September 22, 2005
215 Butterfield Dr.
Novato, CA 94945
415-892-2893
bdganz@hotmail.com

Mr. Haddad,

Attached are the Appendices to Attorney Brent Newell's letter of September 12, 2005, which commented on the FEIR for the Redwood Landfill, on behalf of NWLE. These Appendices were included in a CD, but you requested that they be provided on paper.

David Ganz

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MARIN COUNTY
COMMUNITY DEVELOPMENT

Appendix A

CHAPTER 2: BENEFICIAL USES

State policy for water quality control in California is directed toward achieving the highest water quality consistent with maximum benefit to the people of the state. Aquatic ecosystems and underground aquifers provide many different benefits to the people of the state. The beneficial uses described in detail in this chapter define the resources, services, and qualities of these aquatic systems that are the ultimate goals of protecting and achieving high water quality. The Regional Board is charged with protecting all these uses from pollution and nuisance that may occur as a result of waste discharges in the region. Beneficial uses of surface waters, groundwaters, marshes, and mudflats presented here serve as a basis for establishing water quality objectives and discharge prohibitions to attain this goal.

DEFINITIONS OF BENEFICIAL USES

The following definitions (in italic) for beneficial uses are applicable throughout the entire state. A brief description of the most important water quality requirements for each beneficial use follows each definition (in alphabetical order by abbreviation).

AGRICULTURAL SUPPLY (AGR)

Uses of water for farming, horticulture, or ranching, including, but not limited to, irrigation, stock watering, or support of vegetation for range grazing.

The criteria discussed under municipal and domestic water supply (MUN) also effectively protect farmstead uses. To establish water quality criteria for livestock water supply, the Regional Board must consider the relationship of water to the total diet, including water freely drunk, moisture content of feed, and interactions between irrigation water quality and feed quality. The University of California Cooperative Extension has developed threshold and limiting concentrations for livestock and irrigation water. Continued irrigation often leads to one or more of four types of hazards related to water quality and the nature of soils and crops. These hazards are (1) soluble salt accumulations, (2) chemical changes in the soil, (3) toxicity to crops, and (4) potential disease transmission to humans through reclaimed water use. Irrigation water classification systems, arable soil classification systems, and public health criteria related to reuse of wastewater have been developed with consideration given to these hazards.

AREAS OF SPECIAL BIOLOGICAL SIGNIFICANCE (ASBS)

Areas designated by the State Water Resources Control Board.

These include marine life refuges, ecological reserves, and designated areas where the preservation and enhancement of natural resources requires special protection. In these areas, alteration of natural water quality is undesirable. The areas that have been designated as ASBS in this region are depicted in Figure 2-1. The state Ocean Plan (see Chapter 5) requires wastes to be discharged at a sufficient distance from these areas to assure maintenance of natural water quality conditions.

COLD FRESHWATER HABITAT (COLD)

Uses of water that support cold water ecosystems, including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.

Cold freshwater habitats generally support trout and may support the anadromous salmon and steelhead fisheries as well. Cold water habitats are commonly well-oxygenated. Life within these waters is relatively intolerant to environmental stresses. Often, soft waters feed cold water habitats. These waters render fish more susceptible to toxic metals, such as copper, because of their lower buffering capacity.

OCEAN, COMMERCIAL, AND SPORT FISHING (COMM)

Uses of water for commercial or recreational collection of fish, shellfish, or other organisms in oceans, bays, and estuaries, including, but not limited to, uses involving organisms intended for human consumption or bait purposes.

To maintain ocean fishing, the aquatic life habitats where fish reproduce and seek their food must be protected. Habitat protection is under descriptions of other beneficial uses.

ESTUARINE HABITAT (EST)

Uses of water that support estuarine ecosystems, including, but not limited to, preservation or enhancement of estuarine habitats, vegetation, fish, shellfish, or wildlife (e.g., estuarine mammals, waterfowl, shorebirds), and the propagation, sustenance, and migration of estuarine organisms.

Estuarine habitat provides an essential and unique habitat that serves to acclimate anadromous fishes (salmon, striped bass) migrating into fresh or marine water conditions. The protection of estuarine habitat is contingent upon (1) the maintenance of adequate Delta outflow to provide mixing and salinity control; and (2) provisions to protect wildlife habitat associated with marshlands and the Bay periphery (i.e., prevention of fill activities). Estuarine habitat is generally associated with moderate seasonal fluctuations in dissolved oxygen, pH, and temperatur and with a wide range in turbidity.

FRESHWATER REPLENISHMENT (FRSH)

Uses of water for natural or artificial maintenance of surface water quantity or quality.

GROUNDWATER RECHARGE (GWR)

Uses of water for natural or artificial recharge of groundwater for purposes of future extraction, maintenance of water quality, or halting saltwater intrusion into freshwater aquifers.

The requirements for groundwater recharge operations generally reflect the future use to be made of the water stored underground. In some cases, recharge operations

may be conducted to prevent seawater intrusion. In these cases, the quality of recharged waters may not directly affect quality at the wellfield being protected. Recharge operations are often limited by excessive suspended sediment or turbidity that can clog the surface of recharge pits, basins, or wells.

Under the state Antidegradation Policy, the quality of some of the waters of the state is higher than established by adopted policies. It is the intent of this policy to maintain that existing higher quality to the maximum extent possible.

Requirements for groundwater recharge, therefore, shall impose the Best Available Technology (BAT) or Best Management Practices (BMPs) for control of the discharge as necessary to assure the highest quality consistent with maximum benefit to the people of the state. Additionally, it must be recognized that groundwater recharge occurs naturally in many areas from streams and reservoirs. This recharge may have little impact on the quality of groundwaters under normal circumstances, but it may act to transport pollutants from the recharging water body to the groundwater. Therefore, groundwater recharge must be considered when requirements are established.

INDUSTRIAL SERVICE SUPPLY (IND)

Uses of water for industrial activities that do not depend primarily on water quality, including, but not limited to, mining, cooling water supply, hydraulic conveyance, gravel washing, fire protection, and oil well repressurization.

Most industrial service supplies have essentially no water quality limitations except for gross constraints, such as freedom from unusual debris.

MARINE HABITAT (MAR)

Uses of water that support marine ecosystems, including, but not limited to, preservation or enhancement of marine habitats, vegetation such as kelp, fish, shellfish, or wildlife (e.g., marine mammals, shorebirds).

In many cases, the protection of marine habitat will be accomplished by measures that protect wildlife habitat generally, but more stringent criteria may be necessary for waterfowl marshes and other habitats, such as those for shellfish and marine fishes. Some marine habitats, such as important intertidal zones and kelp beds, may require special protection.

FISH MIGRATION (MIGR)

Uses of water that support habitats necessary for migration, acclimatization between fresh water and salt water, and protection of aquatic organisms that are temporary inhabitants of waters within the region.

The water quality provisions acceptable to cold water fish generally protect anadromous fish as well. However, particular attention must be paid to maintaining zones of passage. Any barrier to migration or free movement of migratory fish is harmful. Natural tidal movement in estuaries and unimpeded river flows are necessary to sustain migratory fish and their offspring. A water quality barrier, whether thermal,

physical, or chemical, can destroy the integrity of the migration route and lead to the rapid decline of dependent fisheries.

Water quality may vary through a zone of passage as a result of natural or human-induced activities. Fresh water entering estuaries may float on the surface of the denser salt water or hug one shore as a result of density differences related to water temperature, salinity, or suspended matter.

MUNICIPAL AND DOMESTIC SUPPLY (MUN)

Uses of water for community, military, or individual water supply systems, including, but not limited to, drinking water supply.

The principal issues involving municipal water supply quality are (1) protection of public health; (2) aesthetic acceptability of the water; and (3) the economic impacts associated with treatment- or quality-related damages.

The health aspects broadly relate to: direct disease transmission, such as the possibility of contracting typhoid fever or cholera from contaminated water; toxic effects, such as links between nitrate and methemoglobinemia (blue babies); and increased susceptibility to disease, such as links between halogenated organic compounds and cancer.

Aesthetic acceptance varies widely depending on the nature of the supply source to which people have become accustomed. However, the parameters of general concern are excessive hardness, unpleasant odor or taste, turbidity, and color. In each case, treatment can improve acceptability although its cost may not be economically justified when alternative water supply sources of suitable quality are available.

Published water quality objectives give limits for known health-related constituents and most properties affecting public acceptance. These objectives for drinking water include the U.S. Environmental Protection Agency Drinking Water Standards and the California State Department of Health Services criteria.

NAVIGATION (NAV)

Uses of water for shipping, travel, or other transportation by private, military, or commercial vessels.

INDUSTRIAL PROCESS SUPPLY (PROC)

Uses of water for industrial activities that depend primarily on water quality.

Water quality requirements differ widely for the many industrial processes in use today. So many specific industrial processes exist with differing water quality requirements that no meaningful criteria can be established generally for quality of raw water supplies. Fortunately, this is not a serious shortcoming, since current water treatment technology can create desired product waters tailored for specific uses.

PRESERVATION OF RARE AND ENDANGERED SPECIES (RARE)

Uses of waters that support habitats necessary for the survival and successful maintenance of plant or animal species established under state and/or federal law as rare, threatened, or endangered.

The water quality criteria to be achieved that would encourage development and protection of rare and endangered species should be the same as those for protection of fish and wildlife habitats generally. However, where rare or endangered species exist, special control requirements may be necessary to assure attainment and maintenance of particular quality criteria, which may vary slightly with the environmental needs of each particular species. Criteria for species using areas of special biological significance should likewise be derived from the general criteria for the habitat types involved, with special management diligence given where required.

WATER CONTACT RECREATION (REC1)

Uses of water for recreational activities involving body contact with water where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, water-skiing, skin and scuba diving, surfing, whitewater activities, fishing, and uses of natural hot springs.

Water contact implies a risk of waterborne disease transmission and involves human health; accordingly, criteria required to protect this use are more stringent than those for more casual water-oriented recreation.

Excessive algal growth has reduced the value of shoreline recreation areas in some cases, particularly for swimming. Where algal growths exist in nuisance proportions, particularly bluegreen algae, all recreational water uses, including fishing, tend to suffer.

One criterion to protect the aesthetic quality of waters used for recreation from excessive algal growth is based on chlorophyll a.

NONCONTACT WATER RECREATION (REC2)

Uses of water for recreational activities involving proximity to water, but not normally involving contact with water where water ingestion is reasonably possible. These uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing, camping, boating, tide pool and marine life study, hunting, sightseeing, or aesthetic enjoyment in conjunction with the above activities.

Water quality considerations relevant to noncontact water recreation, such as hiking, camping, or boating, and those activities related to tide pool or other nature studies require protection of habitats and aesthetic features. In some cases, preservation of a natural wilderness condition is justified, particularly when nature study is a major dedicated use.

One criterion to protect the aesthetic quality of waters used for recreation from excessive algal growth is based on chlorophyll a.

SHELLFISH HARVESTING (SHELL)

Uses of water that support habitats suitable for the collection of crustaceans and filter-feeding shellfish (e.g., clams, oysters, and mussels) for human consumption, commercial, or sport purposes.

Shellfish harvesting areas require protection and management to preserve the resource and protect public health. The potential for disease transmission and direct poisoning of humans is of considerable concern in shellfish regulation. The bacteriological criteria for the open ocean, bays, and estuarine waters where shellfish cultivation and harvesting occur should conform with the standards described in the National Shellfish Sanitation Program, Manual of Operation.

Toxic metals can accumulate in shellfish. Mercury and cadmium are two metals known to have caused extremely disabling effects in humans who consumed shellfish that concentrated these elements from industrial waste discharges. Other elements, radioactive isotopes, and certain toxins produced by particular plankton species also concentrate in shellfish tissue. Documented cases of paralytic shellfish poisoning are not uncommon in California.

FISH SPAWNING (SPWN)

Uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish.

Dissolved oxygen levels in spawning areas should ideally approach saturation levels. Free movement of water is essential to maintain well-oxygenated conditions around eggs deposited in sediments. Water temperature, size distribution and organic content of sediments, water depth, and current velocity are also important determinants of spawning area adequacy.

WARM FRESHWATER HABITAT (WARM)

Uses of water that support warm water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.

The warm freshwater habitats supporting bass, bluegill, perch, and other panfish are generally lakes and reservoirs, although some minor streams will serve this purpose where stream flow is sufficient to sustain the fishery. The habitat is also important to a variety of nonfish species, such as frogs, crayfish, and insects, which provide food for fish and small mammals. This habitat is less sensitive to environmental changes, but more diverse than the cold freshwater habitat, and natural fluctuations in temperature, dissolved oxygen, pH, and turbidity are usually greater.

WILDLIFE HABITAT (WILD)

Uses of waters that support wildlife habitats, including, but not limited to, the preservation and enhancement of vegetation and prey species used by wildlife, such as waterfowl.

The two most important types of wildlife habitat are riparian and wetland habitats.

These habitats can be threatened by development, erosion, andsedimentation, as well as by poor water quality.

The water quality requirements of wildlife pertain to the water directly ingested, the aquatic habitat itself, and the effect of water quality on the production of food materials. Waterfowl habitat is particularly sensitive to changes in water quality. Dissolved oxygen, pH, alkalinity, salinity, turbidity, settleable matter, oil, toxicants, and specific disease organisms are water quality characteristics particularly important to waterfowl habitat. Dissolved oxygen is needed in waterfowl habitats to suppress development of botulism organisms; botulism has killed millions of waterfowl. It is particularly important to maintain adequate circulation and aerobic conditions in shallow fringe areas of ponds or reservoirs where botulism has caused problems.

PRESENT AND POTENTIAL BENEFICIAL USES

SURFACE WATERS

Surface waters in the region consist of freshwater rivers, streams, and lakes (collectively described as inland surface waters), estuarine waters, and coastal waters. Estuarine waters are comprised of the Bay system from the Golden Gate to the regional boundary near Pittsburg and the lower portions of streams flowing into the Bay, such as the Napa and Petaluma rivers in the north and Coyote and San Francisquito creeks in the south.

Inland surface waters support or could support most of the beneficial uses described above. The specific beneficial uses for inland streams include municipal and domestic supply, agricultural supply, industrial process supply, groundwater recharge, water contact recreation, noncontact water recreation, wildlife habitat, cold freshwater habitat, warm freshwater habitat, fish migration, and fish spawning. The San Francisco Bay Estuary supports estuarine habitat, industrial service supply, and navigation in addition to all of the uses supported by streams.

Coastal waters' beneficial uses include water contact recreation; noncontact water recreation; industrial service supply; navigation; marine habitat; shellfish harvesting; ocean, commercial and sport fishing; and preservation of rare and endangered species. In addition, the California coastline within the San Francisco Bay Basin is endowed with exceptional scenic beauty.

Beneficial uses of each significant water body have been identified and are organized according to the seven major watersheds within the region (Figure 2-2). The maps locating each water body (Figures 2-3 through 2-9) and tables keyed to each map (Tables 2-1 through 2-7) describing associated present and potential beneficial uses were produced using a geographical information system (GIS) at the Regional Board. More detailed representations of each location can be created using this computerized version.

The beneficial uses of any specifically identified water body generally apply to all its tributaries. In some cases a beneficial use may not be applicable to the entire body of water, such as navigation in Calabazas Creek or shellfish harvesting in the Pacific

Ocean. In these cases, the Regional Board's judgment regarding water quality control measures necessary to protect beneficial uses will be applied.

GROUNDWATERS

Groundwater is defined as subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated. Where groundwater occurs in a saturated geologic unit that contains sufficient permeable thickness to yield significant quantities of water to wells and springs, it can be defined as an aquifer. A groundwater basin is defined as a hydrogeologic unit containing one large aquifer or several connected and interrelated aquifers.

Water-bearing geologic units occur within groundwater basins in the region that do not meet the definition of an aquifer. For instance, there are shallow, low permeability zones throughout the region that have extremely low water yields. Groundwater may also occur outside of currently identified basins. Therefore, for basin planning purposes, the term "groundwater" includes all subsurface waters, whether or not these waters meet the classic definition of an aquifer or occur within identified groundwater basins.

The areal extent of groundwater basins in the region has been evaluated by the Department of Water Resources (DWR) (Bulletin 118, 1980). Of special importance to the region are the 31 groundwater basins classified by DWR that produce, or potentially could produce, significant amounts of groundwater. Table 2-8 summarizes the hydrogeologic characteristics of basins depicted in Figure 2-10. This computer groundwater mapping GIS system was developed by the Regional Board and has the capacity to present information on each basin at a much higher level of resolution.

Existing and potential beneficial uses applicable to groundwater in the region include municipal and domestic water supply (MUN), industrial water supply (IND), industrial process water supply (PROC), agricultural water supply (AGR), and freshwater replenishment to surface waters (FRESH). Table 2-9 lists the 31 identified groundwater basins located in the region and their existing and potential beneficial uses.

Unless otherwise designated by the Regional Board, all groundwaters are considered suitable, or potentially suitable, for municipal or domestic water supply (MUN). In making any exceptions, the Regional Board will consider the criteria referenced in Regional Board Resolution No. 89-39, "Sources of Drinking Water," where:

- The total dissolved solids exceed 3,000 mg/l (5,000 µS/cm, electrical conductivity), and it is not reasonably expected by the Regional Board that the groundwater could supply a public water system; or
- There is contamination, either by natural processes or by human activity (unrelated to a specific pollution incident), that cannot reasonably be treated for domestic use using either Best Management Practices or best economically achievable treatment practices; or
- The water source does not provide sufficient water to supply a single well capable of producing an average, sustained yield of 200 gallons per day; or
- The aquifer is regulated as a geothermal energy-producing source or has been exempted administratively pursuant to 40 CFR Part 146.4 (revised April 1, 1983)

for the purpose of underground injection of fluids associated with the production of hydrocarbon or geothermal energy, provided that these fluids do not constitute a hazardous waste under 40 CFR Part 261.3 (revised October 30, 1993).

WETLANDS

Federal administrative law (e.g., 40 CFR Part 122.2, revised December 22, 1993) defines wetlands as waters of the United States. National waters include waters of the State of California, defined by the Porter-Cologne Act as "any water, surface or underground, including saline waters, within the boundaries of the State." (CWC §13050 [e]). Wetlands water quality control is therefore clearly within the jurisdiction of the State and Regional Boards.

Wetlands are further defined in 40 CFR 122.2 as "those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas."

The Regional Board recognizes that wetlands frequently include areas commonly referred to as saltwater marshes, freshwater marshes, open or closed brackish water marshes, mudflats, sandflats, unvegetated seasonally ponded areas, vegetated shallows, sloughs, wet meadows, playa lakes, natural ponds, vernal pools, diked baylands, seasonal wetlands, and riparian woodlands.

Mudflats make up one of the largest and most important habitat types in the San Francisco Estuary. Snails, clams, worms, and other animals convert the rich organic matter in the mud bottom to food for fish, crabs, and birds.

Mudflats generally support a variety of edible shellfish, and many species of fish rely heavily on the mudflats during at least a part of their life cycle. Additionally, San Francisco Bay mudflats are one of the most important habitats on the coast of California for millions of migrating shorebirds.

Another important characteristic of the San Francisco Estuary is the fresh, brackish, and salt water marshes around the Bay's margins. These highly complex communities are recognized as vital components of the Bay system's ecology. Most marshes around the Bay have been destroyed through filling and development. The protection, preservation, and restoration of the remaining marsh communities are essential for maintaining the ecological integrity of the San Francisco Estuary.

Identifying wetlands may be complicated by such factors as the seasonality of rainfall in the region. Therefore, in identifying wetlands, the Regional Board will consider such indicators as hydrology, hydrophytic plants, and/or hydric soils. The Regional Board will, in general, rely on the federal manual for wetlands delineation in this region for Section 404 permits (U.S. Army Corps of Engineers Wetlands Delineation Manual, 1987). In the rare cases where the U.S. EPA and Corps guidelines disagree, the Regional Board will rely on the wetlands delineation made by U.S. EPA or the California Department of Fish and Game.

There are many potential beneficial uses of wetlands, including Wildlife Habitat; Preservation of Rare and Endangered Species; Shellfish Harvesting; Water Contact Recreation; Noncontact Water Recreation; Ocean, Commercial, and Sport Fishing; Marine Habitat; Fish Migration; Fish Spawning; and Estuarine Habitat. Table 2-10 lists and specifies beneficial uses for 34 significant wetland areas within the region; generalized locations of these wetlands are shown in Figure 2-11.

It should be noted that most of the wetlands listed in Table 2-10 are saltwater marshes, and that the list is not comprehensive. The Regional Board is facilitating the preparation of a Regional Wetlands Management Plan (RWMP) that will identify and specify beneficial uses of many additional significant wetlands. Because of the large number of small and non-contiguous wetlands, it will probably not be practical to delineate and specify beneficial uses of every wetland area. Therefore, beneficial uses may be determined site specifically, as needed. Chapter 4 of this Plan contains additional information on the RWMP and on the process used to determine beneficial uses for specific wetland sites.

FIGURES

Figure 2-1: Areas of Special Biological Significance

Figure 2-2: Hydrologic Planning Areas

Figure 2-3: Marin Coastal Basin

Figure 2-4: San Mateo Coastal Basin

Figure 2-5: Central Basin

Figure 2-6: South Bay Basin

Figure 2-7: Santa Clara Basin

Figure 2-8: San Pablo Basin

Figure 2-9: Suisun Basin

Figure 2-10: Significant Groundwater Basins

Figure 2-11: General Locations of Wetland Areas

TABLES

Table 2-1: Beneficial Uses of Waterbodies in Marin Coastal Basin

Table 2-2: Beneficial Uses of Waterbodies in San Mateo Coastal Basin

Table 2-3: Beneficial Uses of Waterbodies in Central Basin

Table 2-4: Beneficial Uses of Waterbodies in South Bay Basin

Table 2-5: Beneficial Uses of Waterbodies in Santa Clara Basin

Table 2-6: Beneficial Uses of Waterbodies in San Pablo Basin

Table 2-7: Beneficial Uses of Waterbodies in Suisun Basin

Table 2-8: Groundwater Basin Characteristics

Table 2-9: Existing and Potential Beneficial Uses of Groundwater in Identified Basins

Table 2-10: Beneficial Uses of Wetland Areas

Appendix AA

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

January 21, 1986

MEMORANDUM

SUBJECT: Receptor Locations In Ambient Air

FROM: Joseph A. Tikvart, Chief /s/
Source Receptor Analysis Branch (MD-14)

TO: Regional Modeling Contacts, Regions I-X

As the attachments indicate, OAQPS has reinforced the position that the ambient air policy has been clearly defined and does not require review. The Regional Meteorologists' memorandum (dated 5/16/85) harmonizes modeling procedures with this long-standing policy. In future Model Clearinghouse actions we will use that memorandum to ensure consistent Regional implementation of that policy and to resolve questions about pollutant concentrations at receptor locations where the public has access.

Attachments

cc: R. Campbell
T. Helms
R. Rhoads
D. Tyler
D. Wilson

(Attachments Following)

Attachment

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

January 22, 1986

William F. O'Keefe, Vice President
American Petroleum Institute
1220 L Street Northwest
Washington, D. C. 20005

Dear Mr. O'Keefe:

Mr. Elkins has asked me to respond to your letter of December 18, 1985, in which you perceive a change in our policy with regard to the location of receptors for air quality dispersion modeling.

Let me assure you there is no change in our long-standing national policy with regard to the definition of ambient air. That policy is based on 40 CFR Part 50.1 (e) which defines ambient air as ". . . that portion of the atmosphere, external to buildings, to which the general public has access." A letter dated December 19, 1980, from Douglas Costle to Senator Jennings Randolph, reaffirmed and clarified this definition by stating the exemption from ambient air is available only for the atmosphere over land owned or controlled by the source and to which public access is precluded by a fence or other physical barriers. A copy of Mr. Costle's letter is enclosed. The codified definition plus the 1980 clarification essentially constitute the national policy on ambient air.

The Regional Meteorologists' memorandum to which you refer does not imply any change in this national policy and simply harmonizes modeling procedures with our long-standing policy. It is intended to ensure consistent Regional implementation of that policy and to dispel any questions about pollutant concentrations at locations where the general public has access.

Thus, since the Regional Meteorologists' memorandum does not imply any change in our policy, I do not believe there is any need for policy review at this time.

Sincerely,

/s/

Gerald A. Emison
Director
Office of Air Quality Planning
and Standards

Enclosure

cc: W. Quanstrom
E. Elkins

Attachment

December 19, 1980

Honorable Jennings Randolph
Chairman, Committee on Environment
and Public Works
United States Senate
Washington, D.C. 20510

Dear Mr. Chairman:

Thank you for your letter of October 23, 1980 expressing your continued interest in the Agency's definition of "ambient air." During the time since David Hawkins, my Assistant Administrator for Air, Noise, and Radiation, met with you last February, the definition has been extensively reviewed and debated.

After reviewing the issues and alternatives, I have determined that no change from the existing policy is necessary. We are retaining the policy that the exemption from ambient air is available only for the atmosphere over land owned or controlled by the source and to which public access is precluded by a fence or other physical barriers. EPA will continue to review individual situations on a case-by-case basis to ensure that the public is adequately protected and that there is no attempt by sources to circumvent the requirement of Section 123 of the Clean Air Act.

I hope that this has been responsive to your needs.

Sincerely yours,

/s/ Douglas M. Costle

Douglas M. Costle

Attachment

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Region V

DATE: May 16, 1985

SUBJECT: Ambient Air

FROM: Regional Meteorologists, Regions I-X

TO: Joseph Tikvart, Chief (MD-14)
Source Receptor Analysis Branch

At the recent Regional Meteorologists' meeting in Dallas, we identified inconsistencies among the Regional Offices on what areas are to be considered as ambient air for regulatory purposes. The existing inconsistency on ambient air is due to both the lack of clear National guidance and the allowed Regional Office discretion. A standardized approach is necessary both to satisfy the consistency requirements of Section 301 of the Clean Air Act and in order for those responsible for

Regional modeling activities to provide effective and efficient review of and guidance on modeling analysis. Accordingly, the Regional Meteorologists have decided to address the problem at the working level through the use of a consistent modeling approach.

40 CRF Part 50.1(e) defines ambient air as ". . . that portion of the atmosphere, external to buildings, to which the general public has access." A letter dated December 19, 1980, from Douglas Costle to Senator Jennings Randolph, clarified this definition by stating that the exemption from ambient air is available only for the atmosphere over land owned or controlled by the source and to which public access is precluded by a fence or other physical barriers." The codified definition plus the 1980 clarification essentially constitute the National policy on ambient air.

The Regional Meteorologists propose that for modeling purposes the air everywhere outside of contiguous plant property to which public access is precluded by a fence or other effective physical barrier should be considered in locating receptors. Specifically, for stationary source modeling, receptors should be placed anywhere outside inaccessible plant property. For example, receptors should be included over bodies of water, over unfenced plant property, on buildings, over roadways, and over property owned by other sources. For mobile source modeling (i.e., CO modeling), receptors should continue to be sited in accordance with Volume 9 of the "Guidelines for Air Quality Maintenance Planning".

Unless you disagree with our position, we will require new actions with modeling analyses submitted to EPA after January 1, 1986, to conform to this modeling policy. Please note that all 10 Regional Meteorologists have reviewed and concur with this memo.

cc: Regional Meteorologist, Regions I-X

Appendix B

TABLE 2-6 BASIN 6 - SAN PABLO BASIN

BASIN	WATERBODY	AGR	COLD	COMM	EST	FRSH	GWR	IND	MAR	MIGR	MUN	NAV	PROC	RARE	REC-1	REC-2	SHELL	SPWN	WARM	WILD
San Pablo Bay				E	E			E		E		E		E	E	E	E	E		E
Lake Chabot (Solano)		E	E								P				E	E		E	E	E
Coon Island																				
Dalwick Lake																				
Miller Creek			E							L				E	E	E		E	E	E
Adobe Creek																				
Wildcat Creek										E						E		E	E	E
San Pablo Creek										E						E		E	E	E
Rodeo Creek										E					P	E		E	E	E
Refugio Creek																				
Gallinas Creek			E											E					E	E
White Slough																				
Lake Anza																				
Briones Reservoir			E								E				L				E	
San Pablo Reservoir			E								E				E				E	
San Pablo Creek										E									E	
Miller Creek			E							E				E	E	E		E	E	E
Novato Creek			P							P	E			P	P	P		P	P	P
Stafford Lake			E								E				E				E	
Petaluma River			E						E	E		E		E	E				E	
Willow Creek																				
San Antonio Creek			E							P					P			P	E	
Adobe Creek																				

E: Existing Beneficial Use P: Potential Beneficial Use L: Limited Beneficial Use

Water bodies listed here may not correspond exactly to those that appear on Figure 2-8.

TABLE 2-6 BASIN 6 - SAN PABLO BASIN CONTINUED

BASIN	WATERBODY	AGR	COLD	COMM	EST	FISH	GWR	IND	MAR	MIGR	MUN	NAV	PROC	RARE	REC-1	REC-2	SHELL	SPAWN	WARM	WILD
	Napa Creek																			
	Ritchie Creek																			
	Sarco Creek																			
	Sulphur Creek (Napa)																			
	Suscol Creek																			
	Tulucay Creek																			
	Lake Marie		P												E				P	
	Soda Creek																			
	Huichica Creek																			
	Chiles Creek		E								E				P				E	
	Hennessey Lake		E								E				E				E	
	Conn Creek		E								E				E					
	Sage Creek		E								E				P				E	
	Dry Creek		E								E				E				E	
	Carneros Creek																			
	Rector Reservoir		E								E				L				E	
	Rector Creek																			
	York Creek		E												P					
	Bear Canyon Creek																			
	Browns Valley Creek																			
	Pickle Creek																			
	Redwood Creek																			
Wildcat Creek																				
Pinole Creek			E												P					
San Pablo Creek																				
Rodeo Creek															P					
	Refugio Creek																			

E: Existing Beneficial Use P: Potential Beneficial Use L: Limited Beneficial Use

Water bodies listed here may not correspond exactly to those that appear on Figure 2-8.

TABLE 2-6 BASIN 6 - SAN PABLO BASIN CONTINUED

BASIN	WATERBODY	AGR	COLD	COMM	EST	FISH	GWR	IND	MAR	MIGR	MUN	NAV	PROC	RARE	REC-1	REC-2	SHELL	SPWN	WARM	WILD
Sonoma Creek			E							E				E	E	E		E	E	E
	Graham Creek																			
	Agua Caliente Creek																			
	Arroyo Seco Creek																			
	Stuart Creek																			
	Fowler Creek																			
	Nathanson Creek																			
	Schnell Creek																			
	Yulupa Creek																			
Napa River		E	E							E	E	E		E	E	E		E	E	E
	Dalwick Lake																			
	Bell Canyon Reservoir																			
	Kimball Reservoir										E				E	E			E	E
	Napa River	E	E							E	E	E		E	E	E		E	E	E
	Bear Canyon Creek																			
	Cyrus Creek																			
	Garnett Creek																			
	Hopper Creek																			
	Jericho Canyon Creek																			
	Milliken Reservoir		E								E				L	P		E	E	E
	Milliken Creek																			

E: Existing Beneficial Use P: Potential Beneficial Use L: Limited Beneficial Use

Water bodies listed here may not correspond exactly to those that appear on Figure 2-8.

Appendix BB

United States Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

April 30, 1987

MEMORANDUM

SUBJECT: Ambient Air

FROM: G. T. Helms, Chief /s/
Control Programs Operations Branch (MD-15)

TO: Steve Rothblatt, Chief
Air Branch, Region V

My staff and I have discussed the five ambient air cases which you submitted for our review on January 16, 1987. The following comments are our interpretation of the ambient air policy. However, this memorandum is not a discussion of the technical issues involved in the placement of receptors for modeling.

Our comments on each of the cases follow:

Case 1 (Dakota County, MN): This case involves two noncontiguous pieces of fenced property owned by the same source, divided by a public road. We agree that the road is clearly ambient air and that both fenced pieces of plant property are not.

Case 2 (Warrick County, IN): This case involves two large sources on both sides of the Ohio River. We agree that receptors should be located over the river since this is a public waterway, not controlled by the sources. We also agree that the river does indeed form a sufficient natural boundary/barrier and that fencing is not necessary, since the policy requires a fence or other physical barrier. However, some conditions must be met. The riverbank must be clearly posted and regularly patrolled by plant security. It must be very clear that the area is not public. Any areas where there is any question--i.e., grassy areas, etc.--should be fenced and marked, even if there is a very remote possibility that the public would attempt to use this property.

However, we also feel that current policy requires that receptors should be placed in ALCOA and SIGECO property for modeling the contribution of each source's emissions to the other's ambient air. Thus, ALCOA's property--regardless of whether it is fenced--is still "ambient air" in relation to SIGECO's emissions and vice-versa.

Case 3 (Wayne County, MI): This case involves the air over the Detroit River, the Rouge River and the Short-cut Canal. We agree that the air over all three of these is ambient air, since none of the companies owns them or controls public access to them. Note, however, that one source's property--regardless of whether it is fenced--is the "ambient air" relative to another source's emissions.

Case 4 (Cuyahoga County, OH): This case involves LTV Steel's iron and steel mill located on both sides of the Cuyahoga River.

We do not feel that LTV Steel "controls" the river traffic in that area sufficiently to exclude the public from the river, whether it be recreational or industrial traffic. The fact that there is little or no recreational traffic in that area is not sufficient to say that all river traffic there is LTV traffic. The public also includes other industrial users of the river that are not associated with LTV.

It is difficult to tell from the map whether the railroad line is a through line or not. If the railroad yard serves only the plant then it would not be ambient but the railroad entrance to the plant would have to be clearly marked and patrolled. However, if the line is a through line then that would be ambient air. We would need additional information to make a final determination.

The unfenced river boundaries should meet the same criteria as in Case 2 above.

Case 5 (involves the placement of receptors on another source's fenced property): As mentioned above in Case 2, we feel that present policy does require that receptors be placed over another source's property to measure the contribution of the outside source to its neighbor's ambient air. To reiterate, Plant A's property is considered "ambient air" in relation to Plant B's emissions.

I hope that these comments are helpful to you and your staff. This memorandum was also reviewed by the Office of General Counsel.

cc: S. Schneeberg
P. Wyckoff
R. Rhoads
D. Stonefield
Air Branch Chiefs, Region I-X

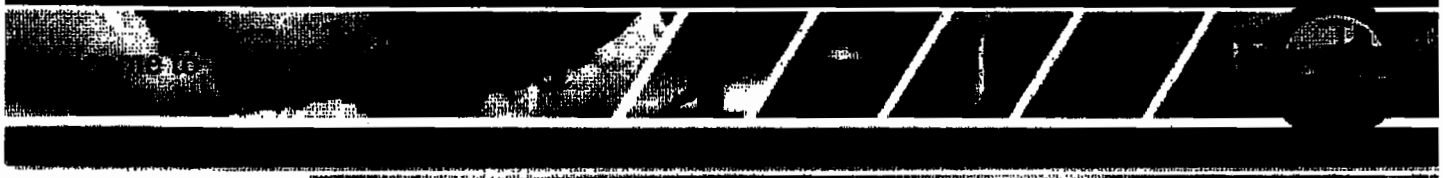
Appendix C

TABLE 2-10 BENEFICIAL USES OF WETLAND AREAS[a]

BASIN/MARSH AREA	WETLAND TYPES: FRESH	WETLAND TYPES: BRACKISH	BENEFICIAL USES: EST	MAR	MUN	COMM	NAV	REC 1	REC 2	SALT	SPWN	WILD
ALAMEDA COUNTY												
Arrowhead			●				●	●	●	●	●	●
Coyote Hills			●				●	●	●	●	●	●
Emeryville Crescent			●				●	●	●	●	●	●
Hayward			●					●	●	●	●	●
CONTRA COSTA COUNTY												
North Contra Costa		●	●				●	●	●	●	●	●
Point Edith		●	●				●		●		●	●
San Pablo Creek			●				●	●	●	●	●	●
Wildcat Creek			●				●	●	●		●	●
MARIN COUNTY												
Abbotts Lagoon				●				●	●	●		●
Bolinas Lagoon				●				●	●	●		●
Corte Madera			●				●	●	●	●	●	●
Drakes Estero								●	●	●	●	●
Gallinas Creek		●	●				●	●	●	●	●	●
Limantour Estero				●				●	●	●		●
Corte Madera Ecological Reserve			●					●	●	●		●
Novato Creek		●	●		●		●	●	●	●	●	
Richardson Bay			●				●	●	●	●	●	●
Rodeo Lagoon				●				●	●	●		●
San Pedro		●	●			●	●		●	●	●	●
San Rafael Creek		●	●				●	●	●	●		●
Tomales Bay				●	●			●	●	●	●	●
NAPA COUNTY												
Mare Island			●						●	●		●
Napa		●	●		●	●	●	●	●		●	
San Pablo Bay			●		●	●	●	●	●	●	●	●
SAN MATEO COUNTY												
Bair Island			●				●	●	●	●		●
Belmont Slough			●				●	●	●	●	●	●
Pescadero	●			●	●		●	●	●	●	●	●
Princeton		●						●	●	●		●
Redwood City Area			●				●	●	●			●
SANTA CLARA COUNTY												
South San Francisco Bay			●		●	●	●	●	●	●	●	●
SOLANO COUNTY												
Southhampton Bay			●				●	●	●	●	●	●
Suisun	●	●	●		●		●	●	●		●	●
White Slough			●		●		●	●	●	●	●	●
SONOMA COUNTY												
Petaluma		●	●		●	●	●	●	●		●	●

NOTE:
a. General locations of wetlands areas are depicted in Figure 2-11.

Appendix C



Air Resources Board

Software - Utilities and Modeling

This page updated March 3, 2005.

This page presents software and documentation available via the California Air Resources Board Information System (CARBIS). The downloading and / or use of any software from this page and its subsequent links designates your agreement to the terms and conditions stated in the **DISCLAIMER**.

Link to All ARB Web-Enabled Databases

Utilities Software

Many files within CARBIS are being made available as Adobe Acrobat files or compressed files. The following utilities will assist you in getting the most from these files. If you have suggestions for freely-redistributable utility software that should be listed here, please send email to our **Webmaster**.

Adobe Acrobat Reader Software

PKWARE Compression and De-Compression Software

E-mail Your Board Item Comments

Join E-Lists

ARB "Text Archive" Search Engine Software and Documentation

Powered By

SWISH-E

The ARB's unique search engine software is available.

FREE for Download

Motor Vehicle Registration Fee Program

Cost-Effectiveness Analysis Tools

Air Quality Models and Documentation

The following is a collection of modeling software and some associated documentation. Please be aware that there may be a fee for reproduction and distribution associated with some of these programs. If you have suggestions for freely-redistributable modeling software that should be listed here, please send e-mail to our helpline attendant. You may also be interested in ARB maintained databases and search engines.

TOXICS AND PERMITTING:

California Emission Inventory Development and Reporting System-Lite (CEIDARS-Lite)

California Air Toxics Emission Factors Database (CATEF)

Health Risk Assessment Computer Program (HRA)

Hot Spots Analysis Reporting Program (HARP)

California Puff Model (CALPUFF)

CALPUFF is maintained by Earth Tech, Inc. The CALPUFF system of files and documentation are located on Earth Tech's website.

http://www.src.com/calpuff/calpuff1.htm

Industrial Source Complex Short Term (ISCST3) Model

ISCST3 is maintained by U.S. EPA. The ISCST3 system of files and documentation are located on U.S. EPA's website.

http://www.epa.gov/scram001/tt22.htm#isc

SCREEN3 Model

SCREEN3 is maintained by U.S. EPA. The SCREEN3 system of files and documentation are located on U.S. EPA's website.

http://www.epa.gov/scram001/tt22.htm#screen3

T-SCREEN Screening Model

TSCREEN is maintained by U.S. EPA. The TSCREEN system of files and documentaion are located on U.S. EPA's website.

http://www.epa.gov/scram001/tt22.htm#tscreen

California Line Source Dispersion Model (CALINE-4)

CALINE-4 is maintained by the California Department of Transportation (Caltrans). The CALINE-4 system of files and documentation are located on the Caltrans website.

http://www.dot.ca.gov/hq/env/air/index.htm

Wind Rose Plotting Program (WRPLOT)

WRPLOT is maintained by U.S. EPA. The WRPLOT files and documentation are located on U.S. EPA's website.

http://www.epa.gov/scram001/tt24.htm#relatedprograms

PHOTOCHEMICAL MODELS:

California Photochemical Grid Model (CALGRID)

Comprehensive Air Quality Model with Extensions (CAMx)

SARMAP Air Quality Model (SAQM)

METEOROLOGICAL MODELS:

California Meteorological Model (CALMET)

CALMET is maintained by Earth Tech, Inc. The CALMET is part of the CALPUFF system of files which, along with documentation, are located on Earth Tech's website.

http://www.src.com/calpuff/calpuff1.htm

Mesoscale Model 5 (MM5)

EMISSION INVENTORY MODELS:

Motor Vehicle Emission Inventory Model (EMFAC/MVEI7G)

Transportation and Land Use Programs Model (URBEMIS 2002)

Emissions Modeling System (EMS95)

MODELING SYSTEMS:

SARMAP Modeling System

Environmental Decision Support System (EDSS)

Models 3

OTHER MODELS:

Census Data Gridding Program (CDGP)

SIMPLEV Electric and Hybrid Vehicle Simulation Model

OTHER MODELING SITES:

U.S. EPA's Library of Air Quality Modeling Software

USER GUIDES:

SCREEN3 User's Guide

SCREEN3 is maintained by U.S. EPA. The SCREEN3 User's Guide is located on U.S. EPA's website.

http://www.epa.gov/scram001/tt22.htm#screen3

ISCST3 User's Guide

http://www.epa.gov/scram001/tt22.htm#isc

T-SCREEN User's Guide

TSCREEN is maintained by U.S. EPA. The TSCREEN User's Guide is located on U.S. EPA's website.

http://www.epa.gov/scram001/tt22.htm#tscreen

U.S. EPA's Library of Air Quality Modeling User's Guides

GUIDANCE DOCUMENTS:

Guideline on Air Quality Models

U.S. EPA's Guideline on Air Quality Models is maintained by U.S. EPA. The Guideline on Air Quality Models, Appendix W to Part 51, Federal Register, 40 CFR Ch. I (1999 Edition) is located on U.S. EPA's website.

http://www.epa.gov/scram001/tt25.htm#guidance

Screening Procedures for Estimating the Air Quality Impact of Stationary Sources

The Screening Procedures for Estimating the Air Quality Impact of Stationary Sources and Update are maintained by U.S. EPA. The Guides are located on U.S. EPA's website.

http://www.epa.gov/scram001/tt25.htm#guidance

Guideline for Regulatory Application of the Urban Airshed Model

Meteorological Monitoring Guidance for Regulatory Modeling Applications

The Meteorological Monitoring Guidance for Regulatory Modeling Applications is maintained by U.S. EPA. The Guide is located on U.S. EPA's website.

http://www.epa.gov/scram001/tt24.htm#relatedprograms

U.S. EPA's Library of Modeling Support and Guidance

RESEARCH REPORTS:

Horizontal Advection Solver Uncertainty

Home Page

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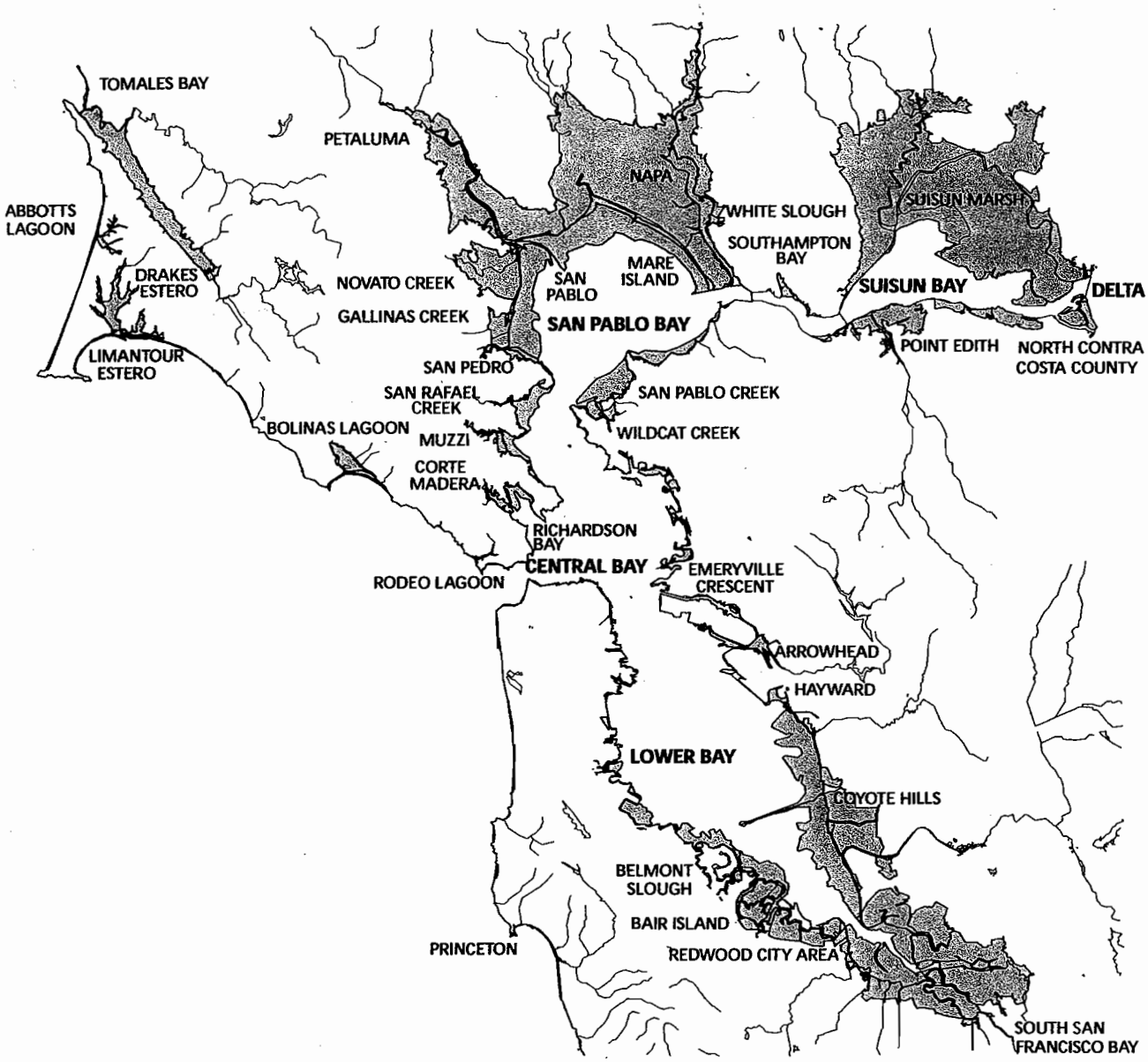
A Department of the California Environmental Protection Agency

Appendix D



SIGNIFICANT SURFACE WATERS

GENERAL WETLAND AREAS

Figure 2-11
General Locations of Wetland Areas

SCALE: 1:640,000

Highest 4 Daily Maximum 8-Hour Ozone Averages

Santa Rosa-5th Street

Year:	2002		2003		2004	
	Date	Measurement	Date	Measurement	Date	Measurement
First High:	Aug 9	0.060	Sep 22	0.079	Sep 5	0.060
Second High:	Sep 1	0.060	Sep 21	0.066	Sep 23	0.050
Third High:	Sep 19	0.055	Sep 13	0.063	Sep 24	0.047
Fourth High:	Sep 2	0.054	Jun 26	0.055	Apr 1	0.046
# Days Above Nat'l Standard:		0		0		0
Year Coverage:		99		99		98

Go Backward One Year | New Top 4 Summary | Go Forward One Year

Notes: All averages are expressed in parts per million.
National exceedances are shown in **orange**. An exceedance is not necessarily a violation.
Year Coverage indicates how complete monitoring was during the time of the year when concentrations are highest. 0 means there was no coverage; 100 means there was complete coverage.
Blanks mean that there was insufficient data available to determine the value.

Switch: Hourly Ozone | PM10 | PM2.5 | Carbon Monoxide | Nitrogen Dioxide | Sulfur Dioxide | Hydrogen Sulfide

Go to: Data Statistics Home Page | Top 4 Summaries Start Page

Highest 4 Daily Maximum 8-Hour Ozone Averages

San Francisco Bay Area Air Basin

Year:	2002		2003		2004	
	Date	Measurement	Date	Measurement	Date	Measurement
First High:	Jul 10	0.106	Sep 22	0.101	Apr 26	0.084
Second High:	Aug 10	0.099	Jun 26	0.097	Sep 24	0.083
Third High:	Aug 9	0.097	Jun 2	0.093	Aug 11	0.081
Fourth High:	Jul 9	0.096	Sep 21	0.092	Sep 5	0.081
# Days Above Nat'l Standard:		7		7		0
Year Coverage:		100		99		—

Go Backward One Year | New Top 4 Summary | Go Forward One Year

Notes: All averages are expressed in parts per million.
National exceedances are shown in orange. An exceedance is not necessarily a violation.
The Year Coverage displayed is the highest Year Coverage of all of the sites in the air basin. It may or may not represent the monitoring site that experienced the highest measurements, averages, or the most days exceeding the standard during the year.
Year Coverage indicates how complete monitoring was during the time of the year when concentrations are highest. 0 means there was no coverage; 100 means there was complete coverage.
Blanks mean that there was insufficient data available to determine the value.

Switch: Hourly Ozone | PM10 | PM2.5 | Carbon Monoxide | Nitrogen Dioxide | Sulfur Dioxide | Hydrogen Sulfide

Go to: Data Statistics Home Page | Top 4 Summaries Start Page

Highest 4 Daily Maximum 8-Hour Ozone Averages

San Rafael

Year:	2002		2003		2004	
	Date	Measurement	Date	Measurement	Date	Measurement
First High:	Sep 1	0.056	Sep 21	0.067	Sep 5	0.063
Second High:	Sep 19	0.054	Sep 22	0.062	Sep 24	0.061
Third High:	Aug 9	0.051	Jun 25	0.052	Sep 23	0.056
Fourth High:	Apr 14	0.046	Sep 13	0.050	Oct 12	0.053
# Days Above Nat'l Standard:		0		0		0
Year Coverage:		99		99		94

Go Backward One Year | New Top 4 Summary | Go Forward One Year

Notes: All averages are expressed in parts per million.
National exceedances are shown in **orange**. An exceedance is not necessarily a violation.
Year Coverage indicates how complete monitoring was during the time of the year when concentrations are highest. 0 means there was no coverage; 100 means there was complete coverage.
Blanks mean that there was insufficient data available to determine the value.

Switch: Hourly Ozone | PM10 | PM2.5 | Carbon Monoxide | Nitrogen Dioxide | Sulfur Dioxide | Hydrogen Sulfide

Go to: Data Statistics Home Page | Top 4 Summaries Start Page

Highest 4 Daily Maximum 8-Hour Ozone Averages

Vallejo-304 Tuolumne Street

Year:	2002		2003		2004	
	Date	Measurement	Date	Measurement	Date	Measurement
First High:	Sep 1	0.071	Jun 26	0.073	Apr 26	0.069
Second High:	Aug 9	0.068	Sep 21	0.072	Sep 5	0.069
Third High:	Aug 10	0.067	Sep 22	0.072	Sep 24	0.068
Fourth High:	Jul 9	0.062	Jun 27	0.070	Apr 25	0.064
# Days Above Nat'l Standard:		0		0		0
Year Coverage:		100		99		99

Go Backward One Year | New Top 4 Summary | Go Forward One Year

Notes: All averages are expressed in parts per million.
National exceedances are shown in orange. An exceedance is not necessarily a violation.
Year Coverage indicates how complete monitoring was during the time of the year when concentrations are highest. 0 means there was no coverage; 100 means there was complete coverage.
Blanks mean that there was insufficient data available to determine the value.

Switch: Hourly Ozone | PM10 | PM2.5 | Carbon Monoxide | Nitrogen Dioxide | Sulfur Dioxide | Hydrogen Sulfide

Go to: Data Statistics Home Page | Top 4 Summaries Start Page

Highest 4 Daily PM2.5 Measurements

Vallejo-304 Tuolumne Street

Year:	2002		2003		2004	
	Date	Measurement	Date	Measurement	Date	Measurement
National:						
First High:	Dec 1	72.3	Jan 12	30.8	Dec 5	39.7
Second High:	Dec 3	55.4	Nov 23	27.3	Dec 4	38.6
Third High:	Dec 6	54.0	Jan 7	25.1	Jan 22	36.9
Fourth High:	Feb 1	42.0	Feb 8	24.6	Jan 4	35.1
California:						
First High:	Dec 1	72.3	Jan 12	30.8	Dec 5	39.7
Second High:	Dec 3	55.4	Nov 23	27.3	Dec 4	38.6
Third High:	Dec 6	54.0	Jan 7	25.1	Jan 22	36.9
Fourth High:	Feb 1	42.0	Feb 8	24.6	Jan 4	35.1
# Days Above Nat'l Standard:		1		0		0
3-Year Average 98th Percentile:		51		45		39
1-Year 98th Percentile:		54.0		25.1		36.9
National 3-Year Average:		12		11		11
National Annual Average:		13.6		9.4		11.1
State 3-Yr Maximum Average:		14		14		14
State Annual Average:		13.6		9.4		11.1

Go Backward One Year | New Top 4 Summary | Go Forward One Year

Notes: All concentrations are expressed in micrograms per cubic meter.
State exceedances are shown in **yellow**. National exceedances are shown in **orange**.
An exceedance is not necessarily a violation.
State and national statistics may differ for the following reasons:
State statistics are based on California approved samplers, whereas national statistics are based on samplers using federal reference or equivalent methods.
State and national statistics may therefore be based on different samplers.
State criteria for ensuring that data are sufficiently complete for calculating valid annual averages are more stringent than the national criteria.
3-Year statistics represent the listed year and the 2 years before the listed year.
Blanks mean that there was insufficient data available to determine the value.

Switch: Hourly Ozone | 8-Hour Ozone | PM10 | Carbon Monoxide | Nitrogen Dioxide | Sulfur Dioxide | Hydrogen Sulfide

Go to: Data Statistics Home Page | Top 4 Summaries Start Page

Air Resources Board

ADAM

Highest 4 Daily PM2.5 Measurements

Santa Rosa-5th Street

Year:	2002		2003		2004	
	Date	Measurement	Date	Measurement	Date	Measurement
National:						
First High:	Dec 4	50.7	Jan 1	38.8	Nov 14	26.6
Second High:	Nov 28	47.4	Nov 29	30.8	Dec 16	25.2
Third High:	Nov 16	42.4	Feb 11	29.8	Dec 17	25.2
Fourth High:	Dec 25	38.0	Jan 9	29.3	Dec 20	25.2
California:						
First High:	Dec 4	50.7	Jan 1	38.8	Nov 14	26.6
Second High:	Nov 28	47.4	Nov 29	30.8	Dec 16	25.2
Third High:	Nov 16	42.4	Feb 11	29.8	Dec 17	25.2
Fourth High:	Dec 25	38.0	Jan 9	29.3	Dec 20	25.2
# Days Above Nat'l Standard:		0		0		0
3-Year Average 98th Percentile:		40		38		32
1-Year 98th Percentile:		42.4		29.8		25.2
National 3-Year Average:		10		10		9
National Annual Average:		10.5		8.8		8.3
State 3-Yr Maximum Average:		11		11		9
State Annual Average:				8.8		8.3

Go Backward One Year | New Top 4 Summary | Go Forward One Year

Notes: All concentrations are expressed in micrograms per cubic meter.
State exceedances are shown in yellow. National exceedances are shown in orange.
An exceedance is not necessarily a violation.
State and national statistics may differ for the following reasons:
State statistics are based on California approved samplers, whereas national statistics are based on samplers using federal reference or equivalent methods.
State and national statistics may therefore be based on different samplers.
State criteria for ensuring that data are sufficiently complete for calculating valid annual averages are more stringent than the national criteria.
3-Year statistics represent the listed year and the 2 years before the listed year.
Blanks mean that there was insufficient data available to determine the value.

Switch: Hourly Ozone | 8-Hour Ozone | PM10 | Carbon Monoxide | Nitrogen Dioxide | Sulfur Dioxide | Hydrogen Sulfide

Go to: Data Statistics Home Page | Top 4 Summaries Start Page

Appendix G

BAY AREA AIR QUALITY MANAGEMENT DISTRICT

Site Search

About BAAQMD | Business Assistance | Public Records Request | Help

Ambient Air Quality Standards & Bay Area Attainment Status

Air Quality Plans
Air Status / Technical Data
Boards/Council
Divisions/Offices
- Administration
- Clerk of the Boards
- Compliance & Enforcement
- Engineering
- Executive
- Human Resources
- Information Systems
- Public Information & Outreach
- Planning
- Technical Services

Grants & Incentives
Opportunities
Permits
Pollution Prevention
Programs
Public Notices
Rules & Regulations
Site Archives

Pollutant	Averaging Time	California Standards[1]		National Standards[2]	
		Concentration	Attainment Status	Concentration[3]	Attainment Status
Ozone	8 Hour	0.070 ppm (137μg/m^3)	9	0.08 ppm	N[4]
	1 Hour	0.09 ppm (180 μg/m^3)	N		5
Carbon Monoxide	8 Hour	9.0 ppm (10 mg/m^3)	A	9 ppm (10 mg/m^3)	A[6]
	1 Hour	20 ppm (23 mg/m^3)	A	35 ppm (40 mg/m^3)	A
Nitrogen Dioxide	Annual Average			0.053 ppm (100 μg/m^3)	A
	1 Hour	0.25 ppm (470 μg/m^3)	A		
Sulfur Dioxide	Annual Average			80 μg/m3 (0.03 ppm^3)	A
	24 Hour	0.04 ppm (105 μg/m^3)	A	0.14 ppm (365 μg/m^3)	A
	1 Hour	0.25 ppm (655 μg/m^3)	A		
Particulate Matter (PM10)	Annual Arithmetic Mean	20 μg/m^3	N[7]	50 μg/m^3)	A

	24 Hour	50 μg/m^3	N	150 μg/m^3	U
Particulate Matter - Fine (PM2.5)	Annual Arithmetic Mean	12 μg/m^3	N[7]	15 μg/m^3)	A
	24 Hour			65 μg/m^3	A
Sulfates	24 Hour	25 μg/m^3	A		
Lead	Calendar Quarter			1.5 μg/m^3)	A
	30 Day Average	1.5 μg/m^3)	A		
Hydrogen Sulfide	1 Hour	0.03 ppm (42 μg/m^3	U		
Vinyl Chloride (chloroethene)	24 Hour	0.010 ppm (26 μg/m^3	No information available		
Visibility Reducing particles	8 Hour(1000 to1800 PST)	See Footnote 8	A		

A=Attainment N=Nonattainment U=Unclassified

mg/m^3=milligrams per cubic meter ppm=parts per million μg/m^3=micrograms per cubic meter

NOTES

1. California standards for ozone, carbon monoxide (except Lake Tahoe), sulfur dioxide (1-hour and 24-hour), nitrogen dioxide, suspended particulate matter - PM10, and visibility reducing particles are values that are not to be exceeded. The standards for sulfates, Lake Tahoe carbon monoxide, lead, hydrogen sulfide, and vinyl chloride are not to be equaled or exceeded. If the standard is for a 1-hour, 8-hour or 24-hour average (i.e., all standards except for lead and the PM10 annual standard), then some measurements may be excluded. In particular, measurements are excluded that ARB determines would occur less than once per year on the average. The Lake Tahoe CO standard is 6.0 ppm, a level one-half the national standard and two-thirds the state standard.
2. National standards other than for ozone, particulates and those based on annual averages are not to be exceeded more than once a year. The 1-hour ozone standard is attained if, during the most

recent three-year period, the average number of days per year with maximum hourly concentrations above the standard is equal to or less than one. The 8-hour ozone standard is attained when the 3-year average of the 4th highest daily concentrations is 0.08 ppm or less. The 24-hour PM10 standard is attained when the 3-year average of the 99th percentile of monitored concentrations is less than 150 µg/m3. The 24-hour PM2.5 standard is attained when the 3-year average of 98th percentiles is less than 65 µg/m3.
Except for the national particulate standards, annual standards are met if the annual average falls below the standard at every site. The national annual particulate standard for PM10 is met if the 3-year average falls below the standard at every site. The annual PM2.5 standard is met if the 3-year average of annual averages spatially-averaged across officially designed clusters of sites falls below the standard.

3. National air quality standards are set at levels determined to be protective of public health with an adequate margin of safety. Each state must attain these standards no later than three years after that state's implementation plan is approved by the Environmental Protection Agency.
4. In June 2004, the Bay Area was designated as a marginal nonattainment area of the national 8-hour ozone standard.
5. The national 1-hour ozone standard was revoked by U.S. EPA on June 15, 2005.
6. In April 1998, the Bay Area was redesignated to attainment for the national 8-hour carbon monoxide standard.
7. In June 2002, CARB established new annual standards for PM2.5 and PM10.
8. Statewide VRP Standard (except Lake Tahoe Air Basin): Particles in sufficient amount to produce an extinction coefficient of 0.23 per kilometer when the relative humidity is less than 70 percent. This standard is intended to limit the frequency and severity of visibility impairment due to regional haze and is equivalent to a 10-mile nominal visual range.
9. This standard was approved by the Air Resources Board on April 28, 2005 and is expected to become effective in early 2006.

Contact
David Fairley (415)749-4656 DFairley@baaqmd.gov Updated 7/14/2005

Disclaimer Email comments

Appendix G

Environmental Consultants

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SCS ENGINEERS

November 29, 2004
File No. 01202197.01

Ms. Carol Allen
Senior Air Quality Engineer
Permit Services Division
Bay Area Air Quality Management District
939 Ellis Street
San Francisco, California 94109

011371

SUBJECT: APPLICATION FOR ATC/PTO AND MODIFICATION TO TITLE V PERMIT, LANDFILL EXPANSION AND NEW FLARE, REDWOOD LANDFILL, NOVATO, CALIFORNIA (PLANT NO. A1197)

Dear Ms. Allen:

Redwood Landfill, Inc. (Redwood) hereby submits two (2) copies of the application for an authority to construct (ATC) and permit to operate (PTO) and modification to the Title V permit for a landfill expansion and new landfill gas (LFG) flare at the Redwood Landfill in Novato, California (Facility No. A1197). This application was prepared by SCS Engineers (SCS) on behalf of Redwood for submittal to the Bay Area Air Quality Management District (BAAQMD).

REASON FOR PROPOSED PERMITTING ACTION

The permitting action described herein is being proposed to accommodate a proposed expansion of the Redwood Landfill. Once approved by the Local Enforcement Agency and the California Integrated Waste Management Board, the expansion will change the landfill's ability to accept refuse on both a daily and annual basis, as described below. These approvals are expected in early 2005. These changes in operation will cause an increase in LFG emissions from refuse decomposition and particulate matter emissions from haul roads and landfill operations. In addition, other changes at the site will affect emissions and should be clarified in the new Title V permit.

As a result of the expansion, Redwood wishes to increase its LFG control capacity. Specifically, Redwood seeks permission to operate an additional ~~flare to create a~~ combined total capacity of 4200 standard cubic feet per minute (scfm) of LFG control capacity. This constitutes a net increase of 200 scfm of LFG control capacity over the existing permitted 4,000 scfm. The existing flare has been in use for nearly eight years and is nearing the end of its useful life. Thus, Redwood proposes to: (1) install a new state-of-the-art flare with a permitted LFG control capacity of 3,000 scfm and (2) reduce the permitted capacity of the existing flare to 1,200 scfm to better fit its actual capacity.

In the next few years, Redwood will make arrangements to replace the existing flare; reducing its permitted capacity now, however, will decrease Redwood's reliance on this older equipment. After installation of the new flare, one flare would serve the southern end and one would serve the northern end of the landfill, reducing the distance LFG must travel on-site.

FACILITY AND EMISSION CHANGES

Various changes are proposed for the Redwood landfill as described below. A brief discussion of how the proposed changes will effect emissions is also presented.

Landfill Expansion---POC and Toxic Emissions

Redwood is requesting a permit modification to accommodate the following increases (or decreases) in the design capacity of the landfill as well as other changes to the landfill (Source No. S-5) and related sources:

- Design capacity to be changed from 19.1 million cubic yards to 34.8 million cubic yards (S-5).
- Design capacity to be changed from 17.1 million tons to 32,3 million tons (S-5).
- Annual disposal rate to be changed from 450,000 tons per year (tpy) to 669,000 tpy for municipal solid waste (MSW) and sewage sludge (S-5).
- Daily disposal rate to be changed from 2300 tons per day (tpd) to 2150 tpd for MSW and sewage sludge (S-5).
- Annual disposal rate to be changed from 6240 tpy to zero (i.e., elimination of activity) for contaminated soil (S-5).
- Annual throughput for sludge in the main pond to be changed from 200,750 tpy to 36,500 tpy ~~(S-2)~~.
- Non-methane organic compound (NMOC) concentration in LFG to be changed from 750 parts per million by volume (ppmv) as hexane to 425 ppmv as hexane (S-5). = 2550 ppmv as C1
- Total reduced sulfur concentration in LFG to be changed from 231 ppmv to 425 ppmv as hydrogen sulfide (S-5).
- Methylene chloride concentration in LFG to be changed from 320 ppmv to 1000 ppmv (S-5). actuals 327-793
- Benzene concentration in LFG to be changed from 340 ppmv to 1000 ppmv (S-5)

Table 1 presents a summary of the LFG generation rate for the expanded landfill using the U.S. EPA's Landfill Gas Emissions Model (LandGEM). Table 2 provides the results of the estimated POC and significant toxic emissions from fugitive LFG, resulting from this capacity increase. The change in POC emissions from contaminated soil and main sludge pond operations is summarized on Table 5.

LFG Flares and Leachate Evaporator

Redwood is proposing to permit a new LFG flare with the following throughput and emission limits. Specifications on the new flare are contained within Attachment 1, including a map showing the new flare location:

- 90 MM BTU/hour capacity
- 2160 MM BTU/day limit
- 788,400 MM BTU/year limit
- NOx emission factor: 0.06 lb/MM BTU
- CO emission factor: 0.2 lb/MM BTU
- PM10 emission factor: 0.017 lb/MM BTU
- NMOC/POC: 98% or 30 ppmv as methane at 3% oxygen.

