ANALYSIS OF MERCURY CONCENTRATIONS IN INDIANA SOIL TO EVALUATE PATTERNS OF LONG-TERM ATMOSPHERIC MERCURY DEPOSITION

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Dedication

To my best friend and my guiding hand from above: my mother, Kathy.

Although our time here has been cut short, I take comfort in knowing that you have been by my side daily. Thank you for believing in me, for the thoughtful words of encouragement, and unwavering strength when I needed it the most. Without you, this long road would have been much more windy and rough. Mom, I love you and miss you every day.

Further, I also dedicate this thesis to my husband, Jason. Thank you for pushing me to succeed and for easing the stressful times. Your steadfast confidence kept me afloat through many semesters. I will always be grateful and I will always love you….

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Abstract

Julie R. Crewe

ANALYSIS OF MERCURY CONCENTRATIONS IN INDIANA SOIL TO

EVALUATE PATTERNS OF LONG-TERM ATMOSPHERIC MERCURY

DEPOSITION

Mercury (Hg) has proven to be a risk to the public, mainly through the consumption of fish. Because of this, many fish consumption advisories have been issued in Indiana. Although much is known about the global cycle of mercury, little is known about how local and regional emission sources of mercury impact local and regional mercury cycling. This study's objective was to determine the scope of mercury concentration in central Indiana by using a broad grid of soil mercury measurements. Sampling was designed to capture the net retained mercury content in soils, and to determine whether spatial patterns in exist in soil mercury contents that could be related to emission sources of mercury and post-emission transport patterns from wind. Results from this study revealed significant differences in mercury concentrations for soils in central Indiana. The core of the study area, concentrated in the urban area of Indianapolis, exhibited soil mercury contents that were 20 times higher than values in the outskirts of the study area. The spatial pattern resembled a bulls-eye shape centered on Indianapolis, and with comparison to the reported Hg emission from local sources, including a coal-fired power plant, indicates a strong regional deposition signal linked to those emission sources but marked by wind-driven transport to the northeast. This effect of local emission sources

resulting in local deposition indicates that limiting mercury emissions will have a net beneficial impact on local environmental quality and human health.

Gabriel Filippelli, PhD, Chair

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1.0 INTRODUCTION

Coal-fired power plants and waste incinerators account for 87% of the anthropological emissions of Hg (US EPA, 1997). There are three species of Hg that are present in the atmosphere: elemental mercury (Hg^0), the most abundant, particulate bound mercury (Hg_p), and reactive gaseous Hg (RGM) (Pleijel and Munthe, 1995). Atmospheric Hg can be deposited via wet and/or dry deposition onto the land and waterways (Pleijel and Munthe, 1995). Mercury is a concern because of the global nature of Hg transport through the atmosphere; however, areas that are in close proximity to Hg releasing industries such as coal-fired power plants, metal smelting companies, and waste incinerators have a greater probability of increased deposition locally.

1.1 Chemical Reactions in the Power Plants and Stacks

Mercury concentration in coal is not particularly high compared to average rocks, but the high volatility of Hg combined with the combustibility and mass of coal used to fuel power plants yields a high mass of Hg entering the flue gas stream. A study conducted in 1995 by the Electric Power Research Institute, EPRI, showed that lignite and bituminous coals have a higher Hg concentration than sub-bituminous, or mid-grade, coal (Chu and Porcella, 1995). This could be a result of the pre-combusted samples being "washed" after mining to remove some pollutants from the coal before combustion. Although many power plants currently utilize flue gas desulfurization (scrubbers), these are not aimed towards the removal or control of Hg (US EPA, 1997); however, scrubbers do remove

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sulfur complexes, consequently removing some of the Hg that is chemically bonded to the complexes (Chu and Porcella, 1995). Other emission control devices for criteria pollutants also have a beneficial side effect of removing Hg from the flue gas. Selective catalytic reduction for nitrogen oxides and electrostatic precipitators for particulates, when combined with flue gas desulfurization, can remove approximately 90 percent of the Hg in the flue gas.

Interchanges of Hg species also can occur in the stacks themselves. Mercury can react easily with Cl^- and sulfite groups, which are both common constituents of flue gas; therefore, it may oxidize and reduce several times in the stacks depending on height of the stack and concentration of those anions (Chu and Porcella, 1995). Hg^0, RGM, and Hg_p are the most relevant species released from coal-fired power plant stacks and the heights of the stacks have an inverse relationship with dry deposition (Pleijel and Munthe, 1995; US EPA, 1997). That is, the lower the stack height, the higher the rate of local deposition.

1.2   Chemical Reactions in the Atmosphere

To determine which species exists where and how they are deposited, it is important to understand the specific nature of the atmospheric species of Hg: elemental (Hg^0), particulate (Hg_p), and reactive gaseous mercury (RGM). Hg^0 is the most common form of Hg in the atmosphere and usually has the longest mean residence time, approximately 1 year (Lindberg et al., 2007; US EPA, 1997; Pleijel and Munthe, 1995). RGM and Hg_p

normally has a mean residence time ranging from only a few hours to a couple of months, therefore, are the most common species to deposit via wet and/or dry deposition and have the highest likelihood of being deposited locally (US EPA, 1997). Both of these species are influenced in the atmosphere by sulfite and ozone (Lamborg et al., 1995; Lindberg et al., 2007; Slemr et al., 2011). RGM will readily complex with ligands such as sulfite, chloride, and hydroxyl; however, Hg has a particular affinity for sulfites (Pleijel and Munthe, 1995; Lamborg et al., 1995). Mercury can also complex with soot particles in the air to form Hg_p, a common form emitted from coal-fired power plants due to the abundance of ash (Figure 1) (US EPA, 1997; Pleijel and Munthe, 1995; Wängberg et al., 2008).

Once the Hg is emitted into the atmosphere, several chemical reactions can occur. If large amounts of both Hg_p and RGM are present, normally the case with flue gas, an increase in dry and wet deposition will most likely occur locally (US EPA, 1997; Pleijel and Munthe, 1997; Lindberg et al., 2007). However, Hg^0 can be dry deposited at high rates in the forest canopies and also can oxidize and become RGM, thus adding to the local soil Hg concentration levels (Lindberg et al., 2007). Hg_p is more reliant on conditions in the atmosphere and particle size than RGM, however, wet and dry deposition increase significantly in areas around a coal-fired power plant due to the amount present in the atmosphere. RGM is much more reactive than Hg_p, and therefore, will be removed from the atmosphere by wet and dry deposition at a higher rate (US EPA, 1997). Local and regional scale RGM concentrations in soil and waterways will be increased due to anthropogenic sources such as coal-fired power plants because there is more RGM

available for removal from the atmosphere (Lindberg, et al, 2007). Conversely, Hg^0 will remain in the atmosphere for much longer than the RGM and, if for example it was emitted in Indiana, it could be deposited anywhere on the globe (US EPA, 1997). These relatively complicated processes involving Hg chemistry have in part made reliable assessments of the spatial scale of Hg deposition problematic.

1.3   Chemical Reactions in the Soil and Water

To complicate the process, RGM deposited on the earth's surface or oceans can be reduced to a volatile Hg^0 and re-enter the atmosphere (US EPA, 1997; Gustin, et al., 2008). This process contributes greatly to the global Hg flux and poses a problem because more Hg is continuously pumped into the atmosphere. The oceans alone contribute 30% of the atmospheric Hg due to this flux process and the percentage rises if Hg deposition increases (US EPA, 1997). Approximately two-thirds of the ocean mercury concentration is anthropogenic in nature (Hudson, et al., 1995). Forest canopies, forest floors, and leaf litter are a sink for mercury and can cause variations in local mercury soil and atmospheric concentrations (Gustin, et al., 2008).

The most toxic form of Hg to humans is methylmercury (MeHg) (US EPA, 1997; Rudd, 1995). Sulfate reducing bacteria mediate the formation of MeHg from Hg. This occurs when the water soluble MeHg enters the phytoplankton, primarily algae, at the base of the food chain. Food web accumulation occurs when the successively higher trophic levels preserve MeHg (Rudd, 1995). Humans may introduce MeHg into their bodies by consuming fish. The MeHg can build up and accumulate in the body causing many severe

neurological disorders in children and adults, and can harm an unborn fetus if the mother already has a high MeHg level in the body or consumes large amounts of upper-level food chain fish (i.e. tuna, shark, catfish, etc.) while pregnant (Ronchetti et al., 2006). High MeHg levels in children can cause learning disabilities, psychological disorders, and other neurological disorders (Ronchetti et al., 2006).

