

Air Meets Water: Atmospheric Deposition on the Horizon

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Abstract

Metals released from industrial processes, vehicle emissions, construction sites, and other sources exist as particles in the air. They settle directly into receiving water bodies or onto streets and rooftops and are then washed into water bodies with urban runoff. In this study, air quality computer models of the transport and fate of metals in the Los Angeles region indicated that atmospheric deposition may be a significant source of metals to local water bodies. The findings are that nearly all the metals deposited on impervious urban surfaces wash off with the next rainfall, but on more natural land surfaces, between 20% and 30% of the metals are sequestered from immediate runoff. Recommendations to deal with the effects of atmospheric deposition on water quality include modifying air quality regulations to allow greater consideration of water quality impacts, reducing known sources of airborne metals, regulating land uses to minimize exposure to these contaminants, and expanding air quality monitoring to include identified water pollutants.

Anyone who has dusted a room or washed a car has encountered the effects of atmospheric deposition. Pollutants in the atmosphere can deposit on all of the solid surfaces of a watershed and then can be washed off by rain, becoming part of the stormwater runoff that reaches rivers, lakes, and coastal waters. Pollutants may also be deposited directly from the atmosphere onto the surface of a water body. A secondary, but important, reason to be concerned about atmospheric deposition is that pollutants that are not washed off may accumulate on surfaces such as soil, forming a reservoir of toxic substances that may later be resuspended back into the air, causing a threat to human and ecosystem health even after the original sources of the pollutant have been removed.

Substances exist in the atmosphere either as molecules of gases or as solid or liquid particles, called aerosols, that range in size from 0.001 to 100 microns. Both gases and particles are deposited on surfaces by one of two general mechanisms. Wet deposition occurs when raindrops drag molecules of gases and particles down with them as they fall. Dry deposition results from the combination of molecular diffusion, impaction, and gravitational settling. Wet deposition is the most important deposition mode in regions with appreciable annual rainfall, but in semi-arid regions such as Southern California, atmospheric deposition is likely to be dominated by dry deposition processes. The most rapid dry deposition rate is the gravitational settling of particles in the 10 to 100 micron size range.

Water pollutants of concern that may deposit from the atmosphere include compounds that increase the acidity of rainfall or fog, nutrients that may cause excess algal growth

(eutrophication), and toxic organic and inorganic (metals) compounds. Acid rain, primarily caused by the emission of nitrogen and sulfur from motor vehicles, industries, and power plants, harms vegetation and impairs water quality. Acid rain has been one of the longest standing issues involving atmospheric deposition in the United States and has been addressed at the federal level by the National Atmospheric Deposition Program (NADP). Eutrophication of water bodies by excess nutrients results in lowered, often zero, dissolved oxygen levels and consequent death of fish and other organisms in addition to dramatic changes in taste and odor of the water. Eutrophication of major water bodies in the United States, notably Lake Erie, was one of the driving forces behind the federal Clean Water Act of 1972 and is still of concern in many regions. In California, nutrient additions by atmospheric deposition are thought to be a primary cause of the decrease in the clarity of Lake Tahoe (Tahoe Environmental Research Center 2008).

Among the organic compounds of interest in aquatic systems are pesticides such as dichlorodiphenyltrichloroethane (DDT), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenols (PCBs), all of which are internationally recognized as important persistent organic pollutants (POPs). Metals identified as important water pollutants are copper, cadmium, chromium, lead, mercury, nickel, and zinc. These organic compounds and metals are present in the sediments of many water bodies and are of concern because of their effects on aquatic organisms and, in the case of lead and mercury, on human health. Mercury currently receives special attention from the NADP because of its ability to travel long distances as a gas before entering water bodies by atmospheric deposition.

Many of the inputs of water pollutants from point sources like treatment plants and other facilities have been reduced by successful treatment and source reduction efforts. However, it is now recognized that non-point sources originating from urban and agricultural activities in a watershed are sufficiently large that water quality improvement objectives have not been met in many locations. Regulatory efforts to improve and protect water quality, particularly by establishing Total Maximum Daily Loads (TMDL), should consider the contribution of atmospheric deposition relative to other point and non-point sources in the watershed. It may be that solving water quality problems resulting from stormwater runoff may need to focus, at least in part, on resolving air pollution/deposition problems.

This article, using the findings of studies conducted over the last ten years at UCLA and the Southern California Coastal Water Research Project (SCCWRP), summarizes the current state of understanding of atmospheric deposition as a contributor to water quality problems. The article focuses on the Los Angeles region as a model for urbanized areas, particularly those in relatively dry climates where dry deposition is the dominant mode of deposition. The discussion deals mainly with the metals identified as water pollutants, but many of the conclusions presented here also apply to acid rain, nutrients, and organic compounds. Deposition of atmospheric mercury is not discussed here, largely because of the absence of upwind sources of mercury on the U.S. West Coast. The article identifies the important sources of metals in Los Angeles, the resulting patterns of deposition, and the relative importance of atmospheric deposition of metals, followed by a discussion of what scientific and institutional steps can be taken to deal with atmospheric deposition.