The existing flare at Redwood will be reduced/changed to the following throughput and emission limits:

- 36 MM BTU/hour capacity
- 864 MM BTU/day limit
- 315,360 MM BTU/year limit
- NOx emission factor: 0.06 lb/MM BTU
- CO emission factor: 0.22 lb/MM BTU
- PM10 emission factor: 0.017 lb/MM BTU
- NMOC/POC: 98% or 30 ppmv as methane at 3% oxygen.

Emissions from the new LFG-fired flare and modified existing LFG flare (Source A-50) are provided on Table 3.

Please note that leachate evaporator (S-50) is being taken out of service, which will provide for a reduction in emissions.

Landfill Expansion—PM10 Emissions

Redwood is requesting a permit modification to accommodate a landfill expansion as described above. This will have an effect on the fugitive dust emissions from the landfill (Source No. S-5) and related sources, as described below.

- Annual disposal rate to be changed from 450,000 tons per year (tpy) to 669,000 tpy for MSW and sewage sludge (S-5).
- Daily disposal rate to be changed from 2300 tons per day (tpd) to 2150 tpd for MSW and sewage sludge (S-5).

- Annual disposal rate to be changed from 6240 tpy to zero (i.e., elimination of activity) for contaminated soil (S-5).
- Annual throughput for sludge in the main pond to be changed from 200,750 tpy to 36,500 tpy (S-2).
- Annual throughout for soil stockpiles and soil cover application to be changed from 105,500 tpy to 355,080 tpy.
- Daily throughout for soil stockpiles and soil cover application to be changed from 1160 tpd to 1600 tpd.
- Annual vehicle miles traveled (VMT) for the unpaved (dirt) road for on-site vehicles to be changed from 19,145 VMT per year to 32,136 VMT per year.
- Daily VMT for the unpaved (dirt) road for on-site vehicles to be changed from 62 VMT per day to 103 VMT per day.
- Annual VMT for the unpaved (dirt) road for off-site vehicles to be changed from 136,500 VMT per year to 227,136 VMT per year.
- Daily VMT for the unpaved (dirt) road for off-site vehicles to be changed from 438 VMT per day to 728 VMT per day.
- Annual VMT for the paved road for off-site vehicles to be changed from 15,600 VMT per year to 39,000 VMT per year.
- Daily VMT for the paved road for off-site vehicles to be changed from 50 VMT per day to 125 VMT per day.
- Annual VMT for the gravel road for off-site vehicles to be changed from 273,000 VMT per year to 374,400 VMT per year.
- Daily VMT for the paved road for off-site vehicles to be changed from 875 VMT per day to 1200 VMT per day.

Emissions of particulate matter with diameter less than 10 microns (PM10) were expected to increase as a result of the landfill expansion. However, this was not the case due to revised emissions calculations, which allowed throughputs to increase while overall emissions decreased. This was mostly due to changes in EPA's *Compilation of Air Pollutant Emission Factors* document (AP-42), which was updated in December 2003 for paved and unpaved roads. These updated AP-42 methodologies actually result in lower emissions for the paved and unpaved roads from previous versions that were used at the site.

A summary of the fugitive dust calculations can be found in Table 4. Sources include paved roads, unpaved roads, dust from erosion, and dust from construction activities. Tables 6 through 7 provide emissions of toxic constituents due to dust emissions. Additional detailed calculations supporting these estimates are provided in Attachment 2.

FACILITY-WIDE EMISSIONS

Table 5 provides a summary of the facility-wide emissions of criteria pollutant emission upon implementation of the proposed landfill expansion and other facility modifications. Table 8 provides a review of the facility-wide emissions and comparison to various offset and modeling thresholds contained within Rule 2-2. Based on the information provided in Table 8, Redwood has drawn the following conclusions:

- Since facility-wide emissions of POCs and NOx are less than 50 tpy and greater than 15 tpy, offsets are required but are requested from the Small Facility Banking Account (SFBA). At less than 50 tpy, modeling and Prevention of Significant Deterioration (PSD) requirements are not triggered for NOx and POCs.

- There is no net increase in CO from this application; therefore, CO modeling is not required. Also, the BAAQMD does not require offsets for CO.

- The application represents a reduction in PM10 emissions, so no modeling or offsets are required. Also, non-fugitive PM10 emissions are less than 100 tpy, so the facility is not a major facility and PSD is not required.

- The application represents an increase in SOx emissions; however, since the non-fugitive SOx emissions are less than 100 tpy, so the facility is not a major facility. Therefore, PSD, offsets, and modeling requirements are not triggered.

OTHER PERMIT CHANGES

In addition to the above, Redwood would like to requests the following changes to the permit conditions in its PTO and Title V:

- Redwood proposes the inclusion of a permit condition whereby an exceedance of the VMT and/or weight limits for vehicle and equipment travel on roads would not automatically be a deviation of the permit. Instead, WM would be able to demonstrate that emissions are below the permitted levels for PM10 by doing a site-specific emission calculation. This would be similar to the permit conditions contained within the Altamont Landfill permit for the proposed road paving emission reduction credit project.

- Redwood also requests a reduction in the record keeping requirements pertaining to the PM10 emissions from travel on landfill roads. Redwood has not problem in compiling the records required under the permit but the monthly summaries (i.e., calculations) of data are very onerous. Instead, Redwood proposes a permit condition whereby the summaries would be done annually as part of the annual compliance certification.

- Redwood also requests that the BAAQMD to add a notation to the permit regarding the requirement to prepare and submit semi-annual startup, shutdown, and malfunction (SSM) plan reports and request that those reports be allowed to be submitted concurrently with the semi-annual Rule 8-34 reports and semi-annual Title V reports (i.e., synchronized reporting periods).

PERMIT APPLICATION FEES

Redwood has included a permit fee in the amount of $7,808 for this permitting action. Please let us know if additional fees are due and we will pay them promptly.

APPLICATION FORMS

BAAQMD application forms are provided for the ATC/PTO for the flare and landfill expansion as well as for Title V modification. A list of the forms included is provided below:

ATC/PTO

- Form 101B (ATC/PTO)
- Form C (Combustion Source; Two Flares)
- Form P (Emission Point; Two Flares)
- Form A (Abatement Device; Two Flares)
- Form RSA (Risk Screening; Two Flares and Landfill Surface)
- Form H (CEQA)

Title V

- Certification Statement
- Stationary Source Summary (Two Pages)
- Total Stationary Source Emissions
- Detailed Emissions Report
- Applicable Requirements and Compliance Summary

Please see Attachments 3 (ATC/PTO forms) and 4 (Title V forms) for signed application forms for this permitting action.

CLOSING

Please note that we are submitting this application in advance of the proposed changes to BAAQMD Rule 2-2, pertaining to New Source Review (NSR). In particular, Redwood wishes to avail itself of the existing offset threshold limit for NOx and POCs of 50 tpy, at which offsets can be provided from the SFBA. It is our understanding that applications submitted prior to the rulemaking deadline (expected to be January 1, 2005) can still use the 50 tpy threshold rather

than the proposed 35 tpy threshold. Any assistance you can provide in the way of expedited review so that this application can be deemed complete before this deadline is greatly appreciated.

If you have any questions in regard to this submittal or should need any further information regarding this matter, please contact the undersigned at (916) 361-1297.

Sincerely,

Patrick S. Sullivan, R.E.A., C.P.P.
Vice President
SCS ENGINEERS

cc: Whitney King; Redwood Landfill
Ramin Khany; Redwood Landfill
Guy Petraborg; Waste Management

Attachments:

	Emission Estimates (Tables 1-8)
1	New Flare Specifications and Drawings
2	Detailed Fugitive Dust Calculations
3	ATC and PTO Application Forms
4	Title V Permit Application Forms

TABLES

TABLE 1. PROJECTED LFG AND NMOC GENERATION RATES
REDWOOD LANDFILL - NOVATO, CALIFORNIA

Year	Disposal Rate (tons/yr)	Refuse In-Place (tons)	Disposal Rate (Mg/yr)	Refuse In-Place (Mg)	Methane Generation Rates (m^3/yr)	LFG Generation Rates (cfm)	LFG Generation Rates (Million ft^3/yr)	NMOC Generation Rates (tons/yr)	NMOC Emission Rates (tons/yr)
1958	120,467	0	109,286	0	0.000E+00	0	0	0	0
1959	123,479	120,467	112,018	109,286	2.732E+05	37	19	1	0
1960	126,566	243,946	114,819	221,304	5.465E+05	73	39	2	0
1961	129,730	370,512	117,689	336,123	8.201E+05	110	58	3	1
1962	132,973	500,242	120,631	453,812	1.094E+06	147	77	4	1
1963	136,297	633,215	123,647	574,443	1.369E+06	184	97	4	1
1964	139,705	769,512	126,738	698,090	1.644E+06	221	116	5	1
1965	143,197	909,217	129,906	824,828	1.920E+06	258	136	6	2
1966	146,777	1,052,414	133,154	954,734	2.198E+06	295	155	7	2
1967	150,447	1,199,191	136,483	1,087,888	2.476E+06	333	175	8	2
1968	154,208	1,349,638	139,895	1,224,371	2.756E+06	370	195	9	2
1969	158,063	1,503,846	143,392	1,364,266	3.038E+06	408	215	10	3
1970	162,015	1,661,909	146,978	1,507,658	3.321E+06	446	235	11	3
1971	166,065	1,823,924	150,652	1,654,636	3.607E+06	485	255	12	3
1972	170,217	1,989,989	154,418	1,805,288	3.894E+06	523	275	13	3
1973	174,472	2,160,206	158,278	1,959,706	4.184E+06	562	296	14	4
1974	184,288	2,334,678	167,183	2,117,984	4.477E+06	602	316	15	4
1975	186,131	2,518,966	168,855	2,285,168	4.784E+06	643	338	16	4
1976	187,992	2,705,097	170,543	2,454,023	5.088E+06	684	359	17	4
1977	189,872	2,893,089	172,249	2,624,566	5.389E+06	724	381	18	5
1978	191,771	3,082,961	173,972	2,796,815	5.686E+06	764	402	19	5
1979	193,689	3,274,732	175,712	2,970,787	5.981E+06	804	422	20	5
1980	195,626	3,468,421	177,469	3,146,499	6.273E+06	843	443	20	5
1981	197,582	3,664,047	179,243	3,323,968	6.561E+06	882	463	21	6
1982	199,556	3,861,629	181,034	3,503,211	6.848E+06	920	484	22	6
1983	207,753	4,061,185	188,470	3,684,245	7.131E+06	958	504	23	6
1984	215,969	4,268,938	195,924	3,872,715	7.426E+06	998	525	24	6
1985	224,205	4,484,907	203,395	4,068,639	7.733E+06	1,039	546	25	7
1986	232,461	4,709,112	210,885	4,272,035	8.050E+06	1,082	569	26	7
1987	240,737	4,941,573	218,393	4,482,920	8.379E+06	1,126	592	27	7
1988	245,935	5,182,310	223,108	4,701,313	8.718E+06	1,171	616	28	8
1989	249,179	5,428,245	226,051	4,924,421	9.060E+06	1,218	640	30	8
1990	255,668	5,677,424	231,938	5,150,472	9.402E+06	1,263	664	31	8
1991	375,110	5,933,092	340,294	5,382,411	9.749E+06	1,310	689	32	8
1992	343,739	6,308,202	311,835	5,722,705	1.036E+07	1,392	732	34	9
1993	346,789	6,651,941	314,602	6,034,539	1.088E+07	1,462	769	36	9
1994	363,984	6,998,730	330,201	6,349,141	1.140E+07	1,532	805	37	10
1995	376,586	7,362,714	341,633	6,679,342	1.195E+07	1,605	844	39	10
1996	398,286	7,739,300	361,319	7,020,975	1.250E+07	1,680	883	41	11
1997	407,097	8,137,586	369,312	7,382,294	1.310E+07	1,760	925	43	11
1998	369,363	8,544,683	335,080	7,751,606	1.370E+07	1,841	968	45	12
1999	454,289	8,914,046	412,124	8,086,687	1.420E+07	1,908	1,003	46	12
2000	445,971	9,368,335	404,578	8,498,811	1.488E+07	1,999	1,051	49	13
2001	439,730	9,814,306	398,916	8,903,389	1.552E+07	2,086	1,096	51	13
2002	423,717	10,254,036	384,390	9,302,305	1.614E+07	2,168	1,140	53	14
2003	423,717	10,677,753	384,390	9,686,695	1.670E+07	2,244	1,179	54	14
2004	423,717	11,101,470	384,390	10,071,084	1.725E+07	2,318	1,218	56	15
2005	529,646	11,525,187	480,487	10,455,474	1.778E+07	2,390	1,256	58	15
2006	540,239	12,054,833	490,097	10,935,961	1.854E+07	2,492	1,310	61	16
2007	551,044	12,595,072	499,899	11,426,058	1.931E+07	2,595	1,364	63	17
2008	562,065	13,146,116	509,897	11,925,956	2.008E+07	2,699	1,419	66	17
2009	573,306	13,708,181	520,095	12,435,853	2.086E+07	2,804	1,474	68	18
2010	584,772	14,281,487	530,496	12,955,948	2.165E+07	2,909	1,529	71	19
2011	596,468	14,866,260	541,106	13,486,444	2.244E+07	3,016	1,585	73	19
2012	608,397	15,462,727	551,929	14,027,550	2.324E+07	3,123	1,641	76	20
2013	620,565	16,071,124	562,967	14,579,479	2.405E+07	3,231	1,698	78	21
2014	632,976	16,691,689	574,226	15,142,446	2.486E+07	3,341	1,756	81	21
2015	645,636	17,324,666	585,711	15,716,672	2.568E+07	3,451	1,814	84	22
2016	658,549	17,970,301	597,425	16,302,383	2.651E+07	3,563	1,872	87	23
2017	671,720	18,628,850	609,374	16,899,809	2.735E+07	3,675	1,932	89	24
2018	685,154	19,300,570	621,561	17,509,182	2.820E+07	3,789	1,992	92	24
2019	698,857	19,985,723	633,992	18,130,744	2.906E+07	3,904	2,052	95	25
2020	712,834	20,684,580	646,672	18,764,736	2.992E+07	4,021	2,113	98	26
2021	727,091	21,397,415	659,606	19,411,408	3.080E+07	4,139	2,175	101	27
2022	741,633	22,124,505	672,798	20,071,014	3.169E+07	4,258	2,238	103	27
2023	756,465	22,866,138	686,254	20,743,812	3.259E+07	4,379	2,302	106	28
2024	771,595	23,622,603	699,979	21,430,065	3.350E+07	4,502	2,366	109	29
2025	787,026	24,394,198	713,978	22,130,044	3.442E+07	4,626	2,431	112	30
2026	802,767	25,181,224	728,258	22,844,023	3.536E+07	4,751	2,497	115	31
2027	818,822	25,983,991	742,823	23,572,281	3.631E+07	4,879	2,564	118	31
2028	835,199	26,802,814	757,680	24,315,104	3.727E+07	5,008	2,632	122	32
2029	851,903	27,638,012	772,833	25,072,783	3.824E+07	5,139	2,701	125	33
2030	868,941	28,489,915	788,290	25,845,617	3.923E+07	5,271	2,771	128	34
2031	886,320	29,358,856	804,056	26,633,906	4.023E+07	5,406	2,841	131	35
2032	904,046	30,245,176	820,137	27,437,962	4.125E+07	5,543	2,913	135	36
2033	922,127	31,149,222	836,539	28,258,099	4.228E+07	5,681	2,986	138	37
2034	228,651	32,071,349	207,429	29,094,638	4.333E+07	5,822	3,060	141	37
2035	0	32,300,000	0	29,302,067	4.278E+07	5,748	3,021	140	37

ESTIMATED NMOC CONCENTRATION IN LFG:	420	ppmv
ASSUMED METHANE CONTENT OF LFG:	50%	
SELECTED DECAY RATE CONSTANT:	0.025	
SELECTED ULTIMATE METHANE RECOVERY RATE	3,204	ft3/ton
METRIC EQUIVALENT:	100	cu m/Mg

avg. rainfall is 27.5 inches/yr

Redwood LFG Generation Model 32 Million.xls

4/1/2004

TABLE 2. EMISSIONS ESTIMATES FOR FUGITIVE LFG
PROPOSED LANDFILL EXPANSION
REDWOOD LANDFILL
NOVATO, CALIFORNIA

Emission Sources: Landfill Gas

Pollutant	Molecular Weight (g/Mol)	Average Concentration Found In LFG (ppmv)	LFG Generation (tons/yr)	Fugitive Emissions from Landfill (lb/yr)	Fugitive Emissions from Landfill (tons/yr)
Significant Toxic Air Contaminants					
1,1,2-Trichloroethane (methyl chloroform)	133.41	0.07	0.036	18.08	0.009
1,1,2,2-Tetrachloroethane	167.85	0.07	0.046	23.05	0.012
1,1-Dichloroethane (ethylidene dichloride)	98.97	0.15	0.058	29.12	0.015
1,2-Dichloroethane (ethylene dichloride)	98.96	0.07	0.027	13.59	0.007
1,3-Butadiene	54.09	0.28	0.059	29.53	0.015
Acrylonitrile	53.06	0.28	0.058	29.14	0.015
Benzene	78.11	1.00	0.306	153.22	0.077
Carbon tetrachloride	153.84	0.07	0.042	21.12	0.011
Chloroform	119.39	0.07	0.033	16.39	0.008
Dichlorobenzene (1,4-Dichlorobenzene)	147.00	0.40	0.231	115.34	0.058
Dichloromethane (Methylene Chloride)	84.94	1.00	0.333	166.61	0.083
Ethylene dibromide (1,2-Dibromoethane)	187.88	0.07	0.052	25.80	0.013
Perchloroethylene (tetrachloroethylene)	165.83	0.45	0.293	146.38	0.073
Trichloroethylene (trichloroethene)	131.40	0.25	0.129	64.44	0.032
Vinyl chloride	62.50	0.88	0.216	107.88	0.054
Sulfur Compounds					
Hydrogen Sulfide	34.08	424.00	56.681	28,340.53	14.170
Cabonyl Sulfide	60.07	0.05	0.012	5.89	0.003
Methyl Mercaptan	48.10	0.30	0.057	28.31	0.014
Ethyl Mercaptan	62.13	0.05	0.012	6.09	0.003
Dimethyl Sulfide	62.13	0.20	0.049	24.37	0.012
Carbon Disulfide	76.13	0.10	0.030	14.93	0.007
iso-propyl Mercaptan	76.16	0.05	0.015	7.47	0.004
n-propyl Mercaptan	76.16	0.05	0.015	7.47	0.004
Dimethyl Disulfide	94.19	0.05	0.018	9.24	0.005
Total Reduced Sulfur, as H2S	34.08	425.00	56.815	28,407.37	14.204
Other Halogenated Compounds					
1,1 Dichloroethylene (vinylidine dichloride)	96.94	0.15	0.057	28.52	0.014
1,1,1 Trichloroethane	133.40	0.07	0.036	18.07	0.009
1,2 Dichloroethene (cis)	96.94	0.58	0.220	109.78	0.055
1,2 Dichloroethene (trans)	96.94	0.28	0.106	52.93	0.026
1,2 Dichloropropane (propylene dichloride)	112.99	0.07	0.031	15.31	0.008
1,2,4 Trichlorobenzene	181.45	0.07	0.049	24.58	0.012
1,3 Dichloropropene (cis)	110.97	0.07	0.030	15.04	0.008
1,3 Dichloropropene (trans)	110.97	0.07	0.030	15.04	0.008
Bromodichloromethane	163.83	3.13	2.012	1,005.84	0.503
Bromoform	252.73	0.28	0.276	137.99	0.069
Chlorobenzene	112.56	0.08	0.034	16.84	0.008
Chloroprene	88.54	0.28	0.097	48.34	0.024
Chlorotoluene	126.59	0.07	0.034	17.15	0.009
Dibromochloromethane	208.28	0.28	0.227	113.72	0.057
Ethyl Chloride (chloroethane)	64.51	0.30	0.076	37.96	0.019
Freon-11 (trichlorofluoromethane)	137.37	0.14	0.075	37.72	0.019
Freon-113 (1,1,2 trichloro 1,2,2 trifluoroethane)	187.38	0.07	0.051	25.39	0.013
Freon-114 (1,2 dichloro 1,1,2,2 tetrafluoroethane)	170.92	0.07	0.047	23.50	0.012
Freon-12 (dichlorodifluoromethane)	120.91	0.66	0.313	156.49	0.078
Hexachlorobutadiene	260.76	0.07	0.071	35.33	0.018
Methyl Bromide	94.94	0.07	0.026	12.86	0.006
Methyl Chloride (chloromethane)	50.49	0.07	0.014	6.84	0.003
Other Non-Halogenated Compounds					
4 Dioxane	88.11	0.28	0.096	48.11	0.024
-Propanol	60.10	5.05	1.191	595.48	0.298

TABLE 2. EMISSIONS ESTIMATES FOR FUGITIVE LFG

4-Ethyl Toluene	120.19	1.03	0.486	243.06	0.122	
Acetone	58.08	3.81	0.869	434.56	0.217	
Butane	58.12	10.31	2.351	1,175.37	0.588	
Cyclohexane	84.16	0.96	0.317	158.48	0.079	
Ethanol	46.07	24.74	4.472	2,235.86	1.118	
Ethyl Benzene	106.17	2.06	0.859	429.38	0.215	
Heptane	100.20	1.13	0.446	222.90	0.111	
Hexane	86.18	0.88	0.298	148.75	0.074	
Methyl Ethyl Ketone	72.11	7.53	2.129	1,064.44	0.532	
Methyl Isobutyl Ketone	100.16	0.76	0.300	149.88	0.075	
Methyl n-Butyl Ketone	100.16	0.28	0.109	54.69	0.027	
Methyl t-Butyl Ether	88.15	0.28	0.096	48.13	0.024	
Pentane	72.15	10.31	2.918	1,459.02	0.730	
Propane	44.10	20.62	3.567	1,783.44	0.892	
Propylene	42.08	0.28	0.046	22.98	0.011	
Styrene	104.15	0.33	0.135	67.40	0.034	
Tetrahydrofuran	72.11	2.06	0.583	291.63	0.146	
Toluene	92.14	10.21	3.689	1,844.63	0.922	
Trimethyl Benzene	120.19	2.56	1.206	602.78	0.301	
Vinyl Acetate	86.09	0.28	0.094	47.00	0.024	
Xylenes (o, m, p)	106.17	7.90	3.290	1,645.18	0.823	Emission
Mercury	200.59	2.92E-04	2.30E-04	0.11	5.74E-05	Factor
Criteria Air Pollutants						(lb/ton)
POCs as Hexane	86.18	421	142.266		35.567	0.0022
Other Regulated Air Pollutants						
NMOCs as Hexane	86.18	425	143.69		35.922	
NPOCs as Hexane	86.18	4.21	1.42		0.355	2.20E-05

MODEL INPUT VARIABLES (PTE):

Estimated Collection Efficiency	75% calculated: actual LFG recovery / LFG generation based on EPA AP-42 (typical collection efficiency achievable with a comprehensive system)
Landfill Gas Generation Rate	5,748 scfm (from LFG generation model for the proposed 32.3 millions tons)
Estimated Methane Content of LFG	50%
Ethane Concentration in LFG	1.78 ppmv as hexane

TABLE 3. EMISSIONS ESTIMATES FOR NEW AND MODIFIED LFG FLARES AND LEACHATE EVAPORATOR
REDWOOD LANDFILL
NOVATO, CALIFORNIA

Emission Sources: Landfill Gas Combustion Sources

Criteria Pollutants					Emission Limits (pounds/MM BTU)						Maximum Annual Emissions (tons/year)					
Source Number	Description	MM BTU/hour	Hours/Year	MM BTU / year	NOx	CO	POC	NPOC	PM10	SO2	NOx	CO	POC	NPOC	PM10	SO2
S-50	Leachate Vaporator	0.000	0	0	0.083	0.083	0.014	9.27E-05	0.009	0.142	0.000	0.000	0.000	0.000	0.000	0.000
	New Landfill Gas Flare	90.000	8760	788400	0.060	0.200	0.014	9.27E-05	0.017	0.142	23.652	78.840	5.519	0.037	6.701	55.803
A-50	Modified Old Flare	36.000	8760	315360	0.060	0.220	0.014	9.27E-05	0.017	0.142	9.461	34.690	2.206	0.015	2.681	22.321
Total	All LFG Combustion Sources										33.113	113.530	7.726	0.051	9.382	78.125

Pollutant	Molecular Weight (g/Mol)	Emission Factor (lb/MM BTU)	New Flare Emissions (tons/yr)	Old Flare Emissions (tons/yr)	Total Flare Emissions (tons/yr)
Significant Toxic Air Contaminants					
1,1,2-Trichloroethane (methyl chloroform)	133.41	9.58E-07	3.78E-04	1.51E-04	5.29E-04
1,1,2,2-Tetrachloroethane	167.85	1.22E-06	4.82E-04	1.93E-04	6.74E-04
1,1-Dichloroethane (ethylidene dichloride)	98.97	1.54E-06	6.09E-04	2.43E-04	8.52E-04
1,2-Dichloroethane (ethylene dichloride)	98.96	7.20E-07	2.84E-04	1.14E-04	3.98E-04
1,3-Butadiene	54.09	1.57E-06	6.17E-04	2.47E-04	8.64E-04
Acrylonitrile	53.06	2.32E-07	9.14E-05	3.65E-05	1.28E-04
Benzene	78.11	1.22E-06	4.80E-04	1.92E-04	6.72E-04
Carbon tetrachloride	153.84	1.12E-06	4.41E-04	1.77E-04	6.18E-04
Chloroform	119.39	8.69E-07	3.43E-04	1.37E-04	4.80E-04
Dichlorobenzene (1,4-Dichlorobenzene)	147.00	6.11E-06	2.41E-03	9.64E-04	3.37E-03
Dichloromethane (Methylene Chloride)	84.94	8.83E-06	3.48E-03	1.39E-03	4.87E-03
Ethylene dibromide (1,2-Dibromoethane)	187.88	1.37E-06	5.39E-04	2.16E-04	7.55E-04
Perchloroethylene (tetrachloroethylene)	165.83	7.76E-06	3.06E-03	1.22E-03	4.28E-03
Trichloroethylene (trichloroethane)	131.40	3.42E-06	1.35E-03	5.39E-04	1.89E-03
Vinyl chloride	62.50	5.72E-06	2.25E-03	9.02E-04	3.16E-03
Sulfur Compounds					
Hydrogen Sulfide	34.08	1.50E-03	5.92E-01	2.37E-01	8.29E-01
Carbonyl Sulfide	60.07	3.12E-07	1.23E-04	4.93E-05	1.72E-04
Methyl Mercaptan	48.10	1.50E-06	5.92E-04	2.37E-04	8.28E-04
Ethyl Mercaptan	62.13	3.23E-07	1.27E-04	5.09E-05	1.78E-04
Dimethyl Sulfide	62.13	1.29E-06	5.09E-04	2.04E-04	7.13E-04
Carbon Disulfide	76.13	7.92E-07	3.12E-04	1.25E-04	4.37E-04
iso-propyl Mercaptan	76.16	3.96E-07	1.56E-04	6.24E-05	2.19E-04
n-propyl Mercaptan	76.16	3.96E-07	1.56E-04	6.24E-05	2.19E-04
Dimethyl Disulfide	94.19	4.90E-07	1.93E-04	7.72E-05	2.70E-04
Total Reduced Sulfur, as H2S	34.08	1.51E-03	5.94E-01	2.37E-01	8.31E-01
Combustion By-Products					
Hydrogen Chloride	36.46	3.85E-03	1.52E+00	6.07E-01	2.13E+00
Hydrogen Fluoride	20.01	2.03E-04	7.98E-02	3.19E-02	1.12E-01
Hydrogen Bromide	80.91	1.99E-03	7.85E-01	3.14E-01	1.10E+00
Other Halogenated Compounds					
1,1 Dichloroethylene (vinylidine dichloride)	96.94	1.51E-06	5.96E-04	2.38E-04	8.35E-04
1,1,1 Trichloroethane	133.40	9.58E-07	3.78E-04	1.51E-04	5.29E-04
1,2 Dichloroethene (cis)	96.94	5.82E-06	2.29E-03	9.18E-04	3.21E-03
1,2 Dichloroethene (trans)	96.94	2.81E-06	1.11E-03	4.42E-04	1.55E-03
1,2 Dichloropropane (propylene dichloride)	112.99	8.12E-07	3.20E-04	1.28E-04	4.48E-04
1,2,4 Trichlorobenzene	181.45	1.30E-06	5.14E-04	2.06E-04	7.19E-04
1,3 Dichloropropene (cis)	110.97	7.97E-07	3.14E-04	1.26E-04	4.40E-04

TABLE 3.

1,3 Dichloropropene (trans)	110.97	7.97E-07	3.14E-04	1.26E-04	4.40E-04
Bromodichloromethane	163.83	5.33E-05	2.10E-02	8.41E-03	2.94E-02
Bromoform	252.73	7.32E-06	2.88E-03	1.15E-03	4.04E-03
Chlorobenzene	112.56	8.93E-07	3.52E-04	1.41E-04	4.93E-04
Chloroprene	88.54	2.56E-06	1.01E-03	4.04E-04	1.41E-03
Chlorotoluene	126.59	9.09E-07	3.58E-04	1.43E-04	5.02E-04
Dibromochloromethane	208.28	6.03E-06	2.38E-03	9.51E-04	3.33E-03
Ethyl Chloride (chloroethane)	64.51	2.01E-06	7.93E-04	3.17E-04	1.11E-03
Freon-11 (trichlorofluoromethane)	137.37	2.00E-06	7.88E-04	3.15E-04	1.10E-03
Freon-113 (1,1,2 trichloro 1,2,2 trifluoroethane)	187.38	1.35E-06	5.31E-04	2.12E-04	7.43E-04
Freon-114 (1,2 dichloro 1,1,2,2 tetrafluoroethane)	170.92	1.25E-06	4.91E-04	1.96E-04	6.88E-04
Freon-12 (dichlorodifluoromethane)	120.91	8.30E-06	3.27E-03	1.31E-03	4.58E-03
Hexachlorobutadiene	260.76	1.87E-06	7.38E-04	2.95E-04	1.03E-03
Methyl Bromide	94.94	6.82E-07	2.69E-04	1.08E-04	3.76E-04
Methyl Chloride (chloromethane)	50.49	3.63E-07	1.43E-04	5.72E-05	2.00E-04
Other Non-Halogenated Compounds					
1,4 Dioxane	88.11	2.55E-06	1.01E-03	4.02E-04	1.41E-03
2-Propanol	60.10	3.16E-05	1.24E-02	4.98E-03	1.74E-02
4-Ethyl Toluene	120.19	1.29E-05	5.08E-03	2.03E-03	7.11E-03
Acetone	58.08	2.30E-05	9.08E-03	3.63E-03	1.27E-02
Butane	58.12	6.23E-05	2.46E-02	9.83E-03	3.44E-02
Cyclohexane	84.16	8.40E-06	3.31E-03	1.32E-03	4.64E-03
Ethanol	46.07	1.19E-04	4.67E-02	1.87E-02	6.54E-02
Ethyl Benzene	106.17	2.28E-05	8.97E-03	3.59E-03	1.26E-02
Heptane	100.20	1.18E-05	4.66E-03	1.86E-03	6.52E-03
Hexane	86.18	7.89E-06	3.11E-03	1.24E-03	4.35E-03
Methyl Ethyl Ketone	72.11	5.64E-05	2.22E-02	8.90E-03	3.11E-02
Methyl Isobutyl Ketone	100.16	7.95E-06	3.13E-03	1.25E-03	4.39E-03
Methyl n-Butyl Ketone	100.16	2.90E-06	1.14E-03	4.57E-04	1.60E-03
Methyl t-Butyl Ether	88.15	2.55E-06	1.01E-03	4.02E-04	1.41E-03
Pentane	72.15	7.74E-05	3.05E-02	1.22E-02	4.27E-02
Propane	44.10	9.46E-05	3.73E-02	1.49E-02	5.22E-02
Propylene	42.08	1.22E-06	4.80E-04	1.92E-04	6.72E-04
Styrene	104.15	3.57E-06	1.41E-03	5.63E-04	1.97E-03
Tetrahydrofuran	72.11	1.55E-05	6.09E-03	2.44E-03	8.53E-03
Toluene	92.14	9.78E-05	3.86E-02	1.54E-02	5.40E-02
Trimethyl Benzene	120.19	3.20E-05	1.26E-02	5.04E-03	1.76E-02
Vinyl Acetate	86.09	2.49E-06	9.82E-04	3.93E-04	1.38E-03
Xylenes (o, m, p)	106.17	8.72E-05	3.44E-02	1.38E-02	4.81E-02
Mercury	200.59	3.05E-07	1.20E-04	4.80E-05	1.68E-04

TABLE 4. EMISSIONS ESTIMATES FOR FUGITIVE DUST
PROPOSED LANDFILL EXPANSION
REDWOOD LANDFILL
NOVATO, CALIFORNIA

Particulate Emissions from S-5 Landfill (2004 Expansion)

Particulate Emission Source	PM10 Emissions	
	Pounds/Day	Tons/Year
Off-Site Vehicle Traffic, gravel roads	533.90	83.29
Off-Site Vehicle Traffic, dirt roads	323.90	50.528
On-Site Vehicle Traffic, dirt roads	60.29	9.405
All Vehicle Traffic, paved roads	24.68	3.850
Waste Disposal Activities	53.37	8.317
Wind Erosion From Active Face	0.79	0.041
Total Emissions from Landfill	**996.92**	**155.429**
Waste Disposal Rates (tons)	**3419**	**669000**
Overall Emission Factor (pounds/ton)	0.292	0.465

Particulate Emissions from S-42 Soil Stockpiles (2004 Expansion)

Particulate Emission Source	PM10 Emissions	
	Pounds/Day	Tons/Year
Soil Dumping and Soil Truck Loading	0.37	0.041
Wind Erosion From Active Stockpile	0.24	0.014
Total Emissions from Soil Stockpiles	**0.61**	**0.055**
Soil Throughput Rates (tons)	1600	355080
Overall Emission Factor (pounds/ton)	3.79E-04	3.08E-04

Table 5. New Maximum Permitted/Potential Emissions From All Equipment at Plant # 1179

	Maximum Annual Emissions (tons/year)					
	NOx	CO	POC	NPOC	PM10	SO2
All Permitted Sources	46.084	117.610	49.855	0.497	170.389	78.356

Calculation Assumptions:

HHV of Methane, BTU/scf at 60 oF:	1013	(from Perry's Chemical Engineers' Handbook)
HHV of Methane, BTU/scf at 70 oF:	993.9	
Molar Volume of Gas at T = 70 oF:	387.0	
Landfill Gas Methane Content:	45%	
Landfill Gas HHV, BTU/scf of LFG (at 70 oF):	447.25	
Landfill Gas Flue Gas Factor:	4.3959	(sdcf of flue gas at 0% O2 per scf of landfill gas)
Landfill Gas Sulfur Content, ppm as H2S	425.0	(proposed permit condition limit)
Ambient Oxygen Content:	20.95%	
Oxygen Correction, 15% to 0%:	3.521	
Oxygen Correction, 3% to 0%:	1.167	
Molecular Weight, NO2:	46.01	
Molecular Weight, CO:	28.01	
Molecular Weight, CH4:	16.04	
Molecular Weight, SO2:	64.06	
Diesel Oil Density, pounds/gallon:	7.10	
Diesel Oil Heat Content, BTU/gallon:	137000	
Diesel Oil Flue Gas Factor, dscf/MM BTU:	9190	

Maximum Potential Emissions from Combustion Equipment

						Emission Limits (pounds/MM BTU)						Maximum Annual Emissions (tons/year)					
Source Number	Description	Horsepower	MM BTU/hour	Hours/Year	MM BTU / year	NOx	CO	POC	NPOC	PM10	SO2	NOx	CO	POC	NPOC	PM10	SO2
S-40	Diesel Engine (TG)	505	3.740		2192	1.875	0.424	0.047		0.121	0.052	2.055	0.465	0.052		0.133	0.057
S-45	Diesel Engine (Pump)	95	0.736	2496	1836	3.387	2.773	0.201		0.284	0.063	3.109	2.546	0.184		0.261	0.049
S-46	Diesel Engine (Tipper)	94	0.658	2496	1641	3.769	0.336	0.223		0.314	0.052	3.094	0.276	0.183		0.258	0.043
S-47	Diesel Engine (Pump)	80	0.548	2496	1368	3.958	0.996	0.161		0.321	0.052	2.707	0.682	0.110		0.220	0.035
S-48	Diesel Engine (Screen)	102	0.712	2496	1778	2.140	0.110	0.098		0.028	0.052	1.903	0.098	0.087		0.025	0.046
S-49	Diesel Engine (BUG)	102	0.685	100	69	3.007	0.391	0.102		0.053	0.052	0.103	0.013	0.003		0.002	0.002
S-50	Leachate Vaporator		0.000	0	0	0.083	0.083	0.014	9.27E-05	0.017	0.077	0.000	0.000	0.000	0.000	0.000	0.000
	New Landfill Gas Flare		90.000	8760	788400	0.060	0.200	0.014	9.27E-05	0.017	0.142	23.652	78.840	5.519	0.037	6.701	55.803
A-50	Modified Old Flare		36.000	8760	315360	0.060	0.220	0.014	9.27E-05	0.017	0.142	9.461	34.690	2.208	0.015	2.681	22.321
Total	All Combustion Sources											46.084	117.610	8.346	0.051	10.281	78.356

Maximum Potential Emissions Due to Other Existing Sources

			tons/year			Emission Factor (pounds/ton)						Maximum Annual Emissions (tons/year)					
Source Number	Description		Throughput Limit			NOx	CO	POC	NPOC	PM10	SO2	NOx	CO	POC	NPOC	PM10	SO2
S-1	Sewage Sludge Storage, Area G Pond		4015					0.010		0.0100				0.020		0.020	
S-2	Sewage Sludge Storage, Main Pond		36500					0.010		0.0100				0.183		0.183	
S-5	Redwood Landfill	waste decomp.	32300000	(tons in place)				0.002	2.20E-05					35.567	0.355		
S-5	Redwood Landfill	waste disposal	669000	(tons/year)						0.4847						155.429	
S-5	Redwood Landfill	contam. soil	0					0.100						0.000			
S-5	Redwood Landfill	VOC soil	105300					0.100						5.265			
S-25	Yard and Green Waste Stockpiles		20000							0.0010						0.010	
S-28	Co-Compost Biosolids Feed Stockpiles		50000					0.010		0.0002				0.250		0.005	
S-34	Active Compost and Co-Compost Windrows		50000					0.010		0.0010				0.250		0.025	
S-35	Compost and Co-Compost Curing Piles		50000					0.002		0.0002				0.050		0.005	
S-37	Compost and Co-Compost Final Product Storage Piles		50000					0.001		0.0002				0.025		0.005	
S-38	On-Site Material Hauling		60000							0.1130						3.390	
S-39	Trommell Screening Processes		50000							0.0004						0.009	
S-41	Yard and Green Waste Shredding		80000							0.0243						0.972	
S-42	Soil Stockpiles		353,080							3.08E-04						0.055	
Totals	Miscellaneous Sources													41.609	0.355	160.108	

Table 6. Toxic Metal Emissions from S-5 Landfill (Active Face) Due to Using Non-Hazardous Soil as Cover

	TTLC	Total PM_{10} Emissions		Chronic		Acute		Risk Screen Trigger Level	
	ppm by wt.	tons/year	pounds/day	pounds/year	g/s	pounds/day	g/s	pounds/year	required ?
Carcinogens									
Arsenic	500	0.549	4.09	0.5486	7.89E-06	0.0020	1.07E-05	0.025	yes
Asbestos	1	0.549	4.09	0.0011	1.58E-08	0.0000	2.15E-08	0.003	
Beryllium	75	0.549	4.09	0.0823	1.18E-06	0.0003	1.61E-06	0.014	yes
Cadmium	100	0.549	4.09	0.1097	1.58E-06	0.0004	2.15E-06	0.046	yes
Chromium VI	500	0.549	4.09	0.5486	7.89E-06	0.0020	1.07E-05	0.0013	yes
Nickel	2000	0.549	4.09	2.1942	3.16E-05	0.0082	4.30E-05	0.73	yes
Non-Carcinogens									
Antimony	500	0.549	4.09	0.5486	7.89E-06	0.0020	1.07E-05		
Barium	10000	0.549	4.09	10.9711	1.58E-04	0.0409	2.15E-04		
Chromium III	2500	0.549	4.09	2.7428	3.95E-05	0.0102	5.37E-05		
Cobalt	8000	0.549	4.09	8.7769	1.26E-04	0.0328	1.72E-04		
Copper	2500	0.549	4.09	2.7428	3.95E-05	0.0102	5.37E-05	460	
Fluoride Salts	18000	0.549	4.09	19.7479	2.84E-04	0.0737	3.87E-04		
Lead	350	0.549	4.09	0.3840	5.52E-06	0.0014	7.52E-06	16	
Mercury	20	0.549	4.09	0.0219	3.16E-07	0.0001	4.30E-07	58	
Molybdenum	3500	0.549	4.09	3.8399	5.52E-05	0.0143	7.52E-05		
Selenium	100	0.549	4.09	0.1097	1.58E-06	0.0004	2.15E-06	97	
Silver	500	0.549	4.09	0.5486	7.89E-06	0.0020	1.07E-05		
Thallium	700	0.549	4.09	0.7680	1.10E-05	0.0029	1.50E-05		
Vanadium	2400	0.549	4.09	2.6331	3.79E-05	0.0098	5.16E-05		
Zinc	5000	0.549	4.09	5.4855	7.89E-05	0.0205	1.07E-04	6800	

Table 7. Toxic Metal Emissions from S-42 Cover Soil Stockpiles Due to Accepting Non-Hazardous Soil

	TTLC	Total PM_{10} Emissions		Chronic		Acute		Risk Screen Trigger Level	
	ppm by wt.	tons/year	pounds/day	pounds/year	g/s	pounds/day	g/s	pounds/year	required ?
Carcinogens									
Arsenic	500	0.055	0.61	0.0547	7.86E-07	0.0003	1.59E-06	0.025	yes
Asbestos	1	0.055	0.61	0.0001	1.57E-09	0.0000	3.19E-09	0.003	
Berylium	75	0.055	0.61	0.0082	1.18E-07	0.0000	2.39E-07	0.014	
Cadmium	100	0.055	0.61	0.0109	1.57E-07	0.0001	3.19E-07	0.046	
Chromium VI	500	0.055	0.61	0.0547	7.86E-07	0.0003	1.59E-06	0.0013	yes
Nickel	2000	0.055	0.61	0.2186	3.14E-06	0.0012	6.37E-06	0.73	
Non-Carcinogens									
Antimony	500	0.055	0.61	0.0547	7.86E-07	0.0003	1.59E-06		
Barium	10000	0.055	0.61	1.0931	1.57E-05	0.0061	3.19E-05		
Chromium III	2500	0.055	0.61	0.2733	3.93E-06	0.0015	7.97E-06		
Cobalt	8000	0.055	0.61	0.8745	1.26E-05	0.0049	2.55E-05		
Copper	2500	0.055	0.61	0.2733	3.93E-06	0.0015	7.97E-06	460	
Fluoride Salts	18000	0.055	0.61	1.9676	2.83E-05	0.0109	5.74E-05		
Lead	350	0.055	0.61	0.0383	5.50E-07	0.0002	1.12E-06	16	
Mercury	20	0.055	0.61	0.0022	3.14E-08	0.0000	6.37E-08	58	
Molybdenum	3500	0.055	0.61	0.3826	5.50E-06	0.0021	1.12E-05		
Selenium	100	0.055	0.61	0.0109	1.57E-07	0.0001	3.19E-07	97	
Silver	500	0.055	0.61	0.0547	7.86E-07	0.0003	1.59E-06		
Thallium	700	0.055	0.61	0.0765	1.10E-06	0.0004	2.23E-06		
Vanadium	2400	0.055	0.61	0.2623	3.77E-06	0.0015	7.65E-06		
Zinc	5000	0.055	0.61	0.5466	7.86E-06	0.0030	1.59E-05	6800	

TABLE 8. REDWOOD LANDFILL EXPANSION PROJECT
NSR AND PSD ISSUES
REDWOOD LANDFILL
NOVATO, CALIFORNIA

	Current Facility Wide Potential Emissions	Proposed Facility Wide Potential Emissions	Change	Offsets	Offsets Source	Major Facility	PSD	Modeling
	tons/year	tons/year	tons/yr					
POC	32.7	49.96	17.26	Yes	SFBA	No	No	No
NOx	37.1	46.08	8.98	Yes	SFBA	No	No	No
CO	117.7	117.61	-0.09	No	N/A	Yes	No	No
PM-10	224.1	170.39	-53.71	No	N/A	No	No	No
SOx	30.6	78.36	47.76	No	N/A	No	No	No
NPOC	0.1	0.41	0.31	No	N/A	No	No	No

Notes

Since facility-wide emissions of POCs and NOx are less than 50 tpy and greater than 15 tpy, offsets are required but are requested from the Small Facility Banking Account (SFBA).

There is no net increase from this application, so CO modeling is not required. The BAAQMD does not require offsets for CO.

The application represents a reduction in PM10 emissions, so no modeling or offsets are required. Also, non-fugitive PM10 emissions are less than 100 tpy, so the facility is not a major facility.

The application represents an increase in SOx emissions; however, since the non-fugitive SOx emissions are less than 100 tpy, so the facility is not a major facility.

ATTACHMENT 1
NEW FLARE SPECIFICATION AND A MAP

LANDFILL GAS FLARING SYSTEM

PART 1. GENERAL

1.01 DESCRIPTION

A. Work Included:

1. The work described in this specification consists of furnishing all labor, materials, equipment, and incidentals necessary to furnish and field test the Landfill Gas Flaring System at Redwood Landfill for Waste Management Incorporated (WMI), as specified herein, including all appurtenances to provide a complete system ready for operation.

2. The Landfill Gas Flaring System shall include the following four sub systems:

   a. Gas Handling System.

   b. Interconnecting Piping System.

   c. Enclosed Ground Flare System.

   d. Control System.

3. All equipment and accessories shall have manufacturer's Shop Drawings approved by the Engineer prior to shipment and shall be tested in conformance with these Specifications prior to acceptance and final payment by WMI.

4. The Manufacturer shall be responsible for furnishing all equipment and accessories as described in these Specifications and as required for satisfactory operation of the system. He shall assume complete system responsibility, including warranty, for all equipment supplied whether he is the manufacturer or not.

5. WMI's Contractor shall be responsible for all electrical wiring connections for operation and control of all equipment related to the Landfill Gas Flaring System.

6. Parts of equipment shall be amply proportioned for all stresses, which may occur during operation, and for any additional stresses, which may occur during fabrication, transportation, handling, and erection.

7. If necessary, modifications shall be made in the manufacturer's standard product to make it conform to the specific requirements of the Specifications and to requirements contained in regulations issued by public agencies. Such modifications shall be noted in Shop Drawing submittals.

8. Equipment shall include all production line improvements made to the delivery or Contract date. All equipment shall comply with applicable requirements of the standards of ASME, AGA, NFPA, and the Underwriters' Laboratories panels shall bear U.L. labels, as of the bid submittal date. Equipment shall not have been in service, except for shop tests, at any time prior to delivery. The equipment shall be furnished factory-assembled to the extent possible and ready for installation.

9. A brass or stainless steel nameplate shall be attached to each piece of equipment in a conspicuous place. The following information shall be plainly marked on the nameplate: name and address of the manufacturer, serial number, model number, and any other information necessary for complete identification.

1.02 SUBMITTALS

A. The following specific information shall be provided:

1. Materials and Shop Drawings. Submittals shall include at least the following:

a. Certified Shop Drawings showing all-important details of construction, anchor plates for anchoring the skid to the concrete slab, dimensions, and weight. The flare manufacturer shall be responsible for the design of the anchor plates.

b. Descriptive literature, bulletins, and/or catalogs of the equipment.

c. A complete total bill of materials for all equipment.

d. A list of manufacturer's recommended spare parts.

e. The total weight of the equipment including the weight of the single largest item.

f. Complete performance data that will indicate full compliance with the Specifications; performance curves; calculations showing the equipment gas-flow and motor corrections required for operation at job-site elevation as specified under Design Criteria.

g. Complete control panel diagrams and elevations showing all components, wires, connections, and numbered terminals.

h. Complete electrical interconnect diagram showing all wires and terminals between the control panel and external devices.

i. All exceptions to the applicable requirements and Specifications provided in these Contract Documents.

B. Complete assembly, foundation and installation drawings, complete wiring diagrams, control panel layout and control schematics, together with detailed specifications, and data covering actual materials used, parts, devices, and other accessories shall be submitted.

C. An operation and maintenance manual shall be furnished. The manual shall be prepared specifically for this installation and shall include all required catalog cuts, drawings, equipment list, descriptions, and information necessary to instruct operating and maintenance personnel unfamiliar with such equipment.

D. A factory representative, with a full knowledge of proper operation and maintenance, shall be provided for a minimum of two (2) 8-hour days to instruct representatives of the WMI and/or the Engineer on proper operation and maintenance of the LFG flaring system. If there are difficulties in operation of the equipment due to manufacturer's design or fabrication, additional service shall be provided at no cost to WMI.

1.03 QUALIFICATIONS

The Landfill Gas Flaring System, including all ancillary equipment, shall be furnished by a manufacturer who is fully experienced, reputable, and qualified in the manufacture of the equipment to be furnished. The equipment shall be designed and fabricated in accordance with the best practices and methods. The manufacturer shall have experience in supplying equipment for the landfill gas handling systems, and shall have a minimum of five years experience in design and manufacture of this type of equipment. He shall have a minimum of ten similar systems in successful operation in the United States.

1.04 DESIGN CRITERIA

A. Landfill Gas Blowers:

1. All equipment specified herein is intended to be standard equipment for use in a landfill gas handling system.

2. Blowers shall be designed for continuous operation in an outdoor environment and shall conform to the following requirement measured at Standard 14.7 psia and 68 degrees F condition:

Number required	2
Rated capacity each, scfm	3000
Minimum capacity each, scfm	1200
Site elevation, feet above MSL	10
Gas composition	
Methane	25 percent - 50 percent
Carbon Dioxide	25 percent - 50 percent
Traces gases, ppm	0 - 70
Actual landfill gas pressure	
Inlet, inches of water (vacuum)	60
Outlet, inches of water (pressure)	20

Landfill gas inlet temperature	
Maximum, degrees F	130
Minimum, degrees F	60
Shaft speed, rpm	3,600
Nominal motor efficiency, percent	91
Minimum motor power factor, percent	87
Motor insulation	Class F
Motor service factor	1.15
Motor horsepower	75
Noise at 3 feet from unit	85 dbA
LFG moisture content	100% Saturated

3. When volumetric capacity is reduced to 40 percent of design, the blower under the specified inlet conditions shall not surge or overload the motor.

4. The blower recommended will be based upon data previously established by tests in accordance with the ASME Power Test Code for Centrifugal Blowers.

B. Enclosed Ground Flare Systems:

1. The landfill gas Enclosed Ground flare systems shall be designed to operate continuously at the following service:

Number required	1
Landfill gas flow rate, scfm	1200 to 3000
Btu loading, mm Btu/hour	18 to 90
Inlet temperature, degrees F	100 to 130
LFG moisture content	100 % Saturated
Barometric pressure, psia	14.7
Landfill gas composition range:	
Methane	25 percent to 50 percent
Carbon Dioxide	25 percent to 50 percent
Trace Gases, ppm	0 to 70
Site elevation	10 feet above MSL
Maximum Height of Stack, feet	50

2. The flare manufacturer shall guarantee the following performance requirements:

   a. The above composition percentages shall be considered approximate due to the complexity of the gas generation and collection process. The flare shall be complete with adjustment features, which will allow odor-free operation of the flare under significant changes in gas composition.

   b. The flare shall be capable of reducing odorous compounds such as hydrogen sulfide, mercaptan, and/or aromatics in the landfill gas to a nonodorous form by the combination of high temperature, excess combustion air, and retention time. Exhaust from the flare stack shall have no visible flame and no visible emissions.

c. Whenever the flare is in operation, a minimum temperature of $1,400^0$ F, as measured by the temperature indicator and recorder, shall be maintained in the flare stack. The thermocouple used to measure the temperature shall be at least 3 feet below the top of the flare shroud and at least 0.6 seconds downstream of the burner. Flare shall be designed and operated so that the flame in the flare remains below the height of the flare's operating thermocouple at all times.

d. The emissions from the flare shall comply with all Bay Area Air Quality Management District (BAAQMD) emissions requirement as outlined in their Rules and Regulations. At a minimum, emissions from the flare shall not exceed the following values when the flare is operating within the designed Btu loading as specified in the Item 1.04B above, without use of auxiliary fuel:

- Nitrogen Oxide (NOx) - 0.05 pound per million Btu.
- Carbon Monoxide (CO) - 0.15 pound per million Btu.
- PM_{10} - 20 pound per million cubic feet of landfill gas.
- Sulfur Oxides (SOx) - 0.023 pound per million Btu.

e. The landfill gas flaring system shall be capable of achieving a minimum weighted average destruction efficiency of > 99 percent of the total organic compounds (TOCs) and > 98 percent of nonmethane organic compounds (NMOCs).

f. The landfill gas pressure loss through the flare at design flow (3000 scfm) shall not exceed 10 inches w.c. as measured from the upstream side of the inlet gas valve to the outlet of the flare. The burner heads shall be designed to provide a sufficient pressure drop at minimum (1200 scfm) flow and heat content conditions in order to maintain a stable flame and proper destruction.

1.05 APPLICABLE CODES AND STANDARDS

A. All equipment shall be manufactured in accordance with codes and guidelines as specifically detailed herein and in accordance with applicable portions of the following (latest edition):

1. Local Laws and Ordinances.
2. State and Federal Laws.
3. National Electrical Code.
4. National Electrical Manufacturers Association (NEMA).
5. Underwriters Laboratories (UL).
6. Uniform Building Code (UBC).
7. American National Standards Institute (ANSI).
8. American Society of Mechanical Engineers (ASME).
9. Institute of Electrical and Electronic Engineers (IEEE).
10. Instrument Society of America (ISA).
11. Industrial Risk Insurance (IRI).
12. Factory Mutual (FM).
13. National Fire Protection Agency (NFPA).

1.06 PRODUCT DELIVERY, STORAGE, AND HANDLING

A. All parts shall be properly protected so that no damage or deterioration will occur during a prolonged delay from the time of shipment until installation is completed and the units and equipment are ready for operation.

B. The equipment shall be delivered on site as fully assembled as transportation will allow. Factory-assembled parts and components shall not be dismantled for shipment unless permission is received in writing from the Engineer.

C. Finished surfaces of all exposed openings shall be protected by wooden blanks, strongly built, and securely bolted thereto.

D. Each box or package shall be properly marked to show its net weight in addition to its contents.

1.07 WARRANTY AND GUARANTEES

A. The equipment manufacturer shall warrant the units being supplied to WMI against defects in workmanship and material for a period of one (1) year from the date of equipment acceptance by the WMI. In the event that the equipment fails to perform as specified, the equipment manufacturer shall promptly repair or replace the defective equipment without any cost to the WMI (including handling and shipment costs).

PART 2. PRODUCTS

2.01 GENERAL

A. All equipment shall be designed and proportioned to have liberal strength, stability, and stiffness and shall be especially adapted for the intended service. Ample room and facilities shall be provided for inspection, repairs, and adjustments.

B. These Specifications are intended to give a general description of what is required, but do not cover all requirements of the equipment as offered. They are, however, intended to cover the furnishing, delivery, and field testing of all materials, equipment, and apparatus as required. Any additional auxiliary equipment necessary for proper operation of the proposed Landfill Gas Flaring System, not mentioned in this Specification, shall be furnished and installed.

C. At all levels of performance of each gas system, the sound pressure shall not exceed 85 dbA over a frequency range of 37.8 and 9,600 cycles per second. Measurement shall be made a distance of 3 feet from the outer face of the equipment. The equipment manufacturer shall certify that the equipment furnished for this project does not exceed the specified sound pressure. This written certification shall be submitted with the Shop Drawings.

D. One (1) enclosed flare base plate foundation template, constructed of 1/4" carbon steel plate for assisting in setting and installing the anchor bolts in the field, shall be furnished by the flare manufacturer. The template shall be shipped prior to the flare, so that it can be utilized at the time the flare foundation is formed and constructed.

2.02 GAS HANDLING SYSTEMS

A. Blower and Motor Assemblies:

1. Blower. Each blower unit shall be the multistage centrifugal type. Impellers shall be mounted on one shaft supported on each end by bearings mounted in the outboard bearing housings. The blower shall be built from parts cast in patterns from which previous units have been built and tested. Blowers shall comply with the design criteria as specified in Item 1.04A of Part 1 - General, of this Specification.

2. Blower Housings. The housings shall consist of cast iron sections held securely between cast iron inlet and outlets heads with steel tie rods.

   a. No contact shall be made between the shaft rotor and the housing, other than through the bearings. Stuffing boxes shall be used as seals to insure no leakage of gas to the atmosphere or air into the landfill gas.

   b. The inlet and outlet connections shall be drilled and tapped flange pattern per ANSI 1316.1, 125-pound, and shall be an integral part of the heads.

3. Impellers:

   a. The impellers shall be one piece cast aluminum alloy, keyed to the shaft and held by a locknut. Hubs of the impellers shall butt against each other directly or through one-piece metal spacers. There shall be ample clearance and tip speed shall not exceed 375 FPS.

   b. Impellers shall be precisely machine balanced. Vibration shall not exceed 2 mils in the vertical plane measured at the blower bearing housings.

4. Diffusers. Diffuser sections, which receive the gas from the impeller and guide the gas to the next impeller, shall be provided. The diffusing vanes shall be an integral part of the sections.

5. Shaft. Each shaft shall be made of high-grade carbon steel of sufficient diameter to operate below first critical speed.

6. Bearing Housings. Each blower shall be provided with two antifriction bearings. It shall be possible to replace bearings without disconnecting any piping or disassembling the compressor casing. Both inlet and outlet bearings shall be sized for a minimum expected life of 10 years continued operation as defined by AFBMA B-10 standards.

7. Casing Drains. Each blower stage shall be provided with 3/8-inch diameter casing drains with manual shut-off valves.

8. Internal Lining. The blower internals shall be furnished with a factory applied Bisonite, Kynar, or phenolic coating minimum 6 mils thick to provide resistance to corrosion by landfill gas. The coating shall be applied to all parts of the blower, which come in contact with the landfill gas stream.

9. Motor. Each blower shall be direct-coupled to a horizontal 460 volt, 3-phase, 60-hertz motor. The directly coupled motors through the full voltage motor starters mounted adjacent to the flare panel shall drive the blowers. The motor rpm shall be 3,600. The minimum horsepower shall be as specified in Item 1.4A above; however, the blower manufacturer shall be responsible for selecting the proper motor size to suit his equipment. The squirrel-cage induction motor shall be totally enclosed fan cooled (TEFC), and UL-approved. The motor shall have a cast-iron frame and copper windings. Motor shall be rated at 104 degrees Fahrenheit ambient with not more than 131 degrees Fahrenheit rise. Bearings shall be of the antifriction type with an AFBMA L-10 life rating of not less than 25,000 hours.

10. Flexible Couplings and Drives. The blowers shall be connected to the drivers with a suitable flexible coupling. The installing contractor shall check and adjust the alignment of the couplings and drives in accordance with the instructions of the blowers' manufacturer to a tolerance of plus or minus 2 mils. Couplings shall be covered with base-mounted aluminum or non-sparking metallic guard.

11. Bases. Hot dip galvanized rolled steel bed plates of suitable size for mounting blowers and drivers shall be furnished by the blower manufacturer. The blower and motor shall be carefully aligned and then bolted in place. Suitable vibration isolation pads shall be provided under the steel bedplates of the units. If the blower manufacturer intends to use a structural steel frame in lieu of the rolled steel plate for the blower base, then a galvanized steel plate shall be installed on top of the frame.

12. The blower-motor assemblies shall be located, installed, and plumbed on the gas handling skid, with a continuous galvanized ¼-inch thick galvanized steel checker plate, either bolted or welded to the top of the skid.

13. Auxiliary Equipment:

    The following auxiliary items shall be provided by along with the blowers:

    a. A 4-1/2-inch-diameter bellows-type vacuum gauge shall be mounted at the inlet of each blower. The range of the vacuum gauge shall be 0 to 100 inches of water, and the gauge shall read "INCHES OF WATER." Graduations shall be at intervals of 1 inch of water.

    b. A 4-1/2-inch-diameter bellows-type pressure gauge shall be mounted at the outlet of each blower. The range of the pressure gauge shall be 0 to 50 inches of water, and the gauge shall read "INCHES OF WATER." Graduations shall be at intervals of 1 inch of water.

    c. Dial-type temperature gauges shall be provided at the inlet and outlet of each blower. The gauge shall range from 0 to 200 degrees F.

d. The manufacturer of the blowers shall provide flanged expansion joints concentric reducers, of sizes shown on the Contract Drawings, on the inlet and outlet of each blower. The flanged expansion joints shall be constructed of synthetic rubber with synthetic fiber reinforcement. The flanged expansion joints shall have pressure ratings of +20 psig and -20 inches of mercury. They shall be capable of withstanding the temperatures up to 250^{0}F. The split retaining rings shall be made of galvanized steel. The split rings shall conform to the requirements of 125-pound ANSI flanged fittings.

e. The manufacturer of the blowers shall provide one calibrated ammeter for each blower. The surge range shall be clearly indicated on the ammeter. The volume of gas in standard cubic feet per minute (scfm) shall be expressed as a function of ampere input (i.e., the ammeter shall have two scales: amps and scfm). The point of full load amps shall be clearly indicated on the ammeter.

14. Blower Controls:

a. Blower-motor starters and controls shall be as provided as shown on the Contract Drawings.

15. Experience:

a. Blowers shall be manufactured in the United States. Blower manufacturers shall have a minimum 5 years experience in the design and manufacture of this type of equipment and have a minimum of 25 operating installations in the United States.

b. Acceptable Manufacturers:

(1) Gardner-Denver Blower Division
100 Gardner Park
Peachtree city, GA 30269
(800) 543-7736

(2) Continental Blowers, L.L.C.
Liverpool, New York 13088
(315) 451-5410

(3) Hoffman Air & Filtration System
P.O. Box 548, East Syracuse, NY 13057
(315) 432-8600

(4) National Turbine Corporation
374 Northern-Lights Drive
Syracuse, New York 13212
(315) 455-5591

B. Moisture Separator:

1. The moisture separator vessel shall be fabricated in steel or aluminum. The moisture separator shall be vertical cylindrical type. The internal surface of the moisture separator shall be furnished with a factory-applied bisonite, kynar, or phenolic coating minimum thickness of 10 mil thicks to provide resistance to corrosion by landfill gas. The moisture separator vessel shall be sized to comply with the design criteria as specified in Item 1.04A of Part 1 - General, of this Specification.

2. The demister shall be made from non-corrosive mesh and shall be supported on and held down by a high open area, stainless steel grid or equivalent. The demister shall be a minimum of 6 inches thick constructed with 316 SS material with mesh pad density of 5 lb/cu ft, and shall be carefully constructed to ensure a tight fit in the separator vessel, thus eliminating any gas passing by. The demister shall be as manufactured by Otto York Company, Fairfield, New Jersey; ACS Industries, Houston, Texas; Koch Engineering Company, Inc., Fairfield, New Jersey; or equal.

3. The demister shall be able to remove >99 percent of droplets greater than 6 micron and shall also remove particulates having a density equal to or greater than water which are greater than 6 micron in size.

4. At the design flow rates, temperatures and pressures, the demister shall not have a pressure drop greater than 3 in. w.c. It shall be capable of withstanding no less than 4.0 psig vacuum.

5. Pressure Drop Monitoring. There shall be two minimum sized 2-inch pipe couplings in the side of the filter, one each upstream and downstream of the filter element material, for the purpose of connecting differential pressure monitoring device(s). Pressure differential gauges shall be furnished and mounted on the face of the moisture separator.

6. Transparent liquid level gauge shall be mounted on the face of moisture separator.

2.03 INTERCONNECTING PIPING SYSTEMS

A. Valves:

1. Butterfly Valves:

a. All valve shafts shall be connected to operators by use of keys and keyways. The use of compression or friction connection will not be accepted.

b. The butterfly valves, for low-pressure/vacuum landfill gas services, shall have cast-iron wafer-style valve body with contoured 316 stainless steel disc, Type 316 stainless steel stem, Acetal stem bushing, and Viton replaceable resilient seat. Valves shall be bubble-tight at 150 psi differential pressure and shall be suitable for installation between ANSI 125-pound flanges.

c. All butterfly valves shall open left or counterclockwise when viewed from the stem. Manual valve operators shall be worm gear. All operators shall have adjustable mechanical stop limiting devices to prevent overtravel of disc. Should an adjustment of the disc be required to maintain a bubble-tight seal, this adjustment shall be made externally without removing the operator housing cover. The operator shall be designed such that all adjustments can be made under pressure and without the possibility of dirt getting into the operator lubricant. Any adjustments through the lower shaft will not be acceptable. Operator components shall, at the extreme operator positions, withstand without damage a pull of 200 lbs for hand wheel or an input torque of 300 ft-lb for operating nuts.

d. Interior of valve body and valve disc except for valve seat and stainless steel valve seat ring shall be coated with a fusion bonded, thermosetting epoxy coating in accordance with AWWA C550, latest revision. Coating shall be holiday-free with a minimum thickness of 12 mils. Surfaces shall be clean, dry, and free from rust and grease before coating.

e. All butterfly valves shall be manufactured by Demco/Copper Cameron Valves, DeZurik, Keystone Valves U.S.A., Kennedy Valve Manufacturing Company, or approved equal.

f. All exterior surfaces of butterfly valves shall be clean, dry and free from rust and grease before coating. The exterior ferrous parts of all valves shall be shop primed at the factory with one coat, minimum dry film thickness 1.5 mils, of a primer with rust-inhibitive pigments and synthetic resins. An additional finish coat, minimum dry film thickness 1.5 mils, of a primer with rust-inhibitive pigments and synthetic resins will be applied prior to shipment.

2. PVC Cock Valves:

a. PVC Cock Valves. Gas and pressure sampling valves shall be 1/4-inch PVC cock valves. Valve seats and seals shall be EPDM. Valves shall have 1/4-inch MPT on one end and hose connection on the other end. Valves shall be as manufactured by Chemtrol, Asahi/America, or equal.

