

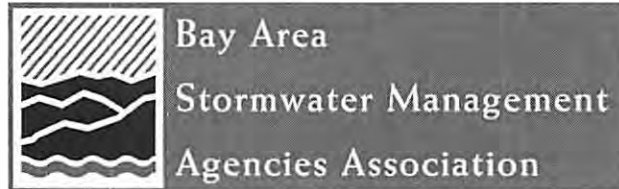
---

**Scoping Study of Air Deposition  
Monitoring Information Relevant to  
Water Quality of San Francisco Bay**

**Final Report: September 1998**

---

**B A S M A A**



Prepared by James Hauri  
San Francisco Estuary Institute

## **Note to Readers**

The uncertainty of the air deposition loading estimates presented in this report cannot be overemphasized. These estimates are based on earlier estimates that used relatively arbitrary assumptions regarding deposition velocities, and very little, if any, empirical air quality data for the San Francisco Bay Area. The uncertainty of the urban runoff and total pollutant loading estimates is relatively lower than the air deposition loading estimates because they are based, at least in part, on empirical data collected over several years. Overall however, the reader should consider the data and conclusions presented in his report as extremely preliminary, and researchers should check all assumptions and information sources presented here.

## TABLE OF CONTENTS

NOTE TO READERS .....	i
TABLE OF CONTENTS.....	ii
LIST OF TABLES .....	iii
INTRODUCTION.....	1
BAAQMD/ARB MONITORING INFORMATION.....	1
POLLUTANT LOADINGS INTO SAN FRANCISCO BAY.....	2
Review of Previous Estimates .....	2
New Preliminary BASMAA Estimates .....	4
ACCURACY OF LOADING ESTIMATES .....	5
EMISSION ANALYSIS .....	6
SOURCE ANALYSIS .....	9
CONCLUSIONS AND RECOMMENDATIONS .....	10
ACKNOWLEDGMENTS .....	12
REFERENCES .....	12
OTHER RESOURCES .....	13
APPENDIX A - SUBSTANCES MEASURED IN THE BAY AREA.....	16
APPENDIX B - LIST OF CONTACTS.....	17
APPENDIX C.....	18
New Tasks that came out of the meeting on August 4, 1997.....	19
APPENDIX D - EXCERPT ON ATMOSPHERIC DEPOSITION FROM 1987 AHI REPORT.....	20

## LIST OF TABLES

Table 1: Compounds thought to be a concern in SF Bay and measured by ARB or BAAQMD ...	2
Table 2: Compounds thought to be a concern in SF Bay, but not measured by ARB or BAAQMD .....	2
Table 3: Estimated total pollutant loading into San Francisco Bay .....	3
Table 4: Theoretical South San Francisco Bay metal concentration in rainfall .....	4
Table 5: BASMAA preliminary revision of City of San Jose estimate of atmospheric metal loading to San Francisco Bay South of the Dumbarton Bridge .....	5
Table 6: Preliminary estimated percent of mean annual runoff load into San Francisco coming from indirect atmospheric deposition.....	6
Table 7: Estimated metal concentration in PM <sub>10</sub> from the San Francisco Bay Area .....	7
Table 8: Estimated metal emissions vs. estimated deposition for South San Francisco Bay .....	8
Table 9: Estimated metal emissions from Santa Clara County vs. estimated deposition into San Francisco Bay south of the Dumbarton Bridge .....	8

## **Introduction**

Air deposition has been shown to be an important source of pollutants to surface waters around the country, specifically in Tampa Bay, the Great Lakes, and Chesapeake Bay. As a result, water quality agencies have become increasingly concerned that aerial deposition of pollutants may be a significant loading pathway to San Francisco Bay as well.

The purpose of this report is to:

- 1) review air monitoring activities conducted by the Bay Area Air Quality Management District (BAAQMD), Air Resources Board (ARB), United States Geological Survey (USGS), and other agencies to determine if current monitoring is adequate for the needs of the Bay Area Stormwater Management Agencies Association (BASMAA), and
- 2) make recommendations for cooperative efforts between water and air quality agencies including additional sampling and analysis if appropriate.

This report refers to pollutant deposition that directly falls onto the surface of San Francisco Bay as direct deposition or direct atmospheric loading. Pollutant deposition that falls on roads and other impervious surfaces and that are then flushed into the Bay via stormwater runoff will be referred to as indirect deposition or indirect atmospheric loading. Indirect deposition (as well as direct deposition) can include both deposition of particles that have been in the air column long enough and high enough to be measured by air monitoring instruments, and particles that fall immediately to the ground (or water) before they can be measured by a traditional air monitoring equipment. These latter particles, which generally are larger in size than particles of human health concern ( $PM_{10}$ ,  $PM_{2.5}$ ), are not always thought of as air pollutants, but they can be transported over various distances by air currents.

## **BAAQMD/ARB Monitoring Information**

A list of compounds currently measured by BAAQMD and ARB in the air of the San Francisco Bay Area was compiled (see Appendix A). Since not all of the monitored compounds are also water pollutants, the list of measured air compounds was compared to a list of water pollutants of concern compiled by the Aquatic Habitat Institute (SFEP, 1991). Table 1 is a list of measured compounds that are a concern in both air and water. All of these compounds are either metals or polycyclic aromatic hydrocarbons (PAHs). Table 2 shows pollutants thought to be of concern to San Francisco Bay, but which are not measured by either air agency.

**Table 1: Compounds thought to be a concern in SF Bay<sup>1</sup> and measured by ARB or BAAQMD**

<u>Metals</u>	<u>PAHs</u>
Arsenic	Benz(b)fluoranthene
Cadmium	Benz(k)fluoranthene
Chromium	Benz(g,h,i)perylene
Copper	Benzo(a)pyrene
Lead	Dibenzo(a,h)anthracene
Mercury*	Indeno(1,2,3-c,d)pyrene
Nickel	
Selenium	
Zinc	

\* Hg air data thought to be invalid due to method  
<sup>1</sup> SFEP, 1991

**Table 2: Compounds thought to be a concern in SF Bay<sup>2</sup>, but not measured by ARB or BAAQMD**

Polychlorinated biphenyls (PCBs)
Chlorinated pesticides
Carbamates
Dioxins
Organophosphate pesticides
Hexachlorobenzene (HCB)
Hexachlorohexane (HCH)

<sup>2</sup> SFEP, 1991 and RWQCB, 1997

## **Pollutant Loadings into San Francisco Bay**

### **Review of Previous Estimates**

Preliminary calculations conducted ten years ago indicated that air deposition was not a large problem (AHI, 1987). However, as the authors of that report noted – the uncertainty of those air deposition loading estimates cannot be overemphasized. In the early 1990s, several attempts were made at estimating pollutant loadings into San Francisco Bay. These are the 1992 State of the Estuary Report (SFEP, 1992), a 1991 City of San Jose Report, and a 1991 study by the Aquatic Habitat Institute (AHI) (SFEP, 1991). The first two reports, however, based most of their loading values on the study by AHI (SFEP, 1991). Table 3 contains the compiled loading data from this

1991 report. The values for atmospheric deposition for all three studies came from AHI (1987). Note that the atmospheric pollution estimates, except for PAHs, are very low compared to the total loading into the Bay. These atmospheric deposition numbers have a high level of uncertainty because of the lack of available data.

