Westlake Landfill Tree Core Analysis Report

Prepared By: Dr. Joel G. Burken, Dr. Shoaib Usman, [redacted]

Contact: Dr. Joel G. Burken, Ph.D., P.E., BCEE;

Missouri University of Science And Technology
224 Butler-Carlton Hall
1401 N Pine St.
Rolla, MO 65409-0030
Ph: 573-341-6547; M 573-201-9106
burken@mst.edu

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207 W High St,
Jefferson City, MO 65101
(573) 751-3321

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1 Acronyms

BTEX	Benzene, Toluene, Ethylbenzene and Xylene
DCE / cDCE	Dichloroethylene and cis- Dichloroethylene (prominent isomer)
ECD / µ ECD	Electron Capture Detector and micro Electron Capture Detector
FID	Flam Ionization Detector
GC	Gas Chromatography
HC	Hydrocarbons
HPGe	High purity Germanium Detector
MCA	Multi-channel Analyser
MS	Mass Spectrometry
MSD	Mass Selective Detector
ND	Not detected
NORM	Naturally Occurring Radioactive Material
PCE	Perchloroethylene or Tetrachloroethylene
PDMS	Polydimethylsiloxane
PPB	Parts per billion
PPM	Parts per million
SPME	Solid Phase Micro-extraction
TCE	Trichloroethylene
WLL	Westlake Landfill

2 Introduction

2.1 Background

2.1.1 Site Description:

The 200-acre Westlake Landfill (WLL) site is located at 13570 St. Charles Rock Road in the Earth City Industrial Park. WLL is surrounded by commercial/industrial and agricultural land on the eastern edge of the Missouri River floodplain. From 1939 to 1985, limestone was quarried on the site. Beginning in 1962, portions of the property were used for landfilling of municipal solid waste and construction debris. Two areas became radiologically contaminated in 1973 when soils mixed with uranium ore processing residues were used as daily cover in the landfilling operation. An adjacent property has also been impacted by erosional migration of radiologically-contaminated material from the landfill proper. This property, known as the Buffer Zone or the Crossroad Property, was subsequently purchased by the landfill operator. It is considered part of the site and is enclosed within the site's perimeter security fence. Also located on the site is the Bridgeton Sanitary Landfill, which ceased operation in 2005.

2.1.2 Rationale and Application of Phytoforensics:

Given concerns regarding potential for radiologic impacted material (RIM) and organic pollutants to transfer off site, tree coring analysis was initiated at the request of the Missouri Attorney General's office in 2015. This approach is termed 'phytoforensics' and related to the use of plants as bio-sentinels of pollutants in the near-surface soil and groundwater. Phytoforensic methods have been established in peer reviewed literature for 20 years, has been accepted internationally, and supported by the US Geological Survey and the US EPA (Simonich and Hites 1995, Simonich and Hites 1995, Vroblesky et al. 1999, Vroblesky 2008, Balouet et al. 2009, Burken et al. 2011). The fundamental basis of the methods are the intimate connection of plants and the surrounding environment. Plants are place-bound, and can acquire all the nutrients, water, gasses, and minerals to be the dominant life on the planet. To accomplish this feat, plants must be efficient in mass transfer with their surroundings. In doing so, plants can accumulate molecules and elements from their surroundings and serve as bio-sentinels for pollutants in their surroundings. The interactions of plants and environment make plants a potential place-bound sampler for air, water and soil pollutants of many different inorganic and organic molecules and numerous elements. The complex processes by which pollutants can transport in the environment and the multiple plant-related process offer an intricate molecular pathway relating the exposure concentration to the *in-planta* concentration, including volatilization (Ma and Burken 2003, Ma and Burken 2004), degradation (Larsen et al. 2008, Weishaar et al. 2009, Wilson et al. 2013), physical losses (Struckhoff et al. 2005) and other biological, chemical and physical factors.

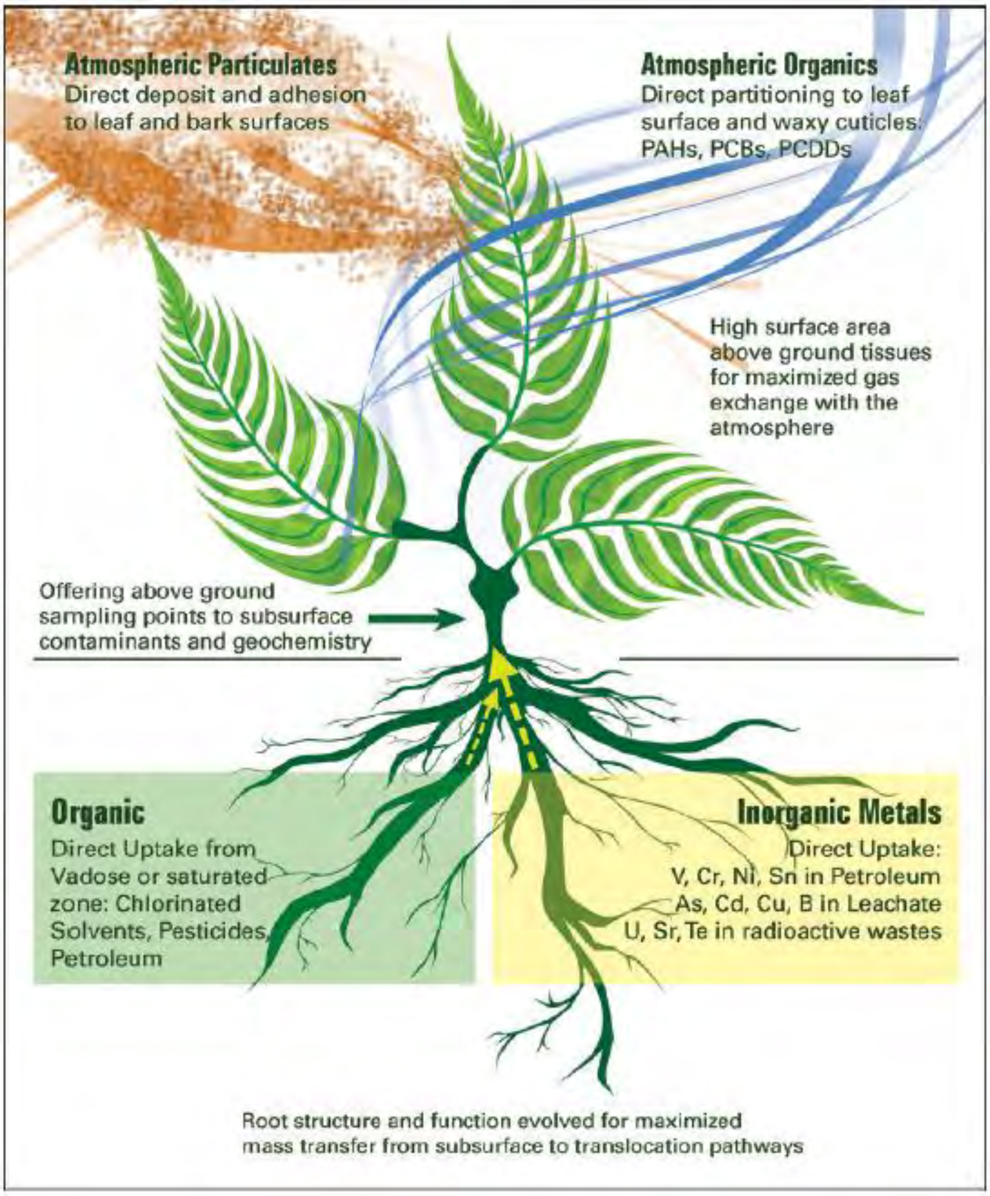


Figure 1 Concepts of phytoforensics transfer of environmental pollutants to plants, exhibiting the environmental processes whereby plants accumulate environmental pollutants from their surroundings. (Burken et al. 2011)

2.2 Objectives

The overall goal of this sampling endeavour was to apply novel phytoforensics to assess potential pollutant distribution and transfer into the biosphere. In order to achieve this goal, specific objectives were established, as follows:

- Obtain tree core samples from the GPS-identified locations where plants serve as bio-sentinels of potential off site migration,
- Develop methodologies for assessing radiation in tree core samples,

- Quantify tree core pollutant levels using SPME-GC-μECD, SPME-GC-FID, and total radiation, and gamma spectroscopy to identify specific radiation source,
- Plot tree core concentrations of contamination respective to their location and accumulated pollutants, and
- Assess potential contaminated plumes and relate concentrations and pollutant profiles to potential pathways of transport.

