DOE/FIU SCIENCE & TECHNOLOGY WORKFORCE DEVELOPMENT PROGRAM

STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

For June 2, 2008 to August 08, 2008

Chemical Reduction/Volatilization to Remove Mercury from East Fork Poplar Creek (EFPC)

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ABSTRACT

East Fork Poplar Creek (EFPC) in Oak Ridge, TN, receives inputs of mercury caused by legacy contamination at the Department of Energy (DOE) Y-12 National Security Complex. Most of that mercury leaves the storm drain network at a single discharge point. This mercury is highly reactive because of the presence of residual chlorine in the water. This project investigates removing the residual chlorine in the water and chemically converting the dissolved mercury (Hg (II)) to gaseous Hg (0). Natural volatilization across the air-water interface and/or air stripping within the storm drain itself could be used to remove the Hg (0). This work studied the reactivity of dissolved mercury in creek water with the reductant stannous chloride (SnCl2), photochemical reoxidation of Hg (0) in daylight and the possible interferences from the de-chlorinating agents. A model was developed to describe the rate of volatilization of gaseous mercury from water flowing through a pipe as a function of flow, depth, velocity, and pipe dimensions. Preliminary design of a system for *in situ* air stripping was also initiated.

The results of the experiments showed that a very low concentration of reductant (~5ug/L Sn (II)) were able of convert 75% of the mercury in the outfall to volatile Hg (0), but that excess de-chlorinating agent (HCl) interfered with the reaction. Sodium thiosulfate was tested as an alternative de-chlorinating agent and it did not interfere with the reaction. Sunlight rapidly oxidized Hg (0) to Hg (II); for that reason, all removal of Hg (0) from water needed to occur in the absence of sunlight. The model predicted that 35% of the mercury in the outfall could be removed by natural volatilization in a well-ventilated pipe. The combination of techniques analyzed in this study could be economically feasible and practical to reduce the concentration of mercury in the EFPC.

EXECUTIVE SUMMARY

The present research work has been supported by the DOE/FIU Science & Technology Workforce Initiative, an innovative program developed by the US Department of Energy's Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FU-ARC). During the summer of 2008, an FIU intern spent 10 weeks doing a summer internship at ORNL's Environmental Sciences Division under the supervision and guidance of Mr. George Southworth. This internship was coordinated and directed by the Higher Education Research Experience program (HERE) and Oak Ridge Institute for Science and Education (ORISE). The project was initiated from June 2 through August 8, 2008 with the objective of analyzing the feasibility of removing mercury from the East Fork Poplar Creek (EFPC) in Oak Ridge, Tennessee.

In the EFPC, mercury can be converted to a highly toxic, organic compound called methyl-mercury. This compound bio-accumulates, or builds-up, in fish or other organisms. The main source of pollution is coming from the storm drain network at a single discharge point which receives water from the outfalls coming from the Y-12 National Security Complex (DOE 2001). The water from the storm drain network of pipes mix with chorine, creating a highly reactive form of mercury. This project investigates the reactivity of this polluted water with SnCl2 and other possible reductants as well as evaluates the feasibility of air stripping in the storm drain pipe. HCl and other alternative de-chlorination chemicals were evaluated in the laboratory and the affect of sunlight on the reaction was observed. Some samples were taken before sunlight to compare both effects. At the end of the project, the percentage of gaseous mercury which is removed from the pipe and from the creek by natural volatilization was predicted and the feasibility of treating the water with stannous chloride and air stripping was evaluated.

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1. INTRODUCTION

The state of Tennessee and other regulatory agencies restrict the disposal and release of mercury because of its toxicity. Mercury is a pollutant which has been extensively studied because of its impact on the environment and its ability to deposit and revolatilize. Because of its toxicity and its ability to bioaccumulate in different organisms, especially fish, mercury has been a concern in many places. The major forms of mercury are elemental mercury (pure form), inorganic mercury compounds and organic mercury (i.e., methyl mercury). Methyl-mercury is created in anaerobic conditions or areas where aerobic bacteria are consuming oxygen. East Fork Poplar Creek (EFPC), which runs from the Oak Ridge Y-12 Federal Security Complex through the city of Oak Ridge, has been contaminated with mercury for many years. The concentration of methyl-mercury in the Poplar Creek is currently about 0.9 ppm while the limit imposed by the state of Tennessee is 0.3 ppm. Remediation efforts of the Upper East Fork Poplar Creek (UEFPC) are currently under way. Fish population has increased over the last few years because of better water quality, as well as the improvement of some weirs. Many laboratory experiments were performed to find the optimal method to reduce the concentration of mercury in the water.

2. PROBLEM DESCRIPTION

Efforts have been made over the last 20 years to reduce the high concentrations of mercury in the UEFPC at the Y-12 National Security Complex in Oak Ridge. A storm drain exit point at the Y-12 site is the main source of pollution into the EFPC. The storm drain receives contaminated water from the outfalls of some of the Y-12 buildings. The water flowing from the outfalls includes rain water from the roof of the buildings, wastewater from the mercury cleaning process inside of the buildings and polluted groundwater. The inorganic mercury in the creek could form methyl-mercury $(CH3Hg)^{+}$ by the action of anaerobic organisms. A high concentration of inorganic mercury in the storm drain exit point (~200 ng/L) can be converted to methyl-mercury in the creek. The purpose of this project is to find a feasible method to change inorganic mercury (Hg (2)) to dissolved gaseous mercury ((Hg (0)). This method should be cheap, simple and have a minimal impact on the environment.

3. HYPOTHESES

The following statements summarize the hypotheses for this research work:

- Trace concentrations of SnCl2 would transform Hg (II) to volatile Hg (0) in EFPC water.
- The rate of photo-oxidation of Hg (0) by direct sunlight in the creek would require that Hg (0) removal occur in the dark.
- Natural transfer of Hg (0) from water in the storm drain network would be rapid enough to substantially reduce total mercury concentration in the stream at the point where flow exits the system.
- In situ air stripping could be a low cost alternative to increase the rate of removal of Hg (0).

