

Atmospheric Deposition



GRADES B+ to C-

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Many of the substances in the atmosphere are completely natural, such as the oxygen we breathe or dust particles that have been resuspended by wind from the Earth's crust. However, human activities have resulted in the presence of other substances that we consider pollutants because they are potentially harmful to human or ecosystem health. Air pollutants posing a risk to human health include gases such as ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide; particle-associated components of combustion exhaust including carcinogenic polycyclic aromatic hydrocarbons; heavy metals; and particles smaller than 2.5 microns (PM_{2.5}). Previous Southern California Report Card articles have dealt with the human health aspects of regional air quality (RC 1998 and 2003), particulates (RC 2001), and personal exposure (RC 2005). In this article, we discuss atmospheric deposition—the transfer of substances from the air to the many surfaces that make up the world we live in, such as soil, vegetation, water, pavement, vehicles, and buildings—with an emphasis on particle deposition. We do so because to date, atmospheric dep-

osition has largely been neglected in considering the effects of air pollutants on human health.

ATMOSPHERIC DEPOSITION

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 be washed off by rain, becoming part of the storm water 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 (it takes a thousand microns to make a millimeter). Both gases and particles are deposited on surfaces by one of two general mechanisms (Figure 1). *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. As noted earlier, because the wet and dry deposition rates for most gases and for very small particles are slow, atmospheric deposition has largely been neglected in considering the effect of air pollutants on human health. Yet atmospheric deposition can be a major environmental problem: acid rain is the most well known problem of atmospheric deposition and some of the country's most important

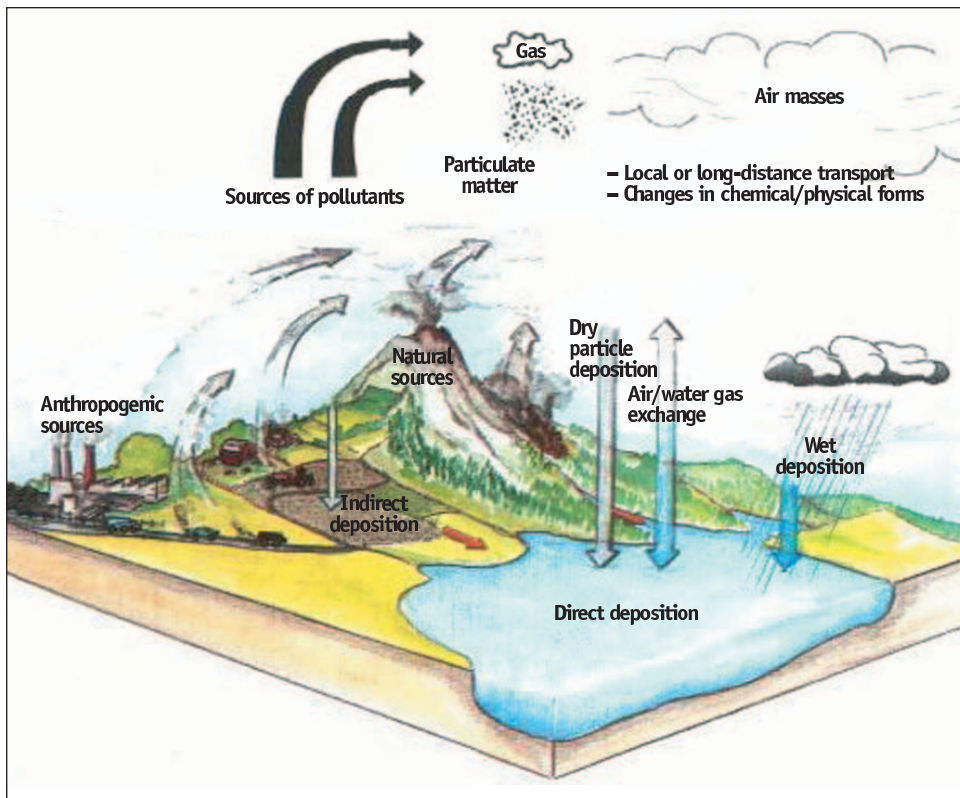


Figure 1: Atmospheric deposition processes.

water bodies, including Lakes Erie and Tahoe, have faced significant pollution from deposits from the atmosphere.

