Mercury budget for stormwater conveyances in the San Francisco Bay Area: Towards achieving TMDL management goals for sediment and fish tissue

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Introduction

Concentrations of mercury (Hg) in fish tissue and the water and sediment of San Francisco Bay pose human and ecological health risk. Our local Regional Water Quality Control Board (RWQCB) has developed a Total Maximum Daily Loads (TMDL) report that calls for a 48% reduction in Hg loads entering the Bay from stormwater conveyances. This is a difficult prospect given there is little local data on the distribution of Hg contamination across land uses in the Bay Area and little understanding of how Hg enters stormwater. Further, there is virtually no information on the effectiveness of municipal source, treatment, and maintenance control programs to remove Hg. It is not clear to stormwater managers how to meet three associated permit goals:

1. Demonstrate Hg mass removed / loads avoided

2. Reduce sediment concentrations in discharges to below 0.2 mg/kg

3. Demonstrate a downward trend in Hg load

This project was designed to assist our RWQCB and the Bay Area Stormwater Agencies Association (BASMAA) to reach consensus on how to best address TMDL goals.

Methods

Given the lack of detailed local data on the sources, concentrations and loads, storage, and removal mechanisms of Hg in stormwater in the Bay Area, an extensive review of world literature was used to develop a mercury mass balance model (budget) (Figure 1). The following equation constrains the movement of Hg mass through the Bay Area stormwater conveyance systems:

Instruments
+
Batteries
+
Switches
+
Lighting
+
Laboratory
+
Paint
+
Gasoline
+
Other Hg Uses
+
Chlor-alkali
-
Storage
-
Street Sweeping
-
Inlet Cleaning
-
Maintenance Dredging
=
Stormwater Conveyance ± Error

Each term in the budget was estimated using local data where available or by scaling estimates for California or the United States based on population. Total Hg input estimates were scaled down using reasonable estimates of losses or storage within the system following a conceptual model (Figure 2). Local data from a few counties on maintenance sediment removal and associated concentrations were extrapolated up to the nine counties of the Bay Area and all these estimates were compared with the TMDL estimate of Hg loads. The resulting outcomes provided an excellent framework for discussing source control options. In order to address treatment control and maintenance options, the data organized by source in the budget were reorganized by land use. This provided a semi-independent check of the assumptions that went into the Hg budget.

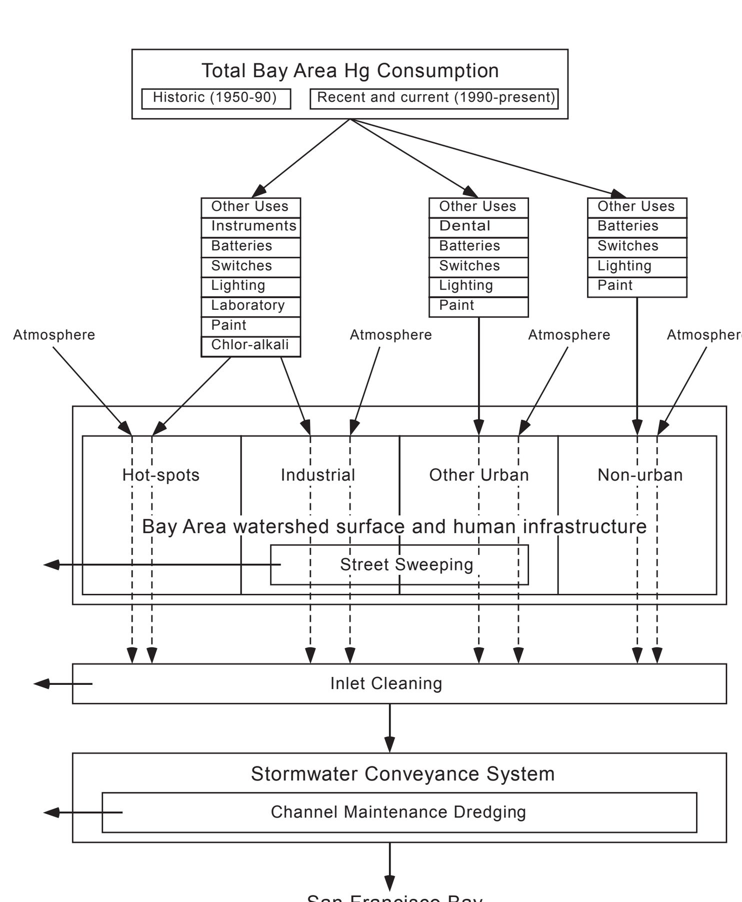

Figure 1. Conceptual model for Hg input into watershed areas of San Francisco Bay. Boxes represent storage in the system. Arrows show direction of mass flow. Dashed lines indicate partial mass transfer.