4. SIMULATION IN THE LABORATORY

4.1 Adding Stannous Chloride (SnCl2)

Different laboratory experiments were performed to find the optimal method to reduce the concentration of mercury in the water. (Looney et al. 2003). Tap water with Hg(II) standard was mixed, sodium thio-sulfate was added as a de-chlorinator and SnCl2 was added in different concentrations to determine the relationship of Hg(0) dissolved versus SnCL2 (Figure 1 and Table 1) using the spectrometer Lumex RA-915 mercury analyzer. Alternative de-chlorinators, like sodium sulfite and hydroxylamine were also investigated.

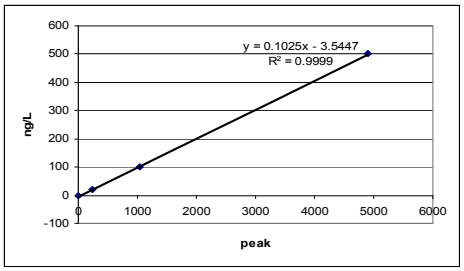
The following reaction occurs when stannous chloride reacts with Hg (II) and is reduced to elemental mercury Hg (0):

$$Hg^{+2} + Sn^{+2} \longleftrightarrow Hg^{0} + Sn^{+4}$$

Figure 1 show an example of data in the laboratory when different concentrations of SnCl2 were added to water with a standard mercury concentration. The mercury Guru software graphs a curve and the highest peak is measured. Then, the concentration of mercury is calculated using a predetermined equation (Slope intercept form). This equation results from measurements of peaks using different concentrations of SnCl2. The graph showed that there is a direct relationship between SnCl2 and dissolved mercury.

Graphs of Hg(0) versus concentration of SnCl2

1: Make up 0.5ug/L Hg in tap water (pH 7.48)							
2: Added 60uL Na-thiosulfate to 100ml of this Hg solution to dechlornate							
3: Put 10ml of 0.5ug/L Hg solution in a clean vial and purge, then add different con. of SnCl2							
using fresh Hg solution for each running							
100ug/L SnCl2 was made freshly from 10mg/L SnCl2							
SnCl2.2H2O	SnCl2.2H2O	Hg(0)	Sn	Hg	Hg		
uLof 100ug/L	ug/L in 10ml	peak	µM/L	µg/L	µM/L		
or 10mg/L			0		0		
10	0.1	811	0.000443	0.079583	0.000398		
20	0.2	1685	0.000886	0.169168	0.000846		
40	0.4	3009	0.001773	0.304878	0.001524		
10	10	4270	0.04432	0.43413	0.002171		
100	100	4406	0.443203	0.44807	0.00224		
peak	std(ng/L)						
0	0						
242	20						
1039	100						
4905	500						



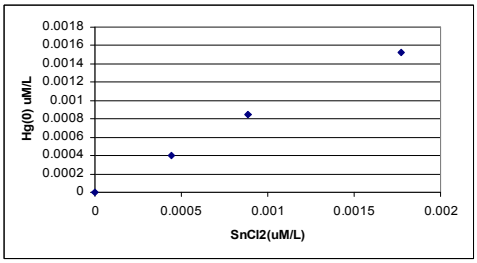


Figure 1. Estimation of Hg (o) using the Lumex spectrometer in the laboratory.

Table 1 shows data obtained from two tests in the laboratory when sodium thio-sulfate was added as a de-chlorinator. Figure 2 shows that adding sodium thio-sulfate does not interfere with the reaction. Other de-chlorinators, like hydrochloric acid (HCl) and sulfur trioxide (SO3), interfered with the reaction. The following chemical reaction occurs when the sodium thio-sulfite is added:

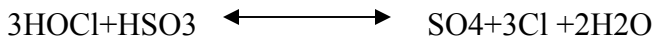


Table 1. Tests Using SnCl2 and Sodium Thio-sulfate in Tap Water

100ug/L SnCl2 was made freshly from 10mg/L SnCl2				test1	
SnCl2.2H2O	SnCl2.2H2O	Hg(0)	Sn	Hg	Hg
uLof 100ug/L	Ug/L in 10ml	Peak	µM/L	µg/L	µM/L
or 10mg/L					
10	0.1	347	0.000443	0.02991	0.00015
20	0.2	595	0.000886	0.05129	0.00026
30	0.3	790	0.00133	0.0681	0.00034
80	0.8	1956	0.003546	0.1865	0.00093
200	2	2412	0.008864	0.23016	0.00115
400	4	2515	0.017728	0.2398	0.00120
1000	10	4434	0.04432	0.4227	0.00211
10,000	100	5107	0.443203	0.4869	0.00243
peak 1160	std(100ng/L)			test 2	
5244	500 ng/l		Sncl2		Hg
			0.000443		0.000398
			0.000886		0.000846
			0.001773		0.001524
			0.04432		0.002171
			0.443203		0.00224