2.0   PURPOSE AND SCOPE

Prior research has shown that higher sediment Hg concentrations exist in Marion County, Indiana. There is a spatial pattern that exists in Marion County's waterway sediments showing that higher concentrations of Hg exist in close proximity to local anthropogenic point sources (Hatcher and Filippelli, 2011). The largest Hg emitter in Marion County, Indiana is Indianapolis Power and Light Company, Harding Street Station (IPL) releasing approximately 137 lbs Hg/year (Table 1) (US EPA Envirofacts, 2007; RAPIDS, 2005). As provided in annual Indianapolis wind data and corresponding wind roses, the predominate energy producing winds (prevailing winds) are from the south to southwest. This carries the emissions from IPL directly over the city of Indianapolis towards the cities of Fishers and Carmel. One limitation to the wind data, however, is the one year time span of the wind rose. A more extensive time period would allow for better interpretation.

Because IPL is the largest Hg emitter in Indianapolis, it is proposed that an identifiable spatial pattern following the prevailing wind direction will exist for Hg concentrations in the soil, indicating that there is long-term local Hg deposition from this source. In order to test this hypothesis, soil samples were taken of Marion County, Indiana and analyzed for total Hg concentration. The study was extended to the four neighboring downwind counties to assess the scope of the Hg spatial pattern.

3.0   STUDY AREA

3.1   Site Description

The entire city of Indianapolis is located within Marion County, Indiana. One significant anthropogenic point source of Hg emissions in Marion County is IPL, Harding Street Station (US EPA Envirofacts, 2007; RAPIDS, 2005). This point source is located on the southwest side of Indianapolis, inside the I-465 loop (Figure 2). The prevailing wind direction of Indianapolis carries the Hg emissions from this point source in a predominately northeastern pattern falling directly over the city (Figure 2).

Other less significant emitters exist in Marion County and several historical anthropogenic point sources were located in Marion County and surrounding areas as well. This study only addresses the largest Hg emission source, IPL.

Soil samples were taken in Marion and the surrounding counties downwind to determine if the anthropogenic source of Hg is contributing to elevated local Hg soil concentrations. Dreher and Follmer (2004) conducted a similar study in Illinois to determine ambient levels of mercury in the soil. This study determined ambient levels of mercury to be 20 ± 9 ppb (Dreher and Follmer, 2004).

This project was a direct follow-up of a previous study that determined increased Hg concentrations were present in the sediments along White River and its major tributaries in Marion County (Hatcher and Filippelli, 2011).

3.2 Sample Locations

The first phase of this study analyzed a total of 73 samples sites in Marion County, Indiana because of the proximity of the point source. Due to increased Hg concentrations from the northeast to east portions of Marion County, a second phase of the study was added to include the scope of the study area to the four bordering counties northeast and southeast of Marion County. The four additional counties: Hamilton, Madison, Hancock, and Shelby included a total of 38 sample sites within this supplemental area.

4.0   METHODS

A 2 x 2 mile (3.2 km x 3.2 km) grid was applied to an aerial map of Marion County to determine locations of sample sites. One sample was taken from as close to the center of each cell in the grid as possible. Sample sites such as cemeteries and parks with long-term minimal ground disturbance were preferred. Sites with minimal ground disturbance are especially important as recently-deposited Hg is likely only present in the topmost layers of soil, therefore if the topsoil is removed or tilled, Hg concentrations will not be representative of that site (Driscoll, 2007). If a park or cemetery was not available in a sample cell, a school, church, or other established buildings grounds were chosen. In several cases, normally due to highly industrialized areas, a sample could not be taken from a sample cell. This occurred in approximately 45% of the sample cells mostly located in northwest and north Marion County (these areas are mostly not in the direction of prevailing wind).

One grab sample and two field replicates of the uppermost 15 cm of soil were collected from each site with a disposable sterile scoop and placed in separate sample baggies. A new disposable scoop was used for each sample. The samples were placed immediately in a cooler on ice and kept below 10°C.

Samples were returned to the Biogeochemistry laboratory at Indiana University - Purdue University Indianapolis (IUPUI), for analysis. All samples and duplicates were air-dried for at least 48 hours in a 100°C oven and sieved using a clean 150 μm sieve to remove

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any large particles, roots, or foreign debris. A previous mercury soil study performed by Kohut, et al. (2000) reported that air-drying and sieving samples did not result in the loss of mercury; in fact, the samples had similar or higher mercury concentrations. The samples were analyzed using the Leco AMA254, which utilizes a direct combustion method comparable to EPA Method 7473 and ASTM D6722. The Leco AMA254 operates with a detection limit of 0.0085 ppm. A calibration method was used with empty nickel boats and three known standards: 1633b, 2709, and 2702 (certified values for these standards are: 0.14 ppm, 1.4 ppm, and 0.0 ppm, respectively). After the instrument was calibrated, three 0.80g sub-samples of each sample were tested and averaged. For each six sub-samples ran in the AMA, one blank and two standards were analyzed to ensure calibration and purge excess Hg in the machine. One Leco AMA254 tray holds 42 nickel boats. Out of the 42 boats, 28 contained samples, 8 contained blanks, and the remaining 6 contained alternating standards (1633b, 2709, and 2702).

In order to understand if a relationship in the samples exists between organic matter (OM) and Hg soil concentrations, 67 sub-samples were chosen to perform loss on ignition (LOI). Approximately one gram of the air-dried and sieved samples was placed in a sterilized crucible, oven-dried for 24 hours at 100°C, reweighed, and then ashed in a muffle furnace at 550°C for three hours. After the samples cooled inside of a desiccator, samples were reweighed to determine the percentage of OM.

During the second phase of this study, the additional four counties were sampled in a five to ten mile grid with preference to convenient sample sites in cemeteries and parks. These

counties were sampled to determine the scope of the Hg deposition from the local point source. All other aspects of analysis remained the same as the Marion County samples.

5.0   RESULTS

5.1   Relationship of Soil Hg Concentration and Organic Matter

A table presenting the OM matter calculations and results is provided in Table 2. A linear regression model was ran on all of the samples (n=67) that were analyzed for OM percentage (Figure 3). The graph resulted in a correlation coefficient value of 0.0489. In Figure 3, there were several outliers and, upon removal of those outliers, a new linear regression model was executed (n=64). This graph resulted in a correlation coefficient value of 0.0461 (Figure 4).

5.2   Spatial Analysis

To determine if a local signature of increased Hg concentrations exist, all of the Hg concentration data was analyzed by ArcGIS[©]. Figure 5 shows the Hg concentrations for all five counties with the highest Hg concentrations located in Marion County. In order to better see this, the other counties were omitted and ordinary kriging was applied to Marion County data only (Figure 6). Figure 6 suggests that a localized hotspot of increased Hg deposition exists downwind from the local point source. The Hg deposition begins to decrease downwind approximately 10-15 km from the point source, reaching ambient levels at approximately 25-30 km downwind (Figure 5).

5.3   Statistical Analysis

Land cover of each soil sample was determined by comparing the locations of the sample sites to the Multi-Resolution Land Characteristics Consortium's (MRLC) National Land Cover Database (NLCD) 2006 version provided by the USGS (Figure 7). It was determined that 10 sample sites were high-intensity developed (urban), 77 were low- to medium-intensity developed (suburban), and 24 were cropland, grassland, forest, etc. (rural). This data was then analyzed with a box plot (Figure 8) to determine if urban and suburban areas have higher Hg soil concentrations than rural areas. The urban areas did indeed have the highest Hg concentrations, followed by suburban, and finally rural with the lowest. Coincidentally, the local point source is located approximately one mile upwind from the downtown (urban) area.

The urban area contained the highest mean, median, and minimum for Hg (Table 2). The highest Hg concentration (711 ppb) was located in a suburban area; however, this sample site was close in proximity to the north central portion of Downtown Indianapolis and the high soil Hg concentration sample sites. To further investigate the variations between the groups, a single factor ANOVA analysis was ran on all samples (Figure 9). This test shows that the means are statistically different (p-value < 0.05).

6.0   DISCUSSION

Mercury has a high affinity to adsorb to organic matter; therefore, OM% was analyzed for each sub-sample of 67 of the 73 Marion County samples. Analysis indicates that only a weak relationship exists between total Hg content in the soil and OM percentage (Figures 3 and 4), with less than 5% of Hg concentration in the soil explained by OM%.

Spatial analysis reveals that the location of the local point source and wind direction play a more central role in the fate of Hg in the surrounding soil (Figures 5 and 6). Soil Hg concentration is considerably lower to the west and southwest (upwind) of the local point source and increases drastically just downwind of this source (Figure 5). The soil Hg concentration begins to decrease significantly approximately 20 km downwind from the point source. These results suggest that the location of the point source, residence time of total Hg, wind direction and wind speed play a significant role in the distribution of Hg in local soils (Figures 5 and 6).