3 Methodology

3.1 Sample Collection

The samples were selected on the basis of accessibility in a random manner to form a map to compile the extent and concentrations of contamination. The core samples were taken on 23 and 24 April 2015 by Missouri S&T students under the guidance of Dr. Joel G. Burken, Ph.D., P.E., BCEE from the West Lake Landfill (WLL) site. Students collecting samples included [redacted] and. Dr. Shoaib Usman, Ph.D. nuclear engineering. A second limited sampling was performed on 12 August 2015by Dr. Burken to confirm samples collected along Old St. Charles Road. Tree cores were obtained using a 0.5-cm increment borer (Forestry Services Inc., Pawleys Island, SC). Increment borers are typically used for assessing tree health and wood quality. The cores were approximately 8 cm in length and were taken at breast height (approximately 1.5 m). Upon extraction, the core was transferred immediately to a 20-mL vial with a screw-top cap and Teflon/silicone septa (Supelco, Bellefonte, PA). Field blanks were taken every 10 to 15 samples. After the sampling was completed, the vials were stored on ice and then transferred directly to Missouri S&T laboratories for analysis or refrigerated storage. Prior to analysis, the samples were warmed to room temperature for equilibration. The target trees sampled were selected on the basis of tree species, trunk diameter and location. The location of each tree sampled was recorded using a highly accurate Global Positioning System (GPS). Pictures of selected sampled trees were taken to identify the tree species.

3.2 Analysis

Three chlorinated solvents (cis-1,2-dichloroethene (cDCE), trichloroethene (TCE), and perchloroethene (PCE)) and six petroleum benzene, toluene, ethylbenzene, ortho-xylene, meta-xylene, and para-xylene (BTEXs) were screened in tree cores by utilizing solid-phase microextraction (SPME) of the vial headspace. Samples were equilibrated for 12 hours to reach equilibrium from the tree core to the vial headspace and then placed on the Agilent 7890 gas chromatograph (GC) equipped with a micro-electron-capture detector (μ-ECD), flame ionization detector (FID), and CombiPAL SPME autosampler. Similar methods have been applied for analytic analysis of tree cores from over 60 sites in Dr. Burken and collaborators lab at Missouri S&T (Ma and Burken 2002, Struckhoff et al. 2005, Legind et al. 2007, Larsen et al. 2008, Burken et al. 2009, Weishaar et al. 2009, Burken et al. 2011, Limmer et al. 2011, Sheehan et al. 2012, Limmer et al. 2013, Wilson et al. 2013)

In summary of analytic methods, chlorinated solvents were absorbed for 5 minutes with a polydimethylsiloxane (PDMS) SPME fiber and then desorbed for 5 minutes in the 230°C inlet in splitless mode. A Supelco Vocol 10m x 200μm x 1.2μm column was used to separate the sample components with a carrier gas pressure of 9.46 psig. The oven was initially held at 40°C for 0.75 minutes and increased at a rate of 20°C/min up to 160°C for a total runtime of 6.75 minutes. The chlorinated solvents were detected with the μ-ECD with retention times for cDCE, TCE, and PCE of 1.451, 2.167, and 3.217 minutes, respectively. A Carboxen/PDMS SPME fiber was used to absorb BTEXs for 5 minutes and then desorbed for 5 minutes in the inlet heated to 290°C in splitless mode. An Agilent 30m x 320μm x 0.25μm HP-5 column was used to separate the sample components with a carrier gas pressure of 10.19 psig. The column oven was held at 40°C for 0.75 minutes and increased at a rate of 20°C/min up to 240°C for a total runtime of 10.75. The BTEXs were detected with the FID with retention times for benzene, toluene, ethylbenzene and xylene (ortho-xylene, meta-xylene, and para-xylene) of 1.45, 2.16, 1.35, and 3.22 minutes, respectively. Greater details on analytic methods have been previously published (Ma and Burken 2002, Limmer et al. 2011, Wilson et al. 2013).

Unknown compound peaks from the chlorinated solvent and BTEX analyses were observed as peaks in the chromatography output of the respective detectors at retention times not indicative of the target chlorinated solvents or BTEX hydrocarbons targeted in the standard pollutant analysis. To assist in identifying these unknown molecules, tree cores were then analysed utilizing SPME-GC-mass selective detector (MSD) in scan mode. The sample was absorbed onto the Carboxen/PDMS fiber for 5 minutes and then desorbed 5 minutes into the 290°C inlet in splitless mode. The initial oven temperature of 35°C was held for 0.75 minutes, ramped at 15°C/min to 160°C, and held at 160°C for 3 minutes for a total run time of 12.08 minutes. The carrier gas flow was held at 3.24 psig. The compounds were separated utilizing an Agilent 30m x .25mm x 25μm HP-5MS column. The MSD heater was held at 280°C while the analytes were detected in scan mode within the range of 35 – 300amu.

3.3 Calibration and Data Analysis

Calibration analysis was completed using 10 mL of water in a 20-mL vial spiked with, PCE, TCE, and the degradation product cis-dichloroethylene (cDCE) for Chlorinated solvents and for the BTEX compounds noted above. The headspaces of the five different standards were sampled and a linear calibration plot was obtained from the average of three standard sets. The concentrations and peak areas were log normalized to ensure equal variances for least squares regressions. Other unknown contaminant peaks were observed and subjected to identification utilizing Mass

Spectrometry (SPME-GCMS) detection to obtain a list of possible compounds. No quantification was completed for the unknowns.

Method detection limits (MDLs) were previously calculated for PCE and TCE using EPA methods. Because the tree core matrix is inherently variable and difficult to mimic in the laboratory setting, water standards must be used to determine the MDL. For PCE, the MDL was 0.5 ppt (part per trillion) at an estimated signal-to-noise ratio ($S/N=\bar{x}/s$) of 11. For TCE, the MDL was 8 ppt.

3.4 Analytical Methods for Radioactivity in Tree Cores

Cores were also analysed for radioactive contamination utilizing a High Purity Germanium (HPGe) Detector. The gamma counting and spectroscopy system was calibrated using standard sources of Cobalt (Co-60), Manganese (Mn-54), and Cesium (Cs-137). No efficiency calibration was possible due to the complex detector sample geometry and consequently no quantitative radioactivity contents in the samples are obtained. The counting system includes standard Multi-channel Analyzer (MCA) coupled with ORTEC MAESTRO Software for gamma spectroscopy. Energy Calibration curve is shown in Figure 2 below.

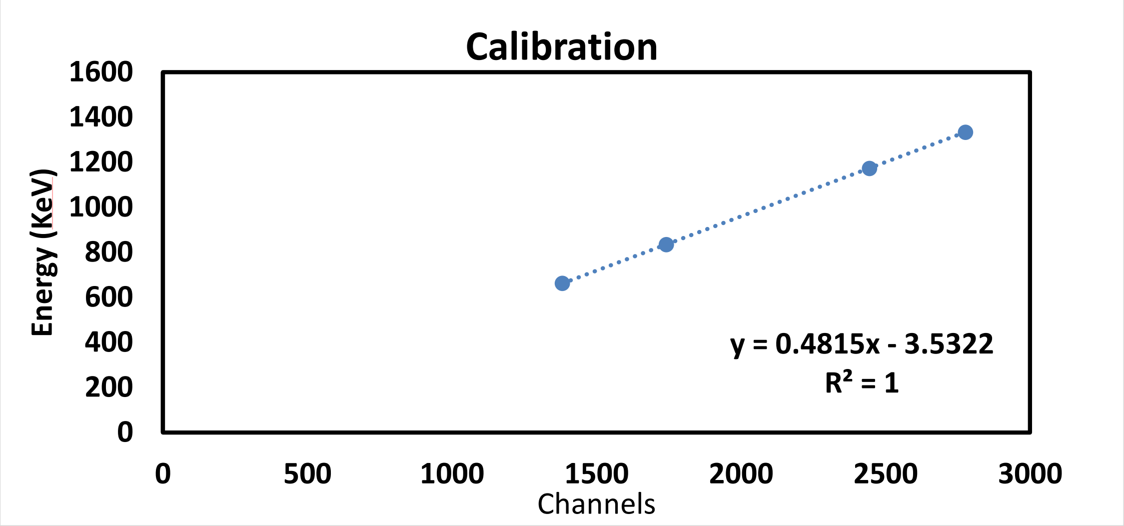


Figure 2 Calibration curve; Channel vs. Energy

All measurements were taken in Fulton Hall low background room lined with lead sheets on the walls and the floor. To assess the radiation background, 100 hours background data without any source or sample was collected. This background spectrum was subtracted from the source spectrum to obtain the net counts.

A large numbers of tree samples were available for analysis. In order to screen samples in a timely manner, 10 samples were grouped together to form a "Batch." These batches were counted (10 tree samples simultaneously) and efficiently covered a larger geographic area for contamination screening. Samples were arranged equally spaced from the detector as shown in figure 3a. The initial batch of 10 cores was counted for 24 hours, and the second batch for 70 hours. All subsequent batches were counted for 50 hours. All sample counts were time normalized to 100 hours for comparison with the background data, analysis and presentation.

