City of Spokane Park Board
Urban Forestry Tree Committee
Tuesday, September 5, 2017, 4:15 p.m. – 5:45 p.m.
Willow Room, Woodland Center
John A. Finch Arboretum
3404 W. Woodland Blvd., Spokane, Washington
Angel Spell – Urban Forester

Committee Members:
Rick Chase – Chairperson
Jennifer Ogden
Guy Gifford
Garth Davis
Kevin Cash
Sally Lodato – Alternate

A regular meeting of the City of Spokane Park Board Tree Committee will be held at 4:15 p.m. on Tuesday, September 5, 2017, in the Woodland Center's Willow Room at John A. Finch Arboretum; 3404 W. Woodland Blvd., Spokane, Washington.

The meeting will be conducted in a standing committee format for the Tree Committee of the City of Spokane Park Board. Because a quorum of the Park Board may be present, the standing committee meeting will be conducted as a committee of the whole Board.

The meeting will be open to the public, with the possibility of moving into executive session only with the members of the Park Board and appropriate staff. Discussion will be limited to appropriate officials and staff. Public testimony may be taken at the discretion of the Committee Chair.

AGENDA

Action Items:

1. 2018 UF Budget – *Angel Spell*

Discussion Items:

1. A case study of heavy metal content in urban residential and park soils, Spokane's South Hill (an EWU analysis and publication in Applied Geochemistry) – *Angel Spell*

Standing Report Items:

1. Citizen Advisory Committee Report – *Guy Gifford*
2. Urban Forestry Financial Report – *Angel Spell*

Please Note: Agenda is subject to change. **AMERICANS WITH DISABILITIES ACT (ADA) INFORMATION:** The City of Spokane is committed to providing equal access to its facilities, programs and services for persons with disabilities. Individuals requesting reasonable accommodations or further information may call, write, or email Human Resources at (509) 625-6363; 808 W. Spokane Falls Blvd., Spokane, WA 99201; or jjackson@spokanecity.org. Persons who are deaf or hard of hearing may contact Human Resources through the Washington Relay Service at 7-1-1. Please contact us forty-eight (48) hours before the meeting date.

City of Spokane - Parks & Recreation
Fund 1400 - Urban Forestry
2018 Recommended Budget

	2016 Actual	2017 Adopted Budget	2017 Thru July	2018 Recommended
Revenues	144,038	120,000	132,254	170,000
ExpenditureCategories:				
Salaries & Wages	377,447	416,884	227,663	467,494
Personnel Benefits	94,982	113,531	63,331	140,469
Supplies	27,127	30,550	13,585	30,550
Svcs. & Charges	121,432	157,655	44,843	207,655
Intergovernmental Services				
Interfund Services		23,800		23,800
Operating Transfers	8,000	2,641		2,641
Capital Outlay	114,489		94,570	
Total Expenditures	743,477	745,061	443,992	872,609
Net Revenues minus Expenditures	(599,439)	(625,061)	(311,738)	(702,609)

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Heavy metal content in urban residential and park soils: A case study in Spokane, Washington, USA[☆]

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ABSTRACT

Urban soils may be contaminated with heavy metals due to historical and current use of fertilizers, pesticides, wood preservatives, and construction materials. To examine the amount of trace metals from natural and anthropogenic sources, we focused on a middle-to-upper income, residential area in Spokane, Washington which was developed in the late 1800s but has not experienced heavy industrial activity. Surface soil was collected from thirty sites (including residential lawns, gardens, and city parks), and digested using EPA Method 3050B. The average As, Pb, and Zn concentrations in residential soils (11 mg kg^{-1}, 59 mg kg^{-1}, and 107 mg kg^{-1}, respectively) exceeded those in below surface rural soils (9 mg kg^{-1}, 15 mg kg^{-1}, and 66 mg kg^{-1}) indicating sources of contamination in this urban environment. Four sites had As or Pb concentrations above Washington State Department of Ecology levels for unrestricted land use (20 mg kg^{-1} and 250 mg kg^{-1}, respectively). At one of these sites, Pb exceeded 1200 mg kg^{-1}, the USEPA threshold for residential soil with unrestricted use, and an additional site had Pb concentrations above the 400 mg kg^{-1}, the limit for children's play areas. The Pb:As ratio in soils with elevated As concentrations suggest that the likely source is arsenical pesticide or an As-bearing fertilizer. In soils with elevated Pb concentrations, Ba, Pb, and Zn were correlated which suggests – along with the soils' proximity to structures – that lead-based paint is likely the source. Although vehicle emissions also add these metals to soils near roadways, traffic density near our study sites was low.

1. Introduction

Lawn soils in residential neighborhoods that have not experienced appreciable amounts of industrial activity are typically assumed to be safe. However, these soils may contain elevated levels of metals and metalloids due to standard homeowner activities: pesticide and fertilizer application, remodeling a structure containing lead-based paint, use of pressure-treated woods for decks, and exposure to vehicular emissions (Folkes et al., 2001a; Renshaw et al., 2006; Schwarz et al., 2016b; Stilwell and Gorny, 1997). Soils may also contain low levels of metals added by distant anthropogenic activities such as mining and smelting of metals, fossil fuel combustion, and waste incineration (Chirenje et al., 2004; Filippelli et al., 2005; Schwarz et al., 2016b).

Although the release of metals (especially lead) to the environment has decreased over the last few decades due to the Clean Air Act and other environmental regulations, elevated levels of metals still remain in surface soils (Grzebisz et al., 2002). In fact, metals are often enriched in the upper 20 cm of soils (Folkes et al., 2001a; Renshaw et al., 2006; Stilwell and Gorny, 1997). Metal mobility is limited in surface soils due to the circumneutral pH and high organic matter typically found in managed residential and municipal park soils. (Dubey and Townsend, 2004; McBride et al., 2014).