The land use analysis reveals that the urban samples have the highest total Hg concentrations followed by the suburban and rural (Figure 7). The Net Atmospheric Deposition (NAD) of the urban area was calculated from the soil Hg concentration results:

$$Volume\ of\ Soil\ (V_S) = (A_U * D_S)$$

$$Net\ Atmospheric\ Deposition = \frac{(\bar{x}_U * V_S)}{1000}$$

Where V_S represent the volume of soil in the urban area of Indianapolis, soil density is represented by 1.3 g/cm^3, and A_U represents the average Hg concentration of urban land (317 ng/g). Hissler and Probst (2006) estimated the residence time in the top 0-60 cm of soil to be approximately 70 years. Therefore, for the purposes of this study, it is estimated that the residence time of the top 0-10 cm of soil is 10 years. With this in mind, the NAD was calculated to be 412.12 kg and a residence time of 10 years indicates that 41.21 kg of Hg is trapped in local deposition.

Using the total mercury emissions in west-central Marion County at approximately 150 kg/Hg per year, 27 percent of the Hg emitted from these sources is trapped within central Marion County's soils.

Further analysis of variations between groups determined that the averages of each land use type are statistically significant indicating that a local Hg signature exists in urban soil downwind from a point source. This is also indicated by a study published in 2010 by Risch et al. that addressed the impact of mercury deposition on Indiana watersheds and streams. In this study, Risch et al. (2010) collected information from 26 mercury monitoring stations located in watersheds that drained approximately 80 percent of Indiana's land area. This study found that Hg stream concentrations are linearly related to levels of suspended sediment and particulates in a stream (Risch et al., 2010). It was also noted that land use influenced the mercury levels in streams with central Indiana having the highest percentage of urban and suburban land use, the highest mercury concentrations, and the highest stream mercury yields (Risch et al., 2010). The mercury

concentrations in streams were moderately correlated to abundance of local point sources and wastewater effluent discharges within each watershed (Risch et al., 2010). This study observed higher soil Hg concentrations in an urban land use that may be attributable to a local point source; therefore, if the soil within the watershed area has high concentrations of Hg, it is likely that transport of this soil to the stream will increase the Hg stream concentrations.

7.0   CONCLUSION

In conclusion, this study showed that elevated mercury concentrations in soils from the study area in Central Indiana can be attributed to land use and local Hg emission sources, including a coal-fired power plant. Hg concentrations in soil from the study area were highest downwind of the leading local Hg emission source and likely were related to deposition of atmospheric Hg contributed in part from this local source. It is possible that higher soil Hg concentrations in urban areas, like those observed in this study, may help explain higher Hg concentrations in streams of urban watersheds that were observed in a statewide study. The findings from our study can be used by other Hg scientists who assess the factors that contribute to Hg in water and MeHg in fish.

Alternative energy sources or cleaner emissions could lead to a decrease in Hg in Indiana's soil and waterways; however, subsequent research is needed to determine the residence time of the Hg already present in the soil and water. Because the residence time of Hg in soils can be up to 70 years, it could take many years before Hg concentrations in streams decrease, and the subsequent removal of fish advisories for Hg in Indiana.

Table 1. Total Hg emissions for study-area. Madison and Hancock have no reported Hg emissions.

2005 Name	Address	Zip	2005 Hg in lbs	2005 Hg in kg
INDIANA DUCTILE, LLC	1600 S. 8TH STREET	46206	0.60	0.27
DAIMLER CHRYSLER - INDPLS. FOUNDRY	1100 S TIBBS AVE.	46241	64.02	28.81
BELMONT WASTEWATER/INDPLS. SLUDGE INCINE	2700 S BELMONT AVE.	46221	95.00	42.75
INDIANAPOLIS POWER AND LIGHT CO. - HARDING STREET	3700 SOUTH HARDING STREET	46217	136.35	61.36
CITIZENS THERMAL ENERGY	366 KENTUCKY AVE	46225	15.45	6.95
INTERNATIONAL TRUCK AND ENGINE CORPORATION	5565 BROOKVILLE ROAD	46219	32.02	14.41
NATIONAL STARCH AND CHEMICAL COMPANY	1515 S DROVER ST	46206	0.37	0.17
INTERSTATE CASTINGS, INC.	3823 MASSACHUSETTS AVE	46218	0.80	0.36
HERITAGE ENVIRONMENTAL SERVICES LLC	7901 W MORRIS ST	46231	1.00	0.45
COVANTA INDIANAPOLIS, INC.	2320 SOUTH HARDING STREET	46221	55.01	24.76
ROLLS ROYCE CORPORATION	2355 & 2001 S TIBBS AVE.	46241	0.19	0.09
VERTELLUS SPECIALTIES INC.	1500 S TIBBS AVENUE	46242	0.23	0.10
SOUTHSIDE LANDFILL, INC.	2561 KENTUCKY AVENUE	46221	0.16	0.07
BUNGE NORTH AMERICA (EAST), INC.	700 NORTH RANGELINE ROAD	46161	0.46	0.21
TOTALS			**401.66**	**180.75**

The table title reads: **2005 Mercury Emission Data for Marion, Shelby, and Hamilton Counties**

Table 2. Organic matter percent calculations from Marion County soil samples and replicates.

Sample Information		100 degrees C		550 degrees C			
Sample ID	Crucible Wt. (grams)	Sample + Crucible (air dry)	Sample + Crucible (oven dry)	Ash + Crucible (grams)	Sample (grams)	Ash (grams)	Organic Matter Percent
E	11.62	12.67	12.65	12.53	1.03	0.91	11.80
SE	11.79	12.75	12.73	12.63	0.94	0.84	10.74
S	12.16	13.17	13.15	13.03	0.99	0.87	12.29
SW	11.69	12.51	12.50	12.39	0.80	0.70	13.47
W	11.95	13.02	13.00	12.87	1.05	0.92	11.98
NW	12.50	13.73	13.70	13.55	1.20	1.06	12.09
N	14.06	15.05	15.03	14.92	0.96	0.86	10.75
NE	12.28	13.17	13.15	13.04	0.87	0.77	12.26
C1T	12.52	13.67	13.65	13.54	1.12	1.01	9.94
C1M	13.86	14.90	14.88	14.79	1.01	0.93	8.69
C1B	12.68	13.46	13.45	13.39	0.77	0.71	7.67
S1A	11.77	12.77	12.75	12.66	0.98	0.88	9.56
S1B	14.11	15.13	15.11	15.02	1.00	0.91	8.71
S1C	12.68	13.59	13.57	13.46	0.90	0.78	12.50
S1D	11.42	12.50	12.49	12.41	1.06	0.98	7.61
S2A	14.54	15.57	15.54	15.42	1.00	0.89	11.50
S2B	12.43	13.38	13.36	13.29	0.93	0.87	7.23
S2C	12.51	13.44	13.42	13.33	0.91	0.83	9.60
S2D	11.95	12.85	12.83	12.75	0.88	0.81	8.60
S3A	12.41	13.17	13.16	13.09	0.75	0.68	8.91
S3B	10.78	11.64	11.63	11.58	0.85	0.80	6.23
S3C	9.74	11.28	11.26	11.15	1.51	1.41	7.13
S3D	10.96	11.74	11.73	11.67	0.76	0.71	7.27
S4A	12.98	13.82	13.81	13.73	0.83	0.75	9.32
S4B	12.13	13.08	13.06	12.99	0.94	0.86	8.48
S4C	11.02	12.26	12.23	12.13	1.21	1.11	8.58
S4D	10.66	11.43	11.42	11.33	0.76	0.67	11.47
S5A	14.18	15.08	15.06	14.97	0.89	0.79	10.46
S5B	12.09	13.22	13.19	13.09	1.10	1.00	9.65
S5C	11.94	12.82	12.80	12.72	0.86	0.77	10.12
S5D	11.94	12.75	12.73	12.61	0.79	0.67	14.55