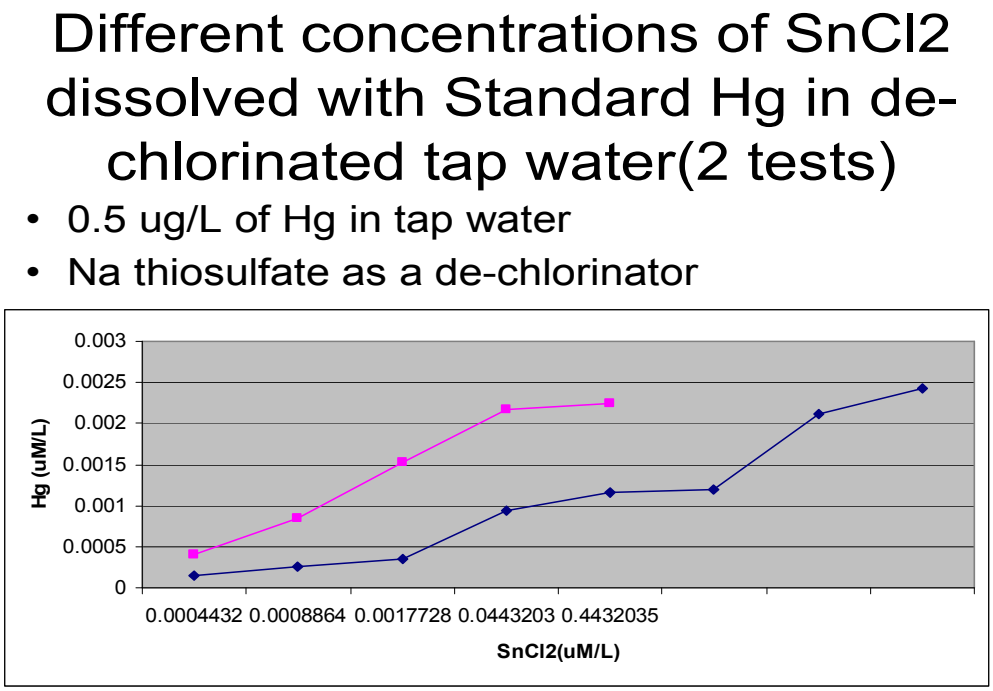


Figure 2: Graphing behavior of mercury using tap water.

4.2 Testing Hydroxylamine

Other reductants for converting Hg(II) to Hg(0) were evaluated, such as the hydroxylamine which could be toxic for aquatic species. The following equation represents hydroxylamine reacting with chlorine:

$Cl2+NH2OH=Cl^{-}+ClNOH+H^{+}$ (Cooper et al. 1993).

Data on the website www.pesticideinfo.org (Kegley et al. 2008) showed the toxicity for hydroxylamine on some aquatic life:

1- Buffalo Sculpin (Fish)=mortality when its applied a LD50 toxic dose of 44 mg/kg
2- Blue-green algae (Phytoplankton)= effect in physiology when its applied a toxic dose of 11,000 ug/L
3- Water Flea (Zooplankton)= change in direct movement when its applied a toxic dose of 100 ml/L

4.3 Using CVAFS spectrometer with gold traps

In the laboratory, another method was tested to measure gaseous mercury using a more sensitive spectrometer, CVAFS, using software Mercury Guru 3.2. This method measures the gaseous mercury "trapped" into the gold trap and not the gaseous mercury dissolved directly from the water. This spectrometer shows the area under the peak instead of the height of the peak used in the Lumex spectrometer. It is necessary to determine the optimal time which the gold traps need to absorb gaseous mercury and the best equation from standards before using it with samples from the creek (see Equation 1 for an

example). Each time the equation is different depending on changes in temperature, noise and others factors.

$$y = 0.073x - 0.2567 \qquad \textbf{Equation 1}$$

where y is the area under the peak in the graph (Mercury Guru) and x is the gaseous mercury (pg/l).

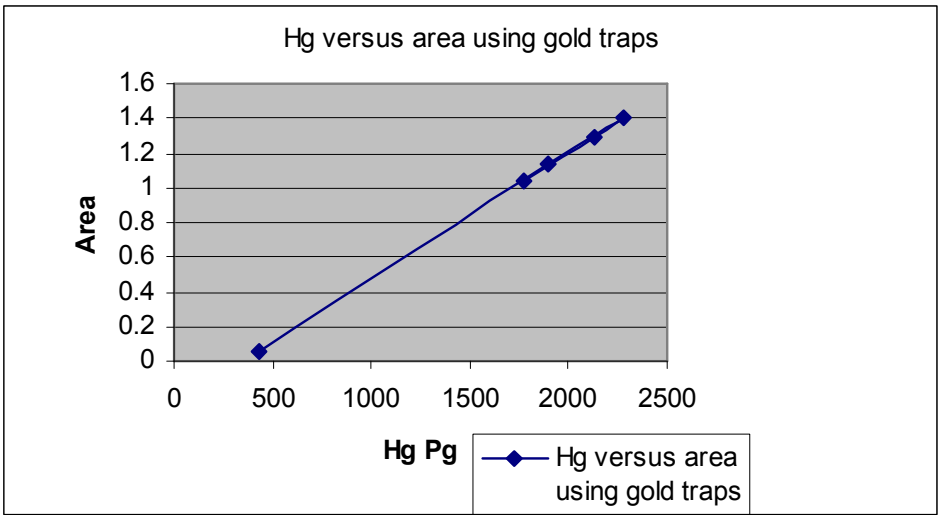


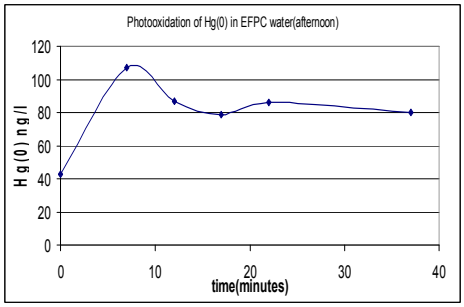
Figure 3: Example of graph using spectrometer CVAFS.

5. EMPIRICAL DATA

Samples of water were collected from Upper East Fork Poplar Creek (UEFPC) at the point where the stream emerges from the storm drain system at Y-12. These samples were mixed with different concentrations of stannous chloride (SnCl2) to evaluate the efficacy of the reduction reaction and the possible interference from excess de-chlorinating agent (ammonium bi-sulfite). Some samples received direct sunlight to evaluate the photo-oxidation of the Hg (0) (Figure 4).

