to be detected in higher levels than in an upslope soil. Since the North Lawrence Community Garden is not directly downslope of the locations of the old coal yards, but it is near railway and roadway transportation corridors, the metals most likely to be detected at elevated levels include lead, copper, and zinc.

Similarly, just to the east of the North Lawrence Community Garden (GP-3), sits GP-8, a strawberry patch at the edge of town that periodically may have been under agricultural production in the past. While the area is not included on a Sanborn map of Lawrence until 1927, it appears to be outside of the flood zone of 1903 (Sanborn Map Company 1905). Because of its nearby location to several transportation corridors, it may also have elevated levels of lead, and, potentially, zinc and copper. GP-8 levels are expected to be less than GP-03, which is closer to the pollution sources.

Near GP-1 in Old East Lawrence, GP-7 is a communal garden at 1113 New York Street worked by several individuals from the area, in addition to an ancillary location just to the north. The primary location is the former residence of Bill Hatke, a legendary local gardener whose friends have devoted a website to his memory (Lassman and Bentley 2009). Mr. Hatke built a house on the lot mostly from scrap materials after the previous house burned down (Alsgaard 2009). Mr. Hatke apparently utilized dubious land management techniques, e.g., diverting storm runoff from the alley into a pit near his backdoor, where he would enjoy long soaks on hot summer days (Alsgaard 2009). Mr. Hatke died of pancreatic cancer in 2007 and now his home is used by communal group of people sharing responsibilities for upkeep and gardening (Alsgaard 2009). The gardeners use composting (including human waste) to increase the quality of the clayey loam soils typical of the area (Alsgaard 2009). Their concern about toxins in the soil may be founded, as the building that burned down likely had been constructed in the period 1883-1889 (Sanborn Map & Publishing Company Ltd. 1883, 1897) when lead was common in plumbing and paint. Contaminants transported to the garden soil from the alley runoff could have contained any combination of the ten metals of interest in this study. Because of this land use history, all metals are anticipated to be detected at higher levels than other gardens in the study.

Garden plots 4 and 9 (GP-4 and GP-9) sit in neighborhoods that are considered to be parts of East Lawrence. The housing development for GP-4 was constructed after World War II, meaning that most of the homes, including the house on the lot with GP-4 are small, ranch-style homes on small lots built in the mid 1950s. The neighborhood of GP-9 appears on the Sanborn Map in 1912, although it remains unclear which dwellings have been built as no details are presented, other than a phrase noting six buildings on the block. No buildings were added for the 1918 or 1927 maps, although updates for the 1927 maps completed in 1935 show that all the homes currently on the block had been constructed. Recall that two small plots are included in GP-9, both very close to adjacent homes, both of which are likely sources of lead paint. The small patch at 2116 New Hampshire Street during sampling appeared to contain higher levels of organic matter due to its darker color, and since the gardener had added compost several years in a row (Kern 2009). The next door garden, located only a few feet away and separated by a concrete driveway at 2120 New Hampshire Street, also contained added compost, but it had been added only recently (Kern 2009). Garden plots at GP-4 and GP-9 have had few modern opportunities for aerial sources of contamination other than road traffic until the 1970s, but they share lots with homes that likely contain lead paint. Because the plots at GP-9 are closer to the homes, it is expected that lead levels will be higher here than at a comparable rural soil, although the small plot where compost has been added may not show as high a signal.

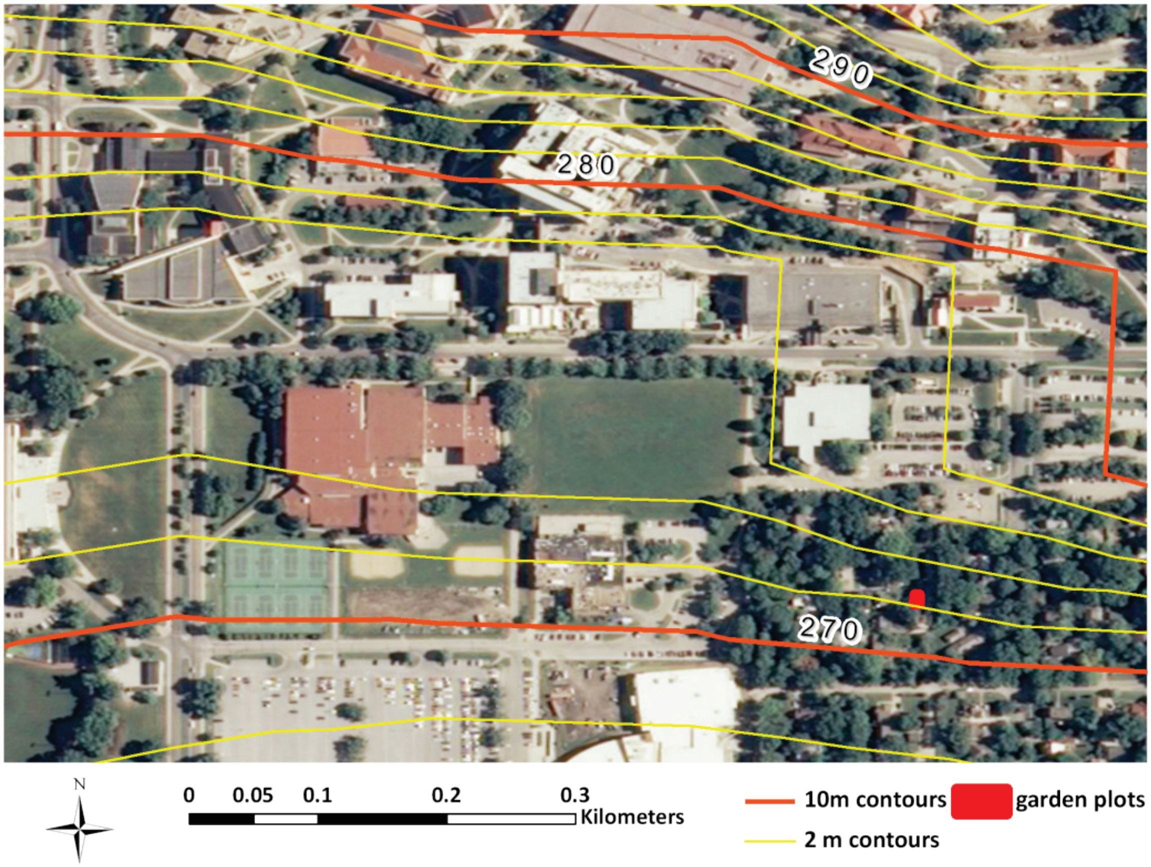


Figure 36. GP-6 is downslope of the university campus, making stormwater runoff a potential source of soil contamination, especially because of the direct upslope location of parking lots. Satellite image courtesy of Douglas County, Kansas. Contours calculated from a digital elevation model (USGS and EROS Data Center 1999).

GP-6 sits downslope of the University of Kansas campus (Figure 36). The owner of GP-6 noted that in previous years, she had difficulty getting any plants to grow in her front lawn (Roth 2009). She suspected that contaminants from an upslope construction site on the campus may have played a role in this problem. The area sampled includes a portion of Ms. Roth's backyard garden, near a composting area and wooden fence where she grows tomatoes. The University appears on the 1905 Sanborn Map, but there were no dwellings on the block where GP-6 is located until four are vaguely noted, but not mapped, in 1912. The same is true on the 1918 and 1927 maps and the 1935 update. Automobile fluids in conjunction with tire and brake wear can be sources of lead, copper, zinc, and cadmium (Wu et al. 2010). Because of its landscape position, approximate age of the home, and proximity to potentially treated wood posts and fencing, elevated levels of arsenic, cadmium, copper, lead, and zinc are predicted. This garden has also been managed with the addition of City compost; as a result, these signals may be weakened by dilution, although the tilth and color of the soil varied somewhat (as noted during sampling) from the first to the last sample location.

Garden plots 5 (GP-5) and 10 (GP-10) are situated in the southwestern and western parts of Lawrence, respectively. Both of these areas contain newer housing, with the West Lawrence location (GP-10) in the newest development in the study. GP-5 had not been tilled when samples were taken, and the gardener added soil and compost after sampling. The house was built in 1981 and was remodeled in 1999-2000 (Williams 2011). A new wooden fence had just been built previous to sampling, but it was unknown as to whether the wood was treated with arsenic-based chemicals. GP-10 also sits near a treated wood deck and a portion of the sampled area was in a raised bed surrounded by stones, while the remaining area sampled was in the untilled lawn. A soil sample was also collected near a children's play area characterized by a wooden play structure. Both GP-5 and GP-10 sit at a relatively safe distance from aerial sources of contaminants and newer construction alleviates risk from lead paint. However, arsenic remains a potential concern due to the incidence of treated wood near both gardens and the plausibility that the plots had been historically used for agriculture when arsenic-containing pesticides, including lead arsenate, were prevalent.

Geographical Information Systems provide a way to visualize these histories, along with an environmental analysis of the region, to help make predictions about where, what, and how much of certain metals may be present at a location. An environmental GIS-based analysis for Lawrence comprises the next section, followed by a table that summarizes predictions for the likelihood of certain metals to be present for each garden.

4.5. Environmental analysis with Geographic Information Systems

A Geographic Information System (GIS) was built for the Lawrence study area and for each garden. The Lawrence GIS includes county-level layers on soils (NRCS 2008), elevation, roadways, urban areas, rivers, water bodies (ESRI 2002), depth to flood (Kanas Applied Remote Sensing 2009), satellite imagery (courtesy of Douglas County), and locations of gardens and soil series type locality sample sites. In addition, some of the more significant current and historic sources of environmental toxins are included. Historic land use maps from the Sanborn Fire Insurance Company were digitized for areas of Lawrence where the gardens in this study are located. By taking into account landscape position (e.g., elevation relative to potential contaminant source or downwind position), even nearby land uses may be a significant source of environmental toxins in a garden. Because of this factor, a broad scale look at the land use history is important, if not equally relevant to the history of a specific lot where a garden is now situated.

Each garden GIS was designed to help visualize garden size, type, and location, soil sample sites, and test results. Site specific historic land uses derived from the Sanborn maps provides a temporal aspect to each garden site, illustrating how land use changed through time, culminating in the snapshot of land use captured in a satellite image from 2009. Regional GIS maps and garden maps, including sampling schemes, are provided throughout the following sections.

To assess risk of contaminant deposition from past flooding, maps of flooding extent are often available from local or state governments or from historic maps, e.g. the Sanborn Maps. When the extent of past flooding is not available, it is reasonable to look at current flooding potential based on topography, although past flood events usually change the surrounding landscape of a flooded river. The assumption that bank elevation and surrounding topography have not changed significantly is reasonable since most gardens will not be located at the river bank. If a garden were located there, the assumption should be made that the soil contains potentially contaminated sediments.

Figure 37 can be used to estimate potential from past and future floods in contaminated sediment deposition on each garden plot. While a few gardens on the south side of the Kansas River may be inundated by an extreme flood event, the North Lawrence garden sites are much more likely to be flooded in the future due to their lower "depth to flood" (Figure 37). As previously mentioned, the flood waters of 1903 and 1993 did not reach any of the gardens in this study, yet came very close to the North Lawrence Community Garden (GP-3) in 1903 and may have flooded it in 1951.

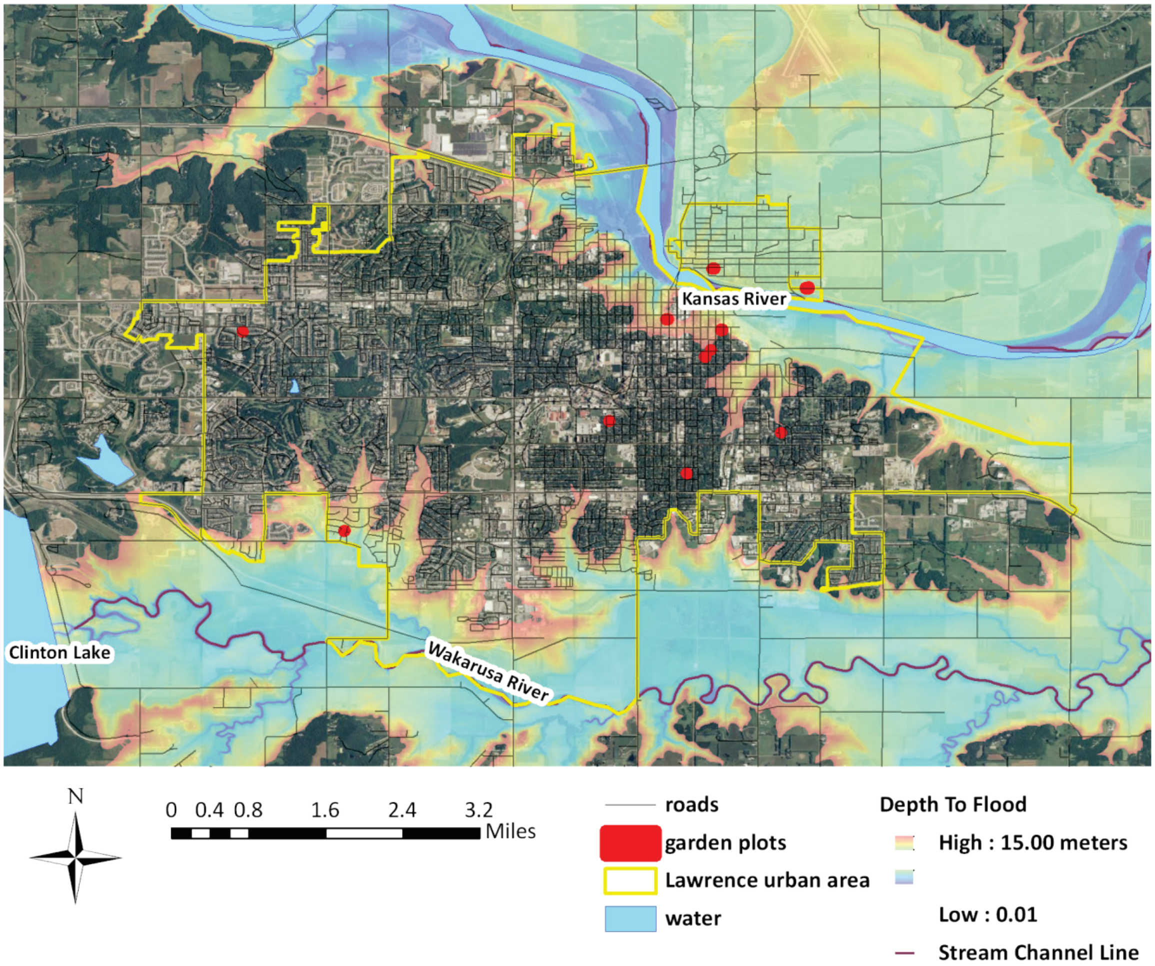


Figure 37. Flooding potential estimated from the Kansas Applied Remote Sensing and the Kansas Biological Survey "Depth to Flood" layer in relation to garden plot locations (2009).

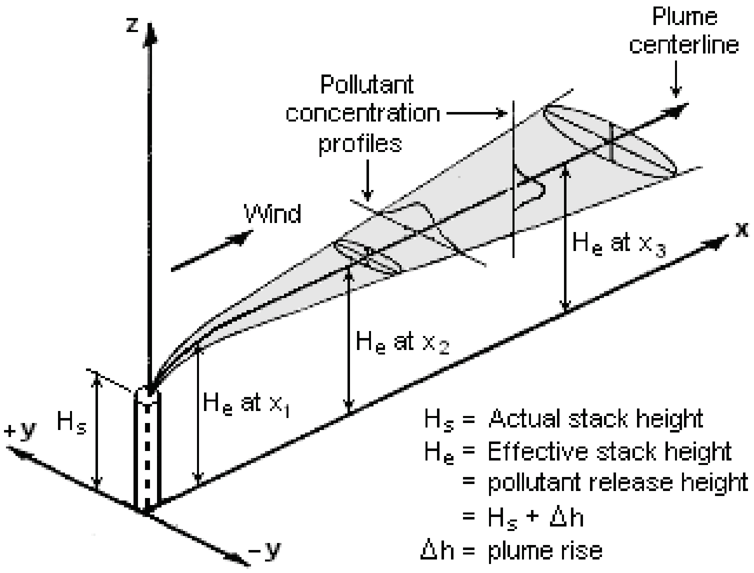


Figure 38. Conceptual model of a Gaussian dispersion model for estimating plumes from a point source (Beychok 2007).

Contaminant transport and deposition from air pollution is less straightforward. A simple methodology for making a fair estimate of soil pollution extent from an aerial point source (e.g., a coal burning plant's stack emissions) can be made by taking into consideration wind speed, wind direction and frequency (percent from cardinal direction). A more detailed modeling effort requires additional information e.g., stack height, effective height (i.e., height plume extends above the stack), buoyancy of the effluent, and air density (Figure 38). The EPA offers a list of preferred models for studying and modeling plumes from a variety of aerial pollution sources (EPA 2010c). Even within the more complex models, wind power and directional time are the strongest predictors of contaminant plumes (Figure 39). For the purposes of this study, a prediction of the direction and extent of air pollution (and, therefore, the potential pattern and extent of soil contaminants) is made based on wind data from AWS Truewind (2008) for Lawrence, KS (summarized in Figure 40).

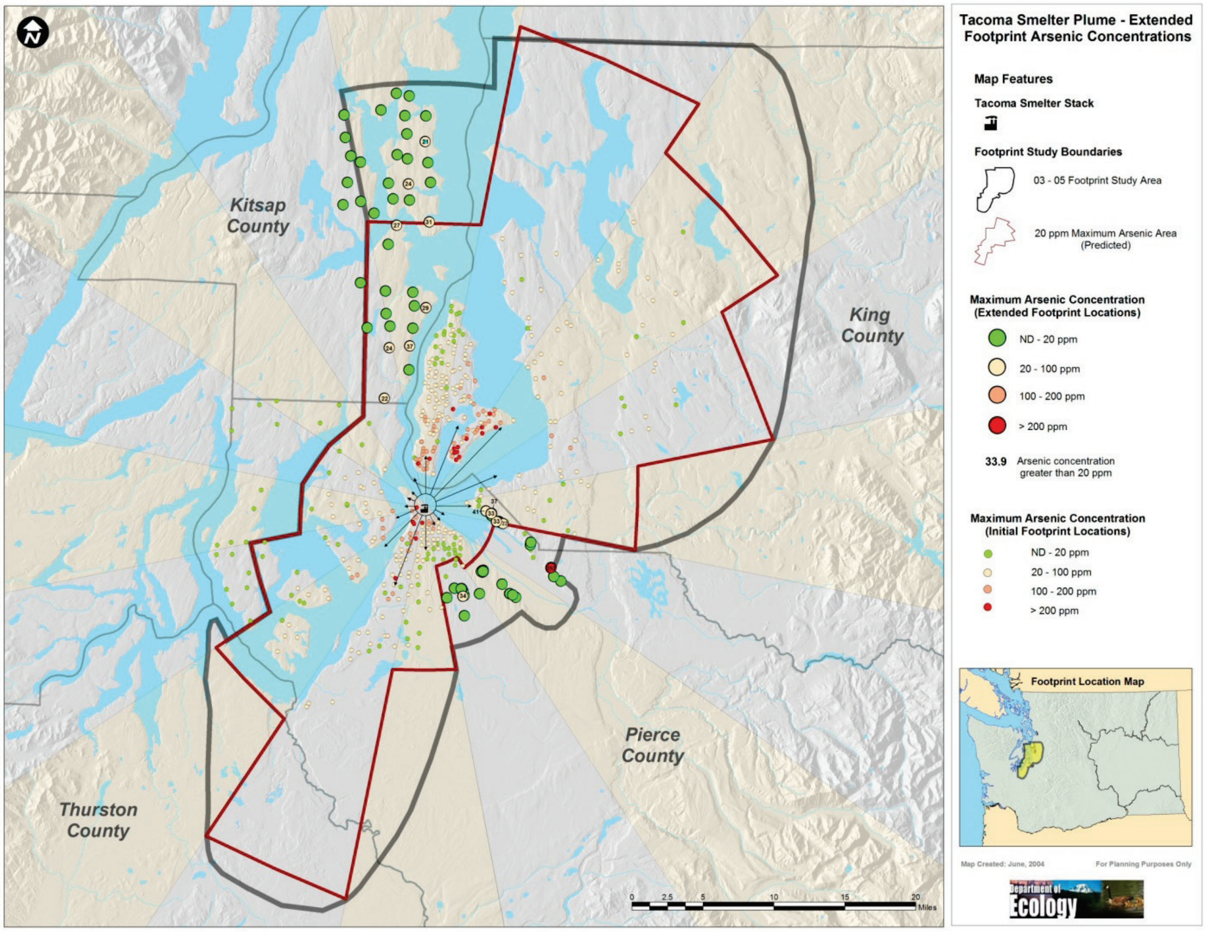


Figure 39. Footprint map of arsenic plume from Tacoma smelter (State of Washington Department of Ecology 2004). Note the correlation between wind speed and direction (as illustrated by scaled directional arrows) with the arsenic contamination pattern and extent.

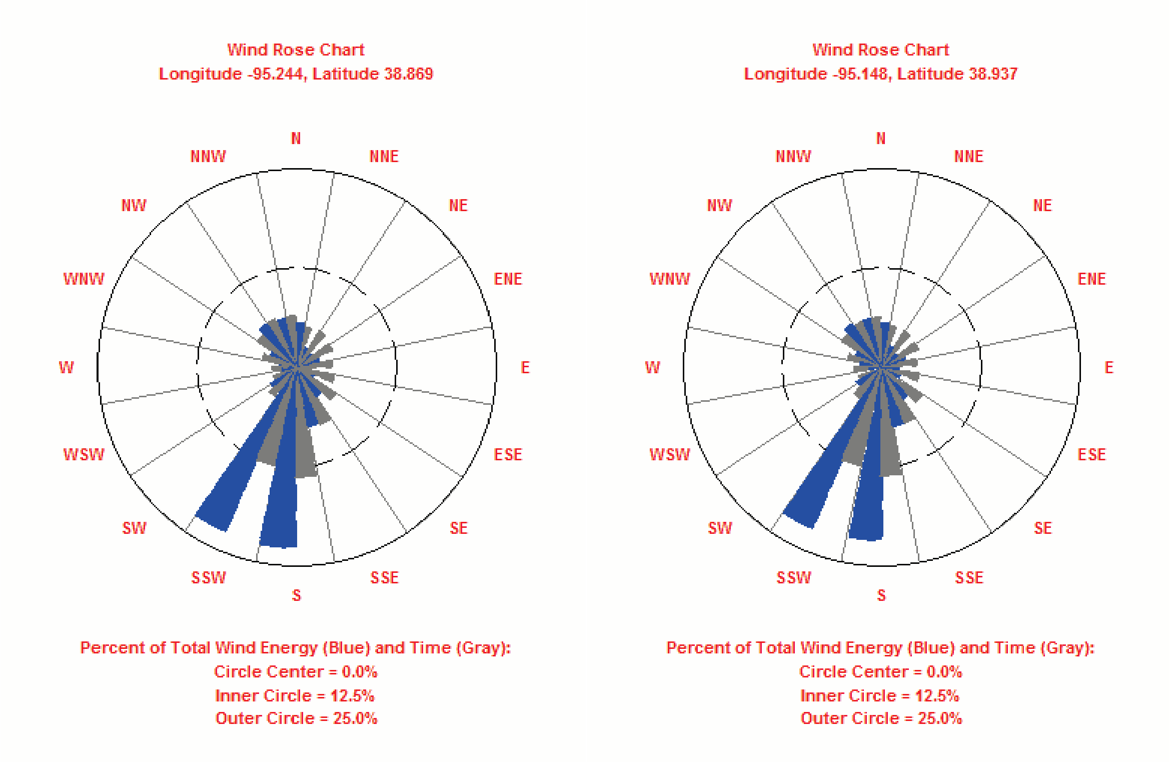


Figure 40. Wind roses for Lawrence, KS area. Winds typically blow from the S/SSW direction with the greatest energy (including the stormy seasons) and time (AWS Truewind LLC 2008).

Plumes in Lawrence extend primarily to the N/NNE direction from the main sources of air pollution, including the Lawrence Energy Center and the Schlumberger Company (Figure 41). Historically, there were other sources of air pollution, e.g., the Kimball Brothers' Foundry, but the effects were more localized since stacks did not extend high into the air (Figure 41). The plume pattern and extent displayed in Figure 41 as "wind factor" was estimated by the equation

(2 * Frequency) * Speed * 0.1 (scaling factor) = approximate extent of plume

for the cardinal directions. This formula simply weights frequency at twice the rate of speed to characterize the likeliest area containing the densest contaminant plume, a sort of contaminant rose rather than wind rose. The scaling factor is based on the assumption that most pollution occurs within one mile (1.6 km) of source stacks (Pullen et al. 2005). By keeping the calculation simple, the method can be used by an individual wishing to estimate levels of potential contaminant fallout from a point source of air pollution. Wind factor calculations extending more than one mile were included on the map as scaled arrows. While none of the garden plots and very little of the Lawrence urban area appear to be influenced by the extent of the mapped plume, these sources of air pollution intersect the nearby Kansas River, which can transport contaminants through ground and surface water, both sources of municipal water in Lawrence.

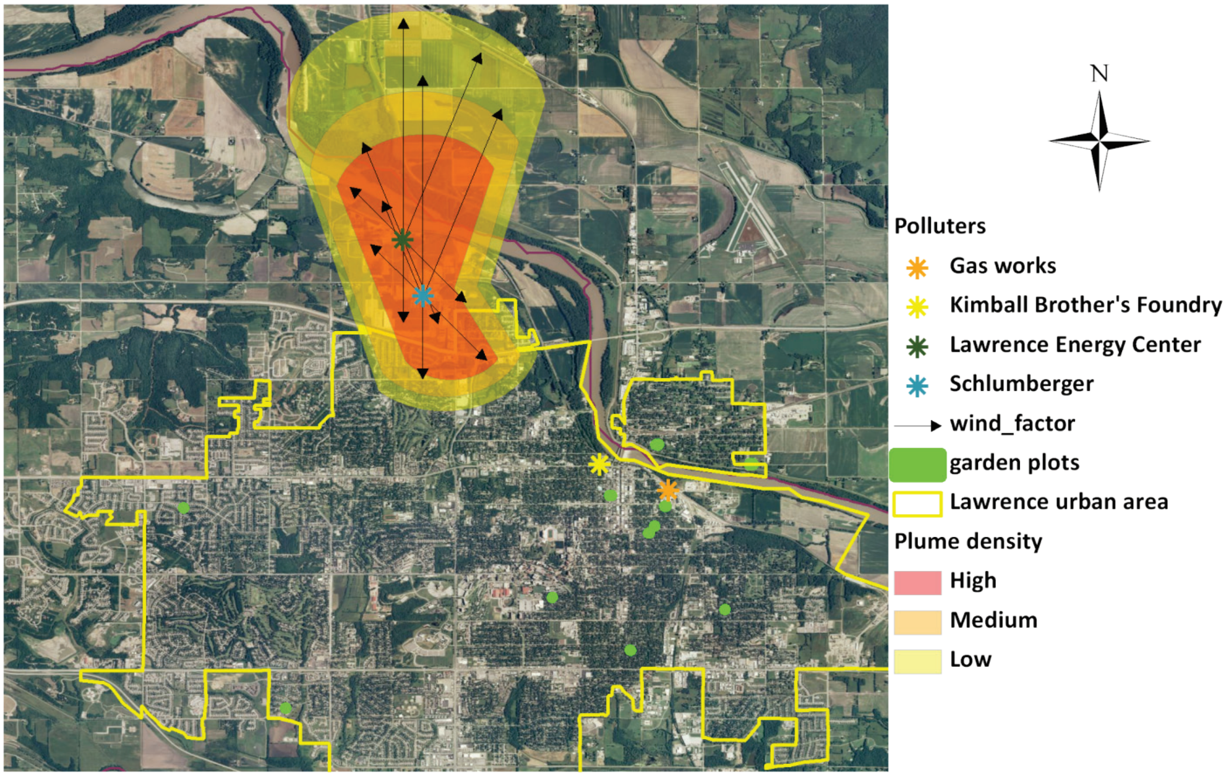


Figure 41. Estimated contaminant plume from the two main point sources of air pollution in Lawrence, KS. Plume pattern and extent based on wind speed, wind direction and frequency data. Most of the Lawrence urban area is generally unaffected, at least directly, by these air contaminant plumes, including the gardens in this study. Scale of the map is approximately one inch to one mile.

Finally, other significant sources of air pollution and subsequent contaminant deposition on soils, plants, and other surfaces include roadways and railroads. As discussed in Chapter 3, decades of lead additives to fuels created high levels of soil lead that has persisted throughout the U.S. despite the phasing out of leaded gasoline from 1973 to 1996 (EPA 1996). The section of U.S. Interstate 70 (I-70) west of Topeka toward Lawrence was the first stretch of interstate highway constructed under the

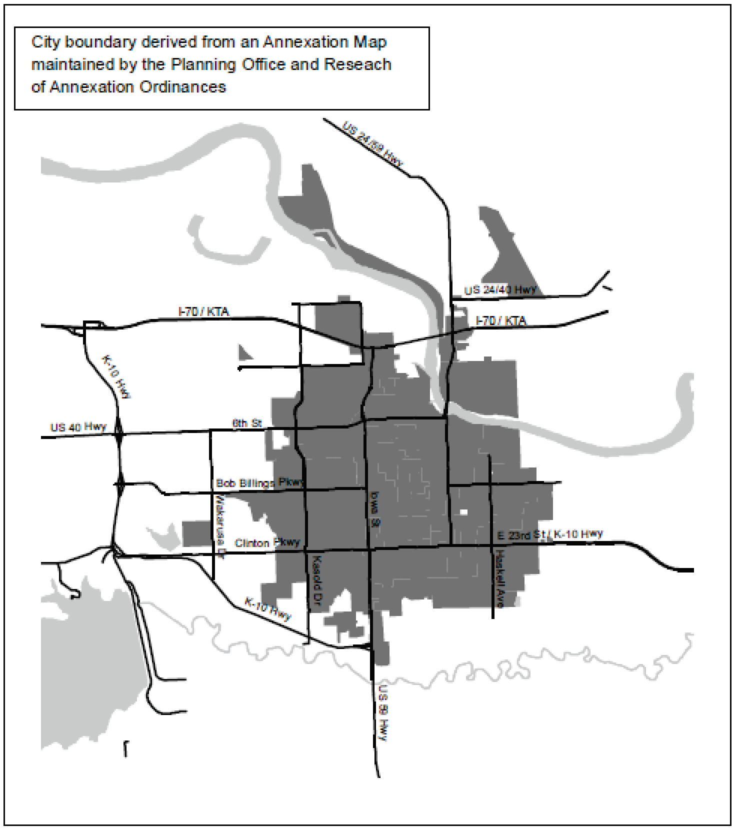


Figure 42. Annex map of "Lawrence Before 1980" used to eliminate more modern roadways that would not be significant sources of lead from gasoline (City of Lawrence 2007).

Federal-Aid Highway Act of 1956 (Weingroff 2010). As a result, for up to forty years, exhaust from automobiles traveling along I-70 deposited lead on the surrounding landscape. Of course, automobiles became a significant part of the Lawrence scene before this period, surging in the 1920s, as depicted in businesses noted on Sanborn maps of the period (Sanborn Map Company 1918). Lead additives were blended with gasoline starting in the 1920s (EPA 1996); the main roadways in Lawrence would have been a source of lead in adjacent soils since this time. To characterize the potential for lead pollution from leaded gasoline, a buffer of the main roadways was constructed. Since a recent study demonstrated that effects from road traffic in an area with similar topography caused elevated levels of lead, cadmium, and copper beyond 300m, this buffer distance was used for these metals (Wu et al. 2010). Traffic elevates levels of zinc up to 200m, therefore a separate buffer was created for zinc (Wu et al. 2010). Most of the lead from gasoline combustion would have accumulated before 1980, so an annexation map for Lawrence for this period (City of Lawrence 2007) is used to eliminate more modern roadways where leaded fuel would not have been a source of contamination (Figure 42).

The railroad that passes through Lawrence, which was once crucial to the town's industrial development, is now the City of Lawrence's vehicle for coal transport for the Lawrence Energy Center (Westar Energy 2008). The railroad and a 300m buffer is included on the corridor risk map to account for coal dust blowing from the train over the past decades and from coal combustion from early steam driven trains (Figure 43). While the railroad corridor only affects GP-2 and GP-3, every garden in the study is within the zone of influence for roadway traffic, meaning that cadmium, copper, lead, and zinc may be elevated in the gardens relative to a comparable rural soil (Figure 43).

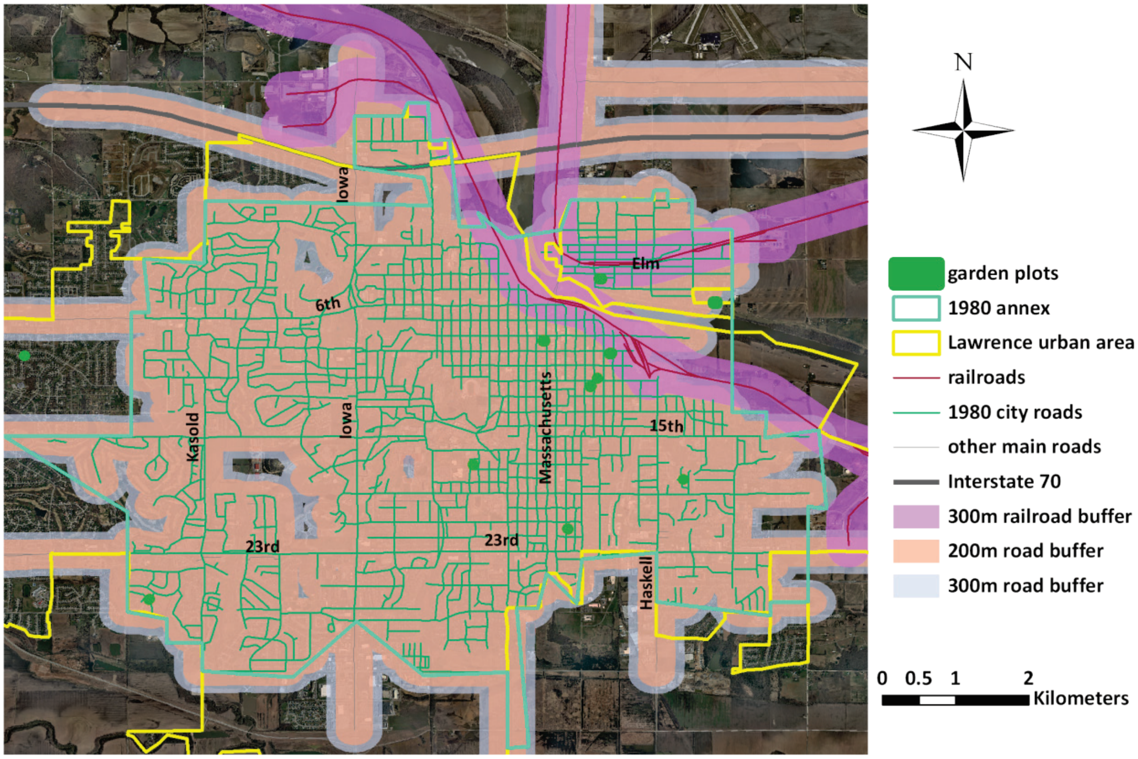


Figure 43. Transportation corridors (railroads and roads) have been and continue to be a source of certain heavy metals in nearby soils. The 300m road buffer marks the area of greatest likelihood of finding elevated levels of copper, cadmium, and lead whereas the 200m buffer shows where elevated levels of zinc are more likely. Every garden in the study is in an area influenced by transportation corridors.

Although unique to Lawrence, the town's history shares many environmental components in common with other cities across the U.S. As with this Lawrence case study, Geographic Information Systems allow the collection and analysis of historic and modern data to help planners make informed decisions regarding next steps in managing the possibility of heavy metals in garden soils. Prepared using qualitative designations (i.e., high, medium, low), Table 6 summarizes predictions for the likelihood of detecting metals of interest in each garden plot based on the land use and environmental histories. An evaluation of how these predictions matched results from the x-ray fluorescence procedure is presented in Table 16.

Table 6. Predictions for detecting heavy metals in garden soils based on general and site specific land use histories for each garden plot. "Low" means that no prior or current land use indicates that the metal will be present; "Med" means that one or more prior or current land use or proximity to a pollution source indicates that the metal may be present, but not at high levels if it is detectable at all (e.g., a garden near a roadway that is not and has never been very busy would receive a "Med" prediction for Pb); "High" indicates that one or more prior or current land use or proximity to a pollution source indicates a high likelihood for the metal to be present (e.g., a garden on a site where a building had burned down would receive a "High" prediction for Cu).