Humans in urban areas may be at a high risk of exposure to metals (Filippelli et al., 2005; Laidlaw and Filippelli, 2008). Children, especially, may ingest and inhale large amounts due to their tendency to play and crawl on the ground, and their high rates of hand-to-mouth transfer (Roels et al., 1980; Watt et al., 1993). The occurrence of higher blood-lead levels of children in large U.S. cities during the summer months confirms their increased exposure, especially due to resuspension of soils (Laidlaw and Filippelli, 2008). Another concern about contaminated soils is the rise of personal and community gardens in urban areas. While plant uptake of metals is often too low to be a health risk, contaminated soils may be ingested when vegetables are not washed sufficiently

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[☆] This paper has been recommended for acceptance by Prof. M. Kersten.

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(McBride et al., 2014; Shiowatana et al., 2001). On the other hand, the practices used to create and maintain urban gardens may reduce human exposure to urban soil lead (Schwarz et al., 2016a). For example, the addition of compost or manure may reduce the bioavailability of lead, as well as provide a cover for the soil (Schwarz et al., 2016a).

A previous study investigated the composition of local soils in rural areas where local anthropogenic activities had not significantly influenced the soil (San Juan, 1994). The authors defined "natural background" as the combination of naturally occurring concentrations, and globally-distributed, low-level anthropogenic contributions. A total of 22 surface soil samples were collected to determine the levels of trace elements and major cations in rural soils in the Spokane Basin (San Juan, 1994). Based on these average concentrations, localized or regional contributions of metals from anthropogenic activities can be distinguished from those naturally occurring in the bedrock or soil. We refer to these latter concentrations as "natural background" throughout the remainder of the manuscript.

To our knowledge, metal contamination in urban or suburban residential soils has not been investigated in Spokane County. The objectives of this study were to 1) establish natural background levels of metals/metalloids in residential and municipal park soils in Spokane, Washington; and 2) identify potential sources of elevated levels in soils. Characterizing metal concentrations in urban soils and identifying sources may alert residents to previously unknown hazards and help to focus remediation efforts. As the percentage of humans living in urban environments is expected to rise globally from ~50% (currently) to 66% by 2050 (Lehmann and Stahr, 2007; Malakoff et al., 2016), identification and remediation of metal-contaminated soils may become more urgent.

2. Materials and methods

2.1. Site description

Our study area is located in Spokane, Washington. Spokane, founded in 1810, is located in Eastern Washington about 20 miles west of the Washington-Idaho border (Fig. 1). Historically, the economy has been dependent on mining, agriculture, and timber in the region. Today, the population in the city of Spokane is about 200,000 people.

The focus of our study is a primarily residential area in southern Spokane called the South Hill where soil contamination has not previously been identified. This area lies south of Interstate 90 (Fig. 1) and contains home with a median value of $230,000 (http://www.unitedstateszipcodes.org/99203/, accessed 10/27/16). The South Hill has never had – nor is it downwind or downstream from – any major industrial activities. Most of the homes in this study area were built in the early 1900s and have likely been remodeled before federal regulations began requiring safe removal of lead-based paint. In addition, many homes have had several homeowners over the years so that the history of the property (e.g., home remodeling or fertilizer/pesticide application) is unknown to the current homeowner.

Generally speaking, the rock and sediment types found in Spokane County have only trace amounts of naturally-occurring metals (Turekian and Wedepohl, 1961). The dominant bedrock is the Columbia River Flood Basalt, which ranges in age locally from 15 to 17 million years. Interbedded with the basalt are lacustrine and fluvial deposits of the middle Miocene Latah Formation. Underlying the basalt is metamorphosed basement rock (saprolitic gneiss and quartzite) which outcrops to the east of our study area (Johnson et al., 1998). Quaternary deposits include Glacial Lake Missoula outburst flood and glaciolacustrine deposits which contain fine-grained to boulder size material (Johnson et al., 1998). Volcanic ash and loess are also present in the area (Johnson et al., 1998; San Juan, 1994).

A total of 30 locations were sampled in Spokane County: 14 park soils, 20 residential yards, and 6 gardens (Table 1). Most of the locations were within a four km radius on the South Hill in Spokane. Three additional sites were collected from residential yards outside of the city limits, or in smaller nearby towns. Some of the garden soils, which were assumed to have been highly amended and/or disturbed by tilling, were paired with a non-garden sample at the same residence.

2.2. Soil sample collection

Soils were collected from the upper 5 cm using a clean plastic trowel and stored in plastic bags. Most samples were composites of three soils which were within a one-meter radius and equidistant from potential anthropogenic sources (e.g., roads, structures). The samples collected by homeowners were grab samples. After rocks and large roots were removed, soils were dried at 60 °C for 3 days. Any soil clumps were mechanically disintegrated using an agate mortar and pestle. At two locations, one each with elevated concentrations of As or Pb, soil profiles were collected using a soil core sampler. Samples were taken in 5 cm increments to a depth of 20 cm and were treated using the same protocol as the surface soils.

2.3. Sequential extraction procedure

Soils were sequentially extracted with a 1 M HNO_3 solution (Nezat et al., 2007) and EPA Method 3050 B which uses concentrated HNO_3 and H_2O_2 under high temperatures (EPA, 1996). Although these extractions are not complete because HF is required to break down the silicates, this procedure removes the environmentally available fraction of metals. In this study, we report only the sum of the two extractions, and refer to it as the total-extractable fraction. Ultrapure water (18 M Ω) and trace-metal grade solutions were used, and all plastic and glassware was acid-washed prior to use. Procedural blanks, soil replicates, and a certified reference material, Montana Soil 2710, were also prepared.