Sources of Metals to the Atmosphere

Estimates of pollutant emissions to the atmosphere have been developed by the combined efforts of the U.S. Environmental Protection Agency (EPA), California Environmental Protection Agency (Cal/EPA), and the South Coast Air Quality Management District (SCAQMD) for three categories of sources (South Coast Air Basin 1997). Point sources are fixed sources associated with specific large industrial facilities; mobile sources are moving vehicles; and area sources include construction vehicles, distributed smaller industrial sources, and resuspended dust.

The most significant source of metals to the atmosphere, in Los Angeles and elsewhere, is resuspension of dust, often called “fugitive” dust, from roads by moving vehicles and from other paved and unpaved surfaces by wind (Figure 1). Chemical studies of the dust indicate it is primarily composed of natural material typical of the earth’s crust, but it also contains significant amounts of the metals, which are water pollutants of concern. These metals have become intimately mixed with the crustal material, making identification of their “real” sources difficult. Recent measurements indicate wild fires can also be a significant source of metal laden dust.

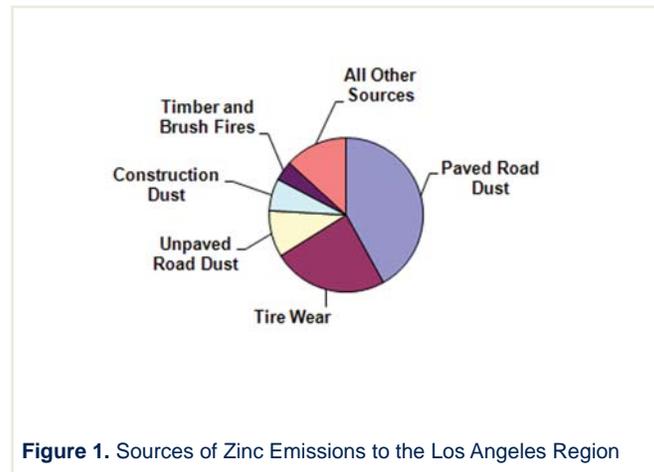


Figure 1. Sources of Zinc Emissions to the Los Angeles Region

Regulatory programs designed to protect human health have successfully reduced emissions of many substances from point and mobile sources. However, tire wear remains a significant source of zinc and brake pad wear is a significant source of copper from mobile sources. The heaviest and largest of the particles containing copper and zinc may deposit directly on the road or surrounding area, but a large fraction is dispersed into the atmosphere.

Studies focusing on lead in the Los Angeles region have shown the current levels of lead present in resuspended dust far exceeds the supply from contemporary sources, especially now that the main historical source of lead to the environment, leaded gasoline, has been reduced to near zero levels (Harrison 2005). Lead levels in the atmosphere and in newly deposited material appear to be supplied by resuspension of “old” lead present in soils and other surfaces. This phenomenon is likely to be important for other pollutants subject to atmospheric deposition.



Traffic on the 110 Freeway, Photo: Miwa Tamahata



Patterns of Atmospheric Deposition

Scientists from UCLA and SCCWRP have used air quality computer models to determine the transport and fate of metals in the Los Angeles region using as inputs the estimates of sources described above (Lu 2003). The models indicate about a fourth to a third of the material emitted into the atmosphere is deposited within the region, and the rest is carried away by the wind. Most of the deposited material falls on land or urban surfaces rather than directly on a water surface, but there is some deposition on coastal waters because of night-time breezes from the land and because of persistent Santa Ana winds. Because of the relatively small total rainfall in Southern California, dry deposition is much more important than wet deposition. The UCLA/SCCWRP measurement program also documented for the first time the presence of significant amounts of particles between 10 to 100 microns in size in the air above Los Angeles (Lim 2006). Although there are substantial amounts of metals on particles smaller than 10 microns, it is the largest particles that are responsible for most of the atmospheric deposition of metals.

The pattern of dust and metal concentrations in the atmosphere and the associated deposition on land is relatively uniform spatially in the Los Angeles urban region. Although deposition near major sources, such as freeways, is higher than the regional background rate within about 100 meters of the road (Sabin 2006). In the urban areas, daytime concentration and deposition of metals is greater than night-time because of the influence of traffic on resuspension. These patterns have been documented by direct measurements of deposition using specially designed deposition surfaces. The modeled and observed patterns of atmospheric concentrations and deposition of heavy metals, combined with the measured properties of regional dust, have led scientists to hypothesize that dust-associated substances, including metals, deposit relatively close to the original source of the material, but then are resuspended and redeposited numerous times before being carried out of the region by

winds, sequestered on the land surface, or washed off by rainfall (Figure 2). Thus deposition from the atmosphere is only one component of a complex system of pollutant transport operating at the land-air boundary.