**Table 3: Estimated total pollutant loading into San Francisco Bay (metric tons/year)**

Compound	Total loading		% of total loading from direct atmospheric deposition	
	Low	High	Low	High
Arsenic	25	147		
Cadmium	3	14	1	12.5
Chromium	211	1594		
Copper	219	762	0.4	1.4
Lead	130	712	0.8	16
Mercury	0.4	3		
Nickel	72	98		
Selenium	7.4			
Silver	3	7		
Zinc	375	2003		
PCBs	0.007	0.4		
Total HC	1100	11000	0.02	0.05
Total PAHs	1	10	8	91

Source: SFEP, 1991

In 1996, the City of San Jose conducted a review of available literature on atmospheric deposition in support of potential pilot studies. Gross estimates of atmospheric deposition to South San Francisco Bay were also made (City of San Jose, 1996b). The City of San Jose estimated that air deposition accounts for only a small fraction of the total pollutant load. In these estimates, wet deposition was assumed to be equal to dry deposition based on a report by Wu *et al.* (1994). However, studies in Washington, D.C. (WRPB and MWCG, 1983), and in England (Revitt *et al.*, 1990) have shown that this is not necessarily the case. The Washington, D.C., study found wet deposition to be much more important than dry deposition for the removal of copper and zinc from the atmosphere. The study conducted in England found that lead and zinc were primarily deposited by wet processes. Presently there are no wet-deposition data available in the literature for the San Francisco Bay Area. Fog has also been reported to

increase the deposition of pollutants, but again, no available data are available for the San Francisco Bay Area.

### New Preliminary BASMAA Estimates

To calculate an estimate for pollutant loading, the 1996 City of San Jose report assumed that about 10% of the material deposited on paved surfaces would be transported by runoff into receiving waters. Since this transport fraction number was chosen somewhat arbitrarily, for this report the transport fraction value was increased to 20% based on findings from Revitt *et al.*, 1990. This value may not be any more accurate than the 10% value, and thus it contributes to the overall uncertainty of an estimate of pollutant loading into San Francisco Bay.

Since no data seem to exist for metal concentrations in rainwater, numbers were generated by transforming air concentration data from the San Francisco Bay Area using a ratio of rain concentration/air concentration for the Chesapeake Bay Region (Table 4). This transformation assumes that the air/rainwater ratio of metals will be constant between the two sample sets which is not necessarily true given the different weather patterns between the regions. Therefore, the accuracy of this assumption determines the usefulness of these generated concentrations.

**Table 4: Theoretical South San Francisco Bay metal concentration in rainfall (actual concentrations could be much different due to different rain conditions in the SF Bay Area)**

Metal	South San Francisco Bay air concentration (ng/m <sup>3</sup> ) <sup>3</sup>	Chesapeake Bay rain concentration/air concentration [(µg/L)/(ng/m <sup>3</sup> )] <sup>4</sup>	Estimated South San Francisco Bay concentration in rain (µg/L)
Cr	5.3	0.29	1.5
Cu	17.7	0.16	2.8
Pb	12	0.13	1.6
Ni	5.2	0.11	0.57
Zn	42.4	0.13	5.5

<sup>3</sup> ARB data average of Fremont and San Jose stations (City of San Jose, 1996)

<sup>4</sup> Chesapeake Bay Program, 1996

BASMAA's revised preliminary estimate of metal loading into San Francisco Bay south of the Dumbarton Bridge indicates a slightly higher pollutant loading of metals into South San Francisco Bay (Table 5).



Both the BASMAA and the 1996 City of San Jose loading estimates indicate that metals deposited on roads and carried to the Bay in runoff are more important than direct deposition of metals. The major difference between the BASMAA estimate and the City of San Jose estimate is the use of a higher transport fraction (i.e., 20% vs. 10%) which gives a higher importance to the runoff load and the inclusion of a wet-deposition fraction. It is possible that the actual transport fraction could be much higher or lower, thereby changing the runoff loading estimate. As previously noted, these estimates should be considered extremely preliminary.

**Table 5: BASMAA preliminary revision of City of San Jose estimate of metal loading to San Francisco Bay South of Dumbarton Bridge**

Metal	Estimated <u>indirect</u> atmospheric deposition to SF Bay south of Dumbarton Bridge via storm runoff (kg/yr) <sup>5</sup>	Estimated <u>direct dry</u> deposition to SF Bay surface south of Dumbarton Bridge (kg/yr) <sup>6</sup>	Estimated <u>direct wet</u> deposition to San Francisco Bay surface south of Dumbarton Bridge (kg/yr) <sup>7</sup>	Estimated total atmospheric deposition contribution to pollutant loading to SF Bay south of Dumbarton Br. (kg/yr)	Estimated total mean annual pollutant loads <sup>8</sup> (kg/yr)	Estimated % of total pollutant loading from atmosphere
	a	b	c	(a+b+c) = d	e	d/e = f
Cr	138	23	24	185	3,270	~6%
Cu	276	46	44	366	4,007	~9%
Pb	180	30	24	234	3,518	~7%
Ni	84	15	9	108	7,561	~1%
Zn	640	107	86	833	20,968	~4%

<sup>5</sup> Revised City of San Jose loading with 0.2, instead of 0.1 as pollutant transport factor

<sup>6</sup> Revised City of San Jose estimated dry deposition assuming 265 days of dry deposition

<sup>7</sup> Wet deposition (kg/yr) = [Surface area(km<sup>2</sup>)] [Estimated atmospheric metal conc. in SF Bay Area (mg/L)] [Avg. rainfall (in/yr)] [conversion factor(25.4)]

<sup>8</sup> Taken from (SCVURPPP, 1997)

Assumed surface area of SF Bay south of Dumbarton Bridge = 41 km<sup>2</sup>

Average rainfall in South SF Bay south of Dumbarton Bridge assumed to be 15 in/yr

## Accuracy of Loading Estimates

In terms of the indirect atmospheric loading from vehicles, some data are available for comparisons. Runoff accounts for approximately 60% to 90% of the chromium, copper, nickel, lead, and zinc loading to South San Francisco Bay below the Dumbarton Bridge (City of San

Jose, 1991). The total mean annual pollutant loads from the 1991 City of San Jose report can be used to calculate an approximate load to South San Francisco Bay from runoff. The percent of metals in runoff from atmospheric deposition can then be calculated. Table 6 shows that only 2% to 10% of metals in runoff seem to originate from atmospheric deposition. These numbers seem very low when compared against emission estimates. For example, deposition of copper in brake linings is thought to account for 42% of the total annual loading to South San Francisco Bay (SCVURPPP, 1997), yet the estimate based on air quality data (Table 6) shows that atmospheric deposition contributes only 10% of the total copper loading in runoff. More work needs to be done on estimating the indirect loading of atmospheric deposition through runoff. Therefore, these estimates should be considered extremely preliminary.