2.4. Analysis of extracts

The leaches and digests were analyzed for As, Cd, Cr, Cu, Pb, and Zn using a Thermo Scientific iCap 6200 Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES). The ICP-OES was calibrated with seven standards. Analysis of certified reference materials (High-Purity Standards™ Soil B and TMDW-B) indicated that the recovery of As, Cu, Pb, and Zn was 100± 10%, and 140 and 130% for Cd and Cr, respectively. The metal concentrations in procedural blanks were negligible. Replicate analysis ($n = 9$) of one sample indicated that the relative standard deviation was less than 25%. The recovery of As, Cd, Cu, Pb, and Zn in the Montana Soil 2710 were 100± 14%. The recovery of Ba was 44% which is consistent with the recovery obtained by other labs (41%) (NIST, 2002). Chromium concentrations are not certified for this standard.

2.5. Data analysis

Outliers were identified as those concentrations greater than the third quartile plus 1.5 times the interquartile range (i.e., the difference between the third quartile and the first quartile). No outliers were found below the first quartile minus 1.5 times the interquartile range. Quartiles were calculated in Excel using the quartile. inc function.

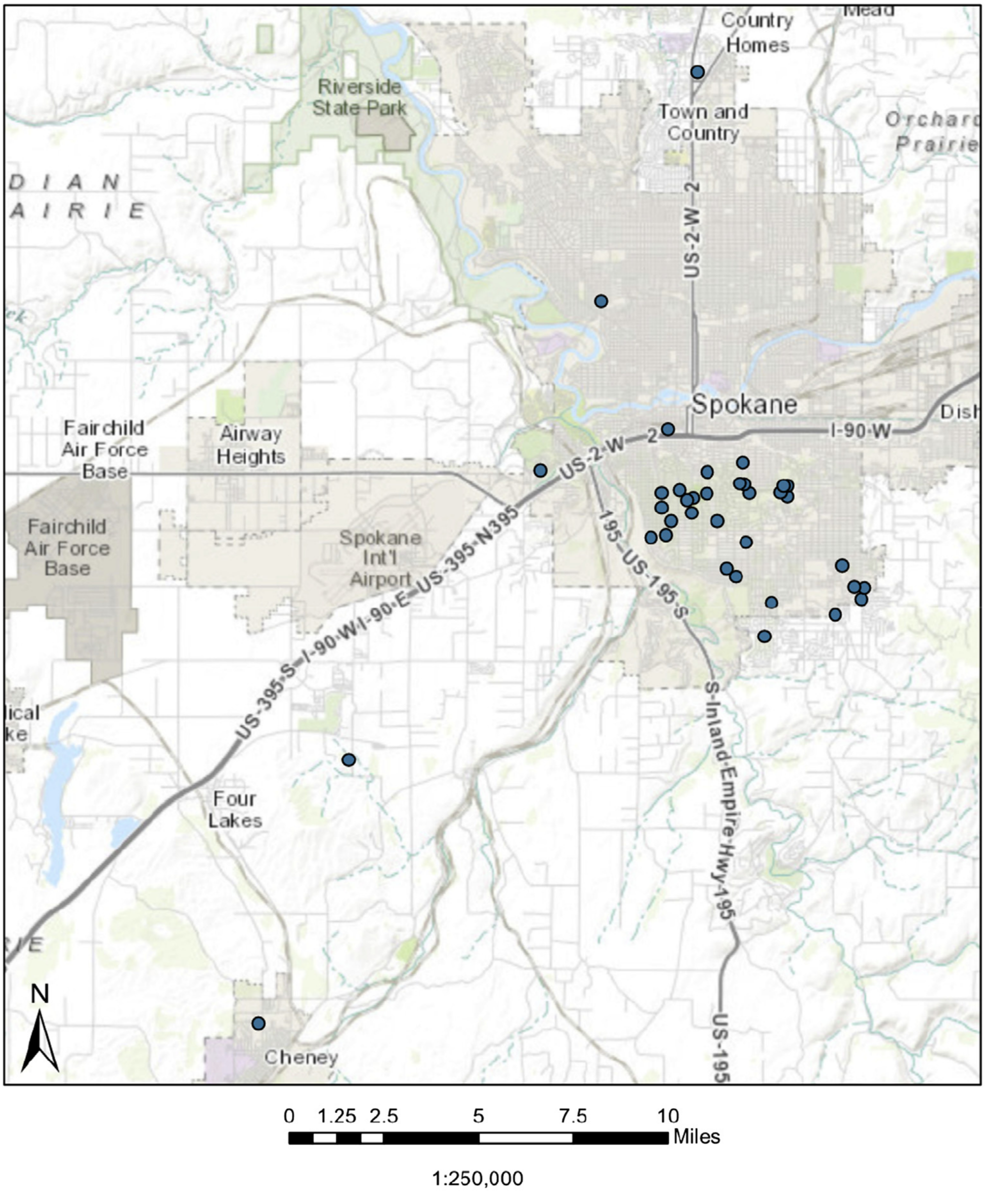

Fig. 1. Sampling locations in or near Spokane, Washington. Most of the soils were collected from a residential area called the South Hill which is south of Interstate 90 and east of US 195.

3. Results and discussion

3.1. Natural background concentrations in urban soil

Following the method of San Juan (1994), we calculated the background concentrations for urban surface soils as the 90th percentile of metal concentrations in the parks and residential yards (Tables 1 and 2). Prior to this calculation, we excluded the outliers for each metal as well as the garden soils with the assumption that these soils have been heavily affected by anthropogenic activities. The outliers are underlined in Table 1 and are discussed in more detail in Section 3.3 along with their potential sources of contamination.

The arsenic concentrations in the residential and park soils ranged from 4 to 55 mg kg^{-1} with a 90th percentile value of 11 mg kg^{-1} (Table 1). This is similar to the 90th percentile value of 9 mg kg^{-1} calculated for the Spokane Basin natural background concentration (Table 2, San Juan, 1994). Although the studies used the same soil digestion procedure (EPA Method 3050B), San Juan (1994) analyzed B and C horizon soils from rural areas which had not been substantially influenced by atmospheric deposition, soil amendments, or physical disturbance. The similarity between these soils suggests that overall As at most of our sites is derived from local bedrock and regolith. Similar increases in As concentrations from rural to urban soils in the Denver area (geometric mean of 3.7 mg kg^{-1} and 6.8 mg kg^{-1}, respectively) were attributed to anthropogenic activities (Folkes et al., 2001b). Two sites had As concentrations which were outliers (21 and 55 mg kg^{-1}) and were above Washington Department of Ecology cleanup levels for residential use (20 mg kg^{-1}, Table 2).