3. Solenoid Valves:

a. Solenoid valves shall be 2-way type for normally closed operation designed for not less than a 150 psi water working pressure. The valves shall have forged brass bodies with NPT threaded ends, Buna N seals/disks, and NEMA 4 solenoid enclosures. The valves shall operate on 120 VAC power, shall have threaded conduit hubs, standby manual operators, and shall not require a minimum operating pressure differential for steady operation. The valves shall be manufactured by Automatic Switch Company or approved equal.

4. Check Valves:

a. Check valves shall be of flapper type. The valves shall have cast aluminum lightweight body, 316 stainless steel internals, Viton or Teflon sealing member materials, and 316 stainless steel spring materials. The valves shall be flanged and shall be faced and drilled to 125-pound ANSI dimensions.

b. Check valves shall be Model 5004-CAL as manufactured by Techno Corporation of Eire, Pennsylvania, or approved equal.

B. Piping:

1. Piping. All piping on the gas handling system skids shall be Schedule 40 6061-T6 or 6063-T6 aluminum. The same specification applies to tees, elbows, wyes, flanges, and other pipe fittings. All flanges shall conform to ANSI 125-pound specifications. All welding of aluminum piping and appurtenances shall conform to AWS D1.2 specifications. Pipe and fittings shall shall be sized to comply with the design criteria as specified in Item 1.04A of Part 1 - General, of this Specification.

2. The gaskets shall be full-face rubber, 1/16 inch to 1/8 inch in thickness, and shall meet the requirements of ANSI Specification A21.11.

3. Where required, pipe and fittings shall be drilled and taped to receive drainage or other piping or plugs. All holes shall be drilled accurately at right angles to the axis of any pipe or fitting.

4. All piping and fittings shall be supported in such a manner as to prevent any strain being transmitted between sections and connected equipment and appurtenances. Release of any joint shall result in no transverse piping movement and shall allow easy removal and replacement of any piping component.

5. In lieu of aluminum piping, the Contractor can furnish stainless steel piping. Stainless steel piping shall be schedule 10, annealed, conforming to the requirements of ASTM A312, Grade TP 304L or TP 316, low carbon.

6. Flexible connectors shall be bellows type, Series 2500 as manufactured by Hyspan Precision Products, of Chula Vista, CA., or approved equal.

C. Landfill Gas Flowmeter:

1. The landfill gas flowmeter shall be comprised of a Kurz Instruments, Inc. Model No.752731-03-23-12-01-88-85-01-0000-21 single point FM approved Mass Flowmeter Element/Transmitter, suitable for installation on a 6-inch diameter stainless steel pipe, and Model No. 750101-04-01-88-04-01-88-88-01-01-00-01 Mass Flowmeter Computer/ Transmitter with a 4-20 mA output. The mounting fittings for the flowmeter and the transmitters shall be 3/4-inch S.S., Model No. 759031-22-20.

2. The landfill gas flowmeter shall provide a 4-20 mA signal from the flow of the landfill gas for connection to the remote indicator. The meters shall be factory calibrated for landfill gas (50 percent methane, 50 percent carbon dioxide) for a range of 750 to 1800 scfm. The flowmeter shall be provided with a flow rate indicator (scfm), totalizer, and recorder.

3. The recorders shall include a NEMA 4X enclosure, which the Manufacturer shall install on the inside flare control panel enclosure.

4. The totalizer panels shall be installed in the flare control panels.

5. The circular chart recorder shall be manufactured by Honeywell, or approved equal.

2.04 ENCLOSED GROUND FLARE SYSTEM

A. Equipment

1. The landfill gas Enclosed Ground flare shall have the following items as minimum:

   a. Burners and burner chamber for landfill gas.

   b. Stack.

   c. Automatic landfill gas and propane gas safety shutoff valves.

   d. Flame arrestor.

   e. Control system, with a programmable logic controller, SLC-500 PLC, 24 inputs, (120V, 60 Hz), 16 outputs relay (120V, 60 Hz), manufactured by Allen Bradley or approved equal.

   f. A complete propane gas pilot system, including two 5-gallon tanks, piping, valves, electric igniter and pressure regulator.

   g. All controls, panel, and wiring, including exit gas temperature control.

   h. Access manhole at the front of the unit for inspection and maintenance of burners.

   i. Flame view ports.

   j. Time clocks mounted inside the flare control panel shall be provided for automatic starting and stopping of the flare operations on preset time, for 7 days per week with a 1-hour minimum duration.

   k. Protective screen to prevent accidental burns.

l. A set of sampling ports shall be spread horizontally and located at least 2 feet above the flame zone and at least 3 feet below the top of the flare shroud. Sampling ports shall be installed 90 degrees apart, and shall consist of 4-inch couplings with plugs.

2. Flare Stack:

a. The circular flare stack shall be constructed of carbon steel, with a minimum thickness of 1/4 inch.

b. The flare stack shall be designed to minimize the danger of accidents to operating and maintenance personnel.

c. The landfill gas burners shall be made from 300 series stainless steel with minimum thickness of 16 gauge. The manifold shall be of a sectional header arrangement to accommodate the removal and repair of individual headers.

d. Three layers of ceramic fiber insulation blanket shall be provided. Two 1-inch-thick layers of ceramic fiber blanket of 8 lbs/ft^3 density shall be installed, using overlap outer face construction methods, over one 2-inch-thick layer of ceramic fiber blanket of 4 lbs/ft^3 density. Insulation shall be attached to stack wall and floor with Inconel 600 series, or approved equal, studs and washers. Prior to the installation of ceramic fiber blanket, internal surfaces of the stack shall be thoroughly cleaned and painted with rust-inhibitive, high-heat resistant paint.

A rain guard shall be provided at the top of the flare stack to prevent water seeping into the insulation.

e. The flare stack shall be provided with lifting eyes near the top of the flare to permit the lifting and upright suspension of the flare at these points. The flare shall arrive on the site with internal supports necessary to permit the lifting of the flare by the lifting eyes without damage to the refractory or other flare components.

f. The flare stack shall be assembled at the factory to the extent possible. Instructions for any unavoidable on-site assembly shall be provided to the WMI per submittal requirements.

g. The flare stack shall be installed on the concrete slab. All necessary support angles, anchor bolt template, and anchor bolts to install the flare on the concrete slab shall be furnished by the flare manufacturer. The landfill gas supply pipe, and pilot light pipe, connections furnished with the flare shall extend a minimum of 1 foot beyond the outermost dimension of the flare.

h. The control panel shall contain all control components not mounted on the flare.

i. In selecting and/or accepting equipment for installation at the project site, the WMI will assume no responsibility for injuries or claims resulting from failure of the equipment to comply with applicable national, state, and local safety codes or requirements, or the safety requirements of a recognized Agency in effect at the time of final review of the Shop Drawings, or failure due to faulty design concepts or

defective workmanship and materials. Equipment manufacturers shall be held responsible for compliance with the requirements included in this paragraph.

j. Shell skin temperature shall not exceed 230 degrees F under maximum Btu loading conditions.

k. All hot surfaces with operating temperatures greater than 140 degrees F and which may inadvertently be touched, backed into, or otherwise contacted by operators or maintenance personnel shall be provided with a protective expanded steel or mesh screen to prevent accidental burns. The protective screen shall be securely attached to the flare, and shall extend outward a minimum of 6 inches from all hot surfaces. The protective screen shall extend completely around the flare, from a maximum height (at the base) of 6 inches above grade to a minimum height (at the top) of 7 feet above grade. The screen shall have a minimum 75 percent open area, with holes not exceeding 1 inch in maximum dimension. The protective screens shall be comprised of a minimum of four sections, each of which shall be easily removable from the exterior, especially at those areas where regular maintenance or operational adjustments may be required.

l. Alternative methods for the prevention of accidental burns may also be proposed by the Manufacturer. Such proposals shall include a complete description of materials and construction methods, and shall address concerns regarding burn protection and accessibility. Hand rails shall not be accepted as an alternative method.

B. Controls:

1. All electrical components shall be UL approved. The controls shall be designed for 120-volt AC operation. All switching shall be accomplished in the "hot" circuit. The electronic flare control system shall be supplied with the following characteristics and components:

   a. The control system shall accomplish a safe start component check during each start, which shall prevent the delivery of landfill gas into the flare unless a sufficient pilot light has been provided to ignite the landfill gas. The control system shall also prevent the discharge of non-combusted landfill gas.

   b. Safety shutdown after automatic restart shall be accomplished within 4 seconds following a flame failure or the opening of any running interlock.

   c. Automatic shutdown of the system shall be accomplished when the design Btu loading has been exceeded, to protect the internal insulating lining of the flare shell. The flare shall shut down automatically when the temperature drops below 1400^0 F

   d. The local alarm panel shall indicate flare shutdown.

   e. The pilot and main flames shall be monitored by a single ultraviolet-sensitive flame scanner, which shall not be actuated by hot refractory.

f. The flame detection scanner and amplifier shall be repetitive self-checking.

g. The scanner shall mount on and sight through a 1-1/2-inch standard pipe, reduced to 1-inch standard pipe. The scanner mount shall be positioned to permit the scanner to sense both the pilot flame and the primary flame at low-flow conditions. However, the manufacturer may opt to provide two scanners, in lieu of one, to individually sense the pilot flame and the primary flame.

h. The scanner shall be suitable for operation up to 200 degrees F, as measured on the mounting hub.

i. The landfill gas inlet shall be equipped with a pneumatic, automatic, fast-closing (within 5 seconds), safety shutoff valve so that landfill gas shall flow to the combustion chamber through the fuel pipe only after the pilot is proven. A system of burner heads shall be located inside the combustion chamber to properly distribute landfill gas for efficient combustion.

j. The pilot gas fuel train shall include double block solenoid valves.

k. All electrically operated valves shall close upon loss of electrical power.

l. The control system shall be accomplished with a programmable logic controller, SLC-500 PLC, 24 inputs, and 16 outputs, manufactured by Allen Bradley or approved equal.

m. Time clocks mounted inside the flare control panel shall be provided for automatic starting and stopping of the flare operations on preset time, for 7 days per week with a 1-hour minimum duration.

2. The flare shall be provided with an adequate number of exit gas temperature control sensors (thermocouples) and ports. The number of ports for mounting the temperature sensor shall be determined by the manufacturer based on the flare capability and quality and quantity of gas expected. All of this information shall be submitted during the Manufacturer's first submittals of the Shop Drawings for the Flare. One of the sensors shall be located approximately 3 feet below the top of the flare stack. The thermocouple tube protruding into the flare shall be high-temperature stainless steel series Inknel made by Willon Industries, Telephone (818) 579-0268, or approved equal.

3. The control panel shall be suitable for board mounting. All necessary brackets shall be furnished. The panel shall be hinged, dust-tight, and weatherized NEMA 4X (stainless steel). The panel shall contain PLC, all components, devices, and instruments not mounted on the flare, including the following:

a. Flare start-up selector switches and push buttons.

b. Emergency shut-down push button.

c. Three position lead/lag selector switch (Blower 1 – off – Blower 2). A "hand-

off-auto" selector switch shall also be included in each motor control circuit.

d. Indicating lights for power on, purging on and complete, pilot gas on, landfill gas on, flame proved, blowers on and fail, LFG inlet valve fail, flare failure, flare high and low temperatures.

e. A push button and a lamp test circuit shall be provided to test the condition of each indicating lamp.

f. Pilot light ignition system.

g. Adjustable pilot fuel valve timer (0 to 15 minutes).

h. Combustion safeguard relay.

i. Elapsed timers and ampere meters for blower motors.

j. Continuous temperature indicator and controller.

k. Circular chart recorder for flare operating temperature, LFG flow to flare.

l. Programmable controller and interfaces.

m. Auto dialer.

n. Mass flow computer totalizer.

o. Interlocking relay contacts for controlling the blowers..

p. Relay contacts for remote alarm auto dialer.

q. Control circuit fuses.

r. Name plates.

s. Terminal strips.

t. A 20 amp, 110 volt duplex utility outlet.

5. Interlocking relay contacts shall be provided to de-energize all blowers if the flare flame is lost.

6. A temperature controller with thermocouple shall operate an integral motor-driven air inlet damper(s) assembly to maintain the exhaust gas temperature as measured by the temperature sensors within 10°F of the temperature set point. The temperature set point shall be field-adjustable.

7. Control System Operation. Provide the required programmable logic control, relays, field devices, and field components to implement the following control operations and features:

- System Startup. System startup shall begin with a time delay cycle to evacuate any fugitive hydrocarbons from the flare enclosure. After purge is completed, the pilot shall be lit by use of propane gas, pilot gas solenoid valve, and spark plug ignition. Provide ignition transformer, pilot spark plug, and ignition timer. Upon proving the pilot flame by a self-checking flame scanner, the landfill gas (electric automatic) valve shall be opened and the landfill gas blower(s) shall be started allowing landfill gas to flow to the flare enclosure allowing the use of the landfill gas for system warm-up.

  After the starting of the blower and the landfill gas (pneumatic) valve is opened, the pilot gas solenoid valve shall then shut off to limit propane gas usage. If a flame is still sensed on the main burner, the system shall continue operation; if not, it shall shut down on flame failure.

- Temperature Control (Air). The unit temperature shall be maintained by automatically adjusting electric actuated air damper(s), opening the dampers to reduce the flue gas temperature by adding quench air. Provide an automatic temperature controller, two compatible damper operators, and temperature element to operate the analog control loop. Provide a temperature recorder on the control panel to continuously record the flare exit gas temperature.

- Automatic Start/Restart. In the automatic mode, the unit shall automatically start when power is applied. If the unit shuts down for any reason except high stack temperature, the auto mode shall allow the unit to attempt to purge and restart for a specified time period. A remote signal is sent if the unit fails to restart.

- Pressure Control. Provide a pressure regulator on the pilot gas line. Provide a pressure gauge on both the pilot gas line and enriched fuel line downstream of the automatic valves.

C. Flame Arrestor:

1. Flame arrestor shall be suitable for installation on line containing saturated LFG and shall be sized to comply with the design criteria as specified in Item 1.04A of Part 1 - General, of this Specification.

2. Flame arrestor shall have 125-pound ANSI flanged connections.

3. The housing construction shall be aluminum. The bank assembly shall be all aluminum and shall be so arranged for easy removal from the housing to facilitate inspection and cleaning. The net free area through the bank assembly shall not be less than four times that of the corresponding size pipe. All grids of the bank shall be arranged for individual removal. The flame arrestor shall be Groth Equipment Corporation Model 7628, Varec Model 5010E, or equal.

D. Automatic Telephone Dialer:

1. General: The system shall receive input from the various monitored items in the form of a change in the status of a dry contact. Upon such change, the system shall automatically dial up to sixteen preselected phone numbers. When answered, the system shall send voice messages reporting the specific alarm condition. The system shall also be capable of reporting the status of all monitored items upon receipt of an inquiry phone call.

2. The system shall make provisions for the following input alarms:

   a. Inlet shut-off valve failure.
   b. Main flame failure.
   c. Blower No. 1 failure.
   d. Blower No. 2 failure
   e. Flare high temperature failure.
   f. Flare low temperature failure.
   g. Condensate storage tank high level.
   h. Low air pressure in air compressor receiver tank.

3. The automatic telephone dialer shall be a self-contained, solid state device. The dialer shall continuously monitor the presence of AC power and the status of up to eight independent N.O. or N.C. contact inputs.

   Each contact input channel shall be keyboard programmable as follows: alarm on open circuit, alarm on closed circuit, or no alarm (status report only on inquiry). Alarm or status shall be reported utilizing a solid state used recorder high fidelity voice. No tape or mechanical voice reproduction devices shall be used.

   AC power failure or violation of alarm criteria for any input shall cause the unit to go into alarm status and begin dial-outs and optional local announcements. Upon initiating an alarm call-out, the system shall speak only those channels currently in alarm status.

   On phone inquiry or during on-site status check, a warning message shall be provided if no dial-out phone numbers are entered, or if the alarm switch is disabled, or if backup battery charge is low, or if AC power is off or has been off since last reset.

4. Phone Link: The dialer shall be FCC approved. It shall operate on a standard dial-up rotary pulse or Touch Tone[R] telephone line and shall be capable of calling from one to sixteen phone numbers, each up to 60 digits in length. Dedicated or leased phone line shall not be required.

5. Programming Capability: Pre-programmed speech shall provide entry guidance and confirmation of programmable features. Coded programming shall provide direct access to specific programmable items via appropriate function codes.

D. Automatic Telephone Dialer:

1. General: The system shall receive input from the various monitored items in the form of a change in the status of a dry contact. Upon such change, the system shall automatically dial up to sixteen preselected phone numbers. When answered, the system shall send voice messages reporting the specific alarm condition. The system shall also be capable of reporting the status of all monitored items upon receipt of an inquiry phone call.

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5. Programming Capability: Pre-programmed speech shall provide entry guidance and confirmation of programmable features. Coded programming shall provide direct access to specific programmable items via appropriate function codes.

A cable connector shall be provided for voice output to a local amplifier.

Gas tube and solid state surge protection shall be integrally incorporated on the circuit board for all inputs including power, phone, and signal lines. Externally mounted protectors shall not be acceptable substitutes.

The dialer shall be suitable for a maximum environmental temperature of 130EF at the enclosure.

8. Automatic dialer - shall be Verbatim Model VSS-8C as manufactured by RACO Manufacturing and Engineering Company.

PART 3. INSPECTION AND TESTING

A. General:

1. A factory representative shall be provided for two (2) days and shall have complete knowledge of proper operation and maintenance to inspect the final installation and supervise the test run of the equipment.

2. Experienced factory-trained personnel, tools, and testing equipment shall be provided as required to perform the installation of the equipment furnished by the manufacturer, as well as test, calibrate, and start up the complete flaring operation and gas flow control as described on the flaring system operation requirement.

3. Experienced factory-trained PLC personnel and programming devices shall be provided as required to perform the programming or reprogramming to meet the actual flaring system operation and variable flow control during testing and start up as described on the flaring system operation requirement.

4. Field tests shall not be conducted until such time that the entire installation is complete and ready for testing.

B. Field Testing:

1. Upon completion of all the mechanical and electrical work, the WMI's Contractor shall conduct testing as specified herein to demonstrate that the equipment performs in accordance with all specifications.

2. WMI's Contractor shall perform initial testing of the equipment, insuring to himself that the tests listed in the Demonstration Test paragraph below can be satisfactorily completed.

3. The Demonstration Test shall demonstrate that all items of these Specifications have been met by the equipment as installed and shall include, but not be limited to, the following tests:

a. That the LFG flaring system has been properly installed and all parts are in correct alignment.

b. That the system satisfactorily operates continuously for 14 days.

c. That there are no mechanical or electrical defects in any of the parts.

d. That the controls perform satisfactorily as to automatic starting and stopping, and remote control of blowers and associated equipment.

e. Alarm call outs

C. Performance Test:

Within sixty (60) days of successful completion of the demonstration test, WMI's consultant shall conduct a performance test on the LFG flaring system in accordance with approved test procedures (prepared by the independent laboratory selected by WMI). The test procedure shall include preparation and submission of testing protocol to the BAAQMD for their review and approval. The tests shall be conducted by an independent testing laboratory with at least three years of experience in successfully conducting such tests. The tests shall include, but not be limited to, testing of inlet gas to the flare and flare exhaust for the following:

1. Methane.

2. Total nonmethane organics.

3. Oxides of nitrogen (exhaust only).

4. Carbon monoxide (exhaust only).

5. Total particulates (exhaust only).

6. Hydrogen sulfide and total reduced sulfur.

7. Sulfur oxides (exhaust only).

8. Reactive organic compounds.

9. Toxic air contaminants including, but not limited to, benzene, chlorobenzene, dichlorobenzene, 1,2-cichloroethane, 1,1-dichloroethene, dichloromethane, tetrachloroethylene, tetrachloromethane, toluene, 1,1,1-trichloroethane, trichloroethylene, trichloromethane, vinyl chloride, and xylene isomers.

10. Carbon dioxide.

11. Oxygen.

12. Nitrogen.

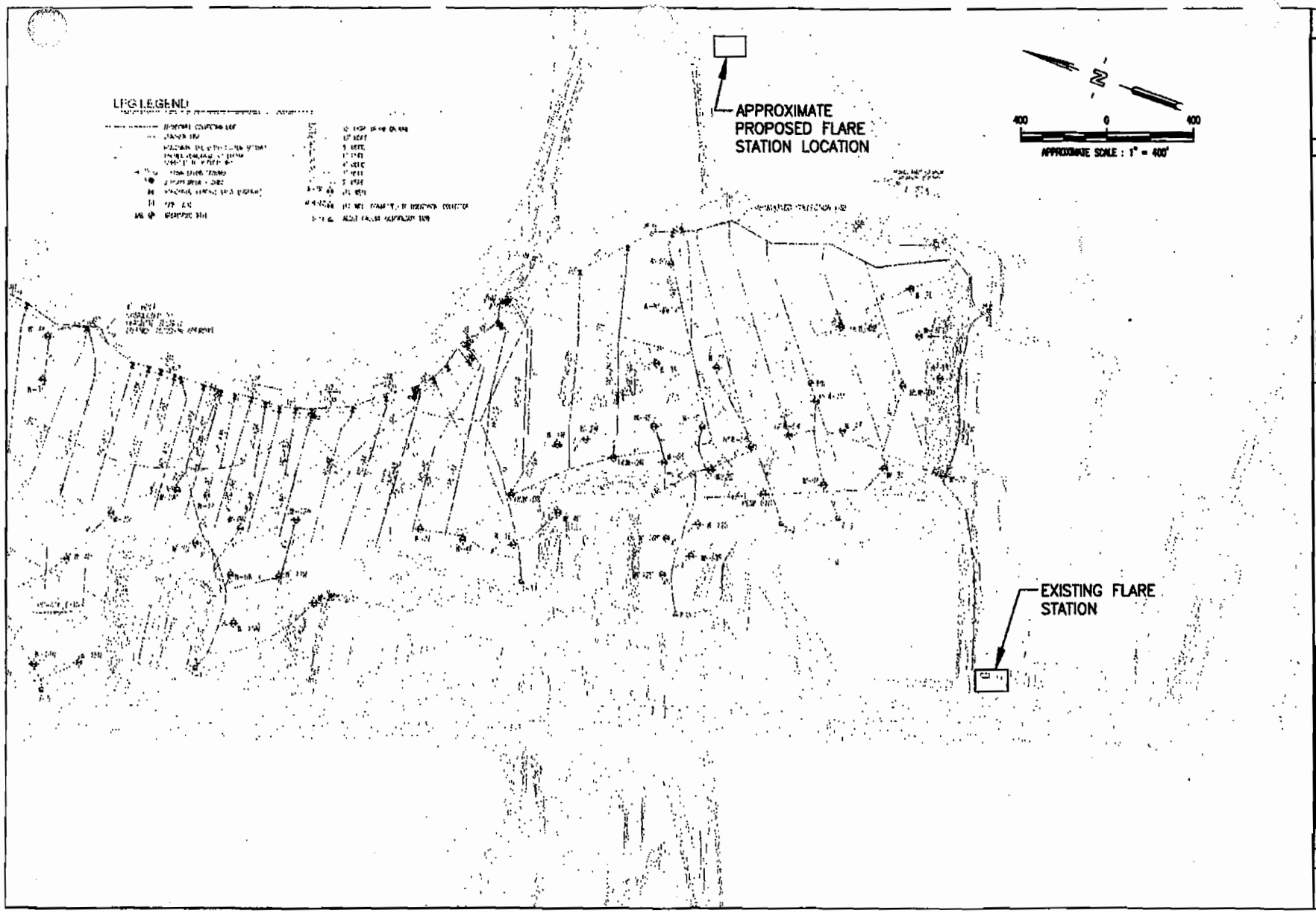
13. Moisture content.

14. Exhaust temperature at the time of the test and exhaust temperature recorded by the sensor required by the permit.

15. Flow rate.

16. Energy content of landfill gas.

If the test results show that the flare has failed to comply with the specified emission criteria, it will be the Manufactures's responsibility to make all modifications and/or adjustments to the flare necessary to meet the emission criteria. After all such modifications and/or adjustments, the performance retest on the flare shall be conducted to demonstrate compliance to the specified emission criteria. The costs of modifications and/or adjustments to the flare and performance tests shall be borne by the Manufacturer.



NO.	REVISION	DATE

SHEET TITLE: REDWOOD LANDFILL EXISTING AND PROPOSED FLARE STATIONS

PROJECT TITLE: REDWOOD LANDFILL WASTE MANAGEMENT, INC. REDWOOD LANDFILL NOVATO, CALIFORNIA

REDWOOD LANDFILL
NOVATO, CALIFORNIA
WASTE MANAGEMENT, INC.

Environmental Consultants

DATE: 11/03/04

SCALE: 1"=400'

DRAWING NO.

1 of 1

ATTACHMENT 2
DETAILED FUGITIVE DUST CALCULATIONS

Particulate Emissions from Waste Disposal Activities at Redwood Landfill

	Materials	Silt (s)	Moisture (M)	PM_{10} per vehicle Pounds/Hour	(per vehicle) Hours/Day	Number of Vehicles	PM_{10} Emissions Pounds/Day	Tons/Year
Bulldozing	waste	12.0	11.0	1.086	6	4	26.07	4.066
Bulldozing	cover	9.0	12.0	0.625	1	3	1.87	0.292
Compacting	waste	12.0	11.0	1.086	6	3	19.55	3.050
Compacting	cover	9.0	12.0	0.625	1	2	1.25	0.195
Excavating	clay/dirt	9.2	14.0	0.520	4	2	4.16	0.649
	Materials	Silt (s)	Moisture (M)	PM_{10} Factor Pounds/Ton	Throughput Tons/Day	Tons/Year	PM_{10} Emissions Pounds/Day	Tons/Year
Dumping	waste	12.0	11.0	0.00013	2150	669000	0.28	0.044
Dumping	cover	9.0	12.0	0.00012	1600	355080	0.18	0.021
							PM_{10} Emissions Pounds/Day	Tons/Year
Total Emissions From All Waste Disposal Activities							53.37	8.317

1. AP-42 Table 13.2.3-1 recommends using factors derived from Table 11.9-1 for bulldozer activities.
   From 11.9-1 for bulldozing (overburden): E (lbs PM_{10}/hour) = 0.75 * 1.0 * s^1.5 / M^1.4

2. AP-42 Table 13.2.3-1 recommends using factors derived from Chapter 13.2.4 for dumping activities.
   From page 13.2.4-4: E (lbs PM_{10}/ton) = 0.35 * 0.0032 * [U/5]^1.3 / [M/2]^1.4
   From the 1994 EIR, the mean wind speed (U) for this site is 6 mph (during summer).

3. Silt and moisture contents were taken from Table 13.2.4-1 for materials at MSW Landfills.

Particulate Emissions from Adding and Removing Soil at the Cover Soil Stockpile

Transfer Operation	Silt (s)	Moisture (M)	PM_{10} Factor Pounds/Ton	Throughput Tons/Day	Tons/Year	PM_{10} Emissions Pounds/Day	Tons/Year
Soil to Stockpiles	9.0	12.0	0.00012	1600	355080	0.18	0.021
Soil to On-Site Trucks	9.0	12.0	0.00012	1600	355080	0.18	0.021
Total for Soil Dumping						0.37	0.041

Wind Erosion Emissions at Redwood Landfill

Basis for Calculations:

AP-42 Chapter 13.2.5 Industrial Wind Erosion

EF = emission factor, g/m^2 (EF_c is for chronic conditions, EF_a is for acute conditions)
k = particle size multiplier, dimensionless
N = number of days of disturbances per year
P_i = erosion potential for disturbed area, g/m^2 (Per AP-42, erosion potential is assumed to be 0 between disturbances and for undisturbed areas.)
u^* = friction velocity, m/s
u_t^* = threshold friction velocity, m/s — From Table 13.2.5-1, u_t^* ranges from 0.43 m/s to 1.00 m/s using salve procedure.
From Table 13.2.5-2, u_t^* ranges from 0.54 m/s for fine coal dust to 1.33 m/s for roadbed material.
From Table 13.2.5-2, u_t^* = 1.02 m/s for overburden at a coal mine.
u_{10}^* = fastest mile of wind, m/s, at reference anemometer height of 10 m.
A = disturbed area, m^2
E = emissions, grams/year

Equation (1): $u^* = 0.053 * u_{10}^*$

Equation (2): $P_i = 58*(u^* - u_t^*)^2 + 25*(u^* - u_t^*)$

Equation (3): $EF = k * \sum_{i=1}^{N} P_i$

Equation (4): $E = EF * A$

V for Conditions at Redwood Landfill:

	Working Face		Daily Cover Stockpile	
Variable	Annual	Daily	Annual	Daily
u_{10}^*	19.21	19.21	19.21	19.21
u^*	1.018	1.018	1.018	1.018
u_t^*	1.000	1.000	1.000	1.000
P_i	0.47	0.47	0.47	0.47
N	312	1	312	1

Comments:
For Redwood Landfill u^* = 42.5 mph (19.00 m/s) at 30 feet (9.144 m)
Calculated using equation (1).
Assume u_t^* = 1.0 for the compacted landfill working face and watered stockpiles
Calculated using Equation (2). Note: If $u^* < u_t^*$, then P_i = 0.
Assume working face and stockpile are disturbed once every working day (312 days/year).
(Note: u_t^* of 1.0 is similar to overburden at a coal mine.)

Wind Erosion Emissions from the Active Face of the Landfill:

	< 30 µm	< 15 µm	< 10 µm	< 2.5 µm
k	1.0	0.6	0.5	0.2
EF_a	147.87	88.72	73.94	29.57
EF_d	0.47	0.28	0.24	0.09
A_a	502	502	502	502
A_d	1505	1505	1505	1505
grams/year	74183	44510	37092	14837
pounds/year	164	98	82	33
tons/year	0.082	0.049	0.041	0.016
grams/day	713	428	357	143
pounds/day	1.57	0.94	0.79	0.31

Comments:
AP-42 values
Calculated using Equation (3) and annual condition variables.
Calculated using Equation (3) and daily condition variables.
Per Redwood Landfill, average surface area of working face is 600 yd^2.
Per Redwood Landfill, maximum surface area of working face is 1800 yd^2.

Calculated using Equation (4) with annual emission factor (EF_a) and average surface area (A_a).
pounds/year = grams/year / 453.59237
tons/year = pounds/year / 2000

Calculated using Equation (4) with daily emission factor (EF_d) and maximum daily surface area (A_d).
pounds/day = grams/day / 453.59237

Wind Erosion Emissions from the Cover Soil Stockpile:

	< 30 µm	< 15 µm	< 10 µm	< 2.5 µm
k	1.0	0.6	0.5	0.2
EF_a	147.87	88.72	73.94	29.57
EF_d	0.47	0.28	0.24	0.09
A_a	167	167	167	167
A_d	454	454	454	454
grams/year	24728	14837	12364	4946
pounds/year	55	33	27	11
tons/year	0.027	0.016	0.014	0.005
grams/day	215	129	108	43
pounds/day	0.47	0.28	0.24	0.09

Comments:
AP-42 values
Calculated using Equation (3) and annual condition variables.
Calculated using Equation (3) and daily condition variables.
Per Redwood Landfill, max soil usage is 100,000 yd3/year. Avg SA = 200 yd^2
Per Redwood Landfill, max soil usage is 1100 yd3/day. Max SA = 543 yd^2

Calculated using Equation (4) with annual emission factor (EF_a) and average surface area (A_a).
pounds/year = grams/year / 453.59237
tons/year = pounds/year / 2000

Calculated using Equation (4) with daily emission factor (EF_d) and maximum daily surface area (A_d).
pounds/day = grams/day / 453.59237

			per stockpile	all stockpiles	they claimed	
	yd3	h =	r =	SA =		
Total Stored, yd3	50000	7	36.9	21510	3250	(assume 8 conical stockpiles)
Avg. per day, yd3	320.5	7	6.8	200.0	45	
Max per day, yd3	1100.0	7	12.2	543.0		

Conical Shapes V=π/3(r²h) SA=π(r²+h²)^0.5

Emission Calculations Template for Paved Roads at Landfills

based on AP-42 Chapter 13.2.1, latest updated 12/03

Equation 1: $E = k (sL/2)^{0.65} (W/3)^{1.5} - C$

where E = size specific emission factor, pounds/vehical mile traveled (lbs/VMT)
k = base emission factor for particle size range (lbs/VMT), from Table 13.2.1-1
sL = road surface silt loading (g/m^2), default from Table 13.2.1-3 = 7.4 g/m^2 for MSW Landfills
W = mean vehical weight of entire fleet traveling the road (tons)
C = Emission factor for exhust, brake wear and tire wear for PM-10 = 0.00047

Notes:
Use the tables below to fill in site specific data. Values in bold text are constants and should not be changed.
For Table 1., values in red text are default values that should be replaced with site specific data if available.
For Tables 2. & 3., values in red are examples of data used for one particular site and should be replaced with site specific data.
For all tables, values in regular text are calculated values. These equations should not be changed.
AP-42 indicates that site specific sL values should be used when mitigation measures (sweeping and watering) are employed.
Lacking any site specific data, mitigation measures are assumed to reduce uncontrolled particulate emissions by 50%.

Table 1. Variables for Equations 1.

	PM-2.5	PM-10	PM-30
k	0.004	0.016	0.082
sL	7.40	7.40	7.40
W	14.44	14.44	14.44

Table 2. Suggested Control Efficiency

Mitigation Measure	PM-2.5	PM-10	PM-30
Sweeping and/or Watering	50%	50%	50%

Table 4. Mean Vehical Miles Traveled by Avg Fleet

Paved Length	3000	feet
Avg. Round Trips	44	trips/day
Avg. Op.Time	312	days/year
VMT/Day	125.00	miles/day
VMT/Year	39000	miles/year

Table 5. Paved Road Emissions

	Emission Factor (Pounds/VMT)		
	PM-2.5	PM-10	PM-30
Uncontrolled	0.10	0.39	2.03
After Sweeping/Watering	0.05	0.20	1.01
	Daily Emissions (Pounds/Day)		
	PM-2.5	PM-10	PM-30
Uncontrolled	12.35	49.36	253.26
After Sweeping/Watering	6.18	24.68	126.63
	Annual Emissions (Tons/Year)		
	PM-2.5	PM-10	PM-30
Uncontrolled	1.927	7.700	39.508
After Sweeping/Watering	0.964	3.850	19.754

Table 2. Mean Vehical Fleet Weight (Off-Site Vehicles)

Vehical Type	Empty Wt tons	Load Wt tons	Full Wt tons	Avg. Wt. tons	# of Round Trips/Day	Operating Time Days/Year	wt*trips	trips/year
roll off box	11.0	11.5	22.5	16.8	45	312	753.8	14040
compactor box	11.5	11.0	22.5	17.0	10	312	170.0	3120
transfer trucks	16.0	24.0	40.0	28.0	40	312	1120.0	12480
sludge trucks	15.5	18.0	33.5	24.5	24	312	588.0	7488
tanker trucks	7.5	10.0	17.5	12.5	2	312	25.0	624
10 yd3 trucks	9.0	3.0	12.0	10.5	40	312	420.0	12480
5 yd3 trucks	6.0	2.0	8.0	7.0	40	312	280.0	12480
end dump trucks	16.0	14.0	30.0	23.0	44	312	1012.0	13728
pick up trucks	2.1	0.7	2.8	2.4	55	312	133.4	17160
front loaders	16.0	8.0	24.0	20.0	30	312	600.0	9360
rear loaders	11.0	10.0	21.0	16.0	35	312	560.0	10920
green waste loader	11.5	4.5	16.0	13.8	20	312	275.0	6240
employee trucks	1.8	0.1	1.9	1.8	20	312	36.0	6240
water trucks	1.8	0.1	1.9	1.8	10	312	18.0	3120
Average Fleet				14.4	415	312	5991.1	129480

(W J)

Emission Calculations for Off-Site Vehicle Travel on Dirt Roads at Redwood Landfill

based on AP-42 Chapter 13.2.2, last updated 9/98

Equation 1: $E = [k (s/12)^a (W/3)^b]/[(M/0.2)^c]^p (S/15)$

Equation 2: $E_{ext} = [k (s/12)^a (W/3)^b]$ last updated 12/03, calcualtion for PM-10 is based on this equation

where E = size specific emission factor, pounds/vehical mile traveled (lbs/VMT)
E_{ext} = annual size specific emission factor, uncontrolled except for natural rainfall mitigation (lbs/VMT)
k, a, b, c = empirical constants based on particle size (see table below)
s = surface material silt content (%), default from Table 13.2.2-1 = 11% for dirt roads
W = mean vehical weight of entire fleet traveling the road (tons)
M = surface material moisture content (%), default for regularly watered roads is 4%
p = number of days per year with at least 0.01" of precipitation, default is 60 for entire Bay Area

Notes: Use the tables below to fill in site specific data. Values in bold text are constants and should not be changed.
For Table 1., values in red text are default values that should be replaced with site specific data when ever possible.
For Tables 2. & 3., values in red are examples of data used for one particular site and should be replaced with site specific data.
For all tables, values in regular text are calculated values. These equations should not be changed.
Equation 2 above is used to calculate uncontrolled particulate emissions from unpaved roads.
Equation 1 above may be used to calculate particulate emissions for unpaved roads that are controlled by regular watering.
For such watered roads, be sure to input a site-specific moisture content. The default moisture content (4%) is assumed to achieve approximately 75% control of particulate emissions compared to uncontrolled particulate emissions.
Equation 1 should not be used for unpaved roads that are chemically stabilized, such as with petroleum resins, MgCl, or CaCl.
For stabilized roads use Equation 2 and an appropriate control efficiency (80% for petroleum resins or CaCl, 85% for MgCl).
To achieve the control efficiencies noted above, minimum application rate is 0.5 gallons/square yard at the manufacturer's recommended concentration (for example, 10% MgCl in water). Minimum application frequency is 2 times/month for petroleum resin and 1 time/month for MgCl & CaCl. For the salts, subsequent regular watering is necessary to maintain the high control efficiency. Some suggested watering schedules are: 0.5 gallons/square yard applied at least: (a) once every 3 hours, or (b) once every 150 vehical trips, or (c) at the frequency necessary to maintain the moisture content specified in Table 1.
Equations 1 & 2 over estimate emissions at low speeds. Per AP-42 page 13.2.2-4, a speed correction factor (S/15) was added to Equations 1 and 2 to correct for this over estimation, but it may only be used if $S \leq 15$ mph.
For short unpaved road sections (<1 mile) near the working face, using this factor is reasonable because speeds are usually very low due to working face traffic controls and poor manuverability.

Table 1. Variables for Equations 1. & 2.

	PM-2.5	PM-10	PM-30
k	0.38	1.50	10.00
a	0.80	0.90	0.80
b	0.40	0.45	0.50
c	0.30	0.30	0.40
s	6.40	6.40	6.40
W	15.42	15.42	15.42
M	20.00	20.00	20.00
M_{dry}	0.20	0.20	0.20
p	60.00	60.00	60.00
S	15.00	15.00	15.00

Table 2. Mean Vehicle Fleet Weight (Off-Site Vehicles)

Vehical Type	Empty Wt tons	Load Wt tons	Full Wt tons	Avg. Wt. tons	# of Round Trips/Day	Operating Time Days/Year	wt*trips	trips/year
roll off box	11.0	11.5	22.5	16.8	45	312	753.8	14040
compactor box	11.5	11.0	22.5	17.0	10	312	170.0	3120
transfer trucks	16.0	24.0	40.0	28.0	40	312	1120.0	12480
sludge trucks	15.5	18.0	33.5	24.5	24	312	588.0	7488
tanker trucks	7.5	10.0	17.5	12.5	2	312	25.0	624
10 yd3 trucks	9.0	3.0	12.0	10.5	40	312	420.0	12480
5 yd3 trucks	6.0	2.0	8.0	7.0	40	312	280.0	12480
end dump trucks	16.0	14.0	30.0	23.0	44	312	1012.0	13728
pick up trucks	2.1	0.7	2.8	2.4	55	312	133.4	17160
front loaders	16.0	8.0	24.0	20.0	30	312	600.0	9360
rear loaders	11.0	10.0	21.0	16.0	35	312	560.0	10920
green waste loads	11.5	4.5	16.0	13.8	20	312	275.0	6240
employee cars	1.6	0.1	1.7	1.7	0	312	0.0	0
employee trucks	1.8	0.1	1.9	1.8	0	312	0.0	0
Average Fleet				15.4	385	312	5937.1	120120

(W J)

Table 3. Suggested Control Efficiencies

	PM-2.5	PM-10	PM-30
Water	75%	75%	75%
Petroleum Resins	80%	80%	80%
Asphalt Emulsions	80%	80%	80%
Adhesives	85%	85%	85%
Salts (MgCl & CaCl)	85%	85%	85%

Table 4. Mean Vehical Miles Traveled by Avg Fleet

Unpaved Length	3000	feet (one way)
# of Round Trips	385	trips/day
Avg. Op.Time	312	days/year
VMT/Day	728.00	miles/day
VMT/Year	227136	miles/year

Table 5. Emissions Comparison

	Equation Used	Daily Emissions (Pounds/Day) PM-2.5	PM-10	PM-30
Uncontrolled	2	269.10	1295.69	5341.31
Watered	1	80.69	325.44	1562.06
Watered	2 & CE	67.28	323.98	2085.33
Petroleum Resins	2 & CE	53.82	259.12	1668.26
Asphalt Emulsions	2 & CE	53.82	259.12	1668.26
Adhesives	2 & CE	40.37	194.34	1251.20
Salts	2 & CE	40.37	194.34	1251.20

	Equation Used	Annual Emissions (Tons/Year) PM-2.5	PM-10	PM-30
Uncontrolled	2	41.96	202.11	1301.24
Watered	1	12.62	50.77	246.80
Watered	2 & CE	10.50	50.53	326.31
Petroleum Resins	2 & CE	8.40	40.42	260.25
Asphalt Emulsions	2 & CE	8.40	40.42	260.25
Adhesives	2 & CE	6.30	30.32	195.19
Salts	2 & CE	6.30	30.32	195.19

Emission Calculations for On-Site Vehicle Travel on Dirt Roads at Redwood Landfill

based on AP-42 Chapter 13.2.2

Equation 1: $E = [k (s/12)^a (W/3)^b]/[(M/0.2)^c]*(S/15)$

Equation 2: $E_{ext} = [k (s/12)^a(W/3)^b][(M_{dry}/0.2)^c]*[(365-p)/365]*(S/15)$, last updated 9/98

Equation 2: $E_{ext} = [k (s/12)^a(W/3)^b]$ last updated 12/03, calculation for PM-10 is based on this equation

where E = size specific emission factor, pounds/vehical mile traveled (lbs/VMT)

E_{ext} = annual size specific emission factor, uncontrolled except for natural rainfall mitigation (lbs/VMT)

k, a, b, c = empirical constants based on particle size (see table below)

s = surface material silt content (%), default from Table 13.2.2-1 = 11% for dirt roads

W = mean vehical weight of entire fleet traveling the road (tons)

M = surface material moisture content (%), default for regularly watered roads is 4%

M_{dry} = surface material moisture content under dry conditions (%), default is 0.2%

p = number of days per year with at least 0.01" of precipitation, default is 60 for entire Bay Area

S = mean vehicle speed (mph), default and maximum is 15 mph

Notes: Use the tables below to fill in site specific data. Values in bold text are constants and should not be changed.
For Table 1., values in red text are default values that should be replaced with site specific data when ever possible.
For Tables 2. & 3., values in red are examples of data used for one particular site and should be replaced with site specific data.
For all tables, values in regular text are calculated values. These equations should not be changed.
Equation 2 above is used to calculate uncontrolled particulate emissions from unpaved roads.
Equation 1 above may be used to calculate particulate emissions for unpaved roads that are controlled by regular watering.
For such watered roads, be sure to input a site-specific moisture content. The default moisture content (4%) is assumed to achieve approximately 75% control of particulate emissions compared to uncontrolled particulate emissions.
Equation 1 should not be used for unpaved roads that are chemically stabilized, such as with petroleum resins, MgCl, or CaCl.
For stabilized roads use Equation 2 and an appropriate control efficiency (80% for petroleum resins or CaCl, 85% for MgCl).
To achieve the control efficiencies noted above, minimum application rate is 0.5 gallons/square yard at the manufacturer's recommended concentration (for example, 10% MgCl in water). Minimum application frequency is 2 times/month for petroleum resin and 1 time/month for MgCl & CaCl. For the salts, subsequent regular watering is necessary to maintain the high control efficiency. Some suggested watering schedules are: 0.5 gallons/square yard applied at least: (a) once every 3 hours, or (b) once every 150 vehical trips, or (c) at the frequency necessary to maintain the moisture content specified in Table 1.
Equations 1 & 2 over estimate emissions at low speeds. Per AP-42 page 13.2.2-4, a speed correction factor (S/15) was added to Equations 1 and 2 to correct for this over estimation, but it may only be used if S ≤ 15 mph.
For short unpaved road sections (<1 mile) near the working face, using this factor is reasonable because speeds are usually very low due to working face traffic controls and poor manuverability.

Table 1. Variables for Equations 1. & 2.

	PM-2.5	PM-10	PM-30
k	0.38	1.50	18.00
a	0.90	0.90	0.80
b	0.45	0.45	0.50
c	0.30	0.30	0.60
s	6.40	6.40	6.40
W	28.37	28.37	28.37
M	20.00	20.00	20.00
M_{dry}	0.20	0.20	0.20
p	60.00	60.00	60.00
S	15.00	15.00	15.00

Table 2. Mean Vehicle Fleet Weight (On-Site Vehicles)

Vehical Type	Empty Wt tons	Load Wt tons	Full Wt tons	Avg. Wt. tons	# of Round Trips/Day	Operating Time Days/Year	wt*trips	trips/year
water tanker 1	7.5	5.8	13.0	10.3	5	312	51.3	1560
water tanker 2	19.0	10.0	29.0	24.0	5	312	120.0	1560
bulldozer d5	23.0	0.0	23.0	23.0	2	312	46.0	624
bulldozer d8	42.5	0.0	42.5	42.5	2	312	85.0	624
bulldozer d9	55.0	0.0	55.0	55.0	2	312	110.0	624
packers	39.5	0.0	39.5	39.5	2	312	79.0	624
dump trucks	24.6	15.4	40.0	32.3	20	312	646.3	6240
back hoe	17.5	0.0	17.5	17.5	2	312	35.0	624
fuel trucks	22.3	0.0	22.3	22.3	4	312	89.0	1248
road grader	19.0	0.0	19.0	19.0	2	312	38.0	624
mechanic trucks	10.0	0.0	10.0	10.0	2	312	20.0	624
loader 980	33.8	0.0	33.8	33.8	2	312	67.6	624
loader 950	20.0	0.0	20.0	20.0	2	312	40.0	624
loader ws 600	52.5	0.0	52.5	52.5	2	312	105.0	624
Average Fleet				28.4	54	312	1532.0	16848
				(W J)				

Table 3. Suggested Control Efficiencies

	PM-2.5	PM-10	PM-30
Water	75%	75%	75%
Petroleum Resins	80%	80%	80%
[illegible]alt Emulsions	80%	80%	80%
[illegible]sives	85%	85%	85%
[illegible]ts (MgCl & CaCl)	85%	85%	85%

Table 4. Mean Vehical Miles Traveled by Avg Fleet

Unpaved Length	3000	feet (one way)
# of Round Trips	54	trips/day
Avg. Op.Time	312	days/year
VMT/Day	103.00	miles/day
VMT/Year	32136	miles/year

Table 5. Emissions Comparison

	Equation Used	Daily Emissions (Pounds/Day) PM-2.5	PM-10	PM-30
Uncontrolled	2	48.59	241.16	1600.72
Watered	1	14.61	60.58	303.60
Watered	2 & CE	12.15	60.29	400.18
Petroleum Resins	2 & CE	9.72	48.23	320.14
Asphalt Emulsions	2 & CE	9.72	48.23	320.14
Adhesives	2 & CE	7.29	36.17	240.11
Salts	2 & CE	7.29	36.17	240.11

	Equation Used	Annual Emissions (Tons/Year) PM-2.5	PM-10	PM-30
Uncontrolled	2	7.56	37.62	249.71
Watered	1	2.28	9.45	47.36
Watered	2 & CE	1.89	9.41	62.43
Petroleum Resins	2 & CE	1.52	7.52	49.94
Asphalt Emulsions	2 & CE	1.52	7.52	49.94
Adhesives	2 & CE	1.14	5.64	37.46
Salts	2 & CE	1.14	5.64	37.46

Emission Calculations for Off-Site Vehicle Travel on Gravel Roads at Redwood Landfill

based on AP-42 Chapter 13.2.2

Equation 1: $E = [k (s/12)^a (W/3)^b]/[(M/0.2)^c]*(S/15)$

Equation 2: $E_{ext} = [k (s/12)^a (W/3)^b]/[(M_{dry}/0.2)^c]*[(365-p)/365]*(S/15)$

Equation 2: $E_{ext} = [k (s/12)^a (W/3)^b]$ last updated 12/03, calcuation for PM-10 is based on this equation and the suggested control efficiency

where E = size specific emission factor, pounds/vehical mile traveled (lbs/VMT)

E_{ext} = annual size specific emission factor, uncontrolled except for natural rainfall mitigation (lbs/VMT)

k, a, b, c = empirical constants based on particle size (see table below)

s = surface material silt content (%), default from Table 13.2.2-1 = 6.4%

W = mean vehical weight of entire fleet traveling the road (tons)

M = surface material moisture content (%), default for regularly watered roads is 4%

M_{dry} = surface material moisture content under dry conditions (%), default is 0.2%

p = number of days per year with at least 0.01" of precipitation, default is 60 for entire Bay Area

S = mean vehicle speed (mph), default and maximum is 15 mph

Notes: Use the tables below to fill in site specific data. Values in bold text are constants and should not be changed.
For Table 1., values in red text are default values that should be replaced with site specific data when ever possible.
For Tables 2. & 3., values in red are examples of data used for one particular site and should be replaced with site specific data.
For all tables, values in regular text are calculated values. These equations should not be changed.
Equation 2 above is used to calculate uncontrolled particulate emissions from unpaved roads.
Equation 1 above may be used to calculate particulate emissions for unpaved roads that are controlled by regular watering.
For such watered roads, be sure to input a site-specific moisture content. The default moisture content (4%) is assumed to achieve approximately 75% control of particulate emissions compared to uncontrolled particulate emissions.
Equation 1 should not be used for unpaved roads that are chemically stabilized, such as with petroleum resins, MgCl, or CaCl.
For stabilized roads use Equation 2 and an appropriate control efficiency (80% for petroleum resins or CaCl, 85% for MgCl).
To achieve the control efficiencies noted above, minimum application rate is 0.5 gallons/square yard at the manufacturer's recommended concentration (for example, 10% MgCl in water). Minimum application frequency is 2 times/month for petroleum resin and 1 time/month for MgCl & CaCl. For the salts, subsequent regular watering is necessary to maintain the high control efficiency. Some suggested watering schedules are: 0.5 gallons/square yard applied at least: (a) once every 3 hours, or (b) once every 150 vehical trips, or (c) at the frequency necessary to maintain the moisture content specified in Table 1.
Equations 1 & 2 over estimate emissions at low speeds. Per AP-42 page 13.2.2-4, a speed correction factor (S/15) was added to Equations 1 and 2 to correct for this over estimation, but it may only be used if $S \leq 15$ mph.
For short unpaved road sections (<1 mile) near the working face, using this factor is reasonable because speeds are usually very low due to working face traffic controls and poor manuverability.

Table 1. Variables for Equations 1. & 2.

	PM-2.5	PM-10	PM-30
k	0.36	1.50	10.00
a	0.90	0.90	0.90
b	0.45	0.45	0.50
c	0.30	0.30	0.40
s	6.40	6.40	6.40
W	15.42	15.42	15.42
M	20.00	20.00	20.00
M_{dry}	0.20	0.20	0.20
p	60.00	60.00	60.00
S	15.00	15.00	15.00

Table 2. Mean Vehicle Fleet Weight (Off-Site Vehicles)

Vehical Type	Empty Wt tons	Load Wt tons	Full Wt tons	Avg. Wt. tons	# of Round Trips/Day	Operating Time Days/Year
roll off box	11.0	11.5	22.5	16.8	45	312
compactor box	11.5	11.0	22.5	17.0	10	312
transfer trucks	16.0	24.0	40.0	28.0	40	312
sludge trucks	15.5	18.0	33.5	24.5	24	312
tanker trucks	7.5	10.0	17.5	12.8	2	312
10 yd3 trucks	9.0	3.0	12.0	10.5	40	312
5 yd3 trucks	6.0	2.0	8.0	7.0	40	312
end dump trucks	16.0	14.0	30.0	23.0	44	312
pick up trucks	2.1	0.7	2.8	2.4	55	312
front loaders	16.0	8.0	24.0	20.0	30	312
rear loaders	11.0	10.0	21.0	16.0	35	312
green waste loader	11.5	4.5	16.0	13.8	20	312
employee cars	1.6	0.1	1.7	1.7	0	312
employee trucks	1.8	0.1	1.9	1.8	0	312
Average Fleet				19.4	385	312

(W 3)

Daily wt*trips	Annual trips/year
753.6	14040
170.0	3120
1120.0	12480
588.0	7488
25.0	624
420.0	12480
280.0	12480
1012.0	13728
133.4	17160
600.0	9360
560.0	10920
275.0	6240
0.0	0
0.0	0
5637.1	120120

Table 3. Suggested Control Efficiencies

	PM-2.5	PM-10	PM-30
Water	75%	75%	75%
Petroleum Resins	80%	80%	80%
Asphalt Emulsions	80%	80%	80%
Adhesives	85%	85%	85%
Salts (MgCl & CaCl)	85%	85%	85%

Table 4. Mean Vehical Miles Traveled by Avg Fleet

Unpaved Length	6000	feet (one way)
# of Round Trips	385	trips/day
Avg. Op.Time	312	days/year
VMT/Day	1200.00	miles/day
VMT/Year	374400	miles/year

Table 5. Emissions Comparison

	Equation Used	Daily Emissions (Pounds/Day) PM-2.5	PM-10	PM-30
Uncontrolled	2	443.58	2135.69	13749.42
Watered	1	133.34	536.44	2607.82
Watered	2 & CE	110.89	533.80	3437.35
Petroleum Resins	2 & CE	88.72	427.12	2749.88
Asphalt Emulsions	2 & CE	88.72	427.12	2749.88
Adhesives	2 & CE	66.54	320.34	2062.41
Salts	2 & CE	66.54	320.34	2062.41

	Equation Used	Annual Emissions (Tons/Year) PM-2.5	PM-10	PM-30
Uncontrolled	2	69.20	333.15	2144.91
Watered	1	20.80	83.68	406.82
Watered	2 & CE	17.30	83.29	536.23
Petroleum Resins	2 & CE	13.84	66.63	428.98
Asphalt Emulsions	2 & CE	13.84	66.63	428.98
Adhesives	2 & CE	10.38	49.97	321.74
Salts	2 & CE	10.38	49.97	321.74

Plant # 1179, Redwood Landfill

Landfill Gas From S-5 Redwood Landfill

Contants Used In Calculations

Molar Volume of Gas at 70 °F, scf/lbmol:	MV	387.006
Methane Content for all Calculations, %	CH4	50%
Methane Heat Content, BTU/ft^3 at 60 °F	HCM	1013
Heat Content for LFG at 50% CH_4, BTU/scf at 70 °F	HCL	496.943
F-Factor at 0% O_2 for LFG at 50% CH_4, sdcf/MM BTU	FFac	9628.24
	Name	Molecular Weight
Hydrogen	Hy	1.00794
Carbon	Ca	12.01100
Nitrogen	Nl	14.00670
Oxygen	Ox	15.99940
Fluorine	Fl	18.99840
Sulfur	Su	32.06000
Chlorine	Cl	35.45300
Bromine	Br	79.90400
Mercury	Hg	200.59000

Compounds, basis	Molecular Weight	Maximum Concen-tration	Uncontrolled Emission Factor lbs / M scf	Uncontrolled Emission Factor lbs / MM BTU	Control Efficiency	Abated Emission Factor lbs / M scf	Abated Emission Factor lbs / MM BTU
Sulfur Compounds, C#19867, Part 18a and site tests		PPBV					
Hydrogen Sulfide	34.08	424000	3.733E-02	7.513E-02	98.0%	7.467E-04	1.503E-03
Cabonyl Sulfide	60.07	50	7.761E-06	1.562E-05	98.0%	1.552E-07	3.123E-07
Methyl Mercaptan	48.10	300	3.729E-05	7.504E-05	98.0%	7.458E-07	1.501E-06
Ethyl Mercaptan	62.13	50	8.027E-06	1.615E-05	98.0%	1.605E-07	3.231E-07
Dimethyl Sulfide	62.13	200	3.211E-05	6.461E-05	98.0%	6.422E-07	1.292E-06
Carbon Disulfide	76.13	100	1.967E-05	3.959E-05	98.0%	3.934E-07	7.917E-07
Iso-propyl Mercaptan	76.16	50	9.839E-06	1.980E-05	98.0%	1.968E-07	3.960E-07
n-propyl Mercaptan	76.16	50	9.839E-06	1.980E-05	98.0%	1.968E-07	3.960E-07
Dimethyl Disulfide	94.19	50	1.217E-05	2.449E-05	98.0%	2.434E-07	4.898E-07
Total Reduced Sulfur, as H_2S	34.08	425000	3.742E-02	7.530E-02	98.0%	7.484E-04	1.506E-03
Halogenated Organic Compounds, Site Tests		PPBV					
1 Dichloroethylene (vinylidine dichloride)	96.94	150	3.757E-05	7.561E-05	98.0%	7.515E-07	1.512E-06
,1 Trichloroethane	133.40	69	2.381E-05	4.791E-05	98.0%	4.762E-07	9.583E-07
1,1,2 Trichloroethane	133.40	69	2.381E-05	4.791E-05	98.0%	4.762E-07	9.583E-07
1,2 Dichloroethene (cis)	96.94	577	1.446E-04	2.910E-04	98.0%	2.892E-06	5.820E-06
1,2 Dichloroethene (trans)	96.94	278	6.973E-05	1.403E-04	98.0%	1.395E-06	2.806E-06
1,2 Dichloropropane (propylene dichloride)	112.99	69	2.017E-05	4.058E-05	98.0%	4.033E-07	8.116E-07
1,2,4 Trichlorobenzene	181.45	69	3.238E-05	6.517E-05	98.0%	6.477E-07	1.303E-06
1,3 Dichloropropene (cis)	110.97	69	1.981E-05	3.986E-05	98.0%	3.961E-07	7.971E-07
1,3 Dichloropropene (trans)	110.97	69	1.981E-05	3.986E-05	98.0%	3.961E-07	7.971E-07
Bromodichloromethane	163.83	3130	1.325E-03	2.666E-03	98.0%	2.650E-05	5.333E-05
Bromoform	252.73	278	1.818E-04	3.658E-04	98.0%	3.635E-06	7.316E-06
Carbon Tetrachloride	153.82	70	2.782E-05	5.599E-05	98.0%	5.565E-07	1.120E-06
Chlorobenzene	112.56	76	2.219E-05	4.465E-05	98.0%	4.438E-07	8.930E-07
Chloroform	119.38	70	2.159E-05	4.345E-05	98.0%	4.319E-07	8.690E-07
Chloroprene	88.54	278	6.368E-05	1.281E-04	98.0%	1.274E-06	2.563E-06
Chlorotoluene	126.59	69	2.259E-05	4.546E-05	98.0%	4.519E-07	9.093E-07
Dibromochloromethane	208.28	278	1.498E-04	3.014E-04	98.0%	2.996E-06	6.029E-06
1.4 Dichlorobenzene	147.00	400	1.519E-04	3.057E-04	98.0%	3.039E-06	6.115E-06
Dichloroethane	98.96	150	3.836E-05	7.718E-05	98.0%	7.671E-07	1.544E-06
Ethyl Chloride (chloroethane)	64.51	300	5.001E-05	1.006E-04	98.0%	1.000E-06	2.013E-06
Ethylene Dibromide	187.86	70	3.398E-05	6.838E-05	98.0%	6.796E-07	1.368E-06
Ethylene Dichloride	98.96	70	1.790E-05	3.602E-05	98.0%	3.580E-07	7.204E-07
Freon-11 (trichlorofluoromethane)	137.37	140	4.969E-05	1.000E-04	98.0%	9.939E-07	2.000E-06
Freon-113 (1,1,2 trichloro 1,2,2 trifluoroethane)	187.38	69	3.344E-05	6.730E-05	98.0%	6.689E-07	1.346E-06
Freon-114 (1,2 dichloro 1,1,2,2 tetrafluoroethane)	170.92	70	3.096E-05	6.230E-05	98.0%	6.192E-07	1.246E-06
Freon-12 (dichlorodifluoromethane)	120.91	660	2.061E-04	4.148E-04	98.0%	4.123E-06	8.296E-06
Hexachlorobutadiene	260.76	69	4.654E-05	9.365E-05	98.0%	9.308E-07	1.873E-06
Methyl Bromide	94.94	69	1.694E-05	3.410E-05	98.0%	3.389E-07	6.819E-07
Methyl Chloride (chloromethane)	50.49	69	9.011E-06	1.813E-05	98.0%	1.802E-07	3.627E-07
Compounds, basis	Molecular Weight	Maximum Concen-tration	Uncontrolled Emission Factor lbs / M scf	Uncontrolled Emission Factor lbs / MM BTU	Control Efficiency	Abated Emission Factor lbs / M scf	Abated Emission Factor lbs / MM BTU

Plant # 1179, Redwood Landfill, Application # 8501 for Heat Input Increases at the A-50 Landfill Gas Flare

Landfill Gas Concentration Data and Flare Emission Factors

Compounds, basis	Molecular Weight	Maximum Concen-tration	Uncontrolled Emission Factor lbs / M scf	Uncontrolled Emission Factor lbs / MM BTU	Control Efficiency	Abated Emission Factor lbs / M scf	Abated Emission Factor lbs / MM BTU
Total NMOC, as hexane, based on C#19867, Part 18	86.18	0.043%	9.464E-02	1.904E-01	98.0%	1.893E-03	3.809E-03
Total NMOC, as methane, based on C#19867, Part 18	16.04	0.255%	1.057E-01	2.127E-01	98.0%	2.114E-03	4.254E-03
Total NMOC, as methane, based on 8-34-301.3	16.04					6.948E-03	1.398E-02
Criteria Pollutants From A-50 Flare		PPMV					
Total NPOC, sum of individual NPOCs	16.04	14.560	1.329E-03	2.674E-03	98.0%	2.658E-05	5.348E-05
Total POC, maximum NMOC as methane - NPOC	16.04					6.921E-03	1.393E-02
NOx, RACT Limit in C#19867, Part 25	46.01					2.982E-02	6.000E-02
CO, RACT Limit in C#19867, Part 26	28.01					1.491E-01	3.000E-01
PM10, New Limit: 6.023 tons/yr / 745000 MM BTU/yr						8.500E-03	1.710E-02
H_2S, **TRS Limit for LFG, C#19867, Part 18a**	64.06					7.035E-02	**1.416E-01**
Significant TACs, basis: C#19867, Part 18b & site test data		PPBV					
Acrylonitrile	53.06	280	3.839E-05	7.726E-05	99.7%	1.152E-07	2.318E-07
Benzene	78.11	1000	2.018E-04	4.062E-04	99.7%	6.055E-07	1.218E-06
1,3 Butadiene	54.09	278	3.890E-05	7.829E-05	98.0%	7.781E-07	1.566E-06
Carbon Tetrachloride	153.82	70	2.782E-05	5.599E-05	98.0%	5.565E-07	1.120E-06
Chloroform	119.38	70	2.159E-05	4.345E-05	98.0%	4.319E-07	8.690E-07
1,4 Dichlorobenzene	147.00	400	1.519E-04	3.057E-04	98.0%	3.039E-06	6.115E-06
1,1 Dichloroethane	98.96	150	3.836E-05	7.718E-05	98.0%	7.671E-07	1.544E-06
Ethylene Dibromide	187.86	70	3.398E-05	6.838E-05	98.0%	6.796E-07	1.368E-06
Ethylene Dichloride	98.96	70	1.790E-05	3.602E-05	98.0%	3.580E-07	7.204E-07
Hydrogen Bromide	80.91	4731	9.891E-04	1.990E-03	0.0%	9.891E-04	1.990E-03
Hydrogen Chloride	36.46	20320	1.914E-03	3.852E-03	0.0%	1.914E-03	3.852E-03
Hydrogen Fluoride	20.01	1947	1.007E-04	2.026E-04	0.0%	1.007E-04	2.026E-04
Hydrogen Sulfide	34.08	424000	3.733E-02	7.513E-02	98.0%	7.467E-04	1.503E-03
Methylene Chloride	84.93	1000	2.195E-04	4.416E-04	98.0%	4.389E-06	8.832E-06
Perchloroethylene	165.83	450	1.928E-04	3.880E-04	98.0%	3.857E-06	7.761E-06
1,1,2,2 Tetrachloroethane	167.85	70	3.036E-05	6.109E-05	98.0%	6.072E-07	1.222E-06
1,1,2 Trichloroethane	133.40	69	2.381E-05	4.791E-05	98.0%	4.762E-07	9.583E-07
Trichloroethylene	131.39	250	8.488E-05	1.708E-04	98.0%	1.698E-06	3.416E-06
Vinyl Chloride	62.50	880	1.421E-04	2.860E-04	98.0%	2.842E-06	5.720E-06

Methylene Chloride	84.93	1000	2.195E-04	4.416E-04	98.0%	4.389E-06	8.832E-06
Perchloroethylene	165.83	450	1.928E-04	3.880E-04	98.0%	3.857E-06	7.761E-06
1,1,2,2 Tetrachloroethane	167.85	70	3.036E-05	6.109E-05	98.0%	6.072E-07	1.222E-06
Trichloroethylene	131.39	250	8.488E-05	1.708E-04	98.0%	1.698E-06	3.416E-06
Vinyl Chloride	62.50	880	1.421E-04	2.860E-04	98.0%	2.842E-06	5.720E-06
Non-Halogenated Organic Compounds, Site Tests		PPBV					
Acrylonitrile	53.06	280	3.839E-05	7.726E-05	99.7%	1.152E-07	2.318E-07
Benzene	78.11	1000	2.018E-04	4.062E-04	99.7%	6.055E-07	1.218E-06
1,3 Butadiene	54.09	278	3.890E-05	7.829E-05	98.0%	7.781E-07	1.566E-06
1,4 Dioxane	88.11	278	6.337E-05	1.275E-04	98.0%	1.267E-06	2.550E-06
2-Propanol	60.10	5052	7.844E-04	1.579E-03	98.0%	1.569E-05	3.157E-05
4-Ethyl Toluene	120.19	1031	3.202E-04	6.443E-04	98.0%	6.404E-06	1.289E-05
Acetone	58.08	3814	5.725E-04	1.152E-03	98.0%	1.145E-05	2.304E-05
Butane	58.12	10309	1.548E-03	3.116E-03	98.0%	3.097E-05	6.231E-05
Cyclohexane	84.16	960	2.088E-04	4.201E-04	98.0%	4.175E-06	8.402E-06
Ethanol	46.07	24742	2.945E-03	5.927E-03	98.0%	5.891E-05	1.185E-04
[illegible]yl Benzene	106.17	2062	5.656E-04	1.138E-03	98.0%	1.131E-05	2.276E-05
Heptane	100.20	1134	2.936E-04	5.909E-04	98.0%	5.872E-06	1.182E-05
Hexane	86.18	880	1.960E-04	3.943E-04	98.0%	3.919E-06	7.886E-06
Methyl Ethyl Ketone	72.11	7526	1.402E-03	2.822E-03	98.0%	2.804E-05	5.643E-05
Methyl Isobutyl Ketone	100.16	763	1.974E-04	3.973E-04	98.0%	3.949E-06	7.946E-06
Methyl n-Butyl Ketone	100.16	278	7.204E-05	1.450E-04	98.0%	1.441E-06	2.899E-06
Methyl t-Butyl Ether	88.15	278	6.340E-05	1.276E-04	98.0%	1.268E-06	2.552E-06
Pentane	72.15	10309	1.922E-03	3.868E-03	98.0%	3.844E-05	7.735E-05
Propane	44.10	20619	2.349E-03	4.728E-03	98.0%	4.699E-05	9.455E-05
Propylene	42.08	278	3.027E-05	6.090E-05	98.0%	6.053E-07	1.218E-06
Styrene	104.15	330	8.878E-05	1.787E-04	98.0%	1.776E-06	3.573E-06
Tetrahydrofuran	72.11	2062	3.842E-04	7.731E-04	98.0%	7.683E-06	1.546E-05
Toluene	92.14	10206	2.430E-03	4.890E-03	98.0%	4.860E-05	9.780E-05
Trimethyl Benzene	120.19	2557	7.940E-04	1.598E-03	98.0%	1.588E-05	3.196E-05
Vinyl Acetate	86.09	278	6.192E-05	1.246E-04	98.0%	1.238E-06	2.492E-06
Xylenes (o, m, p)	106.17	7900	2.167E-03	4.361E-03	98.0%	4.334E-05	8.722E-05
Inorganic Compounds, basis: AP-42		PPBV					
[illegible]ury	200.59	0.292	1.513E-07	3.046E-07	0.0%	1.513E-07	3.046E-07
Secondary Pollutants, sum of site test data		PPBV					
Hydrogen Chloride	36.46	20320	1.914E-03	3.852E-03	0.0%	1.914E-03	3.852E-03
Hydrogen Fluoride	20.01	1947	1.007E-04	2.026E-04	0.0%	1.007E-04	2.026E-04
Hydrogen Bromide	80.91	4731	9.891E-04	1.990E-03	0.0%	9.891E-04	1.990E-03

Appendix H

Same as Appendix G

Appendix I

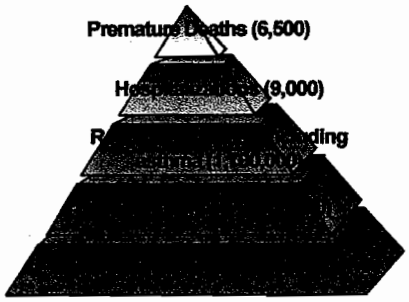
California Environmental Protection Agency
AIR RESOURCES BOARD

AMERICAN LUNG ASSOCIATION® of California

Recent Research Findings:

Health Effects of Particulate Matter and Ozone Air Pollution, January 2004

Health Impacts of Air Pollution
(per year)



Although air pollution levels in California have improved significantly in the past few decades due to aggressive controls on vehicles and industry, many Californians still breathe the worst air in the nation. California's climate and geography are conducive to the formation and accumulation of air pollution (especially in Los Angeles and the Central Valley). These factors, combined with increasing population and economic growth, the dramatically increasing number of vehicle miles traveled, and other factors, make it difficult to reduce pollution levels. Higher and longer summer temperatures have also worsened smog problems. The concentrations of several pollutants not only exceed California's health-based standards, but are often measured at levels up to two or three times the standards.