**Table 6: Preliminary estimated percent of mean annual runoff load into South San Francisco Bay coming from indirect atmospheric deposition (kg/yr)**

<b>Metal</b>	<b>Estimated indirect atmospheric pollutant loading to SF Bay south of Dumbarton Bridge via runoff <sup>9</sup></b>	<b>Estimated mean annual loads from runoff to San Francisco Bay, south of Dumbarton Bridge <sup>10</sup></b>	<b>Estimated percentage of runoff loading from indirect atmospheric deposition</b>
Cr	138	2,983	~ 5 %
Cu	276	2,891	~ 10 %
Pb	180	3,257	~ 6 %
Ni	84	5,507	~ 2 %
Zn	640	10,584	~ 6 %

<sup>9</sup> City of San Jose, 1991

<sup>10</sup> SCVURPPP, 1997

## **Emission Analysis**

Another check of the 1996 City of San Jose loading figures entails estimating the emissions of metals around the Bay Area and then comparing emissions with deposition loading estimates. Metal concentrations in PM<sub>10</sub> particles were approximated using 1995–1996 ARB data from San Francisco Bay Area monitoring stations. The metal concentrations measured in air were divided by the PM<sub>10</sub> concentrations from the same site. Table 7 shows that most of the metal concentrations were similar from site to site. Exceptions included selenium which was lower in San Francisco and South Bay than in the East Bay; zinc, which was lower in San Francisco; and copper, which was higher in Concord. Some of these metal concentrations showed large standard deviations, particularly for copper and zinc at Concord. Metal analysis by ARB was done on the total suspended particulate (TSP) fraction, rather than PM<sub>10</sub>, which may have

introduced some uncertainty. Copper and zinc had a correlation coefficient of about 60% with PM<sub>10</sub> and nickel and PM<sub>10</sub> had a correlation coefficient of about 40%. Of course, there can be large differences in the metal concentrations in the particles depending on the emission source. Therefore, these estimates should be considered extremely preliminary.

**Table 7: Estimated metal concentration in PM<sub>10</sub> from the San Francisco Bay Area (mg/kg)**

Station	As	Cd	Cr	Cu	Pb	Ni	Se	Zn
Concord	31 $\pm$ 15	9 $\pm$ 4	204 $\pm$ 57	1,971 $\pm$ 3,615	441 $\pm$ 314	173 $\pm$ 69	169 $\pm$ 112	2,359 $\pm$ 2768
Fremont	30 $\pm$ 13	9 $\pm$ 6	188 $\pm$ 69	798 $\pm$ 439	364 $\pm$ 166	154 $\pm$ 59	141 $\pm$ 72	1,793 $\pm$ 907
Richmond	32 $\pm$ 25	11 $\pm$ 8	325 $\pm$ 380	788 $\pm$ 478	543 $\pm$ 305	199 $\pm$ 78	176 $\pm$ 87	2,014 $\pm$ 899
San	22 $\pm$ 9	11 $\pm$ 7	176 $\pm$ 55	594 $\pm$ 232	522 $\pm$ 229	204 $\pm$ 94	112 $\pm$ 43	727 $\pm$ 204
San Jose	32 $\pm$ 10	8 $\pm$ 3	201 $\pm$ 50	653 $\pm$ 252	435 $\pm$ 142	205 $\pm$ 51	84 $\pm$ 36	1,744 $\pm$ 520

Source: Based on unpublished 1995–1996 ARB air monitoring data

For comparison with the South of the Bay Bridge deposition estimates, emission analysis was done on the four counties adjacent to the South Bay (Alameda, San Francisco, San Mateo, and Santa Clara). The South of Dumbarton Bridge deposition estimate was compared to the Santa Clara County emission analysis. Metal emissions were calculated by multiplying county-wide PM<sub>10</sub> emission estimates from the ARB emissions inventory by the metal concentration in PM<sub>10</sub> particles from Table 7. No transport modeling was done on the emission estimate, so there is a potential overestimation of emissions for San Francisco Bay since some of the Bay Area emissions are not deposited in the Bay Area. These numbers will, however, generate rough figures to compare with the revised deposition estimates from this scoping study.

As seen in Tables 8 and 9, the estimated deposition load of metals, based on air quality data/estimates, is no more than 15% of the emitted metals estimates for the four South Bay counties and no more than 8% for Santa Clara County.

Along with the uncertainties inherent in the calculations, there is also a certain amount of uncertainty with the emission estimates. Seventy-five to 85% of the estimated PM<sub>10</sub> emissions from the counties are from paved and unpaved road dust, construction, residential fuel combustion, and miscellaneous area-wide processes. All of these sources are diffuse and may be difficult to estimate with great accuracy. It is important to note that the emissions inventory methodology has been revised, though the revised estimates for the San Francisco Bay Area have not yet been released. The revised methodology caused estimates of PM<sub>10</sub> emissions from construction and road dust to decrease by as much as 70% (California ARB, 1997). Therefore, the estimated fraction of emitted particles that are deposited in the Bay should be higher than reported here.

**Table 8: Estimated metal emissions vs. estimated deposition for South San Francisco Bay (kg/yr)**

Metal	Estimated total atmospheric metal emissions from South San Francisco Bay counties <sup>11</sup>		Estimated total contribution from atmospheric deposition to SF Bay South of Bay Bridge <sup>12</sup>	% of pollutant emissions from South SF Bay counties estimated to enter SF Bay via direct and indirect atmospheric deposition	
	Low	High		Low	High
As	785	1,718	55	3	7
Cd	179	635	21	3	12
Cr	5,963	10,993	881	8	15
Cu	13,004	42,981	1,950	5	15
Pb	12,072	27,853	1,148	4	10
Ni	5,601	11,599	469	4	8
Se	2,678	6,882	260	4	10
Zn	40,838	86,642	3,854	4	9

<sup>11</sup> South SF Bay Counties include San Francisco County, Alameda County, Santa Clara County, and San Mateo County. Emission data from BAAQMD, 1997b

<sup>12</sup> Revised City of San Jose, 1996 estimates based on methodology shown for Table 5. Assumed surface area of SF Bay south of Bay Bridge = 490 km<sup>2</sup>

**Table 9: Estimated metal emissions from Santa Clara County vs. estimated deposition into San Francisco Bay South of the Dumbarton Bridge (kg/yr)**

Metal	Estimated Santa Clara County pollutant emissions <sup>13</sup>		Estimated total contribution from atmospheric deposition to SF Bay South of Dumbarton Bridge <sup>14</sup>	% of pollutant emissions from Santa Clara County estimated to enter SF Bay via direct and indirect atmospheric deposition	
	Low	High		Low	High
As	337	647	12	2	4
Cd	71	173	4	2	6
Cr	2,347	3,904	185	5	8
Cu	6,260	14,098	366	3	6
Pb	4,561	9,000	234	3	5
Ni	2,400	3,992	108	3	5
Se	742	1,862	67	4	9
Zn	19,063	35,276	833	2	4

<sup>13</sup> Emission estimates from BAAQMD, 1997b

<sup>14</sup> Revised City of San Jose, 1996 estimates based on methodology shown for Table 5

## Source Analysis

In order to reduce the amount of pollutants in the air it is necessary to identify the source of the pollutants; there are elements that are produced by the same source that can be reduced together if the emitter is abated.