Photo-oxidation of Hg(0) in EFPC

1: add 5 ug/l Sncl2.2H2O to sample in 250 ml bottle					
2:add 1 ml of 250 ml bottle to 9 ml dist water.					
3:add 1 ml dist water to 250 ml bottle to fill headspace and put it in sunlight					
Direct sunlight		Hg(0)	Hg	Hg	
Hour	test #	peak	ng/L	nM/L	
3:00 shade	0	57	42.75	0.21375	
3:07	7	143	107.25	0.53625	
3:12	12	116	87	0.43500	
3:17	17	105	78.75	0.39375	
3:22	22	115	86.25	0.43125	
3:37	37	107	80.25	0.40125	



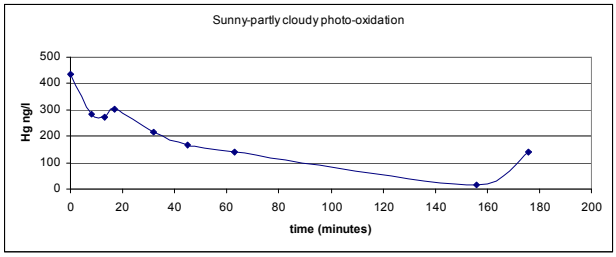


Figure 4. Photo-oxidation of mercury in EFPC

Figure 4 shows that Hg(0) in EFPC is rapidly oxidized to Hg(II) by sunlight (half line=88 minutes in second graph) and reaches a balance between photo-oxidation and photo-reduction. Data of gaseous mercury along the creek taken during the summer was compared with past data from last December (Figure 5). The graph showed that total mercury in summer presents some variations from the total mercury in winter.

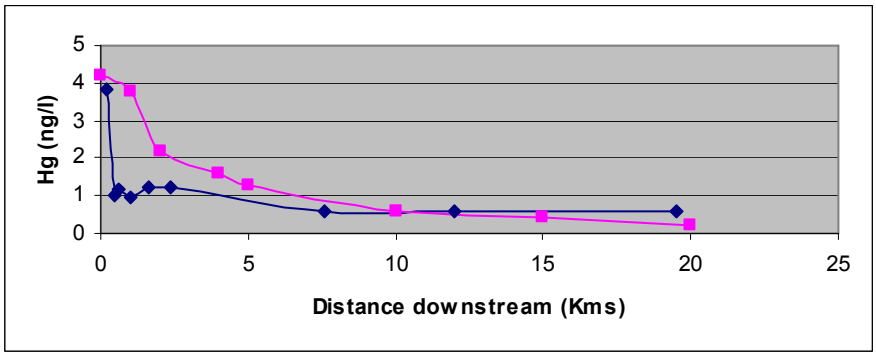


Figure 5. Comparing behavior of mercury in winter versus summer.

6. MODELING

A simple mass transfer model was used to describe the rate of volatilization of Hg(0) as a function of depth, temperature and velocity of water. This model uses Henry's law constant to predict the rate of volatilization of gaseous mercury from water along the creek and in pipes of different diameters and lengths.

6.1 Model use in EFPC

The model successfully predicted the downstream decrease in Hg(0) observed under low light conditions in a December 2007 study and was then applied to predict Hg(0) volatilization within pipes of various lengths, diameters, and flows (Table 2).

The following equations were used in this model to predict the rate of volatilization in EFPC (Southworth 1979):

$Hg\ (0)t=Hg(0)o*e^{kt}$, where t is time **Equation 2**

K=K1/R, where R is the average depth of water **Equation 3**

K1= bxV^.969/R^.673, where V is velocity **Equation 4**

b=23.51*(32/200)^0.67=6.8867 where 0.67=2/3 **Equation 5**

Table 2. Data Modeled in the EFPC Using Henry's Law

EFK		BMAP data			Reach velocity			Calculations of phase constants				
Actual	distance from	width	depth or R				Travel time	K1	K	calculation	Calculation	Hg(0)
										of -kt	of e^kt	
	pipe 200(Km)	m	m	Cm	m/h	m/s	h	*TxV^.969/R^.673	K1/R			Hg(0)o*e^k
								cm/hr	1/hr			ng/L
25	1	5.5	0.17	17	962.57	0.2674	1.038889	6.333508885	0.372559346	-0.387047765	0.6790587	3
24	2	5.6	0.19	19	892.86	0.248	1.12	5.463847006	0.287570895	-0.322079402	0.7246406	2.173922
23	3	5.7	0.23	23	762.78	0.2119	1.311	4.12469771	0.179334683	-0.235107769	0.7904857	1.718454
22	4	6.1	0.255	25.5	668.6	0.1857	1.495673	3.386676287	0.132810835	-0.19864159	0.8198437	1.408864
21	5	6.5	0.28	28	593.41	0.1648	1.685185	2.83291182	0.101175422	-0.170499323	0.8432437	1.188015
20	6	6.9	0.305	30.5	532.19	0.1478	1.879018	2.406684308	0.078907682	-0.148268944	0.8621992	1.024306
19	7	7.3	0.33	33	481.53	0.1338	2.076724	2.071533774	0.062773751	-0.130363763	0.8777761	0.899111
18	8	7.6	0.35	35	451.13	0.1253	2.216667	1.869177287	0.053405065	-0.118381228	0.8883573	0.798732
17	9	8.05	0.35	35	443.66	0.1232	2.254	1.839169826	0.052547709	-0.118442537	0.8883029	0.709516
16	10	8.5	0.35	35	436.97	0.1214	2.288462	1.812326363	0.051780753	-0.118498262	0.8882534	0.63023
15	11	8.95	0.35	35	430.97	0.1197	2.32037	1.788171378	0.051090611	-0.118549139	0.8882082	0.559775
14	12	9.4	0.35	35	425.53	0.1182	2.35	1.766320116	0.050466289	-0.118595779	0.8881667	0.497174
13	13	9.6	0.36	36	651.04	0.1808	1.536	2.61690102	0.072691695	-0.111654444	0.8943533	0.444649
12	14	9.8	0.37	37	606.73	0.1685	1.648182	2.399464047	0.06485038	-0.106885217	0.8986288	0.399574
11	15	10	0.38	38	592.11	0.1645	1.688889	2.301718254	0.060571533	-0.102298589	0.90276	0.36072
10	16	10.2	0.39	39	578.18	0.1606	1.729565	2.210266236	0.056673493	-0.098020503	0.9066303	0.32704
9	17	10.4	0.4	40	564.9	0.1569	1.770213	2.124559579	0.053113989	-0.094023062	0.9102618	0.297692
8	18	10.6	0.41	41	552.23	0.1534	1.810833	2.044109631	0.049856332	-0.090281509	0.9136739	0.271993
7	19	10.8	0.42	42	540.12	0.15	1.851429	1.96847974	0.046868565	-0.086773801	0.9168845	0.249386
6	20	11	0.43	43	528.54	0.1468	1.892	1.897278651	0.044122759	-0.083480261	0.9199092	0.229413
T=23.51(32/200)^0.67=6.8867 where 0.67=2/3												
Hg(0)o=3 ng/l												