Figure 3 HPGe Detector and experimental set-up for the analysis of tree core samples for possible radioactive contamination

As a rule of thumb, all batches with gross counts (sum of the entire spectrum) lower than the background plus three standard deviation (3σ) were considered as clean and were not analysed any further. This choice of background plus 3σ is based on low probability of 0.27% that the sample was a false positive and the higher counts were in fact due to the statistics uncertainty in the background.

Sample with total counts higher than the total background plus 3σ counts were analysed for possible contamination from Uranium and Thorium. Figure 4 shows the decay scheme for ^{238}U, ^{232}Th and ^{235}U, respectively. Based on the site history and the results from previous studies (Mark Fitch, Leaching of Radionuclides from Saint Louis Airport Site Soil, Final report to the US Geological Survey & US EPA) uranium is a likely contaminant at the site. Again for each significant peak we followed the 3σ rule. If the count under the specific energy were at least background+3σ, we considered the specific peak/gamma present in the tree sample, otherwise the tree sample was considered clean.

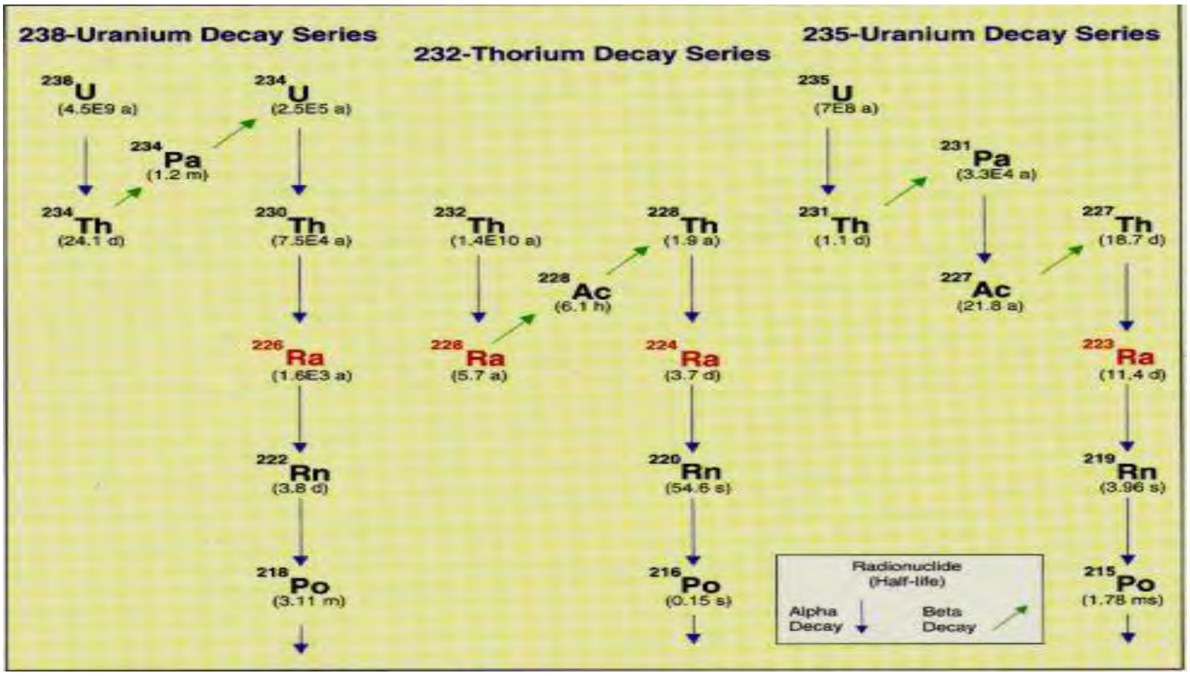


Figure 4 Decay Chain for U238, Th232 and U235.

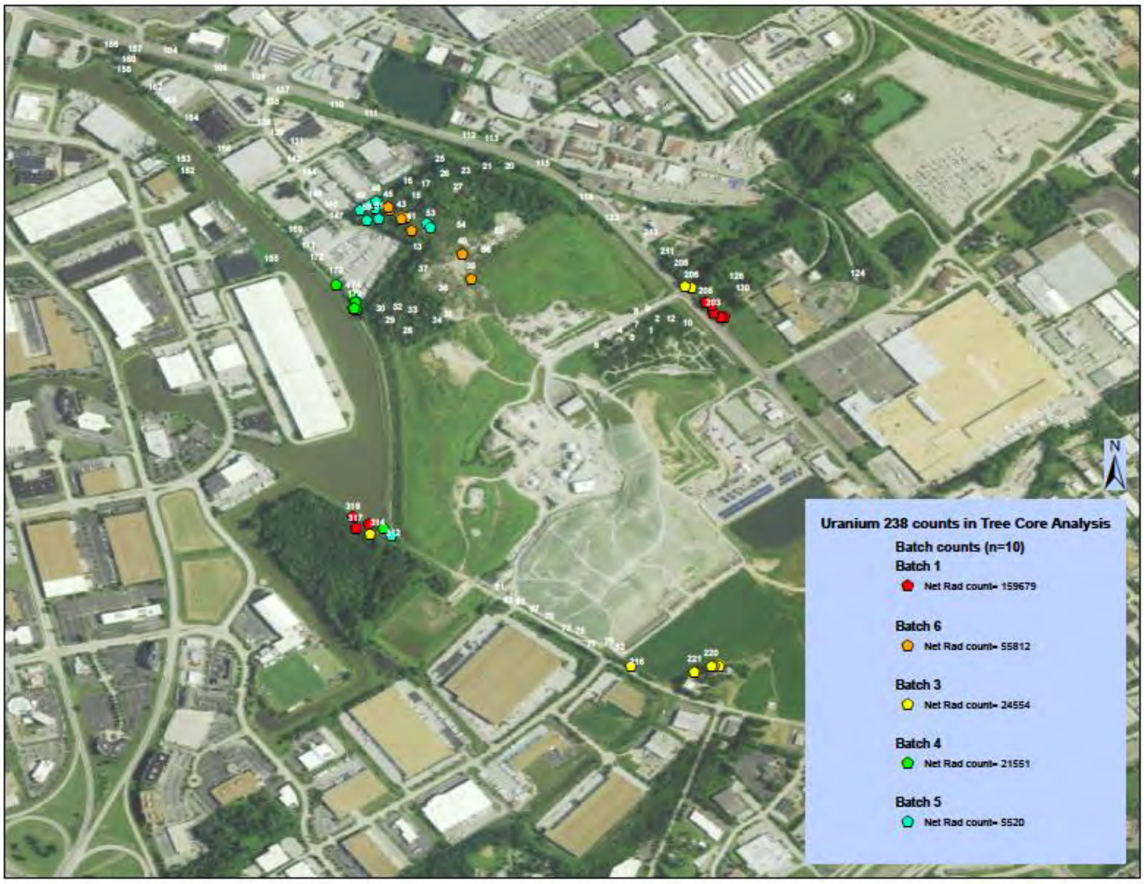


Figure 5 Geographic distribution of elevated count samples – U238.

Figures 5-7 show the spatial distribution of contaminated tree samples. Essentially there are three clusters; North-West cluster i.e., at the top of Radiological Area 2, North-East cluster near Radiological Area 1, South-West cluster and the South-east cluster. The samples right from the top of the Radiological Area 1 showed no traces of U238, U25 and/or Th232. This observation suggest that the top soil and the tree root tips are in geological isolation of the potentially radioactive material in the area, that is the tools and techniques put in place to prevent upward motion of the radioactive material seems to perform as designed.