S6A	10.86	11.98	11.96	11.92	1.10	1.05	4.50
S6B	14.24	15.15	15.14	15.10	0.90	0.86	4.34
S6C	12.70	13.80	13.78	13.71	1.07	1.01	6.37
S6D	11.37	12.28	12.27	12.21	0.89	0.83	6.77
RPS	12.39	13.40	13.38	13.29	0.99	0.90	9.20
RPN	10.75	11.57	11.56	11.50	0.81	0.75	7.86
RPC	12.42	13.44	13.42	13.35	1.00	0.93	7.19
RPE	14.62	15.63	15.61	15.54	0.99	0.92	7.25
RPW	9.90	10.65	10.63	10.58	0.74	0.68	7.29
GWS	12.75	13.65	13.62	13.42	0.87	0.68	21.90
GWN	12.16	13.05	13.03	12.93	0.87	0.77	11.41
GWC	11.26	12.18	12.15	11.98	0.89	0.73	18.42
GWE	11.33	12.31	12.28	12.11	0.95	0.77	18.64
GWW	12.46	13.31	13.29	13.17	0.83	0.71	14.55
PRW	12.68	13.65	13.63	13.55	0.95	0.88	8.25
PRE	11.42	12.41	12.39	12.30	0.97	0.88	9.14
PRC	12.75	13.69	13.67	13.58	0.93	0.84	9.52
PRS	11.02	11.90	11.88	11.77	0.85	0.74	12.87
PRN	12.16	13.01	13.00	12.92	0.84	0.76	9.29
DUBW	11.94	12.72	12.71	12.63	0.77	0.69	9.96
DUBS	9.74	10.82	10.81	10.72	1.06	0.98	7.76
DUBN	11.37	12.19	12.18	12.11	0.81	0.74	8.67
DUBE	9.90	10.77	10.76	10.68	0.86	0.78	9.21
DUBC	14.11	14.94	14.92	14.85	0.81	0.74	8.64
TIBS	11.94	12.80	12.78	12.70	0.85	0.76	10.33
TIBN	12.98	13.94	13.92	13.85	0.94	0.87	7.64
TIBE	12.39	13.59	13.57	13.47	1.18	1.08	8.55
TIBC	12.41	13.20	13.18	13.11	0.78	0.70	9.44
TIBW	11.95	12.86	12.85	12.77	0.90	0.82	8.84
NCW	12.69	13.52	13.50	13.43	0.81	0.74	8.09
NCC	10.86	11.67	11.66	11.58	0.80	0.72	10.07
NCS	10.01	11.15	11.13	11.04	1.12	1.03	8.03
NCN	12.28	13.57	13.54	13.41	1.26	1.13	10.11
NCE	10.52	11.34	11.32	11.25	0.80	0.73	8.06
ARLE	10.48	11.70	11.68	11.58	1.20	1.10	7.96
ARLN	10.17	11.08	11.06	10.98	0.89	0.81	8.43
ARLS	14.18	15.10	15.09	15.03	0.90	0.84	6.51
ARLW	12.46	13.30	13.28	13.22	0.82	0.76	7.60
ARLC	14.54	15.47	15.45	15.38	0.92	0.84	7.77
21S	11.49	12.20	12.18	12.12	0.69	0.64	7.63
21N	11.26	12.16	12.14	12.07	0.88	0.81	7.63

21E	11.79	12.63	12.61	12.54	0.82	0.76	8.00
21C	11.65	12.94	12.91	12.81	1.26	1.16	7.93
21W	11.75	12.71	12.68	12.60	0.93	0.85	8.69
GERC	10.75	11.75	11.73	11.66	0.98	0.91	6.60
GERS	12.70	13.68	13.66	13.59	0.95	0.89	7.23
GERW	10.50	11.44	11.42	11.34	0.91	0.84	7.93
GERE	12.07	13.34	13.31	13.21	1.23	1.14	7.99
GERN	12.68	13.70	13.68	13.61	1.00	0.93	7.22
KITN	11.03	12.20	12.18	12.08	1.15	1.06	7.95
KITW	12.85	13.91	13.89	13.81	1.04	0.96	8.06
KITE	12.51	13.36	13.33	13.25	0.83	0.74	10.75
KITC	14.24	15.01	14.99	14.92	0.75	0.69	8.80
KITS	14.17	15.01	14.99	14.94	0.82	0.76	7.18
WSW	10.50	11.33	11.27	11.18	0.77	0.68	12.09
WSN	12.39	13.71	13.63	13.51	1.24	1.12	9.59
WSE	12.70	13.53	13.48	13.38	0.78	0.68	13.56
WSS	11.88	13.52	13.43	13.26	1.55	1.38	10.64
MOBW	12.51	13.98	13.95	13.88	1.44	1.37	4.69
MOBN	13.37	14.66	14.63	14.57	1.27	1.20	5.35
MOBS	11.94	12.80	12.78	12.74	0.84	0.80	4.68
MOBE	10.01	11.32	11.29	11.22	1.28	1.20	5.96
CHAE	12.51	13.37	13.35	13.29	0.84	0.78	7.30
CHAW	10.98	12.05	12.03	11.95	1.05	0.97	7.36
CHAN	9.74	10.88	10.86	10.77	1.11	1.03	7.89
CHAS	10.48	11.76	11.73	11.64	1.26	1.16	7.60
MPW	11.03	12.11	12.09	12.03	1.06	1.00	5.66
MPS	11.37	12.27	12.25	12.19	0.88	0.81	7.25
MPE	13.86	14.51	14.49	14.45	0.63	0.59	6.77
MPN	10.86	12.08	12.05	11.96	1.18	1.10	6.94
JSN	10.40	11.15	11.13	11.07	0.73	0.67	7.76
JSE	11.65	12.68	12.65	12.58	1.00	0.93	6.70
JSW	11.86	12.75	12.72	12.65	0.87	0.79	8.77
JSS	10.17	11.00	10.98	10.92	0.81	0.76	6.86
LJN	9.90	10.87	10.84	10.80	0.94	0.90	3.83
LJC	11.99	12.99	12.96	12.91	0.97	0.92	5.01
LJS	14.85	15.70	15.66	15.63	0.82	0.78	3.90
APS	10.78	11.52	11.50	11.44	0.73	0.66	8.48
APE	10.52	11.43	11.41	11.33	0.89	0.82	8.21
APW	12.16	13.05	13.03	12.95	0.87	0.79	9.31
APN	14.90	16.13	16.07	15.96	1.17	1.05	9.94
NPS	14.28	15.16	15.10	15.05	0.82	0.77	6.61

NPN	11.11	12.18	12.12	12.05	1.01	0.94	7.22
NPC	13.61	14.39	14.35	14.30	0.74	0.69	6.98
FCN	11.94	12.94	12.91	12.87	0.97	0.93	4.05
FCS	9.75	10.83	10.79	10.75	1.04	1.00	4.39
FCC	13.95	14.80	14.77	14.74	0.82	0.78	4.52
BPS	14.18	14.99	14.97	14.90	0.78	0.72	8.19
BPN	10.75	11.62	11.60	11.53	0.85	0.79	7.93
BPE	12.46	13.47	13.44	13.38	0.99	0.92	6.96
BPW	11.79	12.68	12.66	12.60	0.87	0.81	7.16
SHEW	14.17	15.10	15.08	14.99	0.90	0.82	9.21
SHEN	12.74	14.21	14.17	14.05	1.44	1.32	8.38
SHEE	12.98	13.78	13.77	13.70	0.79	0.72	8.37
SHES	11.26	12.57	12.53	12.42	1.27	1.16	8.64
CAS	14.11	14.93	14.92	14.86	0.81	0.75	6.78
CAN	12.54	13.52	13.50	13.44	0.96	0.90	6.54
CAW	11.42	12.32	12.30	12.25	0.88	0.83	6.34
CAE	14.23	15.24	15.22	15.16	0.98	0.93	5.79
BEGC	10.41	11.40	11.38	11.31	0.97	0.89	7.60
BEGN	12.06	12.93	12.92	12.85	0.86	0.79	7.82
BEGS	13.62	14.55	14.54	14.48	0.92	0.87	6.41
FTN	10.98	11.77	11.76	11.69	0.78	0.71	8.65
FTC	11.77	13.19	13.17	13.06	1.39	1.29	7.56
FTS	12.49	13.35	13.34	13.27	0.84	0.78	7.37
GDPN	10.77	11.57	11.56	11.50	0.79	0.73	7.31
GDPS	10.56	11.39	11.38	11.31	0.82	0.75	7.69
GDPC	12.84	13.99	13.98	13.90	1.14	1.06	6.81
EBPC	12.74	13.51	13.50	13.45	0.76	0.70	7.51
EBPN	14.13	15.04	15.03	14.97	0.89	0.83	6.88
EBPS	14.62	15.54	15.52	15.45	0.90	0.83	8.02
PEPC	13.20	14.41	14.39	14.30	1.19	1.11	6.97
PEPN	10.24	11.17	11.15	11.07	0.91	0.83	8.84
PEPS	10.34	11.16	11.14	11.05	0.80	0.71	11.01
BSPC	12.08	12.95	12.94	12.86	0.85	0.78	8.67
BSPN	10.16	11.12	11.12	11.06	0.95	0.90	5.57
BSPS	10.64	11.61	11.59	11.52	0.95	0.88	7.81
SEWN	12.95	13.88	13.86	13.79	0.91	0.84	7.77
SEWS	11.66	12.43	12.42	12.35	0.76	0.69	8.64
SEWC	12.50	13.62	13.59	13.49	1.10	0.99	9.27
RHPS	11.30	12.62	12.55	12.47	1.25	1.17	6.58
RHPC	11.18	11.96	11.95	11.89	0.77	0.71	7.40
RHPN	11.03	12.03	12.01	11.94	0.98	0.91	7.77