Premature deaths linked to particulate matter or "PM" are now at levels comparable to deaths from traffic accidents and second-hand smoke (CARB 2002a). One of the most dangerous pollutants, fine particulate matter (e.g., from diesel exhaust and fireplace soot) not only bypasses the body's defense mechanisms and becomes embedded in the deepest recesses of the lung, but also can disrupt cellular processes. Population-based studies in hundreds of cities in the U.S. and around the world have demonstrated a strong link between elevated particulate levels and premature deaths, hospital admissions, emergency room visits, and asthma attacks. Groundbreaking long-term studies of children's health conducted in California have demonstrated that particle pollution may significantly reduce lung function growth in children (Peters et al. 1999, Avol et al. 2001, Gauderman et al. 2002).

Another dangerous pollutant is ozone. Ozone is a powerful oxidant that can damage the respiratory tract, causing inflammation and irritation, and induces symptoms such as coughing, chest tightness, shortness of breath, and worsening of asthma symptoms. Ozone in sufficient doses increases the permeability of lung cells, rendering them more susceptible to toxins and microorganisms. The greatest risk is to those who are more active outdoors during smoggy periods, such as children, athletes, and outdoor workers. Exposure to levels of ozone above the current ambient air quality standard leads to lung inflammation and lung tissue damage, and a reduction in the amount of air inhaled into the lungs. Recent evidence has, for the first time, linked the onset of asthma to exposure to elevated ozone levels in exercising children (McConnell 2002). These levels of ozone also reduce crop and timber yields, damage native plants, and damage materials such as rubber, paints, fabric, and plastics.

Scientific research is constantly uncovering new information on air pollution health effects and the mechanisms by which pollutants damage the heart and lungs and contribute to asthma attacks and premature death.

Air Pollution Causes Premature Death

Attaining the California PM standards would annually prevent about 6,500 premature deaths, or 3% of all deaths. These premature deaths shorten lives by an average of 14 years. This is roughly equivalent to the same number of deaths (4,200 - 7,400) linked to second-hand smoke in the year 2000. In comparison, motor vehicle crashes caused 3,200 deaths and homicides were responsible for 2,000 deaths (CARB 2002a, and CDHS 2000).

Air Pollution Leads to Hospitalizations and Emergency Room Visits

Attaining the California PM and ozone standards would annually prevent approximately (CARB 2003a):

- 4,000 hospital admissions for respiratory disease.
- 3,000 hospital admissions for cardiovascular disease.
- 2,000 asthma-related emergency room visits.

Air Pollution Contributes to Respiratory Illnesses and Cancer

Attaining the California PM and ozone standards would annually prevent about (CARB 2003a):

- 400,000 cases of lower respiratory symptoms (such as a cough) in children ages 7-14.

- 400,000 cases of upper respiratory symptoms (such as, runny nose, wet cough, and burning, itching, red eyes) in children ages 9-11.
- 8,000 cases of chronic bronchitis.
- 500,000 cases of respiratory illnesses (including colds and flus) in adults ages 18-65.
- 350,000 asthma attacks (all ages).

Although statistics are not available for cases of lung cancer caused by all air pollutants, it is estimated that exposure to diesel PM causes about 250 excess cancer cases per year in California (CARB 2000). A recent study provides evidence that exposure to particulate air pollution is associated with lung cancer (Pope et al. 2002). This study found that residents who live in an area that is severely impacted by particulate air pollution are at risk of lung cancer at a rate comparable to non-smokers exposed to second-hand smoke. Definitive lung cancer mortality numbers as a result of air pollution cannot yet be determined, but this study found an approximately 16 percent excess risk of dying from lung cancer due to fine particulate air pollution.

Air Pollution Contributes to Cardiac Illnesses

The hearts of sensitive individuals (for example, the elderly) may be affected when they breathe in fine particulate matter. One study shows that individuals with existing cardiac disease can be in a potentially life-threatening situation when exposed to high-levels of ultrafine air pollution (Peters et al. 2001). Fine particles can penetrate the lungs and may cause the heart to beat irregularly or can cause inflammation, which could lead to a heart attack. Understanding this link is extremely important in quantifying the detrimental health effects of air pollution.

Air Pollution Contributes to School Absences

On a statewide basis, 1.3 million school absence days would be avoided annually if the current levels of ozone were reduced to attain the established 1-hour state standard (CARB 2004).

Air Pollution is Costly

Air pollution can and does have a serious impact on the State's economy. Figures related to asthma costs and the valuation of air pollution exposure are significant and staggering. Analyses indicate that the benefits of California's air quality program exceeds the costs by a ratio of about 3 to 1 (CARB 2003c).

In 1998, it was estimated that asthma costs in California totaled $1.3 billion with hospitalizations and medications representing the largest direct expenditure (Asthma and Allergy Foundation of America 1998). Adult asthma patients spent an average of $5,000 annually on medical expenses, lost wages, transportation, asthma-control products, and other asthma related expenses (Cisteinas et al. 2003).

Furthermore, an annual value of over $3.5 billion is associated with hospitalizations and the treatment of major and minor illnesses, and about 2.8 million lost workdays each year, are all related to air pollution exposure in California. In addition, the value of premature deaths resulting from exposure to air pollution in excess of the State's PM2.5 standard is $43 billion (CARB 2003a, CARB 2003b, CARB 2002a, U.S. EPA. 1999).

Sensitive Groups Advised to Restrict Activities

Sensitive groups, including the elderly, people with heart or lung disease, children and infants, can be at increased risk of experiencing harmful effects from exposure to air pollution. Sensitive individuals are advised to restrict certain activities when pollution levels are elevated. Recently, the number of unhealthy days in some areas of California (based on California standards that are more health-protective than federal standards. (CARB 2003b) has been approximately one out of every three days for ozone (CARB 2002b).

Unhealthy Days in 2002		
	South Coast Air Basin	**San Joaquin Valley**
Days Above National 8-Hour Ozone Standard	96	125
Days Above State 1-Hour Ozone Standard	116	127

People in almost every area in California are exposed to PM levels over the current standards.

State's Population Living in Areas that Exceed PM2.5 Air Quality Standards*	
Annual National PM2.5 Standard	61%
Annual State PM2.5 Standard	89%

*Based on the proposed designations for PM2.5.

Summary of the Health Effects of Air Pollution

Particulate Matter Health Effects	Ground-level Ozone Health Effects
➢ Aggravated asthma ➢ Increased respiratory symptoms ➢ Chronic bronchitis ➢ Increased respiratory and cardiovascular hospitalizations ➢ Decreased lung function in children ➢ Lung cancer ➢ Premature deaths	➢ Aggravated asthma and possibly new cases of asthma ➢ Reduced lung capacity ➢ Increased susceptibility to respiratory illnesses ➢ Increased respiratory and cardiovascular hospitalizations

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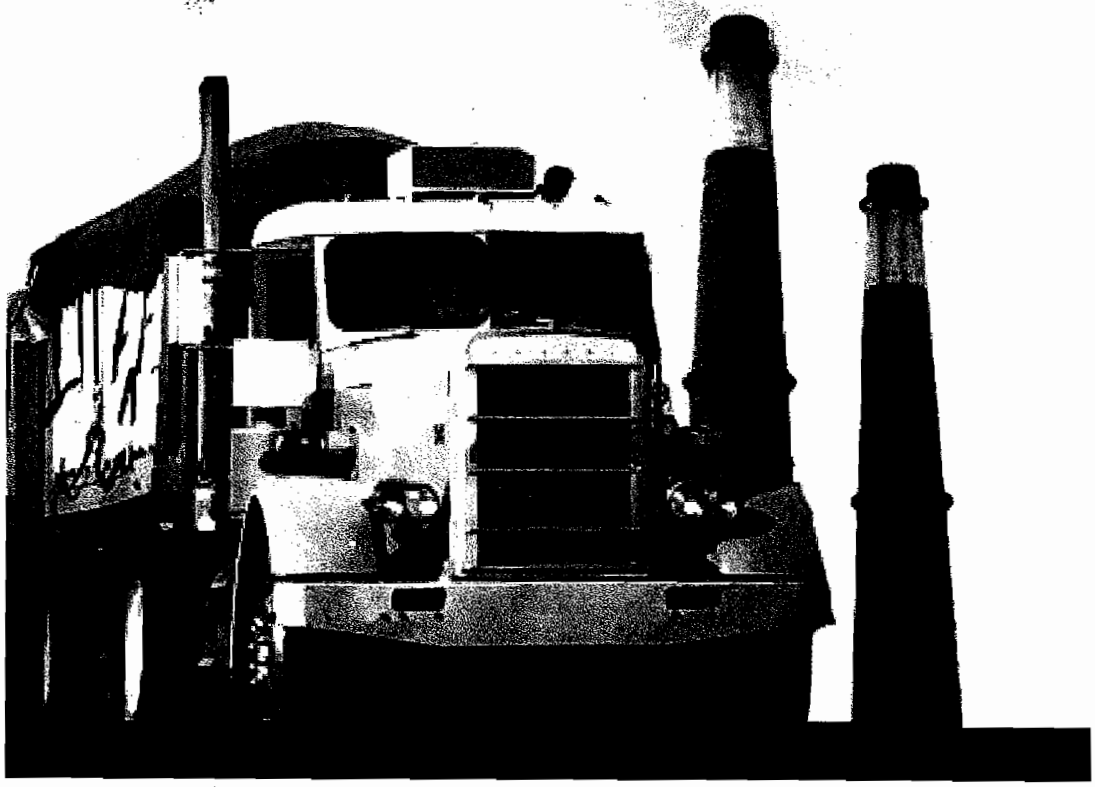
Appendix J

PARTICLE CIVICS

How Cleaner Air in California Will Save Lives & Save Money



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Environmental Working Group

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Executive Summary

Tougher state standards for particulate air pollution could save more than 6,500 lives and half a billion dollars a year.

Airborne soot and dust, technically known as particulate air pollution, causes or contributes to the deaths of more Californians than car accidents, murder and AIDS combined. State health officials are proposing new air pollution rules that could save or extend more than 6,500 lives a year, but the proposal faces strong and well-financed opposition from major oil companies and automakers.

In California, respiratory illnesses caused or made worse by airborne particulate matter (PM) are responsible for 9,300 deaths, 16,000 hospital visits, 600,000 asthma attacks and five million lost work days each year. By saving lives and preventing illnesses, tougher standards could save more than half a billion dollars a year.

In recent years, hundreds of studies worldwide have shown that PM pollution kills people. Both short- and long-term exposure to particulate pollution at levels lower than the levels currently experienced by millions of California residents can cause death. The proposed new PM standards are the first new regulations developed in response to a landmark 1999 state law requiring that air pollution standards must be adequate to protect children's health.

Statewide, total PM emissions are on the rise, and the great majority of Californians are exposed to potentially harmful levels. The worst particulate pollution in the state is found in Imperial County. But far more Californians are affected by the severe problems in the South Coast Air Basin, covering greater Los Angeles, which has the highest PM levels of any U.S. metro area, and the eight-county San Joaquin Valley, which is among the six worst areas in the nation. EWG estimates that the proposed new standards could save more than 4,200 lives a year in the South Coast Air Basin, and more than 800 lives a year in the San Joaquin Valley.

EWG urges the Air Resources Board to resist pressure from polluters and adopt the PM standards recommended by state scientists. Exemptions for agriculture should be eliminated. To further protect children and other sensitive populations, ARB should also set eight-hour PM standards, as it has for ozone. Finally, the state PM standards must be more rigorously enforced.

A Life and Death Decision

Particulate air pollution causes or contributes to the deaths of more Californians than car accidents, murder and AIDS combined, according to an analysis of state data by Environmental Working Group. EWG's investigation found that state health officials are proposing new air pollution rules that could save or extend more than 6,500 lives a year, but the safer standards face entrenched opposition from a deep-pockets alliance of major oil companies and automakers.

Airborne microscopic particles, much smaller than the width of a human hair, are known as particulate matter, or PM. (The smallest particles are often called "fine" particulates; the larger ones, still very tiny, are called "coarse" particulates.) California Department of Health Services (DHS) data shows that respiratory illnesses caused or made worse by PM pollution are responsible for the deaths of more than 9,300 Californians a year. That is three times more than are killed in car accidents, 4.6 times more than those who are victims of homicide and six times the number who die of AIDS. (Table 1.) What's more, even this number is an underestimate of the total number of PM-related deaths each year since it includes all deaths due to long-term exposure but only includes some of those due to short-term exposure to particulate air pollution[1].

The air polluters' lobby tries to divert attention from the overwhelming evidence that particulate matter is deadly by arguing that compliance with the "impossibly stringent" proposed new standards would be too costly and would not produce

Cause of Death	Number of Deaths in 1999
Particulate air pollution	9,340
Motor vehicle accidents	3,140
Suicide	3,047
Accidental poisonings	2,221
Homicide	2,042
HIV/AIDS	1,558
Accidental falls	1,202
Drownings	397

Source: EWG, from California Department of Health Services 1999.

Table 1. Particulate air pollution in California causes or contributes to more than 9,000 deaths each year.

"any greater protection of public health than the current California standards." (Ford 2002, AAM 2002.) But EWG's five-month review of hundreds of state, national and international studies found just the opposite: By saving lives and preventing illnesses, tougher PM standards could save the state and its citizens more than half a billion dollars a year.

The price tag: $1 billion a year

Each year, PM pollution is responsible for more than 16,000 hospital or emergency room admissions, at an estimated health care cost of $132 million. PM-triggered illnesses also cause Californians to miss almost five million work days a year, a loss to the state's economy of more than $880 million[2]. More difficult to put a price tag on are the thousands of less severe illnesses that result every year from PM pollution, including 600,000 asthma attacks and 13,500 cases of chronic bronchitis in California. (Tables 2, 3.)

Particulates, which are taken deep into the lungs by inhalation, have been linked with a long list of respiratory ailments such as chronic cough, chest pain, breathlessness, wheezing, phlegm, chronic bronchitis, decreased lung growth, decreased lung function, and the exacerbation of asthma symptoms.

Table 2. Proposed new standards would prevent hundreds of thousands of illnesses each year.

	Ages Considered	Cases at Current PM Levels	Cases under Proposed Standards	Cases Avoided	Cases Reduced by
Long-term Mortality	30+	9390	2865	6525	69%
Short-term Mortality	All	4063	1772	2291	56%
Chronic Bronchitis	27+	13530	5696	7835	58%
Chronic Obstructive Pulmonary Disease Hospital Admissions	65+	2115	923	1192	56%
Pneumonia Hospital Admissions	65+	3061	1340	1721	56%
Cardiovascular Disease Hospital Admissions	65+	5452	2395	3057	56%
Asthma Hospital Admissions	64-	1624	692	933	57%
Asthma Emergency Room Visits	64-	3992	1691	2301	58%
Asthma Attacks	All	592736	254466	338270	57%

Notes: In this table, the long-term mortality values are for PM2.5 and the short-term mortality values are for PM10. Long-term mortality is deaths from long-term exposure to particulates, while short-term is deaths from short-term exposure. Because the estimates of long-term mortality include some but not all short-term deaths, the two cannot be added together to get an estimate of total mortality.

Source: EWG, from ARB/OEHHA 2001, EWG 2002.

PM concentrations have also been shown to be associated with hospital admissions for a wide variety of cardiovascular and pulmonary diseases, including asthma. Groups particularly at risk include children, the elderly, people who already suffer from respiratory illness, and those of low socioeconomic status, who tend to live in areas where particulate pollution is most severe.

In recent years, a major international scientific effort has produced a flood of studies that has clearly established that PM pollution can kill people. Epidemiological studies have been conducted in over 200 cities worldwide, examining the effects of different exposure durations, and accounting for contributing factors including age, smoking habits, weather, and other pollutants. The results have been remarkably consistent: Both short- and long-term exposure to particulate pollution at levels lower than currently experienced by millions of California residents can cause death. Compared to just a few years ago, scientists today are much more likely to say plainly that PM kills, than that it contributes to death.

Hundreds of studies worldwide confirm that exposure to particulate pollution at levels lower than millions of Californians breathe can cause death.

California's current PM standards were set in 1982. New standards proposed by scientists at the state Air Resources Board (ARB) and Office of Environmental Health Hazard Assessment (OEHHA) would reduce the number of PM-triggered deaths and illnesses dramatically. The scientists say cutting allowable levels of PM to recommended levels will reduce deaths by at least 69 percent, asthma attacks by 57 percent, hospital visits by 56 percent and cases of chronic bronchitis by 58 percent. (Table 2.) Statewide, the recommended standards would result in an annual reduction of about 3 percent of all mortality in the population above age 30. (ARB/OEHHA 2001.) EWG estimates that these new PM-standards would also result in savings of state direct and indirect costs of more than $580 million a year. (Table 3.)

The Children's Environmental Health Act

Gov. Gray Davis' appointed ARB directors are scheduled to vote on the proposed new standards in June 2002. Their decision is being watched closely by health and environmental officials and researchers across the country. In 1999, California enacted the landmark Children's Environmental Health Act (SB 25), the first law anywhere in the U.S. to require that air pollution standards must be stringent enough to protect children – as opposed to almost all other environmental regulations designed to protect the average adult male. SB 25 required the ARB to review all of the state's air pollution standards to determine whether they adequately protect children. A preliminary review determined that the current PM standards were inadequate and that revising them should be ARB's highest priority. Other standards determined to be inadequate must be revised at a rate of one a year[3]. The proposed PM standards could again make California the national leader in air quality standards to protect public health – but not if the air polluters' lobby gets its way.

The Western States Petroleum Association, the Alliance of Auto Manufacturers, the Engine Manufacturers Association and other industry groups and individual companies have mounted a well-financed major campaign against the proposed

Table 3. Costs Associated With PM10-related Illness in California.

	Age Considered	[illegible]	[illegible]	Number Avoided Under Proposed New Standards	Savings Under Proposed New Standards
Chronic Obstructive Pulmonary Disease Hospital Admissions [1]	65+	2,115	$24,792,990	1,192	$13,972,624
Pneumonia Hospital Admissions [2]	65+	3,061	$42,639,263	1,721	$23,971,809
Cardiovascular Disease Hospital Admissions [3]	65+	5,452	$34,362,621	3,057	$19,268,271
Asthma Hospital Admissions [4]	64-	1,624	$28,904,937	933	$16,601,802
Asthma Emergency Room Visits [5]	64-	3,992	$1,193,527	2,301	$687,999
Work Loss Days [6]	64-	4,910,652	$883,917,360	2,814,815	$506,666,700
Total		4,926,896	$1,015,810,698	2,824,019	$581,169,205

Notes:
1) Hospital charge cost only. Mean hospital stay is 6.02 days with a mean charge of $11,722 (1999 dollars). (Abt 2000)
2) Hospital charge cost only. Mean hospital stay is 7.01 days with a mean charge of $13,929 (1999 dollars). (Abt 2000)
3) Hospital charge cost only. Mean hospital stay is 5.44 days with a mean charge of $17,794 (1999 dollars). (Abt 2000)
4) Hospital charge cost only. Mean hospital stay is 3.03 days with a mean charge of $6,303 (1999 dollars). (Abt 2000)
5) The average asthma ER visit cost is $299 (1999 dollars). (Abt 2000)
6) The median per-day income of California residents in the year 2000 was $180. (US Census 2002)

Source: ARB/OEHHA 2001, EWG 2002, Abt 2000, U.S. Census 2000.

standards. Their tactics are familiar: carping on minor inconsistencies between scientific studies, exaggerating uncertainties although PM is perhaps the most-studied type of air pollutant, and drawing on industry-funded studies to dispute the overwhelming consensus of peer-reviewed academic and government research. If their campaign, for which a small army of lobbyists in Sacramento has millions of dollars to spend, is only partly successful in watering down the proposed standards, thousands more Californians will die from dirty air each year.

Unlike most other air pollutants, particulates are regulated by size. Particles with diameters less than or equal to 10 microns are called PM10 and are often referred to as "coarse particles." Particulates with diameters less than or equal

to 2.5 microns are called PM2.5 and are often referred to as "fine particles." (A single human hair has a diameter of 50 to 100 microns.) California's current standards regulate only PM10, but the proposed new standards would also cover PM2.5.

PM contains heavy metals, nitrates, sulfates, aerosols and other toxic chemicals, as well as ordinary soot, soil, dust and smoke from both man-made and natural sources, including cars, industrial pollution and unpaved roads. Recent research suggests that PM from industrial and other man-made sources is more harmful to human health than dust from natural sources. (See Chapter 3.) The makeup of PM pollution varies considerably among different locations and at different times of the year (or even day) in the same location. As a result, two areas in California with the same level of particulates in the air may have distinctly different PM problems, and within counties where overall PM levels are relatively low, individual cities or neighborhoods may be exposed to high levels. Although annual average PM levels have declined in recent years, only small, mostly rural Lake County is in full compliance with current state standards. Statewide, total PM emissions are on the rise, and the great majority of Californians are exposed to potentially harmful levels:

The Los Angeles–Riverside metro area has the worst particulate air pollution in the U.S., and the San Joaquin Valley's problem is also among the worst.

- Over 99 percent of Californians breathe air that violates the current PM10 standards during at least part of the year. (ARB/OEHHA 2000.)

- Fifty-five of fifty-eight counties have average annual PM10 concentrations that exceed the proposed standards and fourteen counties (or portions of counties) have average annual concentrations that are at least twice as high, based on the last three years of ARB monitoring data[4]. (Table 4.)

- Forty-three counties (or portions of counties) have average annual PM2.5 concentrations that exceed the proposed standards, based on the last two years of ARB monitoring data[5]. (Table 4.)

Preventing deaths and asthma

The worst particulate pollution in the state is found in Imperial County (and an adjoining part of Riverside County). But far more Californians are affected by the severe problems in the South Coast Air Basin (Los Angeles, Orange, Riverside and San Bernardino counties) which consistently records the highest PM levels of any U.S. metro area, and the eight-county San Joaquin Valley, which ranks among the six worst air basins in the country for particulate pollution. (Grossi 2002, Table 4.) Considering the same factors state scientists used in calculating statewide PM-related deaths and illnesses, EWG estimates that the proposed new standards could prevent or delay more than 4,200 deaths a year in the South Coast Air Basin, and more than 800 deaths a year in

Table 4.
55 of California's 58 counties are not in full compliance with existing PM standards.

Source: EWG, from ARB/ OEHHA 2001.

Alameda		21.7	15.8
Alpine		16.7	8.5
Amador		23.0	16.6
Butte		24.5	12.3
Calveras		23.0	16.6
Colusa		24.5	12.3
Contra Costa		21.7	15.8
Del Norte		17.5	7.5
El Dorado	Lake Tahoe Basin	20.8	7.5
El Dorado	Mountain Counties Basin	23.0	16.6
Fresno		39.5	22.3
Glenn		24.5	12.3
Humbolt		17.5	7.5
Imperial		70.2	13.1
Inyo		16.7	8.5
Kern	Mojave Basin	21.6	10
Kern	San Joaquin Basin	39.5	22.3
Kings		39.5	22.3
Lake		10.8	≤ 5
Lassen		13.0	≤ 5
Los Angeles	Mojave Basin	21.6	10
Los Angeles	South Coast Basin	40.7	22.2
Madera		39.5	22.3
Marin		21.7	15.8
Mariposa		23.0	16.6
Mendocino		17.5	7.5
Merced		39.5	22.3
Modoc		13.0	≤ 5
Mono		16.7	8.5
Monterey		24.2	7.5
Napa		21.7	15.8
Nevada		23.0	16.6
Orange		40.7	22.2
Placer	Lake Tahoe Basin	20.8	7.5
Placer	Sac Valley Basin	24.5	12.3
Plumas		23.0	16.6
Riverside	Mojave Basin	21.6	10
Riverside	Salton Sea Basin	70.2	13.1
Riverside	South Coast Basin	40.7	22.2
Sacramento		24.5	12.3
San Benito		24.2	7.5
San Bernardino	Mojave Basin	21.6	10
San Bernardino	South Coast Basin	40.7	22.2
San Diego		28.8	15.6
San Francisco		21.7	15.8
San Joaquin		39.5	22.3
San Luis Obispo		23.8	11.8
San Mateo		21.7	15.8
Santa Barbara		23.0	11.8
Santa Clara		21.7	15.8
Santa Cruz		24.2	7.5
Shasta		24.5	12.3
Sierra		23.0	16.6
Siskiyou		13.0	≤ 5
Solano	Sac Valley Basin	24.5	12.3
Solano	San Francisco Basin	21.7	15.8
Sonoma	North Coast Basin	17.5	7.5
Sonoma	San Francisco Basin	21.7	15.8
Stanislaus		39.5	22.3
Sutter		24.5	12.3
Tehama		24.5	12.3
Trinity		17.5	7.5
Tulare		39.5	22.3
Tuolumne		23.0	16.6
Ventura		23.0	11.8
Yolo		24.5	12.3
Yuba		24.5	12.3

the San Joaquin Valley. Each year, more than 76,000 asthma attacks could be averted in Riverside and San Bernardino counties alone. (Table 5.)

In December 2001, ARB and OEHHA staff scientists proposed that California's annual PM10 standard be lowered by one-third, from 30 micrograms per cubic meter of air ($\mu g/m^3$) to 20 micrograms, and that an annual state PM2.5 standard be set at 12 $\mu g/m^3$. But the agencies also had to decide about standards for short-term (24-hour) exposures to PM. They proposed to leave the short-term standard for PM10 unchanged at 50 $\mu g/m^3$. They at first opted not to propose a state short-term standard for PM2.5, continuing to rely on the federal level of 65 $\mu g/m^3$. After criticism from an external scientific review panel and pressure from state environmental advocates, however, ARB and OEHHA decided a state short-term PM2.5 standard was necessary, and in March 2002 proposed a level of 25 $\mu g/m^3$. (Figures 1 and 2.)

Gov. Davis' air quality board should adopt the tougher regulations recommended by state scientists, and enforce them rigorously.

When the ARB directors meet to set the final standards, the stakes are high. If the annual PM10 standard is strengthened only slightly to 28 $\mu g/m^3$, and the PM2.5 standard is set at the federal level of 15 $\mu g/m^3$, as the oil companies and automakers advocate, the result would be 3,000 more premature deaths, 3,000 more hospital admissions, 1,000 more emergency room visits for asthma, 3,500 more cases of chronic bronchitis, and 150,000 more asthma attacks each year than if the standards were set at the proposed levels. For thousands of Californians, it will be literally a life-and-death decision.

Recommendations

- Directors of the Air Resources Board should resist pressure from polluters and adopt both the annual and short-term PM10 and PM2.5 standards recommended by state scientists.
- The *de facto* state exemption from PM regulations for most agricultural activities – a major source of particulate pollution in California – should be eliminated.
- To further protect children and other sensitive populations from acute levels of particulates, ARB should also set shorter-term standards for PM10 and PM2.5, on the model of the state's eight-hour standard for ozone air pollution.
- The PM standards adopted by the state should be rigorously enforced. Currently the standards are non-binding, making enforcement inconsistent and ineffective.

Footnotes

[1] This figure is for estimated mortality due to long-term exposures to PM2.5 air pollution. It is difficult to arrive at an absolute number of PM-related deaths because of overlap in various estimates. For instance, the figures for long-term mortality are believed to encompass some but not all short-term deaths, and therefore estimates of short and long-term mortality can not be simply added together to get an estimate of total mortality.

[2] The median per-day income of California residents in the year 2000 was $180 (=46,802 dollars per year / 260 work days per year). (U.S. Census Bureau 2000.) The actual number of work days lost to PM10-related illness is 4,910,652. (OEHHA/ARB 2001.) The estimated cost to the state's economy is the product of these two numbers.

[3] OEHHA categorized the air pollutants under review into two tiers based on the agency's assessments of potential risks to public health. The first tier includes PM, ozone and nitrogen dioxide. The second tier includes lead, carbon monoxide, and hydrogen sulfide.' (OEHHA/ARB 2001.)

[4] Average PM10 levels were calculated by ARB using the last three years of data available (1998-2000). (OEHHA/ARB 2001.)

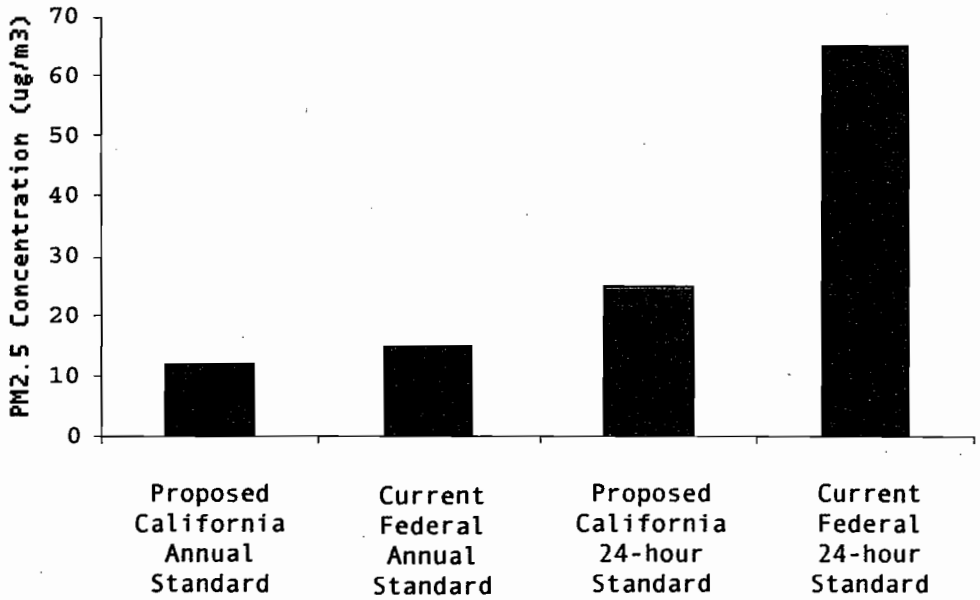
[5] Average PM2.5 levels were calculated by ARB using the last two years of data (1999-2000), which is all the monitoring data available. (OEHHA/ARB 2001.)

California's Particulate Problem

Emissions of particulates have been increasing in California for decades, from 2,017 tons of PM10 per day in 1980, to 2,240 tons per day in 1990, to 2,312 tons per day in 2000. (ARB 2001.) However, the increase has been far from uniform across the state. During this period, PM10 emissions in some counties have remained relatively steady or declined, while other counties have seen a marked increase. For instance, between 1975 and 2000, emissions in San Bernardino County increased by 93 percent and in San Diego County by 70 percent. (ARB 2001.) The increase in emissions comes from many sources, but one clear cause is the ever-growing dependence on automobiles: From 1975 to 2000 the number of vehicle miles traveled in California more than doubled, from 351 million miles per day to 800 million. (ARB 2001.)

While the total *amount* of emissions continues to rise, concentrations of PM10 *measured* by air quality monitors have actually declined. Statewide, annual mean concentrations measured by the state's 250 air monitors dropped 20

Figure 1. Proposed and Existing PM2.5 Standards



percent between 1988 and 1999, from about 80 µg/m³ to 60. A big reason for this apparent discrepancy is that most of the monitors are in the South Coast Air Basin, where in recent years progress has been made in reducing PM emissions. Since the current PM standards were adopted in 1982, improvements in air quality have been achieved statewide, but today all counties except Lake County still fail to meet the state's short-term PM10 standard. (Lassen, Modoc and Siskyou counties lack enough data to measure compliance.) Twenty counties fail to meet even the considerably weaker federal short-term PM10 standard.' (Table 4.)

Problem areas

In most areas of the state with elevated PM levels, the problem is not limited to short-term spikes in concentration but is a year-round concern. By far the highest levels are found in Imperial County and an adjacent portion of Riverside County, with an annual average of 70 µg/m³ of PM10 – almost 3.5 times the proposed state standard. But annual levels of 40 µg/m³ or more of PM10 – twice the proposed standard-- are recorded in twelve other counties or portions of counties: Fresno, Kern, Kings, Los Angeles, Madera, Merced, Orange, Riverside, San Bernardino, Stanislaus, San Joaquin and Tulare. (Table 4.)

PM differs from many other types of air pollution in that it is not a single compound, but rather a highly complex mixture of small solid particles and

Figure 2. Proposed and Existing PM10 Standards.

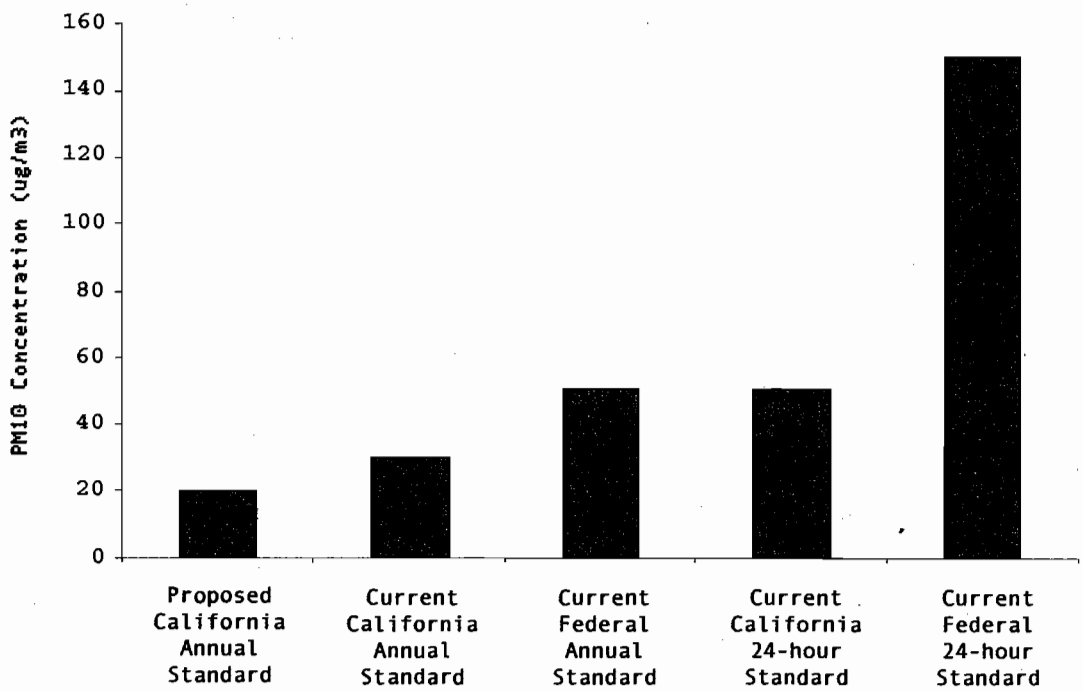


Table 5. Consequences of PM exposure, by county.

County	Deaths Due to PM2.5 at Current Levels	Fewer Deaths if Proposed Standards Achieved	Deaths Due to PM10 at Current Levels	Fewer Deaths if Proposed Standards Achieved	Admissions due to PM10 at Current Levels	Fewer Admissions if Proposed Standards Achieved	Visits Due to PM10 at Current Levels	Fewer Visits if Proposed Standards Achieved	Attacks Due to PM10 at Current Levels	Fewer Attacks if Proposed Standards Achieved	Days lost due to PM10 at current levels	Fewer Days Lost if Proposed Standards Achieved
Alameda	317	178	92	13	36	5	89	13	12,944	1,861	142,140	15,940
Alpine	0	0	0	0	0	0	0	0	6	0	93	0
Amador	12	7	4	1	1	0	2	1	349	80	3,334	626
Butte	32	3	24	8	6	2	14	5	2,257	704	21,072	5,629
Calveras	14	9	5	1	1	0	3	1	404	93	3,845	723
Colusa	2	0	1	0	1	0	1	0	209	65	2,053	548
Contra Costa	197	111	63	9	23	3	58	8	8,507	1,223	92,286	10,349
Del Norte	0	0	2	0	0	0	1	0	160	0	2,156	0
El Dorado	85	52	13	2	4	1	10	2	1,503	304	15,576	2,534
Fresno	311	243	126	83	49	33	121	81	17,894	11,905	138,277	99,442
Glenn	4	0	2	1	1	0	2	1	294	92	2,835	757
Humbolt	0	0	7	0	2	0	5	0	735	0	9,922	0
Imperial	15	4	38	32	17	15	41	35	6,370	5,348	40,840	42,511
Inyo	0	0	1	0	0	0	1	0	93	0	1,242	0
Kern	223	172	98	61	37	23	90	57	13,296	8,317	106,695	69,919
Kings	40	31	16	11	8	5	20	14	2,898	1,928	23,021	16,556
Lake	0	0	0	0	0	0	0	0	38	0	2,639	0
Lassen	0	0	0	0	0	0	1	0	78	0	2,061	0
Los Angeles	3555	2,759	1,387	930	599	405	1,469	997	217,366	146,105	1,672,103	1,220,537
Madera	50	39	21	14	7	5	18	12	2,756	1,833	21,026	15,121
Marin	55	31	16	2	6	1	15	2	2,217	319	23,452	2,630
Mariposa	6	4	2	0	0	0	1	0	170	39	1,644	309
Mendocino	0	0	5	0	1	0	3	0	501	0	6,680	0
Merced	79	62	32	21	13	9	32	22	4,713	3,136	36,585	26,310
Modoc		0	0	0	0	0	0	0	22	0	521	0
Mono	0	0	0	0	0	0	0	0	67	0	1,016	0
Monterey	0	0	27	8	12	4	30	9	4,391	1,318	44,102	11,262
Napa	37	21	11	2	3	0	7	1	1,114	160	11,536	1,294
Nevada	30	18	9	2	2	1	6	1	916	211	8,804	1,655
Orange	956	744	410	277	182	124	447	306	66,218	44,928	506,007	374,751
Placer	25	2	21	6	7	2	19	6	2,733	832	26,429	6,869
Plumas	7	4	2	0	1	0	1	0	207	48	1,981	372
Riverside	583	431	353	256	112	82	272	200	42,149	30,675	296,622	243,660
Sacramento	132	12	106	33	37	12	92	29	13,594	4,238	133,938	35,779
San Benito	0	0	3	1	2	0	4	1	582	175	5,969	1,524
San Bernardino	486	370	231	144	95	60	234	147	34,127	21,263	276,676	180,041
San Diego	560	300	279	131	110	52	273	130	40,465	19,074	358,663	159,824
San Francisco	203	114	60	9	19	3	46	7	6,964	1,001	73,543	8,247
San Joaquin	251	196	101	67	34	23	84	57	12,616	8,393	96,729	69,562
San Luis Obispo	26	0	21	5	7	2	16	4	2,471	581	24,534	4,727
San Mateo	150	84	45	6	17	2	42	6	6,340	912	67,890	7,613
Santa Barbara	37	0	29	7	11	3	27	6	4,000	940	40,532	7,809
Santa Clara	271	152	82	12	42	6	104	15	15,085	2,169	166,914	18,718
Santa Cruz	0	0	20	6	8	2	19	6	2,793	838	28,076	7,170
Shasta	25	2	19	6	5	1	12	4	1,814	566	17,043	4,553
Sierra	1	1	1	0	0	0	0	0	35	8	339	64
Siskiyou		0	0	0	0	0	1	0	102	0	2,428	0
Solano	60	29	23	5	11	2	26	5	3,790	773	40,655	6,672
Sonoma	99	56	35	4	11	1	26	4	3,938	520	42,970	4,336
Stanislaus	193	150	79	52	27	18	67	45	10,006	6,657	76,857	55,272
Sutter	9	1	7	2	2	1	6	2	877	273	8,519	2,276
Tehama	9	1	7	2	2	1	4	1	623	194	5,802	1,550
Trinity	0	0	0	0	0	0	0	0	76	0	966	0
Tulare	145	113	58	38	23	15	56	37	8,238	5,481	63,764	45,855
Tuolumne	18	11	5	1	1	0	3	1	542	125	5,148	968
Ventura	57	0	47	11	21	5	52	12	7,544	1,773	78,649	15,153
Yolo	15	1	13	4	5	2	13	4	1,874	584	18,826	5,029
Yuba	8	1	6	2	2	1	5	1	669	209	6626	1,770
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Source: EWG, from ARB/OEHHA 2001.

liquid droplets suspended in air. These particles may be emitted directly into the air or they may form in the atmosphere from "precursor" chemicals such as sulfur and nitrogen compounds. Substances that comprise PM range from soot, soil, organics, dust, and smoke to heavy metals, aerosols, nitrates, and sulfates. The makeup of PM pollution varies considerably among different locations and at different times of the year (or even day) in the same location. The diverse composition and distribution of particulate pollution makes it especially difficult to assess and control.

Particulate pollution comes from both natural and human sources. The five leading sources of PM10 emissions in California are in the catchall category of "dust" – unpaved road dust, paved road dust, and windblown dust together comprise about 55 percent of the total, with construction and agriculture each contributing another 9 percent. (Table 6.) Other significant human sources of PM10 emissions are industrial pollution and fuel combustion (6 percent combined), fireplaces and wood stoves (6 percent), burning waste (6 percent) and vehicle exhaust (5 percent). (ARB 2000a.)

Unlike most air pollutants, which are regulated based on their chemical composition, particles are regulated based on their size: those with diameters greater than 10 microns, those with diameters less than or equal to 10 microns (PM10), and those with diameters equal to or less than 2.5 microns (PM2.5). (One micron is one millionth of a meter, and a single human hair has a diameter of 50 to 100 microns.) The human respiratory system can filter out most particles larger than 10 microns. But as the particles get smaller they are

Table 6.
Sources of PM10 pollution in California.

PM10 Source	Tons of PM10 Emitted per Year	Percent of Total
Unpaved road dust	235,060	27%
Paved road dust	140,890	16%
Windblown dust	106,945	12%
Construction	74,825	9%
Farming	79,935	9%
Woodstoves & fireplaces	51,465	6%
Waste burning	50,735	6%
Mobile vehicles*	45,625	5%
Wildfires	31,755	4%
Industrial	32,485	4%
Fuel combustion	15,695	2%
Other	11,315	1%
Total	876,730	100%

* includes cars, trucks, airplanes, trains, and boats

Source: EWG, from ARB 2000.

Table 7. Comparison of PM2.5 (Fine Particles) and PM10 (Coarse Particles).

	FINE	COARSE
Formed from	Gases	Large solids/droplets
Formed by	Chemical reaction Nucleation Condensation Coagulation Evaporation	Mechanical disruption (crushing, grinding, etc.) Evaporation of sprays Suspension of dusts
Composed of	Sulfate Nitrate Ammonium Hydrogen ion Elemental carbon Organic compounds Metals Particle-bound water	Resuspended dusts Soil, dust, street dust Oxides of crustal elements Sea salt, calcium carbonate Pollen, mold, fungal spores Plant/animal fragments Tire wear debris
Solubility	Largely soluble	Largely insoluble
Sources	Combusiton of coal, oil, gasoline, diesel, wood Atmospheric transformation products of nitrogen oxides, sulfur dioxide, and organics High temperature processes, smelters, steel mills, etc.	Resuspension of industrial dust and soil tracked onto roads and streets Suspension from disturbed soil, e.g. farming, mining Biological sources Construction Coal and oil combustion Ocean spray
Lifetime	Days to weeks	Minutes to hours
Travel distance	100s to 1000s of kilometers	<1 to 10s of kilometers

Source: EWG, from US EPA 1996.

able to penetrate deeper into the lungs, and are harder for the body to remove. Therefore, over the past two decades, researchers and regulators have focused on ever-smaller inhalable particles. The U.S. Environmental Protection Agency first set standards for PM10 in 1987 and set standards for PM2.5 in 1997.

PM10 and PM2.5 also differ in their sources, how they are formed, composition, and lifetime in the atmosphere. Fine particulates are generated from fossil fuel combustion and other high-temperature processes, are formed from gases which then react and coagulate in the atmosphere and persist in the air for days or weeks. Coarse particulates are usually generated from the suspension of dust from natural or man-made sources, are composed of very small particles or droplets rather than gases, and remain in the air for minutes to hours. (Table 7.) (U.S. EPA 1996.)

Dust in the wind

More than 70 percent of PM10 emissions in the state are from "dust," which includes wind-blown dust from paved and unpaved roads, farming and ranching, and construction sites. Agriculture is a major source of PM10, but its impact is somewhat hidden because ag-related emissions fall into a number of different categories: farming operations, windblown dust, waste burning, industrial processes and farm vehicles. All told, California agriculture produces 459 tons of PM10 a day, or more than 167,500 tons a year. The farm-related particulates problem is so severe in the San Joaquin Valley that the region has repeatedly been unable to meet federal PM standards, and stands to lose more than $2 billion in federal highway funds if the eight counties can't achieve a five percent annual reduction in particulate levels – the only air basin in the country to be hit with such sanctions.

Yet the agricultural industry is exempt from most air pollution laws. The federal Clean Air Act exempts emissions from farm equipment of less than 175

Table 8. Leading Industrial Sources of PM10 Pollution in California.

Facility Name	City	Tons of PM10 Emitted per Year
ADM Inc (Wood Products)	Benicia	1,376
US Borax	Boron	614
Kern Oil & Refining	Bakersfield	544
IMC Chemicals	Trona	526
Mitsubishi Cement	Lucerne Valley	472
Chevron	El Segundo	472
Arco	Carson	452
Ampine (Wood Products)	Martell	447
Port of Stockton	Stockton	436
Martinez Refining Company	Martinez	433

Source: EWG, from ARB 2001.

horsepower. Strictly speaking, California doesn't exempt farm sources from air pollution *regulations*, but does exempt farm operations from having to obtain an air pollution *permit* – and without the conditions attached to a permit, there is no effective control on emissions. The EPA has announced that it will commission the National Academy of Sciences to study agricultural sources of air pollution, which could lead to full-scale regulation of air pollution from farming operations.

Dirty diesels

"Mobile" sources (vehicles) contribute about 5 percent of California's annual PM10 emissions. Passenger cars and light trucks are responsible for about a quarter of this pollution, with most of the rest coming from heavy duty trucks, farm and construction and both commercial and recreational boats. But the bad actor of the category is diesel fuel. Even though diesel-fueled vehicles make up only 4 percent of the 31 million vehicles on the road in California, diesels are responsible for 53 percent of all auto-related PM emissions in California. (ARB 2000b.) And in addition to the adverse health effects associated with all other sources of particulate matter, diesel PM contains many known carcinogens. ARB estimates that diesel-derived PM is responsible for 900 excess cases of cancer per 1 million people exposed over a 70-year lifetime, accounting for 70 percent of the known statewide cancer risk from outdoor air toxics. (ARB 2000b.)

Agriculture is the largest industry in California and a major source of particulates, but is exempt from most air pollution rules.

Industrial emissions account for about 4 percent of California's PM10 pollution. The list of the leading industrial polluters includes petrochemical companies like Chevron, Arco and other refiners, but by far the worst offender is ADM Inc., a manufacturer of wood products in Benicia, Solano County, with more than 1,300 tons emitted in 2000. (Table 8.) Collectively, the ten worst industrial PM polluters in the state emitted 5,300 tons of PM10 in 2000.

Air Pollution, Illness, and Death

Scientists began investigating the link between air pollution, illness and death in response to a number of severe air pollution episodes that sickened and killed thousands of residents in the United States, England and Belgium between 1930 and 1952. Most of the early research looked the effects of very high pollution levels, but more recent inquiry has focused on how low-to-moderate levels of particulates and other air pollutants affect human health. In the past decade the amount of research in this area has exploded, as literally hundreds of studies have been conducted just on the relationship between particulates and death. The scientific consensus is undebatable: Particulates are significantly more harmful than previously realized, and levels well below current state and federal air quality standards can cause or contribute to death.

Relatively small increases in airbone particulates can significantly increase the incidence of respiratory disease and death.

PM pollution has been linked to an array of respiratory ailments in children and adults, including chronic cough, chest pain, breathlessness, wheezing, phlegm, and chronic bronchitis. (Abbey et al. 1995a,b, Pope and Dockery 1991, Braun-Fahulander et al. 1992, Hruba et al. 2001, Zemp et al. 1999.) PM also affects overall lung functioning. Researchers have found that levels of PM commonly experienced by Californians are associated with small but significant decreases in the ability of both children and adults to take and hold deep breaths. (Hoek et al., 1998, Raizenne et al. 1996, Ackerman-Liebrich et al. 1997.)

Kids + PM = Damaged lungs

More troubling, PM can also retard the growth of children's lungs. The Children's Health Study, a long-term investigation of the health effects of air pollution conducted on more than 3,500 children from 12 communities in Southern California, found that PM10 and PM2.5 exposure was associated with decreases in both lung function and lung growth. (Peters et al. 1999, Gauderman et al. 2000.) A follow-up study found that children who moved to areas with lower PM levels showed increased lung growth and functioning, while lung growth and function continued to decline in those who moved to areas with even higher PM levels. (Avol et al. 2001.)

Wherever the link has been investigated, including many studies conducted in California, the results have been consistent: For every 10 micrograms of PM10 added to every cubic meter of air, symptoms of respiratory illness increase, with some studies showing increases of up to 40 percent. State scientists estimate that more than 13,500 current cases of chronic bronchitis in Californians

over the age of 27 are due to particulate air pollution. PM is also responsible for upper respiratory symptoms in an estimated 418,000 California children between the ages of 9 and 11, for lower respiratory symptoms in almost 400,000 children between the ages of 7 and 14, and almost five million lost days of work each year for PM-related illnesses[1]. (ARB/OEHHA 2001.)

Between 1980 and 1994 the prevalence of asthma in the United States increased by more than 75 percent. (Mannino et al., 1998.) Asthma now affects more than 10 million adults and almost five million children. While the current scientific consensus holds that PM pollution does not cause asthma, studies in California and elsewhere have repeatedly found that PM can significantly exacerbate the disease.

The state's proposed 24-hour particulate standards may not cover a short enough exposure period to fully protect public health.

Both PM2.5 and PM10 are associated with many different measures of the severity of asthma, including frequency of attacks, increased use of medication, emergency room visits and hospitalization. (Ostro 2001, Delfino 1998, Pope and Dockery 1992, Yu et al. 2000, Gielen et al. 1997.) A study of asthmatic African-American children in Los Angeles found that one-hour maximum levels, 24-hour averages, and multi-day averages of PM10 were all associated with increases in asthmatic symptoms. (Ostro et al 2001.) State scientists estimate that almost 600,000 asthma attacks, almost 4,000 emergency room visits and more than 1,600 hospital admissions each year are linked to PM-induced asthma.

PM is also associated with increased hospital visits for illnesses other than asthma. Research in dozens of cities in California and other states has consistently found that short-term PM10 and PM2.5 exposures are associated with hospital admissions for cardiovascular and pulmonary diseases such as heart attack, congestive heart failure, cardiac arrhythmia and chronic obstructive pulmonary disease. (Linn et al 2000, Moolgavkar 2000 a,b, Samet et al 2000a, Sheppard et al 1999, among others). Overall, these studies have found that for each 10-microgram increase in PM10 levels in a cubic meter of air, hospital admissions for cardiovascular and respiratory diseases rose by 1.25 to 5 percent. (ARB/OEHHA 2001.) This holds true in locations where PM10 pollution was at low to moderate levels, as well as where levels were high. Data for PM2.5 is more sparse, but suggests that incremental increases in fine particulates may be associated with even greater increases in hospital admissions.

State scientists estimate each year PM10 pollution is responsible for 2,100 hospital admissions for chronic obstructive pulmonary disease, 3,000 admissions for pneumonia and 5,500 admissions for cardiovascular diseases. These estimates account *only* for people age 65 and older, but research has found increases in hospital admissions for these illnesses among younger people as well. (Table 9.)

Common sense says that breathing polluted air daily over an extended period of time is more dangerous than exposure for a few hours or days. Observed increases in mortality from short-term PM exposures are three to four times lower than those from long-term exposures. (ARB/OEHHA 2001.) Yet the impact of short-term PM exposures on public health cannot be ignored. ARB cautions that annual PM averages "do not give an accurate indication of the

seasonal nature of emissions." (ARB 2001.) Averaging means that an area could meet annual standards but have significantly higher PM levels for part of the year, and acutely high levels for a few days of the year.

Shorter-term standard may be needed

A 24-hour standard may actually not be short *enough* to protect public health, as there is evidence that exposure to high levels of particulates over shorter time periods can have significant health effects. One study found that exposure for only two hours was associated with the onset of heart attack symptoms. (Peters et al. 2001.) ARB says it may consider shorter-term standards in the future.

In 1993, Harvard researchers published the results of a 16-year study of 8,000 people in six cities, which found that residents of the city with the highest levels of particulates had a 26 percent higher death rate than the people living in the least polluted city. (Dockery et al. 1993.) An even more extensive seven-year study conducted of more than 550,000 people in 151 metropolitan areas found that residents of cities with the highest PM10 had a 17 percent higher mortality rate than those residing in cities with the lowest levels. (Pope et al. 1995.) These long-term studies have convincingly shown that chronic exposure to particulate matter increases death rates, but recent research shows that short-term PM exposure also is associated with increased mortality.

"The evidence in support of an association between the concentration of particulate air pollution and the mortality rate is consistent."

– Dr. James Ware, Harvard School of Public Health.

Studies in over 200 cities worldwide – cities with significantly different climates, racial profiles, weather patterns, pollution sources and pollution severity – have found a consistent connection between *daily* PM levels and *daily* mortality rates. These studies accounted for numerous other factors such as smoking, age, poverty, weather and other pollutants. Dr. James Ware of the Harvard School of Public Health summarized the findings: "The evidence in support of an association between the concentration of particulate air pollution and the mortality rate is consistent, is not affected by differences in statistical methods, and can be generalized." (Ware 2000.)

In assessing the health risks of a given pollutant, the standard scientific assumption is that risks decrease as exposure rates decrease, and that no harmful effects occur below a certain threshold. But PM does not fit this model. Studies show that the relationship between PM concentration and death is not a tapering curve but a straight line – that is, the health effects of particulates are directly proportional to the level of exposure. No exposure level, including levels below current state and federal standards, has been found at which PM does not have a measurable effect on mortality. (Pope 2000, Daniels et al. 2000.) This has important implications for the development of state air quality standards, which are required to determine the level above which a pollutant is known to harm sensitive populations and incorporate a margin of safety to protect them. (ARB/OEHHA 2001.)

Environmental pollutants do not affect everyone equally, but have greater impact on the very young, the very old, the poor, and those with pre-existing illnesses. The highest rates of PM-related death are among the elderly, especially those with heart or lung diseases.

PM and SIDS

But research into PM's effects on infants and children has found links to pre-term birth or Sudden Infant Death Syndrome (crib death). Most of these studies have been conducted outside the U.S., but indicate a 2 to 4 percent increase in mortality for each 10 micrograms of PM10 in a cubic meter of air. (Loomis et al. 1999, Ostro et al. 1999a.) A study of 98,000 newborns in Southern California born between 1989 and 1993 concluded that the likelihood of pre-term birth was significantly associated with elevated PM levels during the six weeks before birth. (Ritz 2000.)

Some critics argue that PM-related mortality is not a major public health concern, because most deaths are of people who are already ill and only shorten life by days or weeks. Yet in recent years scientists who have thoroughly investigated this notion found it wasn't true. For instance, studies have found that out-of-hospital deaths are between two and four times more strongly related to PM pollution than in-hospital deaths. This indicates that it is not just the critically ill who are more likely to die on days of high PM exposure. (Schwartz 2000, 2001b.) Addressing this issue, the ARB and OEHHA say PM-related mortality is "not the result of just a few days of life shortening . . . it appears that significant reductions in life expectancy may be involved." (ARB/OEHHA 2001.)

Not all particles are created equal. Research indicates that people are much less sensitive to dust and particulates from other natural sources than industrial emissions and auto exhaust. Two studies have found that exposure to particles derived from motor vehicles, coal combustion, and iron and steel manufacturing was significantly associated with daily mortality, while exposure to particles from soil was either not associated or less significantly associated with increased mortality. (Laden et al. 2000, Ozkaynak and Thurston 1987.) Another study was conducted after researchers in Utah noted that hospital admissions and deaths declined following the temporary shutdown of a local steel mill. (Pope 1989.) Scientists then exposed rats to a constant amount of particulates collected before, during and after the mill's closure and found that animals exposed to particulates collected while the mill was closed showed much lower rates of lung damage and related symptoms. (Dye et al. 2001.) The policy implications are clear: The largest sources of particulates, such as road dust, may not be as harmful as particulates from smaller sources such industrial emissions or auto exhaust.

PM-related illnesses carry significant economic impacts. For example, hospital visits for PM-induced COPD, pneumonia and cardiovascular diseases in the population aged 65 and over and visits for pollution-induced asthma in the population under 65 total $132 million a year (Table 3). PM-related illnesses cause Californians to miss almost 5 million work days a year, costing the state's economy more than $880 million[2]. Considering just these costs, the

price of PM air pollution in California exceeds $1 billion a year. (Table 3.) This does not take into consideration many hospital and non-hospital costs of other minor and serious PM-related illnesses.

If California's air quality met the proposed PM standards, an estimated $584 million could be saved each year, cutting the costs of particulate air pollution by more than half. (Table 3.) And if lower standards were reached, these costs would be reduced even further. By achieving a mean ambient PM10 level of 15 micrograms per cubic meter – just 5 micrograms less than the proposed standards – an additional $200 million would be saved each year.

Proposed state standards would prevent hundreds of thousands of asthma attacks each year.

Footnotes

[1] The studies on which OEHHA based their estimates of PM-related illnesses only looked at certain age groups. OEHHA/ARB decided not to extrapolate the results to other age groups and, instead, estimated the illness figures for only these same age groups.

[2] The median per-day income of California residents in the year 2000 was $180 (=46,802 / 260). (US Census Bureau 2000) The actual number of work days lost to PM10-related illness is 4,910,652. (OEHHA/ARB 2001) The estimated cost to the state's economy is the product of these two numbers.

Particle Civics

California has long been a national and global leader in pioneering efforts to improve air quality to protect public health. California developed the nation's first vehicle emission control program in 1963, instituted the nation's first heavy-duty diesel truck standards in 1973, and was the first state to sell unleaded gasoline in 1976. California has also been a trendsetter in developing health-based ambient air quality standards that reflect the most current science available. The existing PM10 standards are a perfect example.

California is the first state to require that air pollution standards be tough enough to protect children, rather than adult males.

In the late 1970s, ARB scientists were among the first to recognize that particulates with diameters of 10 microns or less (PM10) posed more of a human health risk than those with larger diameters. At that time, state and federal air quality standards treated this highly diverse group of compounds as one category called total solid particulates (TSP). But the ARB determined that separate standards were needed for PM10, which took effect in 1982. It took five more years for the U.S. EPA to follow suit, but the federal standards were set 1.5 to three times weaker than the state standards.

Since then, entire libraries of research on particulates and health have been published. There is no disagreement in the scientific and regulatory committees: PM has more profound negative effects on human health than ever before realized, and these effects are measurable at concentrations at or below current air quality standards. This research has established that particles with diameters less than 2.5 microns, or PM2.5, may be particularly hazardous to human health, making the need for tougher and more comprehensive standards more urgent.

Priority: Protecting kids

The need for a revision of California's particulate standards was highlighted with the passage of the Children's Environmental Health Protection Act of 1999 (SB 25 by State Sen. Martha Escutia.) As part of the Act, the ARB and OEHHA were required to review all existing health-based ambient air quality standards in California to determine whether they protected infants and children, as well as other sensitive populations, with a sufficient margin of safety. During this review, it became clear that the current levels of particulate matter in California were responsible for significant and measurable health effects, not

only on children but the public as a whole. As result, the agencies made PM standards the top priority for revision.

In December of 2001 the agencies proposed that California's annual mean PM10 standard be lowered by a third, and added a new standard for PM2.5 that is slightly more stringent than the corresponding federal standard. They recommended leaving the short-term standard for PM10 at current levels, and opted not to recommend establishment of a short-term standard for PM2.5. However, after criticism from an independent scientific review panel and pressure from the environmental community, ARB and OEHHA proposed a short-term standard for PM2.5 that is more than twice as stringent as the existing federal standard. (Figures 1 and 2.)

How many people will California allow to die or become ill each year from the very air they breathe?

The proposed annual standards would dramatically reduce the number of air pollution-related health problems in California. If these standards were attained, thousands of deaths and injuries would be prevented each year: 6,525 premature deaths, 6,903 hospital admissions for respiratory illness, 2,301 emergency room visits for asthma, 7,835 cases of chronic bronchitis, and 338,270 asthma attacks. **(Table 9.)** Overall, the number of PM10-induced illnesses and deaths would decrease by an average of 60 percent, and PM2.5 illnesses and deaths would be cut in half. Because these figures account only for certain illnesses and age groups, the actual health benefits of reducing PM levels would be even greater.

How many will die?

If the standards were set at levels slightly more stringent than those being proposed by the ARB, even more lives would be saved and illnesses avoided. For example, if California met an annual mean PM10 standard of 15 $\mu g/m^3$ and an annual mean PM2.5 standard of 10 $\mu g/m^3$ an additional 1,900 premature deaths, 2,700 respiratory hospital admissions, 850 emergency room visits for asthma, 3,000 cases of chronic bronchitis, and 127,000 asthma attacks could be avoided each year. Overall, PM-induced deaths and illnesses would drop by almost 80 percent.

The consequences of moving in the other direction, toward less stringent standards advocated by the oil and auto industries, would be deadly. EWG analysis shows that if the annual PM10 standard was weakened only slightly from proposed levels, to 28 $\mu g/m^3$, and the annual PM2.5 standard was set to correspond with the federal standard of 15 $\mu g/m^3$, there would be 4,000 more premature deaths, 3,000 more hospital admissions, 1,000 more emergency room visits for asthma, 3,500 more cases of chronic bronchitis, and 150,000 more asthma attacks each year. The question facing the ARB board next month is grim: How many people will California allow to die or become ill each year from the very air they breathe?

Table 9. Savings from Reducing PM-related Illnesses.