As with As, most sites in this study had Cd and Cu concentrations that were similar to those found in rural undisturbed soils. The 90th percentile values for Cd and Cu in urban soils were 1 and 21 mg kg^{-1}, respectively compared to 1 and 22 mg kg^{-1},

Table 1
Element concentrations (in mg kg^{-1}) in the total extractable fraction of surface soils. The underlined concentrations in the park and residential soils are outliers. Samples collected from the same residence are marked with the same superscript letter. The geometric mean and standard deviation are also provided.

	As	Ba	Cd	Cr	Cu	Pb	Zn
Parks							
SouthHill-3	9.9	111	0.12	24.1	11.0	25.4	64.8
SouthHill-4	7.3	104	0.05	27.6	13.9	21.0	55.8
SouthHill-5	10.9	103	0.10	28.3	12.9	17.8	63.6
SouthHill-6	3.6	77	0.19	13.4	18.6	28.4	46.9
SouthHill-9	6.5	78	0.06	26.6	12.9	55.3	68.2
SouthHill-10	7.0	168	0.02	37.4	12.0	28.7	58.1
SouthHill-17	10.7	45	0.06	23.8	7.6	12.2	42.0
SouthHill-19	5.3	159	0.04	23.1	8.9	12.0	37.1
SouthHill-20	7.3	204	0.06	33.3	17.6	15.6	61.0
SouthHill-21	10.6	100	0.04	30.0	11.0	11.7	48.6
SouthHill-22	6.5	130	0.06	25.3	10.6	18.8	56.9
SouthHill-23	13.7	57	0.09	27.5	10.1	11.3	48.2
SouthHill-24	8.4	116	0.17	26.4	30.6	39.5	66.8
SouthHill-25	16.7	56	0.15	22.4	8.9	10.9	45.4
Geometric mean	8.3 ± 1.5	99 ± 1.6	0.07 ± 1.8	25.8 ± 1.3	12.5 ± 1.4	19 ± 2	54 ± 1
Residential							
SouthHill-1	55.3	122	0.64	33.4	16.6	77.3	72.8
SouthHill-2	9.1	107	0.17	28.2	16.3	24.0	68.9
SouthHill-7	9.2	141	0.24	32.6	20.5	46.6	103.2
SouthHill-8	6.6	143	0.11	33.1	15.1	25.1	71.9
SouthHill-11	7.9	126	0.20	26.0	16.6	21.1	64.4
SouthHill-16	6.4	155	0.48	23.9	18.7	71.2	123.4
SouthHill-18	7.4	149	0.05	27.9	8.8	12.9	51.0
SH1.Sp	6.6	160	0.13	20.4	15.9	21.2	80.9
SH3.Sp	20.6	84	0.21	18.5	20.6	29.9	134.0
SH5.Sp	5.2	197	0.78	14.8	12.2	754.6	275.7
SH6.Sp	7.9	123	0.40	19.2	22.7	95.6	152.3
SH7.Sp	7.1	211	0.52	21.4	26.1	148.9	190.6
SH8.Sp	4.5	327	0.63	42.1	35.3	137.1	341.0
SH11.Sp^{a}	9.4	132	0.61	16.4	11.3	11.5	67.6
SH12.Sp^{b}	4.7	339	1.24	30.7	20.4	3863.5	445.3
SH15.Sp	9.5	99	0.20	16.7	17.5	12.2	58.3
SH16.Ch	5.1	122	0.21	13.9	11.7	9.5	48.6
SH19.Ch	3.6	106	0.17	12.1	17.2	9.1	85.9
UrbanSoils-2	7.6	149	1.13	17.0	19.0	244.8	194.8
UrbanSoils-6^{c}	7.3	120	0.91	13.3	9.0	9.8	61.1
Geometric mean	7.9 ± 1.8	145 ± 1.4	0.33 ± 2.3	21.7 ± 1.4	16.6 ± 1.4	48 ± 5	107 ± 2
Garden/Amended Soils							
SH10.Sp^{a}	5.3	148	0.14	19.8	16.3	15.9	86.7
SH13.Sp^{b}	4.8	151	0.19	16.1	16.5	175.1	97.7
SH14.Sp^{b}	4.5	160	0.31	15.3	18.7	171.7	247.9
SH17.Sp	5.2	107	0.14	15.9	17.2	31.0	90.8
UrbanSoils-4	8.8	122	1.39	43.6	17.4	151.0	254.6
UrbanSoils-7^{c}	9.9	86	0.83	13.5	9.9	9.1	65.7
Geometric mean	6.1 ± 1.4	126 ± 1.3	0.33 ± 2.6	18.9 ± 1.5	15.7 ± 1.3	52 ± 4	121 ± 2

Table 2
The 90th percentile was calculated for the residential and park soils in this study and compared to the 90th percentile values of rural Spokane Basin B and C horizon soils (San Juan, 1994). Individual soils were compared to the Washington State Department of Ecology cleanup levels for unrestricted land use (WADOE, 2013). Concentrations are in mg kg^{-1} of soil. NA = not applicable. Cleanup levels are given for both chromium (III) and (VI); our concentrations are for total chromium.