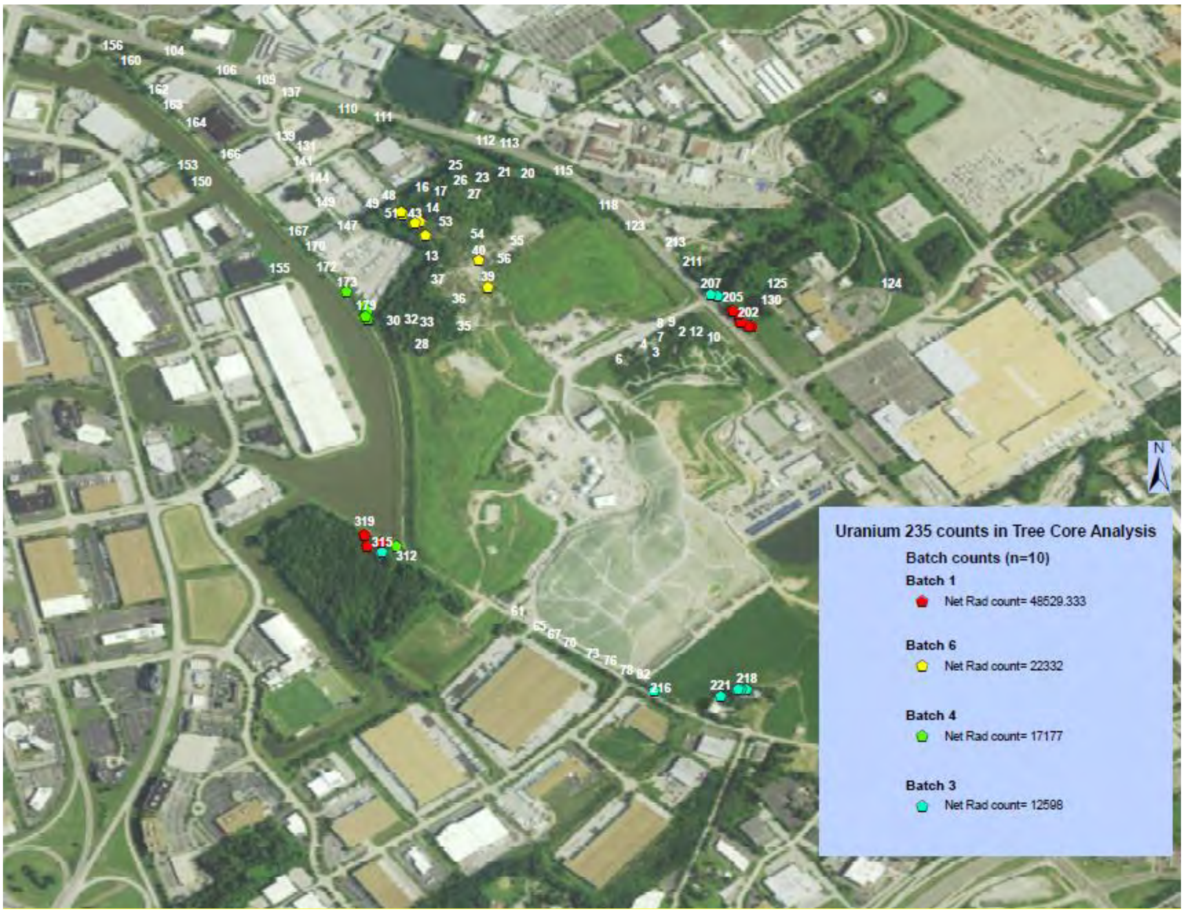


Figure 6 Geographic distribution of elevated count samples – U235.

Also there seems to be a correlation between the U238 and U235 counts, the batches with high and moderately high level of U238 also showed high or moderately high U235. Cluster with high level of U238 also show high level of U235. However, the spatial correlation of Thorium is not consistent with the Uranium.

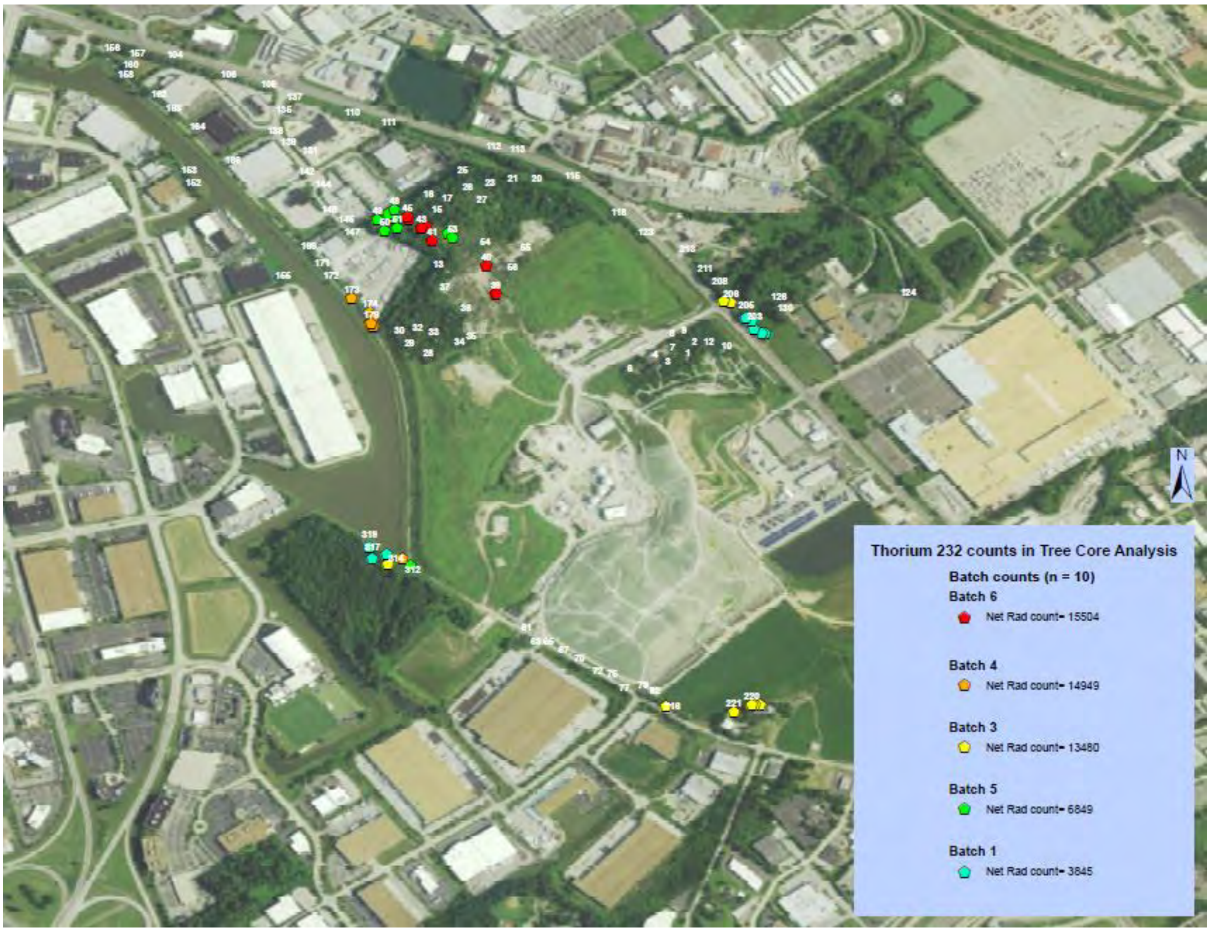
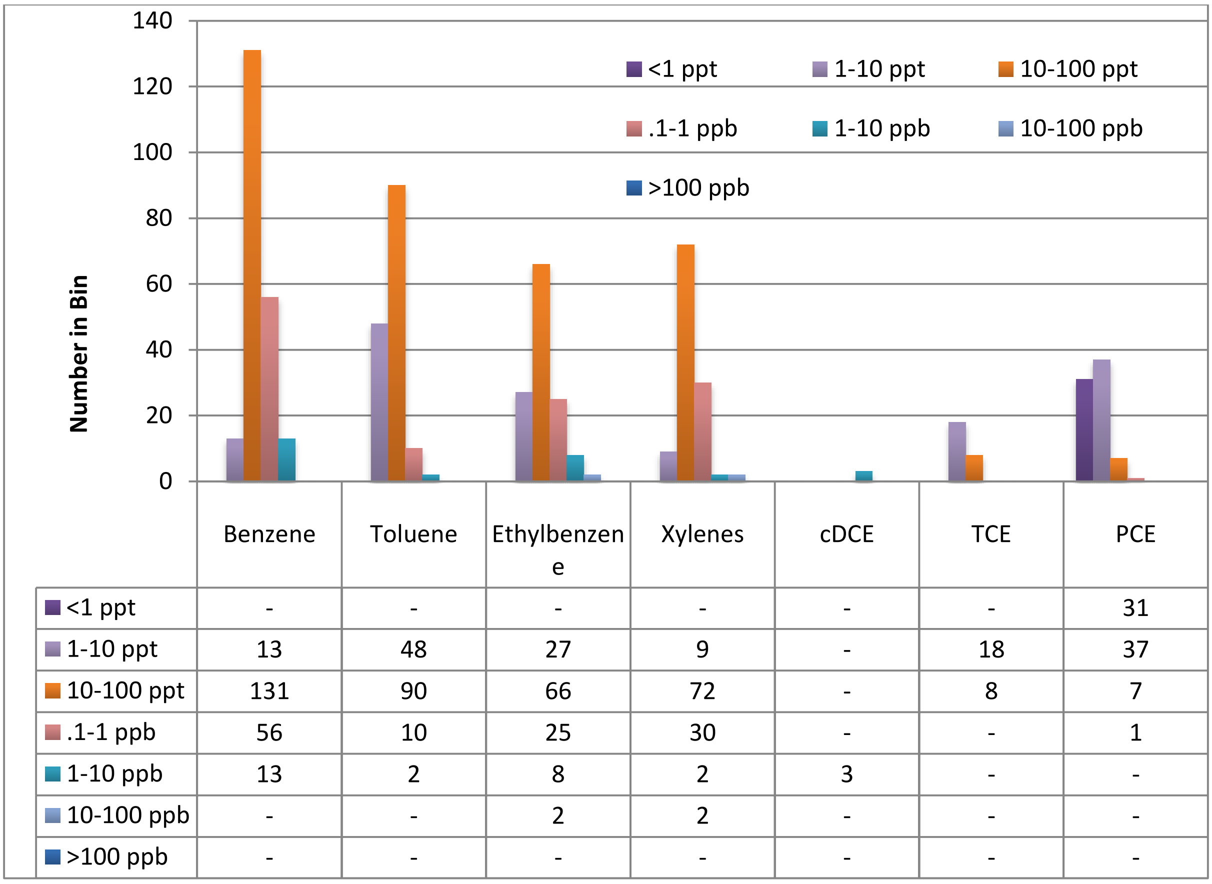


Figure 7 Geographic distribution of elevated count samples – Th232.