PM2.5

	Ages Considered	Number of current annual average PM2.5 level	Cost at current level (1999 $)	Number of proposed standard achieved	Number fewer of proposed standard achieved	Percent fewer	Dollars saved if proposed standard achieved	Additional number saved if proposed standard achieved (1 ug/m3)	Additional dollars saved if proposed standard achieved (1 ug/m3)
Long-term Mortality [1]	30+	9,390	-	2,865	6,525	69%	-	1,895	-
Short-term Mortality	All	4,011	-	2,066	1,945	48%	-	573	-
Chronic Bronchitis [2]	27+	11,409	N/A	5,660	5,749	50%	N/A	1,612	N/A
Chronic Obstructive Pulmonary Disease Hospital Admissions [3]	65+	1,243	$14,575,966	642	601	48%	$7,529,519	179	$2,098,238
Pneumonia Hospital Admissions [4]	65+	1,791	$24,947,738	927	864	48%	$12,914,520	258	$3,593,682
Cardiovascular Disease Hospital Admissions [5]	65+	3,173	$19,999,436	1,646	1,527	48%	$10,376,736	456	$2,874,168
Asthma Hospital Admissions [6]	64-	950	$16,912,004	481	470	49%	$8,550,392	133	$2,366,602
Asthma Emergency Room Visits [7]	64-	2,352	$703,156	1,185	1,167	50%	$348,933	330	$98,670
Work Loss Days [8]	64-	2,923,535	$526,236,300	175,151	1,445,535	49%	$260,196,300	354,479	$63,806,290
Total			$603,374,599				$299,916,400		$74,837,650

PM10

	Ages Considered	Number of current annual average PM10 level	Cost at current level (1999 $)	Number of proposed standard achieved	Number fewer of proposed standard achieved	Percent fewer	Dollars saved if proposed standard achieved	Additional number saved if proposed standard achieved (1 ug/m3)	Additional dollars saved if proposed standard achieved (1 ug/m3)
Long-term Mortality [9]	30+	7,470	-	978	6,492	87%	-	N/A	-
Short-term Mortality	All	4,063	-	1,772	2,291	56%	-	N/A	-
Chronic Bronchitis [10]	27+	13,530	N/A	5,696	7,835	58%	N/A	2,902	N/A
Chronic Obstructive Pulmonary Disease Hospital Admissions [11]	65+	2,115	$24,792,990	923	1,192	56%	$10,815,492	463	$5,427,286
Pneumonia Hospital Admissions [12]	65+	3,061	$42,639,263	1,340	1,721	56%	$18,664,007	671	$9,346,359
Cardiovascular Disease Hospital Admissions [13]	65+	5,452	$34,362,621	2,395	3,057	56%	$15,096,981	1,195	$7,532,085
Asthma Hospital Admissions [15]	64-	1,624	$28,904,937	692	933	57%	$12,311,563	346	$6,156,724
Asthma Emergency Room Visits [15]	64-	3,992	$1,193,527	1,691	2,301	58%	$687,999	850	$254,150
Work Loss Days [16]	64-	4,910,652	$883,917,360	254,466	2,814,815	57%	$506,666,700	953,659	$171,658,534
Total			$1,015,810,698				$564,242,742		$200,375,138

Source: ARB/OEHHA 2001, EWG 2002, Abt 2000, US Census 2000.

Notes - Table 9

1) The reason why the number of PM2.5-related deaths is higher than the number of PM10-related deaths even though PM2.5 particles are a subset of PM10 particles is related to the study which ARB/OEHHA based their calculations of long-term mortality. This study (Krewski et al. 2000) found long-term mortality to be assocaited only with the fine (PM2.5) fraction of PM10. Although the other major long-term mortality study (Dockery et al. 1993) did find an association between chronic exposure and mortality, ARB/OEHHA decided to based their calculations on the Krewski et al. (2000) study. See ARB/OEHHA 2001 for futher details.

2) The costs related to chronic bronchitis could not be calculated.

3) Hospital charge cost only. Mean hospital stay is 6.02 days with a mean charge of $11,722 (1999 dollars). (Abt 2000)

4) Hospital charge cost only. Mean hospital stay is 7.01 days with a mean charge of $13,929 (1999 dollars). (Abt 2000)

5) Hospital charge cost only. Mean hospital stay is 5.44 days with a mean charge of $17,794 (1999 dollars). (Abt 2000)

6) Hospital charge cost only. Mean hospital stay is 3.03 days with a mean charge of $6,303 (1999 dollars). (Abt 2000)

7) The average asthma ER visit cost is $299 (1999 dollars). (Abt 2000)

8) The median per-day income of California residents in the year 2000 was $180. (US Census 2002)

9) The number of PM10 related deaths at an annual average of 15 ug/m3 was not calculated because no studies have been done on mortality where PM10 is less than 18; as a result OEHHA/ARB uses 18 ug/m3 as background level.

10) The costs related to chronic bronchitis could not be calculated.

11) Hospital charge cost only. Mean hospital stay is 6.02 days with a mean charge of $11,722 (1999 dollars). (Abt 2000)

12) Hospital charge cost only. Mean hospital stay is 7.01 days with a mean charge of $13,929 (1999 dollars). (Abt 2000)

13) Hospital charge cost only. Mean hospital stay is 5.44 days with a mean charge of $17,794 (1999 dollars). (Abt 2000)

14) Hospital charge cost only. Mean hospital stay is 3.03 days with a mean charge of $6,303 (1999 dollars). (Abt 2000)

15) The average asthma ER visit cost is $299 (1999 dollars). (Abt 2000)

16) The median per-day income of California residents in the year 2000 was $180. (US Census 2002)

Who's Against Clean Air?

Lobbyists for the petrochemical industry, automakers and engine manufacturers have mounted a major campaign against the PM standards proposed by the Air Resources Board and Office of Environmental Health Hazard Assessment. The dirty-air lobby includes the Alliance of Auto Manufacturers, representing 13 U.S. and international automakers; Western States Petroleum Association, representing 36 oil companies; and the Engine Manufacturers Association, representing 27 companies. Individual corporations include ExxonMobil, General Electric and BP (formerly British Petroleum) ranked by *Forbes* as the second, third and fourth most powerful corporations in the world.

Oil companies and automakers opposed to cleaner air gave Gov. Davis $175,000 in the current election cycle.

According to records filed with the California Secretary of State, 22 industry associations and individual companies opposed to tougher particulate standards spent more than $7.5 million in 2001 on lobbying at the State Capitol. (Table 10.) Most of these associations and companies have full-time lobbyists in Sacramento or are represented by one or more lobbying firms, some of whom employ whole teams of lobbyists. Their lobbying activity is in addition to hundreds of thousands of dollars in campaign contributions to state politicians made by the associations and companies each year. Just three members of the Western States Petroleum Association – BP, Occidental Petroleum and Chevron Texaco— collectively gave $175,000 to Gov. Gray Davis in 2000-2001. (Cal-Access 2002.)

The truth behind the smokescreen

Here's a sampling of their arguments against cleaner air, and the truth behind the smokescreen:

- The Alliance of Auto Manufacturers and Engine Manufacturers Association claim the proposed tougher standards will not "result in any greater protection of public health than the current California standards." (AAM 2002.) But the peer-reviewed risk assessment by state scientists found that attaining the "recommended standards would result in a reduction of . . . about 3 percent of all mortality in the population above age 30." (ARB/OEHHA 2001.)

- According to the Western States Petroleum Association, "as much or more public health benefit would be gained from uniform reduction targets than from a single statewide standard." (WSPA

2002.) But because the heaviest particulate pollution is found in lower-income communities of color, such a policy would perpetuate existing environmental inequities"– as if people who live in highly polluted areas have less right to clean air.

- Ford Motor Co. says the proposed standards are "impossibly stringent . . . with practically no hope of attainment." (Ford 2002.) It is hard to take this claim seriously when the auto industry's estimates of the cost of complying with other recent air quality regulations have been inflated by a factor of 14. (Browner 1997.)

Residents of communities of color, who are more likely to breathe dangerous levels of particulate pollution, would benefit most from cleaner air.

The attack on California's proposed particulate standards is a rerun of the same special interests' efforts to derail tough standards at the federal level.

In 1996, the U.S. EPA proposed for the first time to regulate PM2.5, after research had shown strong links between fine particles and death. The EPA proposed to cut allowable levels of PM2.5 in half, saving an estimated 35,000 lives a year nationwide. In California those standards would have saved an estimated 2,500 lives. In reviewing the EPA's 1997 proposal, the Air Resources Board went further, recommending an even tougher PM2.5 standard that would have saved an estimated 3,000 to 4,000 additional lives in the state.

Even before the EPA and ARB announced their proposals, more than 650 industry associations and companies banded together as the Air Quality Standards Coalition. The coalition included the National Association of Manufacturers, American Petroleum Institute, American Automobile Manufacturers Association, Chemical Manufacturers Association, Edison Electric Institute, National Mining Association, American Forest and Paper Association, and American Trucking Association.

Goodbye to barbecues?

The coalition spent $1.5 million on a nationwide lobbying and misinformation campaign, and millions more on industry-funded "sound science" to undermine the peer-reviewed science relied on by the EPA. They spread exaggerated claims about how the proposed standards would impact the American way of life –for example, forcing an end to backyard barbecues. (Skrzycki 1996) A fake "grassroots" group called Citizens for a Sound Democracy targeted African-Americans and Latinos, warning that the cost of new standards was too high for small minority-owned businesses. (Washington Post 1996.)

To the contrary, in 1997 EWG found that residents of communities of color in California would benefit the most from tougher PM standards, because people in communities of color were nearly three times more likely to breathe dangerous levels of PM pollution than Californians living in predominantly white communities. Based on then-current population and pollution data, residents of communities of color had a 54 percent chance of breathing unsafe levels of particulates, compared to a 19 percent chance for predominantly white communities. (EWG 1997a.)

After the standards were adopted by the Clinton Administration, the American Trucking Association challenged them in court, claiming that EPA had overstepped its authority in setting the regulations and that the agency should consider the cost of compliance as well as the benefits to public health. ATA's arguments were dismissed by the U.S. Supreme Court in 2001. The ruling stated that the law clearly established the agency's right to set standards and that the Act "unambiguously bars cost considerations." But the Supreme Court also sent parts of the case back to the U.S. Court of Appeals for clarification. In March 2002 the appeals court affirmed its ruling that "EPA must err on the side of caution – setting the [standards] at whatever level it deems necessary and sufficient to protect the public health with an adequate margin of safety, taking into account both the available evidence and the inevitable scientific uncertainties."

The unanimous appeals court ruling ended five years of counterattack by the opponents of cleaner air. In that period, according to EPA's estimates, 175,000 Americans died from PM pollution whose lives would have been saved or extended if air quality goals represented by the proposed standards had been achieved.

Table 10. Opponents of new PM standards spent almost $7.5 million to lobby against cleaner air in 2001.

	Lobbying expenditures 2001	Contributions to Gov. Davis, current election cycle
Western States Petroleum Association	$2,137,100	
BP America	$1,253,634	$80,000
Chevron Texaco	$760,456	$35,000
General Motors Corporation	$549,434	
Equilon Enterprises	$521,600	
Ford Motor Company	$418,742	
Phillips Petroleum	$396,143	
General Electric	$255,774	
Nuevo Energy Company	$174,207	
Alliance of Automobile Manufacturers, Inc.	$161,790	
Aera Energy LLC	$151,466	
Occidental Petroleum	$135,225	$60,000
Ultramar Diamond Shamrock Corp.	$120,983	
Exxon Mobil	$112,937	
Toyota Motor Sales, U.S.A., Inc.	$85,673	
DaimlerChrysler Corporation	$51,213	
Kinder Morgan Energy Enterprises	$44,921	
Caterpillar Inc.	$41,735	
Deere and Company	$36,348	
Nissan North America	$25,156	
Venoco Inc.	$3,000	
TOTAL	$7,437,537	$175,000

Source: Compiled from lobbying and campaign finance reports as filed with the California Secretary of State. Available at http://CAL-ACCESS.ss.ca.gov

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Appendix K

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State of the Air 2005

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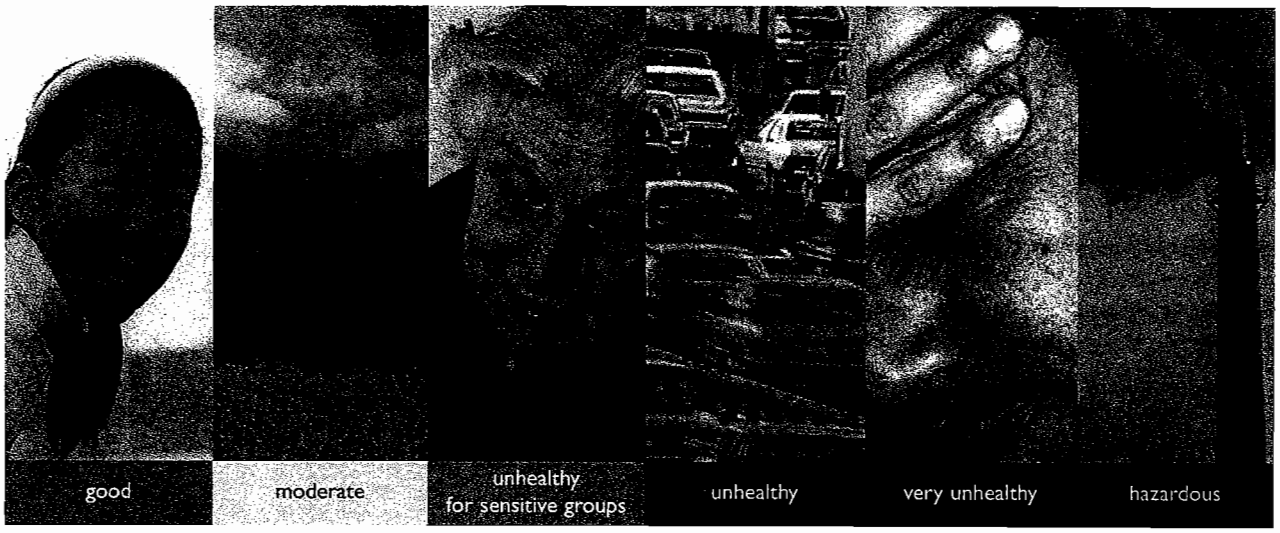

Click on the following links

Executive Summary
Brief rundown of the overall findings. También disponible en español: Resumen ejecutivo.

Introduction
Overview of the purpose and findings.

National and Regional Analysis
Region-by-region differences and changes in air quality.

Populations at Risk in the US
Estimates of people at risk from ozone and particle pollution by county grades in the report.

People at Risk in the 25 Most Polluted US Cities
Lists of cities most polluted by ozone, short-term (24-Hour) and year-round (annual) particle pollution and the numbers of people at risk who live in them.

People at Risk in the 25 Most Polluted Counties
Lists of counties most polluted by ozone, short-term (24-Hour) and year-round (annual) particle pollution across the nation.

Cleanest Cities in the US
Lists of the cities with the least ozone, short-term (24-Hour) and year-round (annual) particle pollution across the nation.

Cleanest Counties in the US
Lists of the counties with the least ozone, short-term (24-Hour) and year-round (annual) particle pollution.

Health Effects of Ozone and Particle Pollution
Evidence mounts showing the dangers found in the air we breathe. Focused look at how air pollution affects children.

Protecting the Nation from Air Pollution
Some polluters want to avoid responsibility to clean up. How can we make sure they follow the rules? How can we tackle dangerous diesel exhaust?

State Tables
Grades and number of people at risk in your state.

Methodology
Look here to see how this report came to be.

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The American Lung Association assumes sole responsibility for the content of the ***American Lung Association State of the Air 2005***.

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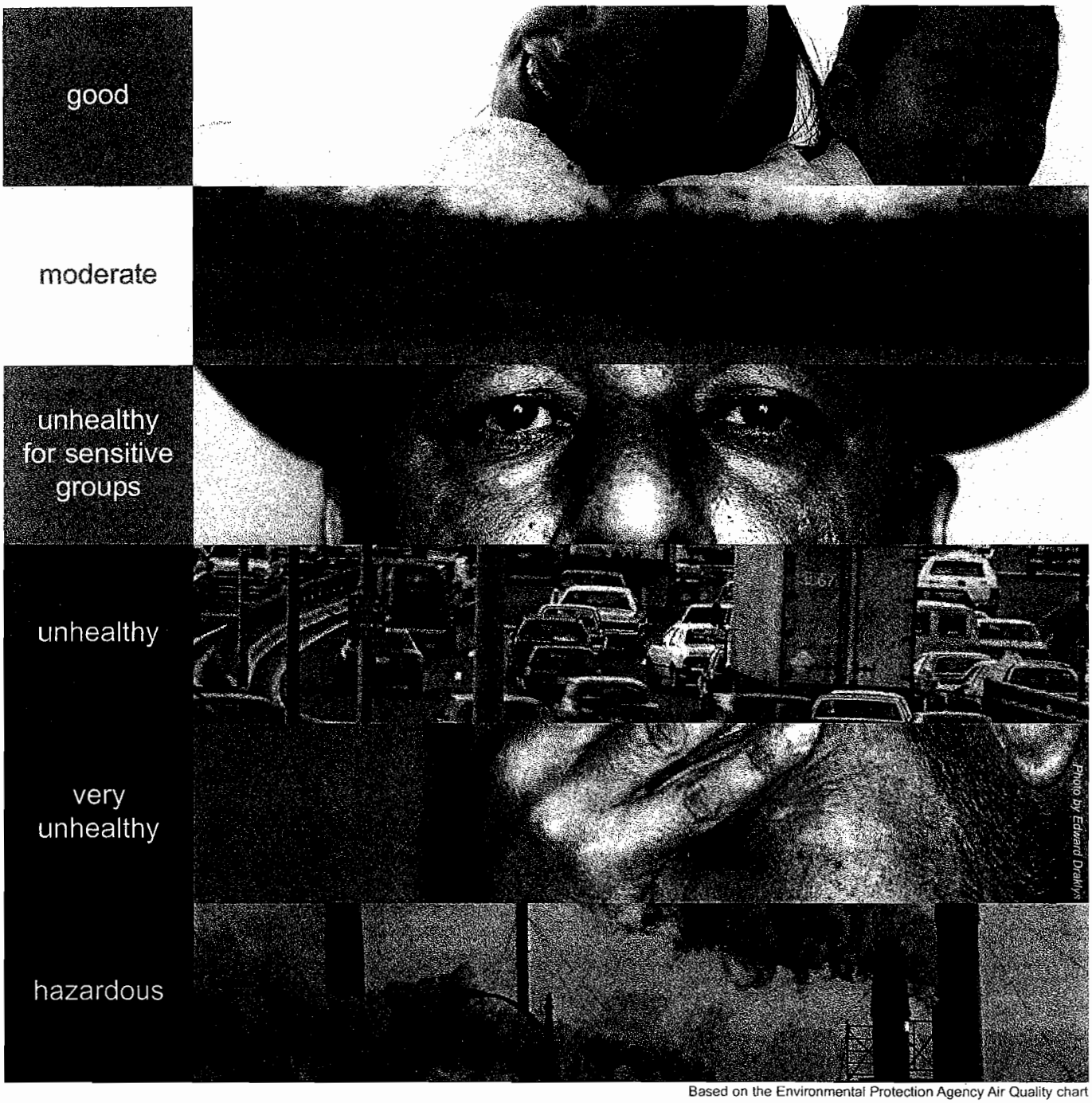
air quality



Based on the Environmental Protection Agency Air Quality chart

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Executive Summary

Air pollution levels improved in many parts of the nation during the years 2001-2003, but millions of Americans still faced dangerous levels of air pollution. The *American Lung Association State of the Air 2005* presents information on air pollution on a state-by-state, county-by-county basis, using the most up-to-date quality assured data available for nationwide comparisons.

American Lung Association State of the Air 2005 provides a county-level report card on the two most pervasive air pollutants: ozone (smog) and particle pollution (soot). In addition, this year's report shows that ozone remains a persistent threat across large parts of the United States.

Some of the facts from this report card on air pollution are below, taking a look at the nation as a whole:

- **Over 52 percent of the U.S. population lives in counties that have unhealthful levels of either ozone or particle pollution.**
  Over 152 million Americans live in 390 counties where they are exposed to unhealthful levels of air pollution in the form of either ozone or short-term or year-round levels of particles.

- **Nearly half the U.S. population—49 percent—lives in areas with unhealthful levels of ozone.**
  Counties that were graded F for ozone levels have a combined population of 142.7 million. Almost half of all Americans are living in counties where the air quality places them at risk for decreased lung function, respiratory infection, lung inflammation and aggravation of respiratory illness.

- **Over 26 percent of the U.S. population lives in areas with unhealthful short-term levels of particle pollution.**
  Over 76.5 million Americans live in areas where they are exposed to unhealthful short-term levels of particle pollution. Short-term, or acute, exposure to particle pollution has been shown to increase heart attacks, strokes and emergency-room visits for asthma and cardiovascular disease, and most importantly, increase the risk of death.

- **One in five people in the United States lives in an area with unhealthful year-round levels of particle pollution.**
  Some 58.3 million Americans suffer from chronic exposure to particle pollution. Even when levels are fairly low, over time exposure to particles can increase risk of hospitalization for asthma, damage to the lungs and significantly increase the risk of premature death.

- **About 50.2 million Americans—nearly 17 percent—live in 47 counties with unhealthful levels of all three: ozone and short-term and year-round particle pollution.**

With the risks from airborne pollution so great, the American Lung Association seeks to inform people who may be in danger. Many groups are at greater risk because of their age or the presence of asthma or other chronic lung disease, a cardiovascular disease or diabetes. Those groups include:

- **Adult and Pediatric Asthma**—Over 3.1 million children and over 8.4 million adults with asthma live in parts of the United States with very high levels of ozone. Over 4.6 million adults and nearly 1.7 million children with asthma live in areas with high levels of short-term particle pollution. Three and a half million adults and nearly 1.3 million children with asthma live in counties with unhealthful levels of year-round particle pollution.

- **Older and Younger**—Over 16.3 million adults age 65 and over and nearly 36.7 million children age 18 and under live in counties with unhealthful ozone levels. Over 8.8 million seniors and over 19.7 million children live in counties with unhealthful short-term levels of particle pollution. Over 6.7 million seniors and nearly 15.1 million children live in counties with unhealthful levels of year-round particle pollution.

- **Chronic Bronchitis and Emphysema**—Over 4.2 million people with chronic bronchitis and 1.5 million with emphysema live in counties with unhealthful ozone levels. Nearly 2.3 million people with chronic bronchitis and 802,000 with emphysema live in counties with unhealthful levels of short-term particle pollution. Over 1.7 million people with chronic bronchitis and over 610,000 with emphysema live in counties with unhealthful year-round levels of particle pollution.

- **Cardiovascular Disease**—Over 18.3 million Americans with cardiovascular diseases live in areas with unhealthful levels of short-term particle pollution; 13.9 million live in counties with unhealthful levels of year-round particle pollution. Cardiovascular diseases include heart disease, heart attacks and strokes.

- **Diabetes**—Over 3.6 million Americans with diabetes live in areas with unhealthful levels of short-term particle pollution; 2.8 million live in counties with unhealthful levels of year-round particle pollution. Research indicates that diabetics face risks from particle pollution's threat to their cardiovascular systems.

In addition to providing specific grades for each county with ozone and particle pollution monitors, the *American Lung Association State of the Air 2005* also discusses key steps needed to improve the air we all breathe. Those steps include:

- **Protect the Clean Air Act.** The American Lung Association is greatly concerned about threats to one of the most effective public health laws ever passed, the Clean Air Act. Threats come from legislative proposals to roll back key provisions of the law and continued delays in putting into place what the science tells us is needed to clean up air pollution. The American Lung Association has taken legal action to protect this valuable clean air tool, and encourages everyone to tell his or her members of Congress to protect the Clean Air Act.

- **Clean Up Dirty Power Plants.** Old, coal-fired power plants are among the biggest industrial contributors to unhealthful air, especially particle pollution in the eastern United States. The toll of death, disease and environmental destruction caused by coal-fired power plant pollution continues to mount. The Environmental Protection Agency (EPA) issued proposed rules in 2003 that would give states the tools to clean up these plants. The rules need to be stronger and, most of all, made final so work can begin.

Individuals can do a great deal to help reduce air pollution outdoors as well. Here are some simple, but effective ways:

- **Reduce driving.** Combine trips, walk, bike, carpool or vanpool and use buses, subways or other alternatives to driving. Vehicle emissions are a major source of air pollution. Support community plans that provide ways to get around that don't require a car, such as more sidewalks, bike trails and transit systems.

- **Refuel cars after dark.** Gasoline emissions evaporating while you fill up your gas tank contribute to ozone formation. Filling up after dark helps prevents the sunlight from turning those gases into ozone.

- **Don't burn wood or trash.** Burning firewood and trash are among the largest sources of particles in many parts of the country. If you must use a fireplace or stove for heat, convert your woodstoves to natural gas, which has far fewer emissions. Compost and recycle as much as possible and dispose of other waste properly; don't burn it. Support efforts in your community to ban outdoor burning of construction and yard wastes.

- **Get involved.** Participate in your community's review of the air pollution plans and support state and local efforts to clean up air pollution.

- **Send a message to decisionmakers.** Send an email or fax to urge your member of Congress to protect the Clean Air Act. Log on at **www.lungusa.org** to see how easy that can be.

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The benefits of cleaning up air pollution

have exceeded the costs by as much as...

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AMERICAN LUNG ASSOCIATION®

June 1, 2001

ANNOTATED BIBLIOGRAPHY OF RECENT STUDIES OF THE HEALTH EFFECTS OF OZONE AIR POLLUTION 1997-2001

In 2001, the U.S. Environmental Protection Agency (EPA) will commence a periodic review of the National Ambient Air Quality Standards (NAAQS) for ozone, a common and pervasive air pollutant in the United States. The review will begin with a compilation of all the scientific and medical studies published on ozone air pollution since EPA's last review.

In 1997, EPA revised the standard for ozone from 0.12 ppm averaged over one hour, to a standard of 0.08 ppm averaged over eight hours. The new standard was set to reflect the findings of chamber studies performed in the early 1990's, which found that ozone poses health problems when people are exposed to lower levels for longer periods of time.

Ozone is the principle component of ground-level smog. It is formed when hydrocarbon and nitrogen oxide pollution from vehicles, power plants, refineries and other sources react in the atmosphere in the presence of sunlight. Ozone is a powerful oxidizing agent that damages lung tissue.

Recent research with laboratory animals, clinical subjects, and human populations has identified a cascade of adverse health effects from ozone at levels common in the United States. Effects include increased respiratory symptoms, damage to cells of the respiratory tract, pulmonary inflammation, declines in lung function, increased susceptibility to respiratory infections, and increased risk of hospitalization and early death.

Four groups of people are especially sensitive to ozone: children, people with chronic obstructive respiratory disease (chronic bronchitis and emphysema) and asthma, persons who exercise or work outdoors, and people who, for reasons that remain unknown, are more sensitive to the physiologic effects of ozone.

This bibliography represents a sampling of the peer-reviewed scientific literature on the health effects of ozone air pollution published since EPA's last revision of the standards in 1997.
Air pollution research may involve epidemiological studies of human populations, chamber studies where human volunteers are exposed to air pollution under controlled conditions, and toxicological studies with laboratory animals. In recent years, air pollution research funds have been largely directed toward the study of particulate matter. Nevertheless, there

were some important developments regarding the health effects of ozone. Important new findings include:

- Identification of the possible genetic basis for susceptibility to ozone;
- Increasing evidence of a mortality effect of ozone;
- Evidence of long-term impacts on lung function from chronic exposure; and
- Increased evidence of the effects of ozone on sensitive groups such as children and asthmatics.

This bibliography does not attempt to be comprehensive: exclusion does not imply that a study is unimportant; inclusion does not imply endorsement.

LONG-TERM STUDIES

Ozone Harms the Respiratory Health of U.S. Military Academy Cadets

Researchers from Columbia University and New York University sought to determine whether changes in lung function or respiratory symptoms would occur over the course of a summer among healthy young adults working outdoors in the presence of ozone. The study followed 72 sophomore cadets from the U.S. Military Academy at West Point, New York, during their summer training at **Fort Benning, GA, Fort Leonard Wood, MO, Fort Sill, OK, and Fort Dix, NJ.** All the subjects on average experienced a decline in lung function over the course of the summer. There were also significant increases in reports of cough, chest tightness, and sore throat. The decline in lung function was greatest in the group of military cadets who attended training in Fort Dix, New Jersey, where peak hourly ozone concentrations above 100 ppb occurred frequently. "*These results suggest a possible adverse respiratory-health impact of exposures to particulate matter and ozone in healthy young adults engaged in intensive outdoor training*," conclude the authors.

Kinney, P.L. and Lippmann, M. Respiratory Effects of Seasonal Exposures to Ozone and Particles. Archives of Environmental Health, Vol. 55, No. 3, pp. 210-216, May/June 2000.

Lifetime Ozone Exposure Exerts Negative Effect on Small Airways of Lung

This pilot study is the first attempt to relate lifetime cumulative ozone exposure to small airway pulmonary function. 130 nonsmoking, non-asthmatic freshmen from the University of California at Berkeley who were lifelong residents of the **Los Angeles Basin** or the **San Francisco Bay Area** volunteered to participate in lung function testing. Researchers observed declines in mid- and end-expiratory flow measures of the small airways that are considered early indicators for pathologic changes that might ultimately

progress to chronic obstructive lung disease. These declines were associated with estimated long-term ozone exposures.

Künzli, N., Lurmann, F., Segal, M., Ngo, L., Balmes, J., and Tager, I.B. Association between Lifetime Ambient Ozone Exposure and Pulmonary Function in College Freshmen—Results of a Pilot Study. Environmental Research, Vol. 72, pp. 8-23, 1997.

Lung Function in Girls and Boys is Diminished by Ozone

The California Children's Health Study followed 3,300 school children that lived in 12 **Southern California** communities that fell along a gradient of air pollution levels for a period of 10 years. Four different measures of pulmonary function were tested, with different pollutants most strongly associated with each measure. Girls with asthma, and boys who spent more time outdoors experienced diminished lung function in association with ozone.

Peters, J.M., Avol, E., Gauderman, W.J., Linn, W.S., Navidi, W., London, S.J., Margolis, H., Rappaport, E., Vora, H., Gong, H., and Thomas, D.C. A Study of Twelve Southern California Communities with Differing Levels and Types of Air Pollution. II. Effects on Pulmonary Function. American Journal of Respiratory and Critical Care Medicine, Vol. 159, pp. 7680775, 1999.

Long-Term Ozone Exposure Diminishes Respiratory Health

Few studies have reported on the respiratory effects of prolonged, multi-year exposures to ozone. This study examined data from health status questionnaires and lung function measurements in relation to residence histories to examine the effect of long-term ozone exposures on over 500 non-smoking Yale college students. Investigators found that "*living for four or more years in regions of the country with high levels of ozone and related copollutants is associated with diminished lung function and more frequent reports of respiratory symptoms.*"

Galizia, A. and Kinney, P.L. Long-Term Residence in Areas of High Ozone: Associations with Respiratory Health in a Nationwide Sample of Nonsmoking Young Adults. Environ Health Perspect, Vol. 107, No. 8, pp. 675-679, August 1999.

Long-Term Ozone Exposure Might Inhibit Lung Function Growth in Children

Frischer et al. followed a group of 1,150 first and second grade children in two counties in Austria from 1994-1996, to investigate the long-term effects of ambient ozone. The highest and lowest exposure to ozone differed by a factor of two. Researchers found small but consistent decrements in lung function associated with ambient ozone. They conclude: "*This is the first study that suggests chronic effects of ozone on lung function growth in children. Thus, ozone would constitute a risk factor for premature respiratory morbidity during later life.*"

A subsequent long-term study in Southern California by Gauderman et al. found an association between particulate matter and children's lung function growth, but not with ozone.

Frischer, T., Studnicka, M., Gartner, C., Tauber, E., Horak, F, Veiter, A., Spengler, J., Kühr, J., and Urbanek, R. Lung Function Growth and Ambient Ozone: A Three-Year Population Study in School Children. Am J Respir Crit Care Med, Vol. 160, pp. 390-396, 1999.

Gauderman, J.W., McConnell, R., Gilliland, F., London, S., Thomas, D., Avol, E., Vora, H., Berhane, K., Rappaport, E.B., Lurmann, F., Margolis, H.G., and Peters, J. Association between Air Pollution and Lung Function Growth in Southern California Children. American Journal of Respiratory and Critical Care Medicine, Vol. 162. pp 1383-1390, 2000.

Long-Term Exposure to Ozone is Related to Asthma Development in Men

Asthma is a multifactor disease with many contributing factors. Air pollution is generally considered to be an exacerbating, rather than a causal factor. This prospective cohort study of over 3,000 adults in the nonsmoking Seventh Day Adventist community sought to examine the whether long-term exposure to ozone air pollution can contribute to the prevalence of asthma. The study found that 8-hour average ambient ozone concentration averaged over a 20-year period was associated with doctor diagnoses of adult-onset asthma in nonsmoking males.

McDonnell, W.F., Abbey, D.E., Nishino, N., and Lebowitz, M.D. Long-Term Ambient Ozone Concentration and the Incidence of Asthma in Nonsmoking Adults: The Ashmog Study. Environmental Research, Section A Vol. 80, pp. 110-121, 1999.

Nasal Biopsies from Children Reveal Ozone Damage

Children in **Mexico City** are routinely exposed to high levels of ozone, particulate, and aldehyde air pollution. Biopsies taken from these children exhibit a wide range of pathologic changes to the cells of the nasal passages. "*The severe structural alteration of the nasal epithelium together with the prominent acquired ciliary defects are likely the result of chronic airway injury in which ozone, particulate matter, and aldehydes are thought to play a crucial role,*" conclude researchers. "*The nasal epithelium in SWMMC [Southwest Metropolitan Mexico City] children is fundamentally disordered, and their mucocilliary defense mechanisms are no longer intact. A compromised nasal epithelium has less ability to protect the lower respiratory tract and may potentially leave the distal acinar airways more vulnerable to reactive gases.*"

Calderón-Garciduenas, L., Valencia-Salazar, G., Rogríguez-Alcaraz, A., Gambling, T.M., García, R., Osnaya, N., Villarreal-Calderón, A., Devlin, R.B., and Carson, J.L. Ultrastructural Nasal Pathology in Children Chronically and Sequentially Exposed to Air Pollutants. American Journal of Respiratory Cell and Molecular Biology, Vol. 24, pp. 132-138, 2001.

SHORT-TERM STUDIES

Lung Function Diminishes Following Exposure to Air Pollution

Swiss researchers followed a group of 3,900 nonsmoking adults from eight areas of **Switzerland** that represent a range of urbanization, air pollution, altitude, and weather conditions. In this study, researchers obtained three different measures of lung function and compared the results with prior days measurements of ozone, total suspended particulates, and nitrogen dioxide. Daily average concentrations of ozone were significantly associated with mean respiratory function measures during the summer months. Associations remained stable after controlling for other pollutants and for pollen. Though the effects were small, researchers conclude that current levels of air pollution have public health significance.

Schindler, C., Künzli, N., Bongard, J.-P., Leuenberger, P., Karrer, W., Rapp, R., Monn, C., Ackermann-Liebrich, U., and The Swiss Study on Air Pollution and Lung Diseases in Adults Investigators. Short-Term Variation in Air Pollution and in Average Lung Function Among Never-Smokers: The Swiss Study on Air Pollution and Lung Diseases in Adults (SAPALDIA). American Journal or Respiratory and Critical Care Medicine, Vol. 163, pp. 356-361, 2001.

School Absences Rise With High Ozone Days

School absenteeism is used as an indicator of the overall health of school-aged children. A study by Chen et al. assessed the association between daily air pollution concentrations and absences among 28,000 elementary school children in **Washoe County, Nevada**, home of **Reno** between 1996 and 1998. Investigators found that ozone and carbon monoxide, but not PM_{10}, were statistically significant predictors of daily absenteeism in elementary schools.

The Children's Health Study is being carried out in twelve southern California communities that fall along a gradient of air pollution. This study explored the effect of ozone, PM_{10}, and nitrogen dioxide on school absenteeism due to upper- and lower-respiratory illness in a cohort of fourth-graders. Researchers found that relatively small short-term changes in ozone, but not the other pollutants, were associated with increases in school absences due to respiratory illness in children 9-10 years of age. "*Because exposures at the levels observed in this study are common, the increase in school absenteeism from respiratory illnesses associated with relatively modest day-to-day changes in ozone concentration documents an important adverse impact of ozone on children's health and well-being,*" state the authors.

Chen, L., Jennison, B.L., Yang, W., and Omaye, S.T. Elementary School Absenteeism and Air Pollution. Inhalation Toxicology, Vol. 12, pp. 997-1016, 2000.

Gilliland, F.D., Berhane, K., Rappaport, E.B., Thomas, D.C., Avol, E., Gauderman, W.J., London, S.J., Margolis, H.G., McConnell, R., Islam, K.T., and Peters, J.M. The Effects of Ambient Air Pollution on School Absenteeism Due to Respiratory Illness. Epidemiology, Vol. 12, No. 1, pp. 43-54, January 2001.

Summertime Haze Air Pollution Exacerbates Asthma in Children

This study focused on children ages 7-13 with moderate to severe asthma who attended a summer "asthma camp" in the early 1990's in the **Connecticut River Valley**. Daily records were kept of environmental conditions, as well as of subject medication use, lung function, and medical symptoms. Air pollution, especially ozone, was consistently correlated with acute asthma exacerbations, chest symptoms, and lung function decrements. "*...the monotonic nature of the relationships of ozone with reduced lung function and increased numbers of asthma symptoms and exacerbations found in this work indicates that these effects extend will below the present 120 ppb concentration level, so that even meeting this standard will not be fully protective for these sensitive individuals. Past medical advice that children with asthma should take care to avoid exposure to air pollutants is further supported by the results of this research.*"

Thurston, G.D., Lippman, M., Scott, M.B., and Fine, J.M. Summertime Haze Air Pollution and Children with Asthma. Am J Respir Crit Care Med, Vol. 155, pp. 654-660, 1997.

Ozone Plus Allergens Exacerbates Asthma

Asthma is an inflammatory disease of the airways. This is the first epidemiologic study to demonstrate a difference in the inflammatory reaction of the upper airways to ozone as compared to allergens in patients with intermittent to severe persistent asthma. The study of sixty asthmatic patients of the **Leiden** University Hospital in **The Netherlands** took samples of nasal lavage and analyzed it in the laboratory for signs of inflammation. Researchers found that "*both ambient ozone and allergen exposure are associated with inflammatory responses in the upper airways of subjects with asthma, although the type of inflammation is qualitatively different.*" They speculate that "*during episodes with both increased allergen levels and high ambient photochemical air pollution asthma exacerbations are more likely to develop than during periods with either increased allergens or ambient photochemical air pollution alone.*"

Hiltermann, T.J.N., de Bruijne, C.R., Stolk, J., Zwinderman, A.H., Spiksma, F.T.M., Roemer, W., Steerenberg, P.A., Fischer, P.H., van Bree, L., and Hiemstra, P.S. Effects of Photochemical Air Pollution and Allergen Exposure on Upper Respiratory Tract Inflammation in Asthmatics. Am J Respir Crit Care Med, Vol.156, pp. 1765-1772, 1997.

Children with Mild Asthma Suffer the Effects of Air Pollution

A number of important studies have been conduced in **Mexico City** where air pollution levels are high. This study involved a panel of Mexican children ages 5-13 with mild asthma. Researchers determined that a 50 ppb increase in the daily 1-hour maximum ozone was related to an 8 percent increase in cough, a 24 percent increase in phlegm, and an 11 percent increase in other respiratory symptoms in the study population.

Romieu, I., Meneses, F., Ruiz, S., Huerta, J., Sienra, J.J., White, M., Etzel, R., and Hernandez, M. Effects of Intermitttent Ozone Exposure on Peak Expiratory Flow and Respiratory Symptoms among Asthmatic Children in Mexico City. Archives of Environmental Health, Vol. 52(5), pp. 368-376, Sep-Oct 1997.

Ozone is a Risk Factor for Respiratory Problems in Kids, Especially Babies, Toddlers, and Adolescents

Burnett et al. examined the association between air pollution and hospital admissions for acute respiratory problems in babies and toddlers during a 15-year period in **Toronto, Canada**. A 35 percent increase in the daily hospitalization rate for respiratory problem was associated average ozone concentrations in the summer, but not during other seasons. The ozone effect persisted after adjustment for other air pollutants and weather.

Braga and coworkers examined daily hospital admission records for children of different ages, compared to daily concentrations of ozone, particulate matter, sulfur dioxide, carbon monoxide, and nitrogen dioxide over a five-year period in **Sao Paulo, Brazil**. The study showed that daily respiratory hospital admissions for children and adolescents increased with air pollution, with children less than two years old the most susceptible, and adolescents were the next most susceptible age group.

Burnett, R.T., Smith-Doiron, M., Stieb, D., Raizenne, M.E., Brook, J.R., Dales, R.E., Leech, J.A., Cakmak, S., and Krewski, D. Association between Ozone and Hospitalization for Acute Respiratory Diseases in Children Less than 2 Years of Age. American Journal of Epidemiology, Vol. 153, No. 5, pp. 444-452, 2001.

Braga, A.L., Saldiva, P.H., Pereira, L.A., Menezes, J.J., Conceicao, G.M., Lin, C.A., Zanobetti, A., Schwartz, J., and Dockery, D.W. Health Effects of Air Pollution Exposure on Children and Adolescents in Sao Paulo, Brazil. Pediatric Pulmonology, Vol. 31 (2), pp. 106-113, Feb. 2001.

Low Levels of Ozone Contribute to Hospitalization for Respiratory Disease

A study by Health Canada researcher Richard Burnett et al. compared air pollution data to hospital admissions in 16 Canadian cities, over a ten-year period. The study controlled for many factors including day of week, season, other air pollutants, and climate. The prior day's peak hourly ozone concentration was positively associated with respiratory hospital admissions during the April-December period. The effects varied from city to city. Researchers conclude that "*these results suggest that ambient air pollution at the relatively low concentrations observed in this study, including tropospheric ozone, is associated with excess admissions to hospital for respiratory diseases in populations experiencing diverse climates and air pollution profiles.*"

In **Brisbane, Australia**, ozone levels are reasonably constant year round. This large study of daily admissions to public hospitals during the period 1987-1994 found that ozone was consistently associated with admissions for asthma and respiratory disease—with little evidence of a threshold.

Burnett, R.T., Brook, J.R., Yung, W.T., Dales, R.El, and Krewski, D. Association between Ozone and Hospitalization for Respiratory Diseases in 16 Canadian Cities. Environmental Research, Vol. 72, pp. 24-31, 1997.

Petroeschevsky, A., Simpson, R.W., Thalib, L., and Rutherford, S. Associations between Outdoor Air Pollution and Hospital Admissions in Brisbane, Australia. Archives of Environmental Health , Vol. 56(1), pp. 37-52, Jan-Feb 2001.

Summertime Ozone Sends the Elderly to the Emergency Room

This study examined daily emergency room visits for respiratory illnesses in 25 hospitals in **Montreal, Quebec** in relation to summertime air pollution. Though the ozone levels never exceeded the 1-hour NAAQS of 120 ppb, statistically significant relationships were found between respiratory emergency room visits for patients over age 64, and both 1-hour and 8-hour maximum ozone levels measured the day before. "*These findings confirm the impression that while air quality standards may protect the respiratory health of the general population, this is not the case for susceptible subgroups such as the elderly,*" conclude the researchers.

Delfino, R.J., Murphy-Moulton, A.M., and Becklake, M.R. Emergency Room Visits for Respiratory Illnesses among the Elderly in Montreal: Association with Low Level Ozone Exposure. Environmental Research, Section A, Vol. 76, pp. 67-77, 1998.

Ozone Exposure May Make the Heart Work Harder

This study is the first chamber study to directly measure the effect of ozone on the function of the human heart. Investigators studied a small group of healthy adult males and those with high blood pressure. Overall, researchers did not find evidence of major short-term cardiovascular effects from ozone exposure. However, they reported that their results "*suggest that ozone exposure can increase myocardial work and impair pulmonary gas exchange to a degree that might be clinically important in persons with significant preexisting cardiovascular impairment, with or without concomitant lung disease.*"

Gong, H. Jr., Wong, R., Sarma, R.J., Linn, W.S., Sullivan, E.D., Shamoo, D.A., Anderson, K.R., and Prasad, S.B. Cardiovascular Effects of Ozone Exposure in Human Volunteers. Am J Respir Crit Care Med, Vol. 158, pp. 538-546, 1998.

Ozone Damages the Lungs of Exercisers

The lungs work harder and take in more air when people are exercising. A study by Frampton et al. of healthy adult smokers and nonsmokers subjected volunteers to exercise while exposing them to ozone and filtered air in a laboratory chamber. The authors conclude that: "*exposure to ozone with exercise, at concentrations relevant to urban outdoor air, results in ozonation of lipids in the airway epithelial lining fluid of humans.*"

A study of adult cyclists in **Parma, Italy** measured levels of lung-specific proteins in the blood following a two hour bicycle ride during the summer, under differing ozone smog conditions. Researchers Broeckaert et al. found increased airway permeability in moderately exercising participants exposed to an average of 0.07 ppm ozone over 2 hours.

Frampton, M.W., Pryor, W.A., Cueto, R., Cox, C., Morrow, P.E., and Utell, M.J. Ozone Exposure Increases Aldehydes in Epithelial Lining Fluid in Human Lung. Am J Respir Crit Care Med, Vol., 159, pp. 11134-1137, 1999.

Broeckaert, F., Arsalane, K., Hermans, C., Bergamaschi, Brustolin, A., Mutti, A., and Bernard, A. Lung Epithelial Damage at Low Concentrations of Ambient Ozone. The Lancet, Vol. 353, pp. 900-901, March 13, 1999.

Ozone Increasingly Implicated in Premature Mortality

Recent studies of air pollution and mortality have looked at the impacts of all the major pollutants, and have increasingly been reporting positive associations with ozone. Dr. Jonathan M. Samet and coauthors from the Johns Hopkins University School of Public Health examined five major air pollutants in 20 of the largest cities in the United States from 1987 to 1994, as part of NMMAPS – the National Morbidity, Mortality, and Air Pollution Study. Ozone levels were positively associated with mortality rates during the summer months when ozone levels were highest, though effects are not as strong as with particulate matter.

A similar study known as the APHEA project – Air Pollution and Health: a European Approach --of six cites in Central and Western Europe examined data on daily deaths and daily air pollution levels. Significant positive associations were found between daily deaths and ozone. Positive associations were also reported for nitrogen dioxide, but study authors believe this may be due to confounding by other vehicle-derived pollutants and needs further study.

Thurston and Ito poled data from 15 studies and estimated a small effect of ozone on total mortality. According to Samet et al.: "*Taken together, the results of these three studies provide consistent evidence that exposure to ozone also increases the risk of death.*"

Samet, J.M., Dominici, F., Curriero, F.C., Coursac, I., and Zeger, S.L. Fine Particulate Air Pollution and Mortality in 20 U.S. Cities, 1987-1994. New England Journal of Medicine, Vol. 343, No. 24, pp. 1742-1749, December 14, 2000

Tuoloumi, G., Katsouyanni, K., Zmirou, D., Schwartz, J., Spix, C., de Leon, A.P., Tobias, A., Quennel, P., Rabczenko, D., Bacharova, L., Bisanti, L., Vonk, J.M., and Ponka, A. Short-Term Effects of Ambient Oxidant Exposure on Mortality: A Combined Analysis Within the APHEA Project. American Journal of Epidemiology, Vol. 146: No. 2, pp. 177-185, 1997.

Thurston, G.D., and Ito, K. Epidemiological Studies of Ozone Exposure Effects. In, Air Pollution and Health, Edited by S.T. Holgate, J.M. Samet, H.S. Koren, and R.L. Maynard, Academic Press, 1999.

OTHER STUDIES

Genetic Basis for Ozone Responsiveness Identified

It is well established that ozone induces lung hyperpermeability and inflammation in humans and in laboratory animals, and that some individuals are more susceptible than others to ozone damage. A number of factors may contribute to this differential responsiveness, including age, sex, nutrition, and pre-existing disease, such as asthma. This study by Dr. Steven Kleeberger of the Johns Hopkins School of Hygiene and Public

Health explores the genetic basis for susceptibility, after controlling for other known susceptibility factors. The study identifies a likely ozone "susceptibility gene" in mice.

Kleeberger, S.R., Reddy, S., Zhang, L.-Y., and Jedlicka, A.E. Genetic Susceptibility to Ozone-Induced Lung Hyperpermeability. Am J. Respir. Cell Mol. Biol., Vol. 22, pp. 620-627, 2000.

Inner-City Asthmatic Children Born Prematurely or with Low Birth Weight Have Greatest Response to Ozone

This study sought to ascertain which subgroups in a cohort of 846 inner-city asthmatic children aged 4-9 years old were most susceptible to the effects of summertime ozone. The children were recruited from emergency departments and primary care clinics in the **Bronx and East Harlem in New York City, Baltimore, Washington, DC, Detroit, Cleveland, Chicago, and St. Louis, MO**. The study reported that "*children of low birth weight or of premature birth are at greater risk for respiratory problems, and appear to be substantially more susceptible to the effects of summer air pollution than children of normal birthweight or full-term gestation.*"

Mortimer, K.M., Tager, I.B., Dockery, D.W., Neas, L.M., and Redline, S. The Effect of Ozone on Inner-City Children with Asthma: Identification of Susceptible Subgroups. Am J Respir Crit Care Med, Vol. 162, pp. 1838-1845, 2000.

During Atlanta Summer Olympics, Decreased Traffic Reduced Asthma Incidents in Children

The 1996 Summer Olympics in **Atlanta**, a concerted effort was made to lower traffic congestion to enable spectators to get to the games. Public transit was enhanced, the downtown was closed to private cars, and businesses were encouraged to promote telecommuting and alternative work hours. As a result, there were large and significant decreases in ozone concentrations, and somewhat lesser reductions in carbon monoxide and PM_{10} concentrations. During this period, researchers found significant reductions in the numbers of urgent care visits, emergency care visits, and hospitalizations for asthma among children ages 1 – 16 years. Dr. Michael S. Friedman of the Centers for Disease Control and Prevention and coauthors conclude: "*Our finding suggest that efforts to decrease ozone and PM_{10} concentrations from moderate to low levels can decrease the burden of asthma.*"

Friedman, M.S., Powell, K.E., Hutwagner, L., Graham, L.M., and Teague, W.G. Impact of Changes in Transportation and Commuting Behaviors During the 1996 Summer Olympic Games in Atlanta on Air Quality and Childhood Asthma. Journal of the American Medical Association, Vol. 285, No. 7, pp. 897-905, 2001.

Appendix M

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Updated March 5, 2001

SELECTED KEY STUDIES ON PARTICULATE MATTER AND HEALTH: 1997 - 2001

NEW STUDIES CONFIRM THAT CURRENT LEVELS OF PARTICULATE AIR POLLUTION ARE HARMFUL TO HUMAN HEALTH

The Clean Air Act requires the U.S. Environmental Protection Agency (EPA) to review and update the National Ambient Air Quality Standards for major air pollutants every five years, in light of the latest scientific evidence.

More than 800 new scientific studies related to the effect of airborne particulates on human health have been published since 1996, when EPA last reviewed the standards for particulate matter. The new studies validate the earlier research and address the most important arguments raised by industry critics. Taken together, the studies confirm the relationship between particulate air pollution, illness, hospitalization, and premature death. The major themes of the new research are that the:

- Major long-term studies have been fully validated.
- New short-term studies from across the U.S. and around the world confirm the mortality effects.
- New analyses show that lives may be shortened by months or years, rather than days.
- Recent studies of laboratory animals and humans have identified cardiac responses to particles, thus elucidating possible biologic mechanisms for mortality.
- New studies demonstrate that infants and children, particularly asthmatic children, are especially sensitive to the effects of fine particle pollution.

In 1997 when EPA announced the establishment of new NAAQS for fine particles, the President directed EPA to complete a review of the standards by July 2002.

The National Academy of Sciences (NAS) has issued several reports recommending research priorities to increase scientific understanding of particle pollution. To address the scientific issues raised by the NAS panel, EPA increased funding for research on particulates to more than $50 million

per year. As part of this effort, the Health Effects Institute, jointly sponsored by industry and EPA, has committed substantial resources to research on PM.

As a result of this infusion of research funds, hundreds of scientific papers and research reports have been published since EPA last issued its "Air Quality Criteria for Particulate Matter" in 1996.

This annotated bibliography presents the findings of some of the most significant new research studies that advance our understanding of the harmful health effects of particulate air pollution. The peer-reviewed papers cited here represent a small sample of the scientific articles on the health effects of particulate air pollution published since 1996. This bibliography does not attempt to be comprehensive: exclusion does not imply that a study is unimportant; inclusion does not imply endorsement.

LONG-TERM STUDIES OF MORTALITY

Prospective Cohort Epidemiological Studies Are Validated in Independent Reanalysis

Two landmark prospective cohort studies reported that chronic exposure to particulate pollution increases the risk of premature mortality. In the 1993 Six Cities Study, Harvard University researchers followed the health of more than 8,000 people in six small cities that fell along a gradient of air pollution concentrations for a period of 14 to 16 years. As particle concentrations increased, there was an almost directly proportional increase in the death rate in the residents studied. Residents of the most polluted city in the study, **Steubenville**, Ohio, had a 26 percent increased risk of premature mortality, compared to the residents of the cleanest city studied, **Portage**, Wisconsin. The increased risks were associated with a difference in ambient fine particle concentrations of 18.6 micrograms per cubic meter.

The 1995 American Cancer Society study reported an association between fine particle air pollution and premature death by cardio-pulmonary and other causes in a study group of over half a million people in **151 U.S. cities**. All cause mortality increased by 17 percent with a 24.5 microgram per cubic meter difference in fine particle pollution between the cleanest and dirtiest city studied.

These original studies used statistical techniques to adjust for age, and to control for the effects of smoking, diet, and occupational exposure.

Health Effects Institute funded researchers, led by Dr. Dan Krewski of the University of Ottawa, undertook a reanalysis of the original studies and a quality audit of the underlying data. Researchers performed an extensive sensitivity analysis using alternative statistical methods, and considering the role of 20 potential confounders such as other pollutants, climate, and socio-economic factors on study results. The sensitivity analysis largely confirmed the original results of the Harvard Six Cities Study and the

American Cancer Society Study. In addition, the sensitivity analysis identified higher educational status as a factor associated with reduced risk to air pollution exposure, and reported an association between sulfur dioxide pollution and mortality.

Krewski, D., Burnett, R.R., Goldberg, M.S., Hoover, K., Siemiatycki, J., Jerrett, M., Abrahamowicz, M., White, W.H, and Others. Reanalysis of the Harvard Six Cities Study and the American Cancer Society Study of Particulate Air Pollution and Mortality. Health Effects Institute, July, 2000.

Dockery, D.W., Pope, C.A., Xu, X., Spengler, J.D., Ware, J.H., Fay, M.E., Ferris, B.G., and Speizer, F.E. An Association Between Air Pollution and Mortality in Six U.S. Cities. New England Journal of Medicine, 1993:329:1753-9.

Pope, C.A., Thun, M.J., Namboodiri, M.M., Dockery, D.W., Evans, J.S., Speizer, F.E., and Heath, C.W. Particulate Air Pollution as a Predictor of Mortality in a Prospective Study of U.S. Adults. American Journal of Respiratory Critical Care Medicine, 1995:151:669-74.

Chronic Exposure to Particulate Pollution Shortens Lives by One to Three Years

There have been two recent attempts to quantify the extent of life shortening predicted by the long-term epidemiological studies. Dutch scientist Dr. Burt Brunekreef made such an estimate in a paper prepared for the World Health Organization's consideration of revisions to the Air Quality Guidelines for Europe. Using risk ratios reported in the Harvard Six Cities Study and the Study of the American Cancer Society cohort, Brunekreef conducted a life table analysis to estimate the effect of particulate air pollution on the survival rate of 25 year-old Dutch men. An extrapolation based on U.S. life tables yields an estimated diminished life expectancy of 1.31 years due to ambient pollution.

Dr. C. Arden Pope III, of Brigham Young University, analyzed reductions in life expectancy in the U.S. population due to chronic exposure to particulate matter. He applied relative risks for premature death derived from the prospective cohort studies, and estimated loss of life expectancy ranging from one to three years, depending upon assumptions about the age at which susceptibility to the effects of air pollution begins.

Brunekreef, Burt. Air Pollution and Life Expectancy: Is There a Relation? Occup Environ Med 1997 Nov; 54(11):781-4.

Pope, C.A. III, Epidemiology of Fine Particulate Air Pollution and Human Health: Biological Mechanisms and Who's at Risk? Environ Health Persect 108 (suppl 4):713-723 (2000).

DAILY MORTALITY STUDIES

90-City National Morbidity, Mortality and Air Pollution Study (NMMAPS) Shows that Contemporary Levels of Air Pollution are Killing People

The Health Effects Institute, which is jointly funded by EPA and industry, commissioned an original nationwide study of the short-term effects of air pollution on human health, known as the National Morbidity, Mortality and Air Pollution Study, or NMMAPS. A team of investigators led by Dr. Jonathan Samet of the Johns Hopkins University School

of Public Health developed and applied a standardized methodology for examining pollution effects across many cities. Investigators from Johns Hopkins University and Harvard University developed and applied state-of-the-art statistical techniques to examine the effects of multiple pollutants, the extent of life-shortening, and the degree of "exposure measurement error" due to reliance on centrally located air quality monitors.

In its study of the **90 largest U.S. cities**, NMMAPS found strong evidence linking daily increases in particulate pollution to increases in death. On average, overall mortality increased by 0.5 percent for every 10 microgram per cubic meter increase in PM_{10} measured the day before death. The effect was slightly greater for deaths due to heart and lung disease than for total deaths. This risk ratio is somewhat lower than reported by earlier meta-analyses, perhaps due to certain methodological assumptions such as a one-day lag.

Samet et al. report that the relative increases in daily mortality partly reflect life shortening on the order of months. The association between particulate matter and mortality persists even when other pollutants are included in the statistical model. Their analyses also provide evidence against arguments that exposure measurement error could explain the associations between particulate matter and adverse health effects.

In addition, in a study of 14 U.S. cities, NMMAPS found strong and consistent associations between particulate air pollution and hospital admissions among the elderly. Hospital admissions data was obtained from the Medicare program. The cities were selected for study because they had daily PM_{10} measurements.

For each 10 microgram per cubic meter increase in PM_{10}, there was approximately a 1 percent increase in hospital admissions for cardiovascular disease, and about a 2 percent increase in admissions for pneumonia and chronic obstructive pulmonary disease. Cities studied were **Birmingham, AL, Boulder, CO, Canton, OH, Chicago, IL, Colorado Springs, CO, Detroit, MI, Minneapolis/St. Paul, MN, Nashville, TN, New Haven, CT, Pittsburgh, PA, Provo/Orem, UT, Seattle, WA, Spokane, WA, and Youngstown, OH**.

Investigators concluded that the complementary analyses of mortality and morbidity provide "*new and strong evidence*" linking particulate air pollution at current levels to adverse health effects.

Some of the results from the NMMAPS study were published in an article in the New England Journal of Medicine. Samet, et al. examined the effect of five of the most widespread outdoor air pollutants – particulate matter, ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide in 20 of the largest cities in the United States. The study was specifically designed to address many of the criticisms of earlier single-city studies. The study found consistent evidence that relatively small daily increases in particulate pollution were followed by daily increases in death rates, particularly from heart- and lung-related causes. Study authors noted that other analyses have demonstrated that the amount of life lost due to particulate pollution goes beyond just a few days. The study

investigators also reported an association between summertime ozone levels and mortality.

The New England Journal of Medicine article concludes, "*there is consistent evidence that the levels of fine particulate matter in the air are associated with the risk of death from all causes and from cardiovascular and respiratory illness. These findings strengthen the rationale for controlling the levels of respirable particles in outdoor air.*"

Samet, J.M., Dominici, F., Zeger,S.L., Schwartz, J., and Dockery, D.W. The National Morbidity, Mortality, and Air Pollution Study. Part I: Methods and Methodologic Issues. Health Effects Institute Research Report 94, Part I, May 2000.

Samet, J.M., Zeger, S.L., Dominici, F., Curriero, F., Coursac, I., Dockery, D.W., Schwartz, J., and Zanobetti, A. The National Morbidity, Mortality, and Air Pollution Study. Part II: Morbidity, Mortality and Air Pollution in the United States. Health Effects Institute Research Report 94, Part II, June 2000.

Samet, J.M., Domnici, F., Curriero, F.C., Coursac, I., and Zeger, S.L. Fine Particulate Air Pollution and Mortality in 20 U.S. Cities, 1987-1994. New England Journal of Medicine, Vol. 343, No. 24, pp. 1742-1749, December 14, 2000.

Air Pollution Effects Persist for Several Days, Increasing the Overall Risk of Exposure

Epidemiological studies have used different assumptions about the number of days following exposure to air pollution that effects will occur. Some studies have assumed that effects occur the day after exposures. However, toxicological evidence suggests that effects of exposure may be observed over several subsequent days. In an analysis using data from **New Haven, Birmingham, Pittsburgh, Canton, Detroit, Chicago, Minneapolis, Colorado Springs, Spokane, and Seattle**, Dr. Joel Schwartz, of the Harvard School of Public Health, has shown that statistical models that assume a one day lag, such as NMMAPS, grossly underestimate the effect of PM_{10} on mortality. Assuming that effects continue over several days, as demonstrated by this analysis, roughly doubles the relative risk of premature mortality.

Schwartz, Joel. The Distributed Lag Between Air Pollution and Daily Deaths. Epidemiology 2000;11:320-326).

$PM_{2.5}$ from Motor Vehicles and Coal Combustion is Linked to Increased Mortality

Investigators from Harvard Medical School used data on the elemental composition of size-fractionated particles to identify the sources of fine particles in six eastern U.S. cities that have been the subject of a long-term air pollution study: **Watertown, MA, Kingston-Harriman, TN, St. Louis, MO, Steubenville, OH, Portage, WI, and Topeka, KS.** For example, lead was used as a tracer for motor vehicle exhaust, selenium for coal combustion, and silicon for soil and crustal matter. Each of these fractions was examined in association with daily mortality rates in each city. The study reported that a 10 $\mu g/m^3$ increase in $PM_{2.5}$ from mobile sources accounted for a 3.4% increase in daily mortality, while the equivalent increase in fine particles from coal combustion sources

accounted for a 1.1% increase. Fine particles from crustal sources were not associated with mortality. The study concludes that "*the results indicate that combustion particles in the fine fraction from mobile and coal combustion sources, but not fine crustal particles, are associated with increased mortality.*"

Laden, F. Neas, L.M., Dockery, D.W., and Schwartz, J. Association of Fine Particulate Matter from Different Sources with Daily Mortality in Six U.S. Cities. Environmental Health Perspectives 108:941-947, October 2000.

Daily Mortality Studies Pour In From Cities Around the World

Studies in new locations and by additional investigators with consistent results help strengthen the case for a causal relationship.

EPA's 1996 review of the PM standards cited over two dozen short-term epidemiological studies. Since then, time series studies reporting an association between short-term exposure to particulate matter and early mortality have been published for these U.S. cities: **Philadelphia; Ogden, Salt Lake City**, and **Provo/Orem, Utah; Seattle; Santa Clara County, California;** and **Buffalo**. Additional studies have been published for these major cities all over the world: **Toronto; Mexico City; London; Edinburgh; Birmingham, UK; Rotterdam; Helsinki; Madrid; Rome; Milan; Brisbane; Sydney; Delhi; Bangkok;** and **Seoul** and **Ulsan, Korea**. Many of the new studies have evaluated the sensitivity of the estimated PM effects to the inclusion of other pollutants in the statistical model. Overall, the associations of PM with adverse effects continue to be consistently observed, and sometimes, effects of other air pollutants such as ozone, sulfur dioxide, nitrogen dioxide, and carbon monoxide are also reported.

A multi-city study of the short-term health effects of air pollution on mortality and hospital emergency admissions was initiated by the European Union Environment Programme. The study, known as Air Pollution and Health: A European Approach or APHEA, investigated the effects of several pollutants on mortality in 12 European cities. The study reported positive associations with sulfur dioxide and PM_{10}, and daily increases in mortality, with stronger and more consistent associations observed in western European cities.

A quantitative meta-analysis by Jonathan Levy et al. of the Harvard School of Public Health set out to compare mortality estimates from over twenty daily time series studies. Their analysis estimated that mortality rates increased by approximately 0.7 percent per 10 microgram per cubic meter increase in PM_{10} concentrations. Investigators reported "*our model finds compelling evidence that the PM_{10}-mortality relationship is stronger in locations with higher $PM_{2.5}/PM_{10}$ ratios, supporting the hypothesized role of fine particles.*"

U.S. EPA Office of Research and Development. Air Quality Criteria for Particulate Matter. EPA/600/P-99/002b, Oct. 1999, External Review Draft.

Katsouyanni, K., Touloumi, G., Spix, C., Schwartz, J., Balducci, F., Medina, S., Rossi, G., Wojtyniak, B., Sunyer, J., Bacharova, L., Schouten, J.P., Ponka, A., and Anderson, H.R. Short Term Effects of Ambient Sulphur Dioxide and Particulate Matter on Mortality in 12 European Cities: Results From Time Series Data From the APHEA Project. British Medical Journal 1997; 314:1658 (7 June).

Levy, J. I., Hammitt, J.K., and Spengler, J.D. Estimating the Mortality Impacts of Particulate Matter: What can be Learned from Between-Study Variability? Environ Health Perspect 108:109-117(2000).

"HARVESTING" THEORY DISPROVEN

Mortality Reported in Short Term Community Health Studies is Not Due to "Harvesting"

Numerous short-term epidemiological studies have reported that short-term increases in air pollution are followed by an increased number of deaths. Some have argued that the associations between day to day variations in mortality and air pollution represent a "harvesting" effect, that is, the advancement of death by a few days in people already about to die from other causes. If air pollution advances death of the very frail by only a few days (the "harvesting" hypothesis), then you would expect that an increase in daily deaths would be followed by a decrease in deaths within a few days.

Professors Scott Zeger and Francesca Dominici of the Johns Hopkins School of Public Health developed a statistical technique to examine harvesting using data on total suspended particulate matter (TSP) and total mortality in **Philadelphia**. They found that removing the shortest term fluctuations from their time series increased rather than decreased the estimates of pollution effects. This is the opposite of what would be expected if "harvesting" accounted for all the deaths.