Results

Based on our best estimates, the hierarchical importance of various sources is: Watershed Surface Sediment Erosion > Atmospheric Deposition > Instruments > Bed and Bank Erosion > Switches and > Thermostats > Fluorescent Lighting > Paint > Railway Lines > Industrial Hotspots (Figure 3 and Table 1). These results imply that source control programs, even if increased, will not reach the TMDL target for loads reduction. It appears that maintenance or treatment activities will be needed.

The preliminary test on the effectiveness of maintenance activities (Table 2) suggested about 9 kg are currently removed from the system by sweeping and facility cleaning and these could conceivably be increased. Increasing channel de-silting is not likely to be the best option given regulations (section 404 and section 401 in the Clean Water Act, and the section 1600 series in the California Department of Fish and Game code).

Reorganizing the data by land use provided a better prediction of how Hg is dispersed in the Bay Area. We estimate about 66% of the mercury enters the stormwater conveyances from residential, commercial and industrial land uses (Figure 4). Our work also provided a hypothesis about unit loadings (Figure 4; Table 3) at the individual storm sewer outfall scale. We predict that industrial areas release about 92 g Hg/km^2/y, a magnitude not dissimilar to our prediction for commercial areas and about 3.5x greater then residential and 7x greater than open space land use (Table 3). These hypotheses appear to be slightly greater than those found in the literature, however, there are few studies of urban systems at scales of 10s of hectares to a few km^2 with which our hypotheses would be truly comparable.

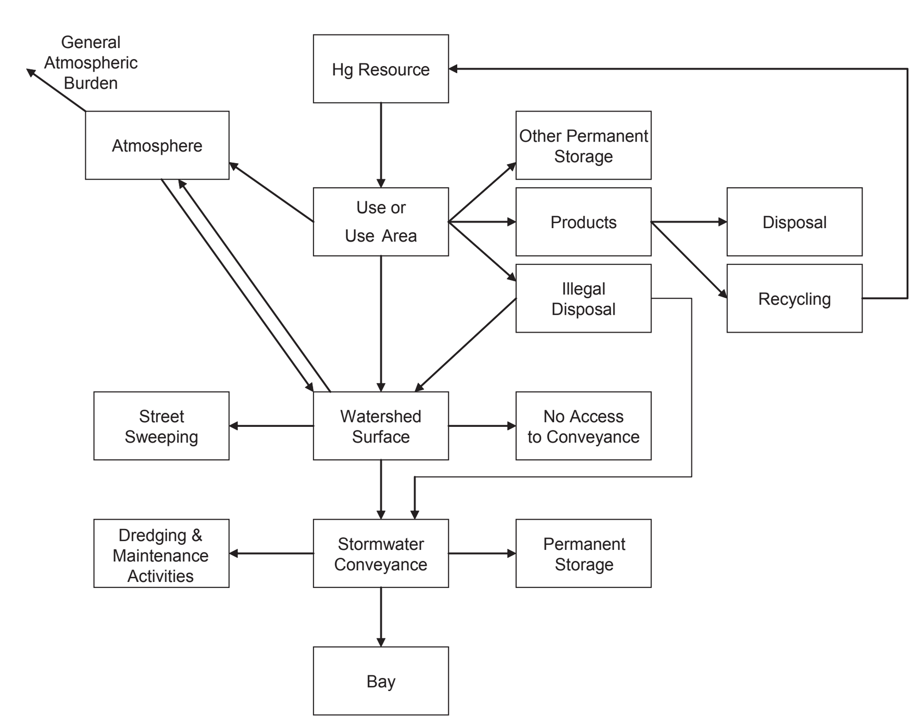

Figure 2. Conceptual model of flow of Hg through the urban environment to San Francisco Bay.

