Impact of atmospheric deposition on the headworks of a wastewater treatment plant – a case study

K.Z. Atasi*, G. Fujita**, G. Le Platte**, C. Hufnagel*, G. Keeler***, J. Graney**** and T. Chen*

*McNamee, Porter & Seeley, Inc. – A Tetra Tech Company, 220 Bagley Ave., Suite 710, Detroit, MI 48226, USA

**Water Quality Division, Detroit Water and Sewerage Department, 6425 Huber, Detroit, MI 48211, USA

***School of Public Health, The University of Michigan, Ann Arbor, MI, USA

****The State University of New York at Binghampton, Binghamton, NY, USA

Abstract Specialized sampling equipment and ultra-clean analytical methodology were employed to quantify the concentrations or fluxes of mercury (Hg), cadmium (Cd) and polychlorinated biphenyl (PCBs) in ambient air, precipitation, runoff, sanitary sewer, and wastewater treatment plant (WWTP) influent. The relationship between the atmospheric deposition and runoff on controlled surfaces were explored for the three pollutants. The impact of the atmospheric deposition and runoff to the headwork loading of the WWTP were investigated. Atmospheric deposition was found to be the primary source of the mass of Cd, Hg, and PCBs in runoff from the controlled surfaces. Neither atmospheric deposition nor the runoff was the main sources of the three pollutants to the Detroit Wastewater Treatment Plant (WWTP). Wet weather flow contributes the main portion of the Cd, Hg, and PCBs loading to the WWTP.

Keywords Air deposition; non-point sources pollution; diffuse sources; mercury; cadmium; PCBs; WWTP headworks; water quality based effluent limits (WQBEL)

Introduction

The City of Detroit Water and Sewerage Department (DWSD) has performed a study to assess the impact of atmospheric deposition of mercury (Hg), cadmium (Cd), and polychlorinated biphenyl (PCB) on surface runoff and combined sewer system and POTWs headwork loading. Previous studies have shown that atmospheric deposition represents a significant portion of the total load to major water bodies, such as the Great Lakes. The study attempts to correlate the atmospheric, a diffuse and transboundary source of pollution to POTWs loading, therefore, to answer to the following key questions:

- What is the contribution of atmospheric deposition to runoff?
- What are the concentrations of the studied pollutants in the air, in rainfall, and in runoff?
- What are the concentrations of the studied pollutants in the WWTP flows?
- What is the contribution of atmospheric deposition to the headwork loading at the WWTP?
- What is the contribution of atmospheric deposition to the WWTP during wet weather events?

Methodology

The monitoring network consisted of three sampling sites located in three distinct geographic areas and land use types within the City. One site was situated in each of a heavy industrial area (Livernois Center, or LV), a light industrial area (St. Maron's Church, or SMC), and a residential/park area (Rouge River Park, or RRP). The industrial sites were intended to determine a "worst-case" scenario for atmospheric deposition and loading impact, relative to residential site which would be expected to provide background level of

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atmospheric deposition. Limited sanitary wastewater sampling was conducted in a residential neighborhood to identify background concentrations of the pollutants present in the sanitary sewage.

This monitoring plan thus allowed for identification of "background" pollutant concentrations in the atmosphere, as well as the localized urban signal within portions of the City of Detroit where monitoring was performed. Some limited sampling of streets with heavy traffic was added to identify the potential significance of the additional component of direct impact sources. This paper used the sampling results from impacted street surfaces for developing quantitative estimates. Further sampling of streets in the future could be performed to refine the estimates contained herein.

Field sampling and sample concentration used very meticulous ultra-clean techniques. all analyses are done in an ultra clean state-of-the-art laboratory. Air and water samples collected for Hg were analyzed by the University of Michigan Air Quality Laboratory (UMAQL) using cold-vapor atomic fluorescence spectrometry with gold trap that allows detection limits to picogram (10^{-12}) levels. Air and water samples collected for Cd were analyzed by UMAQL using inductively coupled plasma mass spectrometry (ICP-MS) that allows detection limits to 0.002 parts per billion (ppb) levels.

Air and water samples collected for PCBs were analyzed for congener-specific determination by the University of Michigan Environmental Chemistry Laboratory and MPS Laboratory, using a high resolution (capillary) gas chromatograph/electron capture detection (HRGC/ECD) technique, that allows detection limits up to parts per trillion levels. All field and laboratory activities followed a strict Sampling and Analysis Quality Assurance Project Plan (SAQAPP) prepared for the study.