Table 2: data modeled in the EFPC using Henry's Law

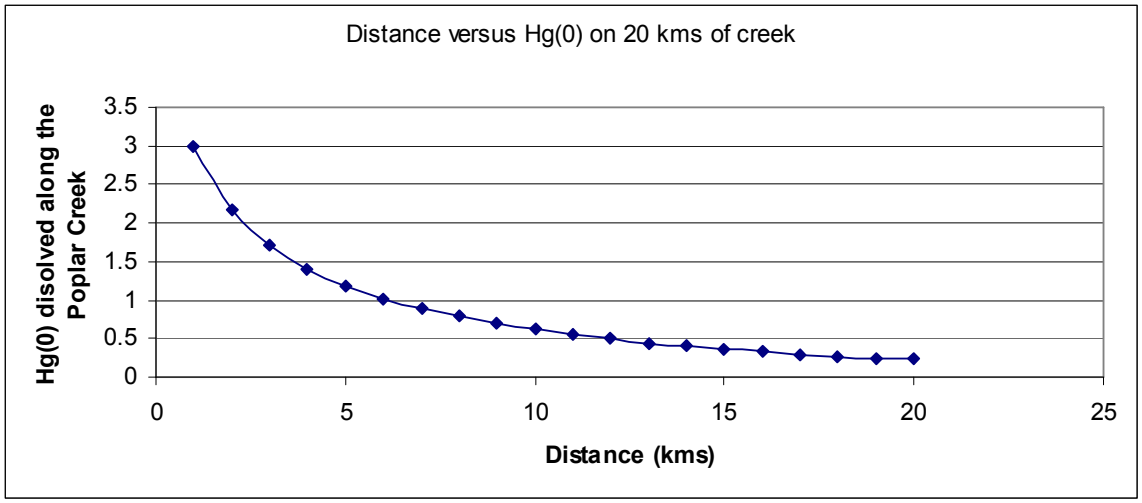


Figure 6. Modeled data in the EFPC.

The model successfully predicted the downstream decrease in Hg (0) observed under low light conditions in a December 2007 study.

Modeled and observed concentrations of Hg(0) in EFPC versus distance from storm drain exit point

*Modeled using mass transfer coefficient (K), which varies as function of velocity and depth

*Hg(0) for any t is $Hg(o)(t)= 3*e^{-kt}$

$K=23.51(v^{0.969}/R^{0.673})(32/Mol.wt\ Hg)^{2/3}$

Where v= velocity of current at determined point, R is the depth of the creek (variable) and Mol wt Hg is 200

*Hg Flux =K * concentration of Hg(0)

$(ng/cm^2/h)= (cm/h)(ng/cm^3)$

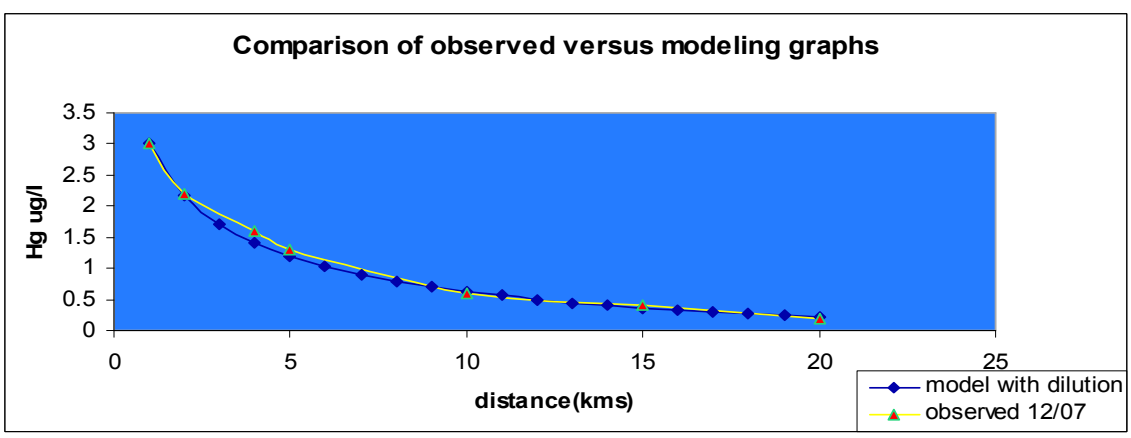


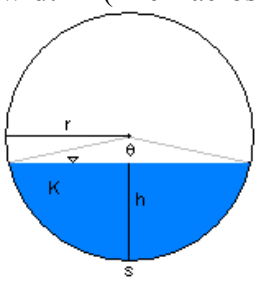
Figure 7. Coincidence between modeled and observed graphs.

6.2 Modeling data in storm pipes

The model was used to determine the rate of volatilization using different pipe diameters. Figure 8 predicts 40% removal of Hg (0) in 500-m of storm drain and it used the following equation:

Wet area of each pipe: $A=1/2r^2*(\Phi-\sin\Phi)$ **Equation 6**

Where r is the radius of the pipe and Φ is the angle in radians form by the top width (line across the water surface) from the center of the pipe.