A winter time source analysis for two ARB monitoring sites in San Jose, including the ARB 4<sup>th</sup> Street site was done for the 1991–1992 winter season. The analysis showed that at that time, 24% to 87% of PM<sub>10</sub> emissions were due to residential wood combustion, 6% to 49% of the emissions were from road dust, 7% to 53 % from vehicle exhaust, and 3% to 40% from ammonium nitrate generated in the atmosphere (Chow *et al.*, 1995). This assessment differs from the emission inventory in that the inventory estimates that road dust is much more important than residential wood burning. The discrepancy, however, may be reduced when the revised emission inventory is completed.

Although Chow's calculations show that residential wood combustion is the primary PM<sub>10</sub> source, vehicle emissions might still be more important when particles that settle before they are measured in the air are taken into consideration. For this scenario, indirect loading of the atmospheric deposition via runoff would be the major transport mechanism. A potential tracer of this pathway is barium. Barium is reported to be 58% of the metal particles that are emitted from brake dust, vehicle exhaust, and tire dust (BAAQMD, 1997a), but was below the detection limit for 80% of the 1995–1996 ARB samples from the Bay Area (California ARB, 1995–1996). Barium was not measured in San Jose street dust either in a San Jose street sweeping experiment (City of San Jose, 1994) or by Chow *et al.*, 1995. It was, however, found to be present at a level of 310±54 ppm in urban street dust in Illinois (Hopke *et al.*, 1980). Barium is not a priority pollutant, and it is not usually measured in stormwater monitoring programs. However, experiments could be performed to determine if barium could be used as a tracer for vehicle emission transport from deposition on highways into stormwater and out into San Francisco Bay.

Another potential surrogate of anthropogenic pollution is PM<sub>2.5</sub> concentrations. Since combustion particles are on average smaller than particles with a geological source (Revitt *et al.*, 1990), PM<sub>2.5</sub> concentrations may give a more accurate picture of atmospheric transport of man-made emissions. Currently, PM<sub>2.5</sub> levels are not measured in the San Francisco Bay Area, however, new PM<sub>2.5</sub> regulations are expected to require the BAAQMD to begin monitoring for PM<sub>2.5</sub> in the near future. These data can then be used to distinguish combustion sources from geological sources and dust re-suspension. The PM<sub>2.5</sub> fraction will not be analyzed for toxics by the ARB, since they are interested only in TSP concentrations. If PM<sub>2.5</sub> concentrations of toxics

are desired, then ARB will need to be asked to do this additional measurement, or the analysis will have to be done by an independent party.

## **Conclusions and Recommendations**

The few studies that have addressed the role of atmospheric deposition in pollutant loading to San Francisco Bay indicate that deposition is not important compared to other pollutant transport mechanisms. A City of San Jose study reported atmospheric loading of metals as only 1% to 2% of the total pollutant loading. The revised preliminary BASMAA estimate in this report raised those estimates, but still atmospheric deposition was estimated to contribute no more than 9% of the total pollutant load for any given metal. Since very little deposition data are available, none of these studies involved anything more than rough calculations. Collecting San Francisco Bay specific data on pollutant deposition is necessary before its importance to total pollutant loading into San Francisco Bay can be determined. Until that work is done, the estimates and conclusions presented herein and in the other reports should be considered extremely preliminary.

Dry deposition data specific to San Francisco Bay would be useful to determine the role of atmospheric deposition in pollutant loadings. Deposition monitoring stations positioned on the surface of San Francisco Bay would give much more accurate information than the estimates that are currently being generated.

Wet deposition data would also provide invaluable information. The 1996 City of San Jose report discounted wet deposition, and this report used calculated values for the deposition estimates. Currently, the ARB runs an air sampling program that analyzes samples for concentrations of heavy metals, however, a similar sample collection and analysis program for rain samples does not exist.

On a fairly regular basis, toxic amounts of organophosphate pesticides are being measured in runoff throughout the Bay Area. Therefore, a study on pesticide transport and deposition is also important to consider. This report concentrated on metals since most of the available estimates were on metals. Information on concentrations of pesticides in Bay Area air would give regulators an idea of whether air transport is a problem in this area.

The ARB is not planning to analyze the PM<sub>2.5</sub> fraction for toxics. It might be useful to conduct such an analysis, either in collaboration with the ARB or through an independent study. Such an experiment would differentiate between the pollutants from anthropogenic sources and those from geological sources.

This report was unable to match indirect deposition estimates of copper with independent copper loading estimates, particularly with brake pad linings as the source. This difference, if it is substantiated by empirical data, indicates that there is a large amount of deposition on the roads of particles that never move high enough above the ground to be detected by air monitors. As suggested earlier, an investigation on whether barium would make a good tracer of vehicle emissions as they move toward the Bay in runoff might be useful. This type of investigation may involve a close to the ground air sampling/deposition study of barium to see how far it moves in the air before deposition. During the rainy season, especially early in the rainy season, barium in highway runoff and in urban creeks can be measured. The barium concentration can then be compared to zinc, copper, nickel, and other metals emitted from vehicles, to see if a correlation exists. If runoff appears to be the major transport pathway of deposited metals, then more controls on highway runoff can be implemented. Further, since several bridges cross San Francisco Bay, increased knowledge on pollutant deposition onto road surfaces could help in deciding how much pollution into the Bay is from bridges.

Finally, it has been asserted in other air deposition studies that pollutants falling directly onto water surfaces are more bioavailable and thus more toxic than pollutants that are flushed into receiving waters via runoff. An experiment measuring the speciation and toxicity of the pollutants falling directly onto water (direct deposition) and those in runoff (indirect deposition) would indicate whether direct atmospheric deposition of pollutants is more important ecologically than runoff, even considering a lower percentage of total pollutant loading comes from direct deposition.

## Acknowledgments

Charlie Blanchard

Geoff Brosseau, Bay Area Stormwater Management Agencies Association

Rainer Hoenicke, San Francisco Estuary Institute

Thomas Mumley, Regional Water Quality Control Board

Davis Sedlak, University of California, Berkeley

Eric Papp, City of San Jose

Lowell Asbaugh, University of California, Davis

## References

AHI (Aquatic Habitat Institute), 1987. *An Assessment of the Loading of Toxic Contaminants to the San Francisco Bay Delta*.

BAAQMD (Bay Area Air Quality Management District), 1997a. *Data on Heavy Metals*. Memo dated September 17, 1997. Bay Area Air Quality Management District, San Francisco, CA.

BAAQMD (Bay Area Air Quality Management District), 1997b. *Emissions Inventory*. BAAQMD web site (<http://www.baaqmd.gov/planning/specproj/summary.htm>).

California ARB (Air Resources Board), 1995–1996. Unpublished air monitoring data. California Air Resources Board, Sacramento, CA.

