A COMPARISON OF FACTORS AFFECTING THE SMALL-SCALE

DISTRIBUTION OF MERCURY CONTAMINATION IN A ZIMBABWEAN

STREAM SYSTEM

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by

Corey S. Green

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APPROVED:

Monte L. Thies, PhD
Thesis Director

Patrick J. Lewis, PhD
Committee Member

Jeffrey R. Wozniak, PhD
Committee Member

John B. Pascarella, PhD
Dean, College of Science & Engineering
Techonology

ABSTRACT

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Artisanal small-scale mining (ASM) operations use mercury liberally in the gold extraction process, as compared to large scale industrial mining operations, and accounts for approximately one third of anthropogenic mercury consumption worldwide. These ASM operations are concentrated in many impoverished and poorly regulated countries such as Zimbabwe, resulting in a number of negative environmental and health impacts. There are three pathways by which mercury generally enters the environment from gold mining: 1) directly via private miners, 2) through stamp mill operations (also used by ASM miners), and 3) industrial-scale mining operations. To examine the levels of mercury contamination resulting in one such geographic locality, sediment and tailing samples in a single, heavily mined watershed in southern Zimbabwe were collected from May – June 2015. Samples were collected from the stream system, as well as six stamp mills and a single industrial mine in the watershed. GPS point location data were taken for mining operations and sampling sites to examine the spatial patterns of mercury concentration relative to each mining operation. Data were first analyzed using linear regression then a MARS model, followed by application of an ANCOVA model to assess the relationship between mercury concentrations and three factors; percent organic carbon, distance downstream, and distance from potential contamination source. Mercury concentrations within the study area ranged between 6-1,541 µg/kg dw (mean 142 µg/kg dw). Analyses of mercury concentrations indicated a positive relationship with percent organic carbon and a negative relationship with distance downstream and distance from

potential contamination source. Results from this study will help to elucidate the relationship between gold production and the spatial scale of mercury contamination in aquatic ecosystems in Africa. These data may lead to a better understanding of the relationship between mercury use and community health, which may aid both the local and global communities in regulating mercury contamination of the environment, thereby reducing the suffering and early death of many people in impoverished countries where ASM is commonplace.

KEY WORDS: Artisanal Small-Scale Mining, Mercury, Zimbabwe

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Figures   **Page**

CHAPTER I

INTRODUCTION

1.1 Mercury in Mining

Mercury has been used in the gold extraction process for thousands of years. Earliest examples date back to 2,700 B.P. when the Phoenicians and Carthaginians first used mercury to concentrate precious metals such as silver and gold (Lacerda and Salomons 1998). The primary application for mercury in mining comes from the formation of an amalgam when it is combined with other metals (Veiga et al. 2006). This property of mercury is especially favorable when collecting fine particles of precious metals from a large amount of crushed ore. Historically, copper plates would be coated with mercury and the finely crushed ore would be sifted over them. An amalgam would form, leaving the particles of precious metals bound to the mercury. The amalgam was then scraped off the copper plates and heated, releasing the mercury through volatilization and leaving behind the precious metals.

Although the use of mercury in large-scale mining operations has largely been eliminated, the practice has persisted in small-scale artisanal mining (ASM), which accounted for 37% of mercury emissions in 2010 and 24% of mercury demands in 2011 (UNEP 2013). According to the Communities and Small Scale Mining Initiative, ASM represents small to large mining activities that are distinguished from formal mining by a low degree of mechanization, high labor intensity, poor occupational and environmental health standards, little to no capital investments, and a lack of long-term planning (Hinton 2006). For the purposes of this study, ASM will refer to individuals or small groups of individuals that follow these guidelines with a particular emphasis on the lack of

mechanization. Industrial mining operations are regarded as any mining practices that do not fall under the definition of ASM. Both ASM and some smaller industrial mines in many African countries still use mercury in the amalgamation process to extract gold (Veiga et al. 2006).

To effectively extract gold from ore, the surface area of gold particles within the ore must be increased. To do this, raw ore is put through a refinement process which crushes ore into particle sizes as small as possible, effectively increasing the surface-to-volume ratio and exposing as much gold to the amalgamation process as possible. How ore is refined can depend on region, financial means of miners, or what is available. In southern Africa, ore is typically refined using stamp mills, ball mills, gyro mills, or any combination of the three (Shoko and Veiga 2003, Spiegel 2009a). While most industrial mines have their own mills, ASM miners by definition do not have mechanized milling equipment and are forced to either refine ore by hand or bring their ore to milling centers where they can pay a fee to have their ore refined for them (Shoko and Veiga 2003).

There are several methods available to extract gold from ore including mercury amalgamation, carbon-in-pulp cyanide processing, and others. Mercury amalgamation has remained as the primary means of gold extraction for ASM miners due to its ready availability, low cost, and the relative quickness of the gold extraction. The gold extraction process typically takes place after the refinement process has been completed. The exception to this is in Zimbabwe, where miners have been reported to add mercury to unmanipulated ore before the refining process has begun (Viega et al. 2006). ASM miners typically have two choices for refinement after ore has been extracted; they can refine their ore themselves using crude methods such a metal pole to crush ore against

another rock or they can take their ore to privately owned milling centers which charge miners a fee to refine their ore. Milling centers are typically much more mechanized and can produce a particle size considerably smaller than what an ASM miner could produce on their own. This difference in refinement quality is enough that the majority of ASM miners choose to have their ore refined at these centers. Once refined, ore can be amalgamated in a variety of ways but the two most common are (1) to cover metal sheets rubbed with cyanide tablets with mercury and to allow refined ore to flow over the top of the mercury, or (2) to take refined (usually concentrated) ore in a small open container where mercury is added and rubbed into the ore by hand. The first method requires considerably more equipment and resources but can process larger volumes of ore at once, and is therefore favored by industrial mining operations or some milling centers. The second method requires little other than refined ore, a container, and mercury. This does not allow for a large amount of processing capacity but is ideal for ASM miners who have limited access to money and resources and who only process small amounts of ore at a time.

ASM miners are encouraged to do any amalgamation at the milling sites where their ore was refined. Miners take what gold they are able to recover in the amalgamated form, but any ore left-over after the refining and amalgamation process, known as tailings, are left at the mill sites where the millers will then extract any remaining gold using cyanide vats. Only about 30% of gold is able to be extracted from ore via mercury amalgamation (Veiga et al. 2006). The remaining 70% is extracted using a cyanidation process. This is where mill operators make the majority of their money. Industrial mining operations primarily rely on the cyanidation processing for gold extraction. Some mines

may use mercury amalgamation for small portions of ore with high gold concentrations but any resulting tailings are added to the rest of the refined ore for cyanide extraction.

1.2 Mercury in the Environment from Mining Activities

Depending on refinement techniques, amalgamation processes, and whether miners use mercury recovery equipment such as retorts, as little as 50% of the mercury used in the amalgamation process is recovered (Cordy et al. 2011). Global estimates of 1-2 grams of mercury are lost for each gram of gold produced (Veiga and Baker 2004, Spiegel and Veiga 2005, Spiegel 2009a, Spiegel 2009b, Spiegel and Veiga 2010). When miners do not use a retort, the majority of unrecovered mercury is released to the atmosphere during the volatilization process (van Straaten 2000, Velásquez-López et al. 2011), which is also regarded as the primary source of mercury exposure to ASM miners (Veiga and Baker 2004). Unfortunately, this mercury loss is difficult to trace within the environment due to multiple factors, including variability in wind conditions and deposition rates of mercury vapors. The second highest and most consistent source of mercury contamination from ASM is through tailings (Veiga and Baker 2004) with reports as high as 46% of mercury being lost to tailings (Cordy et al. 2011). Although most of the mercury forms an amalgam with any gold particles it comes into contact with, a small amount of mercury is bound to ore that it comes into contact with, and is then discharged into the environment with the discarded tailings.

How much mercury is lost to tailings depends on the region and methods used for amalgamation. In Ecuador, Velásquez-López et al. (2010) reported an average loss of 1.4% of mercury through tailings when it was used to amalgamate concentrated ore, and an average loss of 15% when the ore was not concentrated before amalgamation. In a

similar study, Velásquez-López et al. (2011) reported an average loss of 11.2% of mercury to tailings after non-concentrated ore was amalgamated and underwent carbon-in-pulp (CIP) cyanidation. In Zimbabwe, Metcalf and Veiga (2012) estimate a loss of up to 66% of mercury to tailings before cyanidation. In Kenya, Ogola et al. (2002) reported a loss of 40% of mercury to tailings and Cordy et al. (2011) reported a loss of 46% to tailings in Colombia.

Mercury within sediments and tailings is primarily associated with a fine particle size (<63 μm), which is largely dependent on water action for mobility (Pestana et al. 2000, Fernández-Martínez et al. 2006). In addition, mercury is most dangerous when it is within an aqueous environment where it can then be methylated to form methylmercury (Ullrich et al. 2001). Numerous studies have documented mercury's ability to enter aquatic systems from ASM sites (Ikingura and Akagi 1996, Male et al. 2013, Tomiyasu et al. 2013, Ngure et al. 2014, Niane et al. 2014, Pinedo-Hernández et al. 2015). Once mercury has entered aquatic systems, downstream travel distances and elevated mercury levels have been reported to range from 4 km at recent mining sites (van Straaten 2000a) to 20 km at historic mercury mines (Tomiyasu et al. 2012) downstream from point sources. Mercury has also been shown to have a strong positive association with organic carbon, which can affect its dispersion within stream systems by allowing pockets within these systems with high organic carbon to act as reservoirs for mercury (Guedron et al. 2009, Tomiyasu et al. 2012, Tomiyasu et al. 2013, Pinedo-Hernández et al. 2015).

Previous studies have also shown that if mercury is present in sediments it will be present in the water column (Ribeyre and Boudou, 1994, Tessier et al., 2007). While mercury has been shown in laboratory experiments to be found primarily in sediment

layers within aquatic systems (Tessier et al. 2007), studies within controlled natural water

systems have demonstrated similar relationships between sediments and the water

column (Rudd et al. 1983). While only a few distances were reported, Lacerda et al.

(1991) demonstrated that soil mercury concentration was positively correlated with

proximity to tailing piles at a mine in Pocone, Brazil, and van Straaten (2000a)

demonstrated similar results in Tanzania and Zimbabwe.