		Likelihood of detecting elevated levels of metal									
Site	Description	**Ag**	**As**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Se**	**Zn**
GP-1	Vermont Street garden, old building burned down	Low	Low	Low	Low	High	Low	High	High	Low	High
GP-2	Eastside Community Garden, was boat parking lot	Low	Med	Med	Med	Med	Med	Med	High	Low	Med
GP-3	North Lawrence Community Garden, near railroad	Low	Low	Low	Low	Med	Med	Low	Med	Low	Med
GP-4	1950s ranch-style home with backyard garden	Low	Low	Low	Low	Low	Low	Low	Med	Low	Low
GP-5	1970s development - new garden, new wood fence	Low	Med	Low	Med	Med	Low	Low	Med	Low	Med
GP-6	Down slope from University, near wood fence	Low	Med	Med	Med	Med	Low	Low	Med	Low	Med
GP-7	Bill Hatke's old residence, old house burned down	Med	Med	Med	Med	High	Med	Med	High	Low	High
GP-8	North Lawrence garden plot near agriculture	Low	Low	Low	Low	Med	Low	Low	Med	Low	Med
GP-9	Two gardens near old homes in East Lawrence	Low	Low	Low	Low	Med	Low	Low	High	Low	Med
GP-10	Newest house, but a lot of treated wood	Low	Med	Low	Med	Med	Low	Low	Med	Low	Med

4.6. Sampling and laboratory analysis

Soil sampling occurred in March, 2009 for ten gardens in the Lawrence urban area. Two community gardens, one previous community garden (now a private garden producing vegetables for the farmers' market), and seven private gardens were sampled. Soil characteristics varied widely, as five soil series were represented, not to mention vastly different gardening practices and land use histories. A representative sample from the county type locality for these five soil series were collected in November 2010 for comparison.

Figure 44. GP-3 sampling grid established through regularly spaced tape measures. Samples were taken along tape at designated points. Note the differences in garden management between the cardboard area (left, east) compared to the right side (west), which has been recently tilled.

Samples were collected in the Lawrence gardens at a minimum resolution of one per five square meters of garden area in a grid pattern (Figure 44); subsamples were collected at two depths, one in the plow layer (5-15 cm) and one deeper (25-35 cm) to account for discontinuities laterally and with depth. In some cases, shallow soils did not allow for collection at these depths. In these instances, either a single sample was collected at 5-15cm, or the second sample was collected at a deeper depth (e.g., 20-30cm). Sampling depths are reported in Appendix A.

Once collected, a total of 500 samples was transported to the University of Kansas soils laboratory, where they were air dried and stored. Preparation of samples for analysis occurred in

November, 2010 with oven drying (at 60˚C for 24 hours), grinding, and sieving to less than a 2 mm grain size. Next, an x-ray fluorescence (XRF) hand-held device was used for total elemental determination of Ag, As, Ba, Cd, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se, Sn, Ti, Zn, and Zr. The Innov-X XRF Alpha 4000 Classic was regularly standardized and calibrated during the elemental analysis. Tests were conducted at least twice per sample for 30 seconds per test. Longer testing times improve precision (i.e., reduce the margin of error), while repeating the test improves both precision and accuracy (EPA 2006c). Test results were then averaged and are reported in Appendix A with standard range of error for each element.

XRF technology is not only simple to use (point and click), but it is also non-destructive and has undergone field tests by the EPA to demonstrate its efficacy for field and laboratory analysis of soil toxins (EPA 2006c). After completing XRF analysis, Munsell colors (both dry and moist) were recorded based on Schoenberger et al. (2002), followed by percent weight loss on ignition (LOI) for 100 samples (Appendix B). To prepare samples for LOI, they were again oven dried, and 5-10 g samples were weighed in crucibles. Based on an EPA report (Schumacher 2002), a reasonable LOI program to avoid volatilizing inorganic carbonates was to ramp furnace temperatures to 375 ˚C and soak for four hours. Once cooled, samples were reweighed; the loss of weight gives a semi-qualitative estimate of organic carbon in the samples (Appendix B); this step provided data that allowed evaluation of Munsell color as a proxy for estimating organic matter content of garden soils.

4.7. Results and discussion

4.7.1. Summary of detected metals of interest

The “RCRA 8 metals,” (Resource Conservation and Recovery Act) are those metals that have been determined by the EPA to be the most ubiquitous and toxic, including arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver (National Archives and Records Administration 2011). While this list provides a starting point, nickel, copper, and zinc can also be toxic to plants, humans, and other organisms at elevated levels, thus these metals are included in the analysis. No silver or selenium was detected in any of the samples, and toxic barium exposure is unlikely from urban soils. Barium in soils usually occurs as barium sulfate (barite) and barium carbonate (witherite) ores, neither of which is particularly toxic to humans (EPA 1998, rev. 2005). Toxic barium exposure may occur from contaminated drinking water or from inhaling barium-rich dust in certain industrial settings (EPA 1998, rev. 2005). These exposure pathways are unlikely to occur during gardening activities; barium is subsequently excluded from this analysis. Therefore, Ag and Se are only included in the summary and the metals receiving close scrutiny are: As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn.

Table 7. Summary of results from XRF elemental analysis, typical metal concentrations found in surface soils, levels at which adverse effects occur, and typical detection limits for XRF handheld devices. Values reported in ppm (mg kg^{-1}). Typical surface soil ranges, phytotoxic levels, levels adverse to human health, and typical XRF detection limits come from the Environmental Protection Agency study of XRF handheld devices (EPA 2006c).

	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
# samples, metal detected	0	74	5	13	168	17	19	500	0	500
Mean	n/a	17	70	191	51	28	76	54	n/a	105
Median	n/a	13	71	194	40	22	76	33	n/a	75
Minimum	n/a	9	65	160	32	16	55	14	n/a	32
Maximum	n/a	51	73	227	493	78	100	1108	n/a	1193
U.S. surface soil range	.01 - 5	1 - 50	.06 - 1.1	1 - 1000	2 - 100	0.01 - 0.3	5 - 500	2 - 200	0.1 - 2	10 - 300
Phytotoxic effects at	2	10	4	1	100	0.3	30	50	1	50
Adverse to human health at	390	0.39	37	30[a]	3100	6.1[c]	1600	400	390	23,000
Typical XRF detection limit	10 - 45	10 - 20	10 - 50	10 - 50[b]	10 - 50	10 - 20	10 - 60	10 - 20	10 - 20	10 - 30

[a] Value for hexavalent chromium. Level is 10,000 ppm for trivalent chromium.

[b] Value for total chromium. Neither XRF nor ICP-AES can detect species of chromium.

[c] Value for methyl mercury. Level is 23ppm for elemental mercury.

A statistical summary of the elemental analysis of these ten metals is provided in Table 7. Actual detection limits reported by the instrument used in the analysis and error ranges are provided in Table 8. The XRF detection limit of some metals is high (i.e., As and Hg) relative to levels that are toxic to people and plants, which limits the efficacy of the technology for these metals except as a pre-screening technique or where the soil levels are high enough for detection. Copper and zinc were found to be at above-normal levels in some samples at which phytotoxic effects may occur, but not at levels dangerous for people. Nickel was detected within the normal range, but in at least one case at a phytotoxic level. No silver or selenium was detected, which may be the result of high detection limits relative to typical soil abundances of these elements. The maximum value detected for arsenic falls just above the normal range found in all soils. However, even a minute level of arsenic is toxic to humans; hence with 15% of samples containing detectable levels of arsenic, this finding is cause for concern.

Table 8. Limits of detection specific to the XRF instrument and time of test used in this experiment (minimum of two tests with 30 seconds of analysis time each). The XRF instrument provides error range for each reading. These values have been averaged to provide a general idea of precision level.

	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
actual limit of detection (ppm)	10 - 11	60 - 65	145 - 150	30 - 33	13 - 15	50 - 65	11 - 15	10 - 30*
error range when detected (+/- ppm)	5	21	57	12	7	22	6	8
error range when detected (+/- %)	28%	30%	30%	27%	27%	30%	16%	10%

*Detection limit never reached.

Cadmium and chromium were detected in 5 and 13 samples, respectively, but the detection limit was higher than typical ranges according to the EPA (2006c) indicating a need for a longer test time or perhaps that concentrations where these elements were detected were relatively high. Cadmium was detected at levels toxic to both people and plants, but only in five samples. Chromium in thirteen samples may indicate toxicity, but further testing is required to discover the species of chromium present. A similar conundrum occurs with the results for mercury, as the toxic level for elemental mercury (23 ppm) is much higher than that for methyl mercury (6.1 ppm). Since the soils in this study would not provide the typical conditions for methylation of mercury (i.e., oxygen poor, saturated soils), the level for elemental mercury (23 ppm) is used as the toxic level for people in this study. Several soil samples hover near the level toxic for humans and any detectable mercury is phytotoxic. Finally, lead occurred in every sample, mostly within the EPA-designated normal range. Because some U.S. states and other countries have set maximum acceptable levels for lead in bare soil as low as 40 ppm (Murphy 2009), any value between 100-399 ppm will be considered to be an elevated risk for sensitive populations, while 400 ppm and above will be classified as high risk for the purposes of this study. A total of 45 samples fall into the medium risk category, while five samples contained lead levels above 400 ppm, four of these from Mr. Hatke's previous residence (GP-7). Here, one sample measured over 1100 ppm (well over the bare soil and child play area level of 400 ppm) at a level approaching 1200 ppm. Vegetated areas (as opposed to bare soils) are considered hazardous by the EPA at 1200 ppm, so a bare soil measurement approaching 1200 ppm at GP-7 is cause for concern (2010b).

4.7.2. Comparison to analogous rural soils

Five soils representing the type locality of a series within Douglas County were sampled for comparison to garden soils of the same series. Most of the type localities were rural, but every sample site was disturbed by human activities, including agriculture, addition of fences and telephone poles, road construction, and/or unknown previous uses. Table 9 demonstrates that while some metals of interest were detected in more rural locations, the overall picture shows that urban garden soils contain higher levels of these metals than adjacent rural soils from the same series.

Table 9. Results for detected metals of interest in five rural type locality series at two depths (A: 5-15cm, B: 25-35cm). Compared to urban garden soils, the rural type localities show lower levels of As, Cu, Hg, Pb, and Zn, which are common metals associated with anthropogenic activities. Values are in ppm (mg kg-1). "ND" indicates that the metal was either not present or below the detectable limit. Neither silver nor selenium were detected in garden soils or in type locality soils.

	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
WoodsonA	ND	ND	ND	ND	ND	ND	26	32
WoodsonB	**11**	ND	ND	ND	ND	ND	21	**70**
MartinA	ND	ND	ND	ND	ND	ND	24	47
MartinB	ND	ND	ND	ND	ND	ND	25	49
EudoraA	ND	ND	**197**	ND	ND	ND	23	49
EudoraB	**10**	ND	ND	ND	ND	ND	27	47
PawneeA	**11**	ND	ND	ND	ND	ND	14	36
PawneeB	ND	ND	ND	ND	ND	ND	18	**70**
MorrillA	**10**	ND	ND	ND	ND	ND	14	42
MorrillB	ND	ND	ND	ND	ND	**79**	16	40
Garden mean	17	70	191	51	28	75	55	106
Garden median	14	71	187	40	22	75	33	75

Figure 45. Area of Pawnee soil series type locality for Douglas County.

Soils in the most remote locations (i.e., most rural), determined by greatest distance from an urban setting, were Pawnee (at the side of a gravel road in an unplowed field, Figure 45) and Martin (near the intersection of a paved road and a dirt access road, next to a plowed field) returned results generally indicating uncontaminated soil. The one exception is the plow layer of the Pawnee type locality where arsenic was detected at 11 ppm (Figure 47).

Figure 46. Woodson type locality sample was taken in a wheat field (top left) near a major roadway, located about 275 m to the north (top right, looking north). The Eudora type locality sample for Douglas County is also located near a plowed field (middle left), but construction associated with high power transmission lines and the plume coming from the Lawrence Energy Center (middle right) have likely impacted soil characteristics. A profile of the Eudora soil is shown, bottom.

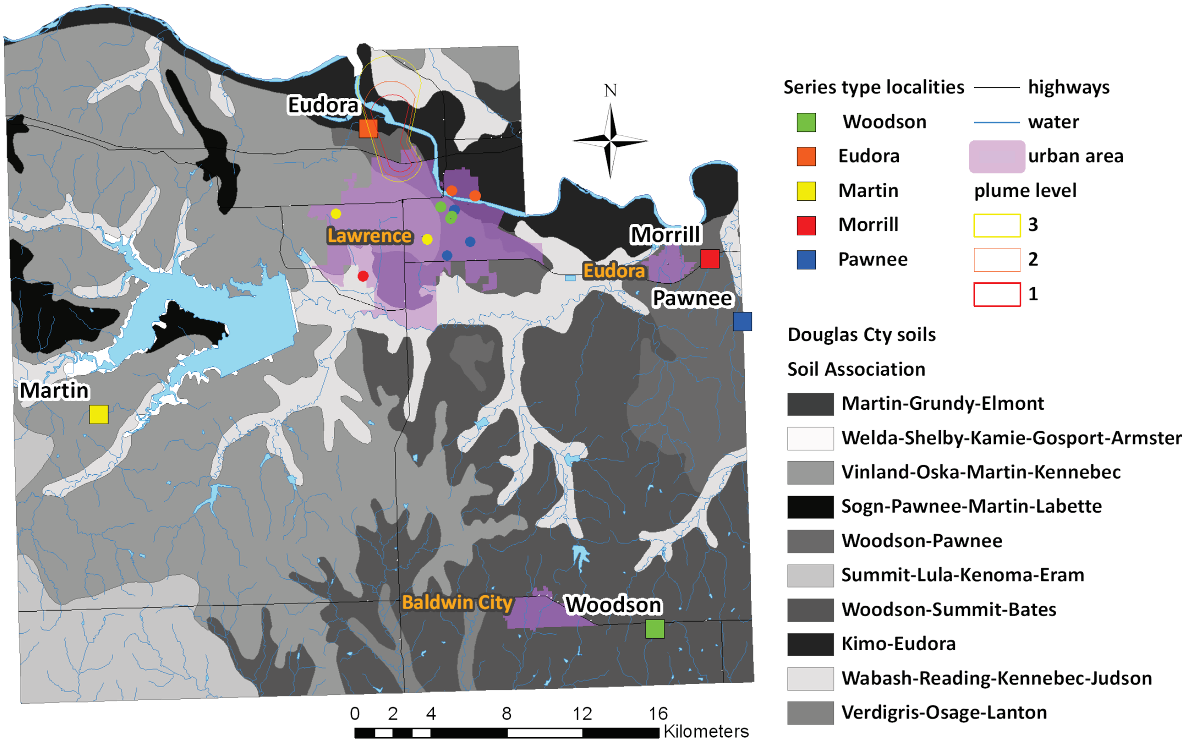


Figure 47. Soil associations of Douglas County (NRCS 2010) in relation to type localities for the soil series of the gardens in the study. Type locality sample sites (squares) are coded the same color as their garden soil counterparts (circles).

Arsenic was also detected in the 5-15 cm layer at the Morrill type locality, in the median of Kansas State Highway 10 (K-10) (Figure 47), at 10 ppm and in the Eudora B sample at 10 ppm. This level of arsenic falls within the normal range for the United States and the detected levels in the type locality samples are near the limit of detection for XRF. Arsenic was only detected in 15% of all samples for Lawrence, but it likely occurs near this level for all Lawrence soils due to the underlying mineralogy. Many limestones in shales in the area (Kanas Geological Survey 1999) contain bits of pyrite, a mineral that is mostly FeS_2, but that often contains other elements, e.g., arsenic, antimony, and bismuth (Ralph and Chau 2011). Thus, it is concluded that while anthropogenic sources of arsenic are plausible in rural areas, especially from pesticides, treated wood does not appear to be the source of arsenic in the rural soils due to the absence of associated elements of copper and chromium in treated wood products. Thus, a county background level of arsenic of geologic origin at 10-11 ppm is more likely. In urban soils with levels above 11 ppm, anthropogenic sources of arsenic are suspected, especially due to the prevalence of CCA treated wood products such as fences, decks, and poles.

The Morrill type locality sample site (in the median of K-10 near Eudora), appears to be one of the most disturbed soils out of the type locality group (Figure 47). The sample site sits about 30 feet west of a highway overpass, therefore the soil was likely intensively mixed during construction of the exit, overpass, and highway. Of the type locality soils, it is the only site to indicate the presence of nickel. Nickel was only detected in 4% of all samples; an anthropogenic origin would likely concentrate the metal at the surface (e.g., from burning fossil fuels, incinerating municipal waste, Ni-Cd batteries, etc.). Its detection in the lower layer supports the idea that the Morrill site has been disturbed; another plausible explanation is nickel's increased mobility in mineral soils of higher pH. Morrill soils have the lowest soil organic carbon of all type localities measured (0.6 % by weight), which helps immobilize nickel deposited at the soil surface (Tyler and McBride 1982), and this soil series is characterized by slight acidity at the surface with gradually increasing acidity at depth (Table 11). Like the Morrill site, the Woodson site series type locality is located near a highway, although rather than in the median, the Woodson site sits in the middle of a plowed field (Figure 46). Woodson contains the highest lead values of the type localities, potentially because it is the closest site to a major roadway (about 275 m away), within the 300 m zone where pollution from road traffic affects soils (Wu et al. 2010).

The Eudora type locality site sits in an urban-rural transition zone just south of the Kansas River (Figure 48). The landscape is dominated by a large swath cleared for high voltage power lines coming from the Lawrence Energy Center located a short distance to the northeast. The transmission lines pass through an agricultural field, bordered by a deep ditch (Figure 46). The site's proximity to the river and recent rains explains the black, saturated soils at the time of sampling. Samples were retrieved just outside of the plowed zone in the agricultural field on the west side of the gravel roadway. Notable detected metals in the Eudora soil include arsenic and chromium. This was the only sample taken within the estimated air contaminant plumes (Figure 41), which provides a plausible explanation for chromium at this site. A secondary explanation could be CCA on the wooden poles supporting the high voltage lines coming from the power plant. A more detailed analysis of findings comparing series type localities to their urban garden counterparts follows.

Figure 48. Relative location of the Eudora series type locality sampling site (orange square) in relation to the Lawrence Energy Center and the Kansas River. It is possible that chromium detected at the Eudora site came from the coal burning plant. Image courtesy of Douglas County.

4.8. Garden physical and chemical soil characteristics

Findings for each garden site are presented here, including physical and chemical soil characteristics and land management techniques. Table 10 lists garden locations and associated soil series, for which Table 11 provides a list of typical series characteristics for Douglas County. To give context to the results, garden plots are discussed in conjunction with series type locality data. While organic matter levels are discussed here, more information may be found in 4.10 and Appendix B.

Table 10. Garden locations and associated soil series. Five soil series are represented, all loamy soils with varying degrees of clay (National Cooperative Soil Survey 1973).

Site	Soil Series	Lawrence Address	Description
GP-1	Ws - Woodson silt loam	809 Vermont Street	Vermont Street garden, old building burned down
GP-2	Pc - Pawnee clay loam	903 Pennsylvania Street	Eastside Community Garden, was boat parking lot
GP-3	Ev - Eudora-Kimo complex	226 North 4th Street	North Lawrence Community Garden, near railroad
GP-4	Pc - Pawnee clay loam	1736 Brook Street	1950s ranch-style home with backyard garden
GP-5	Mr - Morrill clay loam	2515 Morningside Drive	1970s development - new garden, new wood fence
GP-6	Mc - Martin silty clay loam	1632 Alabama Street	Downslope from University, near wood fence
GP-7	Ws - Woodson silt loam	1113 New York Street	Bill Hatke's old residence, old house burned down
GP-8	Ev - Eudora-Kimo complex	800 block of Oak Street	North Lawrence garden plot near agriculture and old house
GP-9	Pc - Pawnee clay loam	2116/2120 New Hampshire St	Two gardens near old homes in East Lawrence
GP-10	Mc - Martin silty clay loam	4600 Grove Street	Newest house, but a lot of treated wood (fences and children’s play structure)

Table 11. Gardens soils in the Lawrence, KS case study include five soil series. Some typical characteristics that have been surmised from the representative sample for Douglas County (i.e., type locality) are listed here for the uppermost layers (National Cooperative Soil Survey 1973).

Soil series	Parent material	horizon	color	structure	other characteristics
Eudora (silt loam)	Loamy alluvium	Ap - 0 to 7 in (0 to 18 cm)	very dark grayish brown (10YR 3/2)	moderate medium granular structure; very friable	slightly acid; gradual smooth boundary
		A - 7 to 12 in (18 to 30 cm)	very dark grayish brown (10YR 3/2)	moderate medium granular structure; very friable	many worm casts; slightly acid; gradual smooth boundary
Martin (silty clay loam)	Residuum from silty and clayey shale	A1 - 0 to 9 in (0 to 23 cm)	very dark brown (10YR 2/2)	moderate medium granular structure; firm	medium acid; gradual smooth boundary
		AB - 9 to 14 in (23 to 36 cm)	very dark brown (10YR 2/2)	moderate to strong fine and medium subangular blocky structure; firm;	most peds have shiny surfaces; medium acid; gradual smooth boundary
Morrill (clay loam)	Glacial till and glaciofluvial deposits	A1 - 0 to 10 in (0 to 25 cm)	very dark gray (10YR 3/1)	moderate medium granular structure; friable	slightly acid; gradual smooth boundary
		B1 - 10 to 16 in (25 to 41 cm)	dark brown (7.5YR 4/2)	very fine and fine subangular blocky structure; firm;	medium acid; gradual smooth boundary
Pawnee (clay loam)	Glacial till and glaciofluvial deposits	Ap - 0 to 7 in (0 to 18 cm)	very dark gray (10YR 3/1)	moderate fine and medium granular structure; friable	many fine roots; slightly acid; gradual smooth boundary
		A - 7 to 14 in (23 to 30 cm)	very dark grayish brown (10YR 3/2)	moderate fine granular to subangular blocky; friable	many fine roots; slightly acid; clear smooth boundary
Woodson (silt loam)	Clayey sediment	Ap - 0 to 8 in (0 to 20 cm)	very dark gray (10YR 3/1)	weak-moderate fine granular structure; friable	common fine roots; strongly acid; clear smooth boundary
		A1 - 8 to 11 in (20 to 28 cm)	very dark gray (10YR 3/1)	weak-moderate fine platy structure to moderate fine subangular blocky; friable	few fine black concretions; common fine roots; medium acid

4.8.1. Garden plots 3 and 8: Eudora-Kimo Association

The Eudora-Kimo soil association characterizes floodplain soils developed on alluvium (Figure 49). Eudora soils (65%) are typically found on higher parts of the floodplain, while Kimo is found on lower, concave areas (25%) (National Cooperative Soil Survey 1973). Garden plots 3 and 8 are higher on the floodplain, thus samples from the Eudora series are used here for comparison.

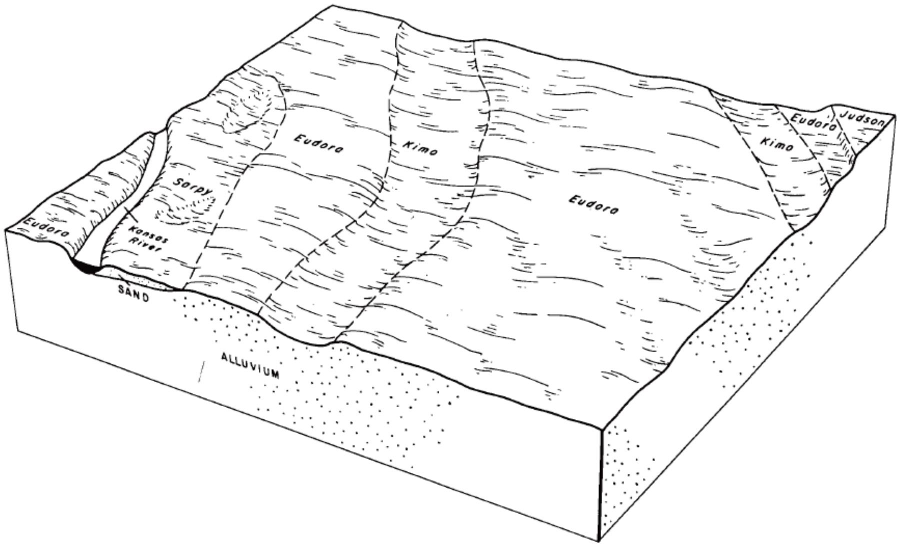


Figure 49. The Eudora-Kimo Association is found on the floodplain of the Kansas River, as shown in this figure from the Douglas County Soil Survey (National Cooperative Soil Survey 1973). The organic rich, loamy soil provides excellent tilth and fertility for agriculture and gardening.

As described in Table 11, the "very dark" color of Eudora soils indicates high organic matter content. Laboratory analyses confirmed this high level, with about 1.5% organic matter by weight at the type locality and an average of 1.3% for "A" garden samples (i.e., 5-15 cm). Gardeners at both plots (3 and 8) had not added compost or other organic matter in recent years, perhaps explaining the slightly lower organic matter content of garden soil and demonstrating the extractive nature of gardening and/or how tilling leads to mineralization of organic matter. Organic matter levels at 25-35 cm for both gardens averaged 0.6%, still rich in organic matter, indicative of the depositional environment and horizon development. Hand texturing revealed a loamy texture, confirming the soil survey description for Eudora soils.

Every metal of interest was detected in the combined results for Eudora garden soils, despite the absence of Cd, Cu, Hg, and Ni from the type locality samples (Table 12). Arsenic was only detected in GP-3 (not GP-8), reaching a maximum of 17 ppm in three samples, two of these at B depths (25-35cm). Arsenic was also detected in the B depth for the type locality sample, which may indicate that arsenic deposited at the surface has moved down through the soil column or that the arsenic is of geologic origin. Arsenic's mobility increases with increasing pH leading to the possibility that the slightly acidic Eudora soils may also provide an explanation of detecting arsenic lower in the soil profile. GP-8, pictured in Figure 53, resides farther away from the industries and main transportation corridors of North Lawrence, perhaps protecting the garden from major contaminant sources.

Like arsenic, cadmium and chromium are only detected in GP-3 (Figure 50). Cadmium appears in two samples, over twenty meters apart, one at each depth (A and B), while chromium is only detected at the B level. Mercury was detected in a single sample in GP-8 at the B level and not detected in GP-3. Detected levels of As, Cd, Cr, and Hg in GP-3 and GP-8 are potentially detrimental to plants and humans, while Ni and Zn (average of 80 ppm) levels may affect only plant health.

Table 12. Summary of results for the Eudora soil series, including GP-3 and GP-8 and the type locality results ("A" subsamples taken at 5-15cm depth and "B" subsamples taken at 25-35cm depth.)

Eudora series	**As**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Zn**
Type locality A	ND	ND	**197**	ND	ND	ND	23	49
Type locality B	**10**	ND	ND	ND	ND	ND	27	47
Garden statistics	n = 206							
Mean	13	72	164	38	16	62	36	77
Median	11	72	164	37	16	60	33	70
Min	10	71	160	32	16	55	15	33
Max	17	73	168	51	16	72	158	329
detection rate	1.5%	1.0%	1.5%	22%	0.5%	1.5%	100%	100%

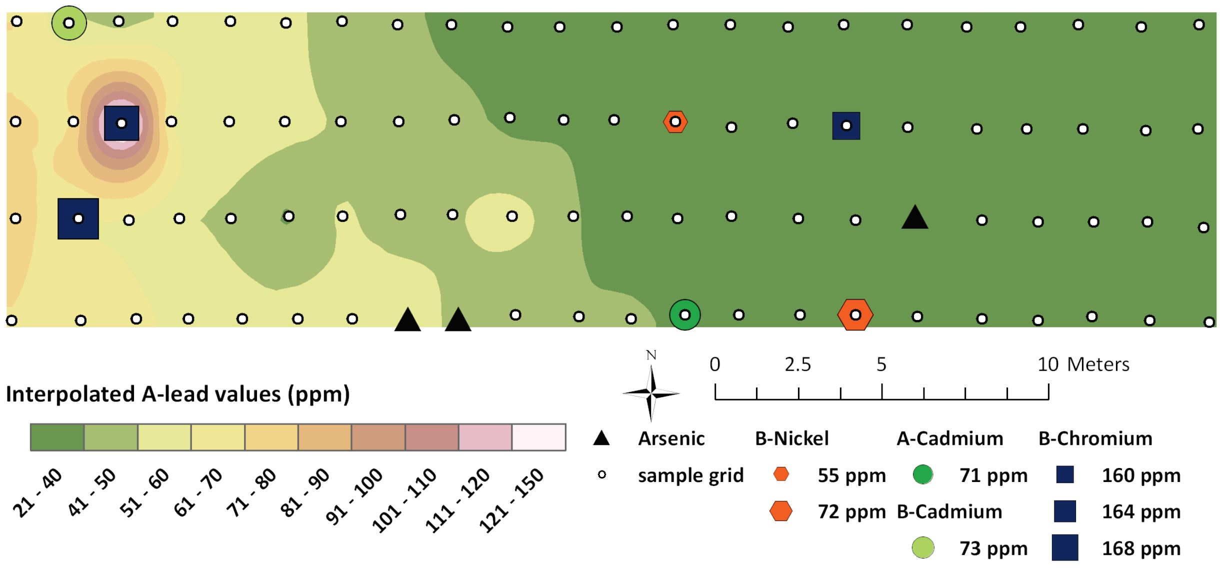


Figure 50. Graphic illustrating detected metals of interest in GP-3 (North Lawrence Community Garden) for A, 5-15cm depth and B, 25-35 cm depth. A-Lead values were kriged to aid visualization of spatial pattern. Only one sample contained lead above 100ppm, which is also in an area containing chromium and cadmium. Arsenic values range from 10-17 ppm, a level detrimental to human health.

Figure 51. GP-3, the North Lawrence Community Garden, looking southwest toward the only building on the lot. The Kansas River is located just beyond the homes in the background. The tilled soil at the right of the image is associated with the contaminated zone shown in the above figure. Photo by T. Jackson.

Lead averages are elevated for the garden soils compared to the type locality samples, but they are all within a relatively safe concentration range. GP-8 lead concentrations were in the range of 17-31 ppm, while GP-3 levels were slightly higher, with only two samples above 100 ppm. Lead values for the top layers of GP-3 (Figure 50) and GP-8 (Figure 52) were kriged (ordinary kriging using exponential semivariogram model with fixed search radius of 6m) for spatial pattern analysis. The result shown in Figure 50 illustrates a likely source of lead in GP-3 to the west of the garden. An old home sits to the west and south of the garden, but at a distance where lead paint chips are an unlikely source (Figure 51). Alternatively, the main roadway from Lawrence to North Lawrence across the Kansas River is about 400m to the west of the garden, and a smaller, albeit old residential road (4th Street) runs north and south just 50m to the west of the garden. Another potential source is the railroad, at its closest point about 200m to the north. Leaded fuel is the likeliest culprit for slightly higher lead levels on the side of the garden nearest the road, while the one site with significantly higher lead level is likely caused by lead paint chipping off a tool or some other point source.

The gardens (GP-3 and GP-8) located on Eudora soils contain high levels of organic matter, and safe levels of lead. There are discrete locations of elevated metals including Cd, Cr, Ni, and As for GP-3 and Hg, Ni, and Zn for GP-8. Overall, because of the neutral pH, loamy texture, and high organic matter content, garden plants and their gardeners are believed to be safe from harmful exposure to noted heavy metals.

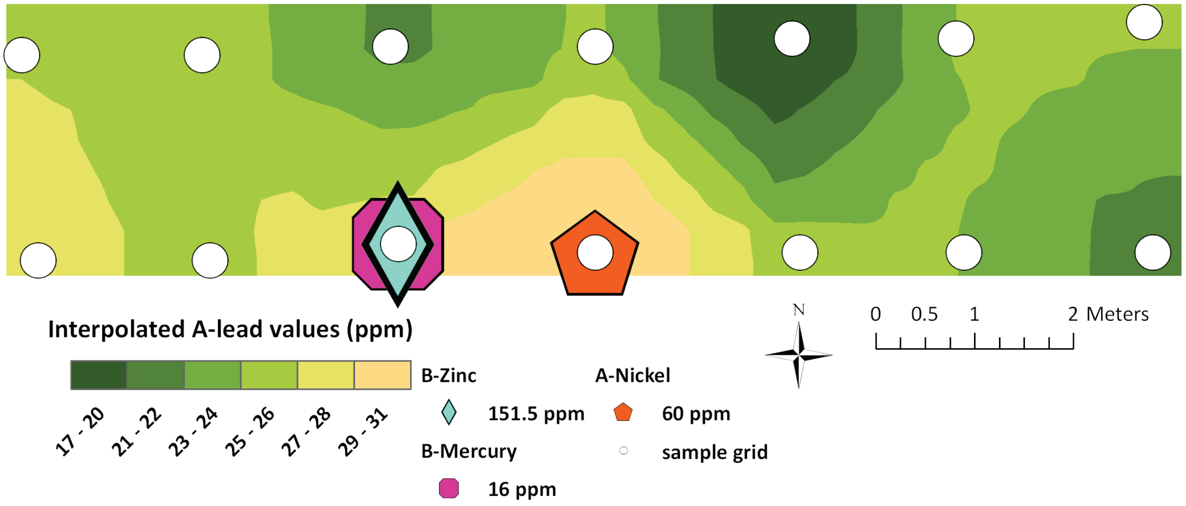


Figure 52. Metals of interest detected in GP-8, a garden located in north Lawrence on Eudora soils. While most metals were not detected, single incidences mercury and nickel correspond to slightly elevated lead and zinc levels. The nearest roadway is situated about to the south (bottom edge) of the map, which likely explains the pattern of metals displayed, especially higher levels of Cu (not shown), Zn, and Pb.

Figure 53. The GP-8 garden was covered with a cornucopia of strawberries at the time of sampling on May 31, 2009. Photo by T. Jackson.

4.8.2. Garden plots 1 and 7: Woodson soils

Woodson soils' upland position and clayey sediment parent material show how varied mollisols can be when comparing Woodson to Eudora soils (Figure 54). The clayey nature of the soils makes gardening or otherwise working the soils a difficult task. Gardeners from both plots (1 and 7) on this soil series add organic matter at least annually to build soil tilth, neutralize the moderately acid pH (6-7), and increase nutrient availability. Addition of organic matter in the gardens is confirmed by significantly higher organic matter content by weight (2.0% and 1.4% in A and B, respectively) than 1.2% for the A layer of the type locality sample as determined by weight loss on ignition. GP-7 soils had been tilled and were dry and structureless (i.e., loessy); consequently, samples were collected at one depth, 15-25 cm.

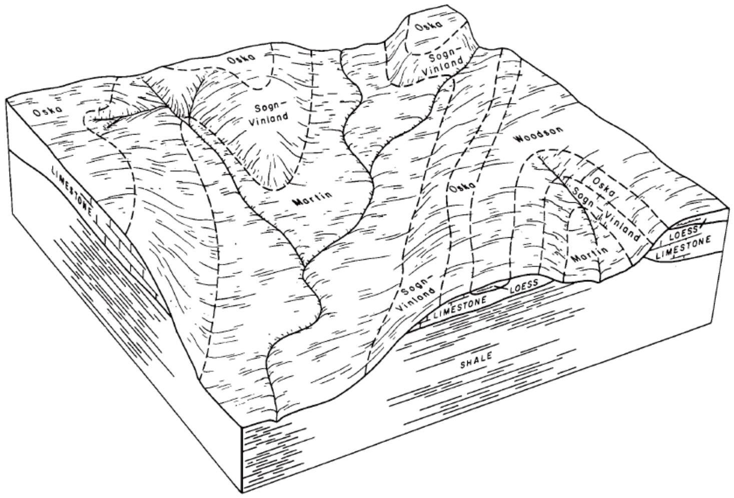


Figure 54. Woodson soils are upland soils developed on clayey parent material, here labeled as loess in this figure from the Douglas County Soil Survey (National Cooperative Soil Survey 1973)

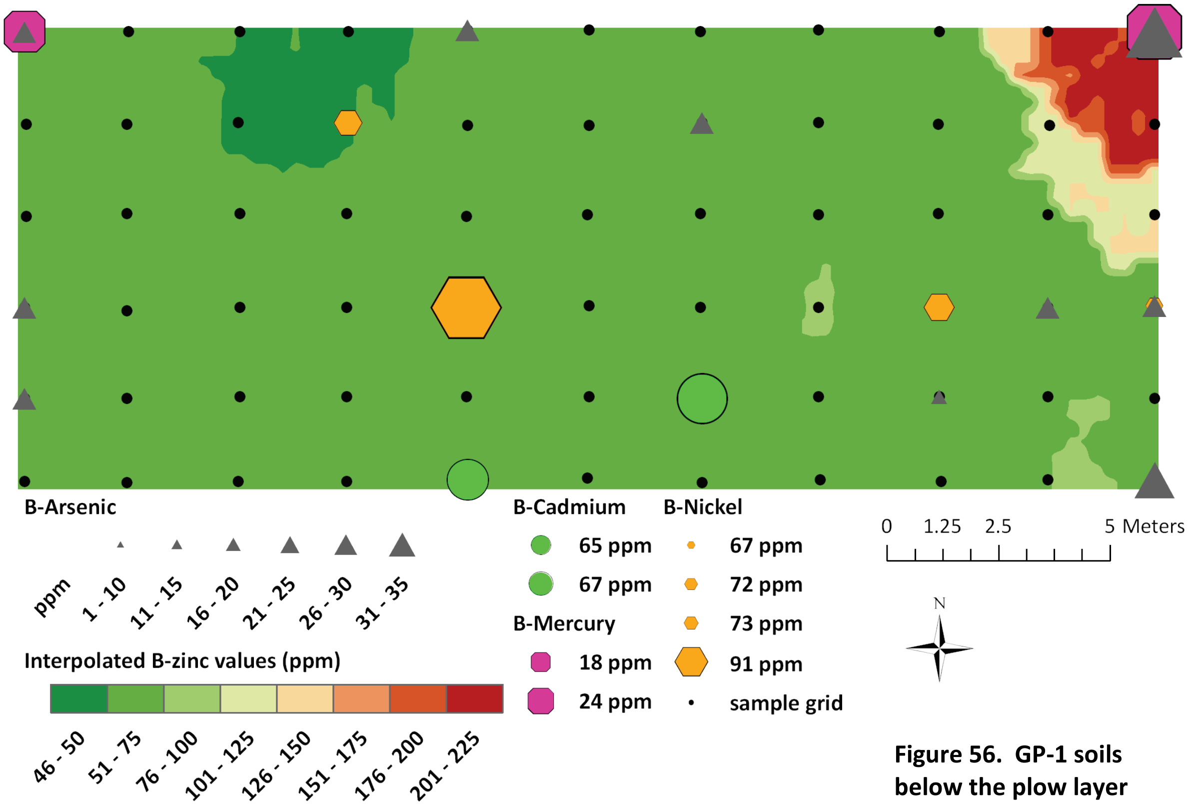
Table 13. Summary of results for the Woodson soil series, including GP-1 and GP-7 and the type locality results ("A" subsamples taken at 5-15cm depth and "B" subsamples taken at 25-35cm depth.)