California ARB (Air Resources Board), 1997. *Emissions Inventory Methodology Draft*, California Air Resources Board, Sacramento, CA.

Chesapeake Bay Program, 1996. *Chesapeake Bay Atmospheric Deposition Study Final Report*. Chesapeake Bay Program, Annapolis, MD.

Chow, J., D. Fairley, J. Watson, R. DeMandel, E. Fujta, D. Lowenthal, Z. Lu, C. Frazier, G. Long, and J. Cordova. 1995. Source apportionment of wintertime PM<sub>10</sub> at San Jose, Calif., *Journal of Environmental Engineering* 378–387.

City of San Jose, 1991. *Site Specific Water Quality Objectives for South San Francisco Bay*. Larry Walker Associates and Kinnetic Laboratories Inc.

City of San Jose, 1994. *San Jose Street Sweeping Equipment Evaluation*. City of San Jose Nonpoint Source Program. Woodward-Clyde Consultants.



- City of San Jose, 1996a. *Atmospheric Deposition Literature Review – Draft*. Larry Walker Associates.
- City of San Jose, 1996b. *Gross Estimates of Atmospheric Deposition to South San Francisco Bay*. Larry Walker Associates.
- Hopke, P., R. Lamb, and D. Natusch, 1980. Multi-elemental characterization of urban roadway dust, *Environmental Science and Technology* 11, 164.
- Revitt, D., R. Hamilton, and R. Warren, 1990. The transport of heavy metal within a small urban catchment, *The Science of the Total Environment* 93, 359–373.
- RWQCB (Regional Water Quality Control Board), 1997. Staff Report.
- SCVURPPP 1997. *Metals Control Measures Plan (Volume I)*. Santa Clara Valley Urban Runoff Pollution Prevention Program. Woodward-Clyde Consultants.
- SFEP (San Francisco Estuary Project), 1991. *Status and Trends Report on Pollutants in the San Francisco Estuary*.
- SFEP (San Francisco Estuary Project), 1992. *State of the Estuary: A Report on Conditions and Problems in the San Francisco Bay/Sacramento-San Joaquin Delta Estuary*.
- WRPB and MWCG (Water Resources Planning Board and the Metropolitan Washington Council of Governments), 1983. *Urban Runoff in the Washington Metropolitan Area – Final Report*.
- Wu, Y., Z. Han, M. Lin, and Z. Chao, 1994. Chesapeake Bay atmospheric deposition study, year I: Sources and dry deposition of selected elements in aerosol particles. *Atmospheric Envir.* 28 (8): 1471.

## **Other Resources**

- Al-Rajhi, M., S. Al-Shayer, M. Seaward, and H. Edwards. 1996. Particle size effect for metal pollution analysis of atmospherically deposited dust, *Atmospheric Environment* 30(1) 145–153.
- Bullin, J., S. Bower, M. Hinz, and R. Moe. 1985. Aerosol near urban street intersection, *Journal of Air Pollution Control Association* 35(4) 355–358.

- Cass, G. and G. McRae. 1983. Source-Receptor reconciliation of routine air monitoring data for trace metals: An emission inventory assisted approach, *Environmental Science and Technology* 17(3) 130-139.
- Cha, S., P. Carter, and R. Bradow. 1983. Simulation of automobile brake wear dynamics and estimation of emission, *SAE Technical Paper Series*, Passenger Car Meeting, Dearborn, MI, June 6-9.
- Chow, J., J. Watson, J. Houck, L. Pritchett, C. Rogers, C. Frazier, R. Egami, and B. Ball. 1994. A laboratory re-suspension chamber to measure fugitive dust size distributions and chemical compositions, *Atmospheric Environment* 28(21) 3463-3481.
- Department of Environmental Programs: Metropolitan Washington Council of Governments. 1993. *Urban Runoff in the Washington Metropolitan Area: Final Report*.
- Fergusson, J. and D. Ryan. 1984. The elemental composition of street dust from large and small urban areas related to city type, source, and particle size, *The Science of the Total Environment* 34, 101-116.
- Gunther, A., C. Blanchard, and K. Gardels. 1991. *The Loading of Toxic Contaminants to the San Francisco Bay-Delta in Urban Runoff*.
- Huang, X., I. Olmez, and N. Aras. 1994. Emissions of trace elements from motor vehicles: Potential marker elements and source composition profile, *Atmospheric Environment*. 28(8) 1385-1391.
- Janssen, N., D. Van Mansom, K. Van Der Jagt, H. Harssema, and G. Hoek. 1997. Mass concentration and elemental composition of airborne particulate matter at street and background locations, *Atmospheric Environment* 31(8) 1183-1193.
- Morrison, G., D. Revitt, J. Ellis, G. Svensson, and P. Balmer. 1988. Transport mechanisms and processes for metal species in a gullypot system, *Water Research* 22(11) 1417-1427.
- Nicholson, K., and J. Branson. 1990. Factors affecting re-suspension by road traffic, *The Science of the Total Environment* 93, 349-358.
- San Francisco Estuarine Institute. 1996. *1995 Annual Report: San Francisco Estuary Regional Monitoring Program*. San Francisco Estuary Institute, Richmond, CA.
- Woodward-Clyde Consultants. 1991. *Alameda County Urban Runoff Clean Water Program: Loads Assessment, Summary Report*.

Woodward-Clyde Consultants. 1993. *Alameda County Urban Runoff Clean Water Program: Annual Monitoring Report FY 91-92.*

Wüst, W., U. Kern, and H. Reimer. 1994. Street wash-off behavior of heavy metals, polyaromatic hydrocarbons, and nitrophenols, *The Science of the Total Environment* 146/147, 457-463.

## Appendix A

### Substances Measured in the Bay Area

Criteria Pollutants	
Agency	Substance
1	Ozone
1	Nitrogen Dioxide
1	Sulfur Dioxide
1	Carbon Monoxide
1	Lead
1,2	PM <sub>10</sub>

VOCs	
Agency	Substance
2	Acetaldehyde
1,2	Benzene
1,2	1,3-Butadiene
2	Chlorobenzene
1,2	Carbon Tetrachloride
1,2	Chloroform
2	meta-Dichlorobenzene
2	ortho-Dichlorobenzene
2	para-Dichlorobenzene
2	Ethyl Benzene
1,2	Ethylene Dibromide
1,2	Ethylene Dichloride
2	Formaldehyde
1,2	Methylene Chloride
1,2	Methyl Chloroform
2	Methyl Ethyl Ketone
1	Methyl Tertiary Butyl Ether
1,2	Perchloroethylene
2	Styrene
1,2	Trichloroethylene
1,2	Toluene
1	Vinyl Chloride
2	meta/ para-Xylene
2	ortho-Xylene

PAHs	
Agency	Substance
2	Benzo(a)pyrene
2	Benzo(b)fluoranthene
2	Benzo(g,h,i)perylene
2	Benzo(k)fluoranthene
2	Dibenz(a,h)anthracene
2	Indeno(1,2,3-cd)pyrene