1.3 Health

The World Health Organization (WHO) lists mercury as one of the top 10

chemicals or groups of chemicals of major public health concern. The WHO established a

maximum allowable ingestion level of 2.0 µg/kg body weight per day for healthy adults

in order to remain without symptoms (WHO 2007). If these limits are exceeded, mild

symptoms may include tremors, insomnia, memory loss, neuromuscular effects,

headaches, and cognitive and motor dysfunction. If mercury blood concentrations

increase to a high enough level, symptoms can include nervous system toxicity, kidney

failure, and immune deficiencies (WHO 2003). Pregnant women and children are

especially vulnerable to mercury exposure (WHO 2007). Methyl-mercury that has

bioaccumulated in fish and then consumed by pregnant women can lead to birth defects

such as mental retardation, seizures, visions and hearing loss, delayed development,

language disorders, and memory loss (WHO 2003). Furthermore, children exposed to

methyl-mercury can develop a syndrome called acrodynia, which is characterized by red

and painful extremities (Gibb and O'Leary 2014). The environmental and health risks

associated with mercury make it an important environmental contaminant to know and

understand. The fact that mercury is primarily sourced anthropogenically also makes it

unique in that it is directly within our power to control. A better understanding of the relationship between mercury use and community health can not only help local communities but benefit the global community by alleviating the suffering and early death of many people in impoverished countries where ASM is commonplace.

1.4 Objectives/Hypotheses

The primary objective of this study was to determine the impact of various gold mining activities on mercury contamination in headwater streams in southern Zimbabwe that were directly associated with ASM. The region possessed a high density of mining activities including industrial mines, small-scale artisanal mines, and stamp mill processing centers. Although the contribution of mercury contaminants from these mining activities have been well documented in other systems, the small scale distribution, levels of contamination, and the subsequent fate of that mercury once introduced into a watershed is not well known. The research questions that guided this study were:

Q1) Does mining activity within this study system contribute to mercury contamination in adjacent streams?

> H1) I hypothesized that mining activities would serve as hot spots for mercury contamination and that mercury concentrations would be highest in stream locations closest to mining activities.

Q2) What is the downstream fate of mercury (e.g., concentration and distance) introduced into a headwater stream system?

H2) I hypothesized that mercury concentrations would decrease with increasing distance downstream and that local mercury contamination would not extend beyond 10 km.

Q3) Does percent organic carbon, distance downstream from contamination source, or position within the stream influence the distribution of mercury after it has been introduced?

H3) I hypothesized that percent organic carbon of sediments and distance from mining operations would be significant predictors of mercury distributions but that distance downstream alone would not.

CHAPTER II

MATERIALS AND METHODS

2.1 Study area

The study area was located 170 km southeast of Bulawayo, Zimbabwe and consisted of a single reservoir and four seasonally flowing streams that were subdivided into six segments for comparative analyses (Fig. 1). Six stamp mills and a single industrial mine, the Farvic Mine, were located within the study area.

Each stream and stamp mill within the study area was given a letter and number code to simplify references. The stream segments were labeled STR to denote stream, followed by a number 1-6 to denote segment. The stamp mills were all labeled with SM and individually number to differentiate them (SM-1, SM-2, etc.). The STR-1 stream segment began at the A6 highway and continues downstream 2 km to the southeast until it meets with the STR-2 stream. The northern end of this stream segment is the closest stream segment to SM-4 (~500 m) and SM-5 (~200 m), whose watershed flows directly into the stream on the northern side of the A6 highway. The STR-2 stream segment starts at the A6 highway, approximately 1.6 km east of STR-1 and continues downstream to the southwest 2.6 km where it is joined by the STR-1 stream. This stream is the closest to SM-2 (~100 m), with STR-1 being ~200 m away at its shortest distance. Stream segment STR-3 starts at the confluence of STR-1 and STR-2, and is a continuation of the same stream as stream segment STR-2. Stream segment STR-3 continues downstream to the southwest where it passes the Farvic Mine (~100 m) and SM-1 (~250 m) before it changes directions toward the southeast and ends at a reservoir directly south of the Farvic Mine for a total distance of 1.6 km. The reservoir is approximately 700 m directly

south of the Farvic Mine and is separated from the mine by a hill. Any water leaving the Farvic Mine would have to flow into the STR-3 stream segment before entering the reservoir. The STR-3 stream segment is the only inflowing stream source for the reservoir, which has an earthen dam at its southern end. All other sources to the reservoir are from surface water. This includes the southern slopes of the hill between the reservoir and Farvic Mine and the eastern slopes of a very large rocky outcropping directly to the west of the reservoir. The STR-4 stream segment starts immediately after the dam from the reservoir and continues south downstream for 1 km until it meets with the STR-6 stream segment. The first 600 m of this stream segment show evidence of remaining permanently dry. The STR-6 stream segment starts at the meeting point with the STR-4 stream segment and continues west upstream for 2 km. This stream segment has several indications of historic mining activity and potentially receives surface water from the southern slopes of the large outcropping where there are two very large tailing piles (~550 m from stream) from a historic mining operation at the summit of the outcropping. Stream segment STR-5 starts at the confluence of STR-4 and STR-6 and is a continuation of the same stream as stream segment STR-4. Stream segment STR-5 continues downstream to the south for 9 k. This stream is devoid of any known mining activity past 1 km from the starting location. With the exception of stream segment STR-6, which flows east, all other stream segments flowed in a southerly direction.
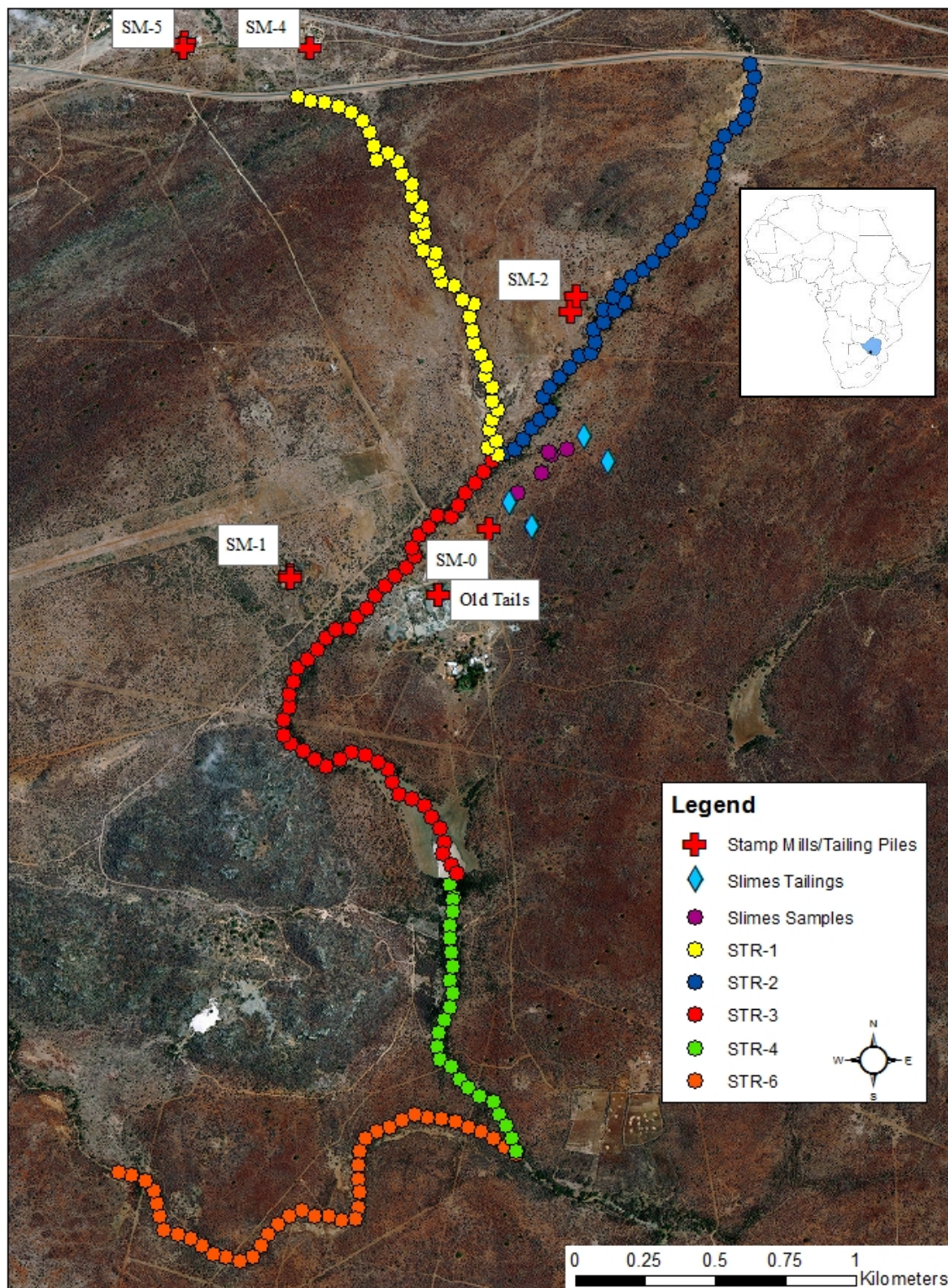
Figure 1. Study site in southeastern Zimbabwe. Stream segmentsare color coded and potential contamination sources are labeled.

2.2 The Farvic Gold Mine

Work in the Farvic Mine yields approximately 120 tons a day of ore 5 days a week from two subsurface shafts; the Prince Olaf and Farvic shafts. The Farvic Mine has an onsite milling and carbon-in-pulp (CIP) cyanidation facility. With the capacity to process 200 tons of ore per day, the facility also reprocesses residual tailing piles that were generated by mining operations from the 1970s that were refined to current standards for recoverable gold.

Ore is currently processed through a series of gyro mills followed by ball mills until a particle size of 75 μm is attained. Approximately 99% of this ore is sent directly into cyanide tanks; however, toward the end of the milling process a small portion (>1 ton/week) of gold-rich ore is separated using a centrifugal separator for mercury amalgamation. Mercury is added to a ball mill with the separated ore and is mixed for several hours before the ore is allowed to flow over a metal plate coated with cyanide and mercury. The mercury is then scraped off the plate and taken for volatilization using a retort. Tails and excess water from this process are collected in a cement basin at the end of the plate and added to the cyanide tanks. After tailings have been processes through the cyanide tanks, they are separated from the carbon pulp and pumped ~500 m away to a plastic-lined slimes tailing pit for final contained storage.

2.3 Geology and other mining activity

The Farvic Mine sits on the eastern edge of the Gwanda Greenstone Belt. Greenstone belts are mafic to ultramafic igneous rock formations that were generally formed between granitoids and gneiss formations. Due to the composition of these belts and the conditions of their formation, they often contain higher concentrations of gold.