Woodson series	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Type locality A	ND	ND	ND	ND	ND	ND	26	32
Type locality B	**11**	ND	ND	ND	ND	ND	21	**70**
Garden statistics	n = 153							
Mean	17	68	207	51	22	80	74	124
Median	13	67	211	43	22	77	29	68
Min	9	65	180	34	18	67	16	40
Max	51	72	227	219	27	100	1108	679
#ND	116	150	149	85	142	142	0	0
detection rate	24%	2.0%	2.6%	44%	7.2%	7.2%	100%	100%

No Cd, Cr, Cu, Hg, or Ni were detected in the type locality samples (Table 13) and lead levels were within a normal range. In contrast, all of these metals were detected in GP-1 (Figure 56 and Figure 57) and GP-7 (Figure 60). While arsenic was detected in the B level of the Woodson type locality, it was found in nearly a quarter of Woodson garden samples, including detection in nearly half of the samples from GP-7, Bill Hatke's previous residence; At this site, detected lead levels averaged three times more (34 ppm) than the type locality B level (11 ppm) (Figure 60).

Lead and zinc values in GP-1 B level demonstrated a similar pattern of contamination at the easternmost edge of the garden, closest to the sidewalk and roadway, with a particularly contaminated site at the northeast corner (high in Hg and As) (Figure 56). This corner is closest to the neighboring building, which was constructed in the late 1800s (Sanborn Perris Map Company Ltd. 1897) (Figure 58). GP-1 contains levels of As, Hg, and Cd that are of concern for human health, while Zn and Ni levels may be problematic for plant life. Copper is detected in 62% of GP-1 samples, whereas it is undetected in the type locality samples, pointing to an anthropogenic source, likely from automobiles (Wu et al. 2010). A reading of 195 ppm of chromium (in the A level) is unlikely to be dangerous due to the health status of these garden soils, including high levels of organic matter (about 2% in the plow later). Further testing would be needed to determine the species of chromium present, but this is not recommended. Since the shallowest soils correspond to the most contaminated soils near the sidewalk and roadway, it is likely that less organic matter has been placed in this area, hence the metal signal is not diluted. In some samples, a record of the 1990 fire is evident (Figure 55).

Figure 55. A soil profile from GP-1 shows a clear indication of a burn layer about 30cm deep.



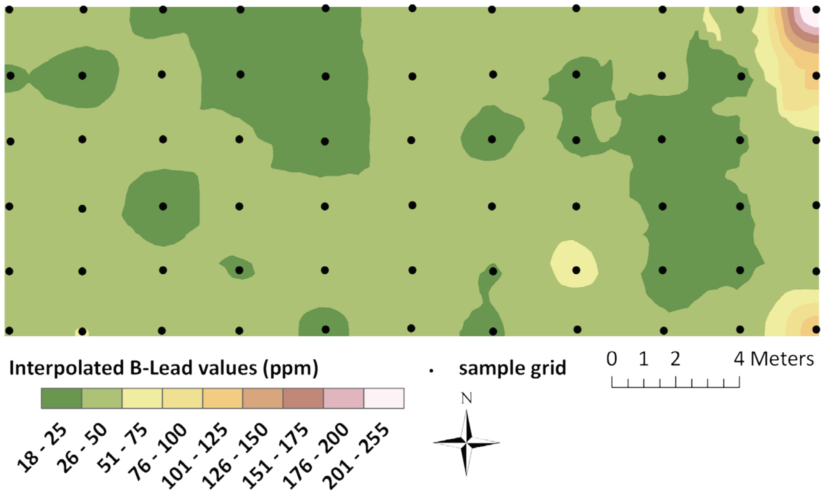


Figure 56. GP-1 soils below the plow layer in the B level (25-35cm) show high values for some toxic metals (above), especially at the front of the garden (eastern edge) near the sidewalk. The same pattern holds true for lead (left), but even the relatively high levels of lead are considered safe for bare soil by the EPA (2010b).

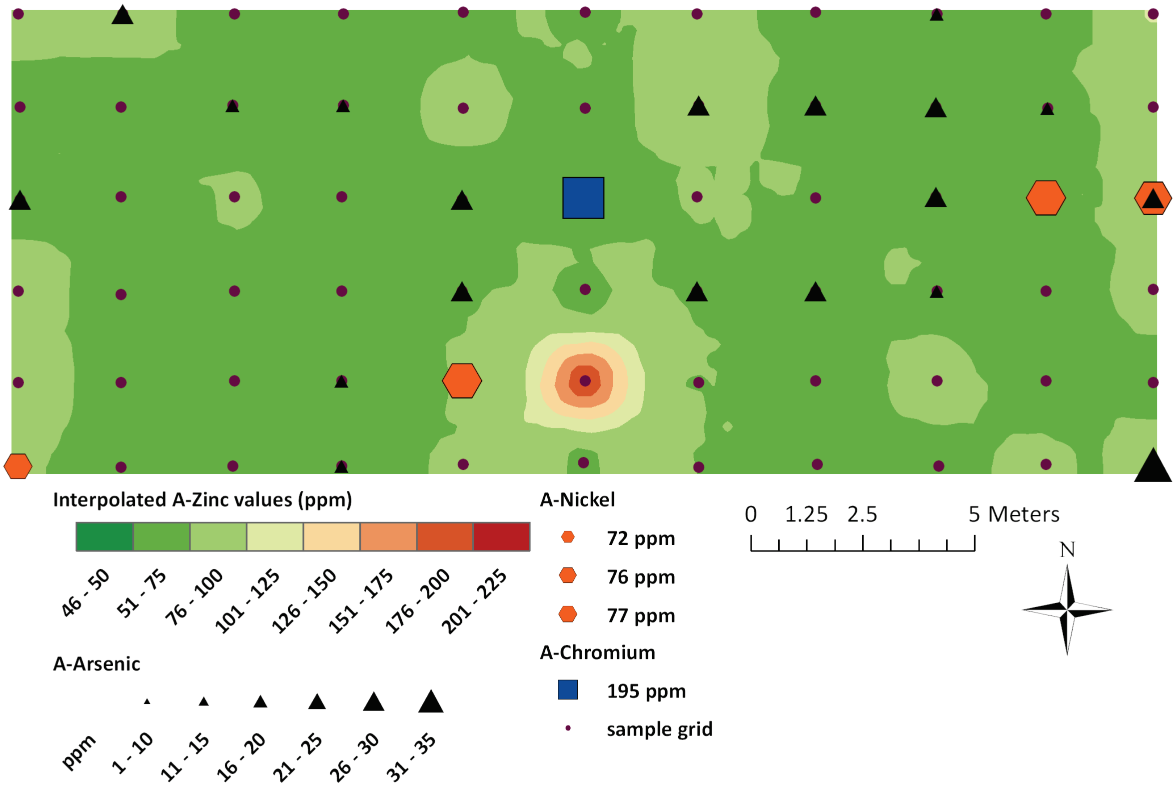


Figure 57. Vermont Street garden (GP-1) plow layer (A, 5-15 cm) values for zinc show one hot spot along with discrete incidences of arsenic, nickel, and chromium.

Figure 58. Looking southeast at the Vermont Street Garden in November of 2008. At the far end of the garden near the red car is a large compost heap, which helps to dilute contaminant levels since the gardener regularly broadcasts compost over the garden. Photo by T. Jackson.

GP-7 contains elevated levels of lead with average readings of 350 ppm, a rate ten times greater than the GP-7 lead average of about 35 ppm. GP-7 results for lead indicate a maximum reading of 1108 ppm, which is cause for concern and appropriate protective action, which is discussed in Chapter 5 (Figure 60). With about one third of the GP-7 garden area containing over 400 ppm of lead, care must be taken to avoid contact of sensitive populations with the soil until action can be taken to ensure safety (e.g., addition of organic matter, phytoremediation, cover crops). In addition, presence of As, Hg, Cd, and high levels of Zn call for corrective land management. In this soil series, the garden soils clearly show evidence of anthropogenic contamination of certain metals (Figure 59), especially when considering the absence of most metals of interest in the Woodson type locality samples.

Figure 59. A gardener down the street from GP-7 reuses discarded materials in his garden for a chicken coop and self composting outhouse (left). Arsenic, chromium, and copper were detected here, indicating that some of the wood has been treated with chromated copper arsenate (CCA). Photo by T. Jackson.

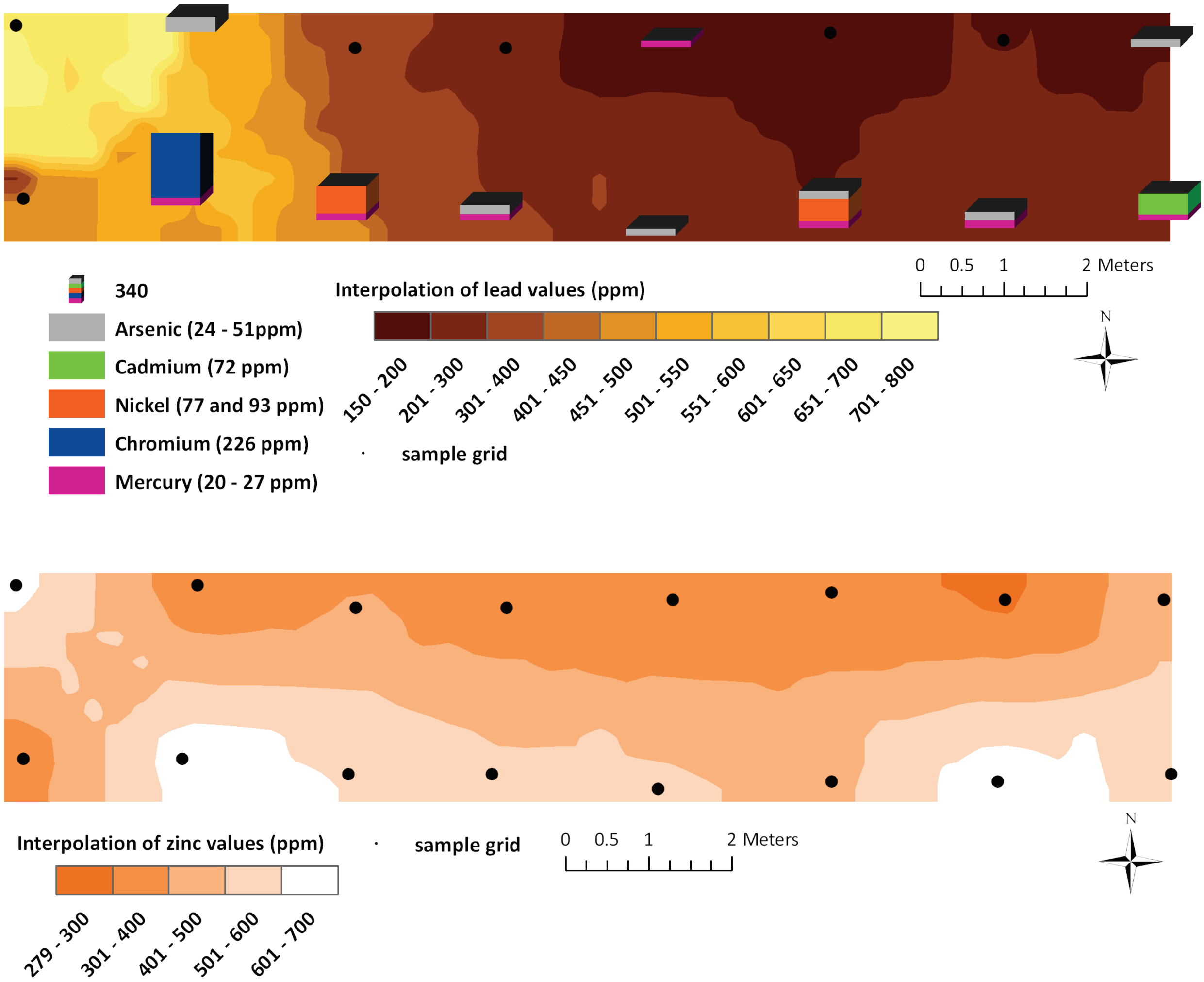


Figure 60. Bill Hatke's old residence site (GP-7) contains several metals of interest (top), including high levels of lead (kriged values, top) and zinc (kriged values, bottom). While bare soil lead levels above 400ppm may be harmful to the health of sensitive populations, the high levels of zinc are of concern for plant health.

4.8.3. Garden plots 2, 4, and 9: Pawnee soils

Pawnee soil characteristics closely follow those of the Martin and Woodson soils, as they are clayey loams, found in upland areas often on ridgetops, with high natural fertility and water capacity, but slow permeability. Gardens on the Pawnee soil series include the Eastside Community Garden (GP-2), and two other sites in East Lawrence, the 1950s neighborhood (GP-4), and the older neighborhood where the gardens sit directly adjacent to the homes (GP-9). Cadmium was not detected in any Pawnee soils, while arsenic, lead, and zinc were detected at fairly typical values for the area in the type locality samples (Table 14). Notably, all metals except cadmium were detected in garden soils, while most of these observations occurred in GP-2, the plot with the longest land use history and the garden closest to industrial activities of the past and present.

Recall that the Eastside Community Garden (GP-2), began with workers from the City of Lawrence spreading a layer of soil over a gravel boat parking lot (Swift 2008). Raised beds were later constructed, resulting in its current form (Figure 61). Some numbered beds in the map were divided into two beds at the time of sampling, and the "communal herbs" section was also sampled, totaling 20 beds with two sample sites each. In addition, seven samples were taken outside the beds (Figure 61), to provide an additional baseline of soil characteristics, especially helpful since every bed appeared to be managed differently and the source of soil for the raised beds is unknown. Results indicate that bed soils generally contain more of the metals of interest than soils outside the bed, although lead levels exceed 100 ppm in the two outer sites on the west side of the garden. Zinc levels outside the beds average 136 ppm, following the trend of above-average zinc for the whole garden including beds. Zinc levels above 50 ppm can begin to be detrimental to plant health.

Table 14. Summary of results for the Pawnee soil series, including GP-2, GP-4, and GP-9 and type locality results ("A" subsamples taken at 5-15cm depth and "B" subsamples taken at 25-35cm depth).

Pawnee series	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Type locality A	**11**	ND	ND	ND	ND	ND	14	36
Type locality B	ND	ND	ND	ND	ND	ND	18	**70**
Garden statistics	n = 103							
Mean	19	n/a	182	65	49	70	70	142
Median	16	n/a	178	43	50	69	60	113
Min	10	n/a	174	34	17	65	15	37
Max	50	n/a	194	493	78	76	290	1193
detection rate	20%	n/a	2.9%	46%	3.9%	2.9%	100%	100%

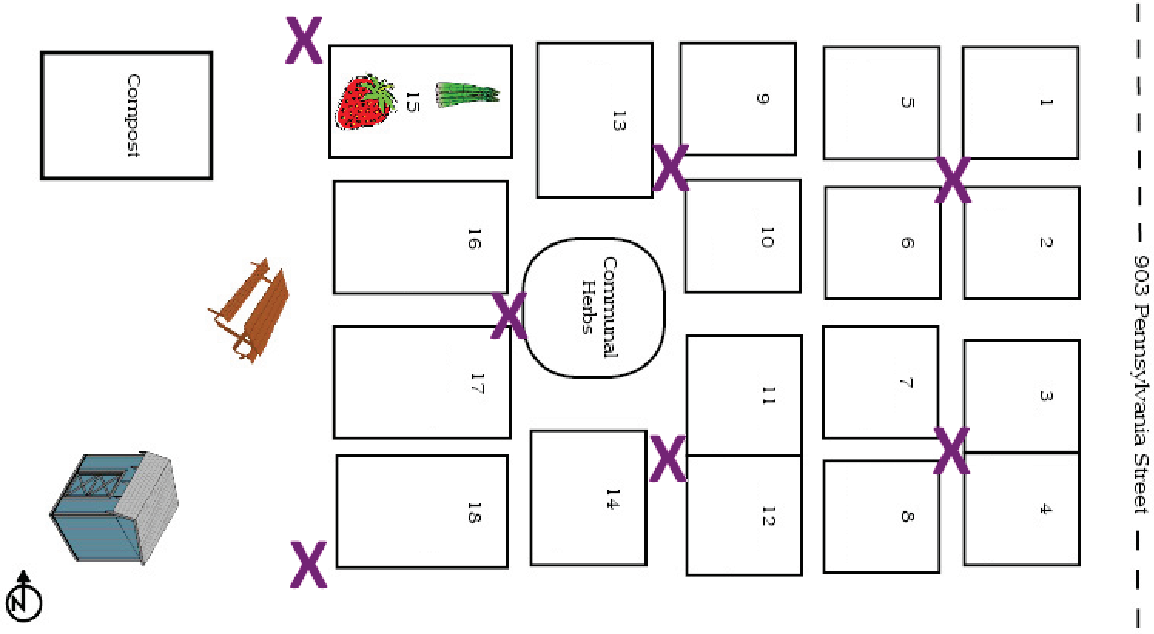
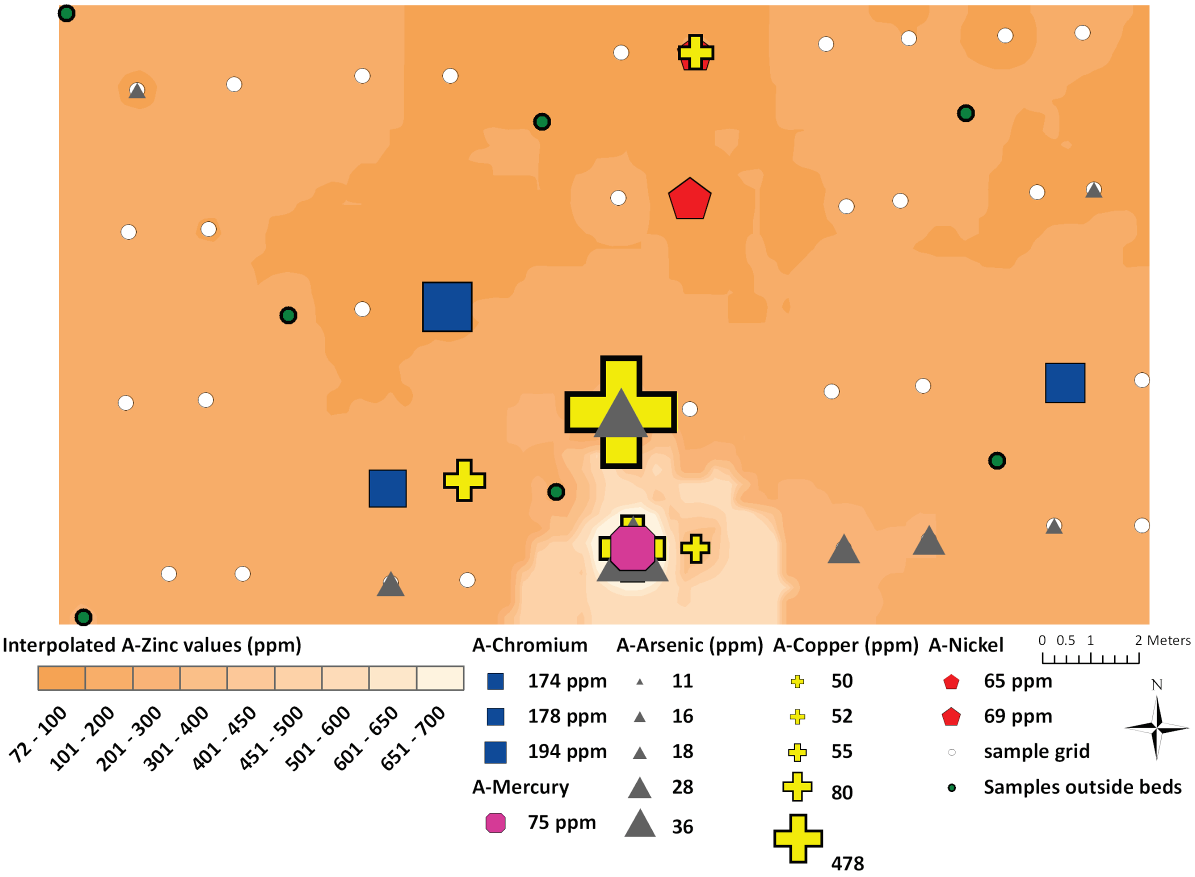


Figure 61. Site map of the Eastside Community Garden (GP-2) provided by one of the gardeners (Mortinger 2009). The community garden is comprised of raised beds, some of which are further subdivided, such as plot 18. Purple "X" marks have been added to indicate where a sample was taken outside a raised bed.

Figure 62. The Eastside Community Garden, GP-2, contains about 20 plots that are managed by an equal number of people. Photo by T. Jackson.



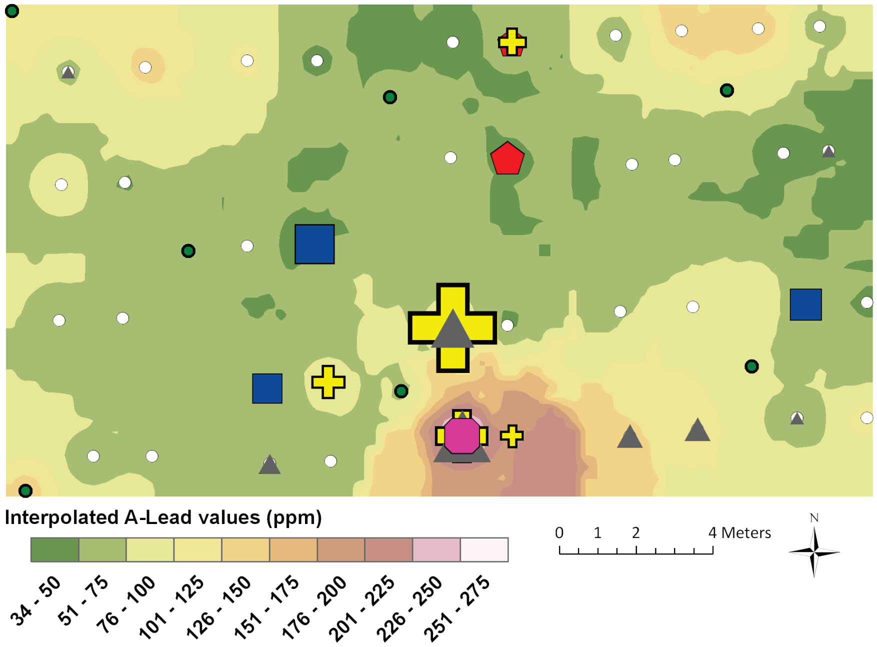


Figure 63. Metals of interest for GP-2 in the plow layer ("A", 5-15cm depth). Top and bottom maps share symbology except kriged zinc values (top) and kriged lead values (left). A clear area of contamination occurs in the central southern beds (nos. 8 and 12), even though none of the metals occur above background levels at the nearby sample taken outside the beds (green dot).

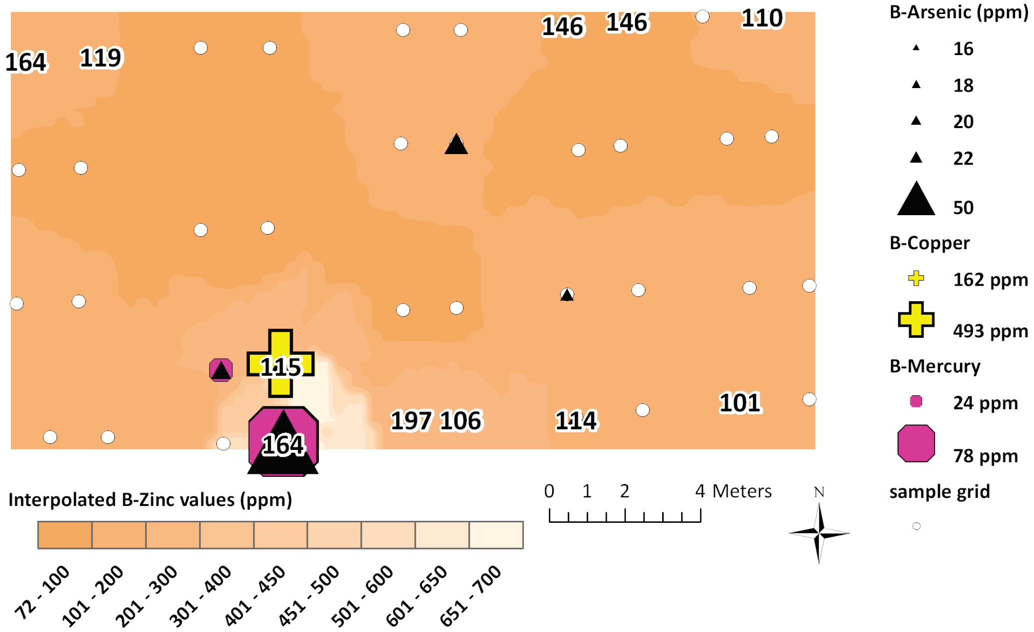


Figure 64. GP-2 metals from 25-35 cm "B" depth. Zinc, copper, mercury, and arsenic contamination occurs predominately in one discrete location. Bold numbers shown on the map are lead values above 100ppm. Although lead levels for the garden are generally below 100ppm, but the highest values occur adjacent to the contaminated bed.

4.8.4. Garden plots 6 and 10: Martin soils

Martin soils are also clay loams found in upland locations, but are developed from weathered shales, responsible for their high natural fertility combined with slow permeability. Two gardens on Martin soils include GP-6, located downslope from the University of Kansas campus, and GP-10, a backyard garden of the newest home in the study. Organic matter was significantly higher for both garden soils than the Martin type locality (2.0% compared to 1.5% by weight, respectively), corroborating the gardeners' reports of adding compost to the gardens. No metals were detected in the Martin type locality samples except for low levels of lead and zinc (Table 15). The opposite case is true for GP-6 and GP-10, where every metal of interest is detected with the exception of cadmium, although most of these incidences occur in GP-10. Lead levels in GP-10 fall just above the type locality levels, while GP-6 includes an average of 47 ppm lead, about twice the type locality average (Figure 65).

GP-6 metals of interest are elevated near the treated wood fence, where the highest lead and arsenic values occur in both gardens (Figure 65). Yet, the southernmost sample in GP-6 also contains lead, arsenic, copper, and chromium, likely due to its location at the inner edge of the gravel driveway and its position at the lowest elevation sampled. Since the sampled area of GP-6 contains several tomato plants, which are known to accumulate arsenic (Burló et al. 1999), action should be taken by the gardener to reduce soil arsenic or dilute the signal with organic matter or new soil. Replacing the fence is not recommended since there is no evidence of copper or chromium along with the arsenic; the fence may well not be a source of arsenic. Even if the fence is a source of arsenic, older wood products treated with CCA leach less through time, so few gains would be made, if any, by replacing the fence (Chirenjea et al. 2003). A more likely explanation for the high arsenic and lead near the fence is that lead arsenate was used as a crabgrass killer at the site or upslope of GP-6 (Folkes 2001).

Table 15. Summary statistics for type locality and garden samples on Martin soils.

Martin series	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Type locality A	ND	ND	ND	ND	ND	ND	24	47
Type locality B	ND	ND	ND	ND	ND	ND	25	49
Garden statistics	n = 21							
Mean	15	n/a	213	39	18	85	39	97
Median	15	n/a	213	39	18	85	28	93
Min	9	n/a	207	37	18	85	14	51
Max	24	n/a	219	42	18	85	204	175
detection rate	38%	n/a	10%	29%	4.8%	4.8%	100%	100%

Figure 65. Metals detected in GP-6. Note the dark line across the top of the map, which is a treated wood fence. This may explain the elevated level of arsenic at the sample site nearest the fence. The contaminated site at the south end of the garden is part of a gravel driveway. Satellite image courtesy of Douglas County.

Metals of interest besides Pb and Zn detected in GP-10 include As, Cr, Cu, Hg, and Ni (Figure 66). The sample site containing As, Cr, Cr, and Hg occur near a deck (Figure 67), probably built with lumber treated with chromated copper arsenate (CCA) to prevent decay (Chirenjea et al. 2003). In a separate sample taken near the children's play area, arsenic was detected under the swing (away from posts) at 13 ppm, indicating the potential for arsenic on the surface of the wooden play structure, although neither copper nor chromium were detected, and arsenic is near the county background level (Figure 66). While the soil arsenic level may not be of concern, it is recommended that children wash their hands after playing on the structure. Mercury and arsenic in the soil can be managed through continued addition of organic matter and avoidance of arsenic accumulating crops. Chromium is likely at a safe level and in a safe form (i.e., trivalent chromium) due to the biogeochemical conditions of this soil (Barnhart 1997). However, the deck can be a continuing source of chromium, copper, and arsenic (Chirenjea et al. 2003), thus caution should be taken in planting food crops near the deck.

Figure 66. Metals of interest detected in a backyard garden in west Lawrence (GP-10). The yellow streak near the center of the image is a slide from a children's play area, where arsenic was detected (13ppm) in a separate sample. Image courtesy of Douglas County.

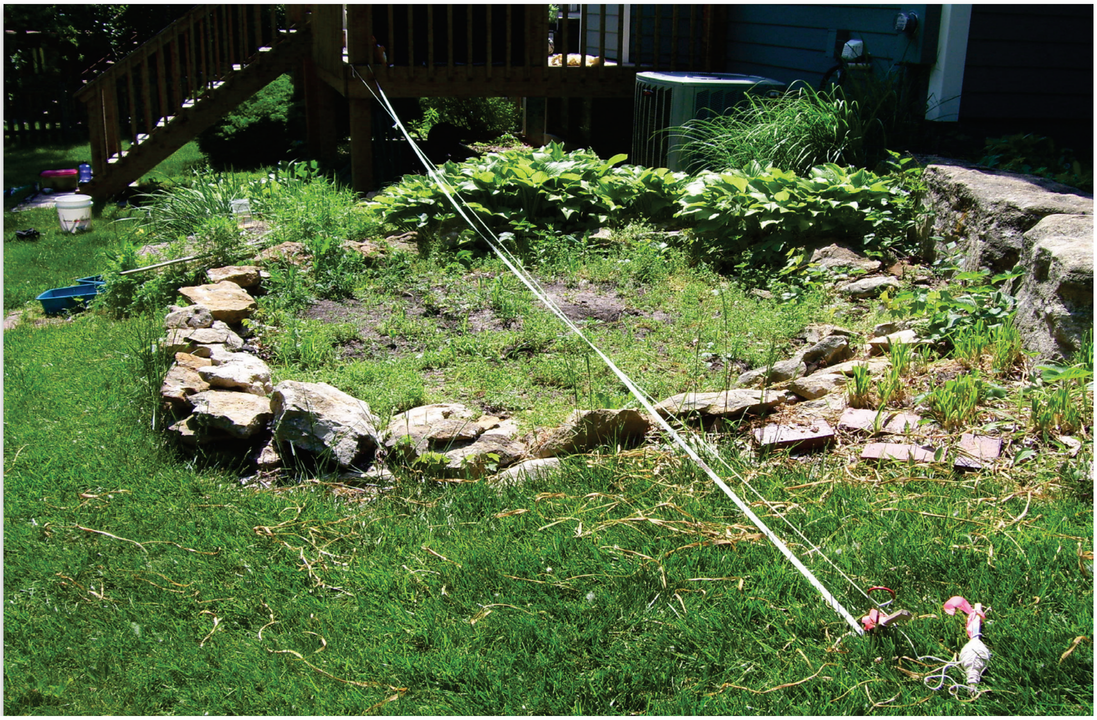


Figure 67. The GP-10 transect passes through several different areas from lawn to raised beds near a wood deck. Photo by T. Jackson.

4.9. Evaluation of land use history as predictor of heavy metal presence

At the end of the section about garden plot land use histories (4.4.2), predictions were made regarding which metals of interest would be elevated compared to type locality samples (Table 6). Table 16 outlines an evaluation of these predictions. Discrete incidences of cadmium, chromium, mercury, and nickel were generally not expected, but occurred in a seemingly unpredictable pattern. Like lead, copper and especially zinc were elevated in most garden settings, with typically higher values in areas with longer human land use histories, probably due to their association with automobile traffic (Wu et al. 2010). Arsenic patterns were difficult to predict, except in gardens with wood products that have probably been treated with CCA. The presence of arsenic in four out of five type locality soils indicates a background level of 10-11 ppm, which is near the lower detection limit for XRF hand-held devices. Lead was predicted to be elevated in all urban garden soils relative to the more rural type locality sample locations, which occurred with the exception of GP-8, the most rural garden in the study.

Overall, land use history provided a good baseline for predicting which metals might be elevated at a given urban location, especially for arsenic, copper, lead, and zinc, which were detected in fairly predictable dispersion patterns in Lawrence. Because the XRF device only detected five incidences of cadmium, all within 65-73 ppm, and cadmium is also typically associated with road traffic, it seems that the XRF technology in this case failed to record cadmium at levels that would allow for contaminant pattern attribution. Chromium, nickel, and mercury contaminant patterns were not predictable in Lawrence, namely because there are few indicators that these metals have been released into the local environment (EPA 2011b). Environmental and land use histories were effective in predicting which metals would be detected and, in many cases, effective in qualitative predictions of urban levels relative to rural soils (Table 16).

Table 16. Evaluation of predictions (see Table 6) of metal levels based on land use history. Blue shading indicates a correct prediction and pink indicates an incorrect prediction. Green shading indicates a prediction that is neither right nor wrong. For instance, if a metal was not predicted to be elevated, but it was detected in few samples at a low level, the prediction is categorized as green. “TL” stands for type locality.

	Likelihood of detecting elevated levels of metal										
Site	**Ag**	**As**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Se**	**Zn**	**Comments**
GP-1	🟦 Low	🟥 Low	🟩 Low	🟩 Low	🟦 High	🟩 Low	🟦 High	🟦 High	🟦 Low	🟦 High	Cu, Ni, Pb, and Zn were expected to be elevated, which was the case. As was elevated, and Cd, Cr, and Hg were detected twice each, all of which were not predicted.
GP-2	🟦 Low	🟦 Med	🟦 Med	🟦 Med	🟦 Med	🟦 Med	🟦 Med	🟦 High	🟦 Low	🟦 Med	As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn were predicted to be elevated, which was the case, although Hg was only detected in one sample.
GP-3	🟦 Low	🟦 Low	🟩 Low	🟩 Low	🟦 Med	🟥 Med	🟩 Low	🟦 Med	🟦 Low	🟦 Med	Elevated Cu, Hg, Pb, and Zn were predicted and only Hg did not occur. Cr values were similar to TL. Two incidences each of Cd and Ni occurred, but were not predicted.
GP-4	🟦 Low	🟦 Low	🟦 Low	🟦 Low	🟦 Low	🟦 Low	🟦 Low	🟦 Med	🟦 Low	🟦 Low	Only Pb was predicted to be elevated, which was the case.
GP-5	🟦 Low	🟦 Med	🟦 Low	🟥 Med	🟦 Med	🟦 Low	🟦 Low	🟦 Med	🟦 Low	🟦 Med	As, Cu, and Cr were anticipated to be higher because of possibly CCA treated wood, but no Cr was detected. Pb and Zn were elevated, as predicted, relative to TL.
GP-6	🟦 Low	🟦 Med	🟥 Med	🟦 Med	🟦 Med	🟩 Low	🟦 Low	🟦 Med	🟦 Low	🟦 Med	As, Cd, Cr, Cu, Pb, and Zn were predicted to be elevated and only Cd was not. A single incidence of Hg occurred, but was not predicted.
GP-7	🟩 Med	🟦 Med	🟦 Med	🟦 Med	🟦 High	🟦 Med	🟦 Med	🟦 High	🟦 Low	🟦 High	All metals were predicted to be elevated, and were except Ag, which may have been elevated, but below the detectable level.
GP-8	🟦 Low	🟦 Low	🟦 Low	🟦 Low	🟦 Med	🟩 Low	🟩 Low	🟥 Med	🟦 Low	🟦 Med	Zinc and copper were slightly elevated, although Pb was not compared with the TL. Single incidences of Hg and Ni occurred, which were not predicted.
GP-9	🟦 Low	🟥 Low	🟦 Low	🟦 Low	🟦 Med	🟦 Low	🟦 Low	🟦 High	🟦 Low	🟦 Med	Pb, Cu, and Zn were elevated, as predicted, but As was also detected, which was not predicted.
GP-10	🟦 Low	🟦 Med	🟦 Low	🟦 Med	🟦 Med	🟩 Low	🟩 Low	🟦 Med	🟦 Low	🟦 Med	As was detected with Cu and Cr (CCA), as predicted. Zn and Pb were elevated, as predicted. Single incidences of Ni and Hg occurred but were not predicted.