SWS	11.06	12.40	12.37	12.25	1.31	1.19	9.39
SWN	10.15	11.34	11.32	11.21	1.17	1.06	9.63
SWC	14.10	14.99	14.97	14.89	0.87	0.79	9.84
GEPC	12.86	13.70	13.69	13.63	0.83	0.77	7.54
GEPS	12.54	13.47	13.45	13.36	0.91	0.82	9.84
GEPN	10.66	11.77	11.75	11.64	1.09	0.97	10.32
CHRS	13.57	14.34	14.32	14.25	0.75	0.68	9.11
CHRN	12.13	13.03	13.01	12.93	0.88	0.80	9.01
CHRC	11.45	12.14	12.13	12.06	0.68	0.62	9.32
SAPC	11.82	13.03	12.83	12.67	1.01	0.85	15.77
SAPN	12.76	13.62	13.54	13.44	0.78	0.68	12.72
WAS3	10.86	11.99	11.84	11.73	0.98	0.88	10.63
WAS2	11.27	12.48	12.35	12.26	1.08	1.00	7.73
WAS1	12.26	13.47	13.33	13.25	1.08	0.99	8.01
GUP1	11.21	12.15	12.05	11.97	0.84	0.76	9.43
GUP2	12.44	13.56	13.42	13.33	0.98	0.89	9.28
GUP3	11.55	12.90	12.75	12.64	1.20	1.09	9.31
HAN1	13.18	14.00	13.94	13.87	0.77	0.69	9.78
HAN2	14.12	14.93	14.89	14.81	0.77	0.69	10.04
HAN3	13.29	14.03	14.00	13.94	0.71	0.66	8.20
STO3	12.20	13.22	13.17	12.99	0.97	0.79	18.64
STO2	12.48	13.25	13.22	13.05	0.73	0.57	22.37
STO1	10.66	11.62	11.57	11.36	0.91	0.70	22.89
EPL1	13.98	14.89	14.86	14.81	0.88	0.83	5.08
EPL2	11.24	12.18	12.14	12.09	0.90	0.85	5.33
EPL3	13.35	14.61	14.56	14.50	1.21	1.15	5.26
GLE1	12.25	13.25	13.15	13.08	0.90	0.83	7.91
GLE2	13.21	14.30	14.22	14.14	1.02	0.94	7.92
GLE3	12.55	13.89	13.80	13.71	1.25	1.16	6.80
H	11.02	11.88	11.87	11.81	0.85	0.79	6.96
R	11.70	12.67	12.67	12.60	0.97	0.90	6.95
A1	12.11	13.14	13.11	12.98	1.00	0.87	12.64
A2	11.27	12.18	12.16	12.04	0.88	0.77	13.08
A3	10.20	11.16	11.14	11.03	0.94	0.82	12.28
A4	12.34	13.67	13.62	13.46	1.29	1.12	13.04
B1	12.45	13.82	13.79	13.67	1.35	1.22	9.54
B2	9.98	10.74	10.73	10.65	0.74	0.67	10.24
B3	11.61	12.58	12.57	12.48	0.96	0.87	9.19
B4	11.94	12.98	12.97	12.88	1.03	0.94	8.85
C1	11.48	12.33	12.31	12.21	0.83	0.73	11.68
C2	11.67	12.62	12.61	12.54	0.94	0.87	7.10

C3	10.66	11.54	11.52	11.44	0.87	0.78	9.54
C4	14.26	15.10	15.08	15.00	0.82	0.73	10.24
D1	11.82	12.98	12.96	12.90	1.15	1.08	5.68
D2	10.31	11.28	11.27	11.21	0.96	0.90	5.78
D3	11.57	12.44	12.43	12.37	0.86	0.80	6.61
D4	9.96	11.03	11.01	10.95	1.04	0.98	5.75
F1	11.45	12.29	12.28	12.23	0.83	0.78	6.03
F2	12.03	13.03	13.02	12.97	0.99	0.94	5.14
F3	12.66	13.73	13.71	13.66	1.05	0.99	5.35
F4	14.35	15.23	15.22	15.17	0.86	0.82	5.60
G1	13.26	14.33	14.31	14.21	1.05	0.95	9.63
G2	9.98	10.96	10.95	10.88	0.97	0.90	6.84
G3	12.51	13.49	13.48	13.42	0.97	0.91	6.29
G4	11.10	11.94	11.92	11.85	0.82	0.76	8.06
H1	12.15	13.52	13.50	13.46	1.35	1.31	2.83
H2	13.86	15.21	15.20	15.17	1.34	1.31	2.24
H3	9.79	10.76	10.75	10.72	0.96	0.93	2.82
H4	13.73	14.74	14.73	14.70	1.00	0.98	2.64
I1	11.73	12.73	12.69	12.48	0.96	0.76	20.94
I2	11.04	12.18	12.14	11.96	1.10	0.93	15.91
I3	11.17	12.04	12.01	11.87	0.84	0.70	16.72
I4	11.85	12.78	12.73	12.55	0.88	0.70	20.43
J1	10.55	11.33	11.31	11.23	0.76	0.69	9.81
J2	12.41	13.34	13.32	13.26	0.91	0.84	6.99
J3	12.60	13.42	13.40	13.33	0.79	0.73	8.46
J4	13.86	14.77	14.74	14.64	0.89	0.79	11.29
K1	10.15	11.16	11.14	11.08	0.99	0.93	6.51
K2	11.77	12.65	12.64	12.58	0.87	0.81	6.79
K3	12.05	13.00	12.98	12.92	0.94	0.87	6.95
K4	12.82	13.90	13.88	13.81	1.06	0.99	6.22
L2	10.78	12.06	11.99	11.88	1.22	1.11	8.90
L3	13.57	14.31	14.27	14.14	0.70	0.57	18.86
L4	9.88	10.86	10.81	10.70	0.93	0.82	11.91
M1	11.84	12.64	12.60	12.53	0.77	0.69	10.04
M2	12.02	13.15	13.09	12.98	1.07	0.96	9.99
M3	12.74	13.64	13.60	13.52	0.86	0.78	9.80
M4	10.91	11.94	11.91	11.83	1.01	0.93	7.94
N1	11.21	12.25	12.21	12.14	1.00	0.92	7.69
N2	11.89	12.78	12.74	12.68	0.85	0.79	6.94
N3	9.79	10.79	10.75	10.68	0.96	0.89	7.01
N4	11.45	12.43	12.39	12.32	0.95	0.87	7.63

O1	11.27	12.24	12.21	12.13	0.94	0.86	8.46
O2	9.52	10.45	10.42	10.35	0.90	0.82	8.59
O3	12.05	13.10	13.07	12.99	1.02	0.94	8.13
O4	14.64	15.65	15.61	15.52	0.98	0.88	10.06
P1	12.94	14.05	14.03	13.97	1.09	1.03	5.47
P2	12.96	14.00	13.98	13.93	1.02	0.97	4.81
P3	10.58	11.72	11.70	11.64	1.12	1.06	5.32
P4	11.82	12.77	12.75	12.70	0.93	0.88	5.21
Q1	12.05	13.14	13.10	13.02	1.06	0.97	8.08
Q2	11.77	12.77	12.72	12.63	0.95	0.86	9.94
Q3	14.64	15.65	15.61	15.52	0.97	0.89	8.80
Q4	12.96	13.90	13.86	13.77	0.90	0.81	9.82
R1	11.27	12.22	12.18	12.09	0.91	0.82	10.20
R2	12.05	12.99	12.95	12.88	0.90	0.82	8.42
R3	10.91	11.93	11.88	11.79	0.97	0.89	8.65
R4	11.85	12.81	12.77	12.68	0.93	0.84	9.91
S1	10.78	11.66	11.63	11.56	0.86	0.79	7.81
S2	11.84	12.79	12.75	12.68	0.91	0.84	8.28
S3	12.41	13.39	13.34	13.27	0.93	0.85	8.07
S4	13.26	14.25	14.21	14.13	0.96	0.88	8.24
T1	10.82	12.25	12.21	12.15	1.38	1.32	4.32
T2	12.82	13.88	13.83	13.77	1.01	0.95	6.23
T3	10.15	11.02	10.99	10.94	0.84	0.79	5.80
T4	9.52	10.47	10.44	10.40	0.92	0.87	4.68
U1	11.17	12.10	12.08	12.02	0.91	0.86	6.32
U2	11.45	12.38	12.36	12.30	0.91	0.86	5.84
U3	12.15	13.15	13.13	13.09	0.98	0.93	4.75
U4	11.03	11.95	11.93	11.88	0.90	0.84	5.76
V01	11.37	12.38	12.31	12.02	0.94	0.65	31.05
V02	9.97	10.87	10.81	10.55	0.84	0.58	30.92
W01	13.20	14.20	14.10	13.77	0.91	0.58	36.52
W02	12.05	13.02	12.93	12.62	0.88	0.57	35.37
X01	11.02	12.07	12.01	11.73	0.99	0.71	27.96
X02	10.66	11.60	11.55	11.28	0.88	0.62	30.02
Y01	11.24	12.11	12.04	11.76	0.81	0.53	34.47
Y02	12.06	13.12	13.07	12.77	1.01	0.71	30.06
Z01	12.84	13.81	13.70	13.40	0.86	0.55	35.38
Z02	13.36	14.36	14.34	14.04	0.98	0.68	31.01
PR1	11.11	12.13	12.10	11.81	0.99	0.70	29.63
PR2	12.27	13.46	13.43	13.13	1.16	0.86	25.74
PR3	12.89	13.88	13.85	13.54	0.97	0.66	31.73