4 Results and Discussion

4.1 Organic Contamination Evaluation

The level of BTEX contamination was observed in selected tree core analysis of the trees both within and near the WLL. The BTEX contamination ranged from undetected to 100 ppt. Benzene was the most detected contaminant within the tree cores and was most prominent within 10 to 100 ppt. Toluene was the next prominent contaminant with 10 to 100 ppt concentration levels. Xylene was also detected, however, with less frequency and concentration than the Benzene and Toluene. Ethylbenzene was detected least frequently but with considerable range i.e. 0.1 ppb to 100 ppt. The chlorinated contamination ranged from undetected to 100 ppt. PCE was the most detected chlorinated solvent within the tree cores and was most prominent within 1 to 10 ppt. TCE was the next prominent chlorinated solvent with 1 to 10 ppt concentration levels. cDCE was also detected, however, with less frequency and concentration.



	Benzene	Toluene	Ethylbenzene	Xylenes	cDCE	TCE	PCE
<1 ppt	-	-	-	-	-	-	31
1-10 ppt	13	48	27	9	-	18	37
10-100 ppt	131	90	66	72	-	8	7
.1-1 ppb	56	10	25	30	-	-	1
1-10 ppb	13	2	8	2	3	-	-
10-100 ppb	-	-	2	2	-	-	-
>100 ppb	-	-	-	-	-	-	-

Figure 8 Histogram of organic pollutant detection in tree cores sampled in and around WLL in May 2015.

The spatial distribution of the detections in and around WLL varied among the contaminants. The chlorinated solvents were detected most frequently in the north west area of WLL property on West Lake OU1 (2), and off property to the north-northeast across St. Charles Rock road from the entrance to WLL and near West Lake OU1(1)and to the southwest along and across the Old St. Charles Road aside South Quarry and the closed section of the Old St. Charles Road aside West Lake OU2 and near the water district impoundments. Summary maps of PCE and TCE concentrations in the collected tree cores are presented in Figure 9. TCE was detected in three samples not directly on or adjacent to the WLL property. These detections were in the light industrial areas that are near the WLL property.

Concentrations of cDCE were low and only detected on the WLL property in limited samples. Analytic sensitivity of cDCE is roughly two orders of magnitude lower than PCE and PCE as noted above. cDCE is a daughter product (metabolite).

Figure 9 Mapped tree core concentrations for TCE and PCE for trees samples in April 2015 at WLL.

Hydrocarbon pollutants in BTEX range were detected across a larger area in the WLL surroundings and with greater frequency as noted. BTEX components were again detected most frequently in the north west area of WLL property, and off property to the north-northeast across St. Charles Rock Road from the entrance to WLL and to the southwest along and across the Old St. Charles Road and the closed section of the Old St. Charles Road near the water district impoundments. Toluene and Benzene detections were more frequent along the Old St. Charles Road and further to the east along the entire length of the WLL property, adjacent the South Quarry and West Lake OU2. Summary maps of Toluene and benzene concentrations in the collected tree cores are presented in Figure 10. For BTEX compounds a number of detections occurred in areas not directly on or adjacent to the WLL property. Benzene was the most commonly detected among the BTEX. These detections were in the light industrial areas that are near the WLL property with a cluster along Crossroads industrial Drive.

Within the analysis of the chlorinated and BTEX analyses, a few common peaks occurred at noticeable peak areas, i.e. relating to elevated concentrations to merit further investigation. Three peaks were prevalent within at least 20 of the tree core samples, two within the BTEX analyses at a retention time of 2.3 minutes (8 tree cores) and 3.9 minutes (12 tree cores) and one within the chlorinated analyses at 1.37 minutes (4 tree cores). Spatial distribution of the trees showing the 2 unknown peaks is shown Figure 11, indicating a cluster for Unknown 1 in the area of West Lake OU1 and a clustering of Unknown 2 along the western edge of South Quarry near Old St. Charles Road. All samples containing the peaks for compound 'Unknown 1' and 'Unknown 2' were on or adjacent WLL property. These tree cores were then reanalysed by SPME-GC-MSD. The ClVOCs and BTEX standards were analysed to determine the retention time and predict where the unknown contaminant peak should elute. Based on the sample number from the collection, tree cores samples before and after the unknown contaminant samples were run as a background samples.

Figure 10 Mapped tree core concentrations for Benzene and Toluene for trees samples in April 2015 at WLL.

The tree cores with the unknown compounds were then analysed to determine the unknown peak and identification of the contaminant. Several tree cores that indicated the presence of unidentified peaks and background tree cores for each of the three unknowns were analysed by SPME-GC-MSD. Based on the standard retention times, the retention time of the unknown contaminant for SPME-GC-MSD was estimated as shown in Table 1.

Table 1 Retention times for target BTEX analytes and the unknown compounds, likely hydrocarbons.

	SPME-GC-FID	SPME-GC-MSD
	Retention time (min)	**Retention time (min)**
Benzene	1.922	2.86
Toluene	2.57	3.87
Ethylbenzene	3.32	4.95
Ortho-Xylene	3.58	---
Meta-Xylene		5.04
Para-Xylene		5.33
Unknown #1	2.3	2.86 < x < 3.87
Unknown #2	3.9	<5.33

Table 2 Retention times for target chlorinated solvent analytes and the unknown compounds in the ECD detection

	SPME-GC-µECD	SPME-GC-MSD
	Retention time (min)	**Retention time (min)**
cDCE	1.451	2.45
TCE	2.167	3.16
PCE	3.217	---
Unknown #3	1.37	<2.45

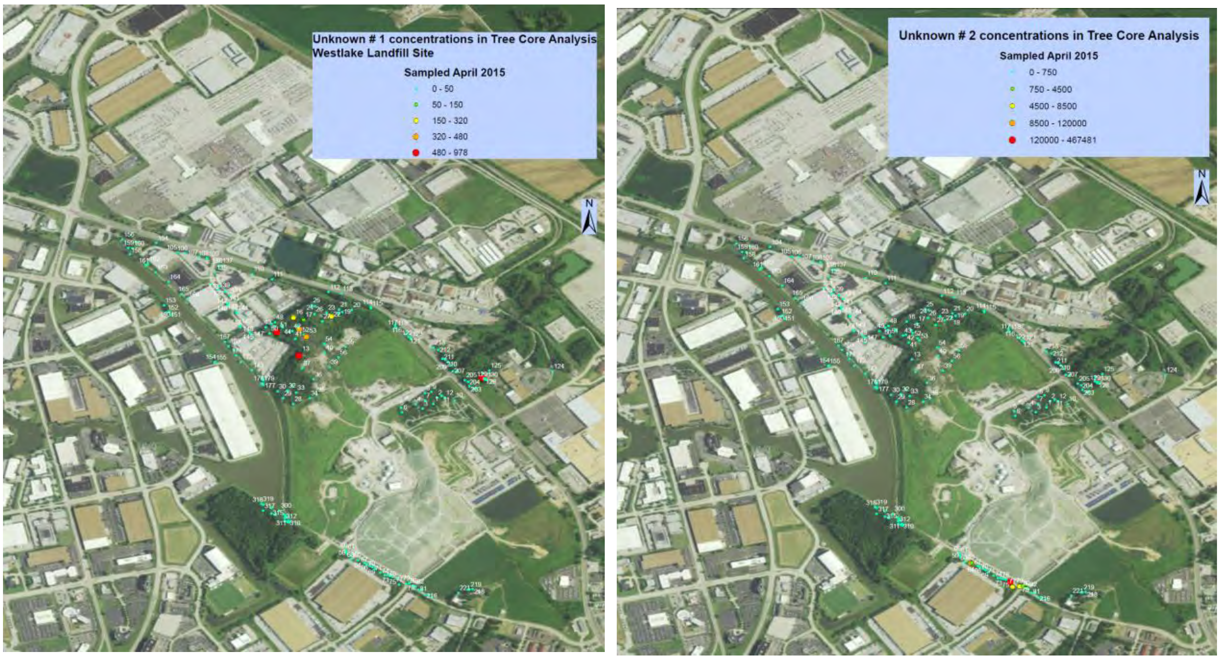


Figure 11 Mapped tree core concentrations for 'Unknown peak 1' and 'Unknown peak 2' for trees samples in April 2015 at WLL.