Metals	
Agency	Substance
2	Aluminum
2	Arsenic
2	Barium
2	Bromine
2	Calcium
2	Cadmium
2	Chlorine
2	Cobalt
2	Chromium
2	Hexavalent Chromium
2	Copper
2	Iron
2	Mercury
2	Potassium
2	Manganese
2	Molybdenum
2	Nickel
2	Phosphorus
2	Lead
2	Rubidium
2	Sulfur
2	Antimony
2	Selenium
2	Silicon
2	Tin
2	Strontium
2	Titanium
2	Uranium
2	Vanadium
2	Yttrium
2	Zinc
2	Zirconium

Agency 1 – Bay Area Air Quality Management District

Agency 2 – California Air Resources Board

## Appendix B

### List of contacts

#### Monitoring

Avi Okin (BAAQMD) (415) 749-4616

#### Criteria Pollutants

Mike Basso (BAAQMD) (415) 749-4613  
MB@merkle.BAAQMD.gov

#### Toxic Pollutants

Mike Redgrave (ARB) mredgrav@arb.gov  
Hanford Chew (BAAQMD) (415) 749-4633

#### Emissions

Stuart Schultz (BAAQMD) (415) 749-4993  
Toch Mangat (BAAQMD) (415) 749-4651  
Patrick Gaffney (ARB) (916) 322-7303

## Appendix C

Task 1: Compile reports and data from the Bay Area Air Quality Management District, the California Air Resources Board, and United States Geological Survey pertaining to the following pollutant categories and the importance of aerial transport and deposition: trace metals, PAHs, chlorinated hydrocarbons, organophosphates and other pesticides currently in use around the Bay Area.

- 1.1 Contact pertinent agency staff and obtain reports and raw data on air deposition and concentrations of trace metals and trace organic pollutants.
- 1.2 Review Atmospheric Deposition Literature Review conducted for the City of San Jose and fill gaps based on newly obtained information.
- 1.3 Conduct an inventory of air monitoring activities by the Bay Area Air Quality Management District, the Air Resources Board, and United States Geological Survey (if applicable) to determine if data can be used to evaluate what kinds of control mechanisms might be necessary/available and where they might be best applied.
- 1.4 Determine if current air quality monitoring activities by the San Francisco Bay Area Air Quality Management District or Air Resources Board are amenable to include additional analyses of interest by water quality agencies.

Task 2: Integrate information collected from air quality agencies with that of water quality agencies nationally and regionally to determine for which pollutants air may represent a significant transport and loading pathway and if rough loading estimates can be made for various pollutant categories.

- 2.1 Review Estuary loading reports and specific loading estimates from stormwater and point source discharges.
- 2.2 Estimate the contribution of direct aerial deposition of the above pollutant categories onto the Estuary surface relative to other source categories.
- 2.3 Evaluate if stormwater loadings from dry and wet deposition onto land surfaces can be estimated.

**New Tasks that came out of the meeting on August 4, 1997:**

1. Compare the emission of metals to the estimated atmospheric loading of those metals to San Francisco Bay in the Larry Walker Report. (part of Task 1.2 of GSA Work Plan).
  - a. Use ARB metal and PM<sub>10</sub> data to estimate an average metal concentration in the PM<sub>10</sub> particles.
  - b. Use ARB PM<sub>10</sub> emission data and estimated metal in PM<sub>10</sub> concentrations to estimate metal emissions from South Bay counties.
2. Determine whether high PM<sub>10</sub> events correspond to low/high wind days (part of Task 1 GSA Work Plan).
3. Find elemental tracers, metal ratios, or other surrogates to determine which source produced the metals (part of Task 2 GSA Work Plan).
4. Determine if the metal concentrations in TSP and PM<sub>10</sub> differ (part of Task 1 of GSA Work Plan).

**Appendix D**

**Excerpt on Atmospheric Deposition from:**

**An Assessment of The Loading  
of Toxic Contaminants to  
The San Francisco-Bay Delta:**

**Executive Summary**

**Andrew J. Gunther  
Jay A. Davis  
David J.H. Phillips**

**Aquatic Habitat Institute  
180 Richmond Field Station  
1301 S. 46th Street  
Richmond, CA 94804**

**August 26, 1987**



## 6. ATMOSPHERIC DEPOSITION

### A. Introduction

This section examines the loading of toxic chemicals into the Bay-Delta due to their deposition from the atmosphere. Through a variety of pathways, including combustion, evaporation, and suspension of dust, toxic substances enter the air in the Bay-Delta region. These materials can then be directly deposited into the waters of the Bay and Delta. Although atmospheric deposition is often assumed to be a small contributor of toxic substances when compared to runoff or point source discharges, this may not always be the case. Webber (1983) concluded that atmospheric deposition of hydrocarbons to Chesapeake Bay is of the same order of magnitude as hydrocarbon discharge from municipal wastewater treatment plants. Atmospheric deposition may supply as much as 90% of the total input of PCBs to Lakes Superior and Michigan (Eisenreich et al., 1981).

The loading of toxic substances to the Bay-Delta by atmospheric deposition has been estimated only twice previously and only for a few trace metals (SFBRWQCB, 1975; Eaton, 1979). Although atmospheric deposition was mentioned by Riseborough et al. (1978) as a source of toxic substances worth exploring, existing data were considered too unreliable for use in developing an estimate. Today there are still very few data on the atmospheric deposition of toxic chemicals in the Bay-Delta region. A major reason for this is the difficulty of measuring dry deposition of these materials; the uncertainty of loading estimates based on the measurements cannot be overemphasized.

This section: (1) presents a brief discussion of the nature of toxic contaminants in the atmosphere and their movement to

aquatic environments; (2) reviews existing data available to estimate loads; and (3) uses data from other regions of the country to derive preliminary estimates for the loading of some contaminants to the estuary.

#### B. Toxic Substances in the Atmosphere

Toxic substances in the atmosphere exist in the vapor phase, as vapors adsorbed on the surface of particles and as aerosols. Although trace metals have been long considered to exist in the atmosphere almost exclusively as aerosols, there is a growing body of evidence to suggest that this may not be the case, at least for certain elements. Harrison and Laxen (1978), for example, have measured significant concentrations of tetraalkyl lead at Morecombe Bay, United Kingdom, in patterns that suggest a source distinct from neighboring urban areas. It would appear that the source is bioalkylation of lead by bacteria in intertidal mudflats.

Organic substances are found in the atmosphere in the vapor phase (both free and adsorbed to particulates) and as aerosols. Factors influencing the partitioning between vapor and particulate phases include the vapor pressure of the substance and the size, surface area, and organic content of the particulates. The size of the particulates in question ranges from sub-micron levels to greater than 5 microns, although particulates in the latter class tend to settle rather quickly and are thus only important components of deposition close to sources. While some investigators have found up to 70% of the mass of organic particulates in the sub-micron fraction, high molecular weight species are detected in significant quantities associated with particles greater than one micron in diameter

(Eisenreich et al., 1981).