As part of the NMMAPS study, Dr. Joel Schwartz of the Harvard School of Public Health studied this issue using data from **Boston**. He reported that for chronic obstructive pulmonary disease and ischemic heart disease, most of the deaths seem to be advanced by a few months on average. The statistical approach did not allow estimates of life shortening beyond two months. In contrast, for pneumonia, the analysis showed that some deaths are brought forward by a few days, consistent with the harvesting hypothesis. Effect estimates increased when examining longer time periods, suggesting that cumulative exposures are more harmful than daily exposures. Overall, these results suggest that the short-term epidemiological studies underestimate the number of early deaths.

Zeger, S.L., Dominici, F, and Samet, J. Harvesting-Resistant Estimates of Air Pollution Effects on Mortality. Epidemiology 1999 Mar;10(2):171-5.

Schwartz, Joel. Harvesting and Long Term Exposure Effects in the Relation between Air Pollution and Mortality. Am J Epidemiol 2000; 151:440-8.

Most Air Pollution Related Deaths Are Being Advanced By Months to Years

While the association between particulate air pollution and mortality is generally acknowledged to be causal, critics have claimed that the public health impact is minor, because people are dying just a few days early. This theory is sometimes called "harvesting." This study is based on an examination of daily deaths and hospital admissions in **Chicago** for the years 1988-1993. If people are dying a few days early, then the death rate should drop a few days after the air pollution event. The analysis shows that this is not the case. The results confirm findings previously reported for **Boston and Philadelphia**, using a different methodology. The author concludes that the results indicate that air pollution may be increasing the overall number of people at risk of death, and that most of the deaths are being advanced by months to years.

Schwartz, Joel. Is There Harvesting in the Association of Airborne Particles with Daily Deaths and Hospital Admissions. Epidemiology, Vol. 12, No. 1, pp 56-61, January 2001.

PM-MORTALITY RELATIONSHIP IS LINEAR, WITH NO THRESHOLDS

No Threshold is Evident for the Effect of PM_{10} on Daily Deaths

In the Schwartz and Zanobetti study, Harvard University researchers applied a statistical method to examine the shape of the dose-response relationship between air pollution and daily deaths in ten U.S. cities. The cities studied were **New Haven, Birmingham, AL, Pittsburgh, Detroit, Canton, OH, Chicago, Minneapolis-St. Paul, Colorado Springs, Spokane,** and **Seattle**. Simulation studies demonstrated that the method used can detect threshold and other nonlinear relationships in epidemiologic studies. But when used to analyze the association between PM_{10} and mortality, no evidence of a threshold was found, and the associations appeared to be linear down to the lowest levels studied. This is consistent with earlier results.

An analysis of data for the 20 largest U.S. cites from 1987-1994 from the NMMAPS study also reported that a linear model, without a threshold, was most appropriate for assessing the effects of particulate air pollution on daily mortality for total mortality and for mortality from cardiovascular and respiratory causes, but not for other causes of mortality. Daniels et al conclude: "*...the continued demonstration of adverse effects of air pollution over recent decades, even as concentrations of pollutants have declined, suggests that exposures have not yet gone below no-effects thresholds, if such exist.*"

Schwartz, Joel and Zanobetti, Antonella. Using Meta-Smoothing to Estimate Dose-Response Trends across Multiple Studies, with Application to Air Pollution and Daily Death. Epidemiology, Vol. 11, No. 6, pp. 666-672, November 2000.

Daniels, M.J., Dominici, F., Samet, J.M., and Zeger, S.L. Estimating Particulate Matter-Mortality Dose-Response Curves and Threshold Levels: An Analysis of Daily Time-Series for the 20 Largest U.S. Cities. American Journal of Epidemiology, Vol. 152, No. 5, pp. 397-406, September 1, 2000.

EXPOSURE MEASUREMENT ERROR CRITICISM REFUTED

Air Quality Monitors Can Be Used to Track Exposure to Fine Particles

Epidemiological studies generally rely on centrally located air quality monitors to assess exposure to ambient air pollutants. Some have argued that these monitors do not represent actual exposures, because people spend a large portion of their day indoors.

A study by Dutch scientist Nicole Janssen et al., of 10 – 12 year old school children in **Wageningen, The Netherlands** compared personal exposure to fine particles with classroom concentrations, and with ambient measurements at an outdoor location. Researchers found that personal fine particle concentrations were highly correlated with ambient concentrations. This finding supports the use of ambient monitoring measurements as an indicator of exposure to fine particles in epidemiological time series studies.

Dr. David Mage, of U.S. EPA's Office of Research and Development, and colleagues, demonstrated that human exposure to fine particles of ambient origin is highly correlated in time to ambient PM concentrations measured at monitoring stations within the communities being studied.

The NMMAPS study discussed above also addressed the issue of measurement error, through the development of a model to systematically test what effect the relationship between personal exposure and ambient exposure might have on the observed increase in mortality associated with PM. While data to test the model is limited, "*theoretical and actual analyses generated appear to refute the criticisms that exposure measurement error could explain the associations between PM and adverse health effects.*"

Janssen, N.A.H., Hoek, G., Narssema, H., and Brunekreef, B. Personal Exposure to Fine Particles in Children Correlates Closely with Ambient Fine Particles. Archives of Environmental Health, March/April 1999, Vol. 54, No., 2, 95-101.

Mage, D., Wilson, W., Hasselblad, V., Grant, L. Assessment of Human Exposure to Ambient Particulate Matter. J. Air & Waste Manage. Assoc. 49:1280-1291, Nov. 1999.

Zeger, S.L., Thomas, D., Dominici, F., Samet, J.M., Schwartz, J., Dockery, D.W., and Cohen, A. Exposure Measurement Error in Time-Series Studies of Air Pollution. In: The National Morbidity, Mortality, and Air Pollution Study, Part I: Methods and Methodologic Issues. HEI Research Report 94, May 2000.

Criteria for Asserting Causality Have Been Met

In responding to an article by Dr. John Gamble, Epidemiologist for Exxon Biomedical Sciences, Dr. David Bates, Professor Emeritus of Medicine at University of British Columbia, has re-evaluated the recent evidence health evidence regarding particulate matter and mortality. Determination of causality does not rest on any one study. Instead, a weight of evidence approach is used to evaluate the scientific literature across a series of criteria such as coherence, consistency, strength of association, temporality, analogy, and biologic plausibility. Dr. Bates asserts that all of these criteria have been met by an avalanche of new data that strengthen the case for a causal relationship.

Bates, D.V. Lines that Connect: Assessing the Causality Inference in the Case of Particulate Pollution. Environ Health Perspect 108: 91-92: 2000.

Gamble, John F. $PM_{2.5}$ and Mortality in Long-term Prospective Cohort Studies: Cause-Effect or Statistical Associations? Environ Health Perspect 106:535-549 (1998).

Kunzli, N. and Tager, I.B. Comments on "$PM_{2.5}$ and Mortality in Long-term Prospective Cohort Studies: Cause-Effect or Statistical Associations?" and Gamble, John. Reply to Kunzli and Tager Regarding Causality in $PM_{2.5}$ Cohort Studies. Environ Health Perspect 107-5, 1999; Correspondence.

People With Pre-Existing Cardiac or Respiratory Conditions Have Higher Than Average Risk of Death from Exposure to Particles

Canada's national health insurance system enables access to detailed health records of patients. This permitted Dr. Mark Goldberg and colleagues at McGill University to conduct a detailed analysis of particle pollution and mortality in **Montreal**. Investigators were able to link individual deaths in Montreal to medical information up to five years before death. These data were used in conjunction with clinical expertise to define susceptible subgroups at risk of premature death from several different measures of particulate pollution. Subjects with acute lower respiratory disease, congestive heart failure, and a combination of cardiovascular diseases died at higher rates for increases in each of the three particulate matter measures. Associations with coefficient of haze and predicted $PM_{2.5}$ were reported for subjects with cancer, chronic coronary artery disease, and coronary artery disease, while effects of sulfate were associated with acute and chronic upper respiratory disease.

Goldberg, M.S., Bailar, J.C. III, Burnett, R.T., Brook, J.R., Tamblyn, R., Bonvalot, Y., Ernst, P., Flegel, K.M., Singh, R.K., and Valois, M-F. Identifying Subgroups of the General Population That May be Susceptible to Short-Term Increases in Particulate Air Pollution: A Time-Series Study in Montreal, Quebec. Health Effects Institute, Research Report Number 97, October 2000.

"Coarse" Particles are Also Linked with Disease and Death

This study by Dr. Morton Lippmann and colleagues from the New York University School of Medicine attempted to identify components of particulate matter and other air pollution mixtures that were associated with excess daily deaths and hospital admissions of the elderly in the **Detroit** metropolitan area. Investigators reported that deaths from repiratory diseases were associated with PM_{10} and total suspended particulates. Unexpectedly, they found that relative risks for $PM_{10\text{-}2.5}$, the coarse particle fraction, were similar to those for $PM_{2.5}$, and even higher in the case of ischemic heart disease and stroke. The authors conclude that "*the finding of elevated and significant effects for $PM_{10\text{-}2.5}$ suggests that there may still be a rationale to consider the health effects of the coarse fraction as well as the fine fraction of PM.*"

Lippmann, M., Ito, K., Nádas, A., and Burnett, R.T. Association of Particulate Matter Components with Daily Mortality and Morbidity in Urban Populations. Health Effects Institute Research Report Number 95, August 2000.

BIOLOGIC MECHANISMS AND CARDIAC EFFECTS

Air Pollution Tied to Low Heart Rate Variability, a Risk Factor for Heart Attacks

Particulate air pollution has been linked to cardiovascular mortality in a number of studies, but the mechanisms for this effect are not well understood. Recent research centers on the effect of pollution on heart rate and heart rate variability. Low heart rate variability is a marker of poor cardiac control by the autonomic nervous system, and is associated with a higher risk of heart attacks and sudden cardiac death. One hypothesis is that inhalation of particle air pollution may trigger an inflammatory response in the lung, followed by the release of chemical mediators that affect autonomic nervous system control of the heart beat.

Pope, et al. measured oxygen saturation and pulse rate in a panel of 90 elderly residents of the **Utah Valley**, using a small medical device known as an oximeter. The experiment was conducted during the winter months, when PM concentrations are highest. Researchers found little evidence of pollution effects on the oxygen carrying capacity of the blood, but observed that a small elevation in pulse rate was associated with a rise in PM_{10} levels. The medical and biological relevance of this effect is unclear.

Dr. Duanping Liao, of the University of North Carolina, and co-investigators, conducted daily electrocardiogram measurements on elderly nursing home residents outside **Baltimore**, Maryland. Harvard physician Dr. Diane Gold et al. studied 53- to 87- year old active residents of **Boston**. 25 minutes of electrocardiogram measurements during different exercise states were taken on a weekly basis. Both the Baltimore and Boston studies found that elevated concentrations of fine particulate matter were associated with lower heart rate variability, and that the association was stronger for people with pre-existing cardiovascular conditions.

Pope, C.A., Dockery, D.W., Kanner, R.E., Villegas, G.M., and Schwartz, J. Oxygen Saturation, Pulse Rate, and Particulate Air Pollution: A Daily Time-Series Panel Study. Am J Respir Crit Care Med 1999; 159:363-372.

Liao, D., Creason, J., Shy, C., Williams, R., Watts, R., and Zweidinger, R. Daily Variation of Particulate Air Pollution and Poor Cardiac Autonomic Control in the Elderly. Environ Health Perspect 107:521-525 (1999).

Gold, D.R., Litonjua, A., Schwartz, J., Lovett, E., Larson, A. Nearing, B., Allen, G., Verrier, M., Cherry, R., and Verrier, R. Ambient Pollution and Heart Rate Variability. Circulation. 2000;101:1267.

Stone, P.H. and Godleski J.J. First Steps Toward Understanding the Pathophysiologic Link Between Air Pollution and Cardiac Mortality. Am Heart J 1999;138:803-7.

Increased Heart Rate and Plasma Viscosity During an Air Pollution Episode Suggest Possible Mechanisms

The World Health Organization Monitoring Survey of Trends and Determinants in Cardiovascular Disease (the "MONICA" survey) took place in **Augsburg**, in Southern Germany during the winter of 1984-1985. Over 4,000 randomly selected adults

participated, and received electrocardiograms to measure their resting heart rate, and donated blood samples to measure plasma viscosity. Electrocardiograms were administered again in 1987-1988.

In January 1985, an air pollution episode occurred throughout central Europe, with elevated concentrations of sulfur dioxide, total suspended particulates, and carbon monoxide. During the air pollution episode, higher heart rates were observed for men and women, after adjusting for cardiovascular risk factors and weather. An elevated resting heart rate is a risk factor for death and fatal heart disease, and may signal changes in the autonomic control of the heart, that might partially account for the adverse health effects observed in association with air pollution.

One hypothesis is that increased plasma viscosity might lead to constricted blood flow in the heart (ischemia), which can be fatal in people with severe coronary heart disease. During the air pollution episode, increases in plasma viscosity were observed, and persisted after adjusting for other cardiovascular risk factors and weather. German researcher Annette Peters, et al. conclude that "*the increased plasma viscosity observed in these analyses of a cross-sectional survey might therefore represent a part of the pathophysiological chain linking high ambient air pollution to increased mortality and hospital admissions for cardiovascular diseases.*"

An alternate hypothesis is proposed by Professsor Anthony Seaton of the University of Aberdeen Medical School. He collected blood samples from 112 elderly people in two cities in the U.K. over an 18-month period, and examined various blood values in comparison to PM_{10} concentrations. Based on the analysis, Seaton suggests that inhalation of some component of PM_{10} may cause sequestration of red blood cells, which may explain the cardiovascular effects reported in other studies.

Peters, A., Perz, S., Doring, A., Stieber, J., Koenig, W., and Wichmann, H.E. Increases in Heart Rate During an Air Pollution Episode. Am J Epidemiol 1999; 150:1094-8.

Peters A., Doring A., Wichmann H.E., and Koenig, W. Increased Plasma Viscosity During an Air Pollution Episode: A Link to Mortality? Lancet 1997 May 31; 349(9065):1582-7.

Seaton, A., Soutar A., Crawford, V., Elton, R., McNerlan, S., Cherrie, J., Watt, M., Agius, R., Stout, R. Particulate Air Pollution and the Blood. Thorax 1999 Nov;54(11):1027-32.

Heart Patients Vulnerability to Potentially Fatal Arrhythmias Increases After Exposure to Air Pollution

A pilot study was designed to test the hypothesis that heart patients with a history of serious arrhythmia requiring implanted cardiac defibrillators experience potentially life-threatening arrhythmias following short term increases in air pollution. Defibrillators monitor electrical activity of the heart and initiate interventions such as pacing or shock therapy to restore a normal heartbeat. The devices record information on arrhythmic events.

One hundred heart patients in **eastern Massachusetts** were followed for a three-year period. The study found that a subgroup of these patients -- those with more than ten defibrillator events -- were most susceptible to pollution, with effects occurring one to two days after exposure. Among these patients, the strongest associations were with nitrogen dioxide, but positive associations were reported for PM_{10} and $PM_{2.5}$ exposures as well.

Peters, A., Liu, E., Verrier, R.L., Schwartz, J., Gold, D.R., Mittleman, M., Baliff, J., Oh, J.A., Allen, G., Monahan, K., and Dockery, D.W. Air Pollution and Incidence of Cardiac Arrhythmia. Epidemiology 2000 Jan; 11(1):11-7.

Combustion Source Metals May Trigger Biologic Responses to Ambient Particulate Matter

Researchers have been trying to determine whether one component of particulate matter – such as metals – is responsible for the toxic effects. U.S. EPA investigators led by Dr. Daniel Costa obtained samples of particulate matter from oil and coal fly ash and ambient air from **St. Louis, MO**, **Washington, DC**, **Dusseldorf, Germany**, and **Ottawa, Canada**. The fly ash is rich in metal components such as iron, copper, nickel, vanadium, and zinc, as well as sulfate. Laboratory rats were instilled with PM samples from these sources, and lung cells were obtained via bronchoalevolar lavage and analyzed for signs of cell injury. Investigators found that the constituent metals and their bioavailability determine the acute inflammatory response of PM samples in lung tissue.

In a second experiment, rats were pretreated with a chemical intended to model certain disease conditions, namely inflammation of blood vessels and high blood pressure in the lungs. These animals were instilled with the fly ash samples, and lung cells were obtained for laboratory examination. After 96 hours of exposure, there was clear evidence of lung inflammation, however many of the test animals had died, apparently due to altered cardiac function. Survivors had increased electrocardiographic changes. Investigators hypothesize that soluble metals from PM mediate an array of injuries to the cardiopulmonary system of healthy and at-risk subjects.

Costa, D. L., and Dreher, K.L. Bioavailable Transition Metals in Particulate Matter Mediate Cardiopulmonary Injury in Healthy and Compromised Animal Models. Environ Health Perspect 105(Suppl 5):1053-1060 (1997).

Laboratory Research on Dogs Suggests that PM May Harm People with Heart Disease

This toxicology study by Harvard pathologist Dr. John Godleski is one of the first to test whether exposure to particulate matter can change heart function in laboratory animals. Two groups of dogs were tested – healthy dogs, and dogs with an induced coronary occlusion intended to simulate human coronary artery disease. Researchers exposed dogs to concentrated particles from the ambient **Boston** air. Both the normal and the compromised animals showed effects, but the clearest sign of PM effects was found in the dogs with the induced heart condition. The occluded animals were more susceptible

to serious arrhythmias when exposed to air pollution. The electrocardiogram signals for these dogs indicated more rapid development of ischemia, an inadequate flow of blood through the heart that can lead to a heart attack. Study reviewers concluded: *"this is a plausible and important mechanism to explain the association of increased cardiopulmonary mortality and exposure to particle pollution."*

Godleski, J.J., Verrier, R.L., Koutrakis, P., and Catalano, P. Mechanisms of Morbidity and Mortality from Exposure to Ambient Air Particles. Health Effects Institute Research Report Number 91, February 2000.

Concentrated Air Particles Induce Pulmonary Inflammation and Blood Changes in Humans

Effects of particles are showing up not only in laboratory animals, but also in a chamber study with human subjects performed by EPA research physician Dr. Andrew Ghio and colleagues. This controlled exposure study of young, healthy volunteers examined the effect of exposure to concentrated ambient particles from **Chapel Hill**, North Carolina. Volunteers alternated between moderate exercise and rest over a two-hour period in a chamber with high particle concentrations. No symptoms or decrements in pulmonary function were noted. However, eighteen hours after exposure, lung tissue had a higher concentration of neutrophils, a marker of inflammation. Blood work indicated a higher concentration of fibrinogen, which is a risk factor for clotting and heart attacks.

Ghio, A.J., Kim, C., and Devlin, R.B. Concentrated Ambient Air Particles Induce Mild Pulmonary Inflammation in Healthy Human Volunteers. In Press.

HOSPITAL AND EMERGENCY ROOM VISITS

Air Pollution May Account for Five Percent of Cardiac Hospital Admissions

Numerous studies have focused on mortality because it is an easy to measure effect for which data is readily available. It is important to note that early deaths represent just the tip of the iceberg of particulate related health effects. For each death, there are many more people admitted to the hospital, and for each hospital admission, many more visits to emergency departments and doctors offices. Similarly, for each patient who visits an emergency clinic, many more experience uncomfortable respiratory symptoms or days when they must restrict their activity, increase their use of medication, or remain indoors.

Increased hospital admission rates represent one of the most serious effects of air pollution. This study examined the association between PM_{10}, carbon monoxide, and hospital admissions of the elderly for heart disease across eight urban counties with different pollution and weather profiles. The eight locations are: **Chicago**; **Colorado Springs**; **New Haven**; **Minneapolis**; **St. Paul**; **Seattle**; **Spokane**; and **Tacoma**. The study design was intended to minimize confounding by weather or other pollutants. Associations of both PM_{10} and CO with cardiovascular hospital admissions were observed in areas with widely varying correlations between these pollutants and weather factors or other air pollutants. Overall, the results suggest that air pollution may be

responsible for five percent of hospital admissions for heart disease, representing an enormous public health impact.

Schwartz, Joel. Air Pollution and Hospital Admissions for Heart Disease in Eight U.S. Counties. Epidemiology 1999; 10:17-22).

Emergency Room Visits for the Respiratory Illness in the Elderly Linked to Air Pollution

Consistent with reports of aggravated symptoms in those with chronic respiratory conditions, a study in **Montreal, Canada** found strong associations between air pollution and emergency room visits for patients over 64 years of age during 1993, when more data were available. Positive associations were reported for ozone, PM_{10}, $PM_{2.5}$, and sulfate, at air pollution levels well below the U.S. air quality standards. The elderly are especially susceptible to the effects of air pollution.

The NMMAPS study, discussed above, reported strong and consistent associations between particulate air pollution and hospital admissions among the elderly for cardiovascular disease, pneumonia, and chronic obstructive pulmonary disease.

Delfino, R.J., Murphy-Moulton, A.M., Burnett, R.T., Brook, J.R., and Becklake, M.R. Effects of Air Pollution on Emergency Room Visits for Respiratory Illnesses in Montreal, Quebec. Am J Respir Crit Care Med 1997; 155:568-576.

Pre-Existing Cardiovascular Disease Increases the Risk of PM-Related Hospital Admissions for Respiratory Causes

This ten-year study of Medicare patients in **Chicago** was designed to identify subgroups that are especially susceptible to particulate pollutions. Researchers examined records of previous hospital admissions and secondary diagnoses to determine wither people with certain conditions were predisposed to having a greater risk from air pollution. Investigators found that people with asthma had double the risk of a PM_{10}-associated hospital admission, and that people with heart failure had double the risk a PM_{10}-induced COPD admission. The authors conclude, "*the results suggest that patients with acute respiratory infections or defects in the electrical control of the heart are a risk group for particulate matter effects.*"

Zanobetti, A., Schwartz, J., and Gold, D. Are There Sensitive Subgroups for the Effects of Airborne Particles? Environmental Health Perspectives Vol. 108, No. 9, pp. 841-845, September 2000.

INFANT MORTALITY AND EFFECTS ON CHILDREN

Growth in Children's Lung Function is Slowed by Air Pollution

Researchers with the Children's Health Study led by the University of Southern California have monitored levels of major air pollutants in a dozen southern California communities since 1993, while tracking the respiratory health of more than 3,000 school age children. The twelve communities, which fell along a gradient of air pollution levels, were all within a 200-mile radius of Los Angeles. The California towns studied were **Alpine, Atascadero, Lake Arrowhead, Lake Elsinore, Lancaster, Lompoc, Long Beach, Mira Loma, Riverside, San Dimas, Santa Maria, and Upland.**
In fourth-graders, significant deficits in growth of lung function were associated with various measures of fine particles (PM_{10}, $PM_{2.5}$, and $PM_{10-2.5}$), nitrogen dioxide, and inorganic acid vapor, but not with ozone. The deficits were larger for children that spent more time outdoors. "*This is the best evidence yet of a chronic effect of air pollution in children,*" said Dr. John Peters, University of Southern California professor of preventative medicine and one of the study authors. The study concluded that "*the results suggest that exposure to air pollution may lead to a reduction in maximal attained lung function, which occurs early in adult life, and ultimately to increased risk of chronic respiratory illness in adulthood.*"

Gauderman, J.W., McConnell, R., Gilliland, F., London, S., Thomas, D., Avol, E., Vora, H., Berhane, K., Rappaport, E.B., Lurmann, F., Margolis, H.G., and Peters, J. Association between Air Pollution and Lung Function Growth in Southern California Children. American Journal of Respiratory and Critical Care Medicine, Vol. 162. pp 1383-1390, 2000.

Doctor Visits Climb In Relation to Air Pollution

In **Paris, France**, doctors still make house calls, and public records on the reason for the visits are available through the French national health insurance program. This enabled investigators to examine a significant but understudied health endpoint, doctor visits, that affects a much larger number of patients than those admitted to hospitals or treated in emergency departments of hospitals. The statistical model of daily air pollution effects used in this study controlled for season, pollen counts, influenza epidemics and weather. Medina et al. report that house calls for asthma for children 0-14 years old showed the strongest association with air pollution.

Medina, S., Le Tertre, A., Quenel, P., Le Moullec, Y., Lameloise, P., Guzzo, J.C., Festy, B., Ferry, R., and Dab, W. Air Pollution and Doctors' House Calls: Results from the ERPURS System for Monitoring the Effects of Air Pollution on Public Health in Greater Paris, France, 1991-1995. Environmental Research 75, 73-84, 1997.

Air Pollution May Contribute to Infant Mortality

A small but growing body of literature suggests that air pollution may contribute to infant mortality. British scientists Bobak and Leon analyzed infant mortality and several measures of long-term exposure to air pollutants in highly polluted regions of the **Czech Republic**. They found a consistent, positive association between PM_{10} levels and post neonatal infant mortality from respiratory causes, after controlling for socioeconomic factors and other pollutants.

Dr. Dana Loomis, of the University of North Carolina, and co-workers found that air pollution is associated with acute increases in infant mortality in **Mexico City** after controlling for temperature and other factors. Increases in fine particles, ozone and nitrogen dioxide resulted in an increased number of infant deaths 3 to 5 days later. The effect of particles was the most consistent and the least sensitive to the presence of other pollutants.

A study by EPA scientist Dr. Tracey Woodruff et al., of **86 cities** in the **United States** reported an association between infant mortality and the level of inhalable particles in the first two months of life.

Bobak, M. and Leon, D.A. The Effect of Air Pollution on Infant Mortality Appears Specific for Respiratory Causes in the Postneonatal Period. Epidemiology 1999;10:666-670.

Loomis, D., Castillejos, M., Gold, D.R., McDonnell, W., and Borja-Aburto, V.H. Air Pollution and Infant Mortality in Mexico City. Epidemiology 1999; 10:118-123.

Woodruff, T.J., Grillo, J., and Schoendorf, K.C. The Relationship Between Selected Causes of Postneonatal Infant Mortality and Particulate Air Pollution in the United States. Environ Health Perspect 1997; 105:607-612.

Air Pollution In Highly Polluted Regions May Cause Low Birth Weight Infants

Low birth weight is the most important predictor for neonatal mortality in developed and developing countries, and is a significant determinant of infant health and survival. A large study in **Beijing, China** looked at maternal exposure to air pollution during pregnancy and subsequent birth weight of infants. Coal stoves used for heating and cooking are a major source of indoor and outdoor air pollution in the study region. Xiaobin Wang of the Boston University School of Medicine and colleagues found a significant exposure-response relationship between maternal exposure to sulfur dioxide and total suspended particles during the third trimester of pregnancy and low birth weight.

Wang, X., Ding, H., Ryan, L., and Xu, X. Association Between Air Pollution and Low Birth Weight: A Community-Based Study. Environ Health Perspect (1997); 105:514-520.

ASTHMA EXACERBATION

Children's Emergency Room Visits for Asthma Increase on High Air Pollution Days

"*Asthma is the most common chronic illness in children and the cause of most school absences,*" state Norris et al., in their study of children's emergency department visits for asthma. University of Washington investigators found significant associations between pediatric hospital visits for asthma and increased daily concentrations of PM and carbon monoxide in **Seattle**. Significantly, exacerbation of asthma was evident even when daily $PM_{2.5}$ concentrations were substantially below the level of the newly adopted National Ambient Air Quality Standard of 15 ug/m^3 annually.

In perhaps the largest study of pediatric asthma visits to date, Dr. Paige Tolbert, of the Rollins School of Public Health at Emory University, and co-investigators, obtained data on emergency department visits for three summers from seven large **Atlanta** area hospitals. The study included information on a variety of pollutants including spatial resolution of ozone data, a broad range of exposure levels, and a balanced distribution of socioeconomic status in the study population.

Increases in both ozone and particulate matter were found to heighten the risk of pediatric emergency room visits for acute asthma. According to the authors, "*the study suggests continuing health risks at pollution levels that commonly occur in many U.S. cities,*" and "*supports accumulating evidence regarding the relation of air pollution to childhood asthma exacerbation.*"

Norris, G., YoungPong, S.N., Koenig, J.Q., Larson, T.V., Sheppard, L., and Stout, J.W. An Association Between Fine Particles and Asthma Emergency Department Visits for Children in Seattle. Environ Health Perspect 107:489-493 (1999).

Tolbert, P.E., Mulholland, J.A., MacIntosh, D.D., Xu, F., Daniels, D., Devine, O.J., Carlin, B.P., Klein, M., Dorley, J., Butler, A.J., Nordenberg, D.F., Frumkin, H., Ryan, P.B., and White, M.C. Air Quality and Pediatric Emergency Room Visits for Asthma in Atlanta, Georgia. Am J Epidemiol 2000;151:798-810.

Children with Asthma are More Susceptible to Respiratory Effects

Increased particle concentrations have been associated with acute reductions in lung function and increased symptom reporting in children, including children with asthma. Dr. Sverre Vedal, Professor of Medicine at the University of British Columbia, and co-workers followed a group of 2,200 elementary school children in a pulp mill community on **Vancouver Island,** in Canada. Concentrations of potentially important copollutants such as sulfur dioxide, ozone, and acid aerosol were very low in the study community.

Vedal et al. found that children experience declines in peak expiratory flow, a measure of respiratory function, and increased symptoms such as cough, phlegm production, and sore throat, after increases in relatively low 24-hour PM_{10} concentrations. Children with asthma were found to be more susceptible to these effects than other children.

Vedal, S., Petkau, J., White, R., and Blair, J. Acute Effects of Ambient Inhalable Particles in Asthmatic and Nonasthmatic Children. Am J Respir Crit Care Med 1998, Vol. 157, No. 4, 1034-1043.

Children's Asthma Symptoms Increase on High Pollution Days

This study followed a group of 133 children with mild to moderate asthma, ages 5-13, in the **Seattle**, Washington area. Daily reports of asthma symptoms were obtained from study diaries and compared with daily air pollution levels during 1994 and 1995. Researchers found that a 30 percent increase in symptoms for each 10 $\mu g/m^3$ increase in $PM_{1.0}$ and an 18 percent increase in symptoms for a 10 $\mu g/m^3$ increase in PM_{10}. Effects were also increased with carbon monoxide increases, which authors assume serves as a marker for vehicle exhaust. Study authors conclude: "*These results for daily symptoms*

complement the other Seattle-area studies that found air pollution health effects for emergency department visits and hospital admissions. Taken together, these studies suggest that the health effects among asthmatics from short-term changes in air pollution levels are an important public health problem."

Yu, O., Sheppard, L., Lumley, T., Koenig, J.Q., and Shapiro, G.G. Effects of Ambient Air Pollution on Symptoms of Asthma in Seattle –Area Children Enrolled in the CAMP Study. Environmental Health Perspectives, Vol. 108, No. 12, pp. 1209-1214, Dec. 2000.

Particulate Pollution Worsens Bronchitis in Asthmatic Children

A University of Southern California School of Medicine study of more than 3,600 fourth, seventh and tenth grade children relied on parent questionnaires to identify children with pre-existing asthma or wheeze, and to assess their bronchitic symptoms. The students lived in **12 communities in Southern California** with a broad range of air pollution levels: **Alpine; Atascadero; Lake Elsnore; Lake Gregory; Lancaster; Lompoc; Long Beach; Mira Loma; Riverside; San Dimas; Santa Maria; and Upland, California.** Children with asthma were much more likely than other children to experience bronchitis and phlegm in relation to PM_{10} exposures.

McConnell, R., Berhane, K., Gilliland, F., London, S.J., Vora, H., Avol, E., Gauderman, W.J., Margolis, H.G., Lurmann, F., Thomas, D.C., and Peters, J.M. Air Pollution and Bronchitic Symptoms in Southern California Children with Asthma. Environ Health Perspect 107:757-760 (1999).

Peters, J.M., Evol, E., Navidi, W., London, S.J., Gauderman, W.J., Lurmann, F., Linn, W.S., Margolis, H., Rappaport, E., Hong, J. Jr., and Thomas, D.C. A Study of Twelve Southern California Communities with Differing Levels and Types of Air Pollution; I. Prevalence of Respiratory Morbidity. Am J Respir Crit Care Med 1999; 159L760-767.

Etzel, Ruth A. Research Highlights: Air Pollution and Bronchitic Symptoms in Southern California Children With Asthma. Environ Health Perspect Vol. 107, No. 9, September 1999.

Cleaning Up Air Pollution Improves the Respiratory Health of Children

A rather dramatic improvement in air quality in East Germany occurred following the German reunification in 1990. Researchers wanted to study if the declines in air pollution had produced a corresponding improvement in health, and they focused in on a cohort of first-, third-, and sixth-grade children in three East German communities. During the study period, bronchitis, ear infections, and frequent colds were dramatically reduced. Authors found that "*the prevalence of nonasthmatic respiratory symptoms and diseases was higher in children living in more polluted communities, especially with respect to TSP and SO_2, suggesting that disease occurrence may be reduced within a short period by improvement in air quality.*"

Heinrich, J., Hoelscher, B., and Wichmann, H.E. Decline of Ambient Air Pollution and Respiratory Symptoms. American Journal of Respiratory and Critical Care Medicine, Vol. 161, pp. 1930-1936, 2000.

RECENT RISK ASSESSMENTS

Air Pollution from Power Plants Responsible for 30,000 Premature Deaths Each Year in U.S.

This analysis by Abt Associates used EPA-approved emissions and air quality modeling techniques to forecast ambient air quality in 2007, assuming full implementation of the Clean Air Act's acid rain control program, and the EPA's 1999 "NO_x State Implementation Plan (SIP) call." Analysts then applied risk functions derived from epidemiological studies to estimate health impacts of power plant emissions in the U.S. The focus of the study was on gaseous emissions of sulfur dioxide and nitrogen oxides that are converted in the atmosphere to fine particle sulfates and nitrates. The analysis estimated that 30,100 deaths may be attributed to power plant emissions each year. In addition, power plant emissions causes 20,100 hospitalizations for respiratory and cardiovascular causes, more than 7,000 asthma-related emergency room visits, 18,600 cases of chronic bronchitis, 600,000 asthma attacks, over 5 million lost work days, and over 26 million minor restricted activity days. Reductions in emissions from uncontrolled power plants could substantially reduce the adverse health effects.

In addition, analysis used a simpler model to estimate the impacts of emissions from on- and off-road diesel engines. The analysis reported that 15,400 premature deaths each year are attributable to the diesel contribution to fine particle concentrations. In addition, there are an estimated 11,100 cases of chronic bronchitis due to diesel emissions, thousands of hospitalizations due to chronic obstructive pulmonary disease, pneumonia, asthma, and cardiovascular causes, and over a million cases of minor illness such as acute bronchitis, upper and lower respiratory symptoms, and asthma attacks. Because of the use of different models, these results are not directly comparable to the power plant estimates.

Abt Associates, Inc. with ICF Consulting, and E.H. Pechan Associates, Inc. Prepared for Clean Air Task Force. The Particulate-Related Health Benefits of Reducing Power Plant Emissions. October 2000.

Air Pollution Causes 40,000 Premature Deaths Each Year in Alpine Countries

As part of an assessment prepared for the World Health Organization, Nino Künzli and coauthors estimated health risk attributable to PM_{10} pollution in three European countries, **Austria**, **France**, and **Switzerland**. Using functions of health risk obtained from epidemiological studies, the authors estimate that air pollution caused six percent of total mortality, or more than 40,000 cases each year, with about half associated with motor vehicle pollution. In addition, the study estimated that 47,000 new cases of chronic bronchitis in adults, more than 500,000 episodes of bronchitis in children, and more than a million asthma attacks are attributable to air pollution each year. Despite uncertainties inherent in risk assessment, this analysis highlights the magnitude of the public health burden attributable to current levels of air pollution.

Künzli, N., Kaiser, R., Medina, S., Studnicka, M., Chanel, O., Filliger, P., Herry, M., Horak, F. Jr., Puybonnieux-Texier, V., Quenel, P., Schneider, J., Seethader, J., Vergnaud, J-C., and Sommer, H. Public-

Health Impact of Outdoor and Traffic-Related Air Pollution: A European Assessment. The Lancet, Vol. 356, pp. 795-801, September 2, 2000.

Appendix N

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Annotated Bibliography of Recent Studies on the Health Effects of Air Pollution

In the last year, hundreds of scientific papers on the health effects of air pollution have been published reporting on effects ranging from respiratory symptoms to premature mortality. The studies extend our understanding of the short- and long-term effects of exposure to common air pollutants, provide new information on potential cardiovascular mechanisms, and identify especially susceptible populations, including children.

This bibliography represents a small sampling of studies published from mid-2001 to mid-2002 in peer-reviewed journals. The new studies link air pollution with lung cancer, heart attacks, strokes, high blood pressure, congenital heart defects, asthma, and even brain damage. They identify diabetics, asthma patients, those with congestive heart failure, and children who play outdoors as being at increased risk. The recent research elucidates several pathways to explain the effects of air pollution on the cardiovascular system.

This bibliography does not attempt to be comprehensive: exclusion does not imply that a study is unimportant; inclusion does not imply endorsement.

LONG-TERM MORTALITY STUDIES

European Long Term Cohort Study Confirms PM-Mortality Link

A study published by The Lancet concludes that *"long-term exposure to traffic-related air pollution may shorten life expectancy."*

Dutch researchers studied 5,000 people in the Netherlands from 1986 to 1994 that were participants in a prospective cohort study on diet and cancer. They found that people living near major roads with higher concentrations of black smoke were at increased risk of premature death from cardiopulmonary causes.

The researchers note that traffic emissions contain many pollutants that might be responsible for the mortality association, including ultrafine particles, diesel soot and nitrogen oxides, though they added that nitrogen dioxide is unlikely to cause death.

"The specificity of the association and the consistency with chronic morbidity studies, adds to the plausibility of traffic-related air pollution effects," conclude the researchers.

The study is significant because it confirms the Harvard Six Cities Study and the American Cancer Society study which linked long-term exposure to particulate air pollution to premature death in the U.S.

Hoek, G., Brunekreef, B., Goldbohm, S., Fischer, P., van den Brandt, P. A. Association Between Mortality and Indicators of Traffic-Related Air Pollution in the Netherlands: A Cohort Study, The Lancet, Vol. 19, pp. 1203-1209, 2002.

Research Links Air Pollution to Lung Cancer

Prolonged exposure to fine particulate air pollution significantly increases the risk of dying from lung cancer and cardiopulmonary causes, according to a new study of 500,000 adults in over 100 American cities.

The new study extended the follow-up period for participants in the study of the American Cancer Society cohort from seven to 16 years, and looked at recent fine particle monitoring information for the years 1999-2000. Importantly, investigators reported that prevailing levels of $PM_{2.5}$ in the U.S. are associated with significant health risks.

Authors concluded that: *"the findings of this study provide the strongest evidence to date that long term exposure to fine particulate air pollution common to many U.S. cities is an important risk factor for cardiopulmonary disease mortality. In addition, the large cohort and extended follow-up have provided an unprecedented opportunity to evaluate associations between air pollution and lung cancer mortality. Elevated fine particulate air pollution exposures were associated with significant increases in lung cancer mortality. Although potential effects of other unaccounted for factors cannot be excluded with certainty, the associations between fine particulate air pollution and lung cancer mortality as well as cardiopulmonary mortality are observed even after controlling for cigarette smoking, body mass, diet, occupational exposure, numerous other individual risk factors, and after using recent advances in statistical modeling to control for regional and other spatial differences."*

Pope, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., and Thurston, G.D. Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution, Journal of the American Medical Association, Vol. 287, No. 9, March 6, 2002.

Mortality Risk Analyses Should be Based on Long-Term Studies

A debate has raged in the public policy arena about whether to use the short-term or the long-term epidemiological studies to estimate the risks of premature mortality attributable to particulate air pollution. A study by K✦nzli et al. presents a conceptual model for the interpretation of these studies, which shows that short-term time-series and long-term cohort studies address different aspects of the association between air pollution and death. Time-series studies capture only cases in which death has been triggered by air pollution exposures that occur shortly before death, while cohort studies capture all air pollution-related categories of death, including deaths of persons whose underlying health condition leads to premature death, without being related to the level of pollution shortly before death.

For these reasons, the authors conclude *"that time-series analyses underestimate cases of death attributable to air pollution and that assessment of the impact of air pollution on mortality should be based on cohort studies."*

The National Academy of Sciences recently issued a report on "Estimating the Public Health Benefits of Proposed Air Pollution Regulations." Importantly, the report concluded that EPA has appropriately based their estimates of morality on long-term cohort studies, which give "a more complete assessment because they include long-term, cumulative effects of air pollution." In particular, the report concluded that EPA's use of the American Cancer Society (ACS) study for the evaluation of PM-related premature mortality was reasonable, given the size and precision of the study.

K✦nzli, N., Medina, S., Kaiser, R., Qu■nel, P., Horak, F., Jr., and Studnicka, M. Assessment of Deaths Attributable to Air Pollution: Should We Use Risk Estimates Based on Time Series or on Cohort Studies? Am. J. Epidemiol. 2001;153:1050-5.

National Research Council, Committee on Estimating the Health-Risk-Reduction Benefits of Proposed Air Pollution Regulations, "Estimating the Public Health Benefits of Proposed Air Pollution Regulations," National Academies Press, 2002.

SHORT-TERM MORTALITY STUDIES

Strong Evidence for PM-Mortality Relationship Persists in Updated Study

In May 2002, researchers reported an error in the default assumptions in the software used to analyze the National Morbidity, Mortality and Air Pollution Study (NMMAPS). The researchers concluded that a refined analysis changes the quantitative estimates of risk, but the major conclusions remain the same. The three important conclusions of the study remain unchanged by the re-analysis: strong evidence of an association between acute exposure to particulate air pollution (PM_{10}) and daily mortality; the association is strongest for respiratory and cardiovascular causes of death; the association can not be attributed to other pollutants including NO_2, CO, SO_2 or O_3, nor to weather.

The software error does affect all time series studies of air pollution, but only certain recent studies with two or more smooth curves in the generalized additive model (GAM).

Further, the reported error has no affect on the results of the landmark long-term studies of particles, the Harvard Six Cities Study and the American Cancer Society study both of which were reanalyzed in depth and upheld in 2000. These studies found that prolonged exposure to particulate air pollution significantly increases the risk of dying from cardiopulmonary causes.

Importantly, the long-term studies provide the basis for the large risk estimates associated with particulate air pollution, so these estimates remain unchanged by recent developments.

Researchers conclude that *"... there was strong evidence for a positive association between acute exposure to PM_{10} and death, even with very conservative adjustments for trend, seasonality, and weather."*

Dominici, F., McDermott, A., Zeger, S.L. and Samet, J.M. On the Use of Generalized Additive Models in Time-Series Studies of Air Pollution and Health, Am. J. Epidemiol., Vol. 156, No. 3, pp 193-203, August 1, 2002.

"Harvesting" Theory Disproven

Some have argued that the short-term increases in mortality associated with air pollution represent a "harvesting" effect, that is, the advancement of death by a few days in very frail people. This theory of mortality displacement has been dispelled by analyses of single-city mortality studies. Two recent studies have strengthened this conclusion by re-examining multi-city data sets in the U.S. and in Europe.

Researchers from Johns Hopkins University conducted an analysis of daily mortality, particulate air pollution, and weather in **Pittsburgh, PA, Minneapolis, MN, Seattle, WA, and Chicago, IL.**

Researchers found larger relative risks of mortality associated with particulate air pollution for periods of 1 to 2 months, compared to shorter periods of 1 to 4 days.

They conclude: *"These analyses provide additional evidence that associations of particle indexes and mortality do not imply only an advance in the timing of death by a few days for frail individuals."*

Another study examined this issue in the context of the multi-city "Air Pollution and Health: A European Approach" (APHEA-2) study. The study showed that the effect size estimate for airborne particles more than doubled when long-term effects, up to 40 days, were considered.

Researchers reported, *" our study confirms that the effects observed in daily time-series studies are not due primarily to short-term mortality displacement."* They also report that, *"risk assessment based on short-term associations likely underestimate the number of early deaths that are advanced by a significant amount, and that estimates based on the cohort studies, or studies such as this one, would more accurately assess the public health impact."*

Dominici, F., McDermott, A., Zeger S.L., and Samet, J. Airborne Particulate Matter and Mortality: Time-Scale Effects in Four U.S. Cities. American Journal of Epidemiology, In press.

Zanobetti, A., Schwarz, J., Samoli, E., Gryparis, A., Touloumi, G., Atkinson, R., Le Tertre, A., Bobros, J., Celko, M., Goren, A., Forsberg, B., Michelozzi, P., Rabczenko, D., Aranguez Ruiz, E., and Katsouyanni, K. The Temporal Pattern of Mortality Responses to Air Pollution: A Multicity Assessment of Mortality Displacement. Epidemiology, Vol. 13, pp. 87-93, 2002.

Air-Conditioning May Account for Regional Differences in Risk Estimates

Studies of acute effects of particulate matter air pollution show variability in the exposure-response relationships between cities. This study explored whether differences in the prevalence of air conditioning and different sources of PM could partially explain the regional heterogeneity.

The study examined data from a study of hospital admissions for cardiovascular and respiratory causes in 14 U.S. cities, data on air conditioning from a 1993 American Housing Survey, and data on PM_{10} emissions source categories, vehicle miles traveled, and population density from U.S. EPA.

Investigators concluded: *"the results suggest that air conditioning and proportion of especially traffic-related particles significantly modify the effect of PM_{10} on hospital admissions, especially for cardiovascular disease."*

Janssen, N.A.H., Schwartz, J., Zanobetti, A., and Suh, H.H. Air Conditioning and Source-Specific Particles as Modifiers of the Effect of PM_{10} on Hospital Admissions for Heart and Lung Disease. Environ. Health Perspect. Vol. 110, pp. 43-49, 2002.

SUSCEPTIBLE POPULATIONS

Airborne Particles Increase the Risk of Heart Disease in Diabetics

Particulate air pollution has been associated with decreased heart rate variability, increased clotting risk factors, and increases in systemic markers of inflammation. Diabetes is a disease characterized by disturbances in all of these cardiovascular risk factors. Researchers hypothesized that since particles and diabetes may affect some of the same pathways, they may interact to increase the risk of cardiovascular disease.

The study examined Medicare data for hospital admissions for heart disease among the elderly in **Cook, County (Chicago), IL.** Investigators found that people with diabetes had twice the PM_{10}-associated risk for heart disease as nondiabetics, and concluded that diabetics are a susceptible population. A follow-up study in **Chicago, IL, Detroit, MI, Pittsburgh, PA, and Seattle, WA** came to similar conclusions.

These findings have important public health implications because more than 5 percent of the U.S. population has been diagnosed with diabetes, and an additional 2.7 percent have undiagnosed diabetes.

Zanobetti, A., and Schwartz, J. Are Diabetics More Susceptible to the Health Effects of Airborne Particles? Am. J. Respir. Crit. Care Med. Vol. 164. pp. 831-833, 2001.

Zanobetti, A., Schwartz, J. Cardiovascular Damage by Airborne Particles: Are Diabetics More Susceptible? Epidemiology, Vol. 13, No. 5, pp. 588-592, Sept. 2002.

PM_{10} and Ozone Have Strong, Immediate Link with Stroke Deaths

Air pollution may play a part in the causation of strokes, one of the leading causes of death and long-term disability, according to a team of researchers from four research centers in Korea and the Harvard School of Public Health. The findings are based on data from **Seoul, Korea,** a city with relatively high PM concentrations and high numbers of fatal strokes.

Researchers reported that rises in PM_{10} and ozone concentrations had a strong, nearly immediate link with stroke deaths. Stroke mortality also increased in association with NO_2, SO_2 and carbon monoxide concentrations. The effects persisted after controlling for potential confounding factors such as weather and season. Researchers conclude *"that PM_{10} and gaseous pollutants are significant risk factors for acute stroke death and that the elderly and women are more susceptible to the effect of particulate pollutants."*

A seven-year follow-up study in **Seoul** examined daily stroke deaths in relation to air pollution. After controlling for influences such as temperature, relative humidity, and atmospheric pressure, researchers observed a statistically significant relationship between same day concentrations of total suspended particulates and sulfur dioxide, and death from ischemic strokes. Ischemic strokes, the most common type of strokes, occur when a blood clot or narrowed artery cuts off blood supply to the brain.

Hong, Y.-C., Lee J.-T., Kim, H., Ha, E.-H., Schwartz, J., and Christiani, D.C. Effects of Air Pollutants on Acute Stroke Mortality. Environ. Health Perspec. Vol. 110, pp. 187-191, 2002.

Hong, Y.-C., Lee, J.-T., Kim, H., Kwon, H.-J., Air Pollution: A New Risk Factor in Ischemic Stroke Mortality, Stroke, Vol. 33, No. 9, pp. 2165.

PM_{10} and Ozone Air Pollution Worsens the Health of Adults with Severe Asthma

Very few panel studies of adults with severe or moderately severe asthma have been conducted. Most previous studies have been of children. Desquoroux and colleagues designed a study with stringent criteria for inclusion, rigorous medical surveillance, and a long period of observation.

Sixty adult patients with severe asthma and receiving medical treatment were followed by their physicians in **Paris, France** for a period of 13 months. Daily levels of SO_2, PM_{10}, NO_2, and ozone were provided by the air quality monitoring network.

Increases in PM_{10} were associated with an increase in the incidence of asthma attacks 3-5 days later. The delayed effect of PM is consistent with impacts on inflammatory mechanisms.

Increases in the maximum 1-hour ozone level were associated with increased asthma attacks among allergic patients, after 2 days. The results suggest that weak concentrations of ozone may increase bronchial reactivity with allergens in allergic asthma patients.

"The results of our study suggest that ambient Paris levels of PM_{10} and O_3 affected health of severe asthmatics, despite their treatment," report the study authors.

Desqueroux, H., Pujet, J.-C., Prosper, M., Squinazi, F., Momas, I. Short-Term Effects of Low-Level Air Pollution on Respiratory Health of Adults Suffering from Moderate to Severe Asthma. Environmental Research Section A, Vol. 89, pp. 29-37, 2002.

Nitrogen Dioxide and Ozone Increase the Risk of Death in Patients with Severe Asthma

A study of 1,000 patients over 14 years old in **Barcelona, Spain** was conducted to assess the relationship between acute exposure to air pollution, pollen, and mold spores in a cohort of patients that had previously been admitted to an emergency room for an asthma exacerbation. Records were evaluated to determine which of these patients died during the period from 1985-1995. Air pollution, pollen, and spore levels were measured a city monitoring station.

Researchers found that asthmatic patients with a history of more than one emergency room admission for asthma had an increased risk of dying on days with high nitrogen dioxide concentrations. High ozone days during the spring and summer also increased the risk of death in patients with severe asthma. The association with particles, pollen and spores was not significant.

"Nitrogen dioxide and ozone may exacerbate severe asthma and even cause death among asthmatic subjects," reported the researchers.

Sunyer, J., Basagana, X., Belmonte, J., and Anto, J.M. Effect of Nitrogen Dioxide and Ozone on the Risk of Dying in Patients with Severe Asthma. Thorax, Vol. 57, No. 8, pp. 687-693, August, 2002.

Air Pollution Exerts Greater Mortality Impact in Patients with Congestive Heart Failure

This study examined the short-term association between a variety of air pollutants and mortality among patients with congestive heart failure in Seoul, Korea.

"... It seems clear that air pollution in Seoul was related to an increased daily mortality and that congestive heart failure patients were particularly susceptible," conclude the researchers, strengthening the case that an important mechanism of air pollution effect involves the cardiovascular system.

Kwon, H.-J., Cho, S.-H., Nyberg, F., and Pershagen, G. Effects of Ambient Air Pollution on Daily Mortality in a Cohort of Patients with Congestive Heart Failure. Epidemiology, Vol. 12, pp. 413-419, 2001.

Sensitive Individuals are Highly Susceptible to Airborne Particles

"Part of the explanation for the persistent epidemiological findings of associations between mortality and morbidity with relatively modest ambient exposures to airborne particles may be that some people are much more susceptible to particle-induced responses than others," write Professor Dale Hattis of Clark University, and coauthors.

This study relied on an analysis of studies of human systemic responses to dust and other agents that induce acute changes in lung function to quantitatively explore variability among individuals in breathing rates and deposition to the deep lung.

The study found that 99.9th percentile individuals respond to doses of particles 150 to 450 times smaller than are needed to affect average people.

Hattis D, Russ A, Goble R, Banati P, Chu M., Human Interindividual Variability in Susceptibility to Airborne Particles. Risk Analysis, Vol. 4, pp. 585-599, August, 2001.

EFFECTS ON CHILDREN

Ozone and Carbon Monoxide Linked to Cardiac Birth Defects

Women in Southern California who are exposed to high concentrations of ozone and carbon monoxide may be at increased risk of giving birth to babies with serious heart defects, including holes in the heart, arterial defects, or pervasively malformed hearts, according to a study by UCLA researchers.

California maintains a registry of birth defects. The study correlated motor vehicle related air quality data with information on more than 9,000 babies born between 1990

and 1993 in **Los Angeles, Riverside, San Bernardino, and Orange counties.** Researchers calculated average monthly pollution exposure estimates for each pregnancy in the study.

Risk of holes in the heart increased in a dose-response fashion with increasing second-month carbon monoxide exposure. The second month of pregnancy is a critical period for fetal heart development. In addition, second-month ozone exposure increased the risk of aortic artery and valve defects.

Researchers concluded, *"...our results substantially extend the epidemiologic data on the potential relation between increases in ambient air pollutants during vulnerable pregnancy periods and congenital malformations."*

Ritz, B., Yu, F., Fruin, S., Chapa, G., Shaw, G.M. and Harris, J.A. Ambient Air Pollution and Risk of Birth Defects in Southern California. Am. J. Epidemiol. Vol.155, No. 1, pp. 17-25, 2002.

Particle Pollution Retards Lung Function Growth In Teenagers, Akin to Smoking

A study of California teenagers has found that PM_{10} air pollution retards lung function growth as much as smoking.

Researchers studied 110 children who had moved from communities that are part of the California Children's Health Study to determine whether changes in air quality caused by relocation were associated with changes in annual lung function growth rates. Researchers found that changes in PM_{10} exposure during adolescent growth years have a *"measurable and potentially important effect on lung function growth and performance."*

Reductions in annual respiratory growth rates during adolescence may be a significant predictor of respiratory health in later life.

The reductions observed *"suggest that ambient air pollution exposure has a similar magnitude of effect on lung function development to that previously observed for children who are active smokers,"* reports the study.

"The results of this study, together with those of the numerous previously reported investigations of PM_{10} and its association with increased morbidity and mortality, underscore the national concern about particulate exposure and its relation to public health," researchers conclude.

Another study followed 1,600 Southern California children enrolled as fourth graders in 1996 for four years. Significant deficits in lung function growth rate were associated with exposure to acid vapor, NO_2, $PM_{2.5}$, and elemental carbon. Exposure to ozone was correlated with reduced growth in peak flow rate. Larger deficits in lung function growth rate were observed in children who spent more time playing outdoors, confirming findings from an earlier study of another similar cohort. The results *"provide further*

evidence that ambient levels of air pollution in southern California have a detrimental effect on lung function growth in children" conclude the authors.

Avol, E.L., Gauderman, W.J., Tan, S.M., London, S.J., and Peters, J.M. Respiratory Effects of Relocating to Areas of Differing Air Pollution Levels. Am. J. Respir. Crit. Care Med. Vol 164, pp. 2067-2072, 2001.

Gauderman, W.J., Gilliland, G.F., Vora,H., Avol, E., Stram, D., McConnell, R., Thomas, D., Lurmann, F., Margolis, H.G., Rappaport, E.B., Berhane, K., and Peters, J.M. Association between Air Pollution and Lung Function Growth in Southern California Children: Results from a Second Cohort. Am. J. Respir. Crit.Care Med. Vol. 166, pp. 76-84, 2002.

Air Pollution Stunts Lung Function Growth in School Children

Researchers in Austria have followed almost a thousand school children from 8 communities for 3 years, with lung function measurements taken in the winter and summer. Higher summertime PM_{10} concentrations were associated with a slower increase in FEV_1 (forced expiratory volume in one second), a proxy for large airways' growth, and with another lung function measure intended to reflect the growth of small airways.

Exposure to NO_2 and ozone also reduced lung-function growth, confirming earlier work.

The authors conclude, *"...the present study provided further evidence for a long-term effect of particulate matter <10 μm in diameter on the development of pulmonary function in elementary schoolchildren. Early impairment of lung-function growth could lead to lower lung-function parameters in adulthood, predisposing to chronic pulmonary diseases."*

Horak, F., Jr., Studnicka, M., Gartner, C., Spengler, J.D., Tauber, E., Urbanek, R., Veiter, A., Frischer, T. Particulate Matter and Lung Function Growth in Children: A 3-yr Follow-up Study in Austrian Schoolchildren. Eur. Respir. J., Vol. 19, pp. 838-845, 2002.

Inner City Children with Asthma Experience Respiratory Symptoms and Decreased Lung Function in Relation to Air Pollution

The effect of daily ambient air pollution was studied in a cohort of 850 asthmatic children ages 4-9 living in eight inner city urban areas in the U.S. The urban areas studied were **Bronx** and **East Harlem, NY, Baltimore, MD, Washington, DC, Detroit, MI, Cleveland, OH, Chicago, IL** and **St. Louis, MO.**

The impact of pollution developed over several days, with the largest effects seen in morning measurements of lung function. NO_2, SO_2, and PM_{10} were associated with an increase in morning asthma symptoms, with NO_2 exhibiting the strongest influence. Ozone exhibited the greatest effect on peak expiratory flow rate. Adverse respiratory effects were reported in all the cities studied.

Researchers conclude: *"this longitudinal analysis supports previous time-series findings that at levels below current USA air-quality standards, summer-air pollution is significantly related to symptoms and decreased pulmonary function among children with asthma."*

Mortimer, K.M., Neas, L.M., Dockery, D.W., Redline, S., Tager, I.B. The Effect of Air Pollution on Inner-City Children with Asthma, Eur. Respir. J. Vol. 19, pp. 699-705, 2002.

Truck Traffic Contributes to Childhood Asthma Hospitalizations

A study in **Erie County, New York** (excluding the city of Buffalo) has shown that children living in neighborhoods with heavy truck or trailer traffic within 200 meters of their homes had increased risks of asthma hospitalization. The study examined hospital admission for asthma amongst children ages 0-14, and residential proximity to roads with heavy traffic.

Lin, S., Munsie, J.P., Hwang, S.-A., Fitzgerald, E., and Cayo, M.R. Childhood Asthma Hospitalization and Residential Exposure to State Route Traffic. Environmental Research, Section A, Vol. 88, pp. 73-81, 2002.

Coarse Particles ($PM_{10-2.5}$) Associated with Asthma Hospitalization Among Children

This study used two analytical techniques to assess associations between different size fractions of particulate matter and asthma hospitalization among children ages 6-12 living in **Toronto, Canada** between 1981 and 1993.

The researchers found a stronger effect of coarse particles ($PM_{10-2.5}$) on asthma hospitalization compared with both $PM_{2.5}$ and PM_{10}, using both analytical techniques. The stronger effect of $PM_{10-2.5}$ persisted, even after adjusting for the effects of gaseous air pollutants.

There are few studies of the coarse particle fraction, and they are of particular interest because U.S. EPA will likely establish a new standard for coarse particles.

Lin, M., Chen, Y, Burnett, R.T., Villeneuve, P.J., and Krewski, D. The Influence of Ambient Coarse Particulate Matter on Asthma Hospitalization in Children: Case-Crossover and Time-Series Analyses. Environ. Health Perspect. Vol. 110, pp. 575-581, 2002.

Decreases in Air Pollution Shown to Improve Children's Health

The reduction in SO_2 and total suspended particulate levels in eastern Germany following reunification provides a natural experiment to assess associated improvements in human health. This study sought to examine the effect of the decline in air pollution due to a reduction in coal combustion on elementary school children's symptoms of bronchitis.

Researchers conclude, *"the prevalence of nonasthmatic respiratory disorders may be reduced within a short time period by improving air quality. Our data on long-term exposures to air pollution indicate the reversibility of adverse health effects in children and add further evidence of a causal association with combustion-related air pollutants."*

Heinrich, J., Hoelscher, B., Frye, C., Meyer, I., Pitz, M., Cyrys, J., Wjst, M., Neas, L., and Wichmann, H.-E. Improved Air Quality in Reunified Germany and Decreases in Respiratory Symptoms. Epidemiology, Vol. 13, pp. 394-401, 2002.

BIOLOGIC MECHANISMS AND CARDIAC EFFECTS

Breathing Smog Causes Blood Vessels to Constrict

A chamber study on healthy human volunteers has demonstrated that breathing ozone and particulate matter for only two hours, at levels typical of a polluted day in Los Angeles, causes a major artery in the arm to constrict significantly.

Scientists observed that breathing air pollutants caused an immediate constriction of 2 to 4 percent in the blood vessel in the arm. Although this is unlikely to harm a healthy person in the short term, it could impact those with existing heart disease or circulatory problems, and could possibly trigger a heart attack, according to researchers.

The authors concluded, *"This finding is important because ... it provides evidence that the observations shown by large epidemiological studies are biologically plausible."*

Brook, R.D., Brook, J.R., Urch, B., Vincent, R., Rajagopalan, S., and Silverman, F. Inhalation of Fine Particulate Air Pollution and Ozone Causes Acute Arterial Vasoconstriction in Healthy Adults. Circulation, Vol. 105, pp. 1534-1536, 2002.

PM_{10} Provokes Inflammatory Response in Laboratory Animals, in Human Lung Cells In Vitro, and in Humans

Scientists have found that inhalation of urban particles will increase the blood levels of endothelins, potent vasoconstrictors which can increase blood pressure and contribute to congestive heart failure. A study in laboratory rats found that exposure to urban particulate matter (PM) increased endothelin levels, and also caused an increase in blood pressure. The researchers found that particles can cause rapid (2 hours) and sustained (24 hours) systemic cardiovascular changes, without a requirement for acute lung injury.

In another study, researchers hypothesized that following PM_{10} exposure, cytokines, proteins produced in the lung, are released into the blood, inducing a systemic inflammatory response, which plays a role in cardiopulmonary effects. This study exposed cultured human bronchial epithelial cells to ambient particulate matter obtained from air filters in **Ottawa, Canada**. Researchers found that concentrations of various proteins produced increased in a dose-dependent manner. They concluded that *"primary human bronchial epithelial cells exposed to ambient PM_{10} produce proinflammatory*

mediators that contribute to the local and systemic inflammatory response, and we speculate that these mediators may have a role in the pathogenesis of cardiopulmonary disease associated with particulate air pollution."

A third study measured cytokines in the circulation of healthy young army cadets in Singapore exposed to air pollution during the 1997 Southeast Asian forest fires.

Vincent, R., Kumarathasan, P., Goegan, P., Bjarnason, S.G., Gu■nette, J., B■rub■, D., Adamson, I.Y., Desjardins, S., Burnett, R.T., Miller, F.J., and Battistini, B. Inhalation Toxicology of Urban Ambient Particulate Matter, Acute Cardiovascular Effects in Rats. Health Effects Institute, Research Report 104, 2001.

Fujii, T., Hayashi, S., Hogg, J.C., Vincent, R., and Van Eeden, S.F. Particulate Matter Induces Cytokine Expression In Human Bronchial Epithelial Cells. Am. J. Respir. Cell Mol. Biol. Vol. 25, pp. 265-271, 2001.

Van Eeden, S.F., Tan, W.C., Suwa, T., Mukae, H., Terashima, T., Fujii, T., Qui, D., Vincent, R., and Hogg, J.C. Cytokines involved in the Systemic Inflammatory Response Induced by Exposure to Particulate Matter Air Pollutants (PM_{10}), Am. J. Respir. Crit. Care Med. Vol. 164. pp. 826-830, 2001.

Inhaled Ultrafine Particles Pass into the Bloodstream

With the aid of a radioisotope enhanced imaging technique, researchers in Belgium have shown that ultrafine particles can enter a person's bloodstream from the lungs. This study of human volunteers was intended to investigate whether the smallest particles can move from the lungs into the circulation, where they might have a direct effect on cardiovascular endpoints.

Alternative hypotheses hold that particles produce pulmonary inflammation with a systemic release of cytokines, which may influence cardiovascular endpoints. Alternately, it has also been proposed that pollutants may cause alterations in cardiac autonomic function thus causing changes in heart rate variability and increasing the risk of sudden cardiac death.

The investigators conclude that *"...we are confident that our findings provide plausible evidence for particle translocation from the lung into the blood and then its distribution to the organs,"* and that this process could account for cardiovascular illness and death related to ambient particle pollution.

Nenmar, A., Hoet, P.H.M., Vanquickenborne, B., Dinsdale, D., Thomeer, M., Hoylaerts, M.F., Vanbillioen, H., Mortelmans, L., Nemery, B., Passage of Inhaled Particles in to the Blood Circulation in Humans. Circulation, Vol. 105, pp. 411-414, 2002.

PM Accelerates and Aggravates Artery Disease

A study of laboratory rabbits found that atherosclerosis, a disease marked by cholesterol-lipid-calcium deposits in the walls of the arteries, was accelerated by exposure to PM_{10},

compared to rabbits exposed to clean air. Athererosclerosis is the leading cause of disease and death in Western societies. The study also found that pollution exposure increased susceptibility to plaque rupture, which can trigger heart attacks.

"Progression of atherosclerosis and increased vulnerability to plaque rupture may underlie the relationship between particulate air pollution and excess cardiovascular death," concluded the investigators.

Suwa, T., Hogg, J.C., Quinlan K.B., Ohgami, A., Vincent, R., van Eeden, S.F. Particulate Air Pollution Induces Progression of Atherosclerosis. J. Am Coll. Cardiol. Vol. 39, pp. 943-945, March 20, 2002.

Healthy Workers Exposed to $PM_{2.5}$ Experience Reduction in Heart Rate Variability

Decreased heart rate variability is an indicator of the diminished ability of the heart to respond to stress, and is a risk factor for mortality from cardiovascular disease. This is the first study to examine the effects of $PM_{2.5}$ on a younger population, by incorporating continuous personal monitoring in an occupational setting.

The study population was relatively young boilermaker construction workers occupationally exposed to residual oil fly ash and metal fumes. Continuous monitoring of $PM_{2.5}$ exposure took place during and away from work. Statistically significant decreased heart rate variability was observed in association with 1-hour average $PM_{2.5}$ concentrations. The effect on heart rate variability was smaller than has been reported in elderly populations.

The findings suggest *"a relatively rapid-acting component in the mechanism of action of $PM_{2.5}$ on heart rate variability changes,"* according to the researchers.