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

(Figure 2) 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 (Figure 3). 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 (Figure 4).

Among the organic compounds of interest in aquatic systems are pesticides such as 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.



Figure 2: A forest devastated by acid rain.



Figure 3: An eutrophic lake choked by an algae bloom.

Although many of the inputs of water pollutants from treatment plants and other facilities (*point sources*) have been reduced by successful treatment and source reduction efforts, 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) (see articles on storm water quality and regulation in RC 2004 and

2005, respectively), must consider the contribution of atmospheric deposition relative to other point and non-point sources in the watershed.

This article, using the findings of studies conducted over the last ten years at UCLA, in collaboration with 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 apply to acidic 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 institution-

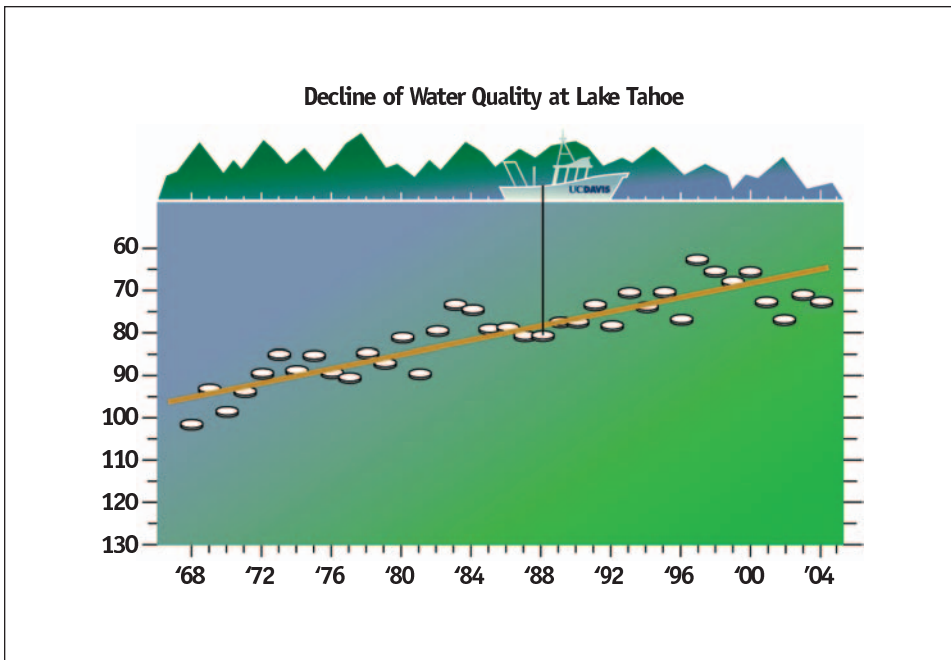


Figure 4: The clarity of Lake Tahoe, as measured by the depth to which a standard secchi disk can be seen, has decreased over the last three decades.

al steps can be taken to deal with atmospheric deposition. The article concludes by awarding grades for past regulation and monitoring efforts and for forward-looking attempts to understand and deal with this important problem.

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), the California Department of Environmental Protection (CALEPA), and the South

Coast Air Quality Management District (SCAQMD) for three categories of sources. *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 5). Chemical studies of the dust indicate it is

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primarily composed of natural material typical of the earth’s crust but also contains significant amounts of the metals we are concerned with here with regard to water pollution. 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. It is not clear whether the high level of metals in the atmosphere following a fire are the result of resuspension of metal laden soil by the strong updrafts associated with wildfires, or if the metals are taken up from the soil by the vegetation and released by the burning.

It is now known that resuspended dust can be transported between continents and that dust from China often reaches the U.S. West Coast. Thus it is likely that contaminants associated with dust could be transported between regions in California, although we do not have any measurements with which to estimate how important this mode of transport is for the Los Angeles region, either as a source or sink.

Atmospheric deposition has largely been neglected in considering the effect of air pollutants on human health yet can be a major environmental problem.

Studies focusing on lead in the Los Angeles region have shown the current levels of lead present in resuspended dust far exceed the supply from contemporary sources now that the main historical source of lead to the environment, leaded gasoline, has been reduced to near zero levels. 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.