Φ=2cos-1((r-depth)/r) and the average depth is A/ Φ*r=R

The average depth is the mean of all the depth of water in a determined cross section of the pipe and was calculated using the following formula:

Average Depth=100*Area/(r* Φ)

The velocity of the water was calculated by dividing the flow over the area:

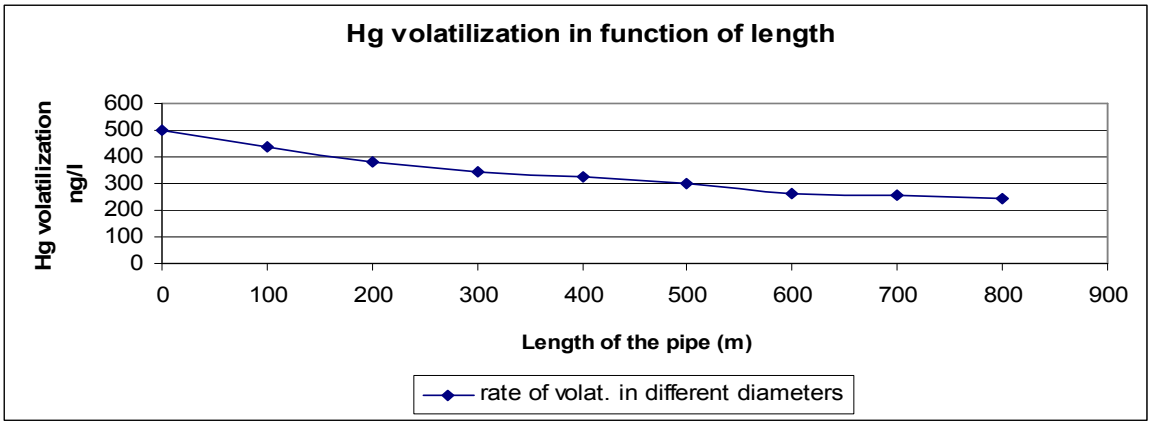
v=Q/Area

and the formula to find mercury flux in function of the time was:

$(Hg\ (t))=Hg(0)*e^{-kt}$,

Where $k=23.51*(v^{0.969}/R^{0.673})*(0.29)$, Schmidt number of 0.29 was obtained from $(32/200)^{2/3}$ which are the gas phase mass transfer coefficients of the mercury and Sn for 25 degrees. The time (t) was the distance over the velocity.

Mass transfer coefficient from creek applied to storm drain



- Predict 40% removal of Hg(0) in 500 m of storm drain
- Calculating wetted area of each pipe: $A=1/2r^2*(\Phi-\sin\Phi)$, $\Phi=2\cos^{-1}((r-depth)/r)$, Average depth=A/ Φ*r=R
- Velocity=Flow/area where flow=0.0694m3/sec
- Using $Hg(0)t=Hg(0)o*e^{-kt}$ where $k=(23.51*v^{o.969}/R^{0.673})*(32/200)^{2/3}$

Figure 8. The rate of volatilization using modeled data.

6.3 Prediction of Hg flux in the storm drains system when SnCl2 is added.

The model was used to predict the rate of volatilization if SnCl2 is added to the different pipes in the storm drain network. Table 3 and Figure 9 show the calculations and results in four different pipes of the network.

Table 3. Calculations of Hg Flux in Storm Drain Pipes

Adding SnCl2 to each outfall											
Calculating circular pipes areas						Area,m2	average	averag depth			
outfall		diameter	radius,r	depth,	Φ, radians	.5rr(Φ-sinΦ	depth (cms	m			
or pipe									length		
name									m		
outfall A		0.9144	0.4572	0.9144	6.283185	0.656693	22.86	0.2286	152.4		
outfall B		0.9144	0.4572	0.095415652	1.315714	0.036379	6.047601	0.060476	152.4		
outfall C		0.9144	0.4572	0.095415652	1.315714	0.036379	6.047601	0.060476	121.9		
outfall D		0.9144	0.4572	0.095415652	1.315714	0.036379	6.047601	0.060476	182.9		
Main pipe		2.3	1.15	0.24	1.315714	0.23	15.2	0.152	800		
Outfall	Flow	averag	velocity	velocity	Time			of -kt	of e^kt	Hg(0)o	Hgt
or pipe	L/min	flow	m/s	m/h	hours	*TxV^.969/	K1/R			ng/l	ng/l
name		m3/s	flow/area		d/v	cm/hr	1/hr				
outfall A	174	0.01667	0.025385	91.38518271	1.667666	1.72	0.075037	-0.125136	0.882388	12000	10588.66
outfall B	255.9	0.005555	0.152698	549.7126747	0.277236	23.88	3.949318	-1.094892	0.334614	5976	1999.651
outfall C	95.92	0.000166	0.004563	16.42705743	7.420684	0.80	0.131585	-0.976454	0.376682	2150	809.8671
outfall D	1277.4	0.001944	0.053437	192.3746966	0.950749	8.63	1.427808	-1.357487	0.257343	343	88.26858
Main pipe	4166	0.013888	0.060383	217.3773913	3.680236	5.23	0.343918	-1.265701	0.282079	610.7956	172.2923
								diference			
Hgo*flow	Hgt*flow			p200(ng/m		sum(ng/mi	sum(ng/mi	ng/min			
ng/min	ng/min		Hgt*flow=	717769.7747		4261635	2544574	1717060			
2088000	1842427			gms/day		gms/day	gms/day				
1529258	511710.8			1.033588476		6.136754	3.664187				
206228	77682.45										
438148.2	112754.3										
				Schimdt number	0.95	from(565/667)^1/2					

Table 3: calculations of Hg flux in storm drain pipes

Predicted of Hg Flux at storm drain exit,SnCl2 added to each outfall

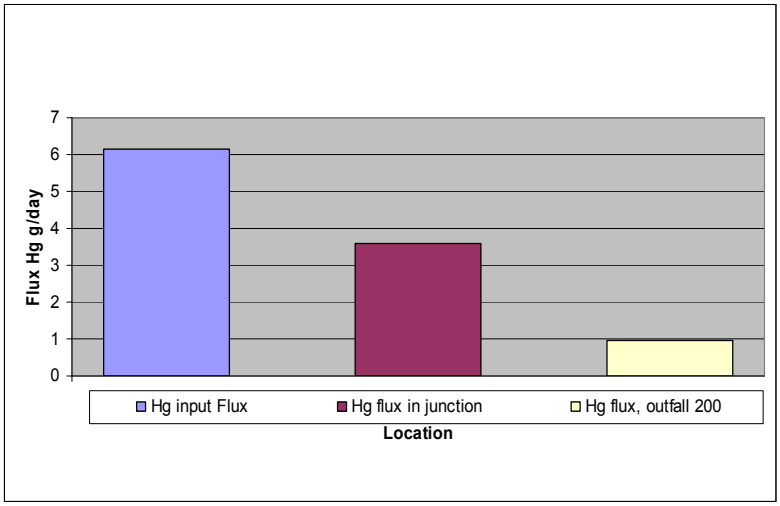


Figure 9. SnCl2 is added to the storm drain network of pipes.