4.10. Evaluation of soil color for estimating soil organic matter

Munsell soil color has been used for decades for estimating organic matter content. Quantification of soil organic matter can be expensive, time consuming and, at times, inaccurate (McCauley et al. 1993). Recent efforts to quantify this relationship have shown that there is a relationship between texture, color, and organic content, but the predictive capability of texture and color for organic matter is not strong (Schulze et al. 1993, Konen, Burras and Sandor 2003). Using a chromameter may improve the precision of predictions, but the equipment is expensive, hence it is not a feasible solution for an urban gardener or municipality. A recent study evaluated Munsell color from a color book as well as a chromameter to evaluate the ability to quantify organic matter based on color and sample depth at a regional level for prairie soils and agricultural soils (Wills, Burras and Sandor 2007). Using a simple stepwise linear regression model, the authors found that Munsell value and chroma with sample depth provided the best model for estimating soil organic carbon.

Here the Wills, Burras, and Sandor procedure (2007) is used to build a model for predicting soil organic carbon (SOC). XRF analysis for heavy metals gives volumetric concentration of iron and manganese, which have long been understood to affect soil color (Murti and Satyanarayana 1971). Starting with the factors of dry and moist Munsell HVC (i.e., Hue, Value, Chroma), sample depth, and iron and manganese content (mg kg^{-1}) for all soil samples, a simple step-wise linear regression was performed to determine which factors were most significant for Lawrence garden soils. The statistical analysis calls for a normally distributed dataset, an often unrealistic possibility for soil datasets. To overcome this obstacle, SOC values (% by weight determined by Loss on Ignition) were $\log_{10}$ transformed to give a more normal distribution. Then, outliers were removed from the dataset (e.g., city compost was eliminated since it is not representative of a local soil and other samples that appeared to contain high levels of compost were also removed), and iron and manganese values were normalized. The best model ($R^2 = 0.634$) (Figure 68) took into consideration normalized iron content (nFe), sample depth midpoint (depth), and moist Munsell value (mMV) to give:

$$y = 1.108 + 0.6693(nFe) - 0.01105(depth) - 0.06919(mMV)$$

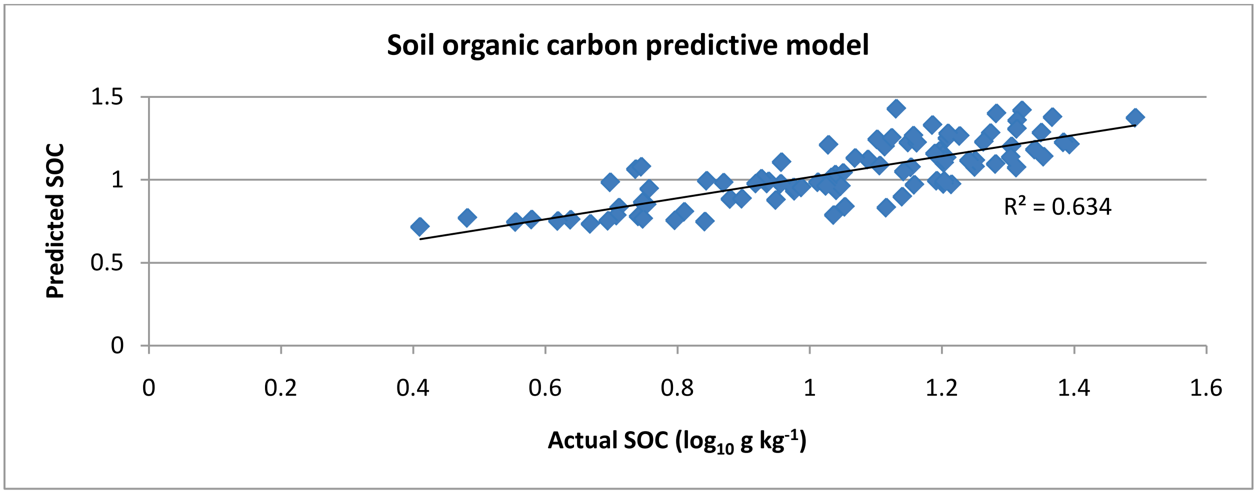


Figure 68. Linear regression model for predicting soil organic carbon (%) in Lawrence gardens using moist Munsell values, sample depth midpoint, and normalized iron content.

The feasibility of creating one predictive model for garden soils across the United States is unlikely due to the vast differences in soil characteristics from place to place. Add to this the infinite variety of management procedures used by gardeners. That said, the creation of localized models is possible with sufficiently high quality data. Perhaps a municipality or local gardening group, collecting data through time, would eventually have a large enough dataset to create a localized model for predicting soil organic carbon in the area. Meanwhile, gardeners can continue to observe Munsell color, particularly value (lightness and darkness), to estimate organic content of soils. A simple goal, e.g., attainment of a field moist Munsell value greater than three, simplifies the procedure while accomplishing the task of ensuring sufficient organic matter to offer protective mechanisms against toxic metals. The Munsell value of three was derived from data for agricultural soils in Wills, Burras and Sandor (2007), since soils with Munsell values nearing 3.5 typically approached 1.5 to 2% organic content.

4.11. Conclusions

The variety of gardens and soil characteristics in this study demonstrates an equally diverse range of land use histories. Land use history proved to be a fair predictor of certain metals (namely As, Cu, Pb, and Zn), while others seemed to randomly appear or not appear in samples (Cd, Cr, Hg, Ni). Since As and Pb are among the most toxic metals to humans that can bioaccumulate in foods, this is promising for the technique. Yet, Cd is also high on this list, and it was difficult to predict its occurrence using land use history, at least for Lawrence.

Metals of interest occurred in every garden, either with elevated levels across the extent of the garden or in elevated levels at discrete locations. Additionally, metals were detected in differing patterns at two depths that were only separated by 10 cm. The broad and discrete patterns of heavy metal contamination and different patterns at depth demonstrate the need for better sampling procedures than is typically recommended, especially at finer scales. Representative samples do not capture discrete contaminant patterns, or at least the signal would be dampened, especially in mixed samples from discrete locations. Even in broader contaminant patterns, such as occurred with zinc, the range of values across a garden varied up to an order of magnitude. The sampling scheme employed here, where a minimum of one sample was taken per five square meters, indicates an effective starting point for characterizing a general contaminant pattern. In gardens with more discrete polluted areas, additional sampling at a finer scale can provide a detailed map of the extent of the contamination.

Sampling and analyzing soils from series type localities is useful for estimating local background levels of trace elements, especially arsenic, copper, lead, and zinc. Lead and zinc occurred in all samples while arsenic levels hovered near the limit of detection. It is supposed that arsenic likely occurs in most soils of the county from geologic sources at or near 10 ppm. Type localities in this case were all affected by anthropogenic activities, but their rural locations demonstrated a contrast between urban and rural trace metal levels, particularly noticeable in levels of Pb, Zn, and Cu.

Soil color in conjunction with sample depth and iron content predicted soil organic carbon with a fair level of precision, but the statistical procedure used to formulate the relationship is not feasible for a typical urban gardener. Only with the support of a group of gardeners or a municipality would one be able to attain a large enough dataset to create a predictive model using step-wise linear regression. Until more work can be done in this area, gardeners can ensure a level of protection from most toxic metals through sufficiently high soil organic carbon based on field moist Munsell values greater than three. These case study findings guide the form and direction of decision support procedures for gardeners and policy makers (Chapter 5), while evidence from the soil analyses and land use histories validates the need for such procedures.

Chapter 5. Helping Gardeners Navigate the Policy and Urban Soil Landscapes

A current rebirth in urban agriculture in the United States stems from several converging ideas. Old ideas have reemerged, like stewardship, connection to nature, improved health in physical, mental, and spiritual realms, and a desire to consume less and to pollute less. Add to this the emergence of new ideas, e.g., moderating urban microclimates (i.e., creating urban cool islands), a focus on local food and people, and a way to connect children with the food they eat. These old and new ideas intersect within the urban and policy landscapes where most people live. Urban landscapes and their soils demonstrably contain higher levels of certain metals that can damage plants, animals, and people. These same urban landscapes are governed by layers of rules imposed by governments, communities, and property owners. Information about how to traverse potential physical barriers like unhealthy soil and access to land and how to overcome rules such as garden-unfriendly policies, will aid gardeners and policymakers in promoting the resiliency of the U.S. food system through local food production. Help with these issues is provided here, in the form of a general policy briefing and decision support procedures, designed to overcome some of the more significant obstacles to healthy urban food production.

5.1. Policy environment for urban gardening in the U.S.

National policies that affect urban gardening do so by either facilitating the growth of local food markets or by encouraging the current food system status quo of vertically integrated food production, processing, and packaging, increasingly centralized ownership, and overproduction of commodities, e.g., corn and soy, which heighten prices for fresh produce, for instance (American Planning Association 2007). Local policies affecting urban agriculture vary widely across the United States, and can also serve to hinder or facilitate local food markets. Local policies that encourage development of the local food market usurp the national food system status quo by decentralizing food production, processing, packaging, land access and ownership, and by increasing production and access of fresh produce (American Planning Association 2007). Because of these circumstances, local planners and policymakers may be best suited to effect change to the food system and to allow grassroots efforts to thrive. Three policy areas have been identified that require attention by gardeners and policy makers wishing to enliven local food production: access to land, clarity of relevant laws and regulations, and the ability to sell produce (Erickson et al. 2009).

The policy and planning landscape of a particular community is outlined in the zoning ordinances and land development codes of the governing municipality. These codes and ordinances concern the first two factors, including access to land (in the sense of allowed land uses) and clarity of governing rules. A first step to understanding rules governing land use is to understand that a plot of land is subject to laws of different levels of government. Especially important are city and county rules, although state and federal rules may also come into play.

For gardeners wishing to establish a garden while following rules and regulations, they can determine most applicable rules by visiting the county's planning commission website or offices. The county planning commission can provide information about allowed land uses (i.e., zoning codes and regulations) and any development regulations that are in place. For instance, the Douglas County Planning Commission website lists the usual land development code, subdivision regulations, commercial design standards, and zoning regulations, but it also lists local phenomena, e.g., the KU-City land use agreement (Douglas County 2011). Although the legal verbiage of these documents may seem intimidating, it is important to understand whether gardening is allowed by determining allowed land uses at one's garden plot.

Zoning documents provide general regulations governing land use, building requirements, and the health and safety of the public. For a particular site, the first step is to identify the property of interest on a zoning map like the one shown for Douglas County (Figure 69) to determine the designated zoning code or base district (i.e., Agriculture, Residential, Commercial, Industrial, etc.). Each base district/zone has specific guidelines for allowed and disallowed activities or land uses outlined in the zoning documents. Exceptions may be granted for particular land uses by the zoning board of a municipality, called Conditional Use Permits, which allow land uses outside the regulatory framework of the designated use.

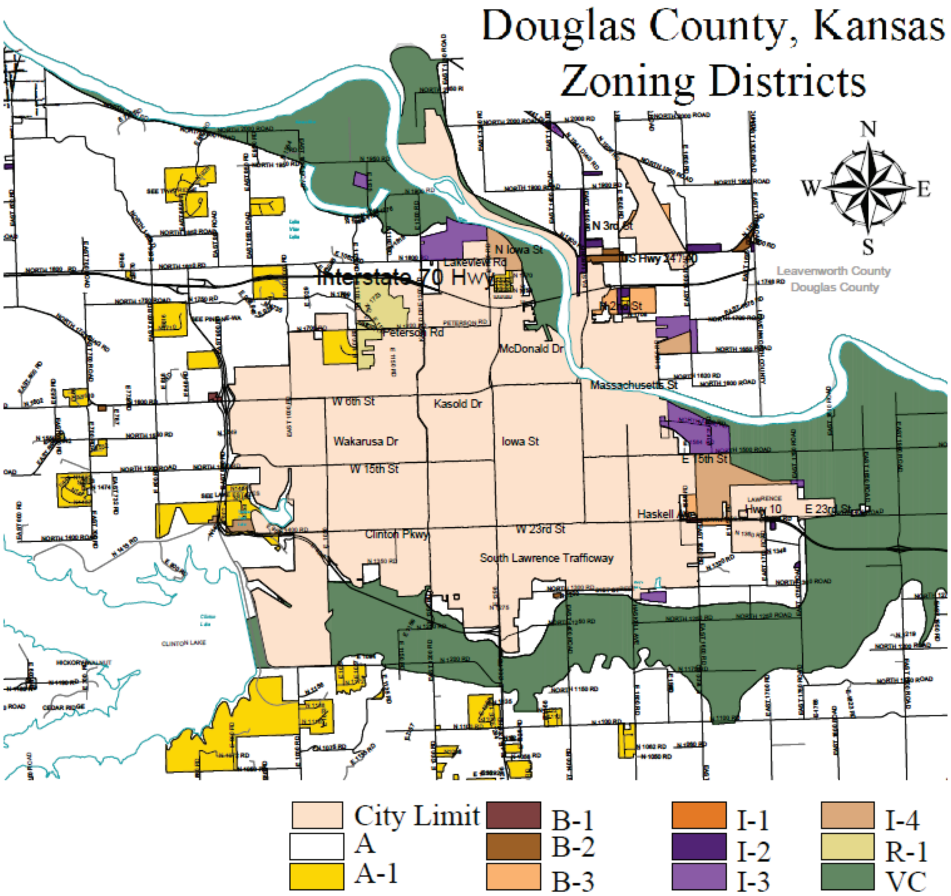


Figure 69. Zoning map for Douglas County depicting zones of allowed land uses outside Lawrence city limits. An interactive zoning map for inside city limits is available on the county planning office website (Douglas County 2011).

Many municipalities, especially those in the Midwest, allow agricultural uses (i.e., gardening) in most land use categories, but this observation should be determined on a case-by-case basis. Many larger cities have historically asserted more restrictions on agriculture in certain zones, e.g., Historic Districts or Historic Landmarks. These “overlay districts” superimpose existing zones and have special rules meant to protect the cultural value, aesthetics, functionality, or specified future land use (i.e., transportation development). The special rules applying to overlay districts are sometimes called restrictive covenants or declarations, but this term is more accurately used to refer to rules established by neighborhood associations or similar entities (New York City Department of Planning 2011). Residential restrictive covenants range from banning unsightly activities (which can sometimes include gardens) to establishing acceptable exterior paint colors. In the United States, restrictive covenants differ from zoning regulation because covenant creation and enforcement lies between landowners whose properties are subject to the covenants compared to governmental policing power with zoning ordinances (Bevans 2009). Commercial restrictive covenants govern such things as heights of buildings which may hinder views of/from culturally significant buildings, building heights near airports, or limiting businesses or business practices that are considered dirty, unhealthy, or unsightly for a particular area (Bevans 2009). Finally, easements or areas designated for access or use by entities other than the land owner (i.e., rights-of-way, power lines, access to public areas, etc.), can influence where a garden is located (Bevans 2009). While gardening in easements is technically allowed in most cases, since the rule primarily concerns access, the garden must not hinder access and the gardener must be aware that it can be damaged by digging, trampling, or paving.

In the U.S., there is a growing effort not only to add urban gardening as a permissible use in some zones, but to promote the practice as a part of urban revitalization. For instance, Cleveland, Ohio has established a zoning code designated as “Urban Garden District” to “meet needs for local food production, community health, community education, garden-related job training, environmental enhancement, preservation of green space, and community enjoyment” (FindLaw 2011). Boston was at the forefront of this movement by creating “Open Space Subdistricts” in 1988 providing a “comprehensive means for protecting and conserving open spaces through land use regulations” (City of Boston 1988). Seattle has a 5-year strategic plan for expansion of community gardens (City of Seattle 2000), Milwaukee has studied community garden trends and recommendations (Bremer, Jenkins and Kanter 2003), and Portland has a Diggable City Plan (Balmer et al. 2005). These advances and accomplishments promoting urban gardening highlight two points: first, that the policy landscape differs from city to city, and second, that urban dwellers, governments, and planners generally are becoming more accepting and even advocating gardens in urban settings. Sustainability in urban design, which often includes more green space, has become a central goal for urban planners who seek to reduce resource consumption, pollution, ecosystem damage, social inequality, and urban heat islands (American Planning Association 2007). Sustainable designs such as the eco-village theme strive for designs that provide services while achieving a harmonious balance among all living things (Dawson 2006).

5.2. Lessons from two cities

As urban gardeners have struggled to overcome obstacles to growing and selling produce within city limits, many have reported lessons learned to help continue advancement in improving our food system. This section focuses on two cities, including Lawrence, Kansas, where forward thinking individuals found ways to encourage progress, even when local policies seemed to be blocking their path forward. Flint, Michigan has a long history of urban gardening efforts and currently maintains a vibrant urban gardening scene despite some policy barriers. Just as we can learn from a land use history, a policymaking history can streamline decision making and planning for the future.

5.2.1. Lawrence policies that affect urban gardening

The City of Lawrence combines its efforts with the related Douglas County offices in planning arenas that concern both entities. One such area includes the future vision for the City and County, as well as the topic of sustainability. The County recently added a Department of Sustainability and the Sustainability Coordinator, Eileen Horn, started her position sharing time between the County and City offices. One of Ms. Horn’s responsibilities includes acting as facilitator of the new Food Policy Council, established in September of 2009 by the Douglas County Commission (Douglas County Department of Sustainability 2011).

The City's and County's emphasis on sustainability is not exceptional in the United States, but it is unusual for a Midwestern city of its size. With Lawrence's agricultural surroundings combined with a history of environmental concern (relative to surrounding cities), the addition of sustainability to a local governmental office is not surprising. According to the Department of Sustainability website (2011), the Food Policy Council (FPC):

> *Will serve as a forum for discussion and coordination for community-wide efforts to improve the Douglas County community's access to local food supply and distribution networks. Therefore, the FPC will focus on the following priority areas:*
>
> - *Economic development and entrepreneurial opportunities related to local food production and consumption*
> - *Improved health outcomes*
> - *Positive environmental quality impacts*
> - *Increased access to, and distribution of wholesome, local food*
> - *Support for local producers of sustainable food products*
> - *Identification, preservation, and/or sustainable development of local resources including soil, agricultural land, important breeds/cultivars, water, skilled labor, capital, and markets*
> - *Increased education and awareness on the part of Douglas County residents regarding the benefits of locally produced foods*

The first meetings of the FPC involved forming subcommittees and discussing the group's charges as listed above (Douglas County Department of Sustainability 2011). The FPC's first year has seen efforts to measure and map the "foodshed" of the region, meaning land in or available for production within 100 miles of a city (Thompson Jr., Harper and Kraus 2008). Unfortunately, the model does not appear to take into consideration soil health. The policy/infrastructure subcommittee has been working to map the foodshed, while the DIRT subcommittee focuses on preserving land (Douglas County Department of Sustainability 2011).

Very few policy barriers, if any, exist for urban gardeners in Lawrence. Table 17 outlines each ordinance that directly or indirectly influences gardening practices, including operating a garden on a site, use of sewage sludge, composting, greenhouses, and farmers' markets. Lawrence is surrounded by rich agricultural land and this pervades the policy environment within the city limits. Every zoning district allows agriculture (i.e., here agriculture includes plant propagation or gardening) with the exception of I-1, limited industrial. Of the industrial and manufacturing uses allowed in this zone, no agriculture is mentioned. Other industrial districts, I-2, I-3, and I-4 allow agriculture, but because of the polluting industries also allowed, gardening may not be appropriate in these zones.

Additional guidelines are found in the City of Lawrence Land Development Code (City of Lawrence Planning and Development Services 2006). This document provides detailed rules related to development and implementation of the Lawrence/Douglas County Comprehensive Land Use Plan, *Horizon 2020* (City of Lawrence 2011*)*. Authored by a joint group representing City and County officials, the Horizon 2020 Comprehensive Land Use Plan "allows the decision makers to look at the entire community and the effects of land use decisions on the community as a whole to determine whether individual proposals are consistent with the overall goals of the community." A proposed environmental chapter starts with the mission statement:

> *Identify environmental resources present in Douglas County, and draft goals, policies and strategies to support protection, conservation, and management of these resources in the context of development activity, planning, and government operations, to achieve a livable, vibrant, and healthy community.*

Lawrence, like many towns and cities across the U.S., is experiencing a gardening renaissance. In 2008, a sub-group of the Lawrence Sustainability Network was formed, called SLUG – Support for Local Urban Gardeners (Lawrence Sustainability Network 2008). The goal of SLUG involves various tasks from education through tilling yards, whatever it takes to help local folks start and maintain a garden. Considering the lack of zoning restrictions, establishment of a Department of Sustainability, the abovereferenced vision for a healthy, vibrant community, as well as the existence of the Farmers' Market and organizations like SLUG, urban gardening in Lawrence has a bright future.

Table 17. City of Lawrence zoning ordinances affecting gardening practices.

Article	Section	Explanation relative to gardening
4. General provisions, districts, and district maps	4-1 Districts established	Defines land use designations, called "zones" or "districts"
	4-6.10.02 Sewage disposal systems	Use of sewage sludge prohibited
	4-6.10.03 Disposal of garbage, rubbish, & refuse	Language prohibits composting practices that were done in a manner where "health hazards and offensive odors" were produced
6. "A" Agricultural district regulations	6-1	Purpose of district is to provide full range of agricultural activities.
7. "A-1" Suburban home district regulations	7-1 and 7-2 Use regulations	Allow same uses as "A" but with low density development on land not served by public sewer facilities.
8. "R-1" Single-family residential district	8-1 and 8-2 Use regulations	Allows same uses as "R-1," but with limitations on raising birds, bees, animals, fish or other creatures to objectionable to surrounding residences. No retail, wholesale office/store.
9. "B-1" Neighborhood business district	9-1 and 9-2 Use regulations	District provides retail shopping and personal service uses. Allows same uses as "R-1."
9A. "B-3" Limited business district	9A-1	District permits and encourages grouping of certain retail activities and services. Item 11 allows for a greenhouse.
10. "B-2" General business district	10-1 and 10-2 Use regulations	Provides sufficient space in appropriate locations for a wide variety of activities. Allows same uses as "B-1" and more.
11. "I-1" Limited industrial district	11-1 and 11-2 Use regulations	Provides sufficient space in appropriate locations, usually in planned industrial subdivisions, for certain types of business and manufacturing, none of which include agriculture.
12. "I-2" Light industrial district	12-1 and 12-2 Use regulations	Intended primarily for light manufacturing, fabricating, warehousing, and wholesale distributing. Allows any use in "B-1" or "B-2" and more.
13. "I-3" and "I-4" Heavy industrial district	13-1 and 13-2 Use regulations	Provides for industrial operations of all types. Protected from intrusion by commercial uses, signs, and dwellings. Item 4 allows for propagation of plants and seasonal sales of these products.
14. "V-C" Valley channel district	14-1 and 14-3 Use regulations	Prevents development in flood prone areas. Item 1 allows for gardening & Item 7 allows one farm dwelling per five acres.
19. Supplemental use regulations – Conditional Uses – Temporary Uses	19-1 and 19-1.01 Conditional uses and conditional use permits	Permits awarded in any district in which certain uses are prohibited when these uses are recognized as desirable because they are in the interest of the public health, safety, morals and general welfare of the community.
	19-4 Conditional Uses Enumerated	Enumerates Farmer's Market, Fruit and Vegetable Stand, Retail Nursery, and Value-added Agricultural Business (e.g., milling wheat, making jam, etc.).
25. Certificate of Occupancy	25-1 and 25-2	No vacant land and no buildings used until a certificate of occupancy and compliance has been issued except for strictly agricultural purposes.

5.2.2. Lessons about urban garden policy from Flint, Michigan

A study outlining recent policy and planning hurdles encountered by urban gardeners in Flint, Michigan provides guidelines for others experiencing similar trials (Masson-Minock and Stockmann 2011). One topic that emerged from public discussions focused on the differing planning and regulating requirements for urban gardening (i.e., community or backyard gardens) versus urban agriculture, which is perceived as consisting of larger-scale, for-profit operations that require more municipal services e.g., trash pick-up, parking, and access to municipal water and a source of electricity. Flint commissioners made the point that the distinction is important from a policy standpoint because more demand for city services and effects on neighbors calls for closer scrutiny of planned operations (Masson-Minock and Stockmann 2011).

Although the planning commission so far has resisted major policy changes, they took away some of the administrative barriers to building permit approval for structures, e.g., hoop houses (Masson-Minock and Stockmann 2011). Hoop houses are composed of a metal or plastic frame of hoops covered in plastic, which allows an extension of the growing season during cold temperatures. Hoop houses fell under regulations as permanent structures since they would be in place longer than 180 days, even though the structures can be easily moved or disassembled. This status meant that an expensive, lengthy permitting process was required, a difficult task for a non-profit organization wishing to erect a hoop house in Flint (Masson-Minock and Stockmann 2011). Other issues receiving public scrutiny were rules about keeping animals including chickens, goats, and bees. While certain allowances were made by the commissioners, they left major changes for the next phase of city master planning.

Authors of the Flint urban agriculture study provided a policy change guidebook of sorts, applicable to planners, policymakers, and gardeners alike (Masson-Minock and Stockmann 2011). Their recommendations have been adapted into a decision tree found in Figure 70. In addition, the authors provide a list of suggested amendments to ordinances that need to be changed (Masson-Minock and Stockmann 2011, 104).

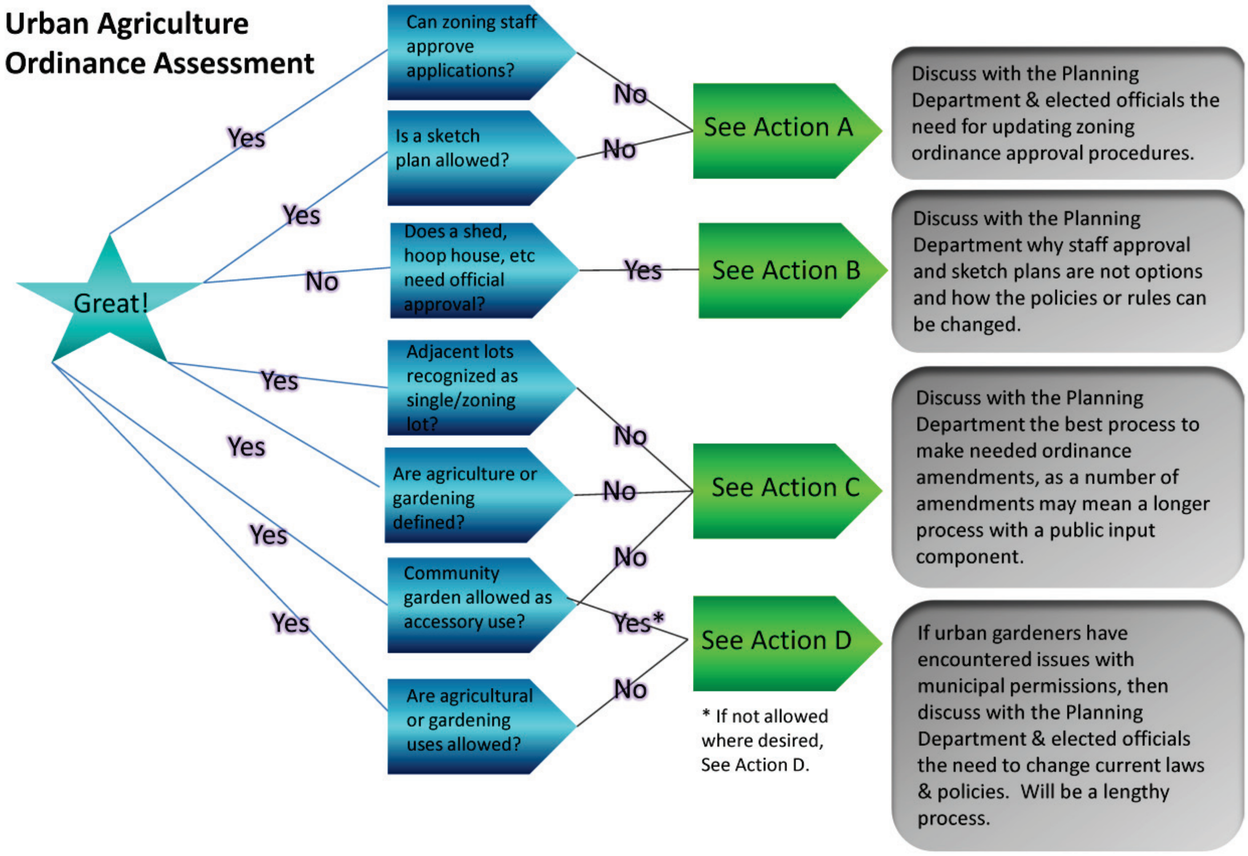


Figure 70. A selection of assessment questions that help urban gardeners and agriculturalists determine the policy landscape of their city and what actions will need to be taken where change is called for. Adapted from Appendix A of Masson-Minock and Stockmann (2011).

5.3. Best practices in plot management for gardeners

Many gardeners continually educate themselves about topics related to gardening, e.g., ways to increase yields or natural pest control. Because of this embedded desire for improvement, it seems reasonable that gardeners, once they become aware of a potential threat to their personal and plant health, would proactively seek solutions just as they have done for other garden issues. The following procedure presumes the proactive nature of the user, while, at the same time, considers various levels of resource availability, including time, money, information, and access to information. Clearly urban gardeners must first become aware of the issue for the procedure to achieve the goal of informed gardeners and working for increased soil resiliency and ultimately, improved community and ecosystem health. Since 2008, at the inception of this project, information on urban soil contamination available on the internet has increased substantially. But as awareness has increased, there is yet no accessible advice for gardeners to detect and manage soil toxins themselves. The following procedure attempts to fill this gap. It is made accessible by its decision tree form and because it offers alternative pathways depending on resource availability.

Step 1: Define goals

Important questions for the gardener to ask include, "What is the scope of this garden? Will the produce be offered for sale at a local market? Will the garden area be expanded?" The answers to these questions establish which policies may affect gardening activities and how to proceed with soil assessment and land management.

Step 2: Understand the relevant policies

If the gardener intends to grow produce for sale, s/he will need to look into rules governing where sale of products can occur. Sometimes antiquated rules place burdens on gardeners wishing to sell produce. A variety of solutions, from offering delivery through the Community Supported Agriculture (CSA) model to trading produce for services or other goods, may be a more achievable goal in the short term. Gardeners wishing to consume their own produce will not encounter restrictive policies in most cases. On the other hand, some neighborhood associations enforce strict guidelines regarding aesthetics, which can affect where a garden may be placed. By initially determining what gardening activities are allowed and where the garden can be legally sited will ensure fewer hurdles. Finally, in order to achieve certain goals, laws and regulations may need to be amended. The guidelines presented in Figure 70 provide a starting point, while the publication by Masson-Minock and Stockmann offers more specific advice (2011).

Step 3: Construct an environmental land use history for your plot

All soils under human occupation for any significant period show a record of that occupation. Since a large majority of soils in the United States have been impacted by human activities at one time or another and many of these activities have left a chemical signature, even in rural garden plots a land use history is worthwhile in planning efforts. The myriad online resources available to the public can aid in making a general assessment for the region or city, while a more concerted effort will be required to reconstruct a more detailed history. General and site-specific information can be derived from Sanborn Maps, often available through the public library system. Many communities store archived historic records, available either through community museums or libraries, city archives, or even individual collectors.

An equally important component to reconstruct is the environmental history of the region. Scorecard.org and Homefacts.com provide compiled environmental data for many cities, searchable by zip code (Scorecard 2005, Homefacts.com 2011). In addition, state health and environment departments maintain public searchable databases, sometimes in interactive map form. The home page of the EPA provides a searchable component (by zip code) that links the user directly to the environmental topic of interest for that region, including water and air quality, national priority sites (e.g., Superfund sites), and other relevant statistics (EPA 2011a). A summary of resources used to reconstruct the environmental and land use history of Lawrence garden is listed in Table 18. The sources listed for air pollution and water quality can also be used to assess continuing sources of contamination, vital information for constructing a feasible plan for safety and resiliency of a garden plot.

Table 18. Suggested sources for constructing an environmental and land use history of a plot.

Information type	Application	Potential sources
Historic land use	Date buildings constructed	Sanborn maps, county registry, building title
	Onsite, nearby land uses over time	Sanborn maps, city archives
	Dates and extent of fires, floods, etc.	Newspaper archives, community museum
Air pollution sources	Prevailing wind speed & direction for plume estimates	Windroses from EPA.gov/ttn/naaqs/ozone/areas/wind.htm
	Type, amount of stack pollution, etc	Scorecard.org, Homefacts.org, EPA.gov/TRI
	Transportation corridor pollution	Historic maps of railroads, roadways, etc.
Water pollution sources	Quality of municipal water supply	Local municipal water supplier, EPA.gov
	Contaminated flood waters	Historic maps; FEMA flood insurance maps
Waste facilities	Past, present municipal, hazardous waste sites	EPA.gov/waste
National priority sites	Location of known and hazardous contaminated places	Homefacts.org, EPA.gov/superfund/
Climate data	Dates, intensity of floods, droughts, climatic averages	National Climatic Data Center at NCDC.noaa.gov

Step 4: Know your soil

County soil surveys are available for virtually every county in the United States, a majority in digital format from the USDA Natural Resource Conservation Service. By simply determining which soil series a garden soil belongs to will provide general information about the parent material (which can be used to estimate background metal levels) and typical physical and chemical characteristics. Even knowing the texture of the soil can help assess mobility of metals (the coarser the soil, the more mobile the metal, in general). Furthermore, where XRF or other semi-quantitative or quantitative soil testing is inaccessible, estimating organic matter content through Munsell value provides a measure of soil resiliency and its ability to sorb metal cations, i.e., keeping them in the soil rather than accumulating in plant tissue.

Step 5: Use the decision support tool

Armed with information, including a land use history, current and past environmental concerns, and basic soil characteristics, the gardener can use the decision support tool (Figure 71) for determining what the next steps should be. For instance, a gardener in West Lawrence, whose house was built in the 1980s and has an organic rich soil, may determine that the best course of action is to compost his/her own food and yard waste (which allows for knowledge of what constituents are contained in the organic matter) and add the organic matter to his garden soil. On the other hand, a gardener in the plume of the biggest polluters in Lawrence may determine that extensive soil testing is necessary to learn about current contamination levels. Furthermore, this gardener may conclude that gardening in the contaminant plume (or living in it) is not in his/her best interest. Once the gardener uses the decision support tool (Figure 71) to find the logical next steps (e.g., further testing, addition of organic matter, appropriate plant selection), the supplemental information will aid in planning (Table 19, Figure 72, and Table 20).

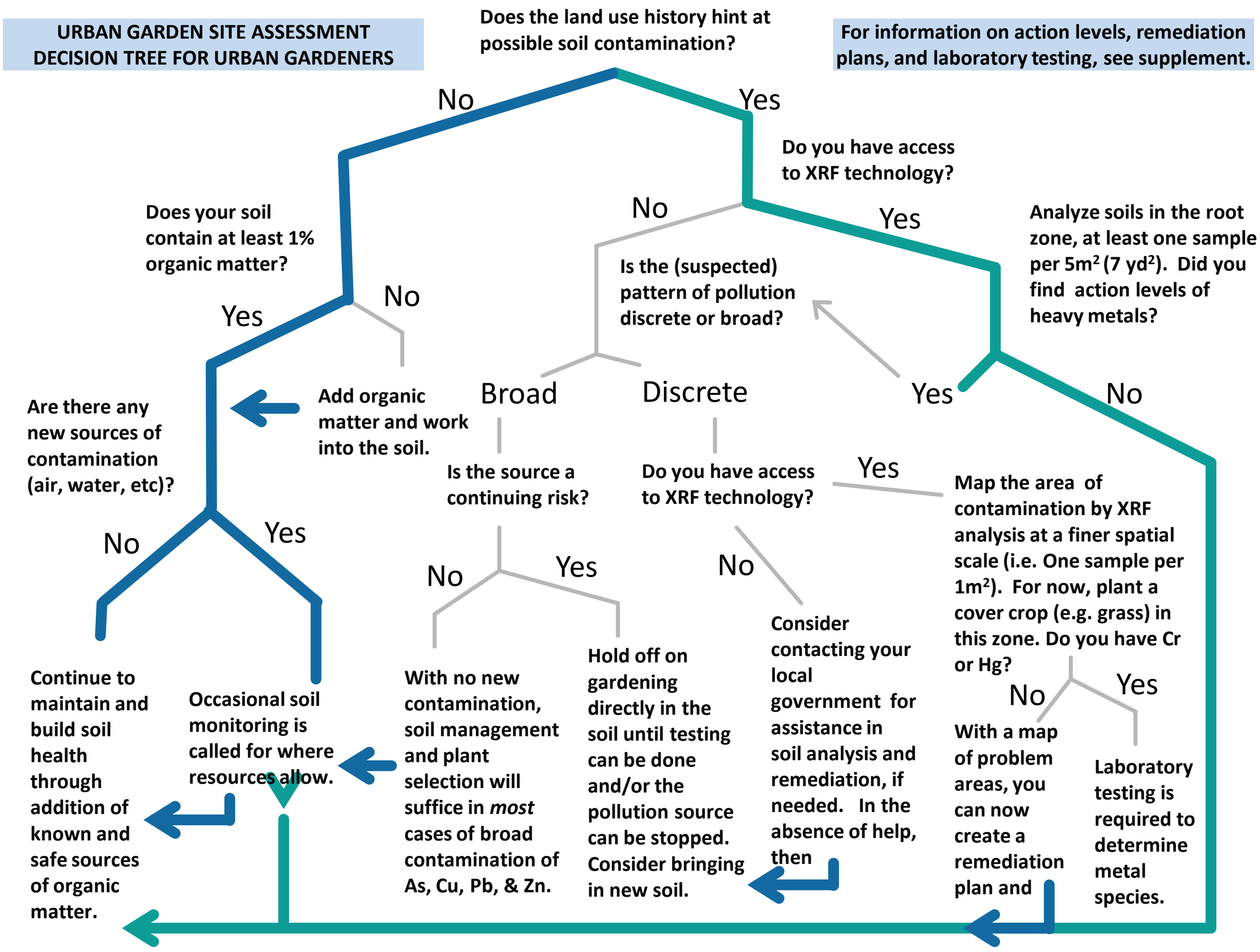


Figure 71. Decision support tool for urban gardeners wishing to assess level of soil contamination for deciding next steps. Action levels and advice on sample collection are available in Table 20 and Figure 72, respectively. Creating recommendations for mitigation or remediation and offering a list of preferred soil testing laboratories are areas of future work.