	90th percentile (this study)	90th percentile, Spokane Basin (San Juan, 1994)	WADOE Soil Cleanup Levels for Unrestricted Land Use
As	11	9	20
Ba	167	NA	NA
Cd	1	1	2
Cr	33	18	19 (VI), 2000 (III)
Cu	21	22	44[a]
Pb	59	15	250
Zn	107	66	132[a]

[a] Data not available in WADOE (2013). A concentration that is twice the 90th percentile calculated by San Juan (1994) was used as a estimate for cleanup levels as recommended by that study.

respectively in deeper, rural soils (Table 2). Cd concentrations at two sites were outliers (1.1, and 1.2 mg kg^{-1}) (Table 1); these same sites also had elevated concentrations of Pb and Zn. Two other sites had Cu concentrations identified as outliers at 31 and 35 mg kg^{-1}, the latter of which also had elevated concentrations of Ba, Pb, and Zn. Thus any Cd and Cu contamination appears to be localized, and associated with a multi-element source.

For Cr, the 90th percentile concentration in urban soils was 33 μg/g, which is almost twice as high as the natural background concentration calculated by San Juan (1994). No outliers were found in our samples. However, Cr concentrations at two sites had values (37 and 42 mg kg^{-1}) that were twice the 90th percentile value of 18 mg kg^{-1} which was suggested by San Juan (1994) as the threshold for cleanup recommendation.

The Pb concentrations ranged from 9 to 3800 mg kg^{-1} in the urban soils. The 90th percentile value was 59 mg kg^{-1}, which was four times higher than that the for the natural background concentrations in deeper, rural soils (San Juan, 1994). This suggests that Pb has been widely dispersed from anthropogenic activities such as the historical use of leaded gasoline, lead based-paints, and smelters (Filippelli et al., 2005). A similar increase in Pb between rural soils and urban soils has been found in other locations (Filippelli et al., 2005; Paterson et al., 1996). There is also an indication that some lawns had additional, isolated sources of Pb: almost half of the soils in this study had concentrations twice that of the natural background content (15 µg/g; San Juan, 1994) including five sites with concentrations ranging from 137 to 3860 mg kg^{-1}. In addition, the geometric mean of residential soils (48 ± 5 mg kg^{-1}) is more than twice that of county and city parks (19 ± 2 mg kg^{-1}) which have fewer painted structures (Table 1). Because Pb is relatively immobile in surface soils, it may remain concentrated in the upper few centimeters (Beesley et al., 2010).

Zn concentrations in the Spokane urban soils ranged from 37 to 445 mg kg^{-1} with a 90th percentile value of 107 mg kg^{-1}. This is nearly twice that of the local, natural background (66 mg kg^{-1}; San Juan, 1994). Five sites which had outlying concentrations from 191 to 445 mg kg^{-1} soil also had elevated levels of Pb which suggests they came from the same source.

The 90th percentile value for Ba is 167 mg kg^{-1}. Two outliers had values of 330 or 340 mg kg^{-1}. While Ba is typically not found in concentrations high enough to be toxic, elevated concentrations of Ba and other metals such as Pb and/or Zn may indicate its source (e.g., paint).

3.2. Metal/metalloid concentrations in soil profiles

Early in the study, two sites were selected for further investigation because of their elevated As (SouthHill-1) or Pb (SouthHill-16) levels in the surface soil (Table 3). At each of these sites, As and Pb were analyzed to a depth of 20 cm to determine their vertical distribution.

In this study, the highest As concentrations were found in the surface soil composite and the soil profiles at SouthHill-1. At this site, As increased from ~40 mg kg^{-1} in the 0–5 cm soil to 60–80 mg kg^{-1} at a depth of 15–20 cm (Fig. 2a and b). These concentrations exceed those in local, rural soils which averaged 9 mg kg^{-1} (San Juan, 1994). Interestingly, the As concentrations increase, rather than decrease, with depth at this location. This is counter to other studies which found that the surface application of an As-bearing compound resulted in the highest As concentrations in the surface soils. For example, As concentrations in Denver, CO residential soils exposed to the crabgrass killer and insecticide, PAX, dropped precipitously from 1200 mg kg^{-1} in the upper 5 cm to ~200 mg kg^{-1} at a depth of 20 cm (Folkes et al., 2001a). In another study, soils exposed to leaching of chromated copper arsenate from pressure-treated wood also exhibited decreased As concentrations with depth (Stilwell and Gorny, 1997).

Table 3
Element concentrations in the total extractable fraction of soil. The “P” in the sample name stands for “soil profile.”

Sample Name		Depth	As	Ba	Cd	Cr	Cu	Pb	Zn
		cm	mg/kg soil						
SouthHill-1P	1–1	0–5	38.8	125	0.51	27.7	16.3	58.5	108.1
SouthHill-1P	1–2	5–10	46.0	127	0.48	24.0	16.6	51.7	103.7
SouthHill-1P	1–3	10–15	61.0	134	0.50	22.0	20.7	42.7	96.5
SouthHill-1P	1–4	15–20	59.6	140	0.52	22.4	18.6	39.6	201.3
SouthHill-1P	2–1	0–5	39.8	137	0.68	34.5	19.7	83.2	110.5
SouthHill-1P	2–2	5–10	63.7	146	0.66	30.0	21.0	58.0	91.7
SouthHill-1P	2–3	10–15	69.0	138	0.61	20.3	18.3	39.3	85.8
SouthHill-1P	2–4	15–20	79.3	147	0.60	20.4	16.6	30.1	70.4
SouthHill-16P	1–1	0–5	5.2	188	0.88	21.0	20.5	127.5	207.9
SouthHill-16P	1–2	5–10	5.3	199	0.96	20.2	21.5	130.3	199.7
SouthHill-16P	1–3	10–15	6.1	236	1.05	21.1	21.8	125.5	192.2
SouthHill-16P	1–4	15–20	6.5	202	1.26	18.3	18.3	88.3	138.8
SouthHill-16P	2–1	0–5	7.8	171	0.41	18.9	19.6	43.4	109.6
SouthHill-16P	2–2	5–10	9.8	97	0.14	16.5	13.5	17.6	66.4
SouthHill-16P	2–3	10–15	7.3	109	0.19	16.1	12.7	24.2	76.8
SouthHill-16P	2–4	15–20	5.8	190	0.42	19.4	20.6	47.1	110.5