Table 4. Hg Flux When Adding SnCl2 Only to 500-m of Main Storm Pipe

Calculating circular pipes areas						Area,m2	average	averag depth					
outfall		diameter	radius,r	depth,	Φ, radians	.5rr(Φ-sinΦ	depth (cms	m					
or pipe									length				
name									m				
outfall A		0.9144	0.4572	0.9144	6.283185	0.656693	22.86	0.2286	152.4				
outfall B		0.9144	0.4572	0.095416	1.315714	0.036379	6.047601	0.060476	152.4				
outfall C		0.9144	0.4572	0.095416	1.315714	0.036379	6.047601	0.060476	121.9				
outfall D		0.9144	0.4572	0.095416	1.315714	0.036379	6.047601	0.060476	182.9				
Main pipe		2.3	1.15	0.24	1.315714	0.23	15.2	0.152	520				
outfall	Flow	averag	velocity	velocity	Time			of -kt	of e^kt	Hg(0)o	Hgt	Hgo*flow	Hgt*flow
or pipe	L/min	flow	m/s	m/h	hours	*TxV^.969/	K1/R			ng/l	ng/l	ng/min	ng/min
name		m3/s	flow/area		d/v	cm/hr	1/hr						
outfall A	174	0.01667	0.025385	91.38518	1.667666	1.72	0.075037	0	1	12000	12000	2088000	2088000
outfall B	255.9	0.005555	0.152698	549.7127	0.277236	23.88	3.949318	0	1	5976	5976	1529258	1529258
outfall C	95.92	0.000166	0.004563	16.42706	7.420684	0.80	0.131585	0	1	2150	2150	206228	206228
outfall D	1277.4	0.001944	0.053437	192.3747	0.950749	8.63	1.427808	0	1	343	343	438148.2	438148.2
Main pipe	4166	0.013888	0.060383	217.3774	2.392153	5.23	0.343918	-0.822706	0.439279	1022.956	449.3631556		
											p200(ng/m	sum(ng/mi	sum(ng/mi
										Hgt*flow=	1872046.906	4261635	4261635
											gms/day	gms/day	gms/day
											2.695747545	6.136754	6.136754

Table 4: Hg Flux when adding Sncl2 only to 500 m of main storm pipe

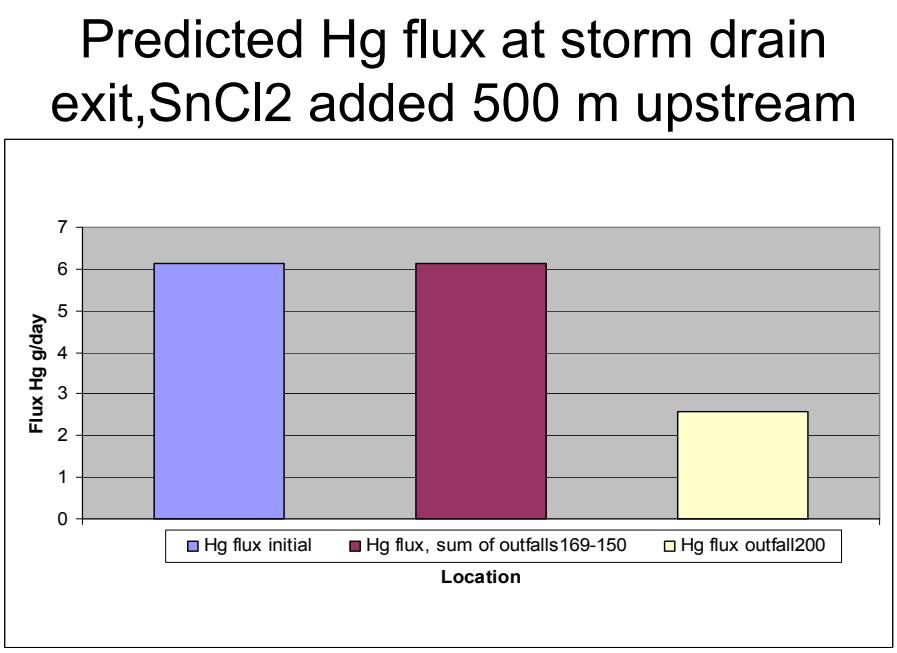
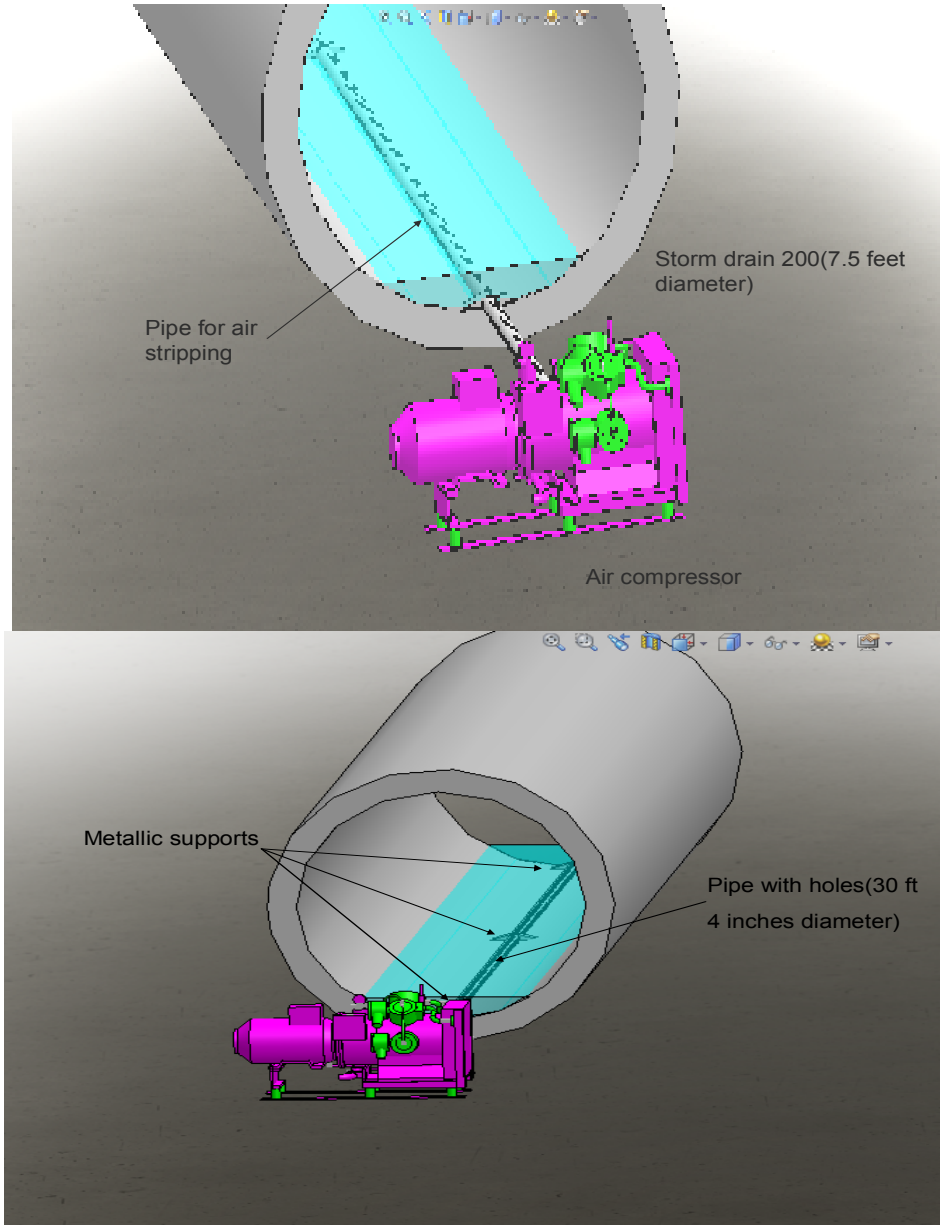