The physical state of toxic substances in the atmosphere exerts a profound influence upon their transport into aquatic environments. Atmospheric contaminants can enter aquatic environments in wet and dry deposition. Although gaseous molecules will diffuse into raindrops, this process is thought to be relatively unimportant compared to the removal of atmospheric particulates by rainfall (Eisenreich et al., 1981). Standardized methods for collection and analysis of precipitation allow for accurate determination of contaminant concentrations (see, for example, Galloway et al., 1982).

By contrast, measuring the movement of gases and particulate contaminants from the atmosphere to aquatic ecosystems by dry deposition is a much more difficult task. Contaminants in the gaseous phase will diffuse across the air-water interface until a chemical equilibrium is established between atmospheric and dissolved concentrations of the contaminant, and the equilibrium concentration in water can be calculated from atmospheric levels using Henry's Law. In practice, however, it is extremely difficult to measure dissolved concentrations of trace organics with the accuracy necessary to determine whether equilibrium concentrations have been achieved. This effort is further complicated by the constant removal of substances from the dissolved state in the aquatic environment.

The dry deposition of particles to aquatic environments is no less difficult to determine, despite extensive research into the topic in an effort to quantify the deposition of acidic particulates to ecosystems (Kerr, 1981). The mechanism of particle deposition is influenced by particle size (diameter) and

includes Brownian diffusion ( $<0.3 \mu\text{m}$ ), interception-impaction ( $0.5\text{-}5 \mu\text{m}$ ), and gravitational settling ( $>5 \mu\text{m}$ ). In practice, particle fluxes can be estimated as the product of atmospheric concentration and deposition velocity, but the latter term is influenced by the deposition surface, particle size distribution, and wind speed. Attempts to measure deposition velocity in the field are often confounded by gaseous diffusion and can easily vary by a factor of six (Eisenreich et al., 1981).

Atmospheric deposition of contaminants is often estimated by measuring bulk deposition (the combination of wet and dry deposition to a collector). A prewashed container is placed at a site, often for a month at a time, and the contents assumed to represent wet and dry deposition of contaminants. This method is thought to underestimate total deposition to aquatic ecosystems by factors between 2 to 10 through inadequately measuring dry deposition (Eisenreich, 1980). This is due in part to the effects of different surfaces on deposition, and also to the influence of particle size and micro-meteorology (Eisenreich et al., 1981).

### C. Loading Estimates

Estimates of the flux of toxic contaminants into the Bay-Delta ecosystem due to atmospheric deposition, which are the basic component of loading calculations, can thus be determined in two ways. One method is to use measurements of the concentration of various particulates in the atmosphere of the region in combination with a reasonable estimate of deposition velocities to determine the flux from dry deposition. These are then added to wet deposition measurements to determine total flux. This method is subject to the uncertainty of the values

used in the calculation, which can be significant. A second method is to use direct measurements of wet and dry deposition, such as bulk deposition monitoring, to determine contaminant flux to the estuary. As mentioned above, however, bulk deposition monitoring can significantly underestimate dry deposition.

In both instances, the flux estimate is multiplied by the water surface area of the Bay-Delta to estimate loads, as atmospheric deposition to the rest of the catchment is accounted for in estimates of runoff and river inputs. Both methods need to be supplemented by a calculation of the molecular diffusion of gaseous contaminants, which is very important for certain chemical species. Eisenreich et al. (1981) point out that, theoretically, 90% of the atmospheric burden of PCBs should be in the vapor phase, and field measurements basically confirm this calculation. Despite the potential for other substances to diffuse into the aquatic environment, even Eisenreich et al. (1981) simplify their loading calculations by combining gaseous and particulate concentrations of all substances except PCBs. Part of the reason for doing this is the difficulty in actually measuring the particulate and gaseous fractions for different organic substances in the atmosphere.

Eaton (1979) estimated the loading of zinc, copper, and nickel to the estuary using a method of approximation that is claimed to be roughly equivalent to direct deposition measurements. He utilized the concentration data of John et al. (1973), taken for a single day from nine sites around San Francisco Bay, and assumed that this atmospheric burden to a height of five kilometers is deposited on the Bay by each of 40 storms annually (Table 71). Although this procedure is driven by

**Table 71. Previous Estimates of Atmospheric Deposition of Toxic Substances to San Francisco Bay. All values in metric tons yr<sup>-1</sup>.**

---

	Eaton (1979)	SFBRWQCB (1975) <sup>c</sup>
Copper	10	12.2
Nickel	1	2.5 <sup>b</sup>
Zinc	30	63 <sup>b</sup>
Mercury		0.24 <sup>b</sup>
Lead		282 <sup>a</sup>
DDT Compounds		0.32 <sup>a</sup>
PCBs		0.32 <sup>a</sup>

a: wet and dry deposition

b: wet deposition only

c: Table 15-15 in SFBRWQCB (1975)

wet deposition, the loading estimate is assumed to represent total deposition. (Table 71 also contains deposition estimates of the Regional Water Quality Control Board [SFBRWQCB, 1975]. Unfortunately, the methods used to calculate these estimates are not described.)

It would be most advantageous to obtain measurements of direct deposition to determine how well this approximation, which the author (Eaton, 1979) acknowledges as somewhat arbitrary, actually matches deposition in the Bay Area. Of course, given the uncertainty of direct deposition measurements, even such verification would still leave much unresolved uncertainty. In addition, the data of John et al. (1973) vary up to a factor of 20 between stations for zinc, indicating that additional sampling is advisable to establish appropriate mean values to use in such calculations. It also should be noted that, while cited as such by Eaton (1979), the data of John et al. (1973) contain no measurement of nickel concentrations in the atmosphere of the Bay Area.

Estimates of the loading of hydrocarbons from the atmosphere have been made for the Hudson Raritan estuary in New York (Connell, 1982), Chesapeake Bay (Webber, 1983), and the Great Lakes (Eisenreich et al., 1981). Although the uncertainties are recognized, this report applies the deposition rates from these studies to provide a preliminary estimate for the Bay-Delta region for hydrocarbons (Table 72) and trace metals (Table 73). These estimates assume a surface area for the Bay of 1,240 km<sup>2</sup> (Conomos et al., 1985), and the flux for the hydrocarbon species in the Great Lakes as derived from Table 7 of Eisenreich et al.