Over 2700 samples were collected from the 3 sites (with 4 sampling stations). Ambient and vapor phase (for mercury), dry deposition, wet deposition, storm runoffs, sewage samples were collected. Each site had a full meteorological station to monitor the weather conditions (e.g. wind speed and direction, air moisture and temperature). The atmospheric deposition equipment, was mounted on a deck 10 feet above the ground. Storm runoff flow was monitored using ultrasonic flow measurement devices. Storm water samples were collected using programmable automatic sampling equipment interfaced with the primary flow measurement device. Each site is equipped with a telemeter system to download flow and meteorological data. Ambient air monitoring used active PS-1 units. A speciality design ambient monitoring unit for the mercury was devised by Dr. Keeler of the University of Michigan. Wet Deposition utilized a MIC sampler and dry deposition used the EAGLE-III sampler designed by Dr. Thomas Holsen of the Illinois Institute of Technology.

Results

What are the concentrations of the studied pollutants in the air, in rainfall, and in runoff? What is the concentration of the studied pollutants in the DWWTP flows?

The ranges of the monitored PCB concentrations from different media are shown in Figure 1.

The lowest overall aqueous concentrations were in precipitation for Cd, Hg, and PCBs. Controlled runoff concentrations were similar to or slightly higher than precipitation. Impacted site runoff concentrations were between 2 to 4 times the controlled site concentrations for all parameters. Sanitary and combined wastewater concentrations were in general higher than or similar to the impacted runoff concentrations. Concentrations monitored at the headworks of the DWWTP were the highest. The concentrations of PCBs in the DWWTP influent were several orders of magnitude higher during wet weather flow than during dry weather flow on several occasions.

There were clear trends in pollutant concentrations in both air and aqueous media based on the surrounding land use, as shown in Figure 2. In general, the pollutant levels were highest at

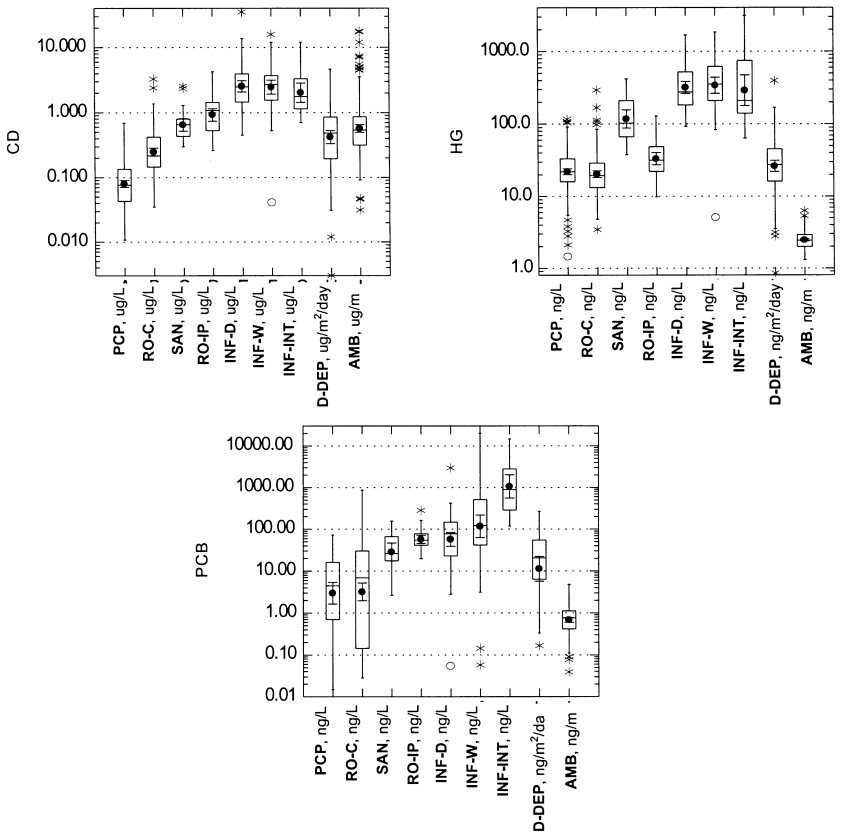


Figure 1 Pollutant concentrations by media

Note: 1. AMB = Ambient; D-DEP = Dry Deposition; PCP = Precipitation; RO-C = Controlled Site Runoff; RO-IP = Impacted Site Runoff; INF-D = dry weather WWTP influent; INF-W = wet weather WWTP influent; INF-INT = wet weather WWTP influent intensive. 2. The low and upper edges of the box represent 25th and 75th percentiles; while the middle cross line represents the 50th percentile of the monitored concentrations. The two whiskers represent the minimum and maximum excluding the outliers. The asterisks and circles represent the outliers and far outliers which are defined as beyond 1.5 and 3 times the length of the box (the difference between 25th and 75th percentile values), respectively. 3. The dark DOT represents the mean of the data and the two dark lines represent the 95% confidence estimation of the mean value