Figure 10. Hg flux after adding SnCl2 only in main storm drain.

7. DESIGN OF AIR SPARGING SYSTEM

Different calculations were made to design an efficient air sparging system in the main storm drain. The ideal pressure and the power of the compressor were determined (5HP), as well as the dimensions and the material of the air sparging pipe. This system, together with the application of the SnCl2, will reduce the concentration of mercury in the creek by more than 50%. The estimated annual cost for the air sparging system is $500. Adding approximately 10 kg/year of SnCl2 would cost $723/year. The total cost of the treatment will be around $1,123/year.



Figures 11 and 12. An air compressor stripping air into the storm drain pipe.

The air stripping pipe could have a length of 40 feet with 2-square-inches of holes for every foot, resulting in 80-square-inches of hole-area in each pipe. For the stripped air to go up through 4 inches of water, it needs 0.215 psi of pressure (0.43 psi in one foot of water). Calculating the major loss of pressure in the pipe by the Darcy-Weisbach equation:

H loss=□(l/dh)(dens*v^2/2) **Equation 7**

=0.015(12.2/0.1)(1.23*15*15/2)=253 Pa or 0.04 psi

where relative roughness=0.0002 feet (steel commercial pipe), □=0.015, density=1.23 kg/m^3, velocity=15 m/s, diameter=0.1m, length=12.2m.

The total pressure required is 0.215+0.04+10%=0.28 psi

Assuming an air-water ratio of 25:1, with 150 cfm of water, it will be necessary to provide 3,750 cfm of air with 10% loss. An air compressor of 5 HP using around 0.5 psi is recommended. For better results, more pressure per square inch is recommended but not a lot more because it could damage or move the air stripping pipe.

The diameter of the air stripping pipe could be 4 inches and the pipe could be made of metal or rubber (PVC should be avoided because the heat generated by the air compressor could damage the pipe). Pipe perforations should be small and loosely scattered near the supply and be larger and more densely spaced at the end. Particles could clog the pipe's holes, so periodic maintenance should be planned. The presence of Fe+2 (>15 mg/l) could generate a lot of Fe+3 when in contact with the air and this could clog the holes.

Air –flow ratio	**1:25**
Water flow rate	**150 cfm**
Air flow rate	**3750 cfm**
compressor	**5hp**
Air Pressure	**0.3psi**

8. CONCLUSIONS AND FUTURE RESEARCH

Stannous chloride (SnCl2) is an excellent reductor of concentration of mercury in water because it rapidly reacts with inorganic mercury to form dissolved gaseous mercury. The results of the experiments showed that a very low concentration of reductant (~5ug/L Sn (II)) were able to convert 75% of the mercury in the outfall to volatile Hg(0), but that excess de-chlorinating agent (HCl) interfered with the reaction. Using sodium thio-sulfate as an alternative de-chlorinator did not interfere with the reaction.

Sunlight and temperature are important parameters in the conversion of mercury. Sunlight rapidly oxidized Hg (0) to Hg (II) and, for that reason, the removal of Hg(0) from water had to occur in the absence of sunlight. During the summer months, when the aquatic life is more active, the concentration of mercury dissolved in the creek water is higher than in the winter months, probably because there is more agitation in the water. The curve obtained using the mathematical model is in good agreement with the curves based on experimental data. The model predicted that 35% of the mercury in the outfall could be removed by natural volatilization in a well-ventilated pipe. To achieve more effective removal of mercury, volatilization would have to be enhanced by in situ air stripping which would remove more than 50% of the mercury. The combination of techniques analyzed in this study could be economically feasible and practical to reduce mercury in EFPC but more calculations and research are necessary to implement this system on a larger scale. Monitoring of the performance of the air stripping system is recommended. Future research is necessary to determine the factors that cause a variation in the quantity of mercury coming from the Y-12 site. In addition, further studies are recommended to determine how the production of methyl-mercury is distributed in the creek.

9. REFERENCES

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