**Table 72. Preliminary Estimates for Atmospheric Depositions of Hydrocarbons to San Francisco Bay. Bay Surface Area = 1,240 km<sup>2</sup> (Conomos et al., 1985).**

---

Source/Site	Substance	Flux (kg km <sup>-2</sup> yr <sup>-1</sup> )	SF Bay Loading (tonnes yr <sup>-1</sup> )
Webber (1983) Chesapeake Bay	total hydrocarbons	36.5 <sup>a</sup>	45
Connell (1982) Hudson Raritan Estuary	Petroleum hydrocarbons	1.7 <sup>b</sup>	2.1
Eisenreich <u>et al.</u> (1981) Great Lakes	total PAHs	0.65-3.9	0.80-4.8
	PCBs	0.1-0.7	0.12-0.87

a: average of rural and urban sites (100 μg m<sup>-2</sup> d<sup>-1</sup>)

b: derived from 6x10<sup>5</sup> tonnes yr<sup>-1</sup> of petroleum hydrocarbons to world's oceans (NAS, 1975)



**Table 73.** Preliminary Estimates of Atmospheric Deposition of Trace Metals to San Francisco Bay Through Application of Fluxes for Lake Michigan. Flux values in  $\text{kg km}^2 \text{yr}^{-1}$ , loads in tonnes  $\text{yr}^{-1}$ . Calculations assume surface area of Lake Michigan = 58,000  $\text{km}^2$ , with area of North and South Basins equaling one-half this total. Source: Eisenreich (1980) Table II. SF Bay surface = 1,240  $\text{km}^2$  (Conomos *et al.*, 1985)

---

	LOW <sup>a</sup>		HIGH <sup>b</sup>	
	Flux	Load	Flux	Load
Cadmium	0.11	0.14	.28	.35
Copper	1.5	1.9	2.5	3.1
Lead	4.8	6.0	17.2	21.3
Zinc	12.8	15.9	25.5	31.6

a: Calculated using data from the north (rural) basin of Lake Michigan

b: Calculated using data from the south (urban) basin of Lake Michigan

(1981) by assuming a surface area for the Great Lakes of 246,000 km<sup>2</sup> (Nalco Chemical Company, 1979). It is assumed that the water surface area of the Delta is sufficiently small relative to the Bay to be safely disregarded.

The estimates derived in Table 72 are, as expected, quite variable. Connell (1982) utilized a deposition estimate developed by the National Academy of Science (NAS) of 600,000 tonnes yr<sup>-1</sup> of petroleum hydrocarbons to the world's oceans (NAS, 1975) to derive a flux of 1.7 kg km<sup>-2</sup> yr<sup>-1</sup>. The loading estimate of 2.1 tonnes yr<sup>-1</sup> generated utilizing this flux is substantially less than the 45 tonnes yr<sup>-1</sup> estimated using the data of Webber (1983). Contributing to this difference is the fact that a global average deposition rate would undoubtedly underestimate the deposition in urbanized estuaries. In addition, the total hydrocarbon flux of Webber (1983) includes biogenic hydrocarbons, which have been shown to be a significant fraction of hydrocarbon deposition in several studies (Wakeham, 1977; Matsumoto and Hanya, 1980; Webber, 1983). It might seem reasonable to assume that the actual input of toxic organic substances to the San Francisco Bay-Delta by atmospheric deposition is within the range defined by those two estimates (2.1-45 tonnes yr<sup>-1</sup>). Given the uncertainty in dry deposition estimates, however, it is possible that the high end of this range could still be underestimated.

The estimates of PCBs and PAHs in atmospheric deposition derived for this report from Eisenreich et al. (1981) are worthy of comment. The estimated range for PCB loading was derived using the range for PCB fluxes in urban areas of the Great Lakes region provided by the authors (0.1-0.7 kg km<sup>-2</sup> yr<sup>-1</sup>). (It should be noted that, unlike the other estimates in Table 72, the

figure for PCBs includes gaseous diffusion of PCBs from the atmosphere into the water column.) This number is of the same order of magnitude as the estimate of SFBRWQCB (1975), which appears in Table 71. The estimated range for mass loads of PAHs to the estuary from atmospheric deposition was obtained by first calculating the flux for PAHs used by Eisenreich et al. (1981). The authors state that this flux,  $1.96 \text{ kg km}^{-2} \text{ yr}^{-1}$ , was derived by selecting a deposition velocity of  $0.3 \text{ cm sec}^{-1}$  from a possible range of  $0.1$  to  $0.6 \text{ cm sec}^{-1}$ . The range for loading in Table 72 was thus derived by recalculating the flux of  $1.96 \text{ kg km}^{-2} \text{ yr}^{-1}$  using the above range for deposition velocities. The estimate of  $0.8$ - $4.8 \text{ tonnes yr}^{-1}$  of PAHs is relatively large given the magnitude of other sources of these substances to the estuary. This suggests, when considered with the estimate of  $5 \text{ tonnes yr}^{-1}$  of PAHs in urban runoff (Section II.2 above), that atmospheric deposition as a source of PAHs to the estuary merits further investigation. The estimates for PAH mass loading from both of these sources, however, are highly uncertain.

Table 73 presents estimates for atmospheric deposition of trace metals to San Francisco Bay using fluxes derived from the work of Eisenreich (1980) on Lake Michigan. A range is presented based upon data from the rural northern basin and the more urbanized southern basin of the Lake. It is most interesting that the estimates so derived for deposition of copper and zinc to San Francisco Bay are rather less than the approximations of Eaton (1979), particularly for copper (Table 71). The loading estimate for lead derived from the Lake Michigan data is much less than the previous estimate (SFBRWQCB, 1975). As the data

from Lake Michigan are from 1975-1976, it would be expected that these data would give rise to an overestimation of current lead deposition, given the reduction in the lead content of gasoline over the last decade.

The loading estimates for copper, cadmium, zinc, and lead (Table 73) and total hydrocarbons (Table 72) are certainly smaller than the estimated loads of these contaminants from point sources, runoff, and rivers discussed in Sections 1 to 4 above. Although there is significant uncertainty associated with many of these loading estimates, it seems reasonable to assume that atmospheric deposition is a relatively unimportant source of total hydrocarbons and trace metals to the estuary.

The uncertainty of these estimates for atmospheric deposition of toxic contaminants to San Francisco Bay cannot however, be overemphasized. Deriving data from the respected work of Eisenreich (1980) and Eisenreich et al. (1981) in the Great Lakes area is of interest in judging the potential magnitude of this source in the Bay Area. Due to the uncertainty in these calculations, however, such data must be considered extremely preliminary. The difference in climates between the Bay-Delta region and the Great Lakes means that the proportion of contaminant loads delivered in wet and dry deposition will vary between the two regions. Given the difficulty of estimating dry deposition, utilizing deposition estimates from the Great Lakes could lead to inaccurate data for the Bay-Delta region. Differences in regional fuel sources and the coastal location of the Bay-Delta could also lead to differences in contaminant concentrations in the atmosphere.

#### D. Conclusions

Toxic chemicals are present in the atmosphere in the Bay-Delta region and reach the waters of the estuary in both wet and dry deposition. As atmospheric concentrations vary considerably and dry deposition is extremely difficult to measure accurately, a significant degree of uncertainty is associated with estimates of the loading of toxic substances to the estuary by atmospheric deposition.

Loading estimates for San Francisco Bay have been made in the past for a few toxic substances using relatively arbitrary assumptions regarding deposition velocities. These estimates indicate that atmospheric deposition is a relatively small source of toxic contaminants to the Bay-Delta ecosystem. As a comparison to previous loading estimates, a new range of values for atmospheric loading was generated for this report using fluxes for toxic contaminants derived from extensive research in the Great Lakes region. These new estimates are somewhat lower than the earlier values, but differences in climate and possibly atmospheric composition in the two regions limit the accuracy of estimates for San Francisco Bay based upon data from the Great Lakes. These new estimates reinforce the concept that atmospheric deposition is a relatively unimportant source of toxic substances to the estuary, with the possible exception of PAHs and PCBs.