A follow-up study by the same group of researchers at the Harvard School of Public Health explored the effect of specific metallic components of $PM_{2.5}$ on the cardiac function of boilermakers. The effect of six metals – vanadium, nickel, chromium, lead, copper and manganese – on heart rate and heart rate variability were examined. Measurements were collected by a portable electrocardiogram monitor and a personal monitor of airborne concentrations. After adjusting for age, baseline heart rate, and smoking status, small changes in heart rate were seen for all the metals, suggesting an association between airborne metals and significant alteration in heart function.

Magari, S.R., Hauser, R., Schwartz, J., Williams P.L., Smith, T.J., and Christiani, D.C. Association of Heart Rate Variability with Occupational and Environmental Exposure to Particulate Air Pollution. Circulation, Vol. 104, pp. 986-991, 2001.

Magari, S.R., Schwartz, J., Williams, P.L., Hauser, R., Smith, T.J., and Christiani, D.C. The Association of Particulate Air Metal Concentrations with Heart Rate Variability. Environ. Health Perspect. Vol. 110, No. 9, pp. 875-880, September 2002.

Diesel Exhaust-Like Particles Lodge in the Lung

Autopsies of lungs from non-smoking female residents of Mexico City reveal that fine particle air pollutants overwhelm the lungs' clearance mechanisms and are retained in lung tissue.

The study compared residents of highly polluted Mexico City with residents of the far cleaner Vancouver, British Columbia, and found significantly higher numbers of particles imbedded in the lungs of in long-term residents of Mexico City. Some of the particles retained in the lungs of Mexico City residents resembled diesel exhaust samples. The study design excluded smokers and those with occupational exposures.

This study provides the first direct evidence that increased lifetime exposure to air pollution results in higher particle retention in the lung. The findings provide biological plausibility to epidemiologic studies showing adverse effects of particles from chronic exposures.

"Our observations indicate that long-term residence in an area of high ambient particle concentrations is associated with greater numbers of retained particles in the lung; this shows for the first time that the aggregated ultrafine particles in ambient air can also be found in lung tissue," the study concludes.

Brauer, M., Avila-Casado, C., Fortoul, T.I., Vedal, S., Stevens, B., and Chung, A. Air Pollution and Retained Particles in the Lung, Environ. Health Perspec. Vol. 109, pp. 1039-1043, 2001.

Blood Pressure Rises During Air Pollution Episode

Blood pressure is a well-established risk factor for cardiovascular disease and deaths.

This study used data from a January 1985 air pollution episode in Central Europe, and a World Health Organization project to monitor measures related to cardiovascular disease in over 2,000 adults in **Augsburg, Germany**.

During the air pollution episode, 24-hour concentrations of total suspended particulates and SO_2 were associated with an increase in blood pressure, after adjusting for other risk factors and weather.

"The observed increase in systolic blood pressure associated with ambient air pollution could be related to a change in cardiovascular autonomic control," report the researchers.

Ibald-Mulli, A., Stieber, J., Wichmann, H.-E., Koenig, W., and Peters, A., Effects of Air Pollution on Blood Pressure: A Population-Based Approach. Am. J. Public Health, Vol. 91, pp. 571-577, 2001.

Particle Exposure Causes Lung Inflammation in Laboratory Animals

Researchers used a concentrating device to test whether short-term exposures to ambient air particles from **Boston, MA** caused pulmonary inflammation in normal rats and in rats with chronic bronchitis. Inflammation was assessed by washing the lungs and measuring concentrations of white blood cells, a marker for inflammation. Concentrated particles were associated with an increase in inflammation in both the normal and the bronchitic animals.

The concentrations used in this study were comparable to cumulative 24-hour concentrations of $PM_{2.5}$ found in developing countries.

The researchers conclude, "*this work demonstrated that short-term exposures to $PM_{2.5}$ concentrated from Boston's atmosphere induce an inflammatory reaction in the lungs of rats. . . .The magnitude of pulmonary inflammation was associated with elements originating from combustion sources.*"

Saldiva, P.H.N., Clarke, R.W., Coull, B.A., Stearns, R.C., Lawrence, J., Murthy, G.G.K, Diaz, E., Koutrakis, P., Suh, H., Tsuda, A., and Godleski, J.J. Lung Inflammation Induced by Concentrated Ambient Air Particles is Related to Particle Composition. Am. J. Respir. Crit. Care Med. Vol. 165, pp. 1610-1617, 2002.

Toxicology Study in Human Volunteers Helps Explain Utah Valley Epidemiology Studies

The temporary closure of a steel mill in the Utah Valley during a labor dispute in the late 1980's provided a unique opportunity to study the health of residents during period the mill was closed, compared to before and after the closure. A series of epidemiological studies published in the 1990s reported associations between elevated PM concentrations and increased elementary school absences, bronchitis and asthma hospital admissions for pre-school aged children, total respiratory hospital admissions, pulmonary function abnormalities, and mortality.

In what commentators call "a strikingly innovative study", researchers obtained the archived air pollution filters from the late 1980s, extracted the particles, and instilled them in the lungs of healthy human volunteers. The following day, they washed the lungs to check for signs of inflammation. They found more inflammation in those exposed to particles from the monitoring site nearest to the steel mill during the years when the steel mill was operating, compared to when it was closed.

"This is the first demonstration that pulmonary effects after experimental exposure of humans to PM can correlate with health outcomes observed in epidemiologic studies of the same material under normal exposure conditions," the study concluded. Researchers suggest that the metals contained on the particles may contribute to the toxic effect.

Ghio, A.J. and Devlin, R.B. Inflammatory Lung Injury after Bronchial Instillation of Air Pollution Particles. Am. J. Crit. Care Med. Vol. 164, pp. 704-708, 2001.

Beckett, W.S. The Air Pollution Detectives. Am. J. Respir. Crit. Care Med., Vol. 164, No. 4, pp. 515-516, August 2001.

AIR POLLUTION AND BRAIN DAMAGE

Air Pollution May Play a Role in Alzheimer's Disease

The nasal cavity is a common route of entry for inhaled air pollutants. A study has shown that the nasal mucus membrane defenses are severely compromised in children in Mexico City, diminishing protection from inhaled pollutants. Researchers hypothesized that inflammatory processes in the respiratory tract could trigger a chain of events involving the brain.

This study found that **Mexico City** dogs chronically exposed to high concentrations of ozone, PM, and other air pollutants had extensive brain damage compared to dogs from a less polluted city. Researchers observed alterations of the blood-brain barrier, degenerating, shrunken nerve cells surrounded by dying white matter cells, plaques, and neurofibrillary tangles.

Researchers concluded that *"the histopathology we observed in these urban dogs is of sufficient magnitude to warrant concern that similar histopathology may be occurring in humans residing in large polluted metropolitan areas,"* and that *"persistent pulmonary inflammation and deteriorating olfactory and respiratory barriers may play a role in the neuropathology observed in the brains of these highly exposed canines. Neurodegeneratiave disorders such as Alzheimer's may begin early in life with air pollutants playing a crucial role."*

Calder✱n-Garcidue✶as, L., Valencia-Salazar, G., Rodr×guez-Alcaraz, A., Gambling, T.M., Garc×a, R., Osnaya, N., Villarreal-Calder✱n, A., Devlin, R.B., and Carson, J.L. Ultrastructural Nasal Pathology in Children Chronically and Sequentially Exposed to Air Pollutants. Am. J. Respir. Cell Mol. Biol. Vol. 24, pp. 132-138, 2001.

Calder✱n-Garcidue✶as, L., Azzarelli, B., Acuna, H., Garcia, R., Gambling, T.M., Oznaya, N., Monroy, S., Del Rosario Tizapantzi, M., Carson, J.L., Villarreal-Calderon, A., and Rewcastle, B. Air Pollution and Brain Damage. Toxicologic Pathology, Vol. 30, No. 3, pp. 373-389, 2002.

Appendix O

Ambient Air Quality Standards

Pollutant	Averaging Time	California Standards [1]		Federal Standards [2]		
		Concentration [3]	Method [4]	Primary [3,5]	Secondary [3,6]	Method [7]
Ozone (O_3)	1 Hour	0.09 ppm (180 µg/m^3)	Ultraviolet Photometry	0.12 ppm (235 µg/m^3)[8]	Same as Primary Standard	Ultraviolet Photometry
	8 Hour	0.070 ppm (137 µg/m^3)*		0.08 ppm (157 µg/m^3)[8]		
Respirable Particulate Matter (PM10)	24 Hour	50 µg/m^3	Gravimetric or Beta Attenuation	150 µg/m^3	Same as Primary Standard	Inertial Separation and Gravimetric Analysis
	Annual Arithmetic Mean	20 µg/m^3		50 µg/m^3		
Fine Particulate Matter (PM2.5)	24 Hour	No Separate State Standard		65 µg/m^3	Same as Primary Standard	Inertial Separation and Gravimetric Analysis
	Annual Arithmetic Mean	12 µg/m^3	Gravimetric or Beta Attenuation	15 µg/m^3		
Carbon Monoxide (CO)	8 Hour	9.0 ppm (10mg/m^3)	Non-Dispersive Infrared Photometry (NDIR)	9 ppm (10 mg/m^3)	None	Non-Dispersive Infrared Photometry (NDIR)
	1 Hour	20 ppm (23 mg/m^3)		35 ppm (40 mg/m^3)		
	8 Hour (Lake Tahoe)	6 ppm (7 mg/m^3)		—	—	—
Nitrogen Dioxide (NO_2)	Annual Arithmetic Mean	—	Gas Phase Chemiluminescence	0.053 ppm (100 µg/m^3)	Same as Primary Standard	Gas Phase Chemiluminescence
	1 Hour	0.25 ppm (470 µg/m^3)		—		
Sulfur Dioxide (SO_2)	Annual Arithmetic Mean	—	Ultraviolet Fluorescence	0.030 ppm (80 µg/m^3)	—	Spectrophotometry (Pararosaniline Method)
	24 Hour	0.04 ppm (105 µg/m^3)		0.14 ppm (365 µg/m^3)	—	
	3 Hour	—		—	0.5 ppm (1300 µg/m^3)	
	1 Hour	0.25 ppm (655 µg/m^3)		—	—	—
Lead[9]	30 Day Average	1.5 µg/m^3	Atomic Absorption	—	—	—
	Calendar Quarter	—		1.5 µg/m^3	Same as Primary Standard	High Volume Sampler and Atomic Absorption
Visibility Reducing Particles	8 Hour	Extinction coefficient of 0.23 per kilometer — visibility of ten miles or more (0.07 — 30 miles or more for Lake Tahoe) due to particles when relative humidity is less than 70 percent. Method: Beta Attenuation and Transmittance through Filter Tape.		No Federal Standards		
Sulfates	24 Hour	25 µg/m^3	Ion Chromatography			
Hydrogen Sulfide	1 Hour	0.03 ppm (42 µg/m^3)	Ultraviolet Fluorescence			
Vinyl Chloride[9]	24 Hour	0.01 ppm (26 µg/m^3)	Gas Chromatography			

*This concentration was approved by the Air Resources Board on April 28, 2005 and is expected to become effective in early 2006.

See footnotes on next page ...

1. California standards for ozone, carbon monoxide (except Lake Tahoe), sulfur dioxide (1 and 24 hour), nitrogen dioxide, suspended particulate matter—PM10, PM2.5, and visibility reducing particles, are values that are not to be exceeded. All others are not to be equaled or exceeded. California ambient air quality standards are listed in the Table of Standards in Section 70200 of Title 17 of the California Code of Regulations.

2. National standards (other than ozone, particulate matter, and those based on annual averages or annual arithmetic mean) are not to be exceeded more than once a year. The ozone standard is attained when the fourth highest eight hour concentration in a year, averaged over three years, is equal to or less than the standard. For PM10, the 24 hour standard is attained when the expected number of days per calender year with a 24-hour average concentration above 150 $\mu g/m^3$ is equal to or less than one. For PM2.5, the 24 hour standard is attained when 98 percent of the daily concentrations, averaged over three years, are equal to or less than the standard. Contact U.S. EPA for further clarification and current federal policies.

3. Concentration expressed first in units in which it was promulgated. Equivalent units given in parentheses are based upon a reference temperature of 25°C and a reference pressure of 760 torr. Most measurements of air quality are to be corrected to a reference temperature of 25°C and a reference pressure of 760 torr; ppm in this table refers to ppm by volume, or micromoles of pollutant per mole of gas.

4. Any equivalent procedure which can be shown to the satisfaction of the ARB to give equivalent results at or near the level of the air quality standard may be used.

5. National Primary Standards: The levels of air quality necessary, with an adequate margin of safety to protect the public health.

6. National Secondary Standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant.

7. Reference method as described by the EPA. An "equivalent method" of measurement may be used but must have a "consistent relationship to the reference method" and must be approved by the EPA.

8. New federal 8-hour ozone and fine particulate matter standards were promulgated by U.S. EPA on July 18,1997. Contact U.S. EPA for further clarification and current federal policies.

9. The ARB has identified lead and vinyl chloride as 'toxic air contaminants' with no threshold level of exposure for adverse health effects determined. These actions allow for the implementation of control measures at levels below the ambient concentrations specified for these pollutants.

California Air Resources Board (7/9/03)

Appendix P

HYDROGEN SULFIDE:
EVALUATION OF CURRENT CALIFORNIA AIR QUALITY STANDARDS WITH RESPECT TO PROTECTION OF CHILDREN

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A. Extended abstract

The current California Ambient Air Quality Standard (CAAQS) for hydrogen sulfide is 0.03 ppm (30 ppb, 42 $\mu g/m^3$) for one hour. The standard was adopted in 1969 and was based on the geometric mean odor threshold measured in adults. The purpose of the standard was to decrease odor annoyance. The standard was reviewed in 1980 and 1984 (CARB, 1984), and was not changed since no new relevant information had emerged. The U.S. EPA presently does not classify hydrogen sulfide as either a criteria air pollutant or a Hazardous Air Pollutant. However, several countries have short-term (usually 30 minute) standards for hydrogen sulfide, as well as long-term (24 hour) standards.

This report focuses on key studies in humans and animals bearing on the health-protectiveness of the CAAQS for hydrogen sulfide. It also includes a discussion of whether significant adverse health effects would reasonably be expected to occur, especially among infants and children, at exposure concentrations below the CAAQS of 30 ppb, based on the findings of published studies. Additional research on odor sensitivity in infants, children, and adults would be useful in evaluating the standard. This would include: (1) testing of the odor threshold for H_2S using the most current methodology among groups of healthy persons of both sexes in different age ranges; (2) odor testing of hydrogen sulfide in adolescents or younger children to determine their odor threshold for H_2S; (3) the identification of children hypersensitive to the odor of hydrogen sulfide; and (4) physiologic testing of anosmic (either specifically anosmic to H_2S or totally anosmic) children at the CAAQS to determine if adverse physiological symptoms occur in the absence of odor detection.

B. Background

The Mulford-Carrell Air Resources Act of 1967 directed the Air Resources Board to divide California into Air Basins and to adopt ambient air quality standards for each basin (Health and Safety Code (H&SC) Section 39606). The existing California state-wide ambient air quality standard (CAAQS) for hydrogen sulfide of 0.03 ppm (30 ppb, 42 $\mu g/m^3$), averaged over a period of 1 hour and not to be equaled or exceeded, protects against nuisance odor ("rotten egg smell") for the general public. The standard was adopted in 1969 and was based on rounding of the geometric mean odor threshold of 0.029 ppm (range = 0.012 – 0.069 ppm; geometric SD = 0.005 ppm) measured in adults (California State Department of Public Health, 1969). The standard was reviewed by the Department of Health Services in 1980 and 1984, and was not changed since no new relevant information had emerged. OEHHA (1999) formally adopted 30 ppb as the acute Reference Exposure Level (REL) for use in evaluating peak off-site concentrations from industrial facilities subject to requirements in H&SC Section 44300 *et seq.* OEHHA (2000) adopted a level of 8 ppb (10 $\mu g/m^3$) as the chronic Reference Exposure Level (cREL) for use in evaluating long term emissions from Hot Spots facilities. The cREL was based on a study demonstrating nasal histological changes in mice.

At the federal level, U.S. EPA does not currently classify hydrogen sulfide as either a criteria air pollutant or a Hazardous Air Pollutant (HAP). U.S. EPA has developed a (chronic) Reference Concentration (RfC) of 0.001 mg/m^3 (1 $\mu g/m^3$) for hydrogen sulfide (USEPA, 1999). The RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.

There are no international standards for H_2S. Many countries have "short-term" (usually 30 minute) standards, which range from 6 to 210 ppb (WHO, 1981). The World Health Organization (WHO) recommends that, in order to avoid substantial complaints about odor

annoyance among the exposed population, hydrogen sulfide concentrations should not be allowed to exceed 0.005 ppm (5 ppb; 7 $\mu g/m^3$), with a 30-minute averaging time (WHO, 1981; National Research Council, 1979; Lindvall, 1970). A very short-lived, peak concentration could also be annoying. Rule 2 of Regulation 9 of the Bay Area Air Quality Management District (BAAQMD) specifies that ambient ground level H_2S concentrations may not exceed 60 ppb averaged over 3 consecutive minutes. Regulating at averaging times less than 30 – 60 minutes may be difficult. Many countries have "long-term" (24 hour) standards (WHO, 1981).

NRC (1979), WHO (1981), Beauchamp *et al.* (1984), Reiffenstein *et al.* (1992), and ATSDR (1999) have published reviews of the health effects of hydrogen sulfide.

C. Principal sources/Exposure assessment

Hydrogen sulfide (H_2S) is used as a reagent and as an intermediate in the preparation of other reduced sulfur compounds (HSDB, 1999). It is also a by-product of desulfurization processes in the oil and gas industries and rayon production, sewage treatment, and leather tanning (Ammann, 1986). Geothermal power plants, petroleum production and refining, and sewer gas are specific sources of hydrogen sulfide in California. The annual statewide industrial emissions from facilities reporting under the Air Toxics Hot Spots Information and Assessment Act in California (H&SC Sec. 44300 *et seq.*), based on the most recent inventory, were estimated to be 5,688,172 pounds of hydrogen sulfide (CARB, 1999).

A specific concern in California has been schools located near workplaces emitting toxic substances. For example, the Hillcrest Elementary School in Rodeo (Contra Costa County; part of the BAAQMD) is adjacent to an oil refinery which, on occasion, has emitted enough malodorous sulfur compounds (including H_2S) for the school to close its doors and for the teachers and children to "shelter-in-place." Thus the school district has planned to relocate the school (West County Times, November 23, 1999). These compounds have also affected other schools in the area.

Hydrogen sulfide is produced endogenously in mammalian tissues from L-cysteine, mainly by two pyridoxal-5'-phosphate-dependent enzymes, cystathionine beta-synthetase and cystathionine gamma-lyase (Hosoki *et al.*, 1997). Abe and Kimura (1996) suggested that hydrogen sulfide may be an endogenous neuromodulator in the hippocampus based on the high level of cystathionine beta-synthetase in the hippocampus and on experimental effects of activators and inhibitors of the enzyme.

D. Key studies of acute and chronic health impacts

D.1. Toxicity to Humans

D.1.1. Adults. Hydrogen sulfide is an extremely hazardous gas (ACGIH, 1991). Exposure to high concentrations of hydrogen sulfide is reported to be the most common cause of sudden death in the workplace (NIOSH, 1977). Estimates of the mortality resulting from acute hydrogen sulfide intoxication include 2.8% (Arnold *et al.*, 1985) and 6% (WHO, 1981). While severe intoxication is especially of concern when exposure occurs in confined spaces, an accidental release of hydrogen sulfide into the ambient air surrounding industrial facilities can cause very serious effects. As a result of an accidental release of hydrogen sulfide due to a malfunctioning flare at an oilfield at Poza Rica, Mexico in 1950, 320 people were hospitalized and 22 died (WHO, 1981).

Most information on H_2S toxicity comes from studies that used levels of H_2S orders of magnitude above the standard of 0.03 ppm. Hazardtext (1994) reported an inhalation LC_{Lo} of 600 and 800 ppm (840 and 1,120 mg/m^3) for 30 and 5 minutes, respectively. A lethal exposure was documented for a worker exposed to approximately 600 ppm H_2S for 5 to 15 minutes (Simson and Simpson, 1971). Inhalation of 1,000 ppm (1,400 mg/m^3) is reported to cause immediate respiratory arrest (ACGIH, 1991). Concentrations greater than 200 ppm (280 mg/m^3) H_2S are reported to cause direct irritant effects on exposed surfaces and can cause pulmonary edema following longer exposures (Spiers and Finnegan, 1986). The mechanism of H_2S

toxicity, cellular hypoxia caused by inhibition of cytochrome oxidase, is similar to that for cyanide. Toxicity can be treated by induction of methemoglobin or by therapy with hyperbaric oxygen (Elovaara *et al.*, 1978; Hsu *et al.*, 1987).

At concentrations exceeding 50 ppm (70 mg/m^3) H_2S, olfactory fatigue prevents detection of H_2S odor. Exposure to 100-150 ppm (140-210 mg/m^3) for several hours causes local irritation (Haggard, 1925). Exposure to 50 ppm for 1 hour causes conjunctivitis with ocular pain, lacrimation, and photophobia; this can progress to keratoconjunctivitis and vesiculation of the corneal epithelium (ACGIH, 1991).

Bhambhani and Singh (1985) reported that exposure of 42 individuals to 2.5 to 5 ppm (3.5 to 7 mg/m^3) H_2S caused coughing and throat irritation after 15 minutes. Bhambhani and Singh (1991) showed that 16 healthy adult male subjects (25.2±5.5 years old) exposed to 5 ppm (7 mg/m^3) H_2S under conditions of moderate exercise exhibited impaired lactate and oxygen uptake in the blood. Subsequently Bhambani *et al.* (1994) compared the effects of inhaling 5 ppm H_2S on physiological and hematological responses during exercise. Subjects were 13 men (mean±SD for age, height, and weight = 24.7±4.6 y, 173±6.6 cm, and 73.1±8.1 kg, respectively) and 12 women (mean±SD = 22.0±2.1 y, 165±8.2 cm, and 63.4±8.6 kg, respectively). Subjects completed two 30-minute exercise tests on a cycle ergometer at 50% of their predetermined maximal aerobic power, while breathing either air or 5 ppm H_2S. There were no significant differences between the two exposures for metabolic (oxygen uptake, carbon dioxide production, respiratory exchange ratio), cardiovascular (heart rate, blood pressure, rate pressure product), arterial blood (oxygen and carbon dioxide tensions, pH), and perceptual (rating of perceived exertion) responses. No one reported adverse health effects following H_2S exposure. The authors believe that healthy adults can safely perform moderate intensity work in environments containing 5 ppm H_2S.

Bhambhani *et al.* (1996) examined the acute effects of "oral" inhalation of 10-ppm H_2S, the occupational exposure limit, on lung physiology as measured by pulmonary function in nine men and ten women. The volunteers inhaled medical air or 10 ppm H_2S through the mouth for 15 minutes each during cycle exercise at 50% of their maximal aerobic power. Routine pulmonary function tests (FVC, FEV_1, FEV_1/FVC, PEFR, maximal ventilation volume, and DL_{CO}) were administered at rest and immediately after the two exposure conditions. There were no significant changes in any of the variables derived from the flow volume loop, maximum ventilation volume, and diffusion capacity of the lung for carbon monoxide (DL_{CO}) in both genders. No subject experienced any sign or symptom as a result of H_2S. The authors concluded that inhalation of 10 ppm H_2S through the mouth at an elevated metabolic and ventilation rate does not significantly alter pulmonary function in healthy people.

Jappinen *et al.* (1990) exposed ten adult asthmatic volunteers to 2 ppm H_2S for 30 minutes and tested pulmonary function. All subjects reported detecting "very unpleasant" odor but "rapidly became accustomed to it." Three subjects reported headache following exposure. No significant changes in mean FVC or FEV_1 were reported. Although individual values for specific airway resistance (SR_{aw}) were not reported, the difference following exposure ranged from –5.95% to +137.78%. The decrease in specific airway conductance, SG_{aw}, ranged from –57.7% to +28.9%. The increase in mean SR_{aw} and the decrease in mean SG_{aw} were not statistically significant for the entire group. However, markedly (>30%) increased airway resistance and decreased airway conductance were noted in two of the ten asthmatic subjects at 2 ppm, which indicated bronchial obstruction and may be clinically important. Two ppm is 67 times the CAAQS of 0.03 ppm.

Hydrogen sulfide is noted for its strong and offensive odor. The existing CAAQS of 0.03 ppm (30 ppb, 42 $\mu g/m^3$) for 1 hour is based on rounding the geometric mean odor detection threshold of 0.029 ppm (range = 0.012 – 0.069 ppm; GSD = 0.005 ppm). The threshold was

determined for a panel of 16 presumably healthy adults (California State Department of Public Health, 1969). No information on the sex or age of the panel members has been located. Amoore (1985) reviewed 26 studies, published between 1848 and 1979, all of which reported average odor detection thresholds for H_2S. The 26 studies seem to be mainly controlled exposures and used various measurement methods. They included (1) at least two studies using only one subject, (2) a study of a panel of 35 people testing odors in natural gas in Southern California, and (3) another study of 852 untrained young adults (age range = 17.5 – 22.4 years) tested at county and state fairs in the Northwest. The average odor detection threshold in the 26 studies ranged from 0.00007 to 1.4 ppm H_2S. The geometric mean of the 26 studies was 0.008 ppm (8 ppb), approximately one-fourth the value determined by the Department of Public Health and lower than the lowest individual threshold of 12 ppb measured in the California panel. Surprisingly the Department of Public Health panel study was not one of the 26 studies used by Amoore and was not even mentioned in his 1985 report to the ARB.

Venstrom and Amoore (1968) reported that, in general, olfactory sensitivities decrease by a factor of 2 for each 22 years of age above age 20. The conclusion was based on a study of 18 odorants in 97 government laboratory workers, ages 20 through 70. Hydrogen sulfide was not tested. The geometric mean odor threshold of 8 ppb for H_2S from the 26 studies is based on an average age of 40 (possibly assumed to be the age of an average adult). Amoore (1985) estimated that an 18-year-old person would have a threshold of 4 ppb H_2S, while a 62-year-old person was predicted to have a threshold of 16 ppb. Amoore also stated that there was no noticeable trend of odor sensitivity between young adults and children down to 5 years but did not present specific data to support the statement.

Concentrations, which substantially exceed the odor threshold for, result in the annoying and discomforting physiological symptoms of headache or nausea (Amoore, 1985; Reynolds and Kauper 1984). The perceived intensity of the odor of H_2S depends on the longevity of the concentration, and the intensity increases 20% for each doubling of the concentration (Amoore,

1985). Several studies have been conducted to establish the ratio of discomforting annoyance threshold to detection threshold for unpleasant odors (Winkler, 1975; Winneke and Kastka, 1977; Hellman and Small, 1974; Adams *et al.,* 1968; and NCASI, 1971). The geometric mean for these studies is 5; therefore an unpleasant odor should result in annoying discomfort when it reaches an average concentration of 5 times its detection threshold. (Two studies that tested only H_2S had a geometric mean of 4.) Applying the 5-fold multiplier to the mean detectable level of 8 ppb results in a mean annoyance threshold of 40 ppb. Amoore (1985) estimates that at 30 ppb, the CAAQS, H_2S would be detectable by 83% of the population and would be discomforting to 40% of the population (Table 1). These "theoretical" estimates have been substantiated by odor complaints and reports of nausea and headache (Reynolds and Kauper 1984) at 30 ppb H_2S exposures from geyser emissions.

In order to avoid substantial complaints about odor annoyance among the exposed population, the World Health Organization (WHO) recommends that hydrogen sulfide concentrations should not exceed 0.005 ppm (5 ppb; 7 $\mu g/m^3$), with a 30-minute averaging time (WHO, 1981; National Research Council, 1979; Lindvall, 1970). The WHO task group believed that 5 ppb averaged over 30 minutes "should not produce odour nuisance in most situations."

Table 1. Predicted effects of exposure to ambient H_2S. (Adapted from Amoore, 1985)

H_2S (ppb)	% able to detect odor[a]	Perceived odor intensity[b] (ratio)	Median odor units[c]	% annoyed by odor[d]
200	99	2.31	25	88
100	96	1.93	12	75
50	91	1.61	6.2	56
40	88	1.52	5.0	50
35	87	1.47	4.4	47
30 (CAAQS)	83	1.41	3.7	40
25	80	1.34	3.1	37
20	74	1.27	2.5	31
15	69	1.18	1.9	22
10	56	1.06	1.2	17
8	50	1.00	1.00	11
6	42	0.93	0.75	8
4	30	0.83	0.50	5
2	14	0.70	0.25	2
1	6	0.58	0.12	1
0.5	2	0.49	0.06	0

[a]Based on mean odor detection threshold of 8.0 ppb and SD±2.0 binary steps
[b] Based on intensity exponent of 0.26 (Lindvall, 1974).
[c]H_2S concentration divided by mean odor detection threshold of 8 ppb.
[d] Based on assumption that mean annoyance threshold is 5x the mean odor detection threshold, and SD±2.0 binary steps.

Kilburn and Warshaw (1995) investigated whether people exposed to sulfide gases, including H_2S, as a result of working at or living downwind from the processing of "sour" crude oil demonstrated persistent neurobehavioral dysfunction. They studied 13 former workers and 22 neighbors of a California coastal oil refinery who complained of headaches, nausea, vomiting, depression, personality changes, nosebleeds, and breathing difficulties. Neurobehavioral functions and a profile of mood states were compared to 32 controls matched for age and educational level. The exposed subjects' mean values were statistically significantly different (abnormal) compared to controls for several tests (two-choice reaction time; balance (as speed of sway); color discrimination; digit symbol; trail-making A and B; immediate recall of a story). Their profile of mood states (POMS) scores were much higher than those of controls. Test scores for anger, confusion, depression, tension-anxiety, and fatigue were significantly

elevated and nearly identical in both exposed residents and former workers, while the scores for controls equaled normal values from other published studies. Visual recall was significantly impaired in neighbors, but not in the former workers. Limited off-site air monitoring (one week) in the neighborhood found average levels of 10 ppb H_2S (with peaks of 100 ppb), 4 ppb dimethylsulfide, and 2 ppb mercaptans. On-site levels were much higher. The authors concluded that neurophysiological abnormalities were associated with exposure to reduced sulfur gases, including H_2S from crude oil desulfurization.

D.1.2. Children. In a case report Gaitonde *et al.* (1987) described subacute encephalopathy, ataxia, and choreoathetoid (jerky, involuntary) responses in a 20-month-old child with long term (approximately one year) exposure to hydrogen sulfide from a coal mine. Levels of up to at least 0.6 ppm (600 ppb) were measured and levels were possibly higher before measurements started. The abnormalities resolved after the emission source ceased operation.

As part of the South Karelia Air Pollution Study in Finland (Jaakkola *et al.*, 1990), Marttila *et al.* (1994) assessed the role of long-term exposure to ambient air malodorous sulfur compounds released from pulp mills as a determinant of eye and respiratory symptoms and headache in children. The parents of 134 children living in severely polluted (n = 42), moderately polluted (n = 62), and rural, non-polluted (n = 30) communities responded to a cross-sectional questionnaire (response rate = 83%). In the severely polluted area, the annual mean concentrations of hydrogen sulfide and methyl mercaptan (H_3CSH) were estimated to be 8 $\mu g/m^3$ (6 ppb) and 2 - 5 $\mu g/m^3$ (1.4 – 3.6 ppb), respectively. The highest daily average concentrations were 100 $\mu g/m^3$ (71 ppb) and 50 $\mu g/m^3$ (36 ppb), respectively. The adjusted odds ratios (OR) for symptoms experienced during the previous 4 weeks and 12 months in the severely versus the non-polluted community were estimated in logistic regression analysis controlling for age and gender. The risks of nasal symptoms, cough, eye symptoms, and

headache were increased in the severely polluted community, but did not reach statistical significance (Table 2). In addition, OEHHA staff noted that the highest percentages of children with symptoms were in the moderately polluted community, not in the severely polluted community. The authors concluded that exposure to malodorous sulfur compounds may affect the health of children. The odor threshold for methyl mercaptan of 1.6 ppb (Amoore and Hautala, 1983) indicates that it also likely contributed to the odor and probably the symptoms.

Table 2. Symptoms Reported in Marttila *et al.* (1994)

Symptom	*Time*	*Odds Ratio*	*95% CI*	*Time*	*Odds ratio*	*95%CI*
nasal symptoms	4 weeks	1.40	0.59-3.31	12 months	2.47	0.93-6.53
cough	4 weeks	1.83	0.75-4.45	12 months	2.28	0.95-5.47
eye symptoms	NR	NR	NR	12 months	1.15	0.43-3.05
headache	NR	1.02	0.36-2.94	12 months	1.77	0.69-4.54

NR = not reported

Studies of controlled exposures in children to study H_2S odor detection have not been located. A recent report studying children concluded that children aged 8 to 14 years have equivalent odor sensitivity to young adults (Cain *et al.*, 1995), although children lack knowledge to identify specific odors by name. Koelega (1994) found that prepubescent children (58 nine-year-olds) were inferior in their detection of 4 of 5 odors compared to 15-year-olds (n = 58) and 20-year-olds (n = 112). Schmidt and Beauchamp (1988) have even tested 3-year-olds (n = 16) for sensitivity to noxious chemicals, such as butyric acid and pyridine.

In March-April 1983, 949 cases (including 727 in adolescent females) of acute non-fatal illness consisting of headache, dizziness, blurred vision, abdominal pain, myalgia, and fainting occurred at schools on the West Bank. However, physical examinations and biochemical tests were normal. There was no common exposure to food, drink, or agricultural chemicals among those affected. No toxins were consistently present in patients' blood or urine. The only environmental toxicant detected was H_2S gas in low concentrations (40 ppb) in a schoolroom at

the site of the first outbreak (from a faulty latrine in the schoolyard). The illness was deemed to be psychogenic and possibly triggered by the smell of H_2S (Landrigan and Miller , 1983; Modan *et al.*, 1983).

D.1.3. Development. Xu *et al.* (1998) conducted a retrospective epidemiological study in a large petrochemical complex in Beijing, China in order to assess the possible association between petrochemical exposure and spontaneous abortion. The facility consisted of 17 major production plants divided into separate workshops, which allowed for the assessment of exposure to specific chemicals. Married women (n = 2,853), who were 20-44 years of age, had never smoked, and who reported at least one pregnancy during employment at the plant, participated in the study. According to their employment record, about 57% of these workers reported occupational exposure to petrochemicals during the first trimester of their pregnancy. There was a significantly increased risk of spontaneous abortion for women working in all of the production plants with frequent exposure to petrochemicals compared with those working in non-chemical plants. Also, when a comparison was made between exposed and non-exposed groups within each plant, exposure to petrochemicals was consistently associated with an increased risk of spontaneous abortion (overall odds ratio (OR) = 2.7 (95% confidence interval (CI) = 1.8 to 3.9) after adjusting for potential confounding factors). Using exposure information obtained from interview responses for (self-reported) exposures, the estimated OR for spontaneous abortions was 2.9 (95% CI = 2.0 to 4.0). When the analysis was repeated by excluding 452 women who provided inconsistent reports between recalled exposure and work history, a comparable risk of spontaneous abortion (OR 2.9; 95% CI = 2.0 to 4.4) was found. In analyses for exposure to specific chemicals, an increased risk of spontaneous abortion was found with exposure to most chemicals. There were 106 women (3.7% of the study population) exposed only to hydrogen sulfide; the results for H_2S (OR 2.3; 95% CI = 1.2 to 4.4) were statistically significant. Unfortunately H_2S exposure concentrations were not reported.

D.2. Effects of Animal Exposure

D.2.1. Adult/mature animals. A median lethal concentration (LC_{50}) in rats exposed to H_2S for 4 hours was estimated as 440 ppm (616 mg/m³) (Tansy *et al.*, 1981). An inhalation LC_{Lo} of 444 ppm for an unspecified duration is reported in rats, and a lethal concentration of 673 ppm (942 mg/m³) for 1 hour is reported in mice (RTECS, 1994). In another study, mortality was significantly higher for male rats (30%), compared to females (20%), over a range of exposure times and concentrations (Prior *et al.*, 1988). A concentration of 1,000 ppm (1,400 mg/m³) caused respiratory arrest and death in dogs after 15-20 minutes (Haggard and Henderson, 1922). Inhalation of 100 ppm (140 mg/m³) for 2 hours resulted in altered leucine incorporation into brain proteins in mice (Elovaara *et al.*, 1978). Kosmider *et al.* (1967) reported abnormal electrocardiograms in rabbits exposed to 100 mg/m³ (71 ppm) H_2S for 1.5 hours.

Khan *et al.* (1990) exposed groups of 12 male Fischer 344 rats to 0, 10, 50, 200, 400, or 500-700 ppm hydrogen sulfide for 4 hours. Four rats from each group were euthanized at 1, 24, or 48 hours post-exposure. The activity of cytochrome c oxidase in lung mitochondria, a primary molecular target of H_2S, was significantly ($p<0.05$) decreased at 50 ppm (15%), 200 ppm (43%), and 400 ppm (68%) at 1-hour post-exposure compared to controls. A NOAEL of 10 ppm for inhibition of cytochrome c oxidase was identified in this study.

Fischer and Sprague-Dawley rats (15 per group) were exposed to 0, 10.1, 30.5, or 80 ppm (0, 14.1, 42.7, or 112 mg/m^3, respectively) H_2S for 6 hours/day, 5 days/week for 90 days (CIIT, 1983a,b). Measurements of neurological and hematological function revealed no abnormalities due to H_2S exposure. Histological examination of the nasal turbinates also revealed no significant exposure-related changes. A significant decrease in body weight was observed in both strains of rats exposed to 80 ppm (112 mg/m^3).

In a companion study, the CIIT conducted a 90-day inhalation study in mice (10 or 12 mice per group) exposed to 0, 10.1, 30.5, or 80 ppm (0, 14.1, 42.7, or 112 mg/m^3, respectively) H_2S for 6 hours/day, 5 days/week (CIIT, 1983c). Neurological function was measured by tests

for posture, gait, facial muscle tone, and reflexes. Ophthalmologic and hematologic examinations were also performed, and a detailed necropsy was included at the end of the experiment. The only exposure-related histological lesion was inflammation of the nasal mucosa of the anterior segment of the noses of mice exposed to 80 ppm (112 mg/m^3) H_2S. Weight loss was also observed in the mice exposed to 80 ppm. Neurological and hematological tests revealed no abnormalities. The 30.5 ppm (42.5 mg/m^3) level was considered to be a NOAEL for histological changes in the nasal mucosa. (Different adjustments were made to this NOAEL by U. S. EPA to calculate the RfC of 1 μg/m^3 and by OEHHA to calculate the chronic REL of 10 μg/m^3 (8 ppb).)

Hydrogen sulfide (0, 10, 30, or 80 ppm) was administered via inhalation (6 h/d, 7 d/wk) to 10-week-old male CD rats (n = 12/group) for 10 weeks (Brenneman *et al.*, 2000). Histological evaluation revealed that rats exposed to 30 or 80 ppm had significant increases in lesions of the olfactory mucosa but not other tissues. Multifocal, rostrocaudally-distributed olfactory neuron loss and basal cell hyperplasia were seen. The dorsal medial meatus and the dorsal and medial portions of the ethmoid recess were affected. The lowest dose (10 ppm) was considered a no observed adverse effect level for olfactory lesions.

Fischer F344 rats inhaled 0, 1, 10, or 100 ppm hydrogen sulfide for 8 hours/day for 5 weeks (Hulbert *et al*, 1989). No effects were noted on baseline measurements of airway resistance, dynamic compliance, tidal volume, minute volume, or heart rate. Two findings were noted more frequently in exposed rats: (1) proliferation of ciliated cells in the tracheal and bronchiolar epithelium, and (2) lymphocyte infiltration of the bronchial submucosa. Some exposed animals responded similarly to controls to aerosol methacholine challenge, whereas a subgroup of exposed rats were hyperreactive to concentrations as low as 1 ppm H_2S.

Male rats were exposed to 0, 10, 200, or 400 ppm H_2S for 4 hours (Lopez *et al.*, 1987). Samples of bronchoalveolar and nasal lavage fluid contained increased inflammatory cells,

protein, and lactate dehydrogenase in rats treated with 400 ppm. Later Lopez and associates (1988) showed that exposure to 83 ppm (116 mg/m^3) for 4 hours resulted in mild perivascular edema.

D.2.2. Developing animals. Saillenfait *et al.* (1989) investigated the developmental toxicity of H_2S in rats. Rats were exposed 6 hours/day on days 6 through 20 of gestation to 100 ppm hydrogen sulfide. No maternal toxicity or developmental defects were observed.

Hayden *et al.* (1990) exposed gravid Sprague-Dawley rat dams continuously to 0, 20, 50, and 75 ppm H_2S from day 6 of gestation until day 21 postpartum. The animals demonstrated normal reproductive parameters until parturition, when delivery time was extended in a dose-dependent manner (with a maximum increase of 42% at 75 ppm). Pups exposed in utero and neonatally to day 21 postpartum developed with a subtle decrease in time of ear detachment and hair development, but with no other observed change in growth and development through day 21 postpartum.

Hannah and Roth (1991) analyzed the dendritic fields of developing Purkinje cells in rat cerebellum to determine the effects of chronic exposure to low concentrations of H_2S during perinatal development. Treatment of timed-pregnant female Sprague Dawley rats with 20 and 50 ppm H_2S for 7 hours per day from day 5 after mating until day 21 after birth produced severe alterations in the architecture and growth characteristics of the dendritic fields of the Purkinje cells. The architectural modifications included longer branches, an increase in the vertex path length, and variations in the number of branches in particular areas of the dendritic field. The treated cells also exhibited a nonsymmetrical growth pattern at a time when random terminal branching is normally occurring. Thus, developing neurons exposed to H_2S may be at risk of severe deficits. However, the lower level of 20 ppm for 7 hours is nearly 2 orders of magnitude above the present one-hour standard.

Dorman *et al.* (2000) examined the effect of perinatal exposure of H_2S on pregnancy outcomes, offspring development, and offspring behavior in rats. Male and female Sprague-

Dawley rats (12 rats/sex/concentration) were exposed to 0, 10, 30, or 80 ppm H_2S 6 h/day, 7 days/week for 2 weeks prior to breeding. Exposures continued during a 2-week mating period and then from Gestation Day (GD) 0 through GD 19. Exposure of rat dams and their pups (eight rats/litter after culling) resumed between postnatal day (PND) 5 and 18. Adult males were exposed for 70 consecutive days. Offspring were evaluated using motor activity (assessed on PND 13, 17, 21, and 60±2), passive avoidance (PND 22±1 and 62±3), functional observation battery (FOB) (PND 60±2), acoustic startle response (PND 21 and 62±3), and neuropathology (PND 23±2 and 61±2). No deaths occurred and no adverse physical signs were seen in F_0 males or females. There were no statistically significant effects on the reproductive performance of the F_0 rats as assessed by the number of females with live pups, litter size, average length of gestation, and the average number of implants per pregnant female. Exposure to H_2S did not affect pup growth, development, or performance on any behavioral test. The authors conclude that H_2S is neither a reproductive toxicant nor a behavioral developmental neurotoxicant in the rat at occupationally relevant exposure concentrations (i.e., at 10 ppm, the current occupational daily average exposure limits - TLV and PEL; however, the ACGIH is considering lowering the TLV to 5 ppm). The lowest level tested (10 ppm) is more than 300-fold higher than the CAAQS of 0.030 ppm.

E. Interactions between hydrogen sulfide and other pollutants

Ethanol can potentiate the effects of H_2S by shortening the mean time-to-unconsciousness in mice exposed to 800 ppm (1,120 mg/m^3) H_2S (Beck *et al.*, 1979).

Endogenous hydrogen sulfide may regulate smooth muscle tone in synergy with nitric oxide (Hosoki *et al.*, 1997).

Hydrogen sulfide is often accompanied by other malodorous sulfur compounds, such as methyl mercaptan, dimethyl sulfide, and dimethyl disulfide. Some of these have odor thresholds

lower than that of hydrogen sulfide. The complex mixture is often referred to as TRS (total reduced sulfur).

Lindvall (1977) reported that the perceived odor strength of H_2S is increased by the simultaneous presence of 600 ppb nitric oxide (600 ppb nitric acid is imperceptible by itself).

F. Conclusions

The current standard of 0.03 ppm (30 ppb) hydrogen sulfide for one hour based on odor is well below NOAEL levels from animal experiments where exposure lasted weeks to months, including the period of intrauterine development. However, it is greater than OEHHA's chronic Reference Exposure Level (REL) of 8 ppb, which is based on histological changes in the nasal area of mice. (The chronic REL is compared to the annual average H_2S concentration.) Ideally neither of these two benchmark levels should be exceeded by the properly averaged concentration.

Additional research might help reduce uncertainties regarding the impacts of hydrogen sulfide on the health of infants and children. This would include:

a. Odor testing of hydrogen sulfide in adolescents or younger children, if ethically permissible, to determine their odor threshold. Current data on odor detection in children are not consistent. Data on H_2S odor detection in children under controlled exposure are lacking.

b. The identification of children hypersensitive to the odor of hydrogen sulfide. While the odor from very low level H_2S would not itself threaten their physical health, the odor might be alarming to hypersensitive children. Psychosomatic complaints might be more confusing to children than to adults.

c. Physiologic testing of anosmic (either specifically anosmic to H_2S or totally anosmic) children at the CAAQS would be useful in determining whether if adverse physiological symptoms occur in the absence of odor detection.

d. Testing of the odor threshold for H_2S using the most current methodology among groups of healthy persons of both sexes in different age ranges. Data from such testing would likely be an improvement over the use of either the mean of 16 people (California Department of Public Health, 1969) or the mean from 26 studies, conducted over a period of 130 years, which found thresholds spanning a 20,000 fold range, from 0.07 ppb to 1400 ppb (Amoore, 1985). (If the highest and lowest values of the range in Amoore (1985) are dropped as outliers - Amoore (1985) stated that these two studies seemed to involve only one subject - the range would be 0.43 ppb to 190 ppb, a 440-fold range).

e. Further research is needed on the topic of when odor is an adverse health effect and how much consideration should be given to psychosomatic complaints accompanying odor annoyance (Dalton *et al.*, 1997; ATS, 2000). A recent American Thoracic Society position paper titled "What Constitutes an Adverse Health Effect of Air Pollution?" (ATS, 2000) indicates that air pollution exposures, which interfere with the quality of life, can be considered adverse. This suggests that, for the purpose of setting a standard, odor-related annoyance should be considered adverse, even if nausea or headache or other symptoms are not present.

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Air Resources Board

Compound Summaries Sorted Alphabetically

This page updated August 31, 2005.

Lists of Toxic Air Contaminants

The following substance names are sorted alphabetically and provide a cross reference to the ass
Abstract Service registry numbers (CAS) and Department of Transportation (DOT) numbers.

- CAS Numbers Table of Contents (HTML - 89K)
- DOT Numbers Table of Contents (HTML - 61K)

	Substance Name	CAS #
	Acetaldehyde	75-07-0
	Acetamide	60-35-5
	Acetonitrile	75-05-8
	Acetophenone	98-86-2
	2-Acetylaminofluorene	53-96-3
	Acrolein	107-02-8
	Acrylamide	79-06-1
	Acrylic acid	79-10-7
	Acrylonitrile	107-13-1
	Allyl chloride	107-05-1
	Aluminum and Compounds	7429-90-5
	Aluminum phosphide (please see Aluminum and Compounds)	20859-73-8
++	Aluminum sulfate (please see Aluminum and Compounds)	10043-01-3
	4-Aminobiphenyl	92-67-1
	Ammonia	7664-41-7
++	Ammonium nitrate	6484-52-2
++	Ammonium sulfate	7783-20-2
	Aniline	62-53-3
	o-Anisidine	90-04-0
	Antimony Compounds	7440-36-0
	Antimony trioxide	1309-64-4

	(please see Antimony Compounds)	
	Arsenic and Compounds	7440-38-2
	Arsenic trioxide (please see Arsenic and Compounds)	1327-53-3
	Arsine (please see Arsenic and Compounds)	7784-42-1
*	Asbestos	1332-21-4
	Aziridine (Ethylene imine)	151-56-4
++	Barium Compounds	7440-39-3
*	Benzene	71-43-2
	Benzidine	92-87-5
	Benzo[a]pyrene	50-32-8
++	Benzotrichloride	98-07-7
++	Benzoyl chloride	98-88-4
	Benzyl chloride	100-44-7
	Beryllium Compounds	7440-41-7
	Beryllium oxide (please see Beryllium Compounds)	1304-56-9
	Beryllium sulfate (please see Beryllium Compounds)	13510-49-1
	Biphenyl	92-52-4
	Bis(2-chloroethyl) ether (Dichloroethyl ether)	111-44-4
	Bis(2-ethylhexyl)adipate	103-23-1
	Bis(2-ethylhexyl)phthalate (DEHP)	117-81-7
	Bis(chloromethyl)ether	542-88-1
	Bromine Compounds (inorganic)	7726-95-6
	Potassium bromate (please see Bromine Compounds)	7758-01-2
	Bromoform	75-25-2
	Bromomethane (Methyl bromide)	74-83-9
*	1,3-Butadiene	106-99-0
	2-Butanone (Methyl ethyl ketone)	78-93-3
	Butyl acrylate	141-32-2
	n-Butyl alcohol	71-36-3
	sec-Butyl alcohol	78-92-2
	tert-Butyl alcohol	75-65-0
	Butyl benzyl phthalate	85-68-7
*	Cadmium and Cadmium Compounds	7440-43-9
	Cadmium sulfate (please see Cadmium and Cadmium Compounds)	10124-36-4
	Cadmium sulfide (please see Cadmium and Cadmium Compounds)	1306-23-6
	Calcium cyanamide	156-62-7

	Caprolactam		105-60-2
	Captan		133-06-2
	Carbaryl		63-25-2
	Carbon black extracts		1333-86-4
	Carbon disulfide		75-15-0
*	Carbon tetrachloride		56-23-5
++	Carbonyl sulfide		463-58-1
	Catechol		120-80-9
	Chloramben		133-90-4
	Chlordane		57-74-9
	Chlorinated camphene (Toxaphene)		8001-35-2
*	Chlorinated dibenzofurans (please see Chlorinated dioxins)		N/A
*	Chlorinated dioxins		N/A
	Chlorinated fluorocarbons		76-13-1
	Chlorine		7782-50-5
	Chlorine dioxide		10049-04
++	Chloroacetic acid		79-11-8
	2-Chloroacetophenone		532-27-4
	Chlorobenzene		108-90-7
	Chlorobenzilate		510-15-6
	Chloroethane (Ethyl chloride)		75-00-3
	1-Chloro-2,3-epoxypropane (Epichlorohydrin)		106-89-8
*	Chloroform		67-66-3
	Chloromethane (Methyl chloride)		74-87-3
	Chloromethyl methyl ether		107-30-2
	Chlorophenols		N/A
	++	m-Chlorophenol (please see Chlorophenols)	108-43-0
	++	o-Chlorophenol (please see Chlorophenols)	95-57-8
	++	p-Chlorophenol (please see Chlorophenols)	106-48-9
		2,3,4,6-tetrachlorophenol (please see Chlorophenols)	58-90-2
	Chloroprene		126-99-8
	Chromium and Compounds		7440-47-3
*		Chromium VI (Hexavalent chromium) (please see Chromium and Compounds)	18540-29
	Cobalt Compounds		7440-48-4
		Cobalt(II) oxide (please see Cobalt Compounds)	1307-96-6
	Coke Oven Emissions		N/A

	Copper Compounds		7440-50-8
		Copper sulfate (please see Copper Compounds)	7758-98-7
	Creosotes		N/A
++		Coal tar (please see Creosotes)	8001-58-9
		Wood (please see Creosotes)	8021-39-4
++	Cresols/Cresylic acid (isomers and mixture)		1319-77-3
		o-Cresol (please see Cresols/Cresylic acid)	95-48-7
		m-Cresol (please see Cresols/Cresylic acid)	108-39-4
		p-Cresol (please see Cresols/Cresylic acid)	106-44-5
	Crystalline silica		7631-86-9
		Quartz (please see Crystalline silica)	14808-60-7
		Tridymite (please see Crystalline silica)	15468-32-3
		Cristobalite (please see Crystalline silica)	14464-46-1
	Cumene		98-82-8
++	Cumene hydroperoxide		80-15-9
	Cyanide Compounds		57-12-5
		Hydrocyanic acid (please see Cyanide Compounds)	74-90-8
	Cyclohexane		110-82-7
	2,4-D, salts and esters		94-75-7
	DDE (p,p-Dichlorodiphenyldichloroethylene)		72-55-9
		DDT (Dichlorodiphenyltrichloroethane) (please see DDE)	50-29-3
	Decabromodiphenyl oxide		1163-19-5
	Di(2-ethylhexyl)phthalate (DEHP)		117-81-7
	Dialkylnitrosamines		N/A
		N-Nitroso-n-methylurea	684-93-5
		N-Nitrosodimethylamine	62-75-9
		N-Nitrosomorpholine	59-89-2
		N-Nitrosodiethylamine (please see Dialkylnitrosamines)	55-18-5
	Diaminotoluene (mixed isomers)		N/A
		2,4-Toluene diamine	95-80-7
		2,5-Diaminotoluene (please see Diaminotoluene - mixed isomers)	95-70-5

	2,6-Diaminotoluene (please see Diaminotoluene - mixed isomers)	823-40-5
	3,4-Diaminotoluene (please see Diaminotoluene - mixed isomers)	496-72-0
	Diazomethane	334-88-3
	Dibenzofuran	132-64-9
	1,2-Dibromo-3-chloropropane (DBCP)	96-12-8
*	1,2-Dibromoethane (Ethylene dibromide)	106-93-4
	Dibutylphthalate	84-74-2
	1,4-Dichlorobenzene (p-Dicholorobenzene)	106-46-7
	3,3'-Dichlorobenzidene	91-94-1
	1,1-Dichloroethane (Ethylidene dichloride)	75-34-3
*	1,2-Dichloroethane (Ethylene dichloride)	107-06-2
	Dichloroethyl ether (Bis(2-chloroethyl) ether)	111-44-4
	1,1-Dichloroethylene (Vinylidene chloride)	75-35-4
*	Dichloromethane (Methylene chloride)	75-09-2
	1,2-Dichloropropane (Propylene dichloride)	78-87-5
	1,3-Dichloropropene (Telone)	542-75-6
	Dichlorvos (DDVP)	62-73-7
++	Dicofol	115-32-2
**	Diesel exhaust	N/A
	Diethanolamine	111-42-2
++	Diethyl sulfate	64-67-5
	3,3'-Dimethoxybenzidine	119-90-4
	Dimethyl aminoazobenzene	60-11-7
	N,N-Dimethylaniline	121-69-7
	3,3'-Dimethyl benzidine (o-Tolidine)	119-93-7
	Dimethyl carbamoyl chloride	79-44-7
	Dimethyl formamide	68-12-2
	1,1-Dimethyl hydrazine	57-14-7
	Dimethyl phthalate	131-11-3
	Dimethyl sulfate	77-78-1
	4,6-Dinitro-o-cresol, and salts	534-52-1
	2,4-Dinitrophenol	51-28-5
	2,4-Dinitrotoluene	121-14-2
	1,4-Dioxane	123-91-1
	1,2-Diphenylhydrazine	122-66-7
	Environmental Tobacco Smoke	N/A
	Epichlorohydrin (1-Chloro-2,3-epoxypropane)	106-89-8
	1,2-Epoxybutane	106-88-7
	Ethyl acrylate	140-88-5
	Ethyl benzene	100-41-4

	Ethyl carbamate (Urethane)	51-79-6
	Ethyl chloride (Chloroethane)	75-00-3
*	Ethylene dibromide (1,2-Dibromoethane)	106-93-4
*	Ethylene dichloride (1,2-Dichloroethane)	107-06-2
	Ethylene glycol	107-21-1
	Ethylene imine (Aziridine)	151-56-4
*	Ethylene oxide	75-21-8
	Ethylene thiourea	96-45-7
	Ethylidene dichloride (1,1-Dichloroethane)	75-34-3
	Fine Mineral Fibers	N/A
*	Formaldehyde	50-00-0
	Gasoline Vapors	N/A
	Glutaraldehyde	111-30-8
	Glycol ethers	N/A
	Ethylene glycol monoethyl ether (please see Glycol ethers)	110-80-5
	Heptachlor	76-44-8
++	Hexachlorobenzene	118-74-1
	Hexachlorobutadiene	87-68-3
	Hexachlorocyclohexanes	608-73-1
	Lindane	58-89-9
	Hexachlorocyclopentadiene	77-47-4
	Hexachloroethane	67-72-1
	Hexamethylene-1,6-diisocyanate	822-06-0
	Hexamethylphosphoramide	680-31-9
	Hexane	110-54-3
*	Hexavalent chromium (Chromium VI) (please see Chromium and Compounds)	18540-29-9
	Hexone (Methyl isobutyl ketone)	108-10-1
	Hydrazine	302-01-2
	Hydrochloric acid	7647-01-0
	Hydrogen fluoride (Hydrofluoric acid)	7664-39-3
	Hydrogen sulfide	7783-06-4
	Hydroquinone	123-31-9
*	Inorganic arsenic (please see Arsenic and Compounds)	N/A
*	Inorganic lead (please see Lead and Compounds)	N/A
	Iodomethane (Methyl iodide)	74-88-4
	Isophorone	78-59-1
	Isopropyl alcohol	67-63-0
	4,4'-Isopropylidenediphenol	80-05-7

	Lead and Compounds	7439-92-1
*	Inorganic lead (please see Lead and Compounds)	N/A
	Lindane (all isomers)	58-89-9
	Maleic anhydride	108-31-6
	Manganese Compounds	7439-96-5
	Mancozeb (please see Manganese Compounds)	8018-01-7
	Mercury Compounds	7439-97-6
++	Mercuric chloride (please see Mercury Compounds)	7487-94-7
	Methyl mercury (please see Mercury Compounds)	22967-92-6
	Methanol	67-56-1
	Methoxychlor	72-43-5
	2-Methyl aziridine (1,2-Propylenimine)	75-55-8
	Methyl bromide (Bromomethane)	74-83-9
++	Methyl tert-butyl ether (MTBE)	1634-04-4
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	Methyl chloroform (1,1,1-Trichloroethane)	71-55-6
	Methyl ethyl ketone (2-Butanone)	78-93-3
	Methyl hydrazine	60-34-4
	Methyl iodide (Iodomethane)	74-88-4
	Methyl isobutyl ketone (Hexone)	108-10-1
	Methyl isocyanate	624-83-9
	Methyl methacrylate	80-62-6
	4,4'-Methylene bis(2-chloroaniline)	101-14-4
*	Methylene chloride (Dichloromethane)	75-09-2
	Methylene diphenyl diisocyanate (MDI)	101-68-8
	4,4-Methylenedianiline	101-77-9
	Molybdenum trioxide	1313-27-5
	Naphthalene	91-20-3
*	Nickel and Compounds	7440-02-0
	Nickel carbonyl (please see Nickel and Compounds)	13463-39-3
	Nitric acid	7697-37-2
	Nitrilotriacetic acid	139-13-9
	Nitrobenzene	98-95-3
	4-Nitrobiphenyl	92-93-3
++	4-Nitrophenol	100-02-7
	2-Nitropropane	79-46-9
	N-Nitroso-n-methylurea	684-93-5

	N-Nitrosodimethylamine	62-75-9
	N-Nitrosomorpholine	59-89-2
	Parathion	56-38-2
	Pentachloronitrobenzene (Quintozene)	82-68-8
	Pentachlorophenol	87-86-5
++	Peracetic acid	79-21-0
*	Perchloroethylene (Tetrachloroethylene)	127-18-4
	Phenol	108-95-2
	p-Phenylenediamine	106-50-3
	2-Phenylphenol	90-43-7
	Phosgene	75-44-5
	Phosphine	7803-51-2
	Phosphoric acid	7664-38-2
	Phosphorus	7723-14-0
	Phthalic anhydride	85-44-9
++	Polychlorinated Biphenyls (PCBs)	1336-36-3
	Polycyclic Organic Matter (POM)	50-32-8
	Acenaphthene (please see POM)	83-32-9
	Acenaphthylene (please see POM)	208-96-8
	Anthracene (please see POM)	120-12-7
	Benzo[a]pyrene (please see POM)	50-32-8
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	Benzo[b]fluoranthene (please see POM)	205-99-2
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	Benzo[g,h,i]perylene (please see POM)	191-24-2
	Chrysene (please see POM)	218-01-9
	Dibenz[a,h]anthracene (please see POM)	53-70-3
	Dibenz[a,e]pyrene (please see POM)	192-65-4
	Fluoranthene (please see POM)	206-44-0
	Fluorene (please see POM)	86-73-7
	Indeno[1,2,3-cd]pyrene	193-39-5

	(please see POM)	
	Phenanthrene (please see POM)	85-01-8
	Pyrene (please see POM)	129-00-0
	1,3-Propane sultone	1120-71-4
++	Propene	115-07-1
	beta-Propiolactone	57-57-8
++	Propionaldehyde	123-38-6
	Propoxur (Baygon)	114-26-1
	Propylene dichloride (1,2-Dichloropropane)	78-87-5
	Propylene oxide	75-56-9
	1,2-Propylenimine (2-Methyl aziridine)	75-55-8
++	Quinoline	91-22-5
	Quinone	106-51-4
	Quintozene (Pentachloronitrobenzene)	82-68-8
	Radionuclides (including radon)	N/A
	Iodine (please see Radionuclides)	7553-56-2
	Radon (please see Radionuclides)	10043-92-2
	Selenium Compounds	7782-49-2
	Selenium monosulfide (please see Selenium Compounds)	7446-34-6
	Silver Compounds	7440-22-4
	Sodium hydroxide	1310-73-2
	Styrene	100-42-5
	Styrene oxide	96-09-3
	Sulfuric acid	7664-93-9
	Telone (1,3-Dichloropropene)	542-75-6
	Terephthalic acid	100-21-0
	2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) (please see Chlorinated dioxins)	1746-01-6
	1,1,2,2-Tetrachloroethane	79-34-5
*	Tetrachloroethylene (Perchloroethylene)	127-18-4
++	Thiourea	62-56-6
++	Titanium tetrachloride	7550-45-0
	o-Tolidine (3,3'-Dimethyl benzidine)	119-93-7
	Toluene	108-88-3
	2,4-Toluene diamine (2,4-Diaminotoluene)	95-80-7
	2,4-Toluene diisocyanate	584-84-9
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*	Trichloroethylene	79-01-6
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	1,2,4-Trimethylbenzene	95-63-6
++	2,2,4-Trimethylpentane	540-84-1
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*	Vinyl chloride	75-01-4
	Vinylidene chloride (1,1-Dichloroethylene)	75-35-4
++	Xylenes (isomers and mixture)	1330-20-7
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	o-Xylene (please see Xylenes - isomers and mixture)	95-47-6
	p-Xylene (please see Xylenes - isomers and mixture)	106-42-3
++	Zinc Compounds	7440-66-6
	Zinc oxide (please see Zinc Compounds)	1314-13-2

#	Number
+	Department of Transportation (DOT) identification number indicates that the chemical is re information was found in the *NIOSH Pocket Guide to Chemical Hazards (June 1994)*.
++	Department of Transportation (DOT) identification number found in *Dangerous Properties Materials, seventh edition,1989, Sax.*
*	Substances which have already been identified by the Board as toxic air contaminants and v numbers developed by the Office of Environmental Health Hazard Assessment and approve Review Panel.
**	Substances currently under review for identification as toxic air contaminants.

Toxic Air Contaminant (TAC) Indentification Program

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Appendix R

ATTACHMENT A TO THE STAFF REPORT

SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

Technology Assessment for:

PROPOSED RULE 1133: EMISSION REDUCTIONS FROM COMPOSTING AND RELATED OPERATIONS

March 22, 2002

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VICE CHAIR: WILLIAM A. BURKE, Ed.D.
Speaker of the Assembly Appointee

MEMBERS:

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EXECUTIVE OFFICER:

BARRY R. WALLERSTEIN, D.Env.

LIST OF ACRONYMS AND ABBREVIATIONS

AB	Assembly Bill
AQMD	South Coast Air Quality Management District
AQMP	Air Quality Management Plan
BACT	Best Available Control Technology
CARB	California Air Resources Board
CEQA	California Environmental Quality Act
CIWMB	California Integrated Waste Management Board
EPA	U.S. Environmental Protection Agency
LEA	Local Enforcement Agency
NH_3	Ammonia
NPDES	National Pollutant Discharge Elimination System
PM10	Particulate Matter with Aerodynamic Diameter less than 10 Microns
RWQCB	Regional Water Quality Control Board
RCRA	Resource Conservation and Recovery Act
ROG	Reactive Organic Gas
SIC	Standard Industrial Classification
SIP	State Implementation Plan
VOC	Volatile Organic Compound

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EXECUTIVE SUMMARY

INTRODUCTION

✓ This chapter provides an Executive Summary

EXECUTIVE SUMMARY

Background

The South Coast Air Quality Management District (AQMD) is the local agency responsible for air quality assessment and improvement in the four-county area that includes Orange, the non-desert portions of Los Angeles and San Bernardino Counties, and most of Riverside County. In order to accomplish its mandate, AQMD is required to adopt and implement an Air Quality Management Plan (AQMP) that identifies the control strategies to achieve federal ambient air quality standards and demonstrate compliance with the state and federal clean air acts. The South Coast Air Basin (Basin) is a serious non-attainment area for PM10 (particulate matter less than 10 microns) and must attain the standard by 2006. The Basin is the only extreme ozone non-attainment area and must attain the standard by 2010. Ammonia is a precursor of PM10, particularly aerosol ammonium nitrate and ammonium sulfate. Volatile Organic Compounds (VOCs) are precursors to ozone. As shown in this report, composting of greenwaste only produces significant VOC emissions and appreciable ammonia emissions. Composting of sewage sludge and manure produces significant ammonia emissions in localized areas, as well as VOC emissions.

The 1997 AQMP and the 1999 Amendments to the 1997 Ozone State Implementation Plan (SIP) for the South Coast Air Basin included Control Measure WST-02 – Emission Reductions from Composting. This technology assessment report provides information developed as part of the rule development efforts undertaken to date by AQMD staff to implement Control Measure WST-02.

This report provides background information and rule development recommendations that will be submitted to the AQMD Governing Board at the April 5, 2001 Pre-Hearing for Proposed Rule 1133 – Emissions Reductions from Composting and Related Operations.