PR4	11.47	12.46	12.42	12.12	0.95	0.65	31.72
GER1	9.70	10.62	10.60	10.35	0.90	0.66	26.76
GER2	12.51	13.53	13.50	13.19	0.99	0.68	31.29
GER3	12.73	13.66	13.64	13.34	0.91	0.61	33.23
GER4	12.52	13.49	13.47	13.17	0.95	0.65	31.60

Table 3. Statistics for entire sample set, Marion County only (location of point source), and by land use.

Samples	N	Hg Concentration in Soil, ppb				
		Min.	Max.	Mean	Median	Std. dev.
All	111	23	711	70	49	93.01
Marion	73	23	711	84	53	112.17
Urban	10	113	610	317	295	193.82
Suburban	77	23	123	53	50	20.33
Rural	24	27	63	42	39	9.49

Table 4. Single factor ANOVA on land use. A p-value of <0.05 shows that the variation between land use averages are statistically different.

ANOVA: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Urban	5	1584.138	316.8275	37556.01
Suburban	82	5239.227	63.89301	5836.515
Rural	24	1001.552	41.73134	90.26525

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	326828.9	2	163414.5	28.23541	1.37E-10	3.080387
Within Groups	625057.8	108	5787.573			
Total	951886.8	110				
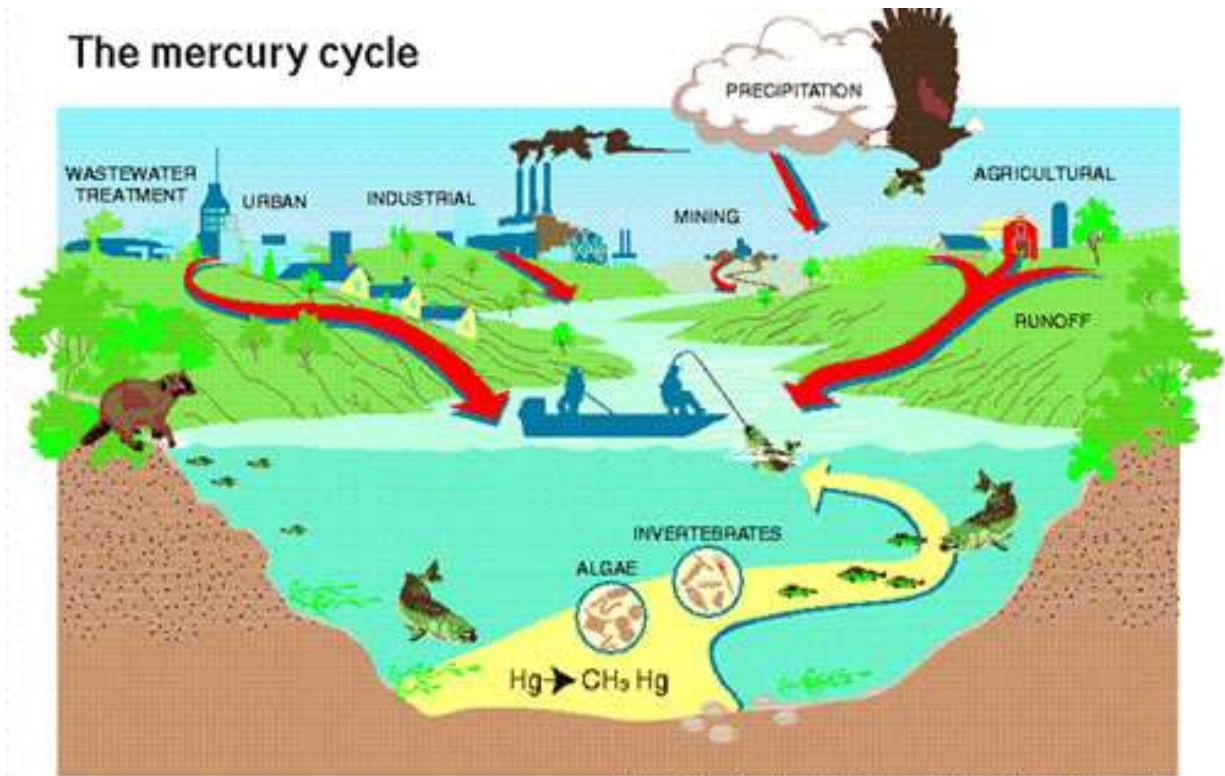
Figure 1. This illustration displays the mercury cycle showing fate and transport of Hg species from both anthropogenic and natural sources.
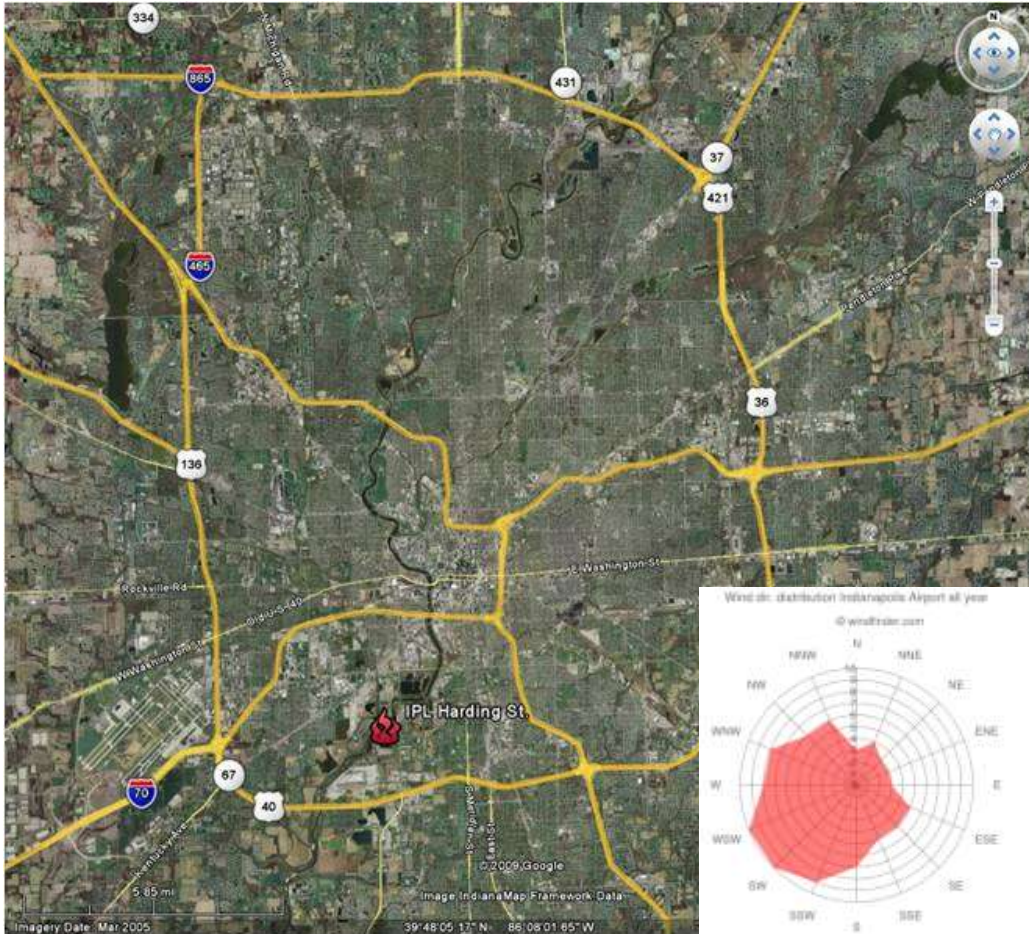
Figure 2. Map (Google 2011©) of Marion County with an inset wind rose plot of Indianapolis. The IPL Harding Street Station is marked by a red flame on the map and the wind rose plot shows that prevailing winds travel in a northeastern pattern.
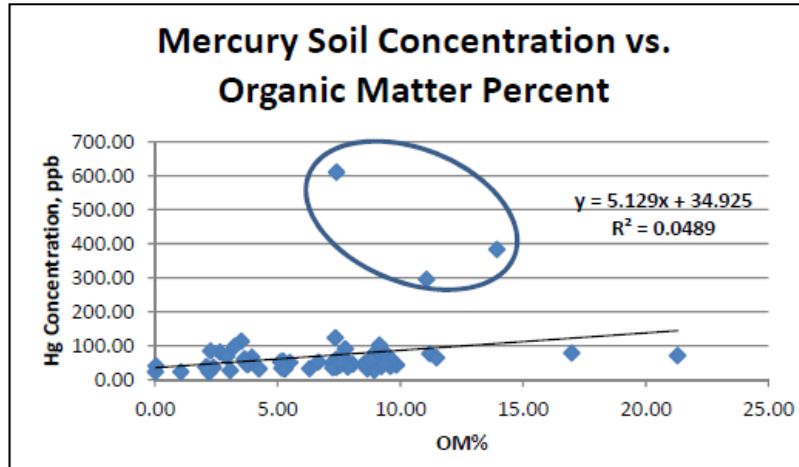
Figure 3. Linear regression model of Hg soil concentration versus organic matter percent.
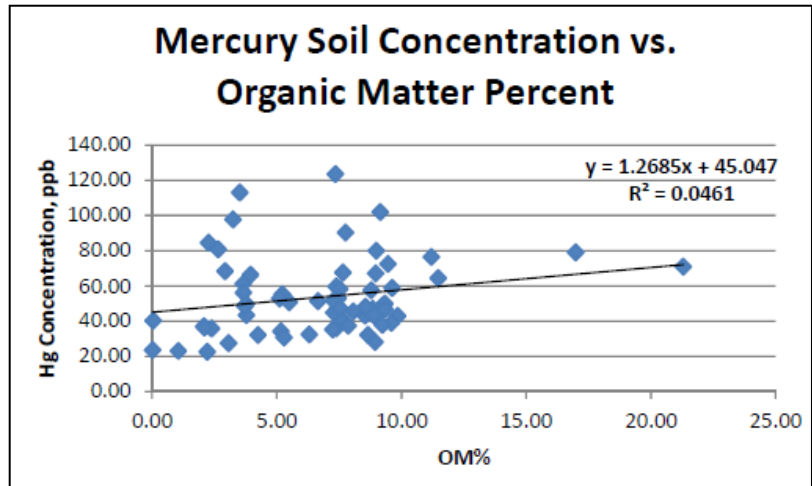
Figure 4. Linear regression model of Hg soil concentration versus organic matter percent