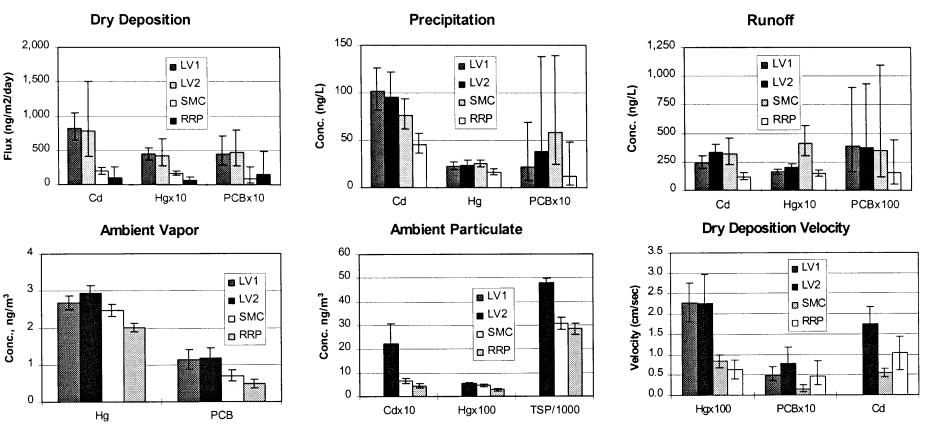
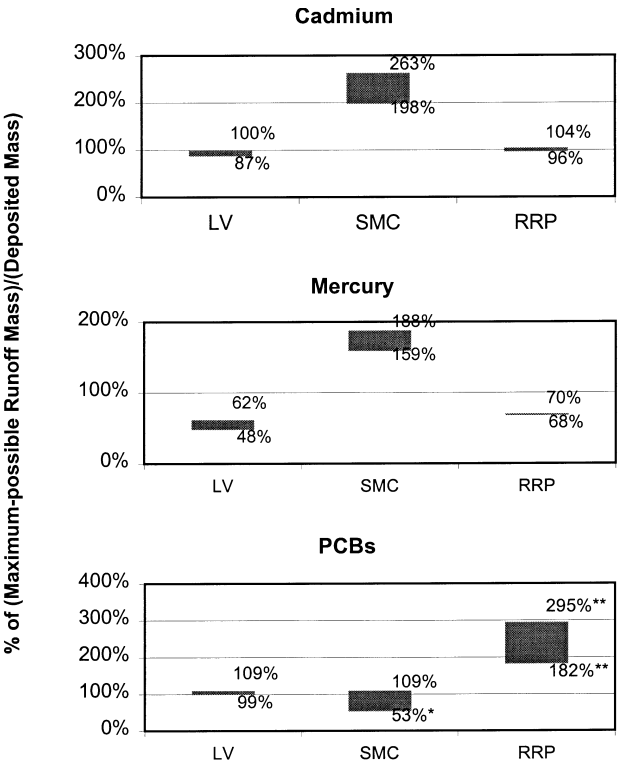


Figure 2 Monitored pollutant concentrations at three monitoring sites



Note: * if excluding the maximum value of the daily dry deposition mass which may have skewed the estimation.
** with insufficient data at this site.
***A value of 100% (such as Cd at LV, RRP and PCBs at LV, SMC) means a complete translation of the deposition mass to the liquid media and absence of additional sources or loss due to surface interaction, etc. A value over 100% (such as Cd and Hg at SMC) may suggest additional sources, and a value less than 100% (such as Hg at LV and RRP) indicates surface interaction (acting as a "sink").
**** the ranges of data represent the results from several calculation methods.