For this reason, mining activity in the area surrounding the Farvic Mine has historically been very high. The area is covered with abandoned mining operations from the early 1900s, many with accompanying ruins from miners' houses, cyanide tanks, and equipment houses. The Farvic Mine remains as the only industrial scaled mining operation in the immediate area, but local artisanal small-scale miners are currently utilizing many shafts from abandoned operations. In addition to old shafts, the owner of the Farvic Mine leases 1 m x 1 m surface plots to individual miners in two separate locations, the first on the back side of the hill where the slimes tailing pile is located, and a second location ~1 km to the west of the Farvic Mine. The miners who lease these plots are encouraged to bring their ore for processing at a stamp mill adjacent to the Farvic Mine, where they will also do the amalgamation for them. However, there are four other stamp mills within a 2.5 km radius of the Farvic Mine where many miners take their ore (Fig. 1). These stamp mill operators encourage miners to do their amalgamation on site; however, whether the miners perform amalgamations at their mining sites or at the stamp mills is not well known. When the amalgamation is done at a stamp mill, it is usually done by pouring mercury into a plastic container with ore that has been processed and concentrated. A plastic cap or a bare hand is used to close the container, which is then shaken for a period of time to forcibly mix the mercury with the ore until an amalgam is formed. The resulting amalgam is then often placed in and open container and heated over an open flame, allowing the mercury to be volatized directly into the open air.

All stamp mills in the area are operated in the same manner in that miners are allowed to keep whatever gold they are able to take away through the amalgamation process, but tailings are left for the stamp mill operators to process further. The tailings

from the stamp mill adjacent to the Farvic Mine and a smaller stamp mill north of the
Farvic Mine are taken to the Farvic Mine for cyanidation. The other stamp mill locations
have their own cyanide tanks where the tailings left by local miners are processed. With
the exception of the stamp mills served by the Farvic Mine, tailings from both before and
after cyanidation are stored in piles at the stamp mill locations. Even with the stamp mills
serviced by the Farvic Mine, tailings may be left for several weeks before they are
collected and transported to the mine's processing facilities.

2.4 Sample collection

Sediment samples (50 g; ≤5 cm deep) were collected using a trowel and placed in
appropriately labelled polypropylene whirl bags. All sediment samples, with the
exception of the STR-5 segment samples, were taken at 50 m intervals along streambeds
at the lowest point in the stream basin. Sampling was begun at the furthest point
downstream in the stream segment and continue upstream to avoid contamination from
any disturbed sediments that may have flowed downstream from preceeding sampling
activities. Sediment samples from the reservoir were taken every 50 m along the central
channel. Care was taken to avoid disturbing sediments on the bottom of the reservoir
when collecting samples to avoid cross contamination from different collecting sites.
Samples from stream segment STR-5 were taken every 1 km up to 10 km downstream.
Sampling started at the furthest location downstream and proceeded upstream to the
reservoir, again to avoid possible contamination from any disturbed sediments flowing
downstream from previous sampling efforts. GPS coordinates were recorded for all
sample locations. Samples were stored in labelled polypropylene whirl bags without any
preservation treatment other than by refrigeration when available.

2.5 Mercury analysis

Samples were transported to the University of Michigan Biological Station for analyses. In preparation for analysis, all sediment samples were freeze dried to eliminate moisture. Subsamples of the original samples were first analyzed for mercury content using a direct mercury analyzer (Milestone Inc., Shelton, CT; DMA-80) following USEPA method 7473 (USEPA 2007). Sediment samples were then sifted to a <63 μm particle size and reanalyzed to isolate sediment particles most commonly associated with accumulated mercury (Fernández-Martínez et al. 2006). Remains of the <63 μm particle portion from each sample were used to determine percent organic carbon using loss on ignition (LOI$_{550}$). Samples were placed in crucibles and dried at 105°C for 4 hours before being weighed. Samples were then heated to 550°C for 15 hours and reweighed to determine the difference in sample weights before and after heating to volatolize organic carbon. Differences between weights before and after heating to 550°C were used to determine percent organic carbon in each sample. Mercury concentrations were directly exported into an Excel spreadsheet from the DMA-80 and reported in μg/kg dry weight.

2.6 Data analysis

Data were parsed based on the six stream segments already described (STR-1, STR-2, STR-3, STR-4, STR-5, and STR-6). Within each of these stream segments, a running mean was calculated using overlapping subsets of three sample locations. The values generated by the running means within each stream segment were used for all subsequent analyses. A linear regression analysis was first used to compare mercury concentrations within each stream segment with the three predictor variables: distance from potential contamination source, percent organic carbon, and distance downstream.

Distance downstream was determined by assigning the furthest up-stream data point within each segment 0 m, the second 50 m, the third 150 m, the fourth 200 m and so on until all points within each stream segment had an assigned distance value. Distance from potential contamination source was calculated using ArcGIS. The straight line distance between each data point and the closest potential contamination source to that point was used. If at its closest point to a stream segment a potential contamination source was more than 300 meters from that segment it was not considered to be a potential contamination source for any points within that segment. Once assessed individually, data from all stream segments were combined for additional linear regression analyses of mercury concentrations and predictor variables. A Pearson Correlation was then used to assess correlations among the combined data for mercury concentration and predictor variables.

A multivariate adaptive regression splines model (MARS, Friedman 1991) model was used to delineate sub-segments within each stream segment based on mercury concentration and distance downstream data. MARS is a nonparametric regression analysis that does not require any assumptions about relationship among independent and dependent variables, thereby allowing it to characterize relationships that normal linear models cannot (Balshi et al. 2009). The MARS model works by breaking independent variable data into sub-sets within the full data range at points known as "knots" (Friedman 1991). The model then fits linear segments, known as piecewise linear basis functions, between knot locations. The slopes of these linear segments are allowed to vary, ensuring that the full fitted function is without breaks or sudden steps (Elith and Leathwick 2007). The model is then fit using a series of forward passes that identify knot

locations, followed by backward pruning routines that eliminate any non-essential knot locations. Whether a knot is fit or pruned is based on changes in residual squared errors using generalized cross-validation (GCV, Friedman 1991).

Once each stream segment was separated into sub-segments, a one-way analysis of covariance (ANCOVA) was applied to examine each stream segment. Stream segment and sub-segment delineators were used as fixed factors and distance downstream, distance from potential contamination source, and percent organic carbon were used as predictor variables. Mercury concentration was used as the dependent variable.

CHAPTER III

RESULTS

A total of 211 samples were collected throughout the watershed system between stream segments and potential contamination sources. These samples yielded 206 data points after running means were calculated for stream segments (Fig. 2, Table 1). With the exception of STR-4 (21 data points) and STR-5 (8 data points), each stream segment had a similar length and number of data points (1,950-2,250 m: N=39-45). All stream segments also shared a similarity in mean percent organic carbon (5.280% ±1.974). Beyond these, stream segments varied in mean mercury concentration, high and low mercury concentrations, and mean distance from potential contamination sources. Samples collected from potential contamination sources had mercury concentrations across the board much higher than any of the stream segments. For stream segments STR-1, STR-2, and STR-3, the primary potential contamination sources of mercury appears to be the stamp mills or industrial mining. For segments STR-6, STR-4, and STR-5, the primary potential source of mercury contamination was attributed to artisanal small-scale miners.

Mercury concentrations varied greatly from stream segment to stream segment as distance downstream increased (Fig. 3). Stream segments STR-1, STR-4, and STR-5 all demonstrated elevated mercury concentrations at the beginning of the segments, with a general decrease of concentration as distance downstream increased; however, starting and ending concentrations varied greatly among segments.
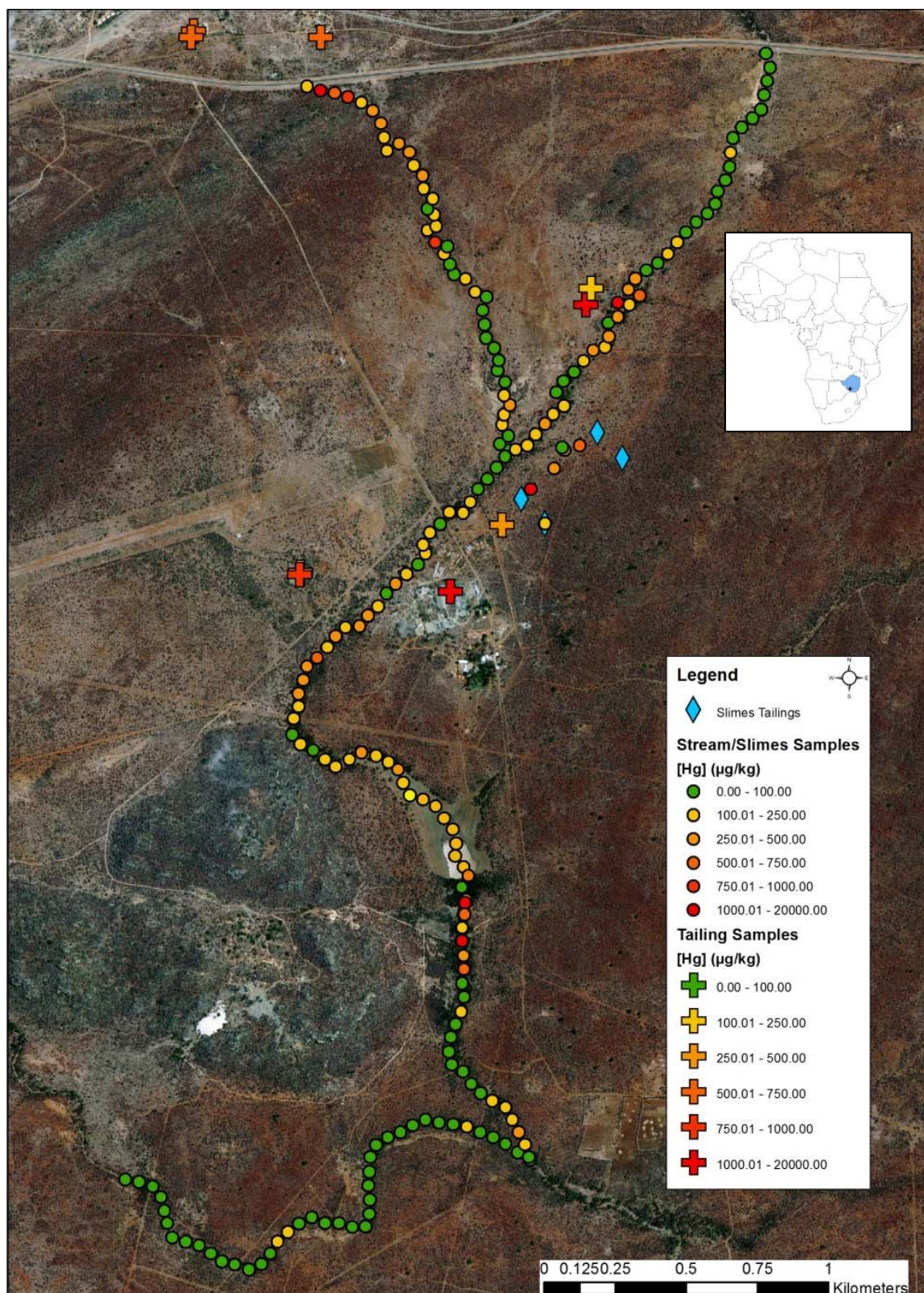
Figure 2. Sample locations for this study, with corresponding mercury concentrations [Hg] (µg/kg dw).