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. Some researchers have suggested that weights used to balance tires are a significant source of lead.

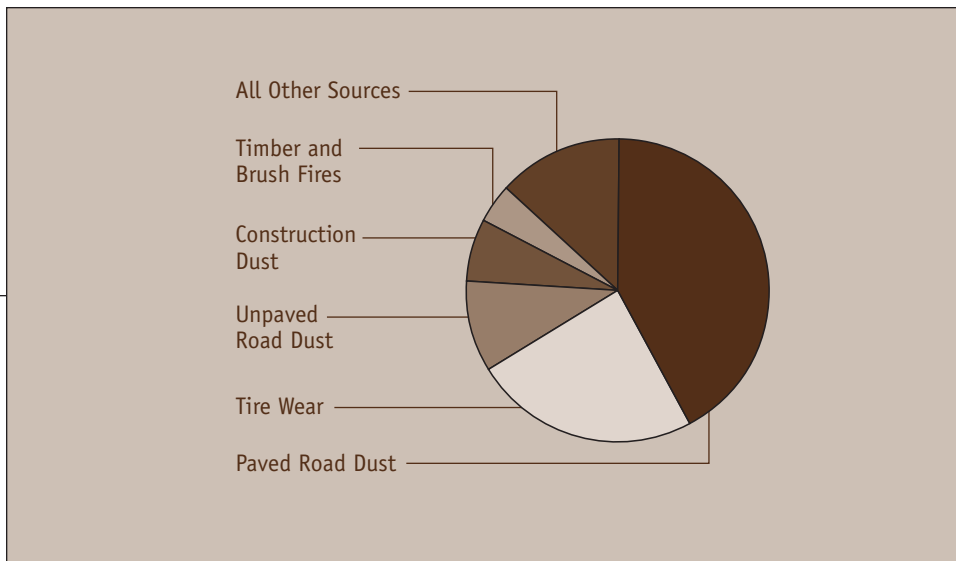


Figure 5: The major sources of atmospheric emission of zinc in the Los Angeles region.

PATTERNS OF ATMOSPHERIC DEPOSITION

Scientists from UCLA and elsewhere 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. 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 (Figure 6). 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 measurement program also documented for the first time the presence of significant amounts of particles between 10 microns and 100 microns in size in the air above Los Angeles. 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

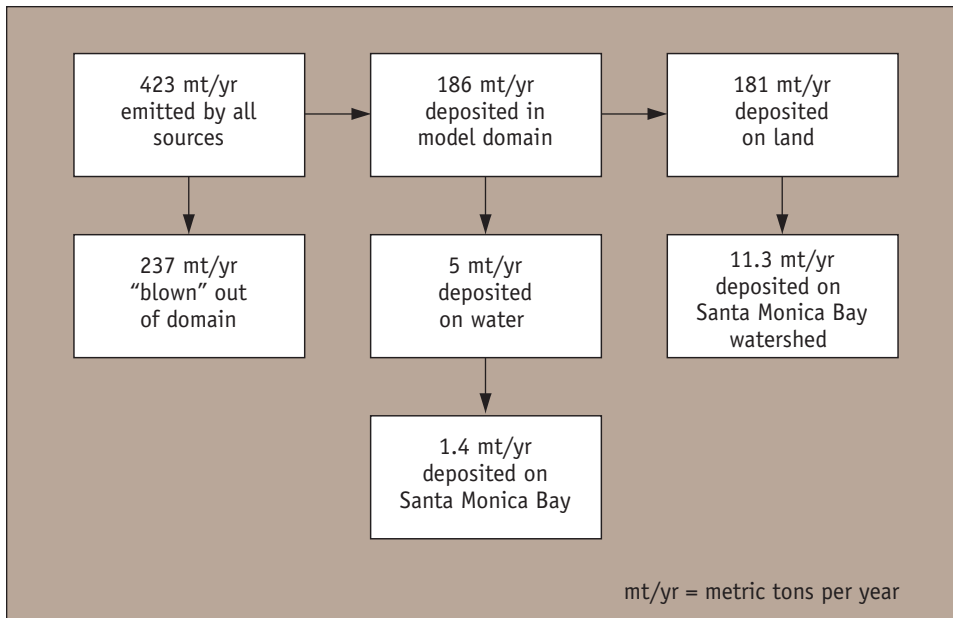


Figure 6: Computed “budget” of zinc emitted in the Los Angeles region.

meters of the road. In the urban areas, daytime concentration and deposition of metals is greater than nighttime 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, has 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 7). Thus deposition from the atmosphere is only one component of a complex system of pollutant transport operating at the land-air boundary.