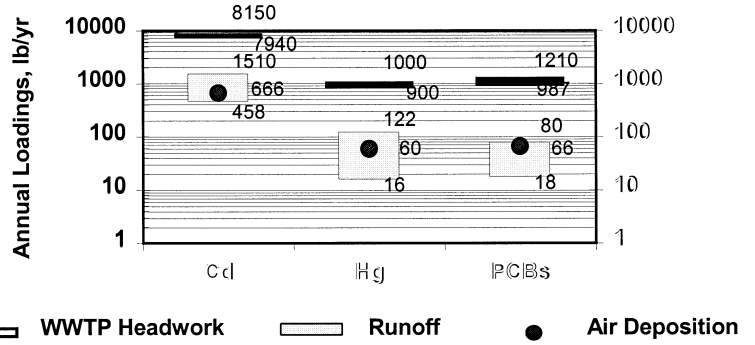
Figure 3 Mass relationship between air deposition and runoff among the three sites

the industrial site and were lowest at the residential site. Exceptions were that PCB concentrations in precipitation and runoff did not show a spatial trend; while Hg concentration in runoff at SMC was higher than the other sites which is believed to be due to traffic impacts.

What is the contribution of atmospheric deposition to runoff?

For comparison among the three sites, contribution of air deposition to surface runoff is estimated by the percentage of maximum-possible runoff mass to air deposition mass. The results are summarized in Figure 3. A value of 100% (such as Cd at LV, RRP and PCBs at LV, SMC) would mean a complete translation of the deposition mass to the liquid media and absence of additional sources or less due to surface interaction, etc. A value over 100% (such as Cd and Hg at SMC) may suggest additional sources, and a value less than 100% (such as Hg at LV and RRP) indicates surface-air interaction (acting as a "sink").

Where traffic impact was minimal (such as in LV and RRP sites), the air deposition mass was found to be the sole source of the runoff mass for Cd, Hg, and PCBs. Runoff contained less than 30% of the air deposited Hg mass, and less than 70% of the deposited Cd or PCBs masses. Where traffic impact was significant (as in SMC site), the Cd and Hg masses in runoff could be up to 2 times the controlled site Cd and Hg masses. However, the limited data showed no significant impact from the traffic on the PCB mass in runoff.



Note: The lower bound estimation of the runoff mass used data collected at controlled site only, while the upper bound (a maximum possible scenario) used the impacted runoff concentration and the precipitation volume (instead of the runoff volume)

Figure 4 Estimated annual pollutant loadings of air deposition, runoff, and DWWTP headwork

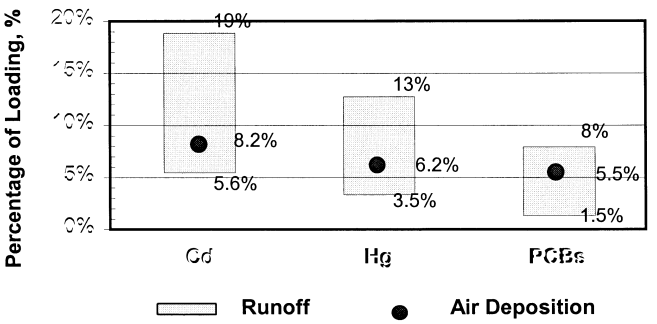


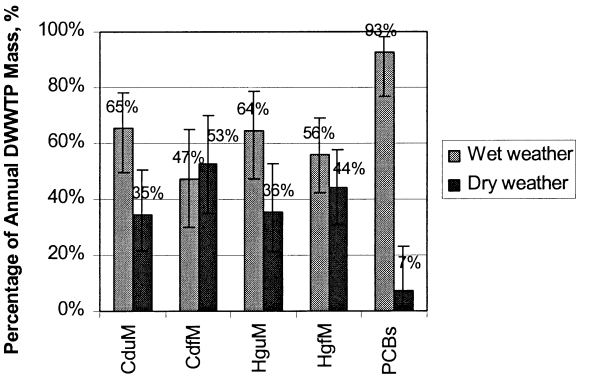
Figure 5 Estimated mass contribution from air deposition to the DWWTP headwork

What is the contribution of atmospheric deposition to the headwork loading at the DWWTP?

Figure 4 summarizes the estimated annual loadings of Cd, Hg, and PCBs in runoff, from air deposition and to the DWWTP headwork, employing several different calculation methods as shown by the ranges of the estimation. For example, the lower bound estimation of the runoff mass used data collected at the controlled site only, while the upper bound (a maximum possible scenario) used the impacted runoff concentration and the precipitation volume (instead of the runoff volume).