Table 19. Action levels and levels at which an expert should be consulted for select metals as determined by toxicity to human and plant health and typical soil ranges. Recommended actions include further testing (FT), plant selection (PS), addition of organic matter (OM), and pH control with liming (Keep pH below ~8; see Error! Reference source not found. **for more information).**

	Ag	**As**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Se**	**Zn**
Typical range in surface soils	0.01 - 5	1 - 50	0.06 - 1.1	1 - 1000	2 - 100	0.01 - 0.3	5 - 500	2 - 200	0.1 - 2	10 - 300
Phytoxic effects at	2	10	4	1	100	0.3	30	50	1	50
Adverse human health at	390	0.39	37	30[a]	3100	6.1[b]	1600	400	390	23,000
Action levels of metals	5	20	1	1	100	1	150	200	2	150
Recommend -ed action(s)	OM	PS, OM	PS, OM, pH	FT, pH	OM, pH	FT	OM, pH	PS, OM, pH	OM	OM, pH
Seek expert advice at	10	40	2	30	200	1	300	400	4	300

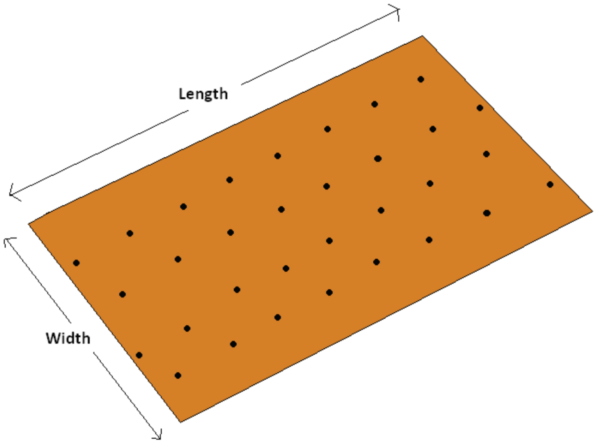
[a] Value for hexavalent chromium. Level is 10,000 ppm for trivalent chromium.

[b] Value for methyl mercury. Level is 23ppm for elemental mercury.

Figure 72. Soil sampling instructions, a supplement to the decision support tool.

SOIL SAMPLE COLLECTION PROCEDURE

1. Gather equipment.
2. Calculate area to be tested: (area = length x width)
3. Calculate number of sample sites: (#samples = area(ft^2) / 50) or (#samples = area(m^2) / 5)
4. Determine grid pattern of sample sites; number the rows for labeling ease.
5. Lay out measuring tape for each column to locate sample sites.
6. Collect samples from just below the surface at each grid point; note depth
   If using XRF, take reading at each grid point. Repeat for higher precision.
7. Place samples in labeled bags.
8. Send samples to appropriate testing facility.



Equipment list

- Notebook, pencil
- Measuring tape
- Ruler
- Small, sealable plastic bags
- Shovel or spade

Optional items

- Camera
- Munsell color book
- Hand texturing chart
- Calculator
- XRF handheld device

Optional steps

1. Besides a written record, picture taking provides another record of the sampling procedure and observations.
2. Use the Munsell soil color book to determine soil color throughout the garden (not necessarily at every sample site; a few would be sufficient, especially where differences are observed).
3. Use a hand texturing chart to determine soil texture class. Note moisture content (i.e., dry, moist, or saturated).
4. Take note of current and recent weather conditions (e.g., has it rained recently? Is it sunny today?).

Step 6: Plan next steps

Gardeners using the decision support tool will be directed to take one or more of several actions, including:

1. Continue to build and maintain soil health through addition of known and safe sources of organic matter.
2. Continue to monitor soil health where continuing sources of contamination exist.
3. Utilize appropriate plant selection to avoid root uptake and subsequent ingestion of certain metals.
4. Contact a soil expert or local government for assistance in soil analysis and remediation.
5. Do not garden until the soil can be tested and the pollution source can be stopped.
6. With a map of soil contamination, a risk mitigation plan can be formulated. Utilize plant selection, pH control, and addition of organic matter for managing known problem areas.

Action number one from the above list mentions “known and safe sources of organic matter.” While much of this document advocates for addition of organic matter to increase overall soil health and resiliency, some products that contain organic matter may also contain harmful constituents, including toxic metals. By composting food items and yard waste from known sources, the gardener controls the quality of organic matter placed on his soil. Action two also takes into consideration new or continuing sources of contamination. The information gathered by the gardener up to this point reveals whether there is a current source and the new awareness includes continued monitoring with ongoing pollution. This is where water and air quality become central themes. For example, even the well-meaning gardener collecting rainwater from his/her roof may need to consider heavy metals that are leaching from asphalt shingles or the consideration that when a neighbor removed lead paint from his house with a pressure washer, some of the contaminated water and paint chips entered the soil.

Plant selection, the third potential recommended action, can help mitigate risk in slightly contaminated soil. Since plants differ physiologically in the way they interact with soil, water, and air contaminants, a list of which plants concentrate which metals in their tissues is helpful (see Table 4). Even with a long history of studying plant uptake of certain metals, many experiments do not mimic *in vivo* conditions, limiting the applicability of the results. However, even a general understanding, e.g., that leafy vegetables should not be planted in soils high in lead or cadmium, can help gardeners minimize consumption of toxic metals. Lead in the home garden is discussed at several websites and at least one offers practical advice specifically geared toward home gardeners (Rosen 2002). More information is available for certain metals than others (Table 20). For instance, since mercury typically is not taken up by plant roots, it was not part of the bioaccumulation studies. Exposure to mercury and chromium will more feasibly happen with touching or breathing contaminated soil. Lead, arsenic, and cadmium are the stronger bioaccumulators, while high levels of nickel, zinc, and copper cause more problems for plants than people. Further collection and synthesis of known bioaccumulation research is needed to aid gardeners in appropriate plant selection. Meanwhile, general advice, such as the example above, will have to suffice.

Table 20. Summary of information on plant bioaccumulators presented in Table 4 and elsewhere in this document. While a "yes" indicates that an aforementioned research study found bioaccumulation of the metal in the plant, the absence of "yes" does not mean the particular plant is not a bioaccumulator of the metal.

Bioaccumulators	As	Cd	Cu	Ni	Pb	Zn
Leafy vegetables		yes	yes	yes	yes	yes
Celery and cabbage	yes	yes				
Root vegetables (mainly peels)	yes	yes	yes	yes	yes	
Tomato	yes	yes				
Squash (e.g., zucchini, cucumber)		yes		yes		yes (leaves)
Mushrooms			yes			yes
Pine nuts		yes				
Nuts						yes

Finally, action step six rewards the highest level of information gathering and synthesis, facilitating advanced planning for risk management and increased soil health. The absence of soil remediation from the action steps is indicative of its challenges. For instance, phytoremediation, (the intentional planting of bioaccumulators to remove a certain metal from the soil) is typically a very slow process, and the plants must be regularly trimmed and plant waste disposed of properly (in a landfill or hazardous waste facility). The process has been demonstrated to be quite effective, but it precludes gardening during the years that phytoremediation is occurring. Since the goal here is to promote gardening, other actions are favored to tackle contaminated soil, e.g., soil removal, addition of new soil, or dilution of the contaminated signal with addition of organic matter. Beyond depression of a signal of contamination, addition of soil organic carbon via biochar provides supreme conditions for the dual benefits of soil rejuvenation and reductions in bioavailability of certain metals such as arsenic (Hartley et al. 2009). Biochar is being hailed as a panacea that will revitalize degraded soils, sequester atmospheric carbon, increase crop yields, and mitigate soil toxins, matters relevant to urban gardening (International Biochar Initiative 2011). Current and future work to quantify these effects from biochar will provide another layer of options for urban gardeners seeking to produce a safe and healthy crop.

Chapter 6. Future Work

A resilient food system requires healthy soil and a distributed production pattern. Resiliency provides more opportunities and a greater capacity to adapt to change. The design of this project, exploring ways to encourage urban gardening, emphasizes a holistic approach, maintaining the need for healthy soils as a foundation to affect change at the community level, eventually extending to the national level. Without resilient soils, both gardening and efforts to modernize food policy fail.

The overarching goals of this project, to help individuals produce safe, healthy food to create bottom-up change on the U.S. food system comprises a life's work. What this project has accomplished is to provide proof-of-concept of some key ideas, including: (1) using land use and environmental histories to predict what metals are most likely present in a plot, (2) establishing a minimum garden soil sampling resolution of one sample per 5 m^2 to effectively capture overall patterns and concentrations of detected metals, (3) rejecting, for now, that Munsell soil color may act as an effective proxy for estimating soil organic matter by gardeners, and (4) developing decision support tools to help gardeners apply these concepts for increasing soil health and provide guidance in navigating policy landscapes.

While proof-of-concept has been established, only a scratching of the surface of applicable procedures has been achieved. More work will be required to make any positive impact on garden soil management and local and national food systems. For the idea of using history to estimate occurrence of metals, the results here provide only guidance for Lawrence gardeners. Repeating the study for multiple cities in a variety of settings with different histories will serve to establish general patterns that can then be applied broadly. A deeper investigation into prior land use linkages to certain metals can be started by conducting a local environmental history for each metal. A local history connected to a GIS analysis of known areas of pollution from anthropogenic and geologic sources can be a powerful tool for land use managers, policymakers, and planners.

The repetition of the Lawrence garden study format will also shed light on new ideas and relationships between the natural and anthropogenic histories of a place. The palimpsest concept will become a lens for interpreting GIS-based soil, garden, human, environmental, and policy landscapes. At the same time, there will be a growing number of gardeners who employ these techniques; as a welcome consequence, decision support tools can evolve as lessons are learned. For example, further work on proxies for estimating soil organic matter will fill a gap in the current tool, which fails to provide a good estimator. A connection was made during the course of this work with the lead author of the Wills, Burras and Sandor soil color study (2007) that successfully predicted soil organic carbon using soil color. Dr. Wills has agreed to collaborate on a study that builds on this concept, using data mined from the National Soil Information System.

Addition of organic matter is endorsed throughout this work as a simple way of immobilizing toxic metals, so communicating effective ways to add healthy sources of organic matter is essential. More work in the field of biochar research will help fill this void, including research on effective production and application procedures (see International Biochar Initiative 2011 for overview, see Odesola and Owoseni 2011 for review of production technologies) as well as how biochar can address toxic metals (Uchimiya et al. 2010, Uchimiya et al. 2011, Cao et al. 2011, e.g., Hartley et al. 2009). Furthermore, more research in the area of organic matter quality in general will be helpful. Biochar is unique in its variable levels of stability and increased purity of composition (Lehmann and Joseph 2009), while compost purchased from a gardening center may contain an array of components including undesirable trace metals. Quantifying the components of biochar and commercially available composts, then educating the public about the results, can further gardeners' understanding of varying qualities of sources of organic matter. This may also provide an incentive for garden composting, which gives ultimate control over what constituents are added to the soil by the gardener.

While adding soil organic matter to a garden soil can help immobilize heavy metals and reduce bioavailability, the metals remain in the soil and can still be ingested, breathed, or enter the body through the skin. More work in the area of exposure pathways of individual metals for urban populations would inform decision making of gardeners and policymakers. Additionally, there is a need for more *in vivo* studies of plant uptake of heavy metals, especially for common garden plants. While some of this has occurred, the contrast in results between studies gives no consensus, no master list of what plants to avoid, for instance, when a garden contains high concentrations of a certain metal. And disagreement among state and federal policies that set “safe” levels of metals in soils adds another layer of complexity to the issue. Some of the disagreement or even lack of established standards occurs because metals behave differently under different conditions. Yet, the same complicated reality occurs in Europe, where many more countries have established soil safety standards.

A major barrier for urban gardeners wanting to make informed decisions remains: the inaccessibility of XRF technology. While it is accessible in the sense of ease of use, the devices are cost-prohibitive (i.e., ~$37,000 to buy or $1000/week to rent based on spring, 2011 prices) for gardeners and most municipal governments. One suggestion for municipal governments suspecting toxic levels of metals in their jurisdiction is purchase the device so that gardeners can request a soil metal analysis for a modest fee, or the device can be rented or borrowed by gardeners. XRF handheld technology is relatively new, so perhaps, as is often true of new technology, the price will drop over time. In any case, the problem of cost of soil analyses has not been addressed in this work, as hoped. Because of this shortcoming, efforts will be redoubled to establish known linkages between land use history, environmental history, and the soil characteristics of a plot, and gardeners will be encouraged to enlist plant selection, composting, and pH control. These components of the study are accessible to all gardeners, serving the goal of increasing resiliency of soils, and ultimately, the U.S. food system.

Chapter 7. Bibliography

Adams, R. M. (1994) The origin of cities. *Scientific American (special issue)*, 12-19.

Adriano, D. C. 1986. *Trace Elements in the Terrestrial Environment*. Heidelberg: Springer-Verlag.

Aitchison, L. 1960. *A History of Metals, Vol. 1.* New York: MacDonald and Evans.

Al-Shawi, A. W. & R. Dahl (1999) The determination of cadmium and six other heavy metals in nitrate/phosphate fertilizer solution by ion chromatography. *Analytica Chimica Acta,* 391, 35-42.

Alegrea, J. C. & D. K. Cassel (1996) Dynamics of soil physical properties under alternative systems to slash-and-burn. *Agriculture, Ecosystems & Environment,* 58, 39-48.

Alloway, B. J. 1995. The origin of heavy metals in soils. In *Heavy Metals in Soils, 2nd ed.,* ed. B. J. Alloway, 38-56. London: Blackie Academic & Professional.

Alsgaard, S. 2009. 1113 New York Street history. ed. T. Jackson. Lawrence, KS.

American Association of Pediatrics (2005) Lead exposure in children: Prevention, detection, and management. *Pediatrics,* 16, 1036-1046.

American Planning Association. 2007. Policy Guide on Community and Regional Food Planning. Washington, D.C.: American Planning Association.

Anton, D. 1993. *Thirsty Cities: Urban Environments and Water Supply in Latin America*. Ottawa, Canada. : International Development Research Centre.

Armillas, P. (1971) Gardens on swamps. *Science,* 174, 653-661.

artist unknown. Nineteenth Century Waste Management in New York City. Photograph. New York, NY: Milstein Division of United States History, Local History & Genealogy, The New York Public Library.

---. 1932. Depression Relief Garden in Youngstown, OH. photography. Washington, DC: Library of Congress.

Associated Press. 1954. The Lawrence Paper Co. has oldest mill west of the Mississippi River. In *The Outlook*.

ASTC & SITES. 1998. Rotten Truth (About Garbage). In *Trash Timeline*. Association of Science-Technology Centers, Inc. (ASTC)

Smithsonian Institution Traveling Exhibition Service (SITES).

ATSDR (2007) Chapter 6: Exposure Evaluation: Evaluating Exposure Pathways. *Agency for Toxic Substances & Disease Registry Public Health Assessment Guidance Manual*. http://www.atsdr.cdc.gov/HAC/PHAmanual/ch6.html#6 (last accessed December 4, 2009).

---. 2009. Agency for Toxic Substances and Disease Registry 2007 CERCLA Priority List of Hazardous Substances. In *CERCLA Priority List of Hazardous Substances*.

---. 2010. Case Studies in Environmental Medicine: Arsenic Toxicity - Where is arsenic found? Agency for Toxic Substances and Disease Registry.

---. 2011. ToxFAQs. Centers for Disease Control and Prevention.

author unknown. Lawrence House. photograph. Lawrence, KS: Watkins Community Museum.

AWS Truewind LLC (2008) Kansas Wind. *Kansas Corporation Commission*. ftp://ftp.kcc.ks.gov/uploads/WindData/ (last accessed July 30, 2010).

Bache, B. W. 1979. pH. In *The Encyclopedia of Soil Science*, 487-492. Stroudsburg, PA: Dowden, Hutchinson, & Ross.

Bailey, G. (2007) Time perspectives, palimpsests and the archaeology of time. *Journal of Anthropological Archaeology,* 26, 198-223.

Balmer, K., J. Gill, H. Kaplinger, J. Miller, M. Peterson, A. Rhoads, P. Rosenbloom & T. Wall. 2005. The Diggable City: Making Urban Agriculture a Planning Priority. In *The Diggable City Project Final Report*.

Baran, P. 1964. On Distributed Communications: I Introduction to Distributed Communications Network. RAND Memorandum RM-3420-PR. RAND.

Barber, S. 1984. *Soil Nutrient Bioavailability – A Mechanistic Approach*. New York: John Wiley.

Barnhart, J. 1997. Chromium in soil: perspectives in chemistry, health and environmental regulation. In *Perspectives in Chemistry, Health and Environmental Regulation*, 561-568. Amherst: Association for the Environmental Health of Soils.

Barrow, N. J. 1987. *Reactions with Variable Charge Soils*. Dordrecht, the Netherlands: Kluwer Academic Publishers.

Basset, T. J. (1981) Reaping on the margins: A century of community gardening in America. *Landscape,* 25, 1-8.

Benson, N. R. (1968) Can profitable orchards be grown on old orchard soils? *Proceedings of the Washington State Horticultural Association,* 64, 1-E-5-E.

Berkowitz, B., I. Dror & B. Yaron. 2008. *Contaminant Geochemistry: Interactions and Transport in the Subsurface Environment*. Berlin Heidelberg: Springer-Verlag.

Berry, W. 2010. Strachan Donnelley Lecture on Restoration and Conservation. In *The Land Institute Prairie Festival*. Salina, KS, USA.

Bevans, N. R. 2009. *Real Estate and Property Law for Paralegals*. New York, NY: Aspen Publishers.

Beychok, M. 2007. Gaussian Plume.

Bingham, H. 1922. *Inca Land: Explorations in the Highlands of Peru*. Cambridge, NY: Houghton Mifflin.

Biofuels Journal (2001) Farmland lays off 68 at Lawrence, KS, nitrogen fertilizer plant. *Biofuels Journal Top Stories*. http://www.biofuelsjournal.com/articles/farmland_lays_off_68_at_lawrence__ks__nitrogen_fertilizer_plant-10559.html (last accessed March 2, 2011).

Blaikie, P. & H. C. Brookfield. 1987. *Land Degradation and Society*. London and New York: Methuen.

Bonan, G. B. 2002. *Ecological Climatology: Concepts and Applications*. Cambridge: Cambridge University Press.

Boserup, E. 1965. *The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure*. Chicago: Aldine.

Bowen, H. J. M. 1979. *Environmental Chemistry of the Elements*. London: Academic Press.

Brack, R. 1991. Old barbed wire building seen as next riverfront attraction. In *Lawrence Journal World*, 4B;10B.

Bradbury, K. L., A. Downs & K. A. Small. 1982. *Urban Decline and the Future of American Cities*. Washington, D.C.: Brookings Institution Press.

Brady, N. C. & R. R. Weil. 2002. *The Nature and Properties of Soils. 13th Edition.* . Upper Saddle River, New Jersey: Prentice Hall.

Bremer, A., K. Jenkins & D. Kanter (2003) Community gardens in Milwaukee. *Milwaukee Urban Gardens*. http://neighbor-space.org/documents/UrbanGardens_Milwauke_May03.pdf (last accessed March 24, 2011).

Bridson, J. 2008. Reply to Request for Information Under Section 104 (e) of the Comprehensive Environmental Response, Compensation, and Liability Act, 42 U.S.c. 9604(e). Topeka, KS: Westar Energy.

Brookfield, H. C. (1984) Intensification revisited. *Pacific Viewpoint,* 25, 15-44.

---. 2001. *Exploring Agrodiversity*. New York: Columbia University Press.

Brush, G. S. 1994. The Chesapeake Bay estuary system. In *The Changing Global Environment*, 297-416. Oxford, UK: Blackwell.

Buck, S. & D. Gerard (2001) Cleaning up mining waste. *Political Economy Research*.

Büntgen, U., W. Tegel, K. Nicolussi, M. McCormick, D. Frank, V. Trouet, J. O. Kaplan, F. Herzig, K.-U. Heussner, H. Wanner, J. Luterbacher & J. Esper (2011) 2500 years of European climate variability and human susceptibility. *Science,* 331, 578-582.

Burke, M. B., E. Miguel, S. Satyanath, J. A. Kykema & D. B. Lobell (2009) Warming increases the risk of civil war in Africa. *Proceedings of the National Academy of Science,* 106, 20670-20674.

Burland, C. A. 1976. *People of the Sun: the Civilizations of Pre-Columbian America*. New York: Praeger Publishers Inc.

Burló, F., I. Guijarro, A. A. Carbonell-Barrachina, D. Valero & F. Martínez-Sánchez (1999) Arsenic species: Effects on and accumulation by tomato plants. *Journal of Agriculture and Food Chemistry,* 47, 1247–1253.

Caldwell, E. F. 1898. *A Souvenir History of Lawrence*. Kansas City, MO: Press of Lawton & Burnap.

Calvert, H. 2008. Stone house cascade. Choquequirao.

Cao, X., M. Lena, L. Yuan, G. Bin & H. Willie (2011) Simultaneous immobilization of lead and atrazine in contaminated soils using dairy-manure biochar. *Enivronmental Science and Technology,* 45, 4884-4889.

Carlson, T. N., J. K. Dodd, S. G. Benjamin & J. N. Cooper (1981) Satellite estimation of the surface energy balance, moisture availability and thermal inertia. *Journal of Applied Meteorology,* 20, 67-87.

Carson, R. 1962. *Silent Spring*. New York, NY: Houghton Mifflen.

Castillo, G. E. (2003) Livelihoods and the city: an overview of the emergence of agriculture in urban spaces. *Progress in Development Studies,* 3, 339-344.

Caviness, P. O. 1988. *Building History: The Consolidated Barb Wire Company Drawing Mill and the Industrial Riverfront of Lawrence, Kansas*. Lawrence, KS.

Chamel, A. 1986. In *Foliar Fertilization*, 66-86. Dordrecht: Martinus Nijhoff.

Chaney, R. L. & P. M. Giordano. 1977. Microelements as related to plant deficiencies and toxicities. In *Soils for Management of Organic Wastes and Waste Waters*, 234-279. Madison, WI: American Society of Agronomy.

Chirenjea, T., L. Q. Maa, C. Clark & M. Reeves (2003) Cu, Cr and As distribution in soils adjacent to pressure-treated decks, fences, and poles. *Environmental Pollution,* 127, 407-417.

City of Boston (1988) Article 33, Open Space Subdistricts. *Article 33, Section 33-1*. http://www.bostonredevelopmentauthority.org/pdf/ZoningCode/Article33.pdf (last accessed March 24, 2011).

City of Kansas City, M. 2009. City of Kansas City, Missouri. In *Climate Protection Plan*.

City of Lawrence (2007) City Growth Study. http://lawrenceks.org/map/CityGrowthStudy.pdf (last accessed March 4, 2011).

---. 2009. 2009 City of Lawrence Water Quality Report. Lawrence, KS: City of Lawrence.

--- (2011) Horizon 2020 - Comprehensive Land Use Plan. *City of Lawrence, Kansas*. http://www.lawrenceks.org/pds/lr-H2020 (last accessed March 24, 2011).

City of Lawrence Planning and Development Services (2006) Chapter 20 - Code of the City of Lawrence, Kansas. *Land Development Code*. http://www.lawrenceplanning.org/documents/DevCode_2009.pdf (last accessed March 24, 2011).

City of Seattle (2000) Resolution Number: 30194. *City Clerk's Online Information*. http://clerk.ci.seattle.wa.us/~scripts/nph-brs.exe (last accessed March 24, 2011).

Clark, H., D. Brabander & R. Erdil (2006) Sources, sinks, and exposure pathways of lead in urban garden soil. *Journal of Environmental Quality,* 35, 2066-2074.

Clark, P. 2010. Agricultural Policy in Kansas. ed. T. Jackson. Topeka, KS, USA: US Department of Agriculture.

Cochrane, W. W. 1979. *The Development of American Agriculture*. Minneapolis: University of Minnesota Press.

Coe, M. (1964) The *chinampas* of Mexico. *Scientific American,* 211, 90-98.

Coe, M., D. Snow & E. Benson. 1986. *An Atlas of Ancient America*. Oxford: Equinox.

Collins, S. & E. Larry. 2007. Caring for Our National Assets - An Ecosystem Services Perspective. Washington, D.C.: U.S. Department of Agriculture.

Conner, J. D., L. S. Ebner, C. A. O'Conner, C. Volz & K. W. Weinstein. 1987. *Pesticide Regulation Handbook*. New York: Executive Enterprises.

Conry, M. J. (1974) Plaggen soils, a review of man-made raised soils. *Soils and Fertilizers,* 37, 319-326.

Conway, G. R. & J. Pretty. 1991. *Unwelcome Harvest: Agriculture and Pollution*. London: Earthscan.

Courtlandt, C. & A. Kocybala. 1990. *A Guide to the Archaeological Sites of Israel, Egypt and North Africa*. New York: Facts on File.

Culman, S. W., S. T. DuPont, J. D. Glover, D. H. Buckley, G. W. Fick, H. Ferris & T. E. Crews (2009) Long-term impacts of high-input annual cropping and unfertilized perennial grass production on soil properties and belowground food webs in Kansas, USA. *Agriculture, Ecosystems and Environment*.

Dalan, R. A., G. R. Holley, W. I. Woods, H. W. Watters Jr & J. A. Koepke. 2003. *Envisioning Cahokia: A Landscape Perspective*. DeKalb, IL: Northern Illinois University Press.

Dale, V. H., K. L. Kline, J. Wiens & J. Fargione. 2010. Biofuels: Implications for Land Use. In *Biofuels and Sustainability Reports*. Washington, DC: Ecological Society of America.

Davis, R. D. & C. Calton-Smith. 1980. Crop as Indicators of the Significance of Contamination of Soil by Heavy Metals. Stevenage, UK: Water Research Centre.

Dawson, J. 2006. *Ecovillages: New Frontiers for Sustainability*. Green Books.

Denevan, W. M. 1976. *The Native Population of the Americas in 1492*. Madison: University of Wisconsin Press.

--- (1998) Comments on prehistoric agriculture in Amazonia. *Culture & Agriculture,* 20, 54-59.

Deneven, W. M. 2001. *Cultivated Landscape of Native Amazonia and the Andes*. Oxford: Oxford University Press.

Denver Urban Gardens. 2010. DUGs Role in Your Community Garden. Denver, CO: Denver Urban Gardens.

Dobyns, H. F. (1966) Estimating aboriginal American population: An appraisal of techniques with a new hemispheric estimate. *Current Anthropology,* 7, 395-416.

Doolittle, W. E. 2000. *Cultivated Landscapes of Native North America*. Oxford: Oxford University Press.

--- (2004) Gardens are us, we are nature: Transcending antiquity and modernity. *The Geographical Review,* 94, 391-405.

Douglas County. 2011. The Department of Zoning & Codes.

Douglas County Department of Sustainability. 2011. Food Policy Council.

Dull, R. A., R. J. Nevle, W. I. Woods, D. K. Bird, S. Avnery & W. M. Deneven (2010) The Columbian encounter and the Little Ice Age: Abrupt land use change, fire, and greenhouse forcing. *Annals of the Association of American Geographers,* 100, 775-771.

Dunn, D. J. 2008. The Science Behind Water Quality and Pipe Restoration. CuraFlo.

DuPlessis VanBreda, A. 2001. Resilience Theory: A Literature Review. Pretoria, South Africa: South African Military Health Service, Military Phychological Health Institute, Social Work Research & Development.

Economic Research Service. 2010. State Fact Sheets: United States. U.S. Department of Agriculture.

Egan, T. 2006. *The Worst Hard Time: The Untold Story of Those Who Survived the Great American Dust Bowl*. New York, NY: Houghton Mifflin.

Energy Information Administration (2008) EIA Independent Statistics & Analysis. *Form EIA-906, EIA-920, and EIA-923 Databases*. http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html (last accessed March 2, 2011).

Author. 2011. The city that grows: Officials, local farmers divided on new urban agriculture rules. *Chicago Tribune* January 3, 2011.

EPA. 1978. Love Canal Protest. Washington, DC.

--- (1996) EPA Takes Final Step in Phaseout of Leaded Gasoline. *U.S. Environmental Protection Agency History*. http://www.epa.gov/history/topics/lead/02.htm (last accessed March 16, 2011).

--- (1998) About the ATSDR. http://www.epa.gov/ttnatw01/urban/aboutatsdr.pdf (last accessed February 16, 2011).

---. 1998, rev. 2005. Toxicological Review of Barium and Compounds. Washington, D.C.: U.S. Environmental Protection Agency.

--- (2005) EPA Commemorates its History and Celebrates its 35th Anniversary. http://www.epa.gov/history/ (last accessed December 5, 2009).

---. 2006a. Environmental Protection Agency Municipal Solid Waste.

---. 2006b. Life Cycles Assessment: Principles and Practice. Cincinnati, OH: United States Environmental Protection Agency.

---. 2006c. XRF Technologies for Measuring Trace Elements in Soils and Sediments. Washington, DC: Environmental Protection Agency.

---. 2009a. Ag 101 - Demographics. Environmental Protection Agency.

---. 2009b. Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2009. Washington, DC: U.S. Environmental Protection Agency.

---. 2010a. Mercury.

--- (2010b) Residential Lead Hazard Standards - TSCA Section 403. *Environmental Protection Agency - Lead in Paint, Dust, and Soil*. http://www.epa.gov/lead/pubs/leadhaz.htm (last accessed February 16, 2011).

---. 2010c. Technology Transfer Network Support Center for Regulatory Atmospheric Modeling.

---. 2011a. Environmental Protection Agency.

---. 2011b. Toxics Release Inventory (TRI) Program - TRI Current Data.

Erickson, C. 2003. Historical ecology and future explorations. In *Amazonian Dark Earths: Origin, Properties, and Management*, 455. Norwell, MA: Kluwer Academic Publishers.

Erickson, L., K. Griggs, M. Maria & H. Serebrin. 2009. Urban Agriculture in Seattle: Policy & Barriers. Seattle, WA.

ESRI. 2002. ESRI Data & Maps. Redlands, California: Environmental Systems Research Institute, Inc. (ESRI).

FAO. 2009. Climate Change and Food Security. In *Profile for Climate Change*, 2. Rome, Italy: Food and Agriculture Organization of the United Nations.

Farm Service Agency. 2010. Cumulative CRP Enrollment by State, FY 1986 - FY 2009. U.S. Department of Agriculture.

Feenstra, G. 1992. Should the food system be decentralized? In *Sustainable Agriculture*. University of California Sustainable Agriculture Research and Education Program.

Ferracane, J. L. 2001. *Materials in Dentistry: Principles and Applications, 2nd ed.* Baltimore, MD and Philadelphia, PA: Lippincott, Williams, & Wilkins.

FindLaw (2011) FindLaw. *City of Cleveland Codified Ordinances Chapter #336, Part III - Zoning Code*. http://caselaw.lp.findlaw.com/clevelandcodes/cco_part3_336.html (last accessed March 24, 2011).

Folkes, D. J. (2001) Contributions of pesticide use to urban background concentrations of arsenic in Denver, Colorado, U.S.A. *Environmental Forensics,* 2, 127-139.

Food Standards Agency of the United Kingdom. 2007. Survey of Metals in a Variety of Foods. London, UK: Food Standards Agency.

Fort, T. 2000. *The Grass Is Greener – Our Love Affair with the Lawn*. New Baskerville: Harper Collins Publishers.

Fowler, M. L. 1997. *The Cahokia Atlas: A Historical Atlas of Cahokia Archaeology*. Urbana, IL: Illinois Transportation Archeological Research Program, University of Illinois.

Francis, M., L. Cashdan & L. Paxson. 1984. *Community Open Spaces: Greening Neighborhoods Through Community Action and Land Conservation*. Washington, D.C.: Island Press.

Francisco, M. P., D. Clay & H. Smeltekop. 2010. Geospatial Soil Conservation Using Andean Technology by the Inca Empire. In *Green Revolution 2.0: Food+Energy and Environmental Security*. Long Beach, CA: American Society of Agronomy, Inc. (ASA), Crop Science Society of America, Inc. (CSSA), and Soil Science Society of America, Inc. (SSSA).

Fuchs, G. 2008. Metals in printing inks. In *NAPIM Bulletin 08-05*. Woodbridge, NJ: National Association of Printing Ink Manufacturers, Inc.

Gad, S. C. & C. P. Chengelis. 2001. Human pharmaceutical products. In *Regulatory Toxicology, 2nd Ed*, 9-69. London: Taylor and Francis.

Gallup. 1976. Gallup Poll, National Garden Survey. Princeton: Gallup.

Gamlin, L. & B. Price (1988) Bonfires and brimstone. *New Scientist*, 48-51.

Geertz, C. 1963. *Agricultural Involution: The Processes of Ecological Change in Indonesia*. Berkeley and Los Angeles, California: University of California Press.

Glaser, B. & W. I. Woods. 2004. *Amazonian Dark Earths: Explorations in Space and Time*. Berlin: Springer-Verlag.

Glover, J. D., J. P. Reganold, L. W. Bell, J. Borevitz, E. C. Brummer, E. S. Buckler, C. M. Cox, T. S. Cox, T. E. Crews, S. W. Culman, L. R. DeHaan, D. Eriksson, B. S. Gill, J. Holland, F. Hu, B. S. Hulke, A. M. H. Ibrahim, W. Jackson & e. al. (2010) Increased food and ecosystem security via perennial grains. *Science,* 338, 1638-1639.

Goldschmidt, W. 1946. Small Business and the Community - Report of the Smaller War Plants Corporation to the Special Committee to Study Problems of American Small Business. Washington, D.C.: U.S. Government Printing Office.

Graham, R. D. 1981. In *J. F. Loneragan; A. D. Robson; R. D. Graham*, 141-163. Sydney: Academic Press.

Grimes, J. 2009. Vermont Street Garden. ed. T. Jackson.

Grimmond, C. S. B. & T. R. Oke (1995) Comparison of heat fluxes from summertime observations in the suburbs of four North American cities. *Journal of Applied Meteorology,* 34, 873-889.

Gunderson, L. H. & L. Pritchard. 2002. *Resilience and the behavior of large-scale systems*. Washington, D.C.: Island Press.

Gurian-Sherman, D. 2009. Failure to Yield: Evaluating the Performance of Genetically Engineered Crops. Cambridge, MA: Union of Concerned Scientists.

Haas, A. 1993. *Gardens of Mexico*. New York: Rizzoli.

Hall, R. A., H. MacGregor, M. Stockwell & P. V. Addyman. 1988. *The Archaeology of York*. Council for British Archaeology.

Hamblin, W. K. 1978. *The Earth's Dynamic Systems, A Textbook in Physical Geology*. Provo, UT: Brigham Young University.

Hammond, N. 1994. *Ancient Maya Civilization, Fifth Edition*. Newark, NJ: Rutgers University Press.

Hanson, B. 2011. Floods and the North Lawrence Community Garden. ed. T. Jackson.

Hartley, W., N. M. Dickinson, P. Riby & N. W. Lepp (2009) Arsenic mobility in brownfield soils amended with green waste compost or biochar and planted with Miscanthus. *Environmental Pollution,* 157, 2654-2662.

Heimer, L. 2008. First World War Liberty Gardens: 1917-1919. In *Sprouts in the Sidewalk*.

Henry, J. A. & S. E. Dicks (1987) Association of urban temperatures with land use and surface materials. *Landscape and Urban Planning,* 14, 21-29.