upon removal of outliers.
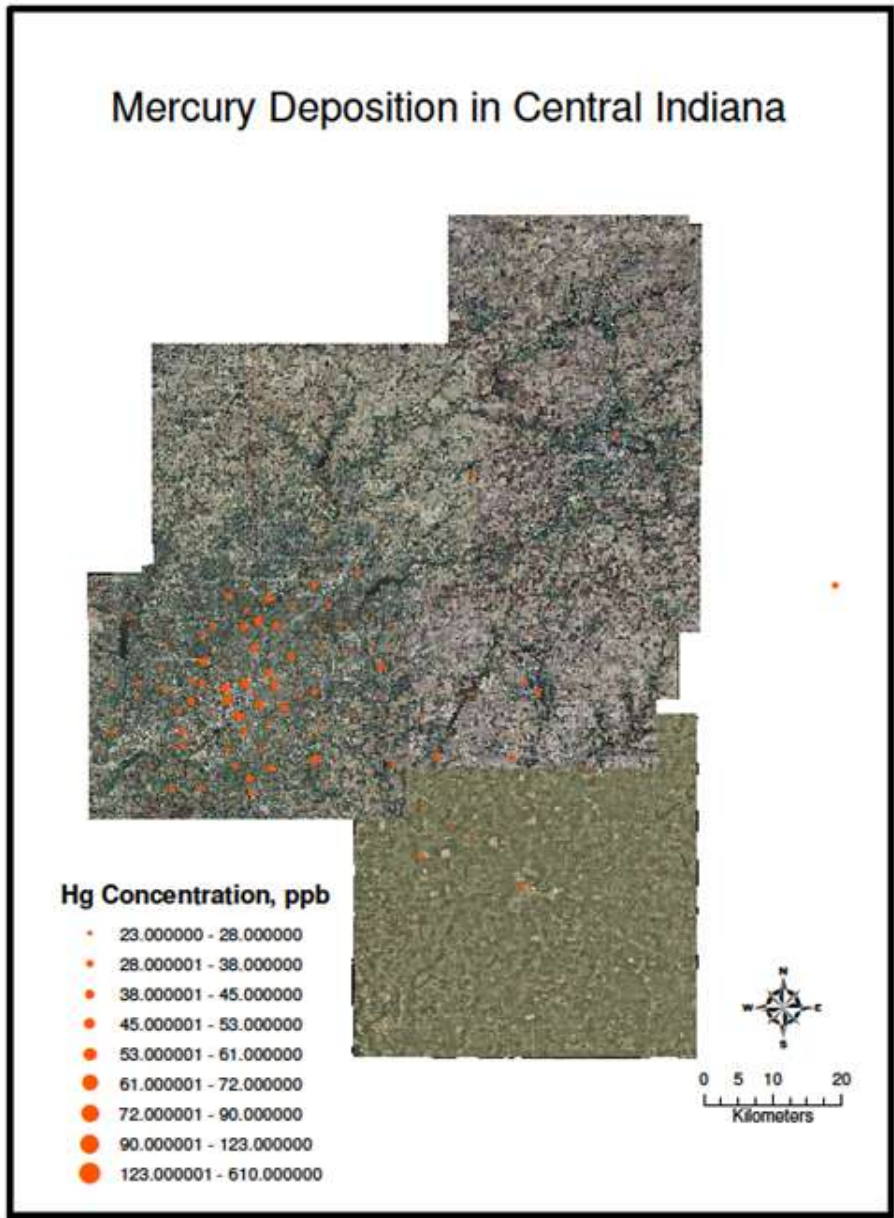
Figure 5. Map of study area, sample sites and corresponding Hg soil concentrations. Wind rose is provided in upper left-hand corner.
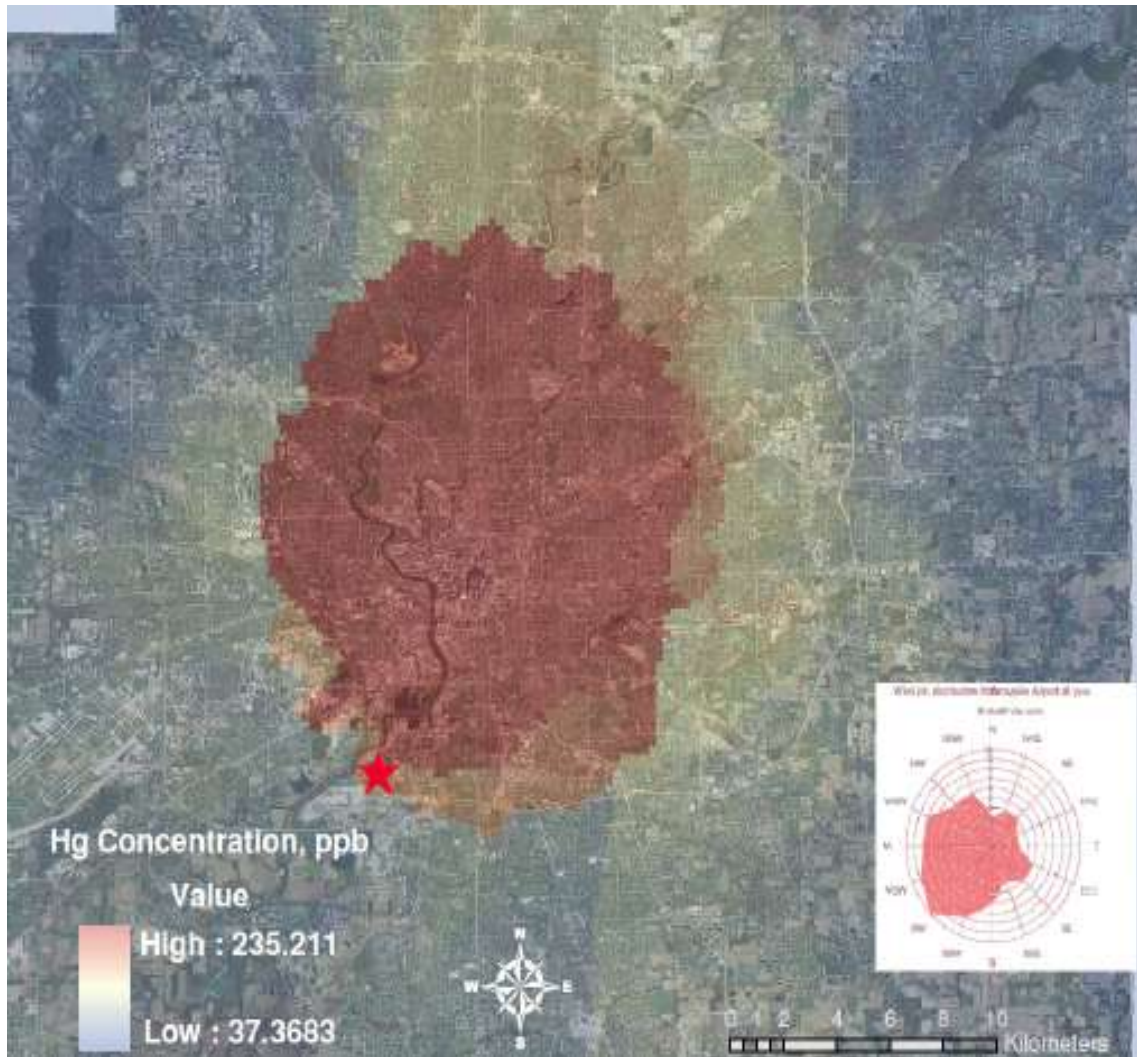
Figure 6. Aerial map of Marion County with ordinary kriging applied to sample Hg concentration data; wind rose map is inset.
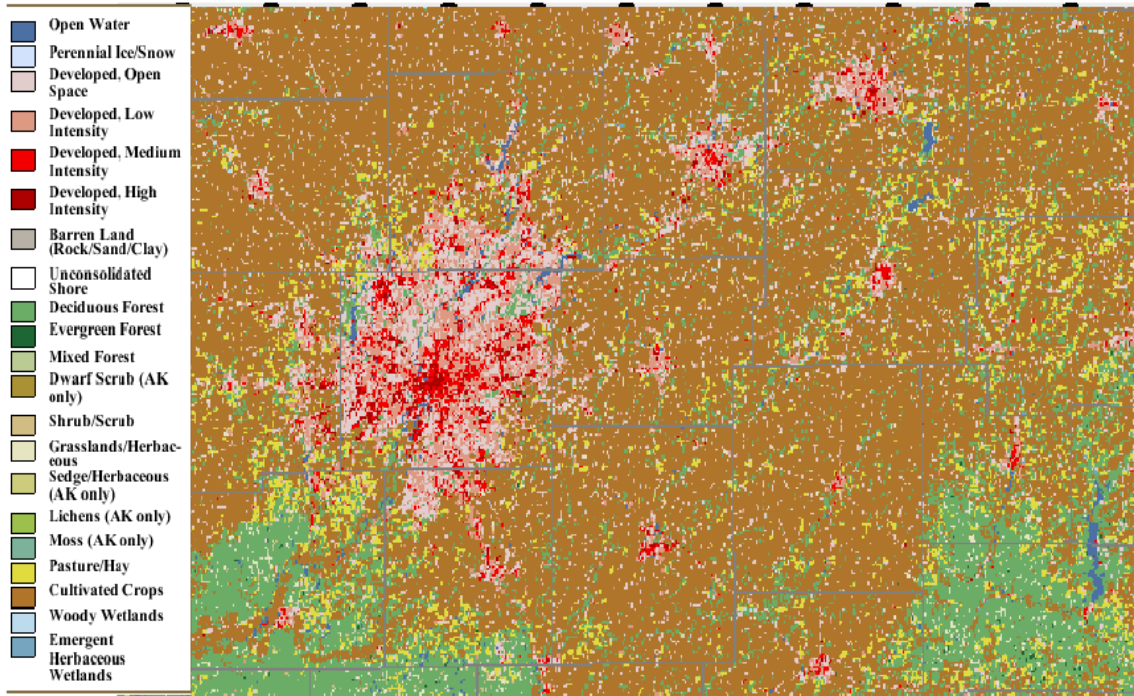
Figure 7. Multi-Resolution Land Characteristics Consortium's (MRLC) National Land Cover Database (NLCD) 2006 version provided by the USGS.
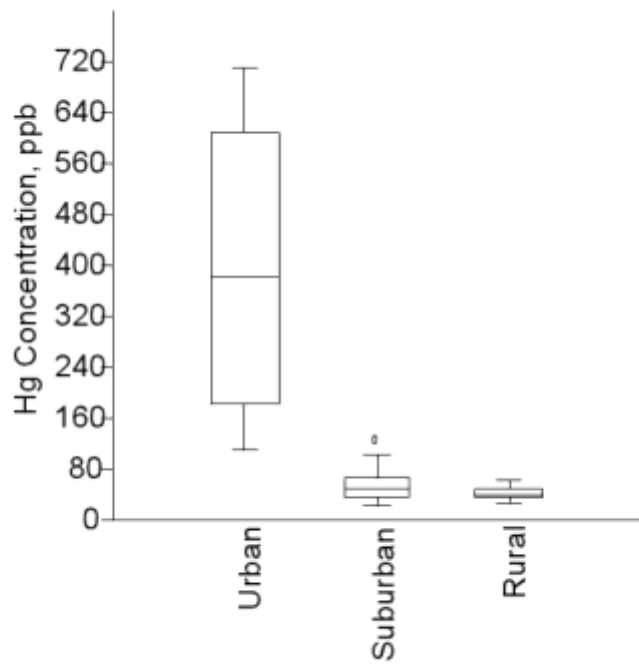
Figure 8. Box plot comparing urban, suburban, and rural land use total Hg concentrations.