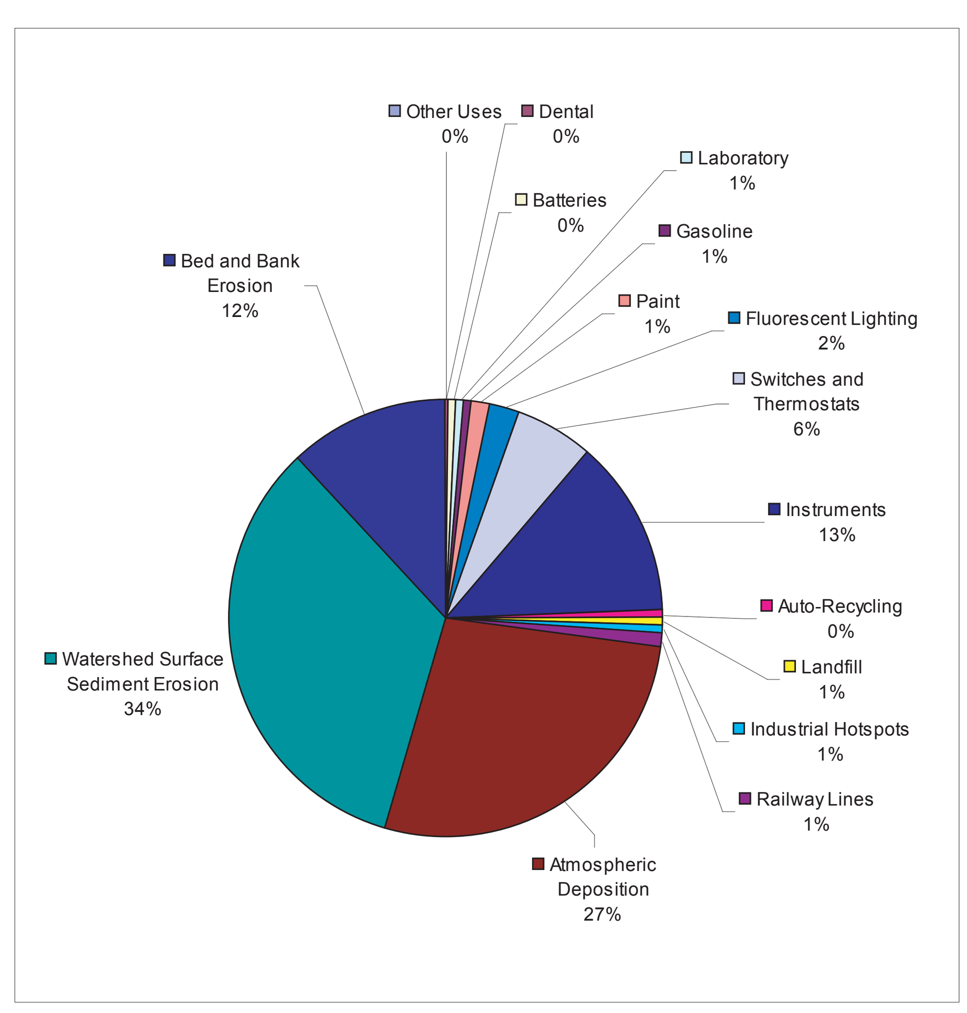

Figure 3. Comparison of mass input of Hg to Bay Area stormwater conveyances based on our best current estimates.

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Table 1. Summary of mass input of Hg to Bay Area stormwater conveyances.

Source	Low		High		Best	
	(kg)	(%)	(kg)	(%)	(kg)	(%)
Watershed Surface Sediment Erosion	30	39.5	182	36.1	59	34
Atmospheric Deposition	20	26.3	93	18.4	48	27
Instruments	8	10.5	28	5.6	23	13
Bed and Bank Erosion	4.1	5.4	160	31.7	21	12
Switches and Thermostats	9	11.8	11	2.2	10	5.7
Fluorescent Lighting	2.4	3.2	5.8	1.1	4.1	2.3
Paint	1	1.3	4	0.8	2.6	1.5
Railway Lines	0.09	0.1	3	0.6	1.5	0.9
Industrial Hotspots	0.25	0.3	7.4	1.5	1.4	0.8
Landfill	0.5	0.7	1.5	0.3	1	0.6
Laboratory	0.2	0.3	1.4	0.3	1	0.6
Gasoline	0.1	0.1	2	0.4	1	0.6
Batteries	0.15	0.2	1.5	0.3	0.8	0.5
Auto-Recycling	0	0.0	3	0.6	0.7	0.4
Dental	0.2	0.3	0.6	0.1	0.4	0.2
Other Uses	0.006	0.0	0.18	0.0	0.09	0.1
	76	100	504	100	176	100