Table 1. Initial results from mercury concentration analysis from sediment and potential contamination

Stream Segment	N	Mean [Hg] (µg/kg)	[Hg] STD	High [Hg] (µg/kg)	Low [Hg] (µg/kg)	Mean Dist Dwn (m)	Mean Dist Src (m)	Dist Src STD	Mean %OC	OC STD
STR-1	39	252.270	304.014	1540.227	39.925	1000	1180	570.088	6.906	5.213
STR-2	38	178.864	191.616	816.854	5.725	975	501	301.054	3.356	1.505
STR-3	45	222.169	93.322	430.509	70.240	1150	584	427.865	3.993	2.052
STR-4	21	316.328	320.767	936.199	24.029	502	40	40.641	5.456	0.990
STR-5	8	43.315	33.629	104.047	21.145	5648	4775	2449.490	6.502	0.635
STR-6	39	62.266	23.733	96.626	11.957	1000	131	99.523	5.463	1.450
SM/Tailings	16	1362.191	2967.381	12269.590	157.389	-	-	-	1.935	0.860
Total	206	280.805	3.034	12269.590	5.725	1171	713	1200.935	4.820	3.034

Figure 3. Mercury concentrations in stream sediments [Hg] (µg/kg dw) as distance increases downstream (m) in stream segments STR 1-6.

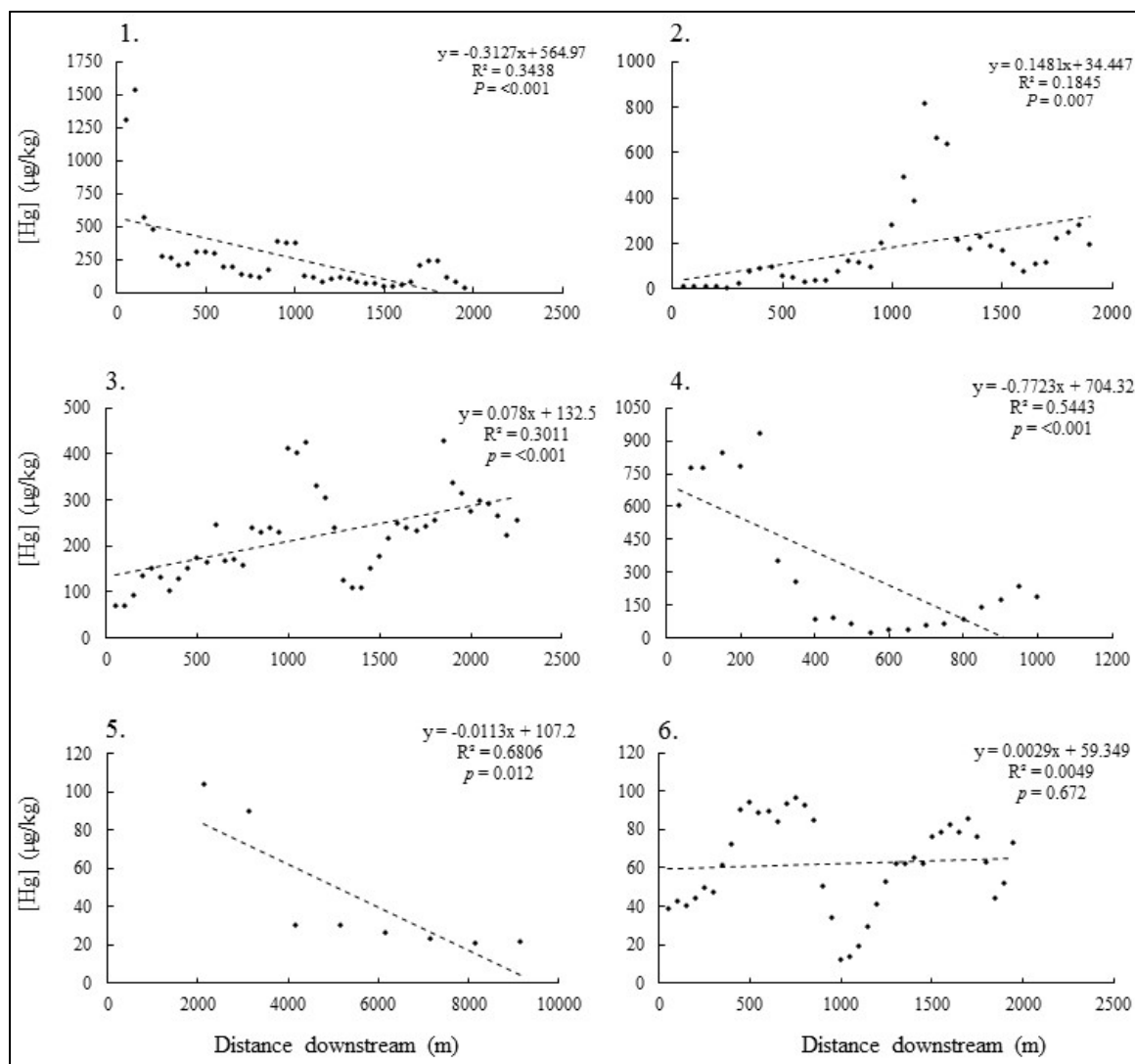The remaining stream segments displayed a series of peaks at some distance downstream. Segment STR-2 had a single large peak at a distance of 1150 m, segment STR-6 had two main peaks at 500 m and 1500 m, and segment STR-3 had one at 950 m but also terminated with an increase in mercury concentration that may be interpreted as a second peak. These three segments also differed from the other segments in that mercury concentration generally increased as distance downstream increased.