In comparison to the background sample, there were no significant peaks within the targeted retention times for the unknown compounds in the MSD analysis. The specific chemical properties of the unknown contaminants are not yet known. However, to further investigate the identification of the unknown contaminants observed within initial analyses, fresh samples should be taken and directly analysed by SPME-GC-MSD to assist in identification. Sample degradation due to the storage time between the initial analyses and identification by MSD could have occurred to limit the ability to identify the contaminants.

Limited confirmation sampling that was undertaken in August 2015 re-affirming BTEX detection in the cluster along Old St. Charles Road along the South Quarry again showed a limited identification of Unknown 2. SPME-GC-MSD analysis was again not able to identify the compound using mass spectra libraries for searching to identify unknown compounds. BTEX detections were again in multiple trees in the cluster along the South Quarry perimeter, reaffirming the presence in the subsurface.

Figure 12 Mapped tree core concentrations for Benzene, Toluene, and 'Unknown 2' for trees samples in April 2015 at WLL.

4.2 Radiation Counting Results

Elevated radiologic counts were observed in many of the analysed batches. To determine the degree of elevation from background radiation experienced in measurement environment a background spectrum was collected for 100 hours. Most samples from the environment will contain low levels of radioactivity. To conclude that the tree sample (or any other environmental sample) does contain excess radiation, we applied the 3σ rule. The probability that a new background measurement would yield counts higher than Bk + 3σ is only 0.27%. If the total count in the sample was higher than Bk+ 3σ, there is a 99.73% confident level that elevation is caused by some radioactive material in the analysed samples. Based on this rule batches exceeding the 3σ levels are considered as possibly radioactive.

Net Count in 4 analysed batches of 16 samples were found to be more than 3σ of background radiation corresponding to a 99.73% confidence level. Considering the specific energy patterns, the U-238 decay chain isotopes are mostly present in the batches exceeding the 3σ rule. Some of the isotopes in U-235 and Th-232 were also seen. Besides Ba-140 in batch 1, there were no fission products found or Naturally Occurring Radioactive Material (NORM) observed in the samples analysed. Naturally occurring radioactive isotopes were mostly below the background level except trace amount of Lead in batch 3 & 4. The elevated batches were plotted and illustrated in Figures 5-7. As one can notice, the active samples are found in clusters and close to the sites with history of radioactive material disposal. There seems to be spatial correlation in the samples analysed.

However, the two south clusters are not in the proximity of any radiological site. Therefore a second round of measurements were performed with a new batch of 12 samples comprising of both the south clusters(tree #s 209,210,225,226, 227, 228, 231, 249, 250, 251, 252 and 255). The repeat measurements also showed elevated counts, significantly higher than the background.

While we are not able to pin point the exact location of the potential contaminations or the exact tree number responsible for the higher than background counts. This limitation is due to the batching of samples. However, it can be stated with high degree of confidence (99.73%) that one or more of the samples in the batch had higher level of radioactive material than the background.

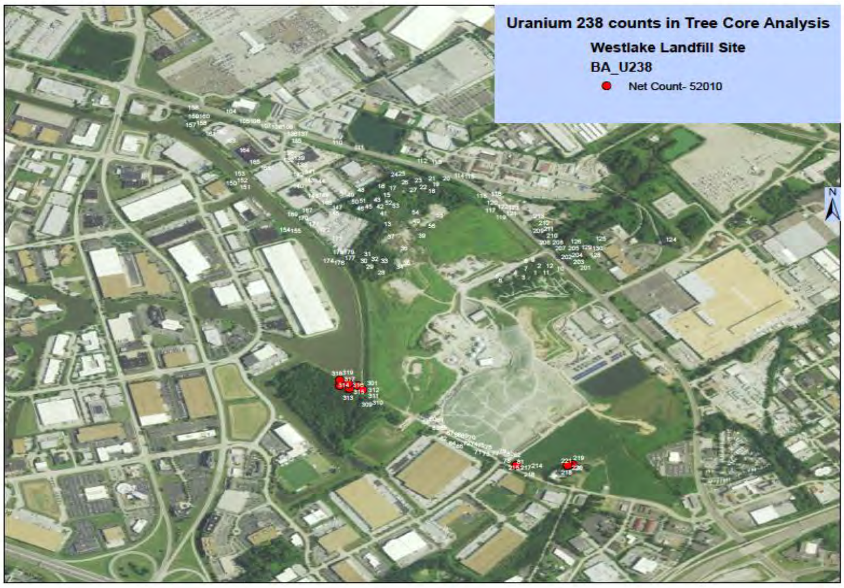


Figure 13a, Repeat measurement of U238 for the two south clusters

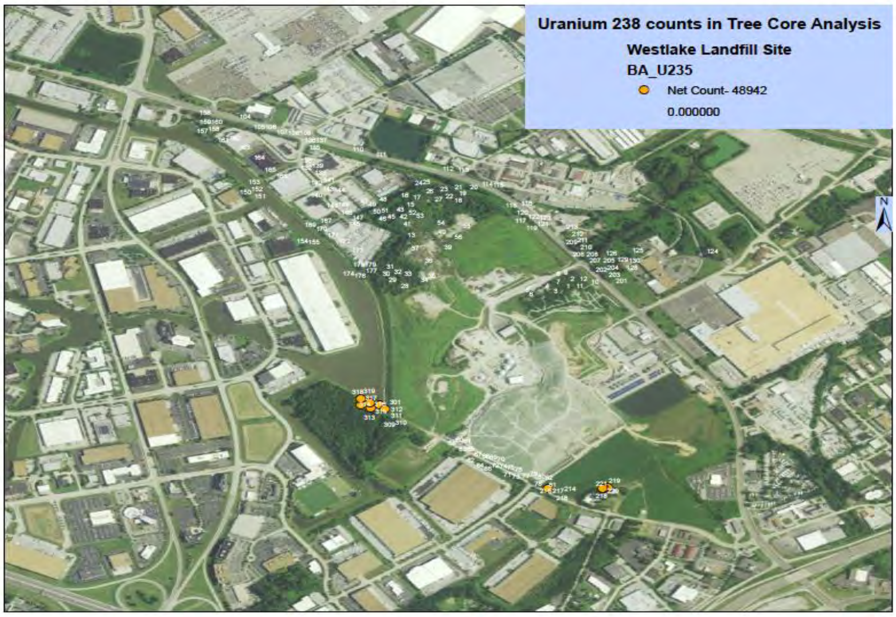


Figure 13b, Repeat measurement of U235 for the two south clusters

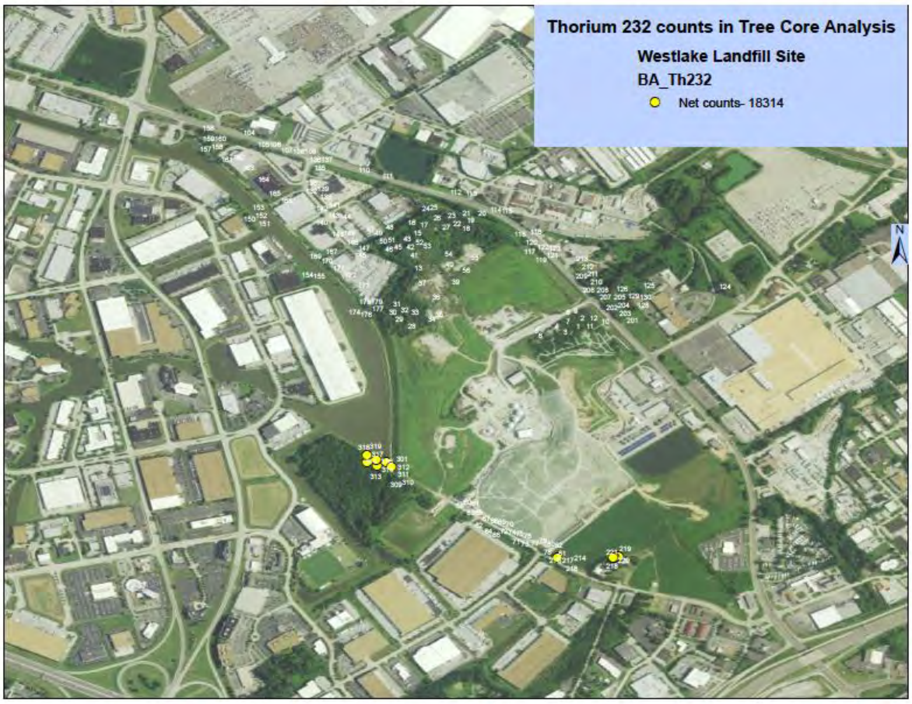


Figure 13c, Repeat measurement of Th232 for the two south clusters Mapped tree core concentrations for U 238, U 235 and Th 232 for trees samples in May 2015 at WLL. Elevated counts are shown for batches of 10 individual samples counted simultaneously. No individual sample data should be interpreted from this figure.