Henry, J. A., S. E. Dicks & G. A. Marotz (1985) Urban and rural humidity distributions: relationships to surface materials and land use. *Journal of Climatology,* 5, 53-62.

Hodge, C. A. & N. N. Popovici. 1994. *Pollution Control in Fertilizer Production*. New York, NY: Marcel Dekker.

Hollem, H. R., photographer. 1944. Jeffersontown, Kentucky. In *Farm Security Administration - Office of War Information Photograph Collection*. Washington, DC: Office of War Information, Overseas Picture Division, Washington Division, Library of Congress.

Homefacts.com. 2011. Lawrence Environmental Hazards.

Hong, B. D. & E. R. Slatick. 1994. Carbon dioxide emission factors for coal. In *Energy Information Administration, Quarterly Coal Report*, 1-8. Washington, DC.

Hovmand, M. F., J. C. Tjell & H. Mossbaek (1983) Plant uptake of airborne cadmium. *Environmental Pollution (Series A),* 30, 27-38.

Ikerd, J. 2010. Corporatization of American agriculture. In *Small Farm Today*.

International Biochar Initiative. 2011. What is Biochar? In *International Biochar Initiative (IBI)*.

International Union of Soil Scientists. 2007. World Reference Base for Soil Resources 2006, first update 2007. Rome: FAO.

Jain, H. K. 2010. *The Green Revolution: History, Impact and Future*. Houston, TX: STUDIUM PRESS.

Jellicoe, G. 1989. *The Landscape of Civilisation*. Northiam, UK: Garden Art Press.

Jenny, H. 1941. *Factors of Soil Formation*. New York: McGraw Hill Co.

Johnson, M. G. 1995. The role of soil management in sequestering soil carbon. In *Soil Management and the Greenhouse Effect*, 351-363. Boca Raton, FL: Lewis Publishers.

Jones, H. O. A., N. Voulvoulis & J. N. Lester (2001) Human pharmaceuticals in the aquatic environment: a review. *Environmental Technology,* 22, 1383-1394.

Juracek, K. E., C. A. Perry & J. E. Putnam (2008) The 1951 Floods in Kansas Revisited *U.S. Geological Survey Kansas Water Science Center*. http://ks.water.usgs.gov/pubs/fact-sheets/fs.041-01.html (last accessed March 4, 2011).

Kabata-Pendias, A. & H. Pendias. 1984. *Trace Elements in Soils and Plants*. Boca Raton, FL: CRC Press, Inc.

Kanas Applied Remote Sensing. 2009. Eastern Kansas Depth-To-Flood Map. Lawrence, KS: Kansas Biological Survey University of Kansas.

Kanas Geological Survey (1999) Geohydrology of Douglas County: Subsurface stratigraphy. *KGS Geology*. http://www.kgs.ku.edu/General/Geology/Douglas/strat01.html (last accessed March 26, 2011).

Kansas Department of Health and Environment. 2011. Solid Waste Database.

Kansas Water Science Center. 2009. In *Kansas River Flood of 1903*. USGS.

Kaplan, R. (1973) Some psychological benefits of gardening. *Environment and Behavior,* 52, 143-62.

Kenyon, D. J., D. C. Elfving, I. S. Pakkala, C. A. Bache & D. J. Lisk (1979) Residues of lead and arsenic in crops cultured on old orchard soils. *Bulletin of Environmental Contamination and Toxicology,* 22, 221-223.

Kern, A. 2009. 2116 New Hampshire. ed. T. Jackson.

Kidder, S. Q. & O. M. Essenwanger (1995a) The effect of clouds and wind on the difference in nocturnal cooling rates between urban and rural areas. *Journal of Applied Meteorology,* 34, 2440-2448.

--- (1995b) The effect of clouds and wind on the difference in nocturnal cooling rates between urban and rural areas. *Journal of Applied Meteorology,* 34, 2440-2448.

Kimber, C. (2004) Gardens and dwelling: People in vernacular gardens. *The Geographical Review,* 94, 263-283.

Kislev, Y. & W. Peterson (1981) Induced Innovations and Farm Mechanization. *American Journal of Agricultural Economics,* 63, 562-565.

Konen, M. E., C. L. Burras & J. A. Sandor (2003) Organic carbon, texture and quantitative color measurements relationships for cultivated soils in north Central Iowa. *Soil Science Society of American Journal*, 1823–1830.

Kraska, R. C. 2001. Industrial chemicals: Regulation of new and existing chemicals (The Toxic Substances Control Act and similar worldwide chemical control laws). In *Regulatory Toxicology, 2nd Ed.*, 244-276. London: Taylor and Francis.

Krochmal, C. (2005) The Role of War Gardens. *Suite101.com*. http://www.suite101.com/article.cfm/fruit_garden/112567/1 (last accessed January 28, 2011).

Landsberg, H. E. 1981. *The Urban Climate*. New York: Academic Press.

Lassman, D. & D. B. Bentley. 2009. Bill Hatke: The Life, Writings and Legend of Our Friend Bill.

Lawhorn, C. (2010) City of Lawrence makes official purchase of former Farmland Industries fertilizer plant. *LJWorld.com*. http://www2.ljworld.com/news/2010/sep/29/city-lawrence-officially-purchase-former-farmland-/ (last accessed March 2, 2011).

Author. 1931. Remodel hotel. *Lawrence Daily Journal-World*.

Author. 1951. $16 million fertilizer plant here. *Lawrence Daily Journal-World* October 11.

Author. 1950. (title unknown). *Lawrence Journal-World* July 22.

Author. 1975. Cable plant to locate in Lawrence. *Lawrence Journal World* January 8.

Lawrence Sustainability Network. 2008. Support for Local Urban Gardeners (SLUG).

Lawson, L. 2005. *City Bountiful: A Century of Community Gardening in America*. Berkeley and New York: University of California Press.

Lee, J. 2009. The White House Blog.

Lehmann, J. & S. Joseph. 2009. *Biochar for Environmental Management: Science and Technology*. Earthscan Publications Ltd.

Lepp, N. W. 1981. *Effect of Heavy Metal Pollution on Plants, Vol. 2. Metals in the Environment*. New Jersey: Applied Science Publishers, Ltd.

Lewis, S. L., P. M. Brando, O. L. Phillips, G. M. F. v. d. Heijden & D. Nepstad (2011) The 2010 Amazon drought. *Science,* 331, 554.

Library of Congress. 1943 and 1944. Victory Gardens. Washington, DC: Library of Congress.

Loomis, R. S. & D. J. Connor. 1991. *Crop Ecology: Productivity and Management in Agricultural Systems*. Cambridge: Cambridge University Press.

Los Angeles County. 2006. Puente Hills Landfill. ed. L. A. County. Los Angeles, CA: Sanitation Districts of Los Angeles County.

Losey, J. E., L. S. Rayor & M. E. Carter (1999) Transgenic pollen harms Monarch larvae. *Nature*.

Luber, G. & M. McGeehin (2008) Climate change and extreme heat events. *American Journal of Preventative Medicine,* 35, 429–435.

Lyle, S. A. 2009. Glaciers in Kansas. Lawrence, KS: Kansas Geological Survey.

MacDonald, J. A. 2010. How Cities Use Parks for Climate Change Management. Chicago: American Planning Association.

MacLean, K. S. & W. M. Langille (1981) Arsenic in orchard and potato soils and plant tissue. *Plant and Soil,* 61, 413-418.

Mahaffey, K. R., J. L. Annest, J. Roberts & R. S. Murphy (1982) National estimates of blood lead levels: United States, 1976-1980: Association with selected demographic and socioeconomic factors. *New England Jounral of Medicine,* 307, 573-579.

Malthus, T. R. 1798. *An Essay on the Principle of Population*. London: J. Johnson.

Marcotullio, P., A. Braimoh & T. Onishi. 2008. The impact of urbanization on soils. In *Land Use and Soil Resources*, 232-250. Stockholm, Sweden: Springer.

Marschner, H. 1986. *Mineral Nutrition in Higher Plants*. London: Academic Press.

Martinez, S. 2010. Local Food Systems: Concepts, Impacts, and Issues Washington, D.C.: United States Department of Agriculture.

Marx, K. 1959. *Book 3, The Process of Capitalist Production as a Whole*. London: Lawrence & Wishart.

Masip, G. 2003. Los Agroecosistemes Tradicionals de la Bisbalde Falset. Andalucía, Baeza: Universidad Internacionalde.

Masson-Minock, M. & D. Stockmann (2011) Creating a legal framework for urban agriculture: Lessons from Flint, Michigan. *Journal of Agriculture, Food Systems, and Community Development,* 1, 91-104.

Mattina, M. I., W. Lannucci-Berger, C. Musante & J. C. White (2003) Concurrent plant uptake of heavy metals and persistent organic pollutants from soil. *Environmental Pollution,* 124, 375–378.

McBride, M. B. (1989) Reactions controlling heavy metal solubility in soil. *Advances in Soil Science,* 10, 1-56.

---. 1991. Processes of heavy and transition metal sorption by soil minerals. In *Interactions at the Soil Colloid-Soil Solution Interface*, 149-174. Dordrecht, The Netherlands: Kluwer Academic Publishers.

McCann, A. M. (1994) The Roman port of Cosa. *Scientific American (special issue)*, 92-99.

McCauley, J. D., B. A. Engel, C. E. Scudder, M. T. Morgan & P. W. Elliot. 1993. Assessing the Spatial Variability of Organic Matter. In *Transactions of the ASAE*. St. Joseph, MI: American Society of Agricultural Engineers.

McLaughlin, M. J., B. Zarcinas, D. Stevens & N. Cook (2000) Soil testing for heavy metals. *Communications in Soil Science and Plant Analysis,* 31, 1661-1700.

McNeill, J. R. & V. Winiwarter. 2006. Preface. In *Soils and Societies: Perspectives from Environmental History,* eds. J. R. McNeill & V. Winiwarter, 1-4. UK: The White Horse Press.

Meagher, R. B. (2000) Phytoremediation of toxic elemental and organic pollutants. *Current Opinion in Plant Biology,* 3, 153–162.

Melosi, M. V. 2005. *Garbage in the Cities: Refuse, Reform, and the Environment*. Pittsburg: University of Pittsburg Press.

Mendels, F. F. (1972) Proto-Industrialization: The first phase of the industrialization process. *The Journal of Economic History,* 32, 241-261.

Mendez, M. O. & R. M. Maier (2008) Phytostabilization of mine tailings in arid and semiarid environments—an emerging remediation technology. *Environmental Health Perspectives,* 116, 278–83.

Middleton, K. A. 1937. Manufacturing in Lawrence, Kansas, 1854 - 1900. Lawrence, KS: University of Kansas.

Mielke, H. W., D. Dugas, J. P W Mielke, K. S. Smith & C. R. Gonzales (1997) Associations between soil lead and childhood blood lead in urban New Orleans and rural Lafourche Parish of Louisiana. *Environmental Health Perspectives,* 105, 950–954.

Millon, R. (1994) Teotihuacan. *Scientific American (special issue)*, 138-148.

Mills, C. W. & M. Ulmer. 1946. Small Business and Civic Welfare - Report of the Smaller War Plants Corporation to the Special Committee to Study Problems of American Small Business. Washington, D.C.: U.S. Government Printing Office.

Milner, G. R. 1998. *The Cahokia Chiefdom: The Archaeology of a Mississippian Society*. Washington, D.C.: Smithsonian Institution Press.

Mokdad, A. H., M. K. Serdula, W. H. Dietz, B. A. Bowman, J. S. Marks & J. P. Koplan (1999) The spread of the obesity epidemic in the United States, 1991-1998. *Journal of the American Medical Association,* 282, 1519-1522.

Mortinger, J. 2009. Eastside Community Garden Map. Lawrence, KS.

Mougeot, L. J. A. 1994. Urban Food Production: Evolution, Official Support and Significance. Ottawa, Canada: International Development Research Centre.

Murphy, K. (2009) For urban gardeners, lead is a concern. *The New York Times Home and Garden*. http://www.nytimes.com/2009/05/14/garden/14lead.html (last accessed February 16, 2011).

Murti, G. S. R. K. & K. V. S. Satyanarayana (1971) Influence of chemical characteristics on the development of soil colour. *Geoderma,* 5, 243-248.

MyFoxNY.com. 2010. Egg Recall 2010.

Naidu, R., D. Oliver & S. McConnell. 2003. Heavy Metal Phytotoxicity in Soils. In *Proceedings of the Fifth National Workshop on the Assessment of Site Contamination,* eds. A. Langley, M. Gilbey & B. Kennedy, 235-241. Adelaide, Australia: National Environment Protection Council Service Corporation.

National Archives and Records Administration (2011) 40 CFR Part 261, Table 1. *Electronic Code of Federal Regulations*. http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=2bc39302b4c7ee7c55e8209deb9fc401&rgn=div5&view=text&node=40:25.0.1.1.2&idno=40 (last accessed March 16, 2011).

National Climatic Data Center. 2006. Climatography of the United States No. 20, 1971-2000. Asheville, NC: U.S. Department of Commerce, National Oceanic and Atmospheric Adminstration.

National Cooperative Soil Survey. 1973. Soil Survey for Douglas County, Kansas. U.S. Department of Agriculture.

National Gardening Association. 2001. National Gardening Survey.

Net Industries. 2011. Waste Management - Agricultural, Mining, And Industrial Waste. In *Science Encyclopedia, Vol. 6*. Net Industries (NI).

New York City Department of Planning. 2011. NYC Zoning - Glossary.

Ng, J., A. Gomez-Caminero, P. Howe, M. Hughes, E. Kenyon, D. R. Lewis, M. Moore, A. Aitio & G. Becking. 2001. Arsenic and arsenic compounds. In *Environmental Health Criteria 224*. Geneva: World Health Organization.

Nichol, J. E. (1996) High-resolution surface temperature patterns related to urban morphology in a tropical city: a satellite-based study. *Journal of Applied Meteorology,* 35, 135-146.

NRCS. 2008. Urban Soil Mapping and Inventory. U.S. Department of Agriculture Natural Resource Conservation Service.

---. 2009. Conservation Reserve Program. In *U.S. Department of Agriculture Natural Resource Conservation Service*.

---. 2010. Soil Survey Geographic (SSURGO) database for Douglas County, Kansas. U.S. Department of Agriculture, Natural Resources Conservation Service.

Nriagu, J. O. 1978. *The Biogeochemistry of Lead in the Environment*. Amsterdam: Elsevier/North Holland.

---. 1979a. *Copper in the Environment; Part 1:Ecological Cycling*. New York: John Wiley & Sons.
---. 1979b. *The Biogeochemistry of Mercury in the Environment*. Amsterdam: Elsevier/North Holland.
---. 1980a. *Cadmium in the Environment, Part 1: Ecological Cycling*. New York: John Wiley & Sons.
---. 1980b. *Nickel in the Environment; Part 1: Ecological Cycling*. New York: John Wiley & Sons.
---. 1980c. *Zinc in the Environment; Part 1: Ecological Cycling*. New York: John Wiley & Sons.
--- (1988) A silent epidemic of environmental metal poisoning. *Environmental Pollution,* 50, 139-161.
Obinaju, B. E. (2009) Mechanisms of arsenic toxicity and carcinogenesis. *African Journal of Biochemistry Research,* 3, 232-237.
Oden, J. 2010. Farming in Kansas. ed. T. Jackson. Sterling, KS.
Odesola, I. F. & A. T. Owoseni (2011) Small scale biochar production technologies: A review. *Journal of Emerging Trends in Engineering and Applied Sciences,* 1.
Oke, T. R. (1982) The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorology Society,* 108, 1-24.
Oldridge, J. (2006) Lawrence.com. *Growing together: Lawrence touts strong crop of community gardens*. http://www.lawrence.com/news/2006/jun/01/growing_together/ (last accessed March 9, 2011).
Ottesen, R. T. & M. Langedal (2001) Urban geochemistry in Trondheim, Norway. *Norges geologiske undersøkelse Bulletin,* 438, 63-69.
Paarlberg, D. & P. Paarlberg. 2000. *The Agricultural Revolution of the 20th Century*. Ames, IA: Iowa State University Press.
Pack, C. L. 1919. *The War Garden Victorious*. Philadelphia: J.B. Lippincott Company.
Penn, J. R. 2001. *Rivers of the World: A Social, Geographical, and Environmental Sourcebook*. Santa Barbara, CA: ABC-CLIO, Inc.
Peterson, M. 1977. Bowersock area gets a 'Yecch!'. In *Lawrence Journal World*.
Pierce, J. T. & O. J. Furuseth (1983) Assessing the adequacy of North American agricultural land resources. *Geoforum,* 14, 413-425.
Ponge, J.-F. (2003) Humus forms in terrestrial ecosystems: a framework to biodiversity. *Soil Biology and Biochemistry,* 35, 935-945.
Post, W. M., R. C. Izaurralde, J. D. Jastrow, B. A. McCarl, J. E. Amonette, V. L. Bailey, P. M. Jardine, T. O. West & J. Zhou (2004) Enhancement of carbon sequestration in US Soils. *Bioscience,* 54, 895-908.
Pullen, J., J. P. Boris, T. Young, G. Patnaik & J. Iselin (2005) A comparison of contaminant plume statistics from a Gaussian puff and urban CFD model for two large cities. *Atmospheric Environment,* 39, 1049–1068.
Purves, D. 1977. The contamination of soil and food crops by toxic elements normally found in municipal wastewaters and their consequences for human health. In *Wastewater Renovation and Reuse*. New York: Marcel Dekker.
Pyne, S. J. 1998. Forged in fire: History, land, and anthropogenic fire. In *Advances in Historical Ecology,* ed. Bal, 64-103. New York: Columbia University Press.
Ralph, J. & I. Chau (2011) Mindat.org. *Pyrite*. http://www.mindat.org/min-3314.html (last accessed March 26, 2011).
Redclift, M. 1987. *Sustainable Development: Exploring the Contradictions*. London, UK, and New York, USA: Routledge.
Retzlaff, D. 1987. Tunnel tied to early Lawrence's industry. In *Lawrence Journal World*, 3.
ReviveTheVictoryGarden.org. 2009. ReviveTheVictoryGarden.org.
Reynolds, S. 1984. *Kingdoms and Communities in Western Europe 900-1300*. Oxford: Clarendon Press.
Roberts, M. J. & R. N. Lubowski (2007) Enduring impacts of land retirement policies: Evidence from the Conservation Reserve Program. *Land Economics,* 83, 516-538.
Roberts, S. (2006) 1956: The roads that changed America. *The New York Times Upfront*. http://findarticles.com/p/articles/mi_m0BUE/is_5_139/ai_n17215590 (last accessed January 28, 2011).
Robinson, S. T. D. 1856. Ruins of the Free State Hotel. In *Kansas: Its Interior and Exterior Life*. Lawrence, KS.
Rodenbeck, M. 1991. Sumer: Cities of Eden. In *Egypt from the Air*. Alexandria, Virginia: Time-Life Books.
Rosen, C. J. (2002) Lead in the home garden and urban soil environment. *University of Minnesota Extension*. http://www.extension.umn.edu/distribution/horticulture/DG2543.html (last accessed March 26, 2011).
Roth, M., T. R. Oke & W. J. Emery (1989) Satellite-derived urban heat islands from three coastal cities and the utilization of such data in urban climatology. *International Journal of Remote Sensing,* 10, 1699-1720.

Roth, S. 2009. 1632 Alabama Street. ed. T. Jackson.

Rowell, D. L. 1981. In *The Chemistry of Soil Processes*, 401-462. Chichester: John Wiley.

RTI International. 2007. Human and Ecological Risk Assessment of Coal Combustion Wastes. Research Triangle Park, NC: RTI.

Rui, Y. K., J. B. Shen & F. S. Zhang (2008) Application of ICP-MS to determination of heavy metal content of heavy metals in two kinds of N fertilizer. *PubMed.gov*. http://www.ncbi.nlm.nih.gov/pubmed/19123422 (last accessed March 2, 2011).

Samsøe-Petersen, L., E. H. Larsen, P. B. Larsen & P. Bruun (2002) Uptake of trace elements and PAHs by fruit and vegetables from contaminated soils. *Environmental Science and Technology,* 36, 3057-3063.

Sanborn Map & Publishing Company Ltd. 1883. Lawrence, Kansas Sheets 1-7. In *Lawrence, Kansas*. New York, NY.

---. 1889. Lawrence, Kansas Sheets 1-13. New York, NY.

Sanborn Map Company. 1905. Insurance Maps of Lawrence, Kansas Sheets 1-19. Brooklyn, NY.

---. 1912. Lawrence, Kansas Sheets 1-23. In *Insurance Maps of Lawrence, Kansas*. New York, NY.

---. 1918. Lawrence, KS Sheets 1-16. New York, NY.

---. 1927. Lawrence, Kansas, Sheets 1-32. New York, NY: Sanborn Map Company.

---. 1927, rev. 1949. Lawrence, Kansas Sheets 1-35. New York.

Sanborn Perris Map Company Ltd. 1897. Lawrence, KS Sheets 1-15. New York, NY.

SARE. 2005. *The New American Farmer, 2nd edition*. Annapolis, MD: Sustainable Agriculture Research & Education (SARE) of the USDA.

---. 2009. *Youth Renewing the Countryside*. Washington, D.C.: Sustainable Agriculture Research & Education (SARE) of the USDA.

Schalk, G. K., R. R. Holmes, Jr. & G. P. Johnson. 1998. Physical and Chemical Data on Sediments Deposited in the Missouri and the Mississippi River Floodplains During the July through August 1993 Flood. Denver, CO: USGS.

Schindler, P. W. & G. Sposito. 1991. Surface complexation at (hydr)oxide surfaces. In *Interactions at the Soil Colloid-Soil Solution Interface*, 115-145. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Schlesinger, W. H. 1997. *Biogeochemistry: An Analysis of Global Change*. San Diego, CA: Academic Press.

Schlosser, E. 2002. *Fast Food Nation: The Dark Side of the All-American Meal*. New York, NY: Houghton Mifflin.

Schoenberger, P. J., D. A. Wysocki, E. C. Benham & W. D. Broderosn. 2002. *Field Book for Describing and Sampling Soils, Version 2.0*. Lincoln, NE: National Soil Survey Center.

Schulze, D. G., J. L. Nagel, G. E. Van Scoyoc, T. L. Henderson, M. F. Baumgardner & D. E. Scott. 1993. Significance of organic matter in determining soil colors. In *Soil Color*, 71-90. Madison, WI: Soil Science Society of America.

Schumacher, B. A. 2002. Methods for the Determination of Total Organic Carbon (TOC) in Soils and Sediments. Las Vegas, NV: Environmental Protection Agency.

Scorecard. 2005. Pollution locator - Lead hazards.

Shen, T. T. 1999. *Industrial Pollution Prevention*. Berlin: Springer.

Shibamoto, T., A. Yasuhara & T. Katami (2007) Dioxin formation from waste incineration. *Reviews of Environmental Contamination and Toxicology,* 190, 1-41.

Slow Food USA. 2010. 2012 Farm Bill update. In *The Slow Food USA blog*.

Sombroek, W. G. 1966. *Amazon Soils: A Reconaissance of the Soils of the Brazilian Amazon Region*. Wageningen: Center for Agricultural Publications and Documentation.

Spaargaren, O. (2006) Anthrosols and Technosols. http://eusoils.jrc.it/events/SummerSchool2006/Presentations/8_Spaargaren_ AnthroTechnosols.pdf (last accessed December 4, 2009).

Sposito, G. & A. L. Page. 1985. Vol. 18 circulation of metals in the environment. In *Metal Ions in Biological Systems* 287-332. New York: Marcel Dekker.

Stanton, A. 2008. Wall-E.

State of Minnesota. 1993. Residential Lead Abatement Standards. Saint Paul, MN: State of Minnesota.

State of Washington Department of Ecology. 2004. Tacoma Smelter Plume - Extended Footprint Study. In *Dirt Alert - Tacoma Smelter Plume Archive*. State of Washington.

---. 2011. Dirt Alert.

Stevens, C. J., N. B. Dise & D. J. Gowing (2009) Regional trends in soil acidification and exchangeable metal concentrations in relation to acid deposition rates. *Environmental Pollution,* 157, 313-319.

Stone, G. D. 2001. Agricultural change theory. In *International Encyclopedia of the Social and Behavioral Sciences*. Oxford, UK: Elsevier Science Ltd.

Stover, S. 2010. Manager, High Plains Unit, Kansas Water Office. ed. T. Jackson.

Svirejeva-Hopkins, A. 2008. Urbanization as a global ecological process. In *Encyclopedia of Ecology*, 3672-3678. Oxford: Academic Press.

Swarns, R. L. (2009) Lead found in White House garden. *The New York Times - The Caucus*. http://thecaucus.blogs.nytimes.com/2009/07/02/lead-found-in-white-house-garden/ (last accessed February 16, 2011).

Swift, J. 2008. Eastside Community Garden. ed. T. Jackson. Lawrence, KS.

Taylor, J. & R. Brack. 1990. Fire guts three downtown buildings. In *Lawrence Daily Journal-World*, 1, 11.

Tele-Shopper. 1979. Lawrence plant reaches milestone. In *Tele-Shopper*.

The Outlook. 1954. Bowersock Mills is now a federal warehouse; Make first ready-mixes. In *The Outlook*.

Thompson Jr., E., A. M. Harper & S. Kraus. 2008. Eat Locally, Think Globally - San Francisco Foodshed Assessment. San Francisco, CA: American Farmland Trust.

Thompson, M. (2011) House defeats EPA mercury requirement that would affect cement companies. *PostStar.com*. http://poststar.com/news/local/article_f6d09b00-3bb1-11e0-8b01-001cc4c03286.html (last accessed March 7, 2011).

Tilman, D., K. G. Cassman, P. A. Matson, R. Naylor & S. Polasky (2002) Agricultural sustainability and intensive production practices. *Nature,* 418, 671-677.

Tucker, D. M. 1993. *Kitchen Gardening in America: A History*. Ames: Iowa State University Press.

Turner, B. L. I., R. Kasperson, P. A. Matson, J. J. McCarthy & R. W. Corell (2003) A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences,* 100, 8074-8079.

Turner II, B. L. & S. B. Brush. 1987. *Comparative Farming Systems*. New York: The Guilford Press.

Tyler, L. D. & M. B. McBride (1982) Mobility and extractability of cadmium, copper, nickel, and zinc in organic and mineral soil columns. *Soil Science,* 3, 198-205.

U.S. Census (2010) 2010 City Population and Housing Occupancy Status. *2010 Census*. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=DEC_10_PL_GCTPL2.ST13&prodType=table (last accessed March 6, 2011).

Uchimiya, M., I. M. Lima, T. K. Klasson & L. H. Wartell (2010) Contaminant immobilization and nutrient release by biochar soil amendment: Roles of natural organic matter. *Chemosphere,* 80, 935-940.

Uchimiya, M., L. H. Wartell, T. K. Klasson, C. A. Fortier & I. M. Lima (2011) Influence of pyrolysis temperature on biochar property and function as a heavy metal sorbent in soil. *Journal of Agricultural and Food Chemistry,* 59, 2501-2510.

UNDP. 1996. Urban Agriculture: Food, Jobs and Sustainable Cities. New York: United Nations Development Programme (UNDP).

---. 2007. Urban Farming Against Hunger. New York, NY: United Nations Development Programme (UNDP).

University of Kansas (2010) Head Count Enrollment. http://www2.ku.edu/~oirp/profiles/new/4-001.pdf (last accessed March 7, 2011).

USDA. 2007. Urban Agriculture and Community Gardening. Washington, D.C.: United States Department of Agriculture.

USGAO. 1999. Animal Agriculture Waste Management Practices. Washington, D.C.: United States Government Accounting Office.

USGS. 1903. 1903 Flood in Lawrence, KS.

USGS & EROS Data Center (1999) National Elevation Dataset (NED). *Kansas Data Access & Support Center*. http://www.kansasgis.org/ (last accessed March 14, 2011).

Verburg, P. S. J., D. v. Dam, J. C. Y. Marinissen, R. Westerhof & N. v. Breemen. 1995. The role of decomposition in C sequestration in ecosystems. In *Carbon Sequestration in the Biosphere: Processes and Prospects*. New York: Springer.

Viterito, A. (1989) Changing thermal topography of the Baltimore-Washington corridor: 1950-1979. *Climatic Change,* 14, 89-102.

Von Eckardt, W. & J. Gottman. 1964. *The Challenges of Megalopolis: A Graphic Presentation of the Urbanized Northeastern Seaboard of the United States*. New York, NY: MacMillan Press.

Vukovich, F. M. (1983) An analysis of the ground temperature and reflectivity pattern about St. Louis, Missouri, using HCMM satellite data. *Journal of Climate and Applied Meteorology,* 22, 560-571.

Watts, D. J. & C. M. Watts (1994) A Roman apartment complex. *Scientific American (special issue)*, 86-91.

Weingroff, R. F. (2010) Public Roads. *Three States Claim First Interstate Highway*. http://www.fhwa.dot.gov/publications/publicroads/96summer/p96su18.cfm (last accessed March 16, 2011).

Weiss, D. 2005. Environmental Movement Timeline: A History of the American Environmental Movement.

Westar Energy. 2008. 2008 Annual Report. Topeka, KS.

White House staff (2010) White House Today. *White House garden 'ex-seeds' expectations*. http://today.msnbc.msn.com/id/34820763/ns/today-today_people/ (last accessed February 15, 2011).

Whittlesey, D. (1929) Sequent occupance. *Annals of the Association of Geographers,* 19, 162-165.

Widgren, M. 1997. Pre-Colonial landesque capital: A global perspective. In *Rethinking Environmental History: World-System History and Global Environmental Change*, 61-78. Lanham, Maryland: AltaMira Press.

Wild, A. 1988. *Russell's Soil Conditions and Plant Growth, 11th ed*. London: Longman.

Williams, L. 2011. 2515 Morningside Drive. ed. T. Jackson. Lawrence, KS.

Williamson, E. A. 2002. A Deeper Ecology: Community Gardens in the Urban Environment. Newark: University of Delaware.

Wills, S. A., C. L. Burras & J. A. Sandor (2007) Prediction of soil organic carbon using field and laboratory measurements of soil color. *Soil Science Society of America Journal,* 71, 380-388.

Wilson, J. & W. McFerron. 2011. Grain Prices Rally Toward 2008 Records on Shrinking World Supply. In *Bloomberg.com*.

Woods, W. I. 1986. Prehistoric settlement and subsistence in the upland Cahokia Creek drainage. In *Dissertation*. Milwaukee, Wisconsin: University of Wisconsin.

--- (2004) Population nucleation, intensive agriculture, and environmental degradation: The Cahokia example. *Agriculture and Human Values,* 21, 255-261.

Woods, W. I. 2008. Anthrosols. In *Graduate Course in Geography at the University of Kansas*. Lawrence, KS, USA.

Woods, W. I. & J. M. McCann. 1999. The Anthropogenic Origin and Persistence of Amazonian Dark Earths. In *Yearbook 1999 - Conference of Latin Americanist Geographers,* ed. C. Caviedes, 7-14. Austin: University of Texas Press.

Wu, S., S. Zhou, X. Li, T. Jackson & Q. Zhu (2010) An approach to partition the anthropogenic and natural components of heavy metal accumulations in roadside agricultural soil. *Environmental Monitoring and Assessment*.

Yan, F., J. Yan, Y. Wang & D. Chen (2007) Site environmental assessment to an old paint factory in China. *Environmental Monitoring and Assessment,* 139, 93-106.

Yanin, V. L. (1994) The Archaeology of Novgorod. *Scientific American (special issue)*, 120- 127.

Yiin, L. M., G. G. Rhoads & P. J. Lioy (2000) Seasonal influences on childhood lead exposure. *Environmental Health Perspectives,* 108, 177-182.

Zhang, D. D., P. Brecke, H. F. Lee, Y.-Q. He & J. Zhang (2007) Global climate change, war, and population decline in recent human history. *Proceedings of the National Academy of Science,* 104, 19214-19219.

Zhang, M. K., Z. L. He, P. J. Stoffella, D. V. Calvert, X. E. Yang, Y. P. Xia & S. B. Wilson (2004) Solubility of phosphorus and heavy metals in potting media amended with yard waste–biosolids compost. *Journal of Environmental Quality,* 33, 373–379.

Zhu, Y., H. Chen, J. Fan, Y. Wang & Y. Li (2000) Genetic diversity and disease control in rice. *Nature,* 406, 718-722.