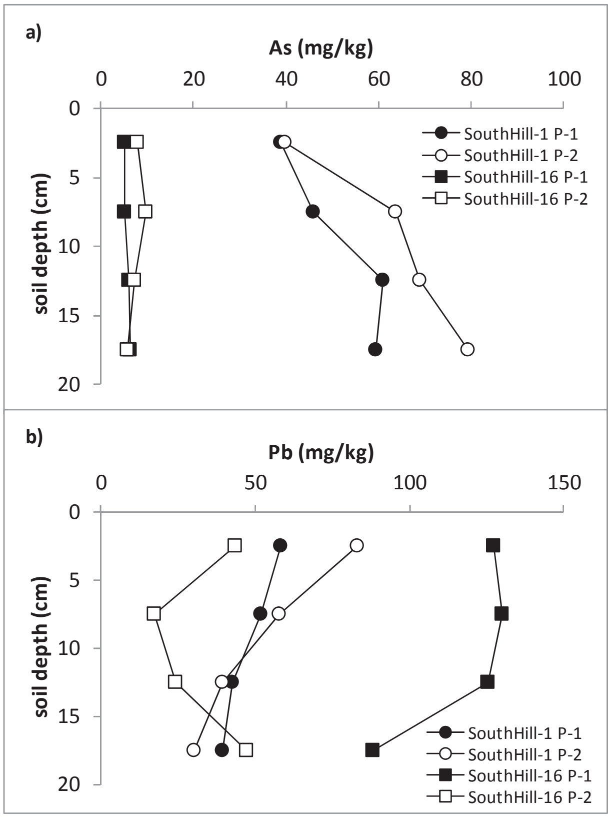

Fig. 2. As and Pb concentrations in two soil profiles at each of two sites.

There are a few possible explanations for the decrease in As concentrations with depth. First, the As may have originated in the parent soil or fill material and was later leached from the surface soil and translocated to greater depths (Brantley et al., 2007). However, dilute nitric acid leaches of local bedrock (Columbia River Basalt, and lacustrine deposits of the Latah Formation) indicate that relatively accessible As is less than 2 mg kg^{-1} and thus does not naturally occur in high concentrations in the local bedrock or regolith (Leavy and Nezat, unpublished). Another scenario is that As was added to the surface soil in the form of a fertilizer or pesticide, the soil was tilled which homogenized the As concentrations down to a depth of at least 20 cm, and As was subsequently mobilized from the surface soils to deeper soils (Fig. 3). Arsenic mobilization can be enhanced by common gardening and lawn care practices such as phosphate additions (Cao et al., 2003; Peryea and Kammereck, 1997).

At locations SouthHill-1 and 16, Pb concentrations generally decreased with depth (Fig. 2b). The profile with the highest lead concentrations was located near a garage. All four profiles were located along a street with low-traffic street.

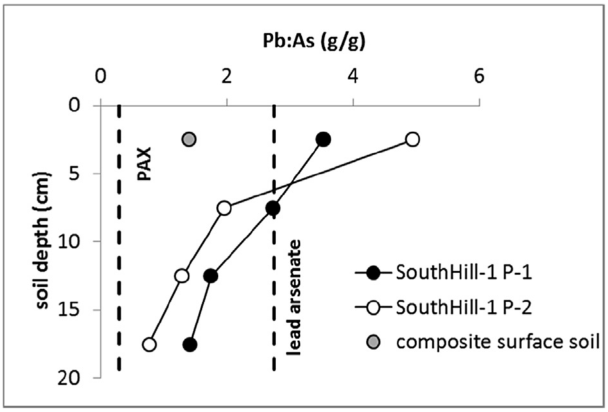

Fig. 3. Pb:As ratios in surface soil composite and profiles at South Hill-1. Pb concentrations decrease with depth while As increases. The dashed lines represent the Pb:As (g/g) ratios in the pesticides PAX® and lead arsenate (EPA, 1986; Folkes et al., 2001b). The Pb:As ratio for Ironite, a fertilizer, ranges from ~0.5 to 1.0 mg/kg (Dubey and Townsend, 2004).

3.3. *Elevated metal concentrations in soils*

The Washington State Department of Ecology (WADOE) has established standards for As and metal concentrations in soils with unrestricted land use (i.e., residential properties) (Table 2). Based on these data, two locations exceeded the limit for As (20 mg kg^{-1}). Two other locations exceeded the WADOE maximum Pb concentrations of 250 mg kg^{-1} (Fig. 2; Tables 1 and 2). In fact, both of these sites had Pb concentrations above the 400 mg kg^{-1}, the USEPA limit for children's play areas, while one of these soils had Pb concentrations greater than 1200 mg kg^{-1}, the USEPA threshold for residential soil with unrestricted use. The Cd, Cr (assuming Cr III), and Cu concentrations in this study are all below the recommended levels; cleanup levels for Ba and Zn are not listed by the Washington State Department of Ecology.

In addition to the four sites which had As or Pb concentrations of concern, several sites had metal concentrations that were identified as outliers (values underlined in Table 1). We investigated the source of these excess metals by looking for chemical fingerprints of anthropogenic sources. Many anthropogenic sources contain more than one metal or metalloid. For example, pressure-treated wood contains chromated copper arsenate (Stilwell and Gorny, 1997) whereas a popular arsenical pesticide in use prior to the 1970s contained lead arsenate (Elfving et al., 1994). In addition, paint (either lead-based or nonlead-based) contains Ti, Zn and sometime Ba.