More work would be needed to analyse each sample individually to develop a more detailed understanding of the geographic distribution of the contamination but at this point, the screen data shows pockets or clusters of elevated radioactivity in the tree samples. Two of the four cluster are in close proximity of the known Radiological area but two other sides appears to contain radioactive material in the tree core. Detailed investigated is recommended for thorough understanding of the source and transport mechanism of the radioactive material at the site.

4.3 Summary Conclusions of analysis.

The co-location of the organic pollutant detections indicates a combined source for multiple analytes detected in the phytoforensic analysis of the WLL area. Proximity of the samples to OU1, OU2 and the sanitary landfill of the South Quarry indicate presence of these chemicals in the shallow subsurface profile. The levels detected in the transpiration stream area mostly likely related to notably higher concentrations in the underlying groundwater, soil vapor, and adsorbed to the soil matrix.

Elevated radiologic counts in similar areas also indicate off site migration of RIM, either in groundwater or in aerial transport of particulate matter. Further investigation is needed to isolate the transport mechanisms and tree-specific concentrations.

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6 Appendix A: All individual Organic Detection Maps

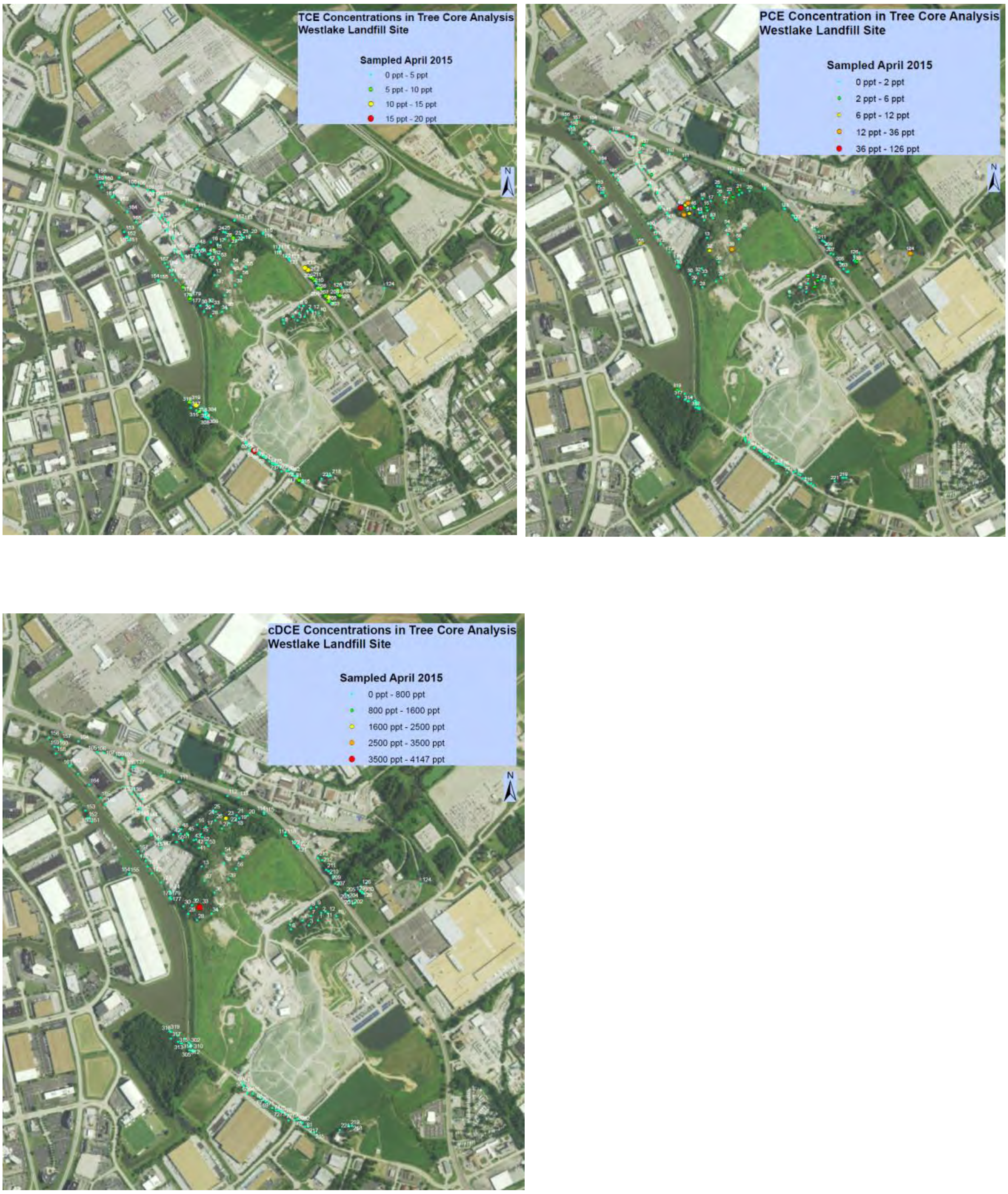
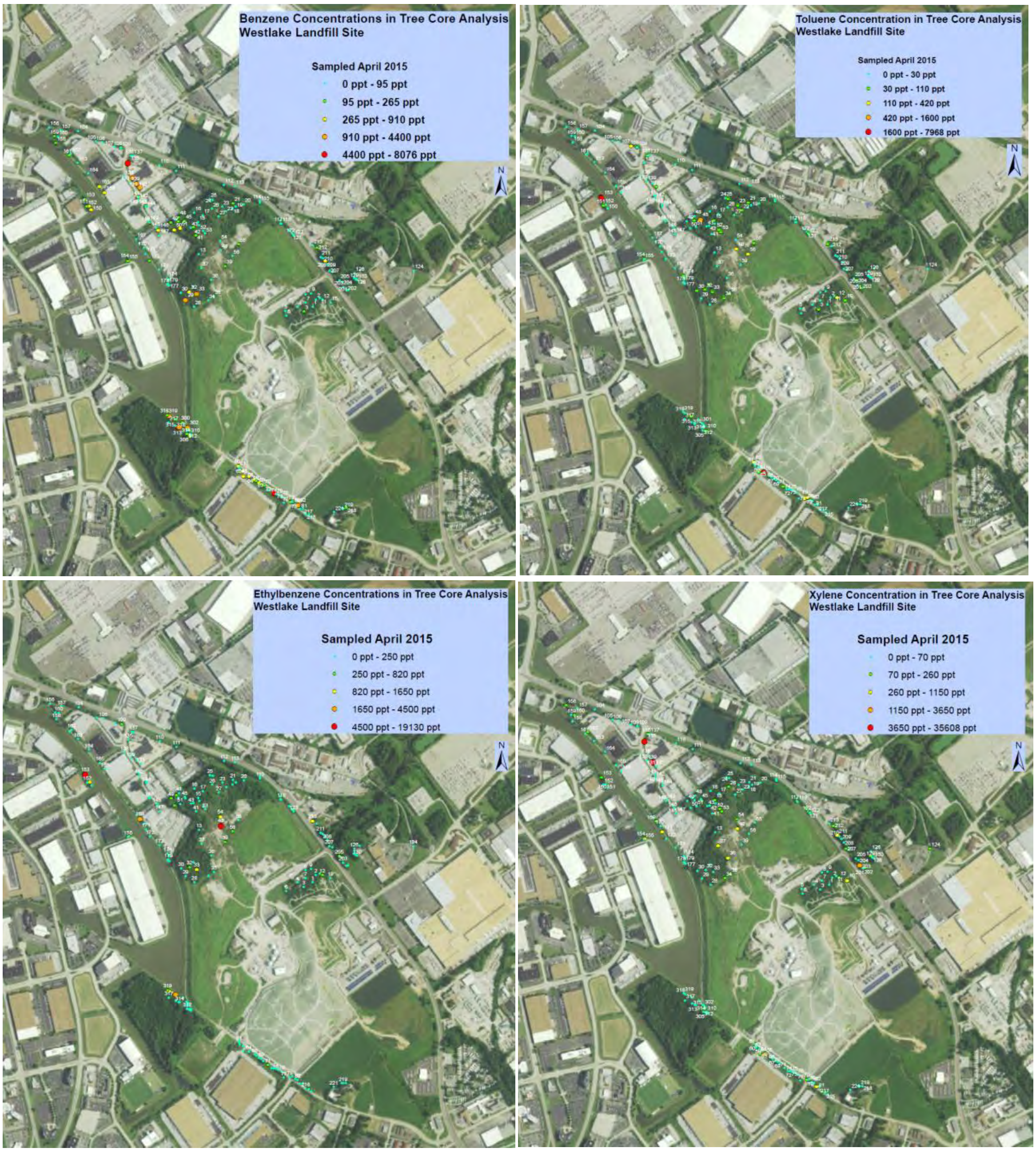
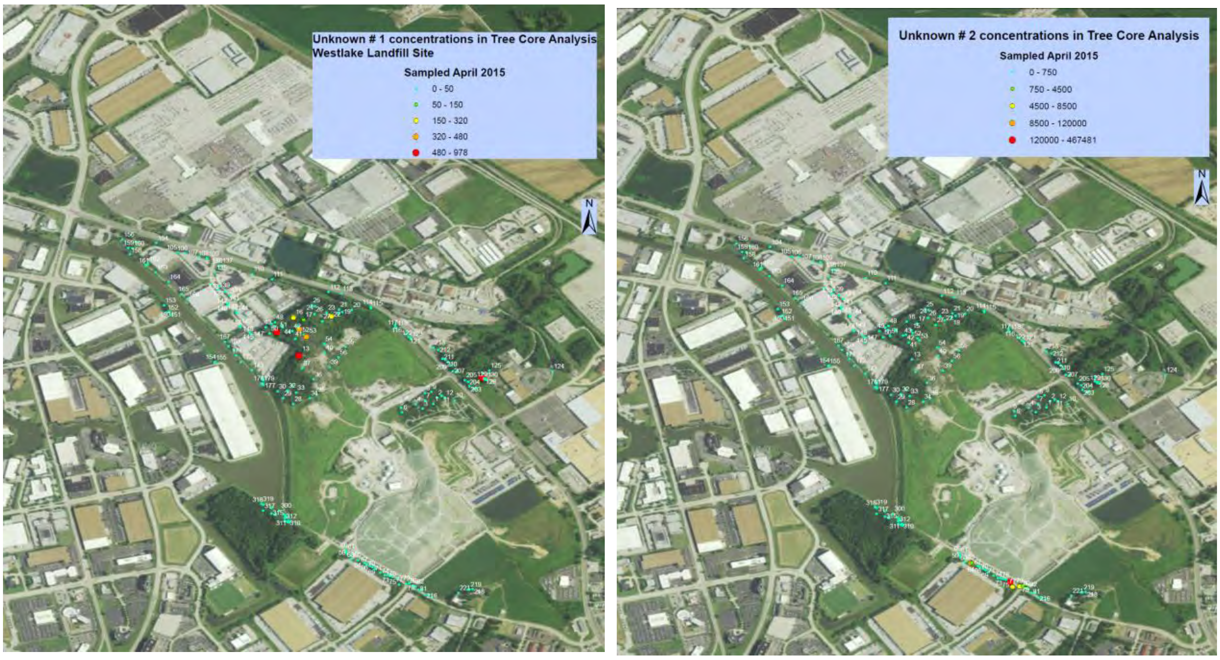