Appendix A

Garden Plot (GP)	sample #	sample depth (cm)	As +/- 5 ppm	Cd +/- 21 ppm	Cr +/- 57 ppm	Cu +/- 12 ppm	Fe +/- 300 ppm	Hg +/- 7 ppm	Mn +/- 46 ppm	Ni +/- 22 ppm	Pb +/- 6 ppm	Zn +/- 8 ppm
1	1	5 to 15	ND	ND	ND	36	16645	ND	369	ND	42	101
1	2	25 to 35	12	ND	ND	40	25052	18	357	ND	40	88
1	3	5 to 15	14	ND	ND	ND	22187	ND	338	ND	31	88
1	4	25 to 35	ND	ND	ND	42	22335	ND	416	ND	36	63
1	5	5 to 15	ND	ND	ND	ND	24160	ND	594	ND	43	74
1	6	25 to 35	ND	ND	ND	ND	18786	ND	280	ND	22	40
1	7	5 to 15	ND	ND	ND	66	26879	ND	496	ND	21	53
1	8	25 to 35	ND	ND	ND	46	22894	ND	261	ND	18	44
1	9	5 to 15	ND	ND	ND	37	21848	ND	496	ND	31	74
1	10	25 to 35	13	ND	ND	54	27842	ND	435	ND	20	58
1	11	5 to 15	ND	ND	ND	35	22460	ND	493	ND	38	65
1	12	25 to 35	ND	ND	ND	ND	23283	ND	382	ND	37	67
1	13	5 to 15	ND	ND	ND	ND	19404	ND	435	ND	33	89
1	14	25 to 35	ND	ND	ND	43	19382	ND	340	ND	44	41
1	15	5 to 15	ND	ND	ND	ND	22503	ND	474	ND	28	57
1	16	25 to 35	ND	ND	ND	ND	22724	ND	466	ND	33	60
1	17	5 to 15	10	ND	ND	35	21076	ND	431	ND	22	62
1	18	25 to 35	ND	ND	ND	37	26349	ND	472	ND	30	64
1	19	5 to 15	ND	ND	ND	ND	21665	ND	388	ND	31	62
1	20	25 to 35	ND	ND	ND	ND	24811	ND	217	ND	22	54
1	21	5 to 15	ND	ND	ND	38	18000	ND	428	ND	34	108
1	22	25 to 35	35	ND	ND	58	67591	24	598	ND	265	509
1	23	5 to 15	ND	ND	ND	ND	17324	ND	305	ND	28	53
1	24	25 to 35	ND	ND	ND	44	21348	ND	438	ND	23	70
1	25	5 to 15	ND	ND	ND	ND	23450	ND	415	ND	21	57
1	26	25 to 35	ND	ND	ND	ND	21210	ND	372	ND	16	51
1	27	5 to 15	10	ND	ND	ND	23312	ND	451	ND	22	75
1	28	25 to 35	ND	ND	ND	ND	24001	ND	390	ND	30	58
1	29	5 to 15	10	ND	ND	ND	23423	ND	340	ND	22	65
1	30	25 to 35	ND	ND	ND	ND	19595	ND	200	72	22	40
1	31	5 to 15	ND	ND	ND	ND	21067	ND	680	ND	27	101
1	32	25 to 35	ND	ND	ND	ND	21343	ND	414	ND	21	51
1	33	5 to 15	ND	ND	ND	ND	22272	ND	584	ND	32	67
1	34	25 to 35	ND	ND	ND	35	26408	ND	418	ND	26	70
1	35	5 to 15	13	ND	ND	ND	20096	ND	446	ND	35	106
1	36	25 to 35	13	ND	ND	47	23810	ND	381	ND	31	63

Garden Plot (GP)	sample #	sample depth (cm)	As +/- 5 ppm	Cd +/- 21 ppm	Cr +/- 57 ppm	Cu +/- 12 ppm	Fe +/- 300 ppm	Hg +/- 7 ppm	Mn +/- 46 ppm	Ni +/- 22 ppm	Pb +/- 6 ppm	Zn +/- 8 ppm
1	37	5 to 15	12	ND	ND	35	24113	ND	404	ND	24	61
1	38	25 to 35	ND	ND	ND	37	27076	ND	549	ND	22	64
1	39	5 to 15	11	ND	ND	ND	20642	ND	326	ND	26	70
1	40	25 to 35	ND	ND	ND	ND	26695	ND	890	ND	28	56
1	41	5 to 15	10	ND	ND	37	24251	ND	532	ND	28	63
1	42	25 to 35	ND	ND	ND	ND	27226	ND	336	ND	18	58
1	43	5 to 15	ND	ND	ND	48	18314	ND	615	ND	35	86
1	44	15-22	ND	ND	ND	ND	42136	ND	943	ND	107	373
1	45	5 to 15	11	ND	ND	ND	19154	ND	341	ND	30	70
1	46	25 to 35	ND	ND	ND	50	23274	ND	1008	ND	28	64
1	47	5 to 15	ND	ND	ND	ND	20672	ND	398	ND	25	74
1	48	25 to 35	ND	ND	ND	ND	21657	ND	419	ND	32	62
1	49	5 to 15	ND	ND	ND	ND	20673	ND	852	ND	33	81
1	50	25 to 35	ND	ND	ND	ND	21184	ND	347	ND	27	50
1	51	5 to 15	ND	ND	ND	40	19450	ND	254	ND	20	51
1	52	25 to 35	ND	ND	ND	34	20823	ND	330	ND	25	54
1	53	5 to 15	11	ND	ND	ND	21162	ND	394	ND	24	53
1	54	25 to 35	ND	ND	ND	36	26485	ND	306	ND	22	66
1	55	5 to 15	ND	ND	195	ND	20024	ND	458	ND	36	49
1	56	25 to 35	ND	ND	ND	ND	27542	ND	449	ND	28	63
1	57	5 to 15	ND	ND	ND	ND	20661	ND	423	ND	28	78
1	58	25 to 35	ND	ND	ND	ND	21300	ND	282	ND	18	43
1	59	5 to 15	ND	ND	ND	ND	22096	ND	1176	ND	26	73
1	60	25 to 35	ND	ND	ND	45	29379	ND	1030	ND	22	70
1	61	5 to 15	12	ND	ND	ND	21527	ND	561	ND	25	69
1	62	25 to 35	ND	ND	ND	40	28010	ND	460	ND	19	59
1	63	5 to 15	ND	ND	ND	42	24619	ND	600	77	32	75
1	64	25 to 35	ND	ND	ND	ND	24827	ND	363	ND	24	63
1	65	5 to 15	13	ND	ND	ND	22161	ND	493	76	37	75
1	66	5 to 15	ND	ND	ND	43	15209	ND	411	ND	29	102
1	67	25 to 35	ND	ND	ND	59	26500	ND	922	ND	48	67
1	68	5 to 15	11	ND	ND	52	22439	ND	681	ND	28	64
1	69	25 to 35	ND	ND	ND	45	20328	ND	367	ND	27	75
1	70	5 to 15	ND	ND	ND	ND	20636	ND	374	ND	28	76
1	71	25 to 35	ND	ND	ND	ND	21861	ND	283	ND	19	56
1	72	5 to 15	ND	ND	ND	36	19396	ND	406	ND	41	72
1	73	25 to 35	ND	ND	ND	ND	19345	ND	269	ND	31	55
1	74	5 to 15	11	ND	ND	ND	22094	ND	341	ND	18	60

Garden Plot (GP)	sample #	sample depth (cm)	As +/- 5 ppm	Cd +/- 21 ppm	Cr +/- 57 ppm	Cu +/- 12 ppm	Fe +/- 300 ppm	Hg +/- 7 ppm	Mn +/- 46 ppm	Ni +/- 22 ppm	Pb +/- 6 ppm	Zn +/- 8 ppm
1	75	15-19	ND	ND	ND	ND	23398	ND	400	91	26	65
1	76	5 to 15	ND	ND	ND	ND	23511	ND	392	ND	38	57
1	77	25 to 35	ND	ND	ND	40	24016	ND	549	ND	27	65
1	78	5-15	15	ND	ND	42	22375	ND	489	ND	24	61
1	79	25 to 35	ND	ND	ND	42	21773	ND	537	ND	45	98
1	80	5 to 15	12	ND	ND	ND	27380	ND	544	ND	27	65
1	81	25-32	ND	ND	ND	ND	20457	ND	513	ND	50	77
1	82	5 to 15	10	ND	ND	ND	20702	ND	466	ND	29	75
1	83	25 to 35	ND	ND	ND	35	27200	ND	408	73	19	82
1	84	5 to 15	ND	ND	ND	ND	21289	ND	360	ND	27	50
1	85	25 to 35	11	ND	ND	ND	25939	ND	558	ND	24	68
1	86	5 to 15	ND	ND	ND	ND	19418	ND	483	ND	51	102
1	87	15-18	15	ND	ND	ND	21032	ND	1202	67	50	62
1	88	5 to 15	ND	ND	ND	ND	17050	ND	546	ND	23	95
1	89	25-32	13	ND	ND	ND	21698	ND	388	ND	42	56
1	90	5 to 15	ND	ND	ND	ND	21286	ND	423	ND	29	69
1	91	25 to 35	ND	ND	ND	ND	24991	ND	486	ND	28	69
1	92	5 to 15	ND	ND	ND	35	23986	ND	504	ND	26	63
1	93	25 to 35	ND	ND	ND	ND	20945	ND	433	ND	26	50
1	94	5 to 15	10	ND	ND	ND	22548	ND	420	ND	22	74
1	95	15-23	ND	ND	ND	ND	20501	ND	430	ND	24	53
1	96	5 to 15	ND	ND	ND	35	20817	ND	395	77	21	69
1	97	25 to 35	ND	ND	ND	ND	20973	ND	404	ND	30	55
1	98	5 to 15	ND	ND	ND	48	26109	ND	426	ND	60	228
1	99	25 to 35	ND	ND	ND	ND	19128	ND	522	ND	29	64
1	100	5 to 15	ND	ND	ND	ND	20677	ND	672	ND	26	67
1	101	25 to 35	ND	67	ND	ND	20009	ND	478	ND	23	56
1	102	5 to 15	ND	ND	ND	ND	19091	ND	318	ND	28	67
1	103	25 to 35	ND	ND	ND	ND	21034	ND	377	ND	62	72
1	104	5 to 15	ND	ND	ND	ND	17798	ND	481	ND	24	97
1	105	20 to 30	10	ND	ND	41	22437	ND	276	ND	20	56
1	106	5 to 15	ND	ND	ND	ND	22219	ND	328	ND	31	48
1	107	25 to 35	ND	ND	ND	38	26178	ND	550	ND	18	61
1	108	5 to 15	ND	ND	ND	ND	23840	ND	750	ND	29	58
1	109	15 to 22	ND	ND	ND	36	22885	ND	453	ND	24	70
1	110	5 to 15	ND	ND	ND	ND	21228	ND	382	72	25	79
1	111	25 to 35	ND	ND	ND	43	22440	ND	514	ND	27	59
1	112	5 to 15	ND	ND	ND	ND	25507	ND	562	ND	22	61

Garden Plot (GP)	sample #	sample depth (cm)	As +/- 5 ppm	Cd +/- 21 ppm	Cr +/- 57 ppm	Cu +/- 12 ppm	Fe +/- 300 ppm	Hg +/- 7 ppm	Mn +/- 46 ppm	Ni +/- 22 ppm	Pb +/- 6 ppm	Zn +/- 8 ppm
1	113	25 to 35	ND	ND	ND	ND	23958	ND	699	ND	53	92
1	114	5 to 15	ND	ND	ND	50	21529	ND	527	ND	24	58
1	115	25 to 35	ND	ND	ND	39	22154	ND	385	ND	36	57
1	116	5 to 15	9	ND	ND	ND	23851	ND	411	ND	19	68
1	117	25 to 35	ND	ND	ND	ND	25190	ND	407	ND	34	77
1	118	5 to 15	ND	ND	ND	ND	21090	ND	682	ND	29	84
1	119	25 to 35	ND	65	ND	ND	22114	ND	687	ND	22	66
1	120	5 to 15	ND	ND	ND	ND	22594	ND	457	ND	27	58
1	121	25 to 35	ND	ND	ND	35	20477	ND	366	ND	29	65
1	122	5 to 15	ND	ND	ND	ND	22141	ND	561	ND	29	71
1	123	25 to 35	ND	ND	ND	ND	22543	ND	295	ND	23	50
1	124	5 to 15	ND	ND	ND	37	20726	ND	473	ND	20	53
1	125	25 to 35	ND	ND	ND	ND	21331	ND	459	ND	27	48
1	126	5 to 15	ND	ND	ND	ND	20688	ND	365	ND	27	67
1	127	25 to 35	ND	ND	ND	ND	21361	ND	461	ND	26	68
1	128	5 to 15	ND	ND	ND	36	21963	ND	469	ND	42	83
1	129	25 to 34	ND	ND	ND	ND	23110	ND	400	ND	45	78
1	130	5 to 15	22	ND	ND	ND	23467	ND	530	ND	96	96
1	131	15 to 23	24	ND	ND	36	22679	ND	426	ND	126	105
1	132	5 to 15	ND	ND	ND	181	18059	ND	1760	100	180	158
1	133	25 to 35	ND	ND	180	219	17667	ND	1665	ND	144	141
2	134	5 to 15	11	ND	ND	ND	17923	ND	495	ND	59	83
2	135	25 to 35	ND	ND	ND	ND	16068	ND	272	ND	164	160
2	136	5 to 15	ND	ND	ND	46	15204	ND	337	ND	148	152
2	137	15 to 25	ND	ND	ND	ND	13949	ND	291	ND	119	124
2	138	5 to 15	ND	ND	ND	ND	15105	ND	264	ND	103	109
2	139	15 to 21	ND	ND	ND	ND	14888	ND	301	ND	38	72
2	140	5 to 15	ND	ND	ND	ND	15931	ND	262	ND	38	87
2	141	15 to 20	ND	ND	ND	35	15813	ND	273	ND	38	87
2	142	5 to 15	ND	ND	ND	ND	17371	ND	289	ND	31	66
2	143	15 to 20	ND	ND	ND	58	14427	ND	263	ND	45	126
2	144	5 to 15	ND	ND	ND	52	15901	ND	406	65	64	105
2	145	15 to 20	ND	ND	ND	ND	14515	ND	325	ND	60	113
2	146	3 to 13	ND	ND	ND	ND	14954	ND	297	ND	60	106
2	147	3 to 13	ND	ND	ND	ND	15783	ND	331	ND	147	99
2	148	5 to 15	ND	ND	ND	41	14336	ND	275	ND	147	78
2	149	10 to 14	ND	ND	ND	ND	13189	ND	296	ND	55	80
2	150	5 to 15	ND	ND	ND	ND	14030	ND	396	ND	58	119

Garden Plot (GP)	sample #	sample depth (cm)	As +/- 5 ppm	Cd +/- 21 ppm	Cr +/- 57 ppm	Cu +/- 12 ppm	Fe +/- 300 ppm	Hg +/- 7 ppm	Mn +/- 46 ppm	Ni +/- 22 ppm	Pb +/- 6 ppm	Zn +/- 8 ppm
2	151	25 to 35	ND	ND	ND	40	16936	ND	506	ND	110	176
2	152	5 to 15	ND	ND	ND	44	17186	ND	468	ND	100	141
2	153	25 to 35	ND	ND	ND	39	15655	ND	373	ND	42	104
2	154	5 to 15	ND	ND	ND	ND	15152	ND	316	ND	44	92
2	155	17 to 27	ND	ND	ND	ND	14479	ND	221	ND	49	73
2	156	5 to 15	ND	ND	ND	ND	14417	ND	245	ND	54	68
2	157	20 to 30	ND	ND	ND	36	14788	ND	267	ND	31	75
2	158	5 to 15	ND	ND	194	34	15059	ND	242	ND	38	61
2	159	15 to 20	ND	ND	ND	37	15152	ND	300	ND	52	84
2	160	5 to 15	ND	ND	ND	ND	15297	ND	235	ND	65	113
2	161	25 to 35	ND	ND	ND	ND	14930	ND	302	ND	39	102
2	162	5 to 15	ND	ND	ND	ND	14642	ND	250	69	42	82
2	163	15 to 20	22	ND	ND	51	15951	ND	346	ND	45	108
2	164	5 to 15	ND	ND	ND	ND	17166	ND	343	ND	55	104
2	165	15 to 20	ND	ND	ND	ND	15773	ND	391	ND	46	82
2	166	5 to 15	ND	ND	ND	ND	15673	ND	427	ND	51	102
2	167	25 to 35	ND	ND	ND	ND	16249	ND	353	ND	46	102
2	168	5 to 15	ND	ND	ND	ND	13828	ND	321	ND	35	79
2	169	15 to 27	ND	ND	ND	ND	13572	ND	394	ND	52	76
2	170	5 to 15	11	ND	ND	ND	14217	ND	348	ND	46	83
2	171	15 to 19	ND	ND	ND	ND	12856	ND	323	ND	38	98
2	172	5 to 15	ND	ND	ND	42	12792	ND	340	ND	57	132
2	173	15 to 25	ND	ND	ND	42	13643	ND	324	ND	69	164
2	174	5 to 15	ND	ND	ND	48	13717	ND	360	ND	75	161
2	175	18 to 28	ND	ND	ND	40	15794	ND	307	ND	56	109
2	176	5 to 15	ND	ND	174	ND	15548	ND	204	ND	39	91
2	177	25 to 35	20	ND	ND	54	21252	24	355	ND	83	194
2	178	5 to 15	ND	ND	ND	55	25118	ND	424	ND	96	218
2	179	25 to 35	20	ND	ND	493	34938	ND	345	ND	115	339
2	180	5 to 15	28	ND	ND	478	31174	ND	296	ND	109	296
2	181	5 to 15	ND	ND	ND	ND	16768	ND	290	ND	35	88
2	182	15 to 22	ND	ND	ND	ND	16697	ND	231	ND	56	94
2	183	5 to 15	ND	ND	ND	48	16168	ND	294	ND	73	117
2	184	25 to 35	16	ND	ND	37	16842	ND	379	ND	82	134
2	185	5 to 15	ND	ND	ND	34	18098	ND	320	ND	91	132
2	186	25 to 35	ND	ND	ND	42	14755	ND	298	ND	65	148
2	187	5 to 15	ND	ND	178	43	15201	ND	360	ND	72	195
2	188	15 to 22	ND	ND	ND	ND	15965	ND	361	ND	69	179

Garden Plot (GP)	sample #	sample depth (cm)	As +/- 5 ppm	Cd +/- 21 ppm	Cr +/- 57 ppm	Cu +/- 12 ppm	Fe +/- 300 ppm	Hg +/- 7 ppm	Mn +/- 46 ppm	Ni +/- 22 ppm	Pb +/- 6 ppm	Zn +/- 8 ppm
2	189	5 to 15	ND	ND	ND	34	15141	ND	334	ND	35	114
2	190	5 to 15	ND	ND	ND	ND	14480	ND	366	ND	48	124
2	191	25 to 35	ND	ND	ND	39	12927	ND	409	ND	53	147
2	192	5 to 15	ND	ND	ND	45	15703	ND	333	ND	61	154
2	193	15 to 25	ND	ND	ND	39	18047	ND	443	ND	73	169
2	194	6 to 16	16	ND	ND	43	16931	ND	422	ND	71	128
2	195	5 to 15	ND	ND	ND	ND	16910	ND	261	ND	67	141
2	196	25 to 35	50	ND	ND	162	67491	78	290	ND	164	992
2	197	7 to 17	36	ND	ND	80	71432	75	429	ND	290	1193
2	198	5 to 15	ND	ND	ND	50	20645	ND	314	ND	197	300
2	199	25 to 35	ND	ND	ND	ND	23153	ND	368	ND	107	240
2	200	5 to 15	18	ND	ND	44	25127	ND	338	ND	135	257
2	201	25 to 35	18	ND	ND	41	21280	ND	332	ND	115	171
2	202	5 to 15	18	ND	ND	ND	21685	ND	355	ND	118	201
2	203	25 to 35	ND	ND	ND	ND	18968	ND	352	ND	78	170
2	204	5 to 15	11	ND	ND	ND	16159	ND	544	ND	46	93
2	205	25 to 35	ND	ND	ND	37	17382	ND	570	ND	101	136
2	206	5 to 15	ND	ND	ND	49	19166	ND	352	ND	117	175
2	207	25 to 35	ND	ND	ND	ND	18313	ND	469	ND	73	116
2	208	5 to 15	ND	ND	ND	ND	16121	ND	468	ND	118	134
2	209	5 to 15	ND	ND	ND	ND	18089	ND	368	ND	151	215
2	210	5 to 15	ND	ND	ND	ND	17050	ND	289	ND	63	125
2	211	5 to 15	ND	ND	ND	ND	16835	ND	335	ND	51	106
2	212	5 to 15	ND	ND	ND	ND	17045	ND	358	ND	63	101
2	213	5 to 15	ND	ND	ND	43	16227	ND	294	ND	85	140
2	214	5 to 15	ND	ND	ND	ND	15801	ND	362	ND	86	134
3	215	5 to 15	ND	ND	ND	ND	14128	ND	362	ND	71	130
3	216	25 to 35	ND	ND	ND	51	13166	ND	333	ND	46	126
3	217	5 to 15	ND	ND	ND	36	10356	ND	269	ND	53	103
3	218	25 to 35	ND	73	ND	42	11178	ND	273	ND	36	84
3	219	5 to 15	ND	ND	ND	39	10503	ND	243	ND	45	103
3	220	25 to 35	ND	ND	ND	33	9707	ND	266	ND	28	61
3	221	5 to 15	ND	ND	ND	ND	10393	ND	237	ND	53	110
3	222	25 to 35	ND	ND	ND	ND	8910	ND	232	ND	24	56
3	223	5 to 15	ND	ND	ND	47	11211	ND	290	ND	57	137
3	224	25 to 35	ND	ND	ND	37	11499	ND	313	ND	158	123
3	225	5 to 15	ND	ND	ND	ND	11518	ND	339	ND	56	119
3	226	25 to 35	ND	ND	ND	ND	10422	ND	265	ND	47	92

Garden Plot (GP)	sample #	sample depth (cm)	As +/- 5 ppm	Cd +/- 21 ppm	Cr +/- 57 ppm	Cu +/- 12 ppm	Fe +/- 300 ppm	Hg +/- 7 ppm	Mn +/- 46 ppm	Ni +/- 22 ppm	Pb +/- 6 ppm	Zn +/- 8 ppm
3	227	5 to 15	ND	ND	ND	37	11448	ND	209	ND	40	112
3	228	25 to 35	ND	ND	ND	ND	9700	ND	244	ND	44	76
3	229	5 to 15	ND	ND	ND	ND	10602	ND	182	ND	45	106
3	230	25 to 35	ND	ND	ND	ND	9472	ND	204	ND	32	66
3	231	5 to 15	ND	ND	ND	ND	9240	ND	179	ND	36	83
3	232	25 to 35	ND	ND	ND	ND	9199	ND	155	ND	32	60
3	233	5 to 15	ND	ND	ND	ND	8751	ND	215	ND	33	78
3	234	25 to 35	ND	ND	ND	ND	7542	ND	117	ND	29	55
3	235	5 to 15	ND	ND	ND	33	9069	ND	147	ND	37	79
3	236	25 to 35	ND	ND	ND	33	7952	ND	128	ND	32	59
3	237	5 to 15	ND	ND	ND	ND	9131	ND	188	ND	35	89
3	238	25 to 35	ND	ND	ND	ND	8595	ND	110	ND	25	43
3	239	5 to 15	ND	ND	ND	ND	9568	ND	180	ND	21	72
3	240	25 to 35	ND	ND	ND	33	10511	ND	149	ND	21	47
3	241	5 to 15	ND	ND	ND	34	8946	ND	171	ND	32	64
3	242	25 to 35	ND	ND	ND	ND	9683	ND	142	ND	33	63
3	243	5 to 15	ND	ND	ND	ND	8744	ND	195	ND	31	65
3	244	25 to 35	ND	ND	ND	33	8972	ND	115	ND	21	55
3	245	5 to 15	ND	ND	ND	ND	9165	ND	172	ND	33	73
3	246	25 to 35	ND	ND	ND	ND	8908	ND	136	ND	25	60
3	247	5 to 15	ND	ND	ND	ND	9264	ND	146	ND	25	66
3	248	25 to 35	ND	ND	ND	ND	9400	ND	151	ND	20	45
3	249	5 to 15	ND	ND	ND	ND	9841	ND	200	ND	34	73
3	250	25 to 35	ND	ND	ND	ND	9278	ND	180	ND	29	54
3	251	5 to 15	ND	ND	ND	43	8898	ND	136	ND	25	59
3	252	25 to 35	ND	ND	ND	ND	9217	ND	171	ND	22	55
3	253	5 to 15	ND	ND	ND	ND	8908	ND	156	ND	35	67
3	254	25 to 35	ND	ND	ND	ND	9220	ND	110	ND	16	37
3	255	5 to 15	ND	ND	ND	ND	9780	ND	158	ND	29	67
3	256	25 to 35	ND	ND	ND	ND	9631	ND	117	ND	21	46
3	257	5 to 15	ND	ND	ND	ND	9440	ND	182	ND	38	69
3	258	25 to 35	ND	ND	ND	ND	9728	ND	183	ND	20	47
3	259	5 to 15	ND	ND	ND	ND	10913	ND	284	ND	75	147
3	260	25 to 35	ND	ND	ND	ND	9920	ND	316	ND	29	76
3	261	5 to 15	ND	ND	ND	34	12411	ND	335	ND	67	156
3	262	25 to 35	ND	ND	ND	ND	9820	ND	250	ND	29	61
3	263	5 to 15	ND	ND	ND	ND	10983	ND	300	ND	152	139
3	264	25 to 35	ND	ND	164	36	9486	ND	252	ND	26	52

Garden Plot (GP)	sample #	sample depth (cm)	As +/- 5 ppm	Cd +/- 21 ppm	Cr +/- 57 ppm	Cu +/- 12 ppm	Fe +/- 300 ppm	Hg +/- 7 ppm	Mn +/- 46 ppm	Ni +/- 22 ppm	Pb +/- 6 ppm	Zn +/- 8 ppm
3	265	5 to 15	ND	ND	ND	ND	10560	ND	283	ND	57	105
3	266	25 to 35	ND	ND	ND	ND	10630	ND	281	ND	46	104
3	267	5 to 15	ND	ND	ND	40	10449	ND	260	ND	58	137
3	268	25 to 35	ND	ND	ND	ND	8652	ND	230	ND	18	38
3	269	5 to 15	ND	ND	ND	ND	9817	ND	192	ND	53	112
3	270	25 to 35	ND	ND	ND	ND	8975	ND	180	ND	28	41
3	271	5 to 15	ND	ND	ND	ND	10478	ND	215	ND	50	107
3	272	25 to 35	ND	ND	ND	ND	9060	ND	213	ND	36	81
3	273	5 to 15	ND	ND	ND	ND	9899	ND	261	ND	43	93
3	274	25 to 35	ND	ND	ND	ND	9203	ND	158	ND	31	62
3	275	5 to 15	ND	ND	ND	ND	10560	ND	173	ND	46	90
3	276	25 to 35	ND	ND	ND	ND	7748	ND	160	ND	23	46
3	277	5 to 15	ND	ND	ND	ND	9845	ND	221	ND	37	90
3	278	25 to 35	ND	ND	ND	ND	9581	ND	209	ND	41	76
3	279	5 to 15	ND	ND	ND	39	9261	ND	228	ND	39	81
3	280	25 to 35	ND	ND	ND	ND	7173	ND	135	ND	19	36
3	281	5 to 15	ND	ND	ND	ND	9229	ND	181	ND	40	75
3	282	25 to 35	ND	ND	ND	34	9711	ND	184	ND	21	56
3	283	5 to 15	ND	ND	ND	32	9562	ND	194	ND	36	84
3	284	25 to 35	ND	ND	ND	ND	9107	ND	167	55	26	46
3	285	5 to 15	ND	ND	ND	ND	8907	ND	176	ND	32	62
3	286	25 to 35	ND	ND	ND	ND	8291	ND	119	ND	21	44
3	287	5 to 15	ND	ND	ND	38	10329	ND	180	ND	35	75
3	288	25 to 35	ND	ND	ND	ND	9563	ND	191	ND	33	79
3	289	5 to 15	ND	ND	ND	ND	9969	ND	99	ND	24	46
3	290	25 to 35	ND	ND	160	42	8617	ND	104	ND	15	36
3	291	5 to 15	ND	ND	ND	44	8958	ND	144	ND	31	67
3	292	25 to 35	ND	ND	ND	ND	8996	ND	137	ND	18	36
3	293	5 to 15	ND	ND	ND	ND	9160	ND	175	ND	23	71
3	294	25 to 35	ND	ND	ND	ND	9217	ND	173	ND	24	87
3	295	5 to 15	ND	ND	ND	ND	9022	ND	161	ND	24	60
3	296	25 to 35	ND	ND	ND	ND	9211	ND	157	ND	23	53
3	297	5 to 15	ND	ND	ND	ND	8530	ND	137	ND	37	62
3	298	25 to 35	ND	ND	ND	36	9749	ND	144	ND	21	38
3	299	5 to 15	ND	ND	ND	ND	8718	ND	200	ND	32	63
3	300	25 to 35	ND	ND	ND	35	8919	ND	156	ND	25	55
3	301	5 to 15	ND	ND	ND	ND	9252	ND	141	ND	33	67
3	302	25 to 35	ND	ND	ND	ND	10335	ND	109	ND	29	41

Garden Plot (GP)	sample #	sample depth (cm)	As +/- 5 ppm	Cd +/- 21 ppm	Cr +/- 57 ppm	Cu +/- 12 ppm	Fe +/- 300 ppm	Hg +/- 7 ppm	Mn +/- 46 ppm	Ni +/- 22 ppm	Pb +/- 6 ppm	Zn +/- 8 ppm
3	303	5 to 15	ND	ND	ND	ND	10978	ND	230	ND	76	131
3	304	25 to 35	ND	ND	ND	ND	8509	ND	218	ND	29	60
3	305	5 to 15	ND	ND	ND	ND	10707	ND	223	ND	58	121
3	306	25 to 35	ND	ND	168	ND	16631	ND	212	ND	35	84
3	307	5 to 15	ND	ND	ND	ND	10647	ND	282	ND	59	120
3	308	25 to 35	ND	ND	ND	ND	9014	ND	226	ND	27	51
3	309	5 to 15	ND	ND	ND	ND	10292	ND	232	ND	51	114
3	310	25 to 35	ND	ND	ND	41	9129	ND	231	ND	28	63
3	311	5 to 15	ND	ND	ND	37	10330	ND	237	ND	49	108
3	312	25 to 35	ND	ND	ND	ND	9754	ND	154	ND	48	80
3	313	5 to 15	ND	ND	ND	40	9592	ND	189	ND	38	97
3	314	25 to 35	ND	ND	ND	ND	13610	ND	260	ND	46	110
3	315	5 to 15	ND	ND	ND	ND	9848	ND	197	ND	52	97
3	316	25 to 35	ND	ND	ND	ND	9223	ND	177	ND	32	80
3	317	5 to 15	ND	ND	ND	34	10114	ND	228	ND	43	93
3	318	25 to 35	ND	ND	ND	ND	10112	ND	265	ND	52	98
3	319	5 to 15	ND	ND	ND	34	9336	ND	268	ND	49	87
3	320	25 to 35	ND	ND	ND	ND	9342	ND	190	ND	37	70
3	321	5 to 15	ND	ND	ND	ND	9802	ND	192	ND	55	100
3	322	25 to 35	ND	ND	ND	ND	8442	ND	160	ND	19	43
3	323	5 to 15	ND	ND	ND	49	9552	ND	212	ND	43	84
3	324	25 to 35	ND	ND	ND	ND	9488	ND	201	ND	39	79
3	325	5 to 15	ND	ND	ND	ND	9165	ND	167	ND	26	80
3	326	25 to 35	ND	ND	ND	ND	10384	ND	220	ND	44	73
3	327	5 to 15	ND	ND	ND	ND	9815	ND	152	ND	32	86
3	328	25 to 35	ND	ND	ND	ND	10702	ND	152	ND	19	33
3	329	5 to 15	ND	ND	ND	ND	9691	ND	173	ND	38	82
3	330	25 to 35	ND	ND	ND	ND	10674	ND	194	ND	26	59
3	331	5 to 15	ND	ND	ND	ND	8979	ND	126	ND	32	72
3	332	25 to 35	ND	ND	ND	ND	9730	ND	179	ND	34	68
3	333	5 to 15	ND	ND	ND	ND	9475	ND	152	ND	39	79
3	334	25 to 35	ND	ND	ND	ND	9654	ND	214	ND	38	65
3	335	5 to 15	10	ND	ND	ND	9509	ND	149	ND	24	84
3	336	25 to 35	ND	ND	ND	ND	9156	ND	157	ND	39	68
3	337	5 to 15	ND	ND	ND	ND	8627	ND	182	ND	28	79
3	338	25 to 35	ND	ND	ND	ND	9052	ND	150	ND	30	58
3	339	5 to 15	ND	ND	ND	34	9580	ND	183	ND	30	75
3	340	25 to 35	ND	ND	ND	ND	10275	ND	163	ND	34	66

Garden Plot (GP)	sample #	sample depth (cm)	As +/- 5 ppm	Cd +/- 21 ppm	Cr +/- 57 ppm	Cu +/- 12 ppm	Fe +/- 300 ppm	Hg +/- 7 ppm	Mn +/- 46 ppm	Ni +/- 22 ppm	Pb +/- 6 ppm	Zn +/- 8 ppm
3	341	5 to 15	ND	ND	ND	ND	9272	ND	177	ND	29	69
3	342	25 to 35	ND	ND	ND	ND	8880	ND	151	ND	34	65
3	343	5 to 15	ND	ND	ND	ND	8535	ND	179	ND	31	70
3	344	25 to 35	ND	ND	ND	ND	9598	ND	161	ND	20	50
3	345	5 to 15	ND	ND	ND	ND	9161	ND	149	ND	29	68
3	346	25 to 35	ND	ND	ND	34	9330	ND	138	ND	24	42
3	347	5 to 15	ND	ND	ND	ND	10761	ND	227	ND	70	146
3	348	25 to 35	ND	ND	ND	ND	9807	ND	262	ND	43	89
3	349	5 to 15	ND	ND	ND	ND	10589	ND	221	ND	67	127
3	350	25 to 35	ND	ND	ND	ND	10298	ND	224	ND	49	110
3	351	5 to 15	ND	ND	ND	36	10772	ND	236	ND	63	118
3	352	25 to 35	ND	ND	ND	ND	8464	ND	230	ND	22	49
3	353	5 to 15	ND	ND	ND	39	9236	ND	209	ND	56	115
3	354	25 to 35	ND	ND	ND	ND	8554	ND	239	ND	32	77
3	355	5 to 15	ND	ND	ND	ND	11062	ND	211	ND	54	124
3	356	25 to 35	ND	ND	ND	ND	9908	ND	220	ND	50	98
3	357	5 to 15	ND	ND	ND	ND	10119	ND	272	ND	53	100
3	358	25 to 35	ND	ND	ND	ND	9323	ND	266	ND	36	83
3	359	5 to 15	ND	ND	ND	ND	10663	ND	233	ND	55	110
3	360	25 to 35	ND	ND	ND	ND	8742	ND	190	ND	29	59
3	361	5 to 15	ND	ND	ND	ND	9836	ND	210	ND	61	100
3	362	25 to 35	17	ND	ND	38	17090	ND	206	ND	52	122
3	363	5 to 15	ND	ND	ND	ND	9599	ND	237	ND	45	99
3	364	25 to 35	11	ND	ND	ND	9955	ND	261	ND	38	94
3	365	5 to 15	ND	ND	ND	ND	9531	ND	221	ND	46	92
3	366	25 to 35	ND	ND	ND	ND	10143	ND	207	ND	51	102
3	367	5 to 15	ND	ND	ND	ND	9403	ND	191	ND	41	99
3	368	25 to 35	ND	ND	ND	ND	10319	ND	236	ND	52	85
3	369	5 to 15	ND	ND	ND	ND	9372	ND	187	ND	44	88
3	370	25 to 35	ND	ND	ND	ND	9544	ND	195	ND	45	83
3	371	5 to 15	ND	71	ND	ND	10103	ND	235	ND	35	83
3	372	25 to 35	ND	ND	ND	ND	9963	ND	216	ND	42	92
3	373	5 to 15	ND	ND	ND	ND	9768	ND	188	ND	40	81
3	374	25 to 35	ND	ND	ND	41	9275	ND	213	ND	33	69
3	375	5 to 15	ND	ND	ND	37	9404	ND	205	ND	37	80
3	376	25 to 35	ND	ND	ND	ND	9728	ND	184	ND	41	76
3	377	5 to 15	ND	ND	ND	ND	8773	ND	169	ND	38	78
3	378	25 to 35	ND	ND	ND	ND	9465	ND	210	72	37	70

Garden Plot (GP)	sample #	sample depth (cm)	As +/- 5 ppm	Cd +/- 21 ppm	Cr +/- 57 ppm	Cu +/- 12 ppm	Fe +/- 300 ppm	Hg +/- 7 ppm	Mn +/- 46 ppm	Ni +/- 22 ppm	Pb +/- 6 ppm	Zn +/- 8 ppm
3	379	5 to 15	ND	ND	ND	ND	9498	ND	228	ND	40	68
3	380	25 to 35	ND	ND	ND	ND	9819	ND	160	ND	38	73
3	381	5 to 15	ND	ND	ND	ND	8827	ND	148	ND	28	61
3	382	25 to 35	ND	ND	ND	ND	11138	ND	165	ND	75	329
3	383	5 to 15	ND	ND	ND	ND	8987	ND	188	ND	30	70
3	384	25 to 35	ND	ND	ND	ND	9182	ND	174	ND	26	83
3	385	5 to 15	ND	ND	ND	ND	8449	ND	167	ND	31	76
3	386	25 to 35	ND	ND	ND	ND	9151	ND	188	ND	35	65
3	387	5 to 15	ND	ND	ND	ND	9032	ND	202	ND	34	72
3	388	25 to 35	ND	ND	ND	ND	9029	ND	156	ND	43	72
3	389	5 to 15	ND	ND	ND	ND	9400	ND	158	ND	28	67
3	390	25 to 35	ND	ND	ND	ND	8057	ND	161	ND	28	54
4	391	5 to 15	ND	ND	ND	ND	21039	ND	724	ND	31	58
4	392	25 to 35	ND	ND	ND	ND	17379	ND	316	ND	21	42
4	393	5 to 15	ND	ND	ND	ND	19706	ND	429	ND	19	47
4	394	25 to 35	ND	ND	ND	ND	14825	ND	312	ND	26	37
4	395	5 to 15	ND	ND	ND	ND	17784	ND	388	ND	15	44
4	396	25 to 35	10	ND	ND	ND	19088	ND	437	ND	21	52
4	397	5 to 15	ND	ND	ND	ND	21091	ND	974	ND	30	54
4	398	25 to 35	ND	ND	ND	ND	21733	ND	647	ND	19	41
5	399	5 to 15	ND	ND	ND	ND	20110	ND	209	ND	20	45
5	400	25 to 35	12	ND	ND	ND	24177	ND	327	ND	19	58
5	401	5 to 15	ND	ND	ND	ND	22583	ND	189	ND	16	48
5	402	25 to 35	ND	ND	ND	ND	20259	ND	352	ND	17	50
5	403	5 to 15	ND	ND	ND	ND	23577	ND	322	ND	23	54
5	404	25 to 35	ND	ND	ND	39	19688	ND	299	ND	22	52
6	405	5 to 15	24	ND	ND	ND	26413	ND	409	ND	204	157
6	406	25 to 35	ND	ND	ND	ND	24142	ND	251	ND	40	81
6	407	5 to 15	ND	ND	ND	ND	25046	ND	319	ND	34	98
6	408	25 to 35	ND	ND	ND	38	22467	ND	346	ND	20	64
6	409	5 to 15	ND	ND	ND	ND	22016	ND	249	ND	34	100
6	410	20 to 30	ND	ND	ND	ND	23602	ND	369	ND	21	68
6	411	5 to 15	ND	ND	ND	37	23870	ND	483	ND	39	92
6	412	25 to 35	ND	ND	ND	ND	22929	ND	371	ND	22	53
6	413	3 to 13	ND	ND	ND	ND	22645	ND	297	ND	41	98
6	414	16 to 26	ND	ND	ND	ND	24438	ND	460	ND	31	139
6	415	5 to 15	15	ND	219	39	25312	ND	439	ND	47	93
6	416	25 to 35	ND	ND	ND	ND	22752	ND	319	ND	30	82

Garden Plot (GP)	sample #	sample depth (cm)	As +/- 5 ppm	Cd +/- 21 ppm	Cr +/- 57 ppm	Cu +/- 12 ppm	Fe +/- 300 ppm	Hg +/- 7 ppm	Mn +/- 46 ppm	Ni +/- 22 ppm	Pb +/- 6 ppm	Zn +/- 8 ppm
7	417	15 to 25	27	ND	ND	61	28558	ND	432	ND	196	469
7	418	15 to 25	ND	ND	ND	41	31833	ND	512	ND	124	270
7	419	15 to 25	ND	ND	ND	50	25341	ND	325	ND	178	348
7	420	15 to 25	ND	ND	ND	41	28542	21	522	ND	164	314
7	421	15 to 25	ND	ND	ND	ND	27772	ND	597	ND	177	343
7	422	15 to 25	ND	ND	ND	62	26074	ND	397	ND	358	406
7	423	15 to 25	51	ND	ND	ND	42806	ND	664	ND	470	306
7	424	15 to 25	ND	ND	ND	64	33080	ND	344	ND	1108	646
7	425	15 to 25	ND	72	ND	44	32688	20	481	ND	241	559
7	426	15 to 25	30	ND	ND	61	45242	26	400	ND	345	679
7	427	15 to 25	28	ND	ND	50	35548	22	345	77	197	474
7	428	15 to 25	24	ND	ND	107	31694	ND	401	ND	285	527
7	429	15 to 25	32	ND	ND	75	28656	21	360	ND	342	531
7	430	15 to 25	ND	ND	ND	63	29719	23	327	93	410	597
7	431	15 to 25	49	ND	226	57	34726	27	322	ND	720	654
7	432	15 to 25	ND	ND	ND	49	17108	ND	393	ND	285	340
7S[1]	433	5 to 15	ND	ND	227	47	29192	ND	355	ND	187	133
7S	434	5 to 15	23	ND	ND	72	32142	20	378	ND	262	629
7S	435	5 to 15	ND	ND	ND	ND	20532	ND	466	ND	477	375
7S	436	5 to 15	ND	ND	ND	72	35352	22	501	ND	235	420
8	437	5 to 15	ND	ND	ND	ND	11457	ND	226	ND	24	54
8	438	25 to 35	ND	ND	ND	36	12001	ND	256	ND	26	56
8	439	5 to 15	ND	ND	ND	ND	11418	ND	209	ND	25	56
8	440	25 to 35	ND	ND	ND	ND	12000	ND	202	ND	22	47
8	441	5 to 15	ND	ND	ND	ND	10625	ND	193	ND	17	54
8	442	25 to 35	ND	ND	ND	38	12041	ND	231	ND	17	54
8	443	5 to 15	ND	ND	ND	35	12457	ND	201	ND	25	67
8	444	25 to 35	ND	ND	ND	ND	11910	ND	243	ND	29	45
8	445	5 to 15	ND	ND	ND	ND	12702	ND	244	ND	22	64
8	446	25 to 35	ND	ND	ND	37	12269	ND	267	ND	30	49
8	447	5 to 15	ND	ND	ND	ND	12618	ND	265	ND	26	65
8	448	25 to 35	ND	ND	ND	ND	11369	ND	236	ND	20	57
8	449	5 to 15	ND	ND	ND	47	11835	ND	248	ND	26	69
8	450	25 to 35	ND	ND	ND	ND	11711	ND	216	ND	24	60
8	451	5 to 15	ND	ND	ND	ND	11585	ND	235	ND	21	52

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[1] Samples taken a few lots north of GP-7 in a few areas of concern in and around a backyard garden.