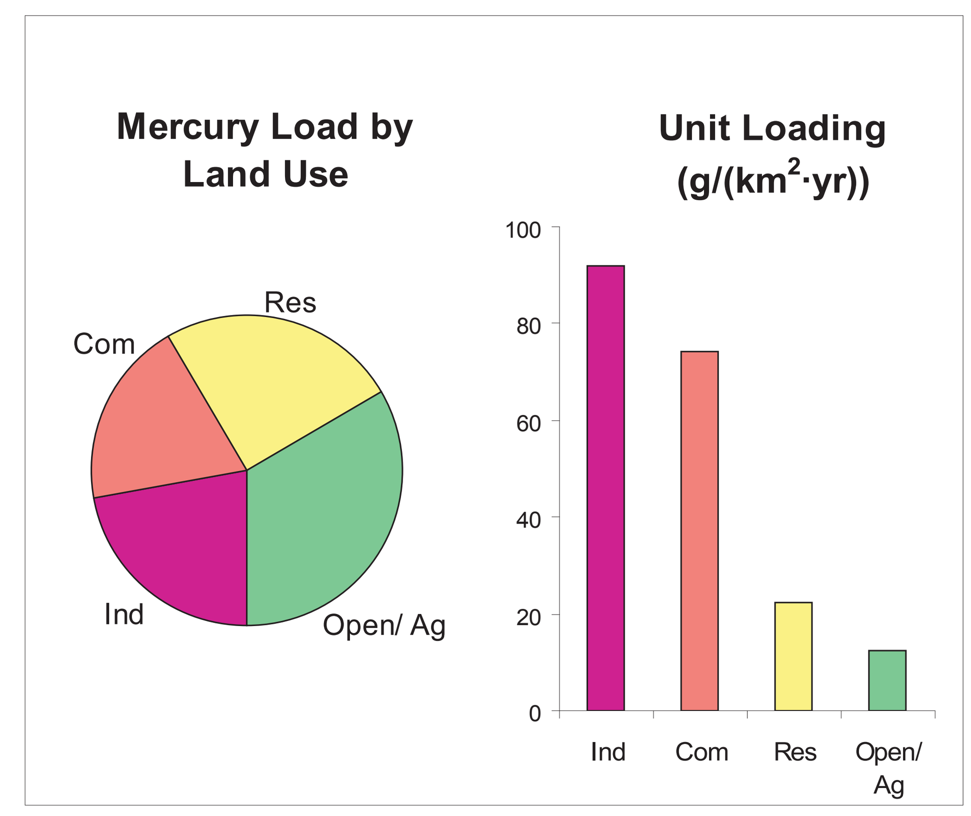

Figure 4. Annual mercury load and unit loading to the stormwater system by land use.

Next Steps

In the next phase of the project, the study team will take approximately 400 measurements of Hg in bed sediment and storm water in selected stormwater sewers focusing on industrial and commercial areas. Our objective is to improve our understanding of the distribution of Hg in the environment and to gather data on Hg in 3 grainsize fractions (<25, 25-75, and >75 micron). These data will be used to understand Hg sources and the potential for treating stormwater. Ultimately, in the last project phase, we will work with RWQCB and BASMAA to develop an implementation plan for the Hg TMDL that includes feasible solutions for reducing Hg loads to San Francisco Bay.

Table 2. Stormwater conveyance Hg budget based on estimates of inputs, removals and outputs in kg. Note output (load to the Bay) is from the Hg TMDL – there are no estimates of the error associated with this number.

	Low Estimate	High Estimate	Best Estimate
Watershed input	76	504	176
Street Sweeping Removal	2.5	8	5
Storm drain Facility Cleaning	2.1	6.3	4
Channel De-silting	33	165	84
Load to the Bay	160	160	160
Error / Unaccounted	-121.6	164.7	-77

Table 3. Mercury lad to the stormwater system by land use.

Land Use	Load (kg/yr)	Area (km^2)	Unit Loading (g/km^2/yr)	Unit Loading Normalized on Open Space
Industrial	34	374	92	7
Commercial	30	404	74	6
Residential	39	1,726	22	2
Open/ Agriculture	52	4,147	12	1
Total	155			

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