About 8,000 pounds of Cd, 1,000 pounds of Hg, and 1,200 pounds of PCBs were estimated to be in the DWWTP headwork loading annually. In comparison, the low estimates for atmospheric deposition and runoff contributions to the DWWTP are 458, 16, and 18 pounds for Cd, Hg and PCBs, respectively. The high estimates from atmospheric deposition and runoff to the DWWTP are 1,500, 120, and 80 pounds. These high estimates at DWWTP headworks are higher than the estimated air deposited mass of 666, 60, and 66 pounds, because the former used a “maximum-possible” approach that could be overestimated. Also, adjustments made for additional sources to the dry and wet depositions (such as traffic impact source) could have increased the DWWTP headwork loading estimates.

The percentages of the air deposition contribution to the DWWTP headwork of Cd, Hg, and PCB are shown in Figure 5. The low estimation is that the contributions from air deposition to the DWWTP headwork are 5.6%, 3.5%, and 1.5% of Cd, Hg, and PCBs, respectively; the high estimation is 19%, 13%, and 8%.



Note: CduM – Total Cd; CdfM – Dissolved Cd; HguM – Total Hg; HgfM – Dissolved Hg; PCBs – Total PCBs

Figure 6 Percentages of wet and dry weather masses in DWWTP headwork

Table 1 Comparison of DWSD's water quality based discharge limits with precipitation and runoff

Item	Hg	Cd	PCB
DWSD NPDES water quality based discharge limit[1]	1.8 ng/l	5 µg/l	0.02 ng/l
Detection limit for DWSD NPDES permit[2]	200 ng/l	n/a (<5 µg/L)	500 ng/l
Sanitary/combined sewer	103	660	26
	(40–400)	(310–2020)	(5–102)
Observed concentration – precipitation[3]	22	77	4.5
	(7.9–57)	(24–350)	(0.068–50)
Observed concentration – runoff (controlled surface)[4]	19.5	218	6.9
	(8.6–59)	(66–1,010)	(0.035–167)
Observed concentration runoff (uncontrolled)	31.7	1,080	54.3
surface)[5]	(13.5–80)	(52–2,820)	(24–149)

Note: 1. DWSD draft NPDES permit; 2. MDL requirements per DWSD draft NPDES permit; 3. and 4. Median and 95% confidence range; 5. Limited data set available

What is the contribution of atmospheric deposition to the DWWTP during wet weather events?

Wet weather flow (including the sanitary flow component of the wet weather) contributes more mass of Cd, Hg, and PCB to the WWTP headwork than the dry weather flow mass. As shown in Figure 6, over 90% of the PCB mass to the DWTTP headwork was from wet weather flow.

Compare the monitored liquid media concentration to the water quality standards

Table 1 compares the monitored various aqueous pollutant concentrations with the WQBEL.

The concentrations of Hg and PCBs in any monitored media have exceeded the WQBEL for Hg and PCBs. Therefore, from the compliance of the EQBEL point of view, both the controllable (i.e., sanitary sewer) and non-controllable source (i.e., air deposition) prevent the DWWTP from achieving WQBEL.

Conclusions

1. Spatial differences in pollutant concentrations were evident among the three sites. Pollutant concentrations at the heavy industrial site (LV) were generally higher than light industrial (SMC) and residential (RRP) sites for most pollutants.

2. Median and volume-weighted concentrations of Cd, Hg, and PCBs are highest in the wet component of the WWTP influent, particularly for PCBs. The most dramatic difference was in PCBs, with 10 to 30 times higher concentrations during wet weather. Impacted runoff concentrations are 15 to 80% lower than the dry weather DWWTP influent concentrations. Residential sanitary samples contained significant amounts of Cd and Hg, although less than DWWTP influent concentrations. Precipitation and runoff from controlled surfaces had the lowest concentration levels.
3. Air deposition was the primary source of the mass of Cd, Hg, and PCBs in runoff from the controlled runoff surfaces where traffic impact is minimal.
4. The conclusion of this study indicates that neither atmospheric deposition nor runoff is likely a significant contributor to Cd, Hg, or PCBs mass at the DWWTP (for Detroit). The annual contribution from atmospheric deposition and runofff to the WTTP headworks is estimated to be 3.5% to 13%, 5.6% to 19%, and 1.5% to 8.0% for Hg, Cd, and PCBs, respectively.
5. A major portion of the annual WWTP influent load was associated with wet weather events for each of the pollutants. A key portion of this mass cannot be directly associated with runoff or atmospheric deposition.
6. All liquid media sampled during this study (precipitation, runoff, sanitary sewer, combined sewer overflow, and WWTP influent) had a higher concentration of Hg and PCBs than the WQBEL of 1.8 ng/L and 0.02 ng/L, respectively, while none of the liquid media types exceeded the WQBEL for Cd of 5 μg/L.

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