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CURRICULUM VITAE
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EDUCATION
- BA in Geology – December, 2008
  Indiana University – Purdue University Indianapolis (IUPUI)
- MS in Geology – August, 2012
  Indiana University – Purdue University Indianapolis (IUPUI)
- 40-hour HAZWOPER certification – September, 2011
- Licensed Asbestos Inspector (AHERA) – June 2012
- Licensed Radon Measurement Provider (NEHA) – June 2012

RELEVANT COURSES
• Sedimentology and Stratigraphy
• Structural Geology
• Mineralogy
• Petrology
• Geochemistry/Biogeochemistry
• Clay Mineralogy
• Geographical Information Science
• Chemistry
• Remote Sensing

WORK EXPERIENCE
Field Geologist (2011-Present)
Robert Walker, ATC Associates, Inc., Indianapolis, IN
• Phase I environmental site assessments
• Phase II activities
• Oversee Geoprobe$^{©}$ drilling activities
• Oxygen releasing compound injections
• Soil sampling and characterization
• Quarterly groundwater sampling
• Quarterly monitoring reports

Adjunct Instructor (2011)
Althea Roberson, Harrison College, Indianapolis, IN
• Instruct one online and one class-based 4 credit hour environmental science course
• Create lesson plans, activities, quizzes, and tests
• Attend staff meetings and training sessions
• Grade all assignments, tests, etc.
• Timely submission of attendance and grades into online grade book

GK-12 Urban Educator (2010-2011)
Dr. Lenore Tedesco, CEES/IUPUI, Indianapolis, IN
• Mobile technology trailer
• Created middle/high school air quality program
• Environmental educator of middle and high school students

Instructor (2009-2010)
Dr. Gabriel Filippelli, IUPUI, Indianapolis, IN
• Instructed two semesters of a one credit hour college environmental geology laboratory
• Designed lesson plans, lab activities, and homework assignments
• Created power point lectures to follow lab book
• Wrote quizzes, midterms, and final exams
• Evaluated and assessed students' performance

Research Assistant (2007-2009)
Dr. Gabriel Filippelli, IUPUI, Indianapolis, IN
• Mercury distribution in Indianapolis
• Collected surface soil and river sediment samples
• Analyzed samples with LECO AMA
• Normalized data for placement in CAD models
• Performed strong acid digestions

Research Assistant (2007)
Drs. Kathy Licht and Jeff Swope, IUPUI, Indianapolis, IN
• Researched provenance of glacial till in Antarctica
• Identified hand specimens
• Constructed thin sections from specimens

ACTIVITIES
• Member of the Geological Society of America
• MURI (Multidisciplinary Undergraduate Research Initiative) Scholar
• Member of Sigma Alpha Pi, the Society of Success and Leadership
• Member of IUPUI's Student Organization of Alumni Relations
• GK-12 Urban Education Fellow (Discovering the Science of the Environment – DSE)