Individual stream segments showed less variation when comparing mercury concentrations to distance from potential mercury contamination source (Fig. 4). With the exception of segment STR-3, all segments showed a negative relationship between mercury concentration and distance from contamination source. Segments STR-6 and STR-4 have considerably lower R^2 values (STR-6: $R^2 = 0.0129$, STR-4: $R^2 = 0.0392$) than the other segments, which was thought to be due to irregular artisanal small-scale mining activity as compared to that of stamp mills or industrial mines. Segment STR-3 was the only segment to exhibit a positive relationship between mercury concentration and distance from contamination source. Segments demonstrated similar variance when comparing mercury concentration with percent organic carbon (Fig. 5). A positive relationship was found between mercury concentration and percent organic carbon for segments STR-1, STR-2, and STR-3, whereas a negative relationship was determined for STR-6, STR-4, and STR-5. Segment STR-1 had three data points with percent organic carbon values above 20%, two of which were considerably higher than all other data points.
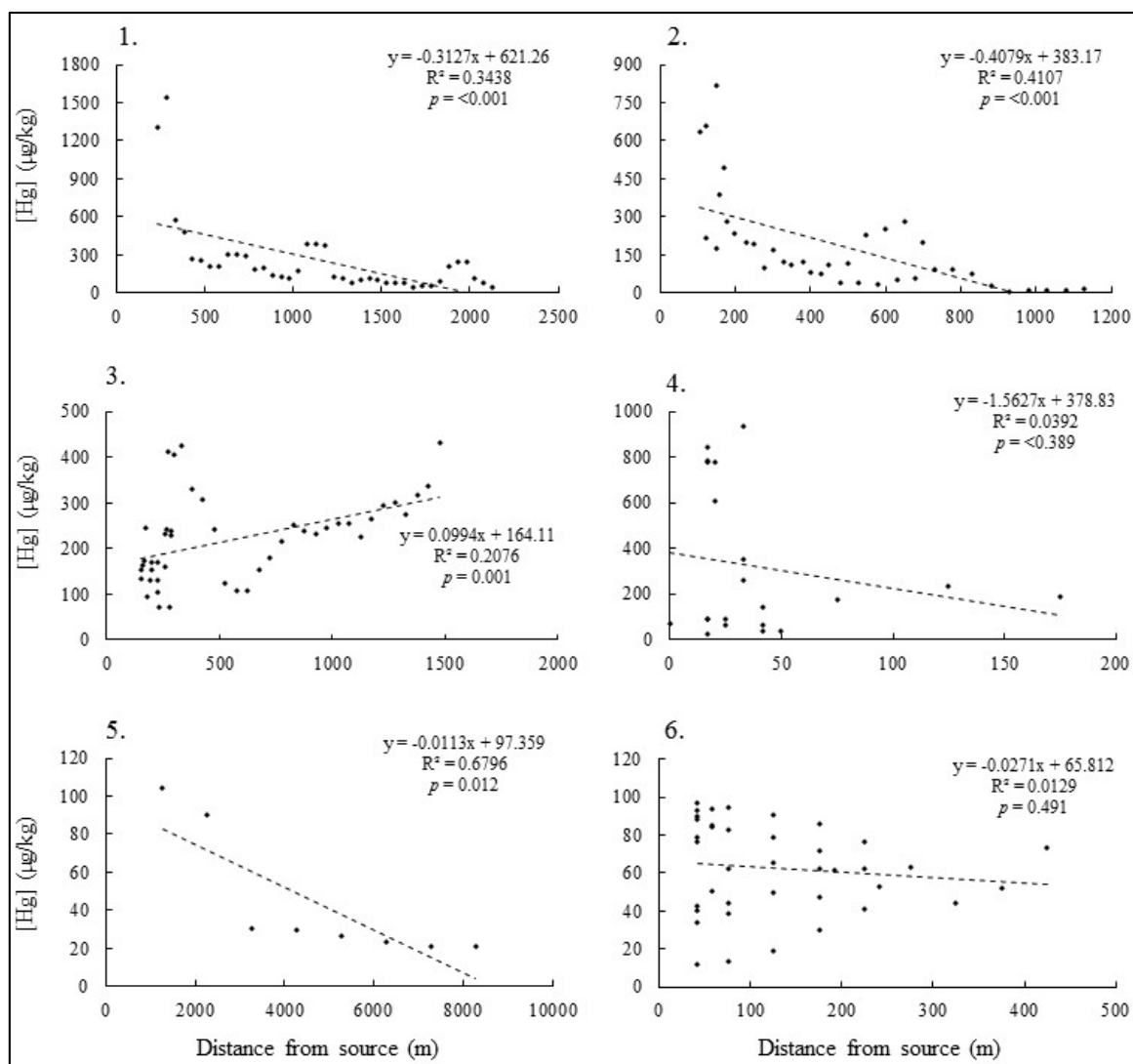
Figure 4. Mercury concentration [Hg] (µg/kg dw) as distance from contamination source (m) increases in stream segments STR 1-6.
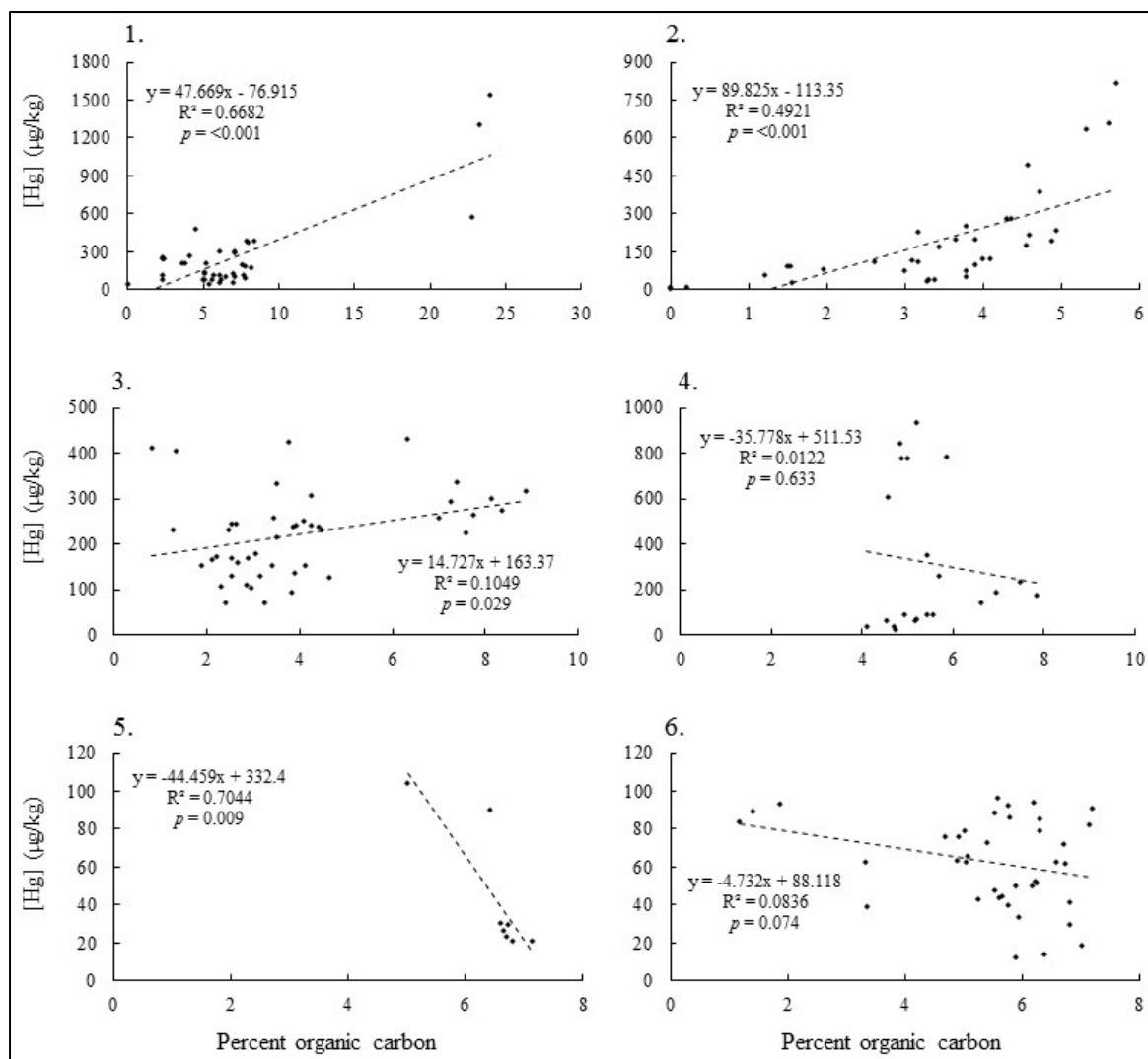
Figure 5. Mercury concentration [Hg] (µg/kg dw) as percentage organic carbon
increases for sediment samples within stream segments STR 1-6.

Table 2. Results of the Pearson Correlation test of relationships among the three variables examined.

	N	r-value	P-value
Distance downstream	190	-0.187	0.010
Distance from source	190	-0.169	0.020
Percent organic carbon	190	0.479	<0.001

If these points are removed from the linear regression, a positive relationship remains between mercury concentration and percent organic carbon, but the R^2 value is greatly reduced (slope = 8.694, $R^2 = 0.0253$).

All segment data for mercury concentrations against distance downstream, distance from contamination source, and percent organic carbon is combined in Fig. 6 for a visual comparison. Initial linear regression analyses of these combined data showed a negative relationship for mercury concentration with both distance downstream and distance from contamination source but a positive relationship for percent organic carbon. Results from the Pearson Correlation analysis show that mercury concentration is significantly correlated to all three covariates (Table 2). The Pearson Correlation also corroborates the nature of the relationship exhibited by the linear regression analysis for all three predictor variables. percent organic carbon shows the strongest correlation with mercury concentrations (0.479) followed by distance downstream (-0.187) then distance from potential contamination source (-0.169). When the three outlying data points that stood out in the percent organic carbon from segment STR-1 are removed from the combined analysis, the positive relationship is still maintained although the R^2 value is reduced (slope = 7.1118, $R^2 = 0.0065$).
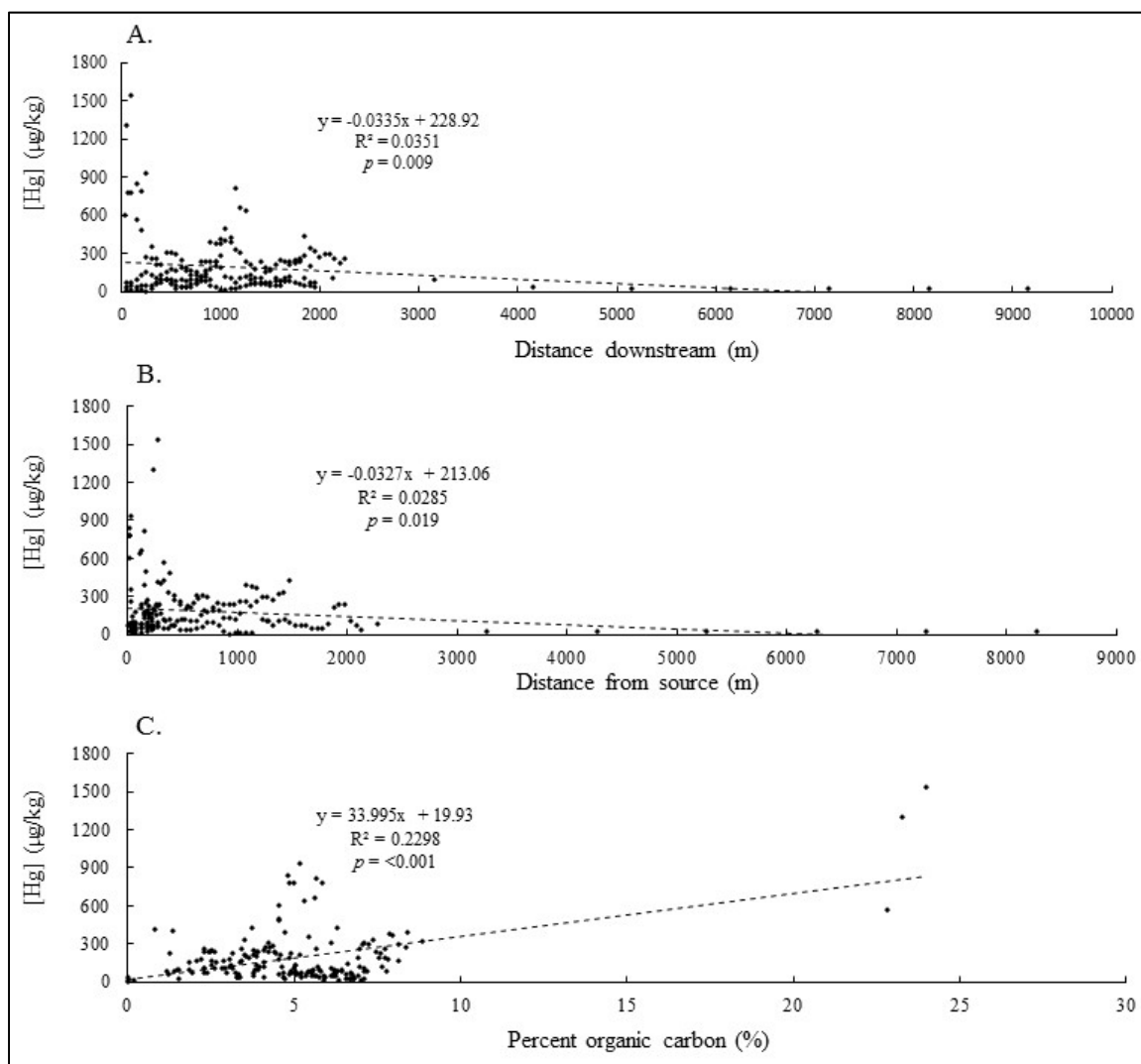
Figure 6. Data for all stream segments combined. A: Mercury concentration [Hg] (μg/kg dw) as distance downstream (m) increases. B: Mercury concentration [Hg] (μg/kg dw) as distance from potential mercury contamination source (m) increases. C: Mercury concentration [Hg] (μg/kg dw) as percent organic carbon increases.
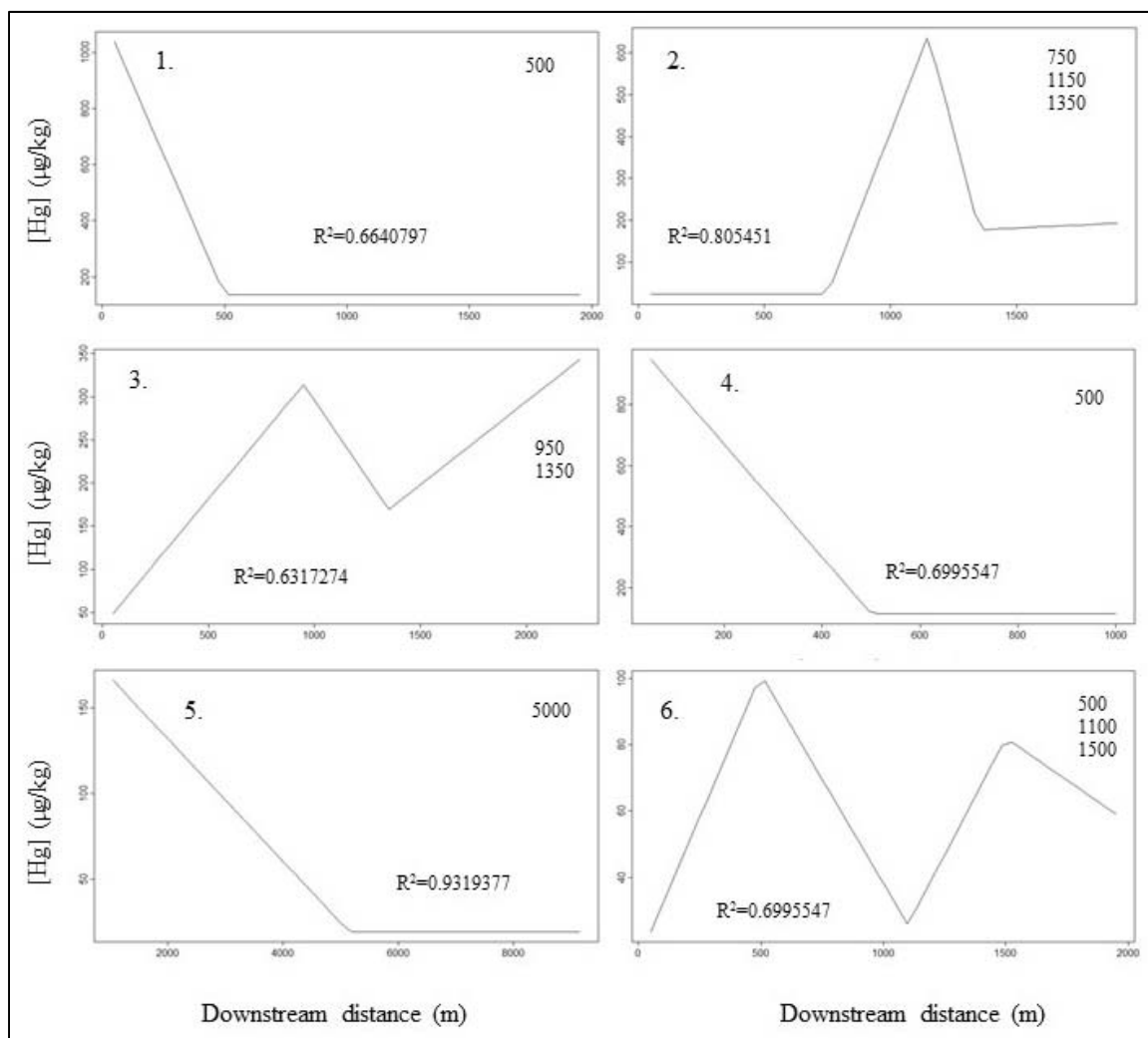
Figure 7. Results of MARS analyses for stream segments STR 1-6. Knot locations (in m) from the start of each of the stream segments are listed in the upper right corner for