3.3.1. *Arsenic*

Two sites had elevated As concentrations (i.e., above 20 mg kg^{-1}). Common As-containing compounds which can be purchased at lawn care stores in the US are pesticides, fertilizers, and wood preservatives (Chirenje et al., 2004; Dubey and Townsend, 2004; Folkes et al., 2001b; Stilwell and Gorny, 1997). Arsenical pesticides have been used in the U.S. since the early 1900s and are known to have contaminated orchard and residential soils. For example, some residential soils in Denver, CO contain elevated levels of As due to the common use of a arsenic trioxide-lead arsenate pesticide (called PAX) prior to the 1960s (Folkes et al., 2001b). These soils had a mean concentration of 140 mg kg^{-1} but some had more than 1000 mg kg^{-1} As. PAX was identified as the source due to the similarity between its Pb:As ratio and that found in the contaminated soils. In addition, elevated As concentrations were only found in lawns associated with residences that were older than the 1960s, the time during which DDT became readily available and was determined to be more effective (Peryea, 1998). Another arsenical pesticide, lead arsenate, was used in apple orchards in Washington State until 1948 (Peryea, 1998) and on residential lawns until it was banned in the US in 1968 (Christen, 2000).

Arsenic can also be found today in fertilizers that are sold in garden-supply stores. Ironite®, for example, is produced from waste from a silver mine in Arizona (Dubey and Townsend, 2004). While studies by the manufacturer found that As and Pb in the fertilizer were present as arsenopyrite and galena, minerals that the manufacturer expected to be stable, additional studies have found that these minerals degrade in the soil environment to release Pb and As (Dubey and Townsend, 2004; Williams et al., 2006).

To determine the likelihood that one of the products was the main source of As at either of these sites, we compared the Pb:As ratios (g/g) in the soil to that of the aforementioned pesticides and fertilizer. Based on their chemical formulas, the Pb:As ratios are 0.29 and 2.8, respectively. In Ironite® products, the ratio ranges from 0.8 (g/g) in the granular products to 1.5 in the liquid form (Dubey and Townsend, 2004). The surface soils at SouthHill-1 and Sh3. Sp range from 1.5 to 5.0, the latter of which suggests another source, or increased mobility of As relative to Pb. Pb is typically less mobile in soils than As (Elfving et al., 1994). In addition, As mobility may be enhanced by the addition of phosphate fertilizers (Cao et al., 2003; Peryea and Kammereck, 1997). The soils between 5 and 20 cm have ratios that are bracketed by the range of As- and Pb-containing pesticides and fertilizer suggesting that a combination of these may be the As source.

We also examined whether chromated copper arsenate (CCA), a common wood preservative, was a possible source of As in these soils although no pressure-treated wood was located at either of these sites at the time of sampling. A study by Stilwell and Gorny (1997) analyzed soils below decks built of lumber treated with chromated copper arsenate to determine the relative amounts of these elements naturally leached from the wood. The authors found that the excess Cu:Cr:As ratio in the soil averaged 1:0.4:1.2 (by weight). We made a similar calculation by subtracting the Cu, Cr, and As concentrations of the local B or C horizon soil (San Juan, 1994) from the urban soils. Although this yields the same Cr:As ratio at site SouthHill-1 (0.4:1.2) as that in the CCA leach, Cu concentrations in the urban soils are similar to than in the local, rural soils. The Cr:As ratio at SH3. Sp is much higher (11:1) than expected from leaching of CCA into soil. In addition, there was no positive correlation between As and Cu ($r^2 = 0.01$) or Cr ($r^2 = 0.45$) in the two soil profiles at SouthHill-1. Thus, the lack of elevated Cu in these soils and the lack of correlation among As, Cu, and Cr in the soil profiles do not support chromated copper arsenate as the source of As. Based on the low Cu concentrations in the residential soils (Table 1), Paris green, an insecticide containing copper acetoarsenite which was used in the US to control codling moths in apple orchards (Peryea, 1998), can also be eliminated as the As source.

3.3.2. *Lead*

We investigated potential sources of Pb in the South Hill soils. All five sites with elevated Pb concentrations also had elevated concentrations of Ba, Cd, Cu, or Zn (Table 1). Common sources of Pb to urban soils are lead-based paint and leaded gasoline (Kallithrakas-Kontos et al., 2016; Paterson et al., 1996). Lead concentrations from lead-based paint are related to the proximity to and age of a structure, while concentrations of metals from vehicle emissions are correlated with distance to roads and traffic density (Clarke et al., 2015; Schwarz et al., 2012). Paint also contains variable amounts of Ba, Cu, and Zn (Kallithrakas-Kontos et al., 2016; see also Material Safety Data Sheets for paint; Turner and Radford, 2010). In addition to lead in leaded gasoline, other vehicle emissions include Ba, Cd Cu, Cr and Zn from wear of tires and brake linings, fuel combustion, and leaked fluids (Birmili et al., 2006; Monaci et al., 2000; Paterson et al., 1996; Trujillo-Gonzales et al., 2016). These metals are often higher in roadside soils compared to park soils (Paterson et al., 1996; Schwarz et al., 2016b).

In this study, Pb concentrations were correlated with Zn indicating a shared source (Fig. 4a). We divided the residential soils into two groups depending on whether they had background, or elevated Pb concentrations (which was defined as greater than 30 mg kg^{-1}, or twice the average value in rural soils; Table 2). In the soils with elevated Pb, Ba and Zn were directly correlated (Fig. 4b) once again suggesting a shared source such as lead-based paint, or vehicle emissions. Ba and Zn concentrations were also strongly correlated in the soil profile at SouthHill-16 (Fig. 5).

Because elemental ratios in lead-based paint and vehicle emissions may vary based on product type or manufacturing era, chemical fingerprints of the sources can be difficult to match to the soil composition. However, we can infer that the likely source of Pb in these soils is lead-based paint due to the proximity of the soils to painted structures, and the distance from high-traffic volume roadways. This is also supported by the fact that park soils, which have few or no structures, had lower average metal concentrations. Furthermore, the soil with the highest Pb concentration is known to have been exposed to lead-based paint during home renovation decades ago. The Pb concentration in the soil near the home was 3673 μg/g whereas two garden soil samples farther away from the house had 171–175 mg kg^{-1}. A second site with a Pb concentration of 755 mg kg^{-1} is near a vacant lot from which the original structures were removed. These results are similar to other studies where soils near roadways and houses had concentrations well above 1000 mg kg^{-1} (Filippelli et al., 2005; Schwarz et al., 2016b).