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, but that on more

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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).

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 (Figure 8). The contribution of atmospheric deposition can be as high as 99% in the case of lead, for which other contemporary sources are negligible.

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

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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 intraregional 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 so we can 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. Current regulations lump water quality concerns in a general category of “welfare effects” and do not enable regulators to consider cross-media issues fully. 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

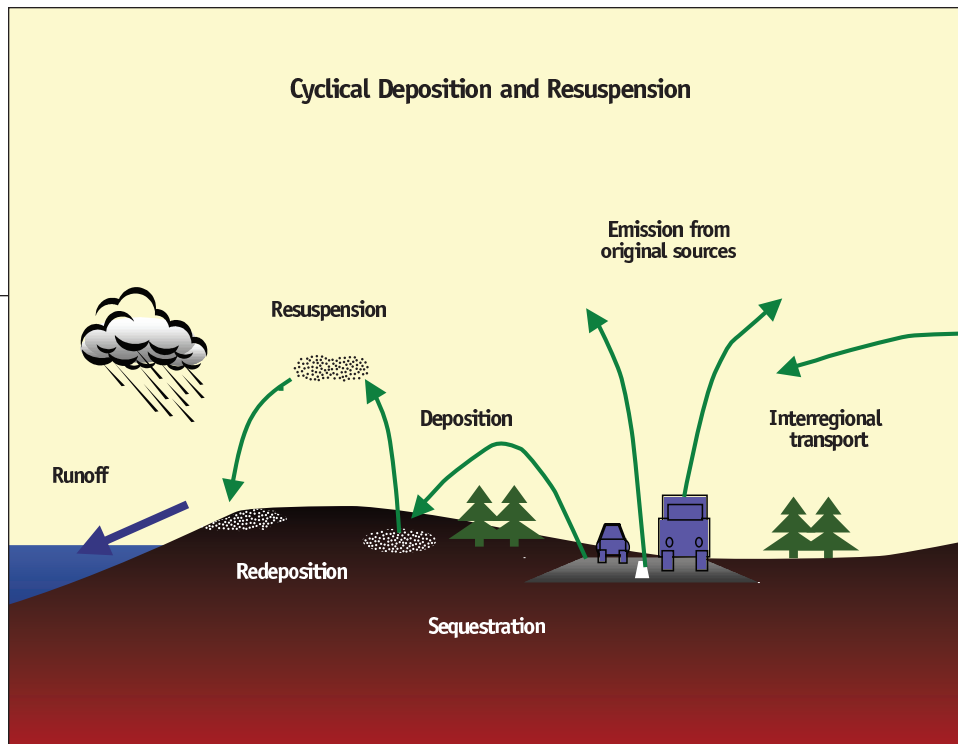


Figure 7: Hypothesized processes affecting coarse particle transport.

the California Air Resources Board and SCCWRP 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.

Annual Loadings to Santa Monica Bay (metric tons/year) from Different Sources				
	Aerial Deposition	Sewage Treatment Plants	Industrial	Power Plants
		Non-Aerial Sources		
Chromium	0.5	0.60	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

Figure 8: Relative importance of atmospheric deposition of metals in Santa Monica Bay.

CONCLUSION

It is clear that achieving air and water quality objectives requires a consideration of atmospheric deposition of pollutants as a significant 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 nat-

ural 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.

Current 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.

GRADES

Past regulation and monitoring of atmospheric deposition: **Grade C-**. Past and current regulations and monitoring priorities have not addressed adequately the cross-media nature of atmospheric deposition.

Recognizing and acting on the problem of atmospheric deposition: **Grade B+**. Water agencies have recently supported studies of atmospheric deposition and the State air and water boards have begun the process of working together on this problem. However these efforts are largely voluntary and virtually no legal apparatus exists to compel agency action.

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.

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