Table 3. Results from one-way analysis of covariance (ANCOVA) model.

	Df	Mean Sq.	F value	P-value	Partial Eta^2
Distance downstream	1	98153.84	5.28	0.023	0.030
Distance from source	1	239190.05	12.87	<0.001	0.071
Percent organic carbon	1	2114801.97	113.79	<0.001	0.404
Stream segment	5	294065.96	15.82	<0.001	0.320
Sub-segment	3	177733.42	2.83	0.040	0.048
Error	168	18585.21			

The MARS analysis broke the six stream segments into a total of 17 sub-segments (Fig. 7). The number of sub-segments within each stream segment ranged from 2-4, depending on the variance within each stream segment. Knot locations between sub-segments correlate with peaks and troughs of mercury concentration as distance downstream increases within stream segment. All covariates assessed in the ANCOVA model have a significant effect on mercury concentration (Table 3). However, results from the partial Eta^2 test showed percent organic carbon to have the highest influence on mercury concentrations (0.404) followed by stream segement (0.320), stream subsegment (0.048), distance from potential contamination source (0.071), and lastly distance downstream (0.030).

CHAPTER IV

DISCUSSION

4.1 Background mercury concentrations

Background levels of mercury in soils and sediments can depend on the region, underlying geology, and what year samples were analyzed. Several studies have reported mercury concentrations for pristine soils and sediments (Ure and Berrow 1982, Lacerda et al. 1991, Biney et al. 1994, Filho and Maddock 1997, CCME 1999, Boszke et al. 2003, Guedron et al. 2009, Beal et al. 2013) (Table 4). Background mercury concentrations in soils have been reported to range from 10-500 μg/kg dw with the higher end of the range coming from organic carbon-rich tropical soils (Ure and Berrow 1982, Boszke et al. 2003, Guedron et al. 2009). Sediment analyses also demonstrated a variety in reported background mercury levels, although they remain generally lower than soils, ranging from 10 – 300 μg/kg dw (Lacerda et al. 1991, Biney et al. 1994, Filho and Maddock 1997, CCME 1999, Boszke et al. 2003, Beal et al. 2013). When looking specifically at background levels of mercury within sediments in regions near mining activities, Lacerda et al. (1991) found lacustrine background sediment mercury concentrations to be 20 μg/kg dw when studying mercury losses from mining activities near Pocone, Brazil. Filho and Maddock (1997) found background levels of fluvial sediments upstream of mining activities in the same region to be 100 μg/kg dw. These concentrations are similar to the mean concentrations across all of Canada reported by the Canadian Council of Ministers of the Environment (CCME) (1999) (74 μg/kg dw lakes; 75 μg/kg dw streams). With the similarities in reported background concentrations of mercury between sediments near mining activity and the mean concentrations across Canada, this study

will reference guidelines set by the CCME, which has set an interim sediment quality guideline at 170 µg/kg dw and a probable effect level at 486 µg/kg dw for freshwater sediments (CCME 1999). Any concentrations below 170 µg/kg dw will be considered below effect level.

Table 4. Reported ranges of background mercury concentrations (µg/kg dw) for studies both within and outside of the African continent.

Study	Reported Background Level of Hg (µg/kg)
Soils	
Ure and Berrow 1982	98
Boszke et al. 2003	10-200
Guedron et al. 2009	10-490
Sediments	
Lacerda et al. 1991	20
Biney et al. 1994	50-300
Filho and Maddock 1997	100
CCME 1999 (lakes)	74
CCME 1999 (streams)	75
Boszke et al. 2003	10-200
Beal et al. 2013	10-115

4.2 Mercury concentrations and distributions in sediments

Sediment mercury concentrations found within the study site (6-1,541 µg/kg dw; mean 142 µg/kg dw) fell within the range of mercury concentrations exhibited by similar studies both within and outside of Africa (Table 5). Although sediment concentrations from this study fell within reported ranges of other studies, they are consistently at the

lower end of ranges reported in other studies. This may be directly related to the concentrations of mercury found within potential mercury contamination sources from the study site being much lower than concentrations reported in other studies. Potential contamination sources, in the form of tailings, ranged between 157-12,270 µg/kg dw (mean 1,362 µg/kg dw) within this study area. Studies that have reported concentrations of mercury exposed tailings had a range of 940-5.0x10^6 µg/kg dw, with the majority of those concentrations falling above 1.0x10^5 µg/kg dw (van Straaten 2000a, Ogola et al. 2002, Ramírez-Requelme et al. 2003, Cordy et al. 2011, Leiva and Morales 2013, Male et al. 2013).

Mercury concentration in sediments generally declined as distance from potential contamination source increased, which is consistent with several other studies (Lacerda et al. 1991, Filho and Maddock 1997, van Straaten 2000a, Santos-Francés et al. 2001, Limbong et al. 2003, Lusilao-Makiese et al. 2013).

Table 5. Reported ranges of mercury concentrations (µg/kg dw) for similar studies near mining activities both within and outside of the African continent.

Location	Study	Hg (µg/kg)	
		Range	Mean
Zimbabwe	Green et al. 2017	6-12,269	280
Africa	van Straaten 2000	10-5,350	
	Ogola et al. 2002	1,540-4.22x10^5	8.8x10^4
	Durand 2012	30-237	94
	Lusilao-Makiese et al. 2013	46-2,316	973
	Ngure et al. 2014	510-1.83x10^6	
	Niane et al. 2014	20-9,930	3,962
Brazil	Filho and Maddock 1997	40-4,100	230
Colombia	Marrugo-Negrete et al. 2015	145-1,021	
	Pinedo-Hernández et al. 2015	196-1,188	524
Guyana	Howard et al. 2011	49-1,200	215
Indonesia	Limbong et al. 2003	0-2.0x10^4	
	Tomiyasu et al. 2013	93-8.52x10^4	
Spain	Nevado et al. 2003	520-1.005x10^6	

This trend was exhibited by all stream segments except for segment STR-3, which demonstrated a positive relationship between mercury concentration and distance from its closest potential contamination source. A possible explanation for this could be that, unlike the other stream segments, segment STR-3 terminated at a reservoir. While the reservoir itself is not in close proximity to mining activity and is sheltered from the industrial mine by a large hill, it does receive the outflow from stream segments STR-1,

STR-2, and the upper portions of STR-3, all of which receive much higher potential influx of mercury from contamination sources. Any contamination originating from an upstream source would be forced to flow downstream into the reservoir. Its earthen dam would not allow a downstream discharge of water unless water levels breached the dam. In addition to potential contaminants, the reservoir also acts as a trap for organic materials flowing down from upstream segments, further adding to mercury concentrations that are positively associated with organic carbon (Guedron et al. 2009, Tomiyasu et al. 2012, Tomiyasu et al. 2013).