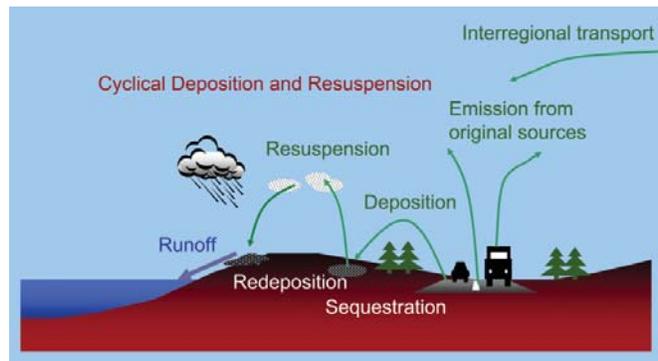


Figure 2. Hypothesized Mechanisms for Coarse Particle Transport

Importance of Atmospheric Deposition

The relationship between atmospheric deposition of metals and water quality has been documented by a combination of model simulations and water sampling in the Los Angeles region. The findings are that nearly all the metals deposited on impervious urban surfaces wash off with the next rainfall (Sabin 2005), but on more natural land surfaces, between 20% and 30% of the metals are sequestered from immediate runoff (although the data on lead indicate sequestered pollutants may be available for resuspension by wind over longer time periods) (Sabin 2006).

Comparison of the mass of metals reaching the land surface by atmospheric deposition, with the mass found in runoff, and with known mass inputs from other sources clearly shows atmospheric deposition is a potentially significant source of metals to water bodies (Table 1). The contribution of atmospheric deposition can be as high as 99% in the case of lead, for which other contemporary sources are negligible.



Table 1. Relative Importance of Atmospheric Deposition of Metals to Santa Monica Bay

	Annual Loadings to Santa Monica Bay (mt/yr) from Different Sources			
	Aerial Deposition	POTW	Industrial	Power GS
Chromium	0.5	0.6	0.02	0.14
Copper	2.8	16.0	0.03	0.01
Lead	2.3	<0.01	0.02	<0.01
Nickel	0.45	5.10	0.13	0.01
Zinc	12.1	21.0	0.16	2.40
NON-AERIAL SOURCES				

Mitigation

Important scientific and institutional steps can be taken to deal with the effects of atmospheric deposition on water quality. It is important to refine current estimates of original sources and of resuspended dust sources of pollutants. Many emissions estimates are based on outdated information. Current estimates of these sources leave many questions unanswered about the relative importance of vehicles and wind as mechanisms for resuspension in urban regions. In addition, it is vital to assess the relative magnitude of local and distant sources of potential pollutants, including intra-regional sources.

Our understanding of key processes is incomplete. In particular, we need to know more about the spatial and temporal variability of resuspension, sequestration, and wash-off to assess the importance of older sources and design and evaluate remediation and control schemes.

The most important institutional step is to modify air quality regulations to allow greater consideration of water quality impacts. It is important for air and water agencies to work together in ways they have not done previously and to take a multidisciplinary approach. This change is long overdue and is key to progress in dealing with atmospheric deposition. Fortunately, agencies such as the California Air Resources

Board and the State Regional Water Quality Control Board are beginning to interact for the first time in an interdisciplinary manner to address this issue.

Regulators should continue to reduce known sources of water pollutants. Efforts are already underway in the San Francisco Bay area, for example, to examine the potential benefits of reducing copper in brake pads, and similar studies should be undertaken for zinc in tires.

Land use regulations can take advantage of what we already know about patterns of deposition near roads and freeways by minimizing use of these hot zones for sensitive uses such as residences and schools. In some cases, it may be possible to provide vegetative buffer zones that reduce the size of the high deposition region near sources.

Finally, regulators should authorize and fund the extension of routine air quality monitoring to include particles larger than 10 microns and identified water pollutants such as metals, as well as conduct direct measurement of deposition rates. These measurements would inform future scientific studies of atmospheric deposition.

Conclusion

It is clear that achieving air and water quality objectives requires a consideration of atmospheric deposition of pollutants as a significant non-point source of pollutants. The effects of atmospheric deposition are linked to a system of dust transport at the air-land interface. Inferences about and control of the effects of human sources to this system are made difficult by the presence of natural material and by the complexity of the transport processes. Progress in understanding and dealing with atmospheric deposition as a non-point source will require continued acquisition of scientific information and the evolution of cross-media and multi-disciplinary regulatory and monitoring approaches.

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His research during the last eight years has involved measurements and modeling of atmospheric deposition in the Los Angeles regions.

Professor Stolzenbach received his Ph.D. from MIT in 1971 after which he worked for the Tennessee Valley Authority for three years and then as a faculty member at MIT for eighteen years before moving to UCLA in 1992.

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