Figure A 1-3 Mapped tree core concentrations for ClVOCs PCE, TCE, and cDCE for trees samples in April 2015 at WLL.



Figures A 4-8 Mapped tree core concentrations for Benzene Toluene, Ethylbenzene and Xylenes for trees samples in April 2015 at WLL.



Figures A 9-10 Mapped tree core concentrations for 'Unknown peak 1' and 'Unknown peak 2' for trees sampled in April 2015 at WLL.

Figures A 11-12 Mapped tree core concentrations for Benzene, Toluene, and 'Unknown 2' for trees sampled in August 2015 at WLL.

7 Appendix B: Radiological Samples Batches and Counts for Significant Peaks

Radiological Samples Batches and Counts for Significant Peaks

Batch 1 Vials	239	247	241	248	246
	242	243	245	244	240

U-238 Decay Chain		U-235 Decay Chain		Th-232 Decay Chain	
Isotopes	Net Counts	Isotopes	Net Counts	Isotopes	Net Counts
U-238	1759	U-235	2683	Th-232	2939
Th-234	7573	Th-231	-	Ra-228	-
Pa-234	2095	Pa-231	-	Ac-228	-
U-234	1392	Ac-227	-	Th-228	1356
Th-230	1781	Th-227	968	Ra-224	-
Ra-226	2651	Ra-223	3118	Bi-212	-
Rn-222	-	Rn-219	-	Pb-212	-
Pb-214	-	Po-215	-	Tl-208	-
Bi-214	-				

Pb-210	2702				

Batch 3 Vials	250	249	238	237	225
	255	254	253	251	251

U-238 Decay Chain		U-235 Decay Chain		Th-232 Decay Chain	
Isotopes	Net Counts	Isotopes	Net Counts	Isotopes	Net Counts
U-238	3131	U-235	1652	Th-232	3750
Th-234	6278	Th-231	-	Ra-228	-
Pa-234	4462	Pa-231	-	Ac-228	-
U-234	2851	Ac-227	-	Th-228	1630
Th-230	6062	Th-227	1018	Ra-224	7349
Ra-226	7858	Ra-223	4772	Bi-212	-
Rn-222	-	Rn-219	-	Pb-212	5940
Pb-214	-	Po-215	-	Tl-208	-

Bi-214	-				
Pb-210	1396				

Batch 4 Vials	200	201	202	203	204
	205	206	207	208	209

U-238 Decay Chain		U-235 Decay Chain		Th-232 Decay Chain	
Isotopes	Net Counts	Isotopes	Net Counts	Isotopes	Net Counts
U-238	-	U-235	2994	Th-232	-
Th-234	4826	Th-231	-	Ra-228	3594
Pa-234	4128	Pa-231	1609	Ac-228	-
U-234	-	Ac-227	-	Th-228	1782
Th-230	1837	Th-227	5978	Ra-224	7266
Ra-226	5251	Ra-223	8001	Bi-212	-
Rn-222	2225	Rn-219	-	Pb-212	5145

Pb-214	-	Po-215	-	Tl-208	-
Bi-214	-				
Pb-210	-				

Batch 5 Vials	54	55	56	57	58
	59	60	61	62	210

U-238 Decay Chain		U-235 Decay Chain		Th-232 Decay Chain	
Isotopes	Net Counts	Isotopes	Net Counts	Isotopes	Net Counts
U-238	-	U-235	-	Th-232	-
Th-234	-	Th-231	-	Ra-228	-
Pa-234	-	Pa-231	-	Ac-228	-
U-234	1103	Ac-227	-	Th-228	-
Th-230	1488	Th-227	-	Ra-224	-
Ra-226	-	Ra-223	-	Bi-212	-

Rn-222	-	Rn-219	-	Pb-212	-
Pb-214	-	Po-215	-	Tl-208	-
Bi-214	-				
Pb-210	-				

Batch 6 Vials	44	45	46	47	48
	49	50	51	52	53

U-238 Decay Chain		U-235 Decay Chain		Th-232 Decay Chain	
Isotopes	Net Counts	Isotopes	Net Counts	Isotopes	Net Counts
U-238	3376	U-235	3257	Th-232	3043
Th-234	9447	Th-231	2720	Ra-228	-
Pa-234	3034	Pa-231	1683	Ac-228	-
U-234	3854	Ac-227	-	Th-228	1969
Th-230	3993	Th-227	1708	Ra-224	7900

Ra-226	6576	Ra-223	4544	Bi-212	-
Rn-222	-	Rn-219	-	Pb-212	-
Pb-214	-	Po-215	-	Tl-208	-
Bi-214	-				
Pb-210	3167				

SW Point Vials	209	210	225	226	227	228
	231	249	250	251	252	255

U-238 Decay Chain		U-235 Decay Chain		Th-232 Decay Chain	
Isotopes	Net Counts	Isotopes	Net Counts	Isotopes	Net Counts
U-238	1590	U-235	3322	Th-232	2471
Th-234	9890	Th-231	7692	Ra-228	2890
Pa-234	11856	Pa-231	1239	Ac-228	2034
U-234	3118	Ac-227	12841	Th-228	3388

Th-230	4157	Th-227	4416	Ra-224	6996
Ra-226	9397	Ra-223	7747	Bi-212	-
Rn-222	5241	Rn-219	-	Pb-212	10449
Pb-214	-	Po-215	-1241	Tl-208	1120
Bi-214	5042				
Pb-210	1715				