Although mercury concentration data for stream segments exhibit a positive relationship when they are correlated with percent organic carbon, only half of the stream segments demonstrated a positive relationship when they are examined individually. Mercury concentrations from segments STR-6, STR-4, and STR-5 each displayed a negative relationship with percent organic carbon. Segments STR-6 and STR-5 also differ from other segments in that their mercury concentrations did not exceed 105 µg/kg, which is lower than CCME interim quality guideline of 170 µg/kg (CCME 1999). These data imply little to no influence from current potential mercury contamination sources as the majority of data points fall below background mercury concentrations. The more random distribution of mercury concentrations could be a remnant of historic mining operations or a result of atmospheric deposition from mining activities within the local region. In addition to organic carbon, mercury has also been shown to have a positive correlation with sediment particle size (Fernández-Martínez 2006, Guedron et al. 2009, Niane et al. 2014); iron and copper concentrations (Filho and Maddock 1997); and Al/Fe-(oxyhydr)oxides (Guedron et al. 2009). These factors were not measured in stream

segments during this study but could have possibly provided a better explanation for the distribution of mercury concentrations within them.

Segment STR-4 is unique in that local evidence suggests that the primary contribution of potential mercury contamination originated almost exclusively from artisanal small-scale mining. When sediment samples were being collected, staff from the Farvic Mine reported that the artisanal small-scale miners, or panners as they were known locally, did not use any mercury at their digging sites. Any ore that was excavated from surface dig sites was reportedly brought directly to stamp mill locations for refinement and any amalgamation. Analysis of sediment samples near dig sites in segment STR-4 strongly suggests that these reports are incorrect. The first 600 m of STR-4 was characterized by heavy artisanal small-scale mining activity. There were consistently between 10-20 dig sites within each 50 m sampling segment. Many of the sediment samples taken along this portion of the stream segment were taken directly from or adjacent to what appeared as tailing piles from dig sites. Analysis of these samples revealed highly variable levels of mercury concentration, with a range of 24.029 - 936.199 µg/kg dry weight. This suggests a number of scenarios, including the possibility that some artisanal small-scale miners are not using mercury at their dig sites while others are, samples were taken from a variety of tailing piles including tails that were not deemed worthy of processing using amalgamation, or some samples were taken from old tailing piles that have already been leached of what mercury they held. Regardless of which scenario is actually correct, the high variability in mercury concentrations and the consistency of processed tailings being present throughout the stream segment could explain the negative relationship between percent organic carbon and mercury

concentration seen in segment STR-4. If highly contaminated data points with mercury concentrations (>600 µg/kg) are removed, the remaining data exhibit a positive relationship between percent organic carbon and mercury concentration, with a greatly increased R^2 value (slope= 49.146, R^2= 0.3192).

Of the three predictor variables, distance downstream produced the most interesting results. This predictor variable accounts for the location of each sediment sample taken within stream segments. The variation among stream segments is best illustrated by Fig. 3 which shows mercury concentrations at their specific positions within each stream segment. The relationship between mercury concentration and potential mercury contamination source becomes more apparent as well. In stream segments STR-1, STR-4, and STR-5, the highest mercury concentrations are at the furthest points upstream, with a noticeable decline as downstream distance increases. For all three of these stream segments, potential contamination sources are closest to the points farthest upstream, resulting in the exhibited pattern. Stream segment STR-2 has one potential contamination source along its length. This source is closest to the sample taken at 1250 m downstream (106 m). Segment STR-2 has a large peak in mercury concentrations that begins upstream and ends downstream from this location as demonstrated in Fig. 3. According to the MARS model, the upward portion of the spike starts at 750 m, peaks at 1150 m, and ends at 1350 m before concentrations levels out for the remainder of the stream segment (Fig. 7).

Distributions of mercury concentrations are not so easily explained for segments STR-6 and STR-3. Both segments exhibit a positive relationship between mercury concentrations and downstream distance, with STR-6 having relatively low to no

influence from mining activities and segment STR-3 having potentially the greatest sources for mercury contamination of the entire watershed system. Linear regression analysis on segment STR-6 shows that while there is a positive relationship, it is a weak relationship (slope= 0.0029, R^2= 0.0049). As previously mentioned, segment STR-6 consistently has mercury concentrations at or below background levels, which suggest minimal influence from contamination sources. Despite this, segment STR-6 exhibits two noticeable peaks at 500 m and 1500 m. Evidence for artisanal small-scale mining activity was minimal along the length of STR-6 but there was activity at both of these sites. However, mining activity was also recorded at points along segment STR-6 where mercury concentrations where the lowest. With the inconsistent nature of artisanal small-scale mining and its contribution of mercury demonstrated in segment STR-4, it cannot be ruled out as a potential contributor to peaks in mercury concentration for segment STR-6.

Segment STR-3 shows a stronger positive relationship between mercury concentration and distance downstream than segment STR-6 after linear regression analysis (slope = 0.1481, R^2 = 0.3011). Segment STR-3 has one noticeable peak in mercury concentrations at 950 m, followed by a short decline until 1350 m, and then a steady increase until the end of the stream segment. The peak at 950 m is difficult to explain. It is not associated with a peak in percent organic carbon, nor is it closest to a potential contamination source and there are no predominant geomorphological features that could trap mercury at this location. The nearest potential contamination source is SM-1, which is 260 m north of the closest point in that stretch of stream. At 1450 m downstream, there is an old dam wall that has been partially destroyed to allow water to

flow past it. The peak of mercury concentration at 950 m may be the result of residual mercury built up when the dam was operational. Stamp mill 1 may be the closest potential contamination point, but the original tailing piles from the Farvic Mine are only about 100 m further away. The old tailing piles at the Farvic Mine date to the 1970s and have shown to contain a considerable amount of mercury (1463.134 µg/kg dw). The combination of a dam and mercury being released from the old tailing pile could have left a mercury footprint that has survived beyond decommissioning of the dam.

Despite the variation in mercury contamination levels on an individual stream segment basis when data from all stream segments are combined, all three predictor variables can be significantly correlated with mercury concentrations. In addition, an ANCOVA model showed all predictor variables to be significant predictors of mercury concentration. Linear regression analysis and results from a Pearson Correlation agree that both distance from potential mercury contamination source and distance downstream has a negative relationship with mercury concentrations. This relationship between distance from potential contamination source and mercury concentration is significant in that previous studies draw this conclusion from general trends within their data but none have shown a statistically significant relationship between distance and mercury concentrations (Lacerda et al. 1991, Filho and Maddock 1997, van Straaten 2000a, Limbong et al. 2003, Santos-Francés et al. 2001, Lusilao-Makiese et al. 2013). The negative relationship displayed between distance downstream and mercury concentrations suggest that mercury concentrations are not randomly distributed throught the stream system in this study. More specifically, this negative relationship is thought to be in large part due to potential contamination sources being at the head of at least half of

the stream segments effectively mirroring distance from potential contamination source data. Linear regression analysis and the Pearson Correlation also showed a positive relationship between percent organic carbon and mercury concentration, which correlates with other studies (Guedron et al. 2009, Tomiyasu et al. 2012, Tomiyasu et al. 2013).

4.3 Small-Scale Distributions

The number of factors that influence mercury concentrations within a stream system make it difficult to define a rate at which mercury concentrations are reduced to background levels after being introduced. Distance from potential contamination source negatively affects mercury concentrations, but the rate at which concentrations are reduced can depend on a multitude of factors including percent organic carbon, stream morphology, Cu/Fe concentrations, sediment particle sizes, and Al/Fe (hydr)oxides content (Filho and Maddock 1997, Fernández-Martínez 2006, Guedron et al. 2009, Tomiyasu et al. 2012, Tomiyasu et al. 2013, Niane et al. 2014). Distances required to reach background concentrations of mercury are better addressed by individual stream segment. Segment STR-1 exhibits extremely high concentrations of mercury within 280 m of the potential contamination source but has a sharp drop in concentrations within the next 50 m. Despite this rapid drop in concentrations, background levels are not reached until 1350 m from the potential contamination source. Segment STR-2 is similar in that it has a large peak in concentrations within 200 m of a potential contamination source with a rapid decline shortly following. Where it differs from STR-1 is that background levels are reached within 400 m of its nearest potential contamination source. Segment STR-2 is also differs in that the potential contamination source lies in the middle of the stream segment creating an upstream and downstream section from where the potential

contamination source is closest to the segment. Mercury concentrations remain below background levels as distance increases past 400 m in the upstream section but has a secondary peak above background levels around 600 m before returning again to background levels at 750 m in the downstream section. Segment STR-3 only has three data points that fall below background levels and all three occur within 300 m of a potential contamination source. Segment STR-6 has no apparent contamination source with all data points falling under background levels.

Segment STR-4 was highly influenced by artisanal small-scale mining and showed no evidence of flowing water for its first 600 m at the time the samples were collected. Mercury concentrations were inconsistent when distances from potential contamination sources where minimal ranging from much higher than background levels (936.199 µg/kg dw) to well below (24.029 µg/kg dw). Only three data points were at a distance greater than 50 m from a potential contamination source and did not exhibit any kind of gradient as distance increased. The high amount of variation in mercury concentrations when close to potential contamination sources could be from the lack of flowing water in the early portion of the stream segment. Mercury is highly dependent on water action for its mobility (Fernández-Martínez et al. 2006) and without flowing water is unlikely to travel far from where it has been introduced.

Segment STR-5 shows mercury concentrations reaching below background levels at a distance of 2150 m, with concentration levels dropping to 30 µg/kg dw or less after 3150 m. This suggests that mercury concentration from a potential contamination source within this system lose influence within a 2 km distance. However, this distance could be affected by the lack of flowing water near potential upstream contamination points.

Without flowing water, potential contamination sources from segment STR-4 do not have the same amount of influence on segment STR-5 as potential contamination sources from segments STR-1 or STR-2 would have for their downstream portions. The only other stream segment that might influence mercury concentrations in segment STR-5 is segment STR-6, which does not exceed concentrations above background levels.

CHAPTER V

CONCLUSION

Mercury concentrations found in this study fall within the range of concentrations reported in similar studies but were consistently at the lower end of that range. This suggests that the study area does have a level of mercury contamination but that level is less than other comparable regions. Despite this distinction, there were still several areas containing mercury concentrations well above the CCME probable effect level of 486 µg/kg dw. When data from stream segments were analyzed as a whole, the distribution of mercury concentrations were shown to be positively correlated with percent organic carbon and negatively correlated with distance downstream and distance from potential contamination source. However, when stream segments were analyzed individually not all of these relationships were maintained. Several other factors could have affected mercury distributions within the individual stream segments including, sediment particle size ratios, stream morphology, Cu/Fe concentrations, and the amount of Al/Fe-(oxyhydr)oxides. In addition, potential sources of mercury contamination seemed to play a part in that industrial mining and stamp mills represented fixed locations of potential contamination whereas ASM panning locations were varied within stream segments and did not always represent potential contamination sources.