Garden Plot (GP)	sample #	sample depth (cm)	As +/- 5 ppm	Cd +/- 21 ppm	Cr +/- 57 ppm	Cu +/- 12 ppm	Fe +/- 300 ppm	Hg +/- 7 ppm	Mn +/- 46 ppm	Ni +/- 22 ppm	Pb +/- 6 ppm	Zn +/- 8 ppm
8	452	25 to 35	ND	ND	ND	45	12186	ND	224	ND	20	57
8	453	5 to 15	ND	ND	ND	ND	11599	ND	235	ND	24	48
8	454	25 to 35	ND	ND	ND	ND	11447	ND	288	ND	28	57
8	455	5 to 15	ND	ND	ND	ND	12058	ND	280	ND	25	60
8	456	25 to 35	ND	ND	ND	ND	11411	ND	234	ND	25	50
8	457	5 to 15	ND	ND	ND	ND	12223	ND	293	60	31	63
8	458	25 to 35	ND	ND	ND	ND	12015	ND	255	ND	26	48
8	459	5 to 15	ND	ND	ND	ND	12991	ND	353	ND	28	65
8	460	25 to 35	ND	ND	ND	ND	12089	16	255	ND	27	152
8	461	5 to 15	ND	ND	ND	ND	12785	ND	263	ND	26	53
8	462	25 to 35	ND	ND	ND	ND	12341	ND	262	ND	33	69
8	463	5 to 15	ND	ND	ND	ND	11693	ND	236	ND	27	58
8	464	25 to 35	ND	ND	ND	ND	11467	ND	254	ND	19	64
8pole[2]	465	0 to 10	ND	ND	ND	33	7268	ND	137	ND	24	47
8pit[3]	466	10 to 20	ND	ND	ND	ND	8226	ND	172	ND	33	54
9A[4]	467	5 to 15	ND	ND	ND	37	21826	ND	432	ND	96	143
9A	468	25 to 35	ND	ND	ND	ND	29821	ND	1130	ND	27	65
9	469	5 to 15	ND	ND	ND	34	21931	ND	453	ND	71	264
9	470	25 to 35	ND	ND	ND	ND	17807	ND	247	ND	26	58
9	471	5 to 15	ND	ND	ND	46	20087	ND	501	ND	93	169
9	472	25 to 35	ND	ND	ND	43	16227	ND	172	ND	25	58
9	473	5 to 15	15	ND	ND	36	21361	ND	681	ND	82	202
9	474	25 to 35	15	ND	ND	39	32694	ND	1754	ND	25	65
9	475	5 to 15	14	ND	ND	ND	21424	17	738	ND	104	181
9	476	25 to 35	ND	ND	ND	44	30536	ND	1617	76	35	72
9	477	5 to 15	ND	ND	ND	ND	20584	ND	507	ND	90	161
9	478	25 to 35	12	ND	ND	36	27815	ND	690	ND	30	77
9	479	5 to 15	16	ND	ND	ND	21950	ND	398	ND	74	162
9	480	25 to 35	14	ND	ND	48	31334	ND	983	ND	28	73
10	481	5 to 15	9	ND	ND	ND	14883	ND	226	ND	21	51
10	482	25 to 35	ND	ND	ND	ND	14316	ND	229	ND	24	79
10	483	5 to 15	9	ND	ND	ND	17339	ND	317	ND	14	75
10	484	25 to 35	23	ND	ND	42	34284	ND	547	85	60	175
10	485	5 to 15	15	ND	207	ND	25252	ND	573	ND	25	134

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[2] Sample taken near a pole downslope of an area used as a burn pit for electronics in the vicinity of GP-8.
[3] Sample taken at the approximate site of a burn pit for electronics in the vicinity of GP-8.
[4] Sample taken in a lettuce patch in the lot just south of the main sample area.

Garden Plot (GP)	sample #	sample depth (cm)	As +/- 5 ppm	Cd +/- 21 ppm	Cr +/- 57 ppm	Cu +/- 12 ppm	Fe +/- 300 ppm	Hg +/- 7 ppm	Mn +/- 46 ppm	Ni +/- 22 ppm	Pb +/- 6 ppm	Zn +/- 8 ppm
10	486	25 to 35	ND	ND	ND	38	31311	18	828	ND	26	77
10	487	5 to 15	ND	ND	ND	ND	25254	ND	512	ND	28	97
10	488	20 to 30	15	ND	ND	42	25709	ND	455	ND	28	115
10pg[5]	489	0 to 10	13	ND	ND	ND	26033	ND	519	ND	25	120
compost	490	n/a	ND	ND	ND	35	7841	ND	338	ND	33	148
WoodsonA	491	5 to 15	ND	ND	ND	ND	13287	ND	322	ND	26	32
WoodsonB	492	25 to 35	11	ND	ND	ND	24082	ND	421	ND	21	70
MartinA	493	5 to 15	ND	ND	ND	ND	19871	ND	421	ND	24	47
MartinB	494	25 to 35	ND	ND	ND	ND	32005	ND	636	ND	25	49
EudoraA	495	5 to 15	ND	ND	197	ND	18000	ND	562	ND	23	49
EudoraB	496	25 to 35	10	ND	ND	ND	20820	ND	439	ND	27	47
PawneeA	497	5 to 15	11	ND	ND	ND	22992	ND	228	ND	14	36
PawneeB	498	25 to 35	ND	ND	ND	ND	21636	ND	347	ND	18	70
MorrillA	499	5 to 15	10	ND	ND	ND	20839	ND	444	ND	14	42
MorrillB	500	25 to 35	ND	ND	ND	ND	21758	ND	817	79	16	40

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[5] Refers to sample taken in vicinity of GP-10 near child's wooden play structure.

Appendix B

Garden Plot (GP)	sample#	LOI % SOC by weight	Dry			Moist		
			Hue (shade)	Value (lightness)	Chroma (intensity)	Hue (shade)	Value (lightness)	Chroma (intensity)
1	1		10YR	4	3	10YR	3	3
1	2		10YR	5	4	10YR	4	4
1	3		2.5Y	4	4	10YR	3	3
1	4		2.5Y	5	4	10YR	3	3
1	5	2.24	10YR	4	3	10YR	3	3
1	6		2.5Y	6	4	10YR	4	4
1	7		2.5Y	5	3	10YR	3	3
1	8		10YR	6	4	10YR	4	4
1	9		10YR	4	3	10YR	3	3
1	10	2.26	10YR	5	3	10YR	3	3
1	11		2.5Y	4	3	10YR	3	3
1	12		10YR	5	4	10YR	3	3
1	13		10YR	4	2	10YR	2	2
1	14		2.5Y	5	4	10YR	3	3
1	15	1.61	10YR	5	3	10YR	3	3
1	16		10YR	5	3	10YR	3	3
1	17		10YR	4	2	10YR	2	2
1	18		10YR	5	3	10YR	3	3
1	19		10YR	4	3	10YR	2	2
1	20	1.78	10YR	5	4	10YR	3	3
1	21		10YR	4	2	10YR	3	3
1	22		10YR	4	2	10YR	2	2
1	23		2.5Y	5	4	10YR	3	3
1	24		2.5Y	6	4	10YR	4	3
1	25	1.61	2.5Y	5	4	10YR	5	3
1	26		2.5Y	6	4	2.5Y	4	4
1	27		2.5Y	5	3	2.5Y	3	3
1	28		2.5Y	6	4	2.5Y	4	4
1	29		2.5Y	5	3	2.5Y	4	4
1	30	1.30	2.5Y	6	4	2.5Y	5	4
1	31		2.5Y	4	4	2.5Y	3	3
1	32		2.5Y	6	4	2.5Y	4	4
1	33		2.5Y	5	4	10YR	4	3
1	34		2.5Y	5	3	2.5Y	3	3
1	35	4.01	2.5Y	4	4	10YR	3	3
1	36		2.5Y	6	4	2.5Y	4	4

Garden Plot (GP)	sample#	LOI % SOC by weight	Dry			Moist		
			Hue (shade)	Value (lightness)	Chroma (intensity)	Hue (shade)	Value (lightness)	Chroma (intensity)
1	37		2.5Y	5	3	10YR	3	3
1	38		2.5Y	5	4	10YR	3	3
1	39		2.5Y	4	3	10YR	3	3
1	40	1.78	2.5Y	6	4	2.5Y	3	3
1	41		2.5Y	4	3	2.5Y	3	3
1	42		2.5Y	5	4	2.5Y	4	4
1	43		2.5Y	4	3	10YR	3	3
1	44		2.5Y	3	3	10YR	2	2
1	45	2.19	2.5Y	4	3	10YR	3	3
1	46		2.5Y	4	3	10YR	3	3
1	47		2.5Y	4	4	10YR	3	3
1	48		10YR	4	3	10YR	3	3
1	49		10YR	5	3	10YR	3	3
1	50	0.95	10YR	5	4	10YR	4	4
1	51		10YR	5	4	10YR	3	3
1	52		10YR	5	4	10YR	4	3
1	53		10YR	5	3	10YR	3	3
1	54		10YR	5	4	10YR	3	3
1	55	1.30	10YR	5	4	10YR	3	3
1	56		10YR	5	4	10YR	3	3
1	57		10YR	5	3	10YR	3	3
1	58		10YR	7	4	10YR	5	4
1	59		10YR	5	3	10YR	4	3
1	60	1.60	2.5Y	6	3	2.5Y	4	4
1	61		2.5Y	5	3	10YR	3	3
1	62		2.5Y	5	4	2.5Y	4	4
1	63		2.5Y	5	4	2.5Y	3	3
1	64		10YR	5	4	10YR	3	4
1	65	1.26	10YR	5	3	10YR	3	3
1	66		10YR	4	3	10YR	2	2
1	67		10YR	4	2	10YR	2	2
1	68		10YR	4	3	10YR	3	3
1	69		10YR	4	2	10YR	3	3
1	70	2.47	10YR	5	3	10YR	3	3
1	71		2.5Y	6	6	2.5Y	4	4
1	72		2.5Y	5	3	2.5Y	3	3
1	73		2.5Y	5	3	2.5Y	4	4
1	74		2.5Y	5	4	2.5Y	4	4

Garden Plot (GP)	sample#	LOI % SOC by weight	Dry			Moist		
			Hue (shade)	Value (lightness)	Chroma (intensity)	Hue (shade)	Value (lightness)	Chroma (intensity)
1	75	1.22	2.5Y	5	3	2.5Y	4	3
1	76		2.5Y	5	3	2.5Y	4	3
1	77		2.5Y	5	3	2.5Y	4	4
1	78		2.5Y	5	3	2.5Y	4	4
1	79		2.5Y	5	2	2.5Y	3	3
1	80	1.88	2.5Y	5	4	2.5Y	4	4
1	81		2.5Y	5	4	2.5Y	3	3
1	82		2.5Y	4	3	2.5Y	3	3
1	83		2.5Y	6	4	2.5Y	4	4
1	84		2.5Y	5	4	2.5Y	4	4
1	85	1.09	2.5Y	6	3	2.5Y	4	4
1	86		2.5Y	5	3	2.5Y	3	3
1	87		2.5Y	5	3	2.5Y	4	4
1	88		2.5Y	4	4	2.5Y	3	3
1	89		2.5Y	6	3	2.5Y	4	4
1	90	2.42	2.5Y	5	3	2.5Y	3	3
1	91		2.5Y	6	4	2.5Y	4	4
1	92		2.5Y	6	4	2.5Y	4	4
1	93		2.5Y	6	4	2.5Y	4	4
1	94		2.5Y	5	3	2.5Y	4	4
1	95	1.12	2.5Y	6	4	2.5Y	4	4
1	96		2.5Y	5	3	2.5Y	3	3
1	97		2.5Y	6	3	2.5Y	4	3
1	98		2.5Y	6	4	2.5Y	4	4
1	99		2.5Y	5	2	2.5Y	3	3
1	100	2.88	2.5Y	5	3	2.5Y	4	3
1	101		2.5Y	5	3	2.5Y	4	3
1	102		2.5Y	5	3	2.5Y	4	4
1	103		2.5Y	5	3	2.5Y	4	4
1	104		2.5Y	5	4	2.5Y	3	3
1	105	1.08	2.5Y	5	3	2.5Y	4	4
1	106		2.5Y	6	4	2.5Y	4	4
1	107		2.5Y	5	4	2.5Y	4	4
1	108		10YR	5	3	10YR	4	3
1	109		10YR	5	3	10YR	4	4
1	110	1.41	10YR	5	3	10YR	3	3
1	111		10YR	5	2	10YR	2	2
1	112		10YR	5	3	10YR	4	3

Garden Plot (GP)	sample#	LOI % SOC by weight		Dry			Moist	
			Hue (shade)	Value (lightness)	Chroma (intensity)	Hue (shade)	Value (lightness)	Chroma (intensity)
1	113		10YR	5	2	10YR	3	2
1	114		10YR	5	3	10YR	3	3
1	115	0.95	2.5Y	5	3	2.5Y	4	4
1	116		2.5Y	6	4	2.5Y	4	4
1	117		2.5Y	5	3	2.5Y	4	4
1	118		2.5Y	5	3	2.5Y	4	4
1	119		10YR	6	4	10YR	4	4
1	120	1.33	10YR	5	4	10YR	3	4
1	121		10YR	5	3	10YR	4	3
1	122		10YR	6	3	10YR	3	3
1	123		10YR	6	4	10YR	4	4
1	124		10YR	5	3	10YR	4	4
1	125	1.10	10YR	6	4	10YR	4	4
1	126		10YR	5	3	10YR	3	2
1	127		10YR	6	4	10YR	4	4
1	128		10YR	4	2	10YR	3	2
1	129		10YR	6	3	10YR	3	3
1	130	2.02	10YR	5	2	10YR	4	3
1	131		10YR	5	2	10YR	4	3
1	132		10YR	4	2	10YR	2	1
1	133		10YR	5	2	10YR	3	2
2	134		10YR	4	2	10YR	2	2
2	135	1.38	10YR	5	2	10YR	3	2
2	136		10YR	5	2	10YR	2	2
2	137		10YR	6	2	10YR	2	2
2	138		10YR	5	2	10YR	3	2
2	139		10YR	5	2	10YR	3	2
2	140	1.74	10YR	5	2	10YR	3	2
2	141		10YR	6	2	10YR	3	2
2	142		10YR	5	2	10YR	2	2
2	143		10YR	5	2	10YR	3	3
2	144		10YR	4	2	10YR	2	2
2	145	2.05	10YR	4	3	10YR	2	2
2	146		10YR	4	3	10YR	3	3
2	147		10YR	4	2	10YR	3	3
2	148		10YR	4	3	10YR	3	3
2	149		10YR	5	2	10YR	3	2
2	150	2.99	10YR	4	3	10YR	3	3

Garden Plot (GP)	sample#	LOI % SOC by weight	Dry			Moist		
			Hue (shade)	Value (lightness)	Chroma (intensity)	Hue (shade)	Value (lightness)	Chroma (intensity)
2	151		10YR	4	3	10YR	2	2
2	152		10YR	5	2	10YR	2	2
2	153		10YR	5	2	10YR	3	3
2	154		10YR	4	3	10YR	3	3
2	155	0.97	10YR	5	3	10YR	3	3
2	156		10YR	4	3	10YR	3	3
2	157		10YR	5	3	10YR	3	3
2	158		10YR	5	3	10YR	3	3
2	159		10YR	5	3	10YR	3	3
2	160	4.89	10YR	4	3	10YR	2	2
2	161		10YR	4	3	10YR	3	3
2	162		10YR	5	3	10YR	3	3
2	163		10YR	5	3	10YR	3	3
2	164		10YR	4	3	10YR	3	3
2	165	1.11	2.5Y	5	3	2.5Y	4	4
2	166		10YR	4	3	10YR	3	3
2	167		10YR	5	3	10YR	3	3
2	168		10YR	4	3	10YR	2	2
2	169		10YR	5	2	10YR	3	3
2	170	4.37	10YR	4	2	10YR	2	2
2	171		10YR	4	2	10YR	2	2
2	172		10YR	3	3	10YR	2	2
2	173		10YR	4	2	10YR	2	2
2	174		10YR	4	2	10YR	2	2
2	175	1.44	10YR	5	3	10YR	3	3
2	176		10YR	4	3	10YR	2	2
2	177		10YR	4	2	10YR	2	2
2	178		10YR	5	3	10YR	3	3
2	179		10YR	5	3	10YR	3	3
2	180	1.35	10YR	4	3	10YR	3	3
2	181		10YR	5	3	10YR	3	3
2	182		10YR	4	3	10YR	3	3
2	183		10YR	4	3	10YR	2	2
2	184		10YR	4	3	10YR	3	3
2	185	9.36	10YR	4	2	10YR	2	1
2	186		10YR	4	3	10YR	2	2
2	187		10YR	4	2	10YR	2	2
2	188		10YR	4	3	10YR	3	3

Garden Plot (GP)	sample#	LOI % SOC by weight	Dry Hue (shade)	Dry Value (lightness)	Dry Chroma (intensity)	Moist Hue (shade)	Moist Value (lightness)	Moist Chroma (intensity)
2	189		10YR	4	3	10YR	3	3
2	190	7.97	10YR	4	3	10YR	2	2
2	191		10YR	4	3	10YR	2	2
2	192		10YR	4	2	10YR	2	2
2	193		10YR	5	3	10YR	3	3
2	194		10YR	4	3	10YR	3	2
2	195	2.01	10YR	4	3	10YR	3	2
2	196		10YR	4	2	7.5YR	2.5	2
2	197		10YR	4	2	7.5YR	2.5	3
2	198		10YR	4	2	10YR	2	2
2	199		10YR	4	3	10YR	3	2
2	200	3.11	10YR	4	3	10YR	2	2
2	201		10YR	4	4	7.5YR	3	3
2	202		10YR	4	3	10YR	3	3
2	203		10YR	4	3	10YR	2	2
2	204		10YR	4	3	10YR	2	2
2	205	1.56	10YR	3	3	10YR	2	2
2	206		10YR	4	3	10YR	2	2
2	207		10YR	4	4	10YR	2	2
2	208		10YR	4	3	10YR	2	2
2	209		10YR	4	3	7.5YR	2.5	2
2	210	1.57	10YR	4	2	7.5YR	2.5	2
2	211		10YR	4	3	10YR	3	3
2	212		10YR	4	3	10YR	3	3
2	213		10YR	4	3	7.5YR	2.5	3
2	214		10YR	4	3	10YR	3	2
3	215	1.59	10YR	4	2	10YR	2	2
3	216		10YR	4	2	10YR	3	2
3	217		10YR	4	2	10YR	2	2
3	218		10YR	4	2	10YR	2	2
3	219		10YR	4	2	10YR	2	2
3	220	1.13	10YR	4	2	10YR	2	2
3	221		10YR	4	2	10YR	2	2
3	222		10YR	4	3	10YR	2	2
3	223		10YR	4	2	10YR	2	2
3	224		10YR	4	3	10YR	2	2
3	225	1.91	10YR	4	2	10YR	2	2
3	226		10YR	4	3	10YR	2	2

Garden Plot (GP)	sample#	LOI % SOC by weight	Dry			Moist		
			Hue (shade)	Value (lightness)	Chroma (intensity)	Hue (shade)	Value (lightness)	Chroma (intensity)
3	227		10YR	4	3	10YR	2	2
3	228		10YR	4	3	10YR	2	2
3	229		10YR	4	2	10YR	2	2
3	230	0.51	10YR	4	3	10YR	2	2
3	231		10YR	4	2	10YR	2	2
3	232		10YR	4	3	10YR	2	2
3	233		10YR	4	2	10YR	2	2
3	234		10YR	4	3	10YR	3	2
3	235	0.90	10YR	4	2	10YR	3	2
3	236		2.5Y	4	3	2.5Y	3	3
3	237		2.5Y	5	2	10YR	3	2
3	238		10YR	5	3	10YR	3	3
3	239		10YR	4	2	10YR	3	2
3	240	0.51	10YR	4	3	10YR	3	3
3	241		10YR	4	2	10YR	3	2
3	242		10YR	4	3	10YR	3	2
3	243		10YR	4	2	10YR	3	2
3	244		10YR	5	3	10YR	3	2
3	245	0.86	10YR	4	3	10YR	3	2
3	246		10YR	5	3	10YR	3	3
3	247		10YR	4	3	10YR	3	2
3	248		10YR	5	3	10YR	3	3
3	249		10YR	4	2	10YR	3	2
3	250	0.43	10YR	5	3	10YR	3	3
3	251		10YR	4	3	10YR	3	2
3	252		10YR	4	3	10YR	3	3
3	253		10YR	4	2	10YR	3	3
3	254		10YR	5	4	10YR	3	3
3	255	0.87	10YR	5	3	10YR	3	2
3	256		10YR	5	3	10YR	3	3
3	257		10YR	4	3	7.5YR	3	3
3	258		10YR	5	3	10YR	3	3
3	259		10YR	4	2	10YR	2	2
3	260	0.65	10YR	4	2	10YR	2.5	2
3	261		10YR	4	2	10YR	2	2
3	262		10YR	4	2	10YR	2	2
3	263		10YR	5	2	10YR	2	2
3	264		10YR	4	2	10YR	3	2

Garden Plot (GP)	sample#	LOI % SOC by weight		Dry			Moist	
			Hue (shade)	Value (lightness)	Chroma (intensity)	Hue (shade)	Value (lightness)	Chroma (intensity)
3	265	1.42	10YR	4	2	10YR	2	2
3	266		10YR	4	2	7.5YR	2.5	2
3	267		10YR	4	2	7.5YR	2.5	2
3	268		10YR	4	2	7.5YR	2.5	3
3	269		10YR	4	2	10YR	3	2
3	270	0.50	10YR	4	3	10YR	3	2
3	271		10YR	4	2	10YR	3	2
3	272		10YR	4	3	10YR	3	2
3	273		10YR	4	2	10YR	3	2
3	274		10YR	4	3	10YR	3	2
3	275	0.84	10YR	4	2	10YR	3	2
3	276		10YR	4	3	10YR	3	3
3	277		10YR	4	3	10YR	3	2
3	278		10YR	4	3	10YR	3	2
3	279		10YR	4	3	10YR	3	3
3	280	0.26	10YR	4	3	10YR	3	3
3	281		10YR	4	2	10YR	2	2
3	282		10YR	4	3	10YR	3	3
3	283		10YR	4	3	10YR	3	2
3	284		10YR	4	3	10YR	3	3
3	285	1.64	10YR	4	3	10YR	3	2
3	286		10YR	4	3	10YR	3	3
3	287		10YR	4	3	10YR	3	3
3	288		10YR	4	3	10YR	3	3
3	289		10YR	5	3	10YR	3	3
3	290	0.36	10YR	5	3	10YR	3	3
3	291		10YR	4	3	10YR	3	2
3	292		10YR	4	3	10YR	3	3
3	293		10YR	4	3	10YR	2	2
3	294		10YR	4	3	10YR	3	3
3	295	1.59	10YR	4	3	10YR	3	2
3	296		10YR	4	3	10YR	3	3
3	297		10YR	4	3	10YR	3	2
3	298		10YR	5	3	10YR	3	3
3	299		10YR	4	3	10YR	3	2
3	300	0.42	10YR	5	3	10YR	3	3
3	301		10YR	4	3	10YR	3	2
3	302		10YR	5	3	10YR	3	3

Garden Plot (GP)	sample#	LOI % SOC by weight		Dry			Moist	
			Hue (shade)	Value (lightness)	Chroma (intensity)	Hue (shade)	Value (lightness)	Chroma (intensity)
3	303		10YR	4	2	10YR	2	2
3	304		10YR	4	2	10YR	3	2
3	305	2.59	10YR	4	2	10YR	2	2
3	306		10YR	4	3	10YR	3	2
3	307		10YR	4	2	10YR	3	2
3	308		10YR	4	2	10YR	3	2
3	309		10YR	4	2	10YR	2	2
3	310	0.63	10YR	4	2	10YR	3	2
3	311		10YR	4	2	10YR	2	2
3	312		10YR	4	3	10YR	3	2
3	313		10YR	4	2	10YR	2	2
3	314		10YR	4	3	10YR	3	2
3	315	1.60	10YR	4	2	10YR	3	2
3	316		10YR	4	2	10YR	3	2
3	317		10YR	4	3	10YR	2	2
3	318		10YR	4	2	10YR	3	3
3	319		10YR	4	3	10YR	3	2
3	320	0.38	10YR	4	3	10YR	3	3
3	321		10YR	4	2	10YR	3	2
3	322		10YR	4	3	10YR	3	3
3	323		10YR	4	2	10YR	3	2
3	324		10YR	4	3	10YR	3	3
3	325	1.06	10YR	4	3	10YR	3	3
3	326		10YR	4	3	10YR	3	3
3	327		10YR	4	3	10YR	3	3
3	328		10YR	4	3	10YR	3	3
3	329		10YR	4	3	10YR	3	2
3	330	1.09	10YR	5	3	10YR	3	3
3	331		10YR	4	3	10YR	3	3
3	332		10YR	4	3	10YR	3	2
3	333		10YR	4	3	10YR	3	2
3	334		10YR	4	3	10YR	3	3
3	335	0.50	10YR	4	3	10YR	3	3
3	336		10YR	4	3	10YR	3	2
3	337		10YR	4	2	10YR	2	2
3	338		10YR	4	3	10YR	3	2
3	339		10YR	5	2	10YR	3	2
3	340	0.55	10YR	5	3	10YR	3	3

			Dry			Moist		
Garden Plot (GP)	sample#	LOI % SOC by weight	Hue (shade)	Value (lightness)	Chroma (intensity)	Hue (shade)	Value (lightness)	Chroma (intensity)
3	341		10YR	4	3	10YR	3	3
3	342		10YR	4	3	10YR	3	2
3	343		10YR	4	3	10YR	3	3
3	344		10YR	4	3	10YR	3	3
3	345	0.83	10YR	4	2	10YR	3	2
3	346		10YR	5	3	10YR	3	3
3	347		10YR	4	2	10YR	2	2
3	348		10YR	4	3	10YR	3	3
3	349		10YR	4	2	10YR	2	2
3	350	0.57	10YR	4	2	10YR	2	2
3	351		10YR	4	2	10YR	2	2
3	352		10YR	4	3	10YR	3	3
3	353		10YR	4	2	10YR	2	2
3	354		10YR	4	2	10YR	2	2
3	355	1.28	10YR	4	2	10YR	2	2
3	356		10YR	4	3	10YR	3	2
3	357		10YR	4	2	10YR	3	2
3	358		10YR	4	2	10YR	3	3
3	359		10YR	4	2	10YR	3	2
3	360	0.69	10YR	4	2	10YR	3	2
3	361		10YR	4	2	10YR	2	2
3	362		10YR	4	3	10YR	3	2
3	363		10YR	4	2	10YR	2	2
3	364		10YR	4	2	10YR	3	2
3	365	1.03	10YR	4	3	10YR	3	2
3	366		10YR	4	3	10YR	3	2
3	367		10YR	4	3	10YR	3	2
3	368		10YR	4	3	10YR	3	2
3	369		10YR	4	2	10YR	3	2
3	370	0.56	10YR	4	3	10YR	3	2
3	371		10YR	4	2	10YR	2	2
3	372		10YR	4	3	10YR	3	2
3	373		10YR	4	3	10YR	2	2
3	374		10YR	4	3	10YR	3	2
3	375	0.74	10YR	4	2	10YR	3	2
3	376		10YR	4	3	10YR	3	2
3	377		10YR	4	2	10YR	2	2
3	378		10YR	4	3	10YR	3	3

				Dry			Moist	
Garden Plot (GP)	sample#	LOI % SOC by weight	Hue (shade)	Value (lightness)	Chroma (intensity)	Hue (shade)	Value (lightness)	Chroma (intensity)
3	379		10YR	4	2	10YR	2	2
3	380	0.30	10YR	4	3	10YR	3	2
3	381		10YR	4	2	10YR	3	2
3	382		10YR	4	3	10YR	3	2
3	383		10YR	4	2	10YR	2	2
3	384		10YR	4	2	10YR	3	2
3	385	1.06	10YR	4	2	10YR	3	2
3	386		10YR	4	3	10YR	3	3
3	387		10YR	4	2	10YR	3	2
3	388		10YR	4	3	10YR	3	2
3	389		10YR	4	2	10YR	3	2
3	390	0.47	10YR	4	3	10YR	3	3
4	391		10YR	4	3	10YR	2	2
4	392		10YR	3	3	10YR	2	2
4	393		10YR	4	3	10YR	3	2
4	394		10YR	4	2	10YR	2	2
4	395	1.45	10YR	4	3	10YR	2	2
4	396		10YR	4	3	10YR	2	2
4	397		10YR	4	3	10YR	2	2
4	398		10YR	4	3	10YR	3	2
5	399		10YR	5	4	10YR	3	4
5	400	0.55	10YR	4	4	10YR	3	4
5	401		10YR	5	4	10YR	3	4
5	402		10YR	5	4	10YR	3	4
5	403		10YR	5	4	10YR	4	4
5	404		10YR	5	4	10YR	4	4
6	405	1.92	10YR	4	2	10YR	2	2
6	406		10YR	4	3	10YR	2	2
6	407		10YR	4	2	10YR	2	2
6	408		10YR	4	2	10YR	2	2
6	409		10YR	4	2	10YR	2	2
6	410	1.60	10YR	4	3	10YR	2	2
6	411		10YR	4	2	10YR	2	2
6	412		10YR	4	2	10YR	2	2
6	413		10YR	4	2	10YR	2	2
6	414		10YR	4	3	10YR	2	2
6	415	2.33	10YR	4	2	10YR	2	2
6	416		10YR	4	3	10YR	2	2

Garden Plot (GP)	sample#	LOI % SOC by weight		Dry			Moist	
			Hue (shade)	Value (lightness)	Chroma (intensity)	Hue (shade)	Value (lightness)	Chroma (intensity)
7	417		10YR	4	2	10YR	2	2
7	418		10YR	4	3	10YR	3	2
7	419		10YR	4	2	10YR	2	2
7	420	1.69	10YR	4	2	10YR	3	2
7	421		10YR	4	2	10YR	2	2
7	422		10YR	4	2	10YR	3	2
7	423		10YR	4	3	10YR	3	2
7	424		10YR	5	2	10YR	3	2
7	425	2.09	10YR	4	2	10YR	2	2
7	426		10YR	4	2	10YR	2	2
7	427		10YR	4	2	10YR	3	2
7	428		10YR	3	2	10YR	2	2
7	429		10YR	4	2	10YR	2	2
7	430	2.06	10YR	3	2	10YR	2	2
7	431		10YR	4	2	10YR	2	2
7	432		10YR	3	2	10YR	2	2
7S[6]	433		10YR	5	3	10YR	3	3
7S	434		10YR	4	2	10YR	3	2
7S	435	1.62	10YR	3	2	10YR	2	2
7S	436		10YR	4	2	10YR	2	2
8	437		10YR	4	2	10YR	3	2
8	438		10YR	4	2	10YR	2	2
8	439		10YR	3	2	10YR	2	2
8	440	0.76	10YR	4	2	10YR	2	2
8	441		10YR	4	2	10YR	2	2
8	442		10YR	4	2	10YR	3	2
8	443		10YR	4	2	10YR	3	2
8	444		10YR	4	3	10YR	3	2
8	445	1.39	10YR	4	2	10YR	3	2
8	446		10YR	4	3	10YR	3	2
8	447		10YR	4	3	10YR	2	2
8	448		10YR	4	2	10YR	2	2
8	449		10YR	4	2	10YR	3	2
8	450	0.89	10YR	4	2	10YR	2	2
8	451		10YR	4	2	10YR	2	2

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[6] Samples taken a few lots north of GP-7 in a few areas of concern in and around a backyard garden.

Garden Plot (GP)	sample#	LOI % SOC by weight	Dry			Moist		
			Hue (shade)	Value (lightness)	Chroma (intensity)	Hue (shade)	Value (lightness)	Chroma (intensity)
8	452		10YR	4	2	10YR	2	2
8	453		10YR	4	3	10YR	2	2
8	454		10YR	4	3	10YR	2	2
8	455	0.91	10YR	4	2	10YR	2	2
8	456		10YR	4	2	10YR	2	2
8	457		10YR	4	2	10YR	2	2
8	458		10YR	4	2	10YR	3	2
8	459		10YR	4	2	10YR	2	2
8	460	0.79	10YR	4	2	10YR	2	2
8	461		10YR	4	2	10YR	2	2
8	462		10YR	4	2	10YR	2	2
8	463		10YR	4	3	10YR	3	2
8	464		10YR	4	3	10YR	3	2
8pole[7]	465	0.70	10YR	4	3	10YR	3	3
8pit[8]	466		10YR	4	2	10YR	3	2
9A[9]	467		10YR	4	3	10YR	3	3
9A	468		2.5Y	6	3	2.5Y	3	3
9	469		2.5Y	4	2	7.5YR	2.5	2
9	470	0.56	2.5Y	7	2	2.5Y	4	2
9	471		10YR	4	3	10YR	2	2
9	472		2.5Y	4	2	2.5Y	4	2
9	473		2.5Y	4	3	10YR	3	2
9	474		2.5Y	4	3	2.5Y	3	3
9	475	1.83	2.5Y	4	3	10YR	3	2
9	476		2.5Y	5	3	2.5Y	3	2
9	477		2.5Y	4	3	10YR	3	2
9	478		2.5Y	5	3	2.5Y	3	2
9	479		2.5Y	5	3	2.5Y	3	2
9	480	1.07	2.5Y	4	3	2.5Y	3	2
10	481		10YR	3	2	10YR	2	2
10	482		10YR	4	3	10YR	2	2
10	483		10YR	3	2	10YR	2	1
10	484		2.5Y	5	3	2.5Y	3	3
10	485	2.06	2.5Y	4	3	2.5Y	3	2

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[7] Sample taken near a pole downslope of an area used as a burn pit for electronics in the vicinity of GP-8.
[8] Sample taken at the approximate location of a burn pit for electronics in the vicinity of GP-8.
[9] Sample taken in a lettuce patch in the lot just south of the main sample area of GP-9

Garden Plot (GP)	sample#	LOI % SOC by weight	Dry			Moist		
			Hue (shade)	Value (lightness)	Chroma (intensity)	Hue (shade)	Value (lightness)	Chroma (intensity)
10	486		2.5Y	5	4	10YR	3	3
10	487		2.5Y	4	3	10YR	3	3
10	488		2.5Y	5	4	10YR	3	3
10pg[10]	489		2.5Y	5	3	10YR	3	2
compost	490	11.35	10YR	2	2	10YR	2	1
WoodsonA	491	1.17	10YR	4	2	10YR	2	2
WoodsonB	492		10YR	4	3	10YR	2	2
MartinA	493	1.43	10YR	4	2	10YR	2	2
MartinB	494		2.5Y	5	4	10YR	3	3
EudoraA	495	1.55	2.5Y	5	3	10YR	3	3
EudoraB	496		2.5Y	5	4	2.5Y	4	4
PawneeA	497	1.53	10YR	3	2	10YR	2	2
PawneeB	498		10YR	4	2	10YR	2	2
MorrillA	499	0.56	2.5Y	6	4	2.5Y	5	4
MorrillB	500	0.57	10YR	6	4	10YR	4	4

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[10] Refers to sample taken in vicinity of GP-10 near child's wooden play structure.