Interestingly, site SH8. Sp had the second highest Ba and Zn concentrations (330 and 341 mg kg^{-1}, respectively) but lower Pb concentrations (137 mg kg^{-1}) than expected. We speculate that this may be due to remodeling a home that contained both lead-based paint and non-lead-based paint.

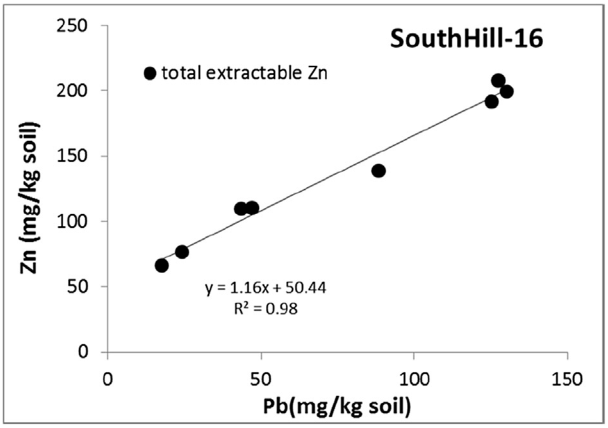

Fig. 5. Pb and Zn concentrations in soil profiles at SouthHill-16.

4. Conclusions

This study was designed to analyze heavy metals in soils located in an urban neighborhood that had not been exposed to industrial activity. Overall, the urban soils had elevated concentrations of metals such as Pb when compared to local, rural B and C horizon soils (San Juan, 1994) indicating that non-point sources (such as the historic use of leaded gasoline) have affected surface soils. Elements found in lead-based paint (Ba, Pb, and Zn) were on average higher in urban, residential soils than in city park soils signifying the importance of painted structures when it comes to potential Pb contamination in soils. While most of the residential soils were considered safe by state and federal standards, we identified two sites each which exceeded the Washington State Department of Ecology levels for As and Pb for unrestricted land use (20 mg kg^{-1} and 250 mg kg^{-1}, respectively). At one of these sites, Pb exceeded 1200 mg kg^{-1}, the USEPA threshold for residential soil with unrestricted use, and an additional site had Pb concentrations above the 400 mg kg^{-1}, the limit for children's play areas.

Homeowners who live in areas which have not experienced

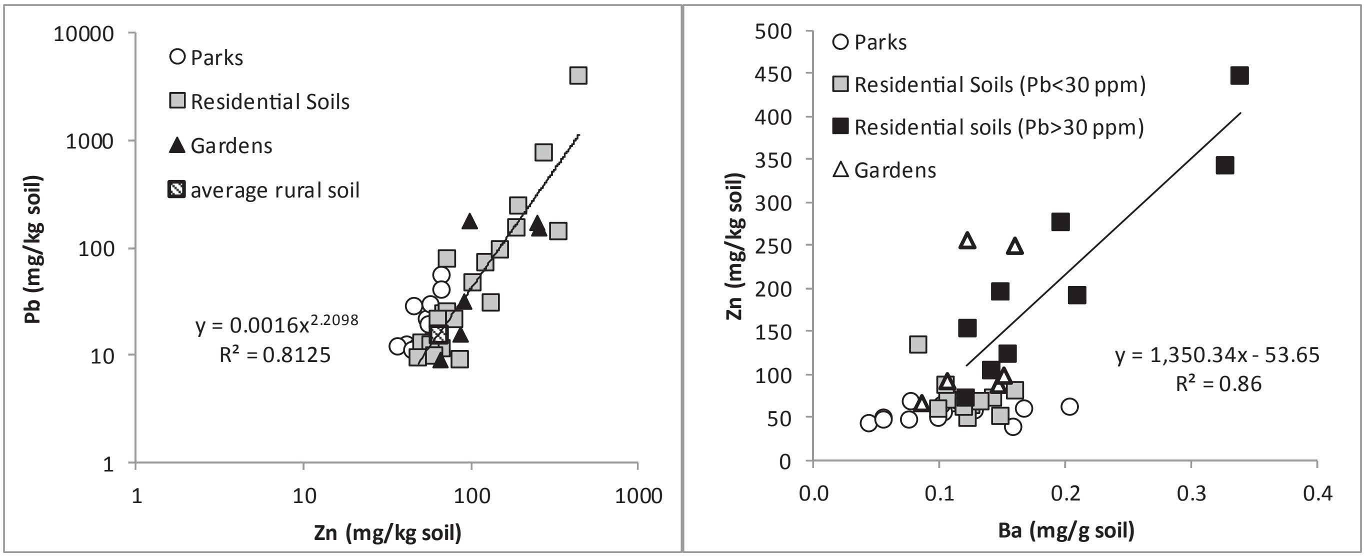

Fig. 4. a) Pb and Zn concentrations in urban soils compared to the average rural soil (San Juan, 1994). b) Ba and Zn concentrations in urban soils. In the soils with elevated Pb concentrations, Ba and Zn are directly correlated.

heavy industrial activity may be unaware that their soils can have elevated levels of metals or metalloids due to their own activities, or those of previous homeowners. While the presence of lead-based paint in older homes is commonly known, most do not know that products, which contain leachable forms of As and Pb, can still be purchased today in lawn and garden stores.

More research is needed to characterize the geochemical fingerprints of anthropogenic sources in soils especially given the differences in metal(loid) mobility, the variable soil conditions, and the timing since addition. Having this capability may help predict the potential for contamination based on factors such as age of the structure and distance to a roadway, and thus minimize the amount of time and resources needed to characterize an entire yard. These data may also inform health care specialists of the risk of metal exposure for individuals, especially children, in their own yards.

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