5.1 Containment and Remediation

Mercury concentrations found within the study area were sufficiently high to represent a potential health risk for the local workers and residents within the area. Ultimately, the only way to completely prevent mercury from entering local stream systems would be to discontinue the use of mercury in mining operations. There are

several methods available of extracting gold from ore without the use of mercury. However, these methods require resources that can be nearly impossible for local ASM miners to obtain which makes it unrealistic to expect miners to adopt these methods. Therefor, the most realistic option to keep mercury out of stream systems are to take preventative measures. These mearsure can be as simple as digging ditches around tailing piles to prevent run-off entering streams such as employed by the Farvic Mine to using retorts in the volatilization process. Both of these methods cost little to no money and are easy to facilitate.

In regards to the mercury that is already present in the stream system, data from this study effectively demonstrates areas of particular concern. With the smaller resolution offered, remediation efforts can be localized making them more cost efficient and less labor intensive. The biggest area of concern is the reservoir that is fed by 3 of the 6 stream segments. All stream segments within the study area are only seasonally flowing but the reservoir remains filled throughout the year and acts as a pool for any mercury contamination coming from up stream. This reservoir is used for everything from washing clothes and bathing to watering cattle and fishing. Mercury concentrations found in sediment samples from the reservoir were all above the CCME interim quality guideline of 170 µg/kg dw. It is highly recommended that remediation efforts are taken if the reservoir is to continue being used to avoid any further risks from mercury contamination.

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VITA

Education

Sam Houston State University (SHSU), Huntsville, TX   *Aug. 2014 – Present*
Masters of Science - Biological Sciences
Expected graduation date: May 2017

Northern Michigan University (NMU), Marquette, MI   *Aug. 2008 – May 2013*
Bachelor of Science - General Biology Emphasis in Ecology

Universidade Federal Rural de Amazonia, Belem, Para, Brazil   *Feb. 2011 – June 2011*
No degree - Forest Ecology and Entomology

Publications

A note on the distribution of the Big Brown Bat (*Eptesicus fuscus*)
Brian Chapman and Corey S. Green
Manuscript in preparation for submission

Analysis of the completeness of vascular plant records in Michigan
Corey S. Green and Justin K. Williams
Manuscript in preparation for submission

Research and Field Experience

Texas Invasive Insect Survey   *May 2016 - Present*
Texas Invasive Species Institute

I was responsible for setting out traps for pest ambrosia and invasive pine sawyer beetle species throughout east Texas. Once placed, traps were revisited every two weeks to be emptied and to replace any lures. Trap contents were sorted by hand. All beetles belonging to cerambycidae were removed and shipped for further identification. Target species of ambrosia beetle (*Xyleborus glabratus*) were removed from samples and reported. Currently I am responsible for identifying to species and pinning all remaining ambrosia beetles for a museum collection.

Mercury as an Environmental Contaminant from Small-Scale Gold   *Aug. 2014 – Present*
Mining in Zimbabwe
Sam Houston State University, *Huntsville, TX*
Farvic Gold Mine, *Zimbabwe*

This is my Master's thesis research. I planned, organized, and then executed sample collection in southern Zimbabwe in the summer of 2015. Samples were returned to USA where I analyzed them at the University of Michigan Biological Field Station for mercury content. Mercury data was analyzed and results put into a manuscript which is currently awaiting approval from the SHSU library as a masters thesis.

Internal Parasite Assessment of Arctic Bird Species   *Aug. 2016 – Oct. 2016*
Texas Research Institute for Environmental Studies, *Huntsville, TX*

I dissected the digestive organs from two species of migratory arctic birds for internal parasite assessments. Dissections involve identifying various internal parasites including new or poorly describes species, staining specimens, and creating permanent slides from specimens.

Fort Maxey Bat Survey   *May 2016 –*
Aug. 2016
Texas Research Institute for Environmental Studies, *Huntsville, TX*

I worked as a research assistant to Dr. Brian Chapman conducting bat surveys using mist netting techniques at Fort Maxey, TX. Surveys took place once a month over a three day – two night period. Nets were placed at various locations each night at dusk and monitored until dawn. I assisted in the removal, identification, measurement, and photographing of each bat caught.

Fish Diversity Assessment   *Sep. 2015 – Dec. 2015*
Sam Houston State University, *Huntsville, TX*

I collected fish in 10 stream locations over a four day period using seines, gill nets, and shore based electroshocking throughout eastern Oklahoma and western Arkansas as part of an ichthyology course. Fish were collected and returned to the lab where they were identified using taxonomic keys and a species list was recorded.

Analysis of the Completeness of Vascular Plant Records in Michigan   *Sept. 2014 – Dec.*
2014
Sam Houston State University, *Huntsville, TX*

I used herbarium data in contrast to a species-area richness formula to predict completeness of vascular plant records for each county in Michigan.

Fish Stomach Content Analysis   *Aug. 2012 – Dec.*
2012
Northern Michigan University, *Marquette, MI*

I identified various insects taken from stream samples using a dissection microscope and species keys. Upon identification, I measured body size and kept a tally of individuals within like species.

Island Tree Diversity   *Aug. 2012 – Dec.*
2012
Northern Michigan University, *Marquette, MI*

I planned and executed a study of island tree diversity on two islands near Marquette, MI. I used random sampling to record tree species, quantity, and DBH. This data was compared to similar

data obtained from the mainland in order to determine severity of island isolation on the island populations.

Elevation Preferences of Mosquitos within the Caxuana *May 2011 – Aug. 2011*
Research Preserve
Museu Paranese Emilio Goeldi, *Belem, Brazil*

I set up CDC and black cloth traps at predetermined locations and heights. Twice a day I collected samples from the traps and prepared them for transportation. I recorded daily observations in a field journal. Samples were collected over a 20 day period.

Research Presentations

Texas Academy of Science Annual Conference – San Antonio, TX
March 2015
- Distance based mercury contamination in association with small-scale gold mining in Zimbabwe

Graduate Student Research Poster Presentations – SHSU
Dec. 2014
- Distance based mercury contamination in association with small-scale gold mining in Zimbabwe

Population Ecology – NMU *May 2012*
- A population model of the moose (*Alces alces*) population on Isle Royale, MI

Ecology Theories and Methods – NMU *Dec. 2011*
- Island tree population dynamics in comparison to mainland populations

Guest Presenter – Capac High School and Macomb Academy of Arts and Science
Dec. 2011
- Elevation preference according to specie of mosquito in the amazon rainforest

Professional Service

Poster Judge *April 2015*
Undergraduate Research Symposium – SHSU

Poster Judge *March 2015*
Texas Academy of Science Annual Conference

Professional Society Membership

Sigma Xi	*Sept. 2015 – Present*
Texas Academy of Science	*Sept. 2014 – Present*
Biological Sciences Graduate Student Organization (BSGSO)	*Aug. 2014 –*
Present	
Better Understanding of Global Sustainability (BUGS)	*Aug. 2014 –*
Present	

Academic Scholarships, Grants, and Awards

Outstanding Teaching Assistant Award Nominee (2014)	SHSU, Huntsville,
TX	
Graduate Teaching Assistantship (2014)	SHSU, Huntsville,
TX	
Government Scholar Certificate (2013)	Ministry of Education, Republic of
Korea	
Brazil – USA Student Exchange Program (2011)	NMU, Marquette,
MI	
NMU Honors Award (2008-2012)	NMU, Marquette,
MI	

Teaching Experience

Graduate Teaching Assistant *Aug. 2014 – May 2016*
Sam Houston State University
I taught four lab sections of general botany fall of 2014, four lab sections of environmental science spring 2015, three lab sections of zoology fall 2015, and three lab sections of general ecology spring 2016. I set up lab materials and taught general concepts laid out by the lecture professor in the lab manual.

Substitute Teacher *Jan. 2014 – May 2014*
St.Clair, Macomb, and Lapeer Counties, MI

I worked as a substitute teacher working in schools across St.Clair, Macomb, and Lapeer Counties, MI. I taught all classes from elementary to high school. Teachers left a variety of lesson plans from watching movies to teaching an actual lesson. My primary role was to maintain order within a classroom and complete whatever lesson was left the class.

Elementary English Teacher *Aug. 2012 – Aug. 2013*
Yeongchun, Republic of Korea

I wrote weekly lesson plans for grades 1-6 and constructed a curriculum for the year. Classes were taught in an immersion setting: no Korean was spoken throughout the lessons.

Volunteer Instructor *Sept. 2012 – Aug. 2013*
Jecheon, Republic of Korea

I volunteered for an hour once a week to help to teach a mothers group conversational English. The class was primarily instructed by a Korean National while I gave support for pronunciation, sentence structure, and grammar.

Science in English Teacher *Jan. 2013 – Aug. 2013*
Jecheon, Republic of Korea

I taught middle school students ranging from 12-15 years old general science in an immersion setting. I taught a three hour lesson once every two weeks. Lesson planning was done following a text book.

Private Instructor *May 2013 – Aug. 2013*
Jecheon, Republic of Korea

I taught two hour private English lessons for an adult twice a week. One day per week was spent on listening comprehension while the other was spent on conversational skills.

Technical Skills

ArcGIS	SPSS	Trap maintenance and repair
MARK (Pop. modeling)	Radio Telemetry	Manual map construction
STELLA (Pop. modeling)	Wildlife Necropsy	Electroshocking
Mark-recapture	Trapping: CDC and black cloth	Microsoft Office
Seining	Gill netting	Mist netting

International Experience

Zimbabwe *May 2015 – June 2015*
Researcher/Student

Republic of Korea *Aug. 2012 – Aug. 2013*
Elementary Foreign English teacher

Thailand, Cambodia, and Vietnam *Jan. 2013*
Vacation

Brazil *Jan. 2011 – Aug. 2011*
Student
- 6 week language immersion program (conversational in Brazilian Portuguese)

- 1 semester at Universidade Federal Rural de Amazonia
  - o Forest Ecology
  - o Entomology
- 4 month internship at Museu Paranese Emilio Goeldi

Language Skills

English
- Native language
- Intimate knowledge of English in foreign settings both educationally and recreationally

Brazilian Portuguese
- Highly conversational
- Above adequate reading and writing

Spanish
- Reading and listening skills are above elementary level
- Speaking and writing skills are at elementary level

Korean
- Elementary level
- Reading and writing skills are adequate but with elementary comprehension

Research Interests, Additional Training, and Experience

My research interests include; population ecology, population modeling, wildlife ecology, ecotoxicology, and environmental conservation.

Registered Substitute Teacher   *Jan. 2014*
      St.Clair County, MI
      Lapeer County , MI
      Macomb County, MI

Teaching and cultural training course   *Aug. 2012*
      Republic of Korea
      Ministry of Education