Industry Profile

The composting and related operations industry within the AQMD's jurisdiction includes 277 facilities categorized as follows: co-composting facilities; greenwaste only composting facilities; chipping and grinding facilities; and, exempt facilities. Co-composting facilities use putrescible materials, such as, wastewater sludge, manure, or food waste in combination with greenwaste as their process feedstock. Greenwaste composting facilities are composting facilities that only use greenwaste as process feedstock. Chipping and grinding facilities are facilities dedicated to the size reduction of greenwaste for uses such as alternative daily cover, biomass fuel, mulch, soil amendments, or composting feedstock. Finally; exempt facilities are facilities that are part of this industry but are likely to be exempt from regulation under Proposed Rule 1133.

Emissions Inventory
The baseline emissions inventory estimated for the industry is 4.7 and 6.8 tons per day for ammonia and VOC, respectively. The co-composting emissions inventory is estimated at 3.7 and 2.2 tons per day of ammonia and VOC, respectively. The greenwaste composting emissions inventory is estimated at 1.0 and 4.4 tons per day of ammonia and VOC, respectively.

The largest co-composting facilities are estimated each to emit 100 to 300 tons per year of VOC and 150 to 500 tons per year of ammonia. The largest greenwaste composting facilities are estimated each to emit 250 to 600 tons per year of VOC emissions, which would rank them among the largest VOC sources in the Basin.

The baseline emission inventory is based on source tests and emissions studies conducted by AQMD staff. The CIWMB subsequently conducted a series of source tests at greenwaste processing and composting facilities in December of 2001. Although the final results have not been completely reviewed by AQMD staff in time to be included in this report, AQMD staff will incorporate those test results to the greewaste composting emissions analysis and report the revised analysis to stakeholders as soon as possible.

Technical Assessment
AQMD staff has conducted a technology assessment of the composting and related operations industry. The technology assessment reviews composting processes available to industry including the following: windrow, aerated static piles, and in-vessel. The analysis also evaluated ASP systems and enclosures in combination with bio-filtration systems. Based on this analysis, AQMD staff demonstrated that there are technological options that will significantly reduce emissions from the composting and related operations industry.

Control Options and Socioeconomic Analysis
AQMD staff developed three control scenarios to evaluate the potential emission reductions and cost of controlling co-composting and greenwaste composting.

Scenario one assumes the enclosure of the active and curing parts of the composting process, the use of an ASP or in-vessel system, and venting of emissions to control equipment (i.e., biofilter). *Scenario two* assumes enclosure of the active phase of the process and the use of an ASP or in-vessel system with emissions vented to control equipment. For the curing phase of the process, scenario two has a variation for co-composting and greenwaste composting. For co-composting, scenario two assumes the use of a negative-pressure ASP system with emissions vented to controls (no enclosure). For the greenwaste composting, scenario two assumes no controls for the curing phase of the process. Finally, *scenario three* assumes the use of a negative-pressure ASP system for both the active and curing phases of the process with emissions vented to control equipment (no enclosures).

As part of the cost analysis, AQMD staff has analyzed cost-effectiveness and compliance affordability. In general, while the control options for the co-composting sector of the industry are seen as feasible and effective, they are costly.

Relative to co-composting, the control options for the greenwaste composting sector of the industry are more cost effective. However, the affordability analysis, as presented in Chapter IV, demonstrates that the cost impact for this industry would be substantial.

Recommendation

Based on information in this report, AQMD staff is recommending that AQMP Control Measure WST-2 – Emission Reductions from Composting, be implemented in two phases. The first phase would consist of an adoption of a fact-finding rule that would have the elements listed below. The first phase would also include control requirements for new co-composting facilities with total throughput design capacity of 100,000 tons per year. The second phase would consider composting control technologies for new and existing facilities based on the results of additional technical work described below.

Requirements for Co-Composting

As described in this report, co-composting facilities are major sources of VOC and ammonia emissions (e.g., a 100,000 ton/year total throughput facility has annual emissions of 89 tons/year VOC and 147 tons/year ammonia). Based on local community concerns and industry studies, siting of large co-composing facilities in urban areas now requires active consideration of enclosed and controlled facilities to address public health and nuisance concerns. Enclosed ASP or in-vessel systems with control equipment, while feasible and effective at significantly reducing emissions, are costly. Therefore, AQMD staff recommendations are as follows:

Existing and new Co-Composting Facilities

- One-time registration with AQMD;
- Annual reporting requirements;
- PM10 controls to prevent visible PM10 emissions over the property line during operations and from compost piles; and,
- Compliance with all applicable AQMD rules, regulations and permit conditions.

New Co-Composting Facilities with a Design Capacity > 100,000 tpy

- Scenario II control requirements for new facilities with total throughput designed capacity of 100,000 tons per year;
  - ✓ Enclosure and ASP for the active phase of the process with emissions vented to a bio-filtration system;
  - ✓ Open ASP for the curing phase of the process with emission vented to a bio-filtration system;

Greenwaste Composting

As described in this report, the greenwaste industry represents a significant source of VOC emissions. Control options, in general, are more cost-effective; however, our affordability analysis indicates that these controls may have adverse impacts on the industry. As a result, the staff is proposing minimal requirements on greenwaste

composting at this time. The requirements are intended to primarily track operations and emissions, so that emission reductions can be claimed if specific controls are implemented in the future. The following summarizes the proposed requirements for existing and new greenwaste composting operations.

- One-time registration
- Annual reporting requirements
- PM10 controls to prevent visible PM10 emissions over the property line during operations and from compost piles; and,
- Compliance with all applicable AQMD rules, regulations and permit conditions.

In light of the fact that there are feasible control options for this industry that are not yet affordable, AQMD staff is recommending that, through the District's Legislative Committee, special funding from the state legislature be sought to implement state-of-the-art composting methods, including but not limited to, enclosed ASP. AQMD staff will work with the CIWMB and CARB to seek additional funding and/or make existing funding directed more towards air quality spending.

The administrative requirements for the proposed rule are detailed in Chapter V of this report. These requirements would include a one-time registration with AQMD and annual reporting.

Chipping and Grinding Operations

Chipping and grinding operations can be sources of PM10 and VOCs. PM10 results from the chipping, grinding and screening of green materials. It can also result when high winds entrain material from processed material piles. Chipped and ground material that is not removed or further processed can decompose anaerobically, resulting in odors and higher levels of VOCs. To address these issues, AQMD staff is proposing the following requirements:

- One-time registration;
- PM10 controls to prevent visible PM10 emissions over the property line during operations and from processed material piles;
- Holding time restrictions on curbside fines and processed green material piles; and
- Compliance with all applicable AQMD rules, regulations and permit conditions

As part of this proposal, AQMD staff is also recommending that the Governing Board direct staff to continue the rule development efforts with the following objectives: 1) continue to evaluate ongoing emissions studies and refine the emissions inventory for the industry; 2) refine the socioeconomic analysis; 3) work with the Integrated Waste Management Board, sanitation districts and other pertinent agencies to identify sources of funding to help reduce the cost of compliance for the greenwaste composting sector of the composing industry. Finally, AQMD staff is further recommending that a Technical Advisory Committee be formed and serve as a forum

to address technical issues related to Proposed Rule 1133. There will be annual status reports to the AQMD Stationary Source Committee on facility emissions and the feasibility of implementing additional cost-effective controls.

CHAPTER I

BACKGROUND INFORMATION

INTRODUCTION

This chapter discusses the following:

- ✓ Air quality;
- ✓ Composting Process;
- ✓ Chipping and Grinding Activities;
- ✓ Overview of Current Regulatory Requirements;
- ✓ Other Issues Facing the Composting Industry; and,
- ✓ Necessity for Proposed Rule 1133.

AIR QUALITY

The AQMD is the local government agency responsible for air quality assessment and improvement in Orange county, the non-desert portions of Los Angeles and San Bernardino counties, and most of Riverside county. AQMD jurisdictional boundaries include all of the South Coast Air Basin (SCAB) and portions of the Salton Sea Air Basin (SSAB). AQMD air monitoring indicates that these air basins exceed State and federal health-based air quality standards for PM10 (small particulate matter less than 10 microns in diameter) and ozone. Accordingly, the U.S. EPA has designated both the SCAB and the SSAB as serious non-attainment areas for PM10. The designation for ozone is extreme and severe-17[1] for SCAB and SSAB, receptively. Under the federal Clean Air Act, the AQMD is required to attain the PM10 standards for both of these air basins by 2006. For ozone, the AQMD is required to attain the ozone standards by 2010 and 2007 for SCAB and SSAB, respectively.

In order to attain healthful air, federal and state laws require the AQMD to adopt an Air Quality Management Plan (AQMP) that identifies a control strategy to demonstrate compliance with federal ambient air quality standards and expeditious progress toward state air quality standards.[2] To address these state and federal mandates, the 1997 AQMP and 1999 Amendments to the 1997 Ozone State Implementation Plan for the SCAB included Control Measure WST-02 – Emission Reductions from Composting. These air plans identified composting as a source of ammonia, PM10, and VOC emissions. As such, Control Measure WST-02 calls for the development of viable controls to reduce the emissions from this industry by 2001. Proposed Rule 1133 – Emission Reductions from Composting Operations and Related Operations, has been developed to implement Control Measure WST-02.

Following is a brief description of the health and environmental concerns with air contaminants emitted from composting and related operations that contribute to the formation of PM10 and ozone. Bioaerosols, which are organisms (including aspergillus fumigatus, endoctoxin, and organic dust) dispersed through the air that can affect human health, are not addressed in this report. Finally, since U.S. EPA regulates pathogens, which are bacteria, viruses, and parasites found in most compost

[1] Name given to a severe ozone non-attainments are with a 1988 ozone design value between 0.19 and 0.28. The attainment date is 17 years (instead of 15 years) after the date of enactment of the Clean Air Act Amendments of 1990.

[2] California Health and Safety Code Section 40460(a).

feedstocks, and the regulations are considered effective in pathogen destruction by experts in the field, this issue is also not addressed in this technology assessment.

Particulate Matter (PM10)
Composting and related operations (i.e., chipping and grinding) are sources of direct PM10 and ammonia, which is a PM10 precursor. Ammonia in the atmosphere reacts with nitric acid and sulfuric acid to produce nitrate and sulfate particles, a constituent of PM10.

PM10 is generated when composting piles are turned, moved, and from wind entrainment of static uncovered piles. Associated activities like chipping and grinding also produces PM10 emissions when the wood and greenwaste are mechanically ground and shredded. Biological degradation (or decomposition) of organic materials (i.e., yard waste, manure, sewer sludge, etc.) that occurs during composting and when chipped and ground material begins to rot produces ammonia. Ammonia is produced in both aerobic (in the presence of oxygen) and anaerobic (in the absence of oxygen) environments. Composting is an aerobic process but can become anaerobic when for example, a pile is built incorrectly, the pile gets too little oxygen, the temperature is too high, or there is too little or too much moisture. Chipped and ground material that is left unmanaged likewise begins to decompose and produce ammonia emissions for the same reasons as composting.

PM10 is a public health concern since particles less than 10 microns can be deposited in, and can damage, the airways of the lower respiratory tract and the gas-exchange portions of the lung. The adverse health effects of particulates, especially PM10, are well documented. Various health studies have linked PM10 emissions to increased respiratory infections, more severe asthma, declines in pulmonary function, and shortened life spans. Specifically, recent studies indicate that the current ambient levels of PM10 (30 to 150 $\mu g/m^3$) experienced in many different communities in the United States are associated with increases in daily cardio-respiratory mortality and in total mortality, excluding accidental and suicide deaths. Increases in ambient PM10 levels have also been shown to result in increases in acute respiratory hospital admissions, school absences in children, and increases in the use of medications in children and adults with asthma.

Ozone
VOCs are produced during the anaerobic (in the absence of oxygen) decomposition of organic material. Decomposition occurs when chipped and ground material is composted or when the material is left in an unmanaged state and begins to rot.

There are no state or national ambient air quality standards for VOCs because they are not classified as criteria pollutants. VOCs are regulated, however, because VOCs contribute to the formation of ozone and are transformed into organic aerosols in the atmosphere, contributing to higher PM10 and lower visibility levels. Ozone is formed in the atmosphere through a photochemical reaction of VOC and NOx.

Ozone is a deep lung irritant, causing the lung passages to become inflamed and swollen. Exposure to ozone produces alterations in respiration, the most characteristic of which is shallow, rapid breathing and a decrease in pulmonary

performance. Ozone reduces the respiratory system's ability to fight infection and to remove foreign particles. People who suffer from respiratory diseases such as asthma, emphysema, and chronic bronchitis are more sensitive to ozone's effects. Early studies suggested that long-term exposure to ozone results in adverse effects on morphology and function of the lung and acceleration of lung-tumor formation and aging. Ozone exposure also increases the sensitivity of the lung to bronchoconstrictive agents such as histamine, acetylcholine, and allergens.

COMPOSTING PROCESS

Composting is a biological process where organic materials (i.e., leaves and grass, yard trimmings, agricultural crop residues, etc.) are decomposed by microorganisms to create a soil-like material called compost. While decomposition occurs naturally anywhere plants grow, the process has also been industrialized whereby green and wood wastes are mechanically ground and shredded accelerate and control the decomposition process.

Sometimes the green and wood waste is mixed with putrescible wastes (i.e., manure, horse shavings, food waste, sewer sludge, etc.). In this region, with the exception of three facilities, the material is moved with front-end loaders into long piles called windrows. The windrows are then mechanically turned generally with front-end loaders to increase aeration and provide oxygen to facilitate the decomposition process. The temperature and moisture are monitored to optimize and hasten decomposition. After two to four months in the windrows, the material becomes compost.

Composting is an important component of the solid waste industry. It provides resource conservation through source reduction, recycling, and reuse. However, as with other industrial processes, composting produces air emissions that are currently uncontrolled. In terms of air quality, composting is an exothermic process that releases carbon dioxide, water vapor, and other organic and inorganic gases such as ammonia, methane, VOCs, amines, and sulfides. The emissions impacts of composting are presented in the emission inventory section of this report.

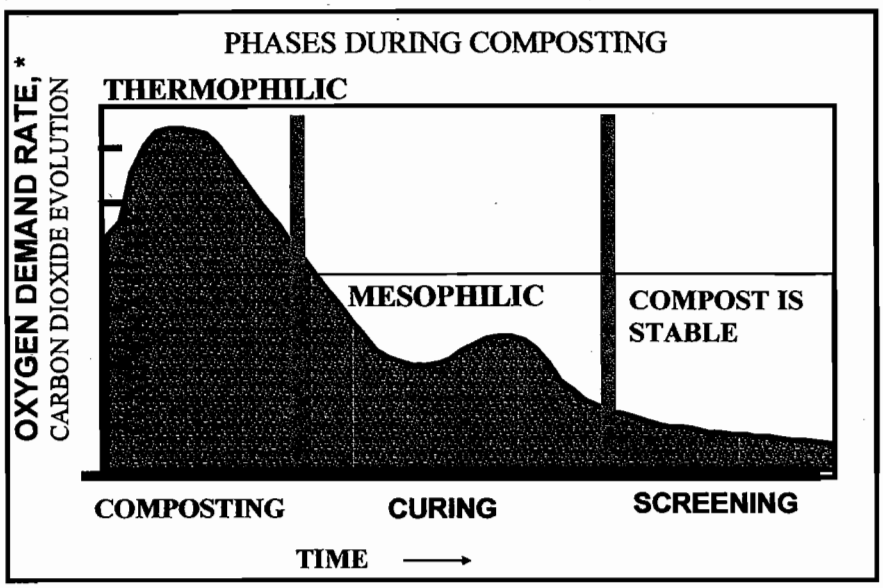
From an industrial perspective, composting is a three-stage process that begins as soon as appropriate materials are combined and piled together. The initial stage of the process is referred to as active composting followed by curing or finishing, and storage and/or processing of composted products.

During the composting process microorganisms such as bacteria, fungi, and actinomycetes, consume oxygen while feeding on organic material such as wood/greenwaste, food-waste, livestock manure, sewer sludge (the semisolid residue of domestic sewage treatment processes) and other putrescible materials. The microbial activity results in the decay of the initial mixture and at the completion of the composting cycle wastes are transformed into a stable, pathogen-free composted material.

The microorganisms that contribute to the composting process contain both thermophilic and mesophilic species. Themophilic and mesophilic microorganisms

are microorganisms that can sustain life under high (110-150 °F) and low (50–105 °F) temperatures, respectively. The type of microbial activity present can characterize the active and curing stages of the composting process. Active composting is where the thermophilic microorganisms' population is the highest. This stage is characterized by high temperatures, high level of oxygen demand and high evaporation rates due to temperature. Conversely, the curing stage of the process is where the mesophilic microorganism population is the highest and the need for oxygen and the evaporation rates decreases. There is also a linkage between the microbial activity and the VOC emissions profile from composting operations. Specifically, emissions can be correlated to the activity of these microorganisms in that the emissions are generally higher during thermophilic temperatures and lower during mesophilic temperatures. Figure 1-1 illustrates the oxygen demand and microbial profile of the various composting stages. This figure can be used to illustrate the corresponding VOC emissions.

Figure 1-1
PHASES DURING COMPOSTING



This graphic was provided by Eliot Epstein, Ph.D. Chief Environmental Scientist, Tetra Tech, Inc.

*VOC emissions are expected to follow the similar profile as oxygen demand.

As stated before, it is the ability to control the physical and chemical characteristics of the process that makes composting a viable industrial process. Following is a description of the main characteristics that are optimized in an industrial composting process.

Carbon-to-Nitrogen ratio (C:N) represents the weight of decomposable carbon to the weight of total nitrogen in an organic material. Carbon and nitrogen are two fundamental elements for microbial activity. Microorganisms utilize carbon for energy and growth, and nitrogen for protein and reproduction. C:N ratio is significant to the composting process because insufficient nitrogen (higher ratio) will limit microbial growth, but excess nitrogen (lower ratio) will generate ammonia or other compounds that cause odors. For the best composting, the recommended C:N range from 25:1 to 40:1, and a ratio of 30:1 is ideal. C:N ratio can be adjusted by adding organic materials high in nitrogen such as grass, sewage sludge, or animal manure, or by adding materials high in carbon such as leaves. Using commercial fertilizer as nitrogen supplement is not recommended because it will modify salt concentration in the compost and impede microbial activity.

Moisture content is the water portion of the material's total weight, expressed in a percentage. Moisture is an essential part of composting. It allows microorganisms to move about and transport nutrients, as well as provides the medium for chemical reactions. Insufficient moisture content will lead to microorganisms entering a dormant stage. Excessive moisture will limit air movement to and in the compost pile, causing an anaerobic decomposition that generates unpleasant odors. In addition, excessive moisture will also result in leachate. Since moisture content decreases as composting proceeds, a starting moisture content of 40% to 60% is recommended, and 50% to 60% is considered to be ideal. Usually, a mixture that feels moist, like a well-wrung sponge, indicates sufficient moisture. Moisture content can be adjusted either by adding water or moisture-rich organic materials, such as liquid sewage sludge, or by adding dry bulking agents such as leaves or wood chips.

Oxygen is critical to composting, especially during the early stage when microorganisms rapidly metabolize and grow. Insufficient oxygen supply will slow down the composting process and lead to an anaerobic decomposition that generates obnoxious odors, and ammonia and VOC emissions. Excess oxygen (or air) will also lower the pile's temperature slowing down the composting rate. Oxygen concentration fluctuates in response to the microbial activity. Usually, at the beginning of the composting process, oxygen concentration within the pore spaces is identical to oxygen concentration in the air (about 15% to 20%). However, as the compost ages, the oxygen concentration decreases and carbon dioxide concentration increases. A 5% to 15% oxygen concentration must be maintained for fast, aerobic composting. Oxygen (or air) can be provided by mechanical turning or by forced aeration, where air is either drawn or forced through the compost pile.

Temperature is an important aspect of composting since composting occurs within two temperatures ranges, known as mesophilic (50°F to 105°F) and thermophilic (over 105°F). Thermophilic temperatures are preferred because they promote rapid

composting, and destroy pathogens, weed seeds, as well as fly larvae. However, extreme temperatures (above 160°F) will kill most of the active, important microorganisms. According to composting experts, temperatures in the range of 110°F to 150°F are best for composting. The U.S. EPA requires that a minimum temperature of 131°F be maintained for several days to eliminate bacteria and pathogens. Usually, adding external heat is unnecessary because during the composting process, heat is generated by microorganisms and is accumulated due to the pile's self-insulation. To prevent the temperature from rising to an extreme level that creates a fire hazard, frequent aeration is necessary.

pH value indicates the level of acid or base in the compost. pH value is critical to composting since it affects the nutrient and metabolism of the microorganisms. Microorganisms consume organic acid very quickly; however, the majority of them can not survive an extreme acidic environment (i.e., where the pH value is far less than 7). According to composting experts, optimum pH values range between 6.5 and 8.0. Increasing the pH value by the addition of lime or other additives is not advised because of the potential ammonia loss. pH values above 8.5 encourage the conversion of nitrogen compounds to ammonia, creating an odor problem. pH value changes during the composting process, and it can be adjusted by aeration or through a natural process called carbonate buffering. Through the carbonate buffering process, carbon dioxide combines with water to produce carbonic acid that will lower the compost pH. As a result, the final compost product always has a stable, close to neutral pH value.

Particle size affects the efficiency of the composting process. Generally, microbial activity occurs on the surface of the particles. Therefore, an increase in the surface area by using smaller particles will increase the rate of decomposition. However, smaller particles also reduce the porosity, which is a measurement of the air space within the composting mass. This can result in poor aeration and increased emissions. Good particle sizes range from 1/8 to 2 inches average diameter and can be achieved by chopping, shredding, mowing, or breaking up the materials.

Pile structure, in particular the mixing of materials, size and shape are important to start off the composting process properly. The materials to be composted must be thoroughly blended to evenly distribute moisture, porosity, and C:N ratio. A compost pile must be well constructed to prevent rapid dissipation of heat and moisture, yet allow good air circulation. The pile should be at least 3 ft x 3 ft x 3ft (1 cubic yard) to keep sufficient heat, but not larger than 5 ft x 5 ft x any length so air can diffuse to the center of the pile. Some composting system use forced air or mechanical turning to compensate for larger size piles.

Feedstock also affects the composting process. One of the most important aspects of feedstock is how it affects the C:N ratio of the compost pile overall. Some feedstocks, like grass clippings, digested sewer sludge and food waste are higher in nitrogen content, while tree limbs and wood scraps are lower in nitrogen content. As such, waste materials are blended to achieve an optimum C:N ratio and decomposition rate. For the purpose of this rule, the composting industry has been divided into two main categories based on feedstocks handled: co-composting and

greenwaste composting. Co-composting uses putrescible feedstock materials including, but limited to, sewer sludge, cow and horse manure, and food waste combined with bulking agents like greenwaste or wood chips. The feedstock comes from sewage treatment plants, dairies, horse stables, restaurants, etc.

Greenwaste composting only uses greenwaste feedstock materials such as wood, leaves and related raw materials. The feedstock comes from landscape maintenance activities, construction sites, agriculture, curb side recycling programs, etc. One of the primary factors affecting greenwaste supply from curb side recycling programs is the level of contamination (i.e., mixing of yard waste with other trash). The level of contamination varies widely among curb side recycling programs and is influenced by the amount of public outreach, the containment method, and frequency of pick-up.

Products Produced

Composted products are used in many applications depending on the characteristics of the raw materials and the quality of the product produced. In general, high quality compost may be used in agriculture, horticulture, landscaping and home gardening. Composting facilities that use sewer sludge as a feedstock generally rate the quality of their compost as high. Medium quality compost can be used in applications such as erosion control and roadside landscaping. Low quality compost can be used as a landfill cover or in land reclamation projects. In southern California, most of the composting products are used in agricultural and horticultural operations. Smaller markets for composting products include municipal, Caltrans, local residents, etc. Most composting facilities make between one and five different composting products. Some compost facilities also provide specialized services including special product blending, spreading, bagging and delivery.

CHIPPING AND GRINDING ACTIVITIES

The chipping and grinding component of the composting and related operations industry include operations that are dedicated mainly to the mechanical size reduction of greenwaste. Mobile chippers and/or tub grinders are used to shred the green material. Sometimes the equipment is connected to screens and magnetic separators to produce certain end products and improve the quality of the end product. These operations chip and grind greenwaste such as tree trunks, residential and commercial landscaping, curbside green-waste recycling, and debris from construction sites. The chipped and ground material produced is then used as an alternative daily cover (ADC) at landfills, fuel in waste-to energy facilities, mulch, raw material for greenwaste composting, or bulking agents for co-composting operations. Chip and grind operations can be a stand-alone operation or a part of a composting facility.

Business Structure

Composting and chipping and grinding facilities generate income from two sources. First, these facilities charge haulers "tipping" fees when they drop off the raw feedstocks. Second, these facilities sell the final products (e.g., compost, fuel for waste-to-energy plants, mulch, etc.). Tipping fees vary across the state. Table 1-1 provides a summary of tipping fees throughout California from a study sponsored by the CIWMB in 2000. The study indicates that southern California has lower tipping fees than northern California.

Table 1-1
Solid Waste Tipping Fee Survey of California

Region	Average Tipping Fee (per ton)
Northern	$58.49
Bay Area	$47.73
Central Coast	$39.21
Central Valley	$35.79
Southern (includes SCAB)	$35.42

In the SCAB, based on staff survey, tipping fees for greenwaste range from $10 to $15 per ton and tipping fees for sewer sludge range from $30 to $40 per ton. If the material was landfilled, the tipping fee would be $30 per ton.

The sale price of compost varies widely and competes with fertilizers. Composting facilities generally sell their final compost product for around $30 per ton. Very high quality and specialty compost can command a price of $90 a ton. Chipping and grinding facilities sell a final product like fuel for waste-to-energy plants for about $10 per ton.

For facilities that compost by windrowing the feedstock (which is the dominate method in the SCAB) operational costs include leasing unimproved land, leasing equipment (i.e., grinders and front-end loaders), and low-skilled labor. These operations are generally not labor intensive. An average size composting facility has 5 to 10 employees. Operational costs are higher for facilities that transport their final products since they incur additional costs for trucks and drivers. Generally, these cost are recouped by having the customer pay shipping costs. Chippers and grinders incur similar costs to composting facilities.

Sanitation agencies that do not currently compost sewer sludge incur costs for disposing of the sludge by land spreading. These agencies must pay for the sludge to be transported (to Kerns, Kings, and/or Riverside Counties). Currently the transport cost including labor and tipping fee is approximately $38 per ton and is expected to increase if the disposal site is further away from the SCAB.

OVERVIEW OF CURRENT REGULATORY REQUIREMENTS

There are three levels of regulatory requirements that apply to the composting and chipping and grinding industries: 1) federal requirements (i.e., U.S. Environmental Protection Agency or EPA; 2) state (i.e., the California Air Resources Board (CARB) and the California Integrated Waste Management Board (CIWMB)), and, 3) local (i.e., the AQMD, local governments, and local enforcement agencies). Each of these agencies' regulatory structure is designed to deal with different issues and while not necessarily driven by air issues some may indirectly benefit air quality. None of the existing regulations directly address air quality impacts from these operations. The following is an overview of federal, state and local regulatory programs that are applicable to the chipping and grinding and composting industries.

Federal Requirements

The federal Clean Air Act requires the AQMD to adopt an AQMP that identifies a control strategy to demonstrate compliance with the federal ambient air quality standards. To address this federal mandate, the 1997 AQMP and 1999 Amendments to the 1997 Ozone State Implementation Plan for the SCAB included Control Measure WST-02 – Emission Reductions from Composting. The U.S. EPA approved these plans making the development of this control measure federally enforceable. In addition to air quality issues, there are other federal requirements that apply to composting operations. Specifically, the federal requirements focus mainly on water and solid waste (i.e., sewage sludge) issues. The following is a brief summary of these requirements.

Resource Conservation and Recovery Act

In 1976, Congress enacted the Resource Conservation and Recovery Act (RCRA), an amendment to the 1965 Solid Waste Disposal Act. RCRA calls for conservation of energy and natural resources, waste reduction, and environmentally sound waste management practices. In addition, RCRA encourages states to develop plans for non-hazardous industrial solid waste and municipal solid waste (MSW) management, sets criteria for MSW landfills, as well as for other solid waste disposal facilities, and prohibits the opening dumping of solid waste. Congress delegated authority to U.S. EPA to develop specific regulations to implement the requirements of RCRA. Solid waste regulations have been promulgated in the Code of Federal Regulations under Title 40, Chapter I, Subchapter I, Parts 240-282 (40 CFR Parts 240-282). As a result of RCRA's prohibition on open dumping of solid waste other disposal alternatives for sewage sludge has been pursued including land spreading (treated sludge is spread over crop land as fertilizer), aerobic digestion, and composting.

National Pollutant Discharge Elimination System

The National Pollutant Discharge Elimination System (NPDES) is an EPA-implemented program that requires permits for discharging pollutants from facility operations into water[3]. Even though the NPDES program focuses on water pollution from all types of industries, NPDES also applies to owners or operators of facilities that treat and handle sewage sludge, including composting with sewage sludge. The criteria and standards for NPDES are quite extensive and have been promulgated in several parts of the Code of Federal Regulations under Title 40, Chapter I, Subchapter D, Parts 122, 123, 124 and 125 (40 CFR Parts 122–125).

Sewage Sludge Disposal Standards

EPA promulgated standards for the use or disposal of sewage sludge in Title 40, Chapter I, Subchapter O, Part 503 of the Code of Federal Regulations (40 CFR Part 503). 40 CFR Part 503 contains requirements for the control of pathogens, vectors, and heavy metal for sludge composting operations. In particular, to qualify as Class A compost Appendix B to Part 503-Pathogen Treatment Processes, generally requires processes to further reduce pathogens (PFRP). PFRP requires that open windrow composting maintain the temperature of the compost to be 55^0 C or higher for 15 days or longer, and during this time there must be a minimum of 5 turnings of the

[3] 40 CFR Part 122, §122.1 (b).

windrows. For in-vessel or aerated static pile (ASP) composting, the PFRP requires the active pile temperature be at least 55^0 C or higher for 3 days.

State Requirements

State law also requires the AQMD to adopt an AQMP that identifies a control strategy to demonstrate progress towards achieving the state ambient air quality standards. The 1997 AQMP and 1999 Amendments to the 1997 Ozone State Implementation Plan for the SCAB that included Control Measure WST-02 – Emission Reductions from Composting, was also submitted to the CARB to comply with state law. These air plans identified composting as a source of ammonia, PM10, and VOC emissions. As such, Control Measure WST-02 required the development of viable control to reduce the emissions from this industry by 2003. In addition to air quality requirements, there are several other state requirements that may apply to chipping and grinding and composting operations. Specifically, these state requirements focus on air, water and solid waste (i.e., sewage sludge) issues. The following is a summary of these requirements.

California Air Resources Board

In addition to reviewing and approving the AQMP, CARB permitting requirements can affect composting and chipping and grinding operations that use portable equipment. As of December 1, 1999, CARB runs the "Statewide Registration Program" which regulates portable engines and portable engine-driven equipment units. Once equipment is registered in this program, engines and equipment units can operate throughout California without the need to get individual permits from local air pollution control districts, such as the AQMD. The AQMD is preempted from permitting, registering, or regulating portable engines and portable equipment units properly registered with the CARB.

Owners and operators of portable engines and portable equipment units that meet the definitions and requirements of the registration program are eligible for statewide registration. Facilities that conduct chipping and grinding or composting activities operate portable engines that are affiliated with equipment, including but not limited to, wood chippers, tub grinders and trommel screens. It is common for these types of facilities to have equipment operating pursuant to Statewide Registration Permits.

California State Legislature: California Integrated Waste Management Act

Recognizing the need for integrated waste management practices, in September 1989, the California state legislature passed Assembly Bill (AB) 939 – California Integrated Waste Management Act, into law, which was incorporated into the California Public Resources Code, Division 30, §40000 et seq. (Division 30). Division 30 is implemented by CIWMB. Section 41780-41786 of the law contains mandates for cities and counties to achieve a total waste diversion of 25 percent by 1995, and a total waste diversion of 50 percent by 2000, as established by a 1990 baseline. Division 30 also requires California to secure and plan for adequate long-term disposal capacity. Since organic materials, such as food and greenwastes, represented approximately 25 percent of California's waste stream in 1999, recycling, reuse, and source reduction have been widely promoted to achieve the goals of Division 30.

California Integrated Waste Management Board

In June 1995, the CIWMB promulgated a set of regulations governing composting operations and facilities. The CIWMB currently regulates approximately 87 composting facilities operating in California in accordance with the California Code of Regulations, Title 14, Division 7, Chapter 3.1 – Composting Operations Regulatory Requirements (Chapter 3.1). Depending on the type of composting materials and the throughputs, affected facilities are required to obtain a Registration Permit, a Standardized Composting Permit, or a Full Solid Waste Facilities Permit (Full Permit). Full Permits require the preparation of an Environmental Impact Report (EIR) and are issued by CIWMB while Registration and Standardized Permits are issued through local enforcement agencies (LEAs), such as the environmental health departments. According to the CIWMB data-base, sixteen of the twenty-seven facilities in the AQMD's jurisdiction are identified as having a CIWMB permit.

Currently, the CIWMB is revising these regulations to address a number of issues relating to composting activities including an increasing number of complaints regarding odor at compostable organic materials transfer/processing operations and facilities. The CIWMB's staff is concerned that continued problems with odors could limit the growth of the composting industry. As such, the CIWMB is proposing to revise its regulations to require odor minimization plans developed by the composting facilities. The odor minimization plans would be reviewed only if there exists a documented public nuisance. While odors are under the regulatory oversight of the jurisdiction's local enforcement agency, odors are an indication that the piles are emitting ammonia and VOCs. The AQMD retains authority over emissions from these facilities.

Though chipping/grinding facilities are not currently required to obtain permits, CIWMB is developing a proposal to amend the permit requirements in Chapter 3.1 to include chipping/grinding and other operations that handle compostable organic materials.

Regional Water Quality Control Board

The Regional Water Quality Control Board (RWQCB), a state agency with regional offices throughout California, enforces EPA-issued National Pollutant Discharge Elimination System (NPDES) permits. In addition, the RWQCB focuses on wastewater generation, water demand, the capacity of existing or planned stormwater drainage systems and potential new sources of polluted run-off, and potential depletion of groundwater supplies or interference with groundwater recharge. In the case of composting and chipping/grinding facilities, the RWQCB has required various sites to be graded, paved, and surrounded by berms and other drainage-related protections to prevent run-off and the leaching of composted/chipped ground materials into the groundwater.

Local Requirements

There are several local requirements that may apply to chipping/grinding and composting operations. Specifically, these requirements focus on air, land use and solid waste (i.e., sewage sludge) issues. The following is a summary of these requirements.

AQMD Rule Requirements

Currently, operators of composting and chipping/grinding facilities located in the district are required to comply with AQMD Rule 402 – Nuisance, Rule 403 – Fugitive Dust, and Rule 203 – Permit to Operate for equipment that require permits. However, none of these rules require specific emission controls at composting or related facilities.

Local Enforcement Agency Requirements

There are several different local (i.e., city or county) enforcement agencies or LEAs that act as the either the permitting or enforcement division of the CIWMB, depending on the throughput and type of compostable materials. For example, the local department of health services, on behalf of the CIWMB, issues Registration and Standardized permits and enforces the requirements in these permits for facilities with lower throughputs. However, for facilities that have throughputs that require a Full Permit issued by the CIWMB, the LEA is only responsible for enforcing the requirements in the Full Permit. For either type of permit scenario, the LEAs are responsible for handling and investigating complaints from composting and chipping/grinding operations.

City or county offices in the jurisdiction where a facility is located approve or deny conditional use permits, and have the authority over land use and the siting of composting facilities, transfer stations, or other solid waste management activities.

Sewage Sludge Ordinances

In addition to EPA's federal requirements regarding the use or disposal of sewage sludge, there are local ordinances or restrictions throughout California and other states that ban the import and land application use of certain grades of sewage sludge. For example, 14 counties within California, with Riverside county being the only one located within the AQMD's jurisdiction, have passed ordinances or permitting requirements that either ban or restrict the application of certain grades of sewer sludge onto farmland[4]. In addition, recent litigation and regulations in both Kern and Kings counties have resulted in ordinances that ban the import of certain classes of sewage sludge starting early 2003. Other states such as Pennsylvania, Vermont, and New Hampshire, have also passed similar ordinances to ban or limit the application of sewer sludge onto land. These restrictions will likely force the water treatment plants within the AQMD's jurisdiction, throughout California and the nation to further process the sewage sludge so that it can be recycled and used on farmland.

Local Governments

Local government zoning and general plan standards determine where composting and chipping and grinding activities can occur. In addition, local governments grant conditional use permits if the jurisdiction has determined that special conditions and approvals are necessary. Local governments, through curb side recycling programs, may also be providing some composters with greenwaste feedstock.

[4] County of Riverside Ordinance No. 744 – Regulating the Processing of Greenwaste.

OTHER ISSUES FACING THE COMPOSTING INDUSTRY

Public Nuisance Issues

Uncontrolled emissions, odors, and dust generated by windrow composting and chipping and grinding operations are often sources of public complaints. Emissions and odors can dramatically increase if the windrows are not maintained properly or chipped and ground material is allowed to decompose. Some feedstocks like food waste, dairy products, manure, sewer sludge, are odorous. Also, some outdoor blending operations of putrescible feedstocks generate odor related public nuisance complaints. Dust may also result from open feedstock preparation areas, chipping and grinding operations, and compost turning, curing, screening, storage, and loading. The problem can be worse during high winds.

Over the last two years, *thousands* of odor and dust complaints have been filed with the AQMD and with local enforcement agencies (LEAs). In particular, between January 1, 2000 and December 31, 2001, the AQMD received 470 public complaints regarding composting and chipping and grinding operations. The LEAs have received over 2,600 complaints regarding composting and chipping and grinding operations.[5] The AQMD staff has issued notices to comply (NC) and notices of violation (NOVs). The AQMD does not have records of enforcement actions taken by the LEAs. Table 1-2 summarizes this information.

Table 1-2
2000-2001 Public Complaints/AQMD Enforcement Actions
On Composting and Chipping and Grinding Operations

Agency	# of Complaints	# of NCs/NOVs
AQMD	470	55 (30 NCs and 27 NOVs)
LEAs	2,600+	N/A

The AQMD's role in addressing public complaints from these facilities has been affected by AB 59 that become law in 1995. Under this law, all air districts in California are to refer public complaints pertaining to odors from a composting facility that is subject to the CIWMB's regulatory requirements to the LEA. Odors from non-composting activities like chipping and grinding activities, mulching, and ADC are under the AQMD's jurisdiction. Non-odor related public complaints including dust-, permitting-, or emissions-related nuisances affecting the public are within the AQMD's jurisdiction.

Waste Diversion (AB 939)

AQMD staff has received public testimony that composting is an integral program used to comply with AB 939 (the California Integrated Waste Management Act of 1989) Waste Diversion requirements. AB 939 is implemented by the CIWMB, and mandates cities and counties to achieve a 25 percent total waste diversion by the year

[5] This number underestimates the total number of complaints to LEAs because not all the LEAs maintain the data in a tabulated format and not all the composting and chipping and grinding facilities were included in the AQMD's data request.

1995, and a 50 percent waste diversion by the year 2000, based on the 1990 baseline year. Organic materials, one component of the waste stream, can be diverted from landfills through methods including use as ADC, fuel at waste-to-energy facilities, mulch, composting, soil amendments and erosion control.

AQMD staff has conducted an evaluation of the current practices in achieving the waste diversion goals of AB 939. The CIWMB measures compliance with AB 939 waste diversion goals by measuring the reduction in the amount a given jurisdiction disposes to the landfill. There is no quantifiable measurement of the quantity of waste actually being diverted. For each jurisdiction a maximum allowable disposal amount is calculated which represents a 50 percent reduction of disposed waste from 1990. To meet the diversion rate requirement, a jurisdiction may not dispose more than the maximum allowed amount. Each jurisdiction must also submit an annual report that includes information on all programs being implemented to divert waste disposal to a landfill. Organics are only one of the waste categories that is affected to achieve the AB 939 goals. Jurisdictions also promote source reduction and the recycling of paper, glass, and aluminum cans, and household hazardous waste.

The CIWMB estimates that the year 2000 statewide diversion rate is at 42 percent. As indicated above, it is unknown how much each individual waste diversion program contributes to the overall waste diversion rate. AB 939 requires each jurisdiction to prepare, adopt, and submit to the CIWMB a source reduction and recycling element (SRRE) that demonstrates how the jurisdiction will meet the CIWMB's mandated diversion goals. The CIWMB approves the information submitted by each jurisdiction, but does not keep track of each individual program's effect on diversion. It is the burden of each individual jurisdiction to show to the CIWMB that the diversion mandate is being met. While the database does not provide specific information on the amount of waste diverted from each of these programs, it does indicate an intention to divert waste by using a variety of programs. These programs include: source reduction, composting, recycling, specials waste, public education, policy incentives, facility recovery, transformation, and household hazardous waste. Recycling and source reduction are the preferred programs used by the most number of jurisdictions to achieve the targets. Recycling programs included curb-side pick up, drop-off programs and special programs. Source reduction included thrift shops, business programs, xeriscaping, and backyard composting (proposed to be exempt from PR 1133).

The CIWMB further analyzes the SRRE documents to determine waste stream characteristics. Based on a 1999 waste characterization study conducted by the CIWMB, all organics contribute about 35.1 percent to the overall waste stream. Organics include materials that are eligible for composting programs. Organics waste includes food, landscaping materials, agricultural crop residues, manures, textiles, etc. Table 103 lists a break-down of the organics-only waste stream based on the CIWMB's records.

Table 1-3
Types of Organics Contributing to Waste Stream

Organic Material Type	Percentage of Waste Stream
Food	15.7%
Leaves & Grass	7.9%
Prunings & Trimmings	2.2%
Branches & Stumps	0.1%
Agricultural Crop Residues	0.0%
Manures	0.1%
Textiles	2.1%
Remainder/Composite Organic	6.9%

Recent studies by the CIWMB show that while organics are prevalent in the waste stream, many of these organic materials are also associated with odor and emissions problems. For example, Table 1-4 indicates the top ten materials in the waste stream. Food waste makes up the highest percentage of the waste stream. The AQMD staff has received a significant number of odor complaints from composting-related activities that includes food wastes. Grass is another organic waste material that has odor problems associated with it. Grass can be an issue in greenwaste composting leading to higher emissions and odors because of its moisture and rapid decomposition.

Table 1-4
Top Ten Materials in Waste Stream

Material	Percentage of Waste Stream
Food	15.7%
Remainder/Composite Paper	9.6%
Leaves & Grass	7.9%
Remainder/Composite Organic	6.9%
Lumber	4.9%
Uncoated Corrugated Cardboard	4.6%
Other Miscellaneous Paper	4.4%
Newspaper	4.3%
Film Plastic	3.9%
Other Ferrous Metal	2.4%

There are a number of different programs being used to divert greenwaste that rely on source reduction, transformation, public education, incentive programs, and composting. These programs are listed in Table 1-5.

Table 1-5
CIWMB Identified Examples of Programs to Divert Greenwaste

Programs	Description
Xeriscaping, grasscycling	Landscaping to reduce waste
Backyard composting	Composting at home by residents
Mulching	Gardening product
Seasonal Collections	Holiday foliage
Commercial Composting	Creation of commercially sold gardening products
Alternative Daily Cover	Substitute cover for soil at landfills
Fuel	For waste-to-energy facilities
Bulking agent	For use in co-composting of sewer sludge, food waste, manure
Landfill ban on greenwaste	Not accept greenwaste
Tipping fee incentives	Structure fees to benefit source reduction
Collection rate incentives	Structure fees to benefit source reduction
School composting	Composting conducted at schools with on-site materials

A review of the CIWMB's database on local government's SRRE's indicates ADC appears to be an important program currently being using to achieve the AB 939 diversion targets. For example, in the facility recovery component of the SRRE, approximately 58 local governments (in the four counties) indicated that they rely on a composting facility program, while approximately 103 local governments indicated they rely on ADC programs.

A study was also conducted by the CIWMB to assess California's compost and mulch producing infrastructure. The study analyzed both composters and processors (i.e., process material, but do not compost). The surveys of the chippers and grinders are good general indicators of the types of programs being relied upon to divert greenwaste from landfills for several reasons. All the greenwaste that is diverted from landfills must be processed (i.e., chipped and ground) before it can be put to other uses, including the greenwaste collected by local jurisdictions in curb-side recycling programs. The chippers and grinders in the survey are stand-alone operations that do not compost on site, so it is good indication of the overall market demands for processed greenwaste.[6] There are more chippers and grinders (47) than composters (28) in the AQMD's jurisdiction and the chippers and grinders handle 3 times more greenwaste than the composters. This study (focusing on the chippers and grinders data) indicates that in southern California alternative daily cover (ADC) is the most heavily relied upon method jurisdictions use to divert greenwaste from landfills (46%), followed by fuel for waste-to-energy facilities (25%), and then composting (18%). The study also acknowledged that southern California's use of ADC leads other regions in California. Even when the composters' product distribution is considered, ADC and fuel are still important to waste diversion.

[6] The survey of the chippers and grinders was viewed as a better overall indicator of the markets since chippers and grinders facilities serve as the first stage in the diversion process. For example, chippers and grinders provide raw feedstock to composters. Therefore, using composter data may result in double counting of product markets. Further, any chipping and grinding performed by the composters is primarily for processing composting-related products and not as reflective of the other markets for processed green waste.

Composters in southern California produce compost (50% of their products), ADC (16%), fuel (6%), and mulch (13%).

The AQMD staff conducted a survey of composting and related facilities in the region. The composting facilities and most of the chipping and grinding facilities were visited by AQMD staff and the surveys completed as part of that visit. Surveys were also mailed to other facilities and some facilities were surveyed over the telephone. Part of the AQMD's survey included collecting information on the amount of greenwaste that was being composted in the AQMD's jurisdictional boundaries. The AQMD's survey of the chipping and grinding and composting facilities supports the finding that ADC and fuel for waste-to-energy facilities are key programs being relied on by local governments in general for achieving the AB 939 waste diversion goals. Based on this survey, the AQMD staff also determined that the total amount of greenwaste used either as a bulking agent for co-composting or at a greenwaste composting facilities was approximately 1.1 million tons a year. Of the 3 million tons of material processed at chipping and grinding facilities, approximately 15-40% of the material is used for waste-to-energy, 50-60% for ADC, and 10% for mulching or composting.

The prevalence of ADC as a key program for greenwaste diversion is also recognized by the CIWMB. The CIWMB has summarized the reported waste-derived ADC since 1996 in Table 1-6.

Table 1-6
CIWMB Statewide ADC Analysis (tons/year)

ADC Type	1996	1997	1998	1999	2000
Green Material	560,266	625,198	1,083,673	1,396,026	4,302,443[7]
Other (mainly Sludge; Treated Auto Shredder Residue; C&D)	383,669	659,339	587,285	791,786	666,042
Total ADC	943,935	1,284,537	1,670,958	2,187,812	4,968,485
ADC % of Total Disposal	3.0%	3.5%	4.5%	5.5%	15%

Based on available data, AQMD staff has not been able to quantify the extent to which these programs are actually being utilized to achieve the AB 939 waste diversion goals. There are no records that indicate which programs are the most important to achieving the AB 939 waste diversion goals. Therefore, a qualitative assessment of surveys and other information has been conducted to determine the relative importance of each program in diverting waste.

To further address the waste problem in California, the CIWMB is exploring conversion technologies that would convert organic materials, including greenwaste, into high-value products like energy, alternative fuels (ethanol), solvents, and other products. These technologies include hydrolysis, gasification, and anaerobic digestion. Hydrolysis is the chemical decompostion process that uses water to split the chemical bounds of substances. This process can be used to create products such

[7] Preliminary amounts. CIWMB Staff is currently reviewing revised DRS reports from counties.

as ethanol, specialty chemicals, fuels, and citric acid for the beverage industry. Gasification is a process that uses heat, pressure, and steam to convert materials directly into a gas composed primarily of carbon monoxide and hydrogen. The products from this process can be used as a fuel to generate electricity or a gasoline additive. Anaerobic digestion is the biological decomposition of matter in the absence of oxygen and is used to produce compost, fertilizer, and methane. The emissions from all of these processes are controlled unlike the emissions from windrow composting.

The CIWMB is currently analyzing the regulatory issues surrounding the use of conversion technologies including permitting, public health standards, and diversion credits. The current law allows for 10 percent of the diversion credit to be met by these transformation technologies if certain requirements are met.

Regardless of the fact that composting does not appear to be as highly relied upon as other programs, the AQMD staff is cognizant of the AB 939 requirements on local governments and is striving to draft a regulatory program that would not adversely affect AB 939, while achieving clean air objectives. For this reason, AQMD staff has focussed its efforts in identifying and quantifying the impacts to the specific industries affected by the proposal.

Environmental Justice

In California, environmental justice is generally considered to be a call for the fair treatment of people of all races, cultures, and incomes with respect to the development, adoption, implementation, and enforcement of environmental laws and polices. In October 1997 the AQMD Governing Board adopted an environmental justice policy. The four guiding principles are:

- All basin residents have the right to live and work in an environment of clean air, free of airborne health threats;
- Government is obligated to protect public health;
- The public and private sectors have the right to be informed of scientific findings concerning hazardous and toxic emission levels, and to participate in the development and implementation of adequate environmental regulations in their communities; and
- The (AQMD) governing board is to uphold the civic expectation that the public and private sectors of the basin will engage in practices that contribute to a healthy economy and truly livable environment."

Environmental justice can be an issue in the siting of composting operations because of odors and dust impacts on neighborhoods from uncontrolled operations. The number of public nuisance complaints that the AQMD and LEAs have received regarding composting and related activities shows that these operations are having an impact on the surrounding community. As such, regardless of air quality regulations, environmental justice issues will affect the ability for future expansion of composting operations unless these issues can be adequately addressed. Controls to reduce emissions are expected to go a long way in addressing these impacts and would be consistent with the AQMD's environmental justice policy.

Regulatory Limits on Land-Application of Wastewater Sludge

Currently, sewer sludge that has been treated to reduce pathogens and metals is trucked from this region to Kings and Kern Counties where it is spread on croplands. Sewer sludge enriches the soil and can supplement or replace commercial fertilizers. There are two classes of processed sludge. Class A sludge must undergo pathogen reduction to be below detectable levels. Class A can be used on edible vegetables and plants. Class B sludge must undergo pathogen reduction to ensure the pathogens are reduced to levels that are protective of public health and the environment. Class B sludge is only used on non-edible crops, forests, and reclamation sites. Class B sludge can not be used for composting. Public concerns over Class B sludge used on croplands in Kings and Kern Counties has resulted in these jurisdictions placing limitations on Class B sludge. As a result, additional options to deal with the Class B sludge will need to be developed. This could include additional composting of sludge in the region if the sludge is treated to Class A levels. Therefore, there is an increased need to resolve the environmental impacts issues associated with co-composting operation so that additional co-composting facilities can be sited in the AQMD's jurisdiction. The majority of the co-composting facilities in the region have already indicated that they will enclose active composting and vent emissions to a control device.

NECESSITY FOR PROPOSED RULE 1133

PR 1133 was developed to fulfill the AQMD's commitment in the 1997 AQMP and 1999 Amendments to reduce ammonia and VOC emissions from composting and related operations. As such, this rulemaking is part of an integral plan to achieve healthful air in the region. Currently, the manner in which composting is conducted by windrows results in a source of VOC and ammonia emissions. Composting is also a source of numerous public nuisance complaints regarding dust and odors. The former would be addressed by this rulemaking. Various control techniques have been applied to bio-solid composting throughout the U.S. to reduce emissions and public nuisance complaints. This report examines viable control options for the local composting industry.

CHAPTER II

INDUSTRY PROFILE AND EMISSIONS INVENTORY

INTRODUCTION

This chapter discusses the following:

- ✓ Industry Profile; and,
- ✓ Emissions Inventory.

INDUSTRY PROFILE

The AQMD staff developed an industry profile for the composting and related operations industry based on information obtained from the CIWMB permit database, AQMD permit system, AQMD-conducted surveys and site visits, and comments from the public. Through this process, the AQMD staff identified 277 facilities. For the purpose of rule development, the facilities that make up the composting and related operations industry are classified into four categories: 1) co-composting facilities; 2) greenwaste composting facilities; 3) chipping and grinding facilities; and, 4) exempt facilities.

Co-composting facilities include facilities that compost putrescible materials such as, sewage sludge, manure, and food wastes in combination with greenwaste. Greenwaste composting facilities are composting facilities that use only greenwaste as feedstock materials. Chipping and grinding facilities are facilities that chip and grind greenwaste for use in composting, waste-to-energy, and alternate daily recovery (ADC) at landfills, or to produce mulches. Finally, exempt facilities are those facilities that are categorically exempt from Proposed Rule 1133 based on the type of operation (i.e., transfer station/MRF, sewage treatment, fertilizer blending/bagging, manure shredding, landscaping/nursery/gardening, agricultural farm composting, winery, community composting, portable chipping/grinding, botanical garden/arboretum, and public park/camping.)

Facility and throughput information was compiled based on information obtained from the CIWMB, the AQMD Permit System, the AQMD-conducted surveys and site visits, and independent contractor's studies.

Table 2-1 - Composting Industry and Related Operations, provides a profile of the composting and related operations industry.

Table 2-1
Composting Industry and Related Operations

CATEGORY	Number of Facilities	Throughput (tons/year)
Co-Composting	12	922,190
Greenwaste-composting	16	832,191
Chipping/Grinding	47	3,033,092
Exempt Facilities	202	36,865
Total	**277**	**4,824,338**

The geographical distribution of the composting and related operations industry is approximately 42, 19, 16, and 23 percent for Los Angeles, Orange, Riverside, and San Bernardino counties, respectively. Table 2-2, Composting Facilities by County, provides number of facilities and throughputs in each of the counties by industry sector.

Table 2 – 2
Composting Facilities by County

Category	Number of Facilities by County (Throughputs – tons/year)			
	Los Angeles	Orange	Riverside	San Bernardino
Co-Composting	3 (18,570)	2 (38,329)	1 (365,000)	6 (500,291)
Greenwaste-composting	6 (52,516)	3 (240,490)	4 (189,745)	3 (349,690)
Chipping/Grinding	20	9	13	5
Exempt Facilities	87	39	26	50
Total	116	53	44	64

EMISSIONS INVENTORY

The 2001 baseline emissions inventory for the composting and related operations industry includes emissions from 12 co-composting and 16 greenwaste composting facilities operating in the AQMD's jurisdiction. Emissions for co-composting and greenwaste composting were estimated by multiplying the facilities' annual throughput with facility-wide average emission factors. For all but two facilities that compost in an aerated static pile (ASP) and an in-vessel system, the emissions are considered to be baseline emissions representing the existing setting and do not take into consideration future plans. In addition, the inventory includes emissions from the exempt facilities. This inventory therefore, represents the existing settings. The emissions inventory does not include PM10 emissions from fugitive dust at any of the facilities including chipping and grinding operations. From work on similar facilities (Rules 1158, 403, 1186), public nuisance complaints, and site visits, the AQMD staff believes that there are PM10 emissions from these operations. As such, the total air quality impact of this industry is underestimated.

Emission Factor Development

The emission factors used for the development of the inventory are based on field measurements that were conducted by the AQMD's Technical Services Division. Specifically, field measurements were conducted at four co-composting facilities including, three outdoor windrow co-composting facilities and one in-vessel composting facility. The AQMD staff also conducted tests at one greenwaste composting facility. Complete source test reports are available from the AQMD.

In general, the field measurements conducted included several samples in order to develop an emissions profile that would be reflective of different phases of the composting process (i.e., active composting and curing). The following section

provides more information on the development of the emission factors and emissions profiles for co-composting and greenwaste composting only.

Emission Factors for Co-Composting

In 1995, as part of the PM10 Technical Enhancement Program (PTEP), the AQMD staff conducted an emission evaluation of four co-composting facilities, using the EPA approved Emission Isolation Flux Chamber method. The following summarizes the results of the source tests. Full source test reports are available from the AQMD.

Based on the PTEP data for three windrow co-composting facilities, the AQMD staff developed the emission factors used to estimate ammonia and VOC emissions from co-composting operations. Only data from the windrow type of operations were used since the windrow composting method represents the current state of the industry, and this method of composting is considered to be the source of baseline emissions. The estimated emission factors for ammonia and VOC are 2.93 and 1.78 lb/ton mix, respectively. The estimated emission factors were calculated as the arithmetic average of data presented in Table 2-3 – Windrow Emissions Factors.

Table 2-3
Windrow Emissions Factors

Facilities	NH3 E.F. (lb/ton mix)	(VOC) E.F. (lb/ton mix)
RECYC Inc. @ Corona (1995)	2.7	0.53
EKO System @ Corona (1996)	3.28	1.7
San Joaquin Composting, Inc. @ Lost Hills (1996)	2.81	3.12
Average	**2.93**	**1.78**

The emission factors presented in Table 2-3 are the weighted-average emissions factors for emission rates from different compost piles at different days in the cycle. The source tests used for this analysis contain data from the second day through the sixtieth day of composting cycle.

Based on the available source test data, EPA's pathogen reduction 15-day requirement, and information from other studies, for emissions purposes, staff assumed that the active phase of the composting cycle takes approximately 22 days. The active composting phase of the process is the time period where organic material decomposes at its fastest rate and emissions are generated at a high rate.

The 22-day assumption is anecdotally supported by information found in EPA 503 regulations and other studies found in the literature. In particular, an odor-emission study on manure composting conducted by University of Minnesota demonstrates that

odor emissions generated from 3-day piles are at least six times greater than odor emissions of 28-day piles. By way of example, Figures 2-1 and 2-2 provide a graphical representation of the composting process, based on the source test conducted. These figures representing methane and ammonia emissions over time, which are consistent with AQMD staff assumptions on the emissions split time period for the active and initial curing phases of the composting process.

Figure 2-1 - Methane Emissions vs. Time

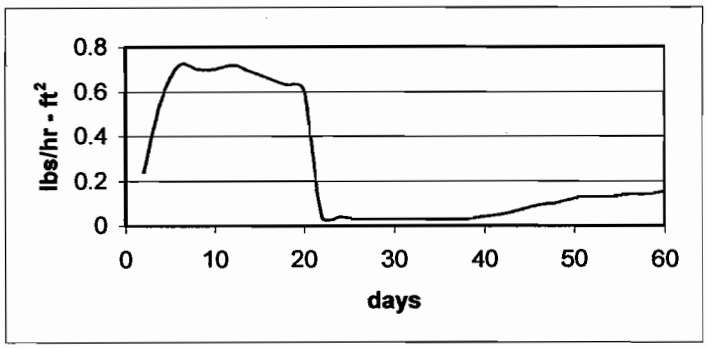
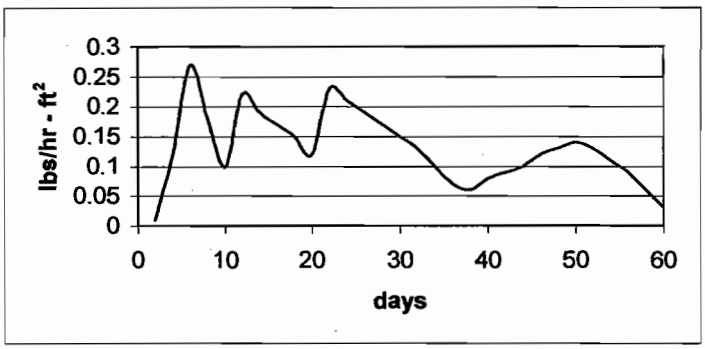


Figure 2-2 - Ammonia Emissions vs. Time



Furthermore, PTEP data was also used to determine the emissions distribution for the co-composting process. The weighted-average emission factors of composting piles up to 22-days old were used to calculate the emission factors for the active phase of composting process. The weighted-average emissions factors of composting piles up to 60-days old were used to calculate the emission factors for the curing stage of the process.

Based on the 22-day assumption, staff analysis indicated that, for ammonia, 50% of the emissions are released during the active phase and 50% of the emissions are released during the curing phase of the process. For VOC, staff analysis indicated

that 80% of the emissions are released during active phase and 20% of the emissions are released during the curing phase of the process.

Based on the results of emissions profile analysis, the estimated ammonia emission factor for both active and curing phases of the process is equally estimated to be 1.47 lb/ton mix. For VOC, the estimated emission factors are 1.42 lb/ton mix and 0.36 lb/ton mix, for the active and curing phases, respectively.

Emission Factors for Greenwaste Composting

The AQMD staff conducted two source testing for greenwaste in September and November-December of 2001. Based on the weather conditions, the September and November-December tests are referred to as early fall and early winter tests, respectively. The early fall test was conducted using the EPA approved Emission Isolation Flux Chamber method. The early winter test was conducted using a remote sensing measurement technology called Boreal Laser Gas Finder. Basically, this technique measures the concentration and the volumetric airflow rate through large cross sections of the pile. The results of the cross section analysis are used to provide an estimate of emissions from the entire pile. For the purpose of this analysis, both early fall and early winter test results were used to develop the weighted-average emission factors for greenwaste composting. The early fall source test report is available upon request, and the early winter source test report will be available shortly.

The following summarizes the results of AQMD staff's greenwaste composting source tests and the development of related emission's factors.

Early Fall Source Testing

The early fall test was conducted on four piles that were approximately 2-day, 14-day, 45-day, and 70-day-old. Different age piles were tested to ensure representation at various stages of the composting process.

To obtain the composite samples, testing was also conducted at various positions (up to ten positions) of each pile. The results of the composite sample's emission rates are presented in Table 2-4 – Composite Emission Rates (Early Fall Test).

Table 2-4
Composite Emission Rates (Early Fall Test)

	2-day Pile	14-day Pile	45-day & 70-day Pile
NH_3 Emission Rate (lb/hr•1000 ft^2)	0.091	0.071	0.004*
VOC Emission Rate (lb/hr•1000 ft^2)	0.368	0.226	0.079*

(*) Average of two piles

The above emission rates were then used to estimate the emission factors presented in Table 2-5 – Composite Emission Factors (Early Fall Test).

Table 2-5
Composite Emission Factors (Early Fall Test)

	2-day Pile	14-day Pile	45-day & 70-day Pile
NH_3 Emission Factor (lb/ton greenwaste)	0.69	0.61	0.02
VOC Emission Factor (lb/ton greenwaste)	2.8	1.95	0.3

Based on previously described 22-day active phase assumption, the estimated active and curing emissions factors for greenwaste composting are presented in Table 2-6 – Emission Factors for Greenwaste Composting (Early Fall Test).

Table 2-6
Emission Factors for Greenwaste Composting (Early Fall Test)

	Active Composting	Curing
NH_3 Emission Factor (lb/ton greenwaste)	1.3	0.02
VOC Emission Rate (lb/ton greenwastes)	4.75	0.3

Early Winter Source Testing
The early winter test was conducted on three piles that were approximately 2-days and 14-days old. Different aged piles were also tested to ensure representation at various stages of composting process; however, the winter test was not conducted on the curing pile. Instead, the average emission rates in lb/hr/1000 ft^2 of the 45 and 70-day piles from the early fall test were used to represent curing emissions for the early winter test.

The early winter emission rates are presented in Table 2-7 – Emission Rates (Early Winter Test).

Table 2-7
Emission Rates (Early Winter Test)

	2-day Pile	14-day Pile	45-day & 70-day Pile
NH_3 Emission Rate (lb/hr•1000 ft^2)	0.018	0.048*	0.004
VOC Emission Rate (lb/hr•1000 ft^2)	0.28	0.21*	0.079

(*) Average of two piles

The above emission rates were then used to estimate the emission factors presented in Table 2-8 – Emission Factors (Early Winter Test).

Table 2-8
Emission Factors (Early Winter Test)

	2-day Pile	14-day Pile	45-day & 70-day Pile
NH_3 Emission Factor (lb/ton greenwaste)	0.06	0.24	0.03
VOC Emission Factor (lb/ton greenwaste)	0.91	1.06	0.5

Based on previously described 22-day active phase assumption, the estimated active and curing emissions factors for greenwaste composting are presented in Table 2-9 – Emission Factors for Greenwaste Composting (Early Winter Test).

Table 2-9
Emission Factors for Greenwaste-Composting (Early Winter Test)

	Active Composting	Curing
NH_3 Emission Factor (lb/ton greenwaste)	0.3	0.02
VOC Emission Rate (lb/ton greenwaste)	1.96	0.5

In summary, greenwaste composting weighted-average emission factors presented in Table 2-10 are used to develop an emission inventory profile of the composting and related operations industry.

Table 2-10
Weighted-Average Emission Factors for Greenwaste Composting

	Active Composting	Curing
NH_3 Emission Factor (lb/ton greenwaste)	0.83	0.02
VOC Emission Rate (lb/ton greenwastes)	3.44	0.4

Based on this analysis, it was determined that for greenwaste composting, the majority of ammonia and VOC emissions are generated during active composting. These emission factors are believed to represent emissions for the current state of the industry. In general, instead of using windrow composting, with frequent turning by scarabs or wildcats, greenwaste facilities process mounded stockpiles of greenwaste without frequent turning.

Additional Greenwastes Testing

In addition to the early fall and early winter source testing conducted by the AQMD, the CIWMB and the City of Los Angeles also conducted three source tests: one at a chipping/grinding facility and two tests as greenwaste composting facilities, one of

which is using the windrow composting technique. The testing was conducted with the Emission Isolation Flux Chamber approach. The staff, at both CIWMB and City of Los Angeles, have worked cooperatively with the AQMD staff to ensure consistent emissions analysis. Although the final results have not been completely reviewed by AQMD staff in time to be included in this report, AQMD staff will incorporate those test results to the greenwaste composting emissions analysis and report the revised analysis to stakeholders as soon as possible.

Baseline Emissions

Table 2-11 – Baseline Emissions Inventory provides an emission inventory profile of the composting and related operations industry. As shown in Table 2-11, the composting and related operations industry, as a whole, generates approximately 6.8 tons per day of VOC emissions, which would place this industry as the second largest stationary source category, with the refinery industry being the highest source category.

Table 2-11
Emissions Inventory

Process	Throughput Tons/year	Emissions Factors		Emissions (tons/year)				Total Emissions (tons/year)	
				NH_3		VOC			
		NH_3 lbs/ton	VOC lbs/ton	Active	Curing	Active	Curing	NH_3	VOC
Co-Composting	922,190	2.93	1.78	677.8	677.8	654.8	166.0	1355.6	820.8
Greenwaste-Composting	832,191	0.85	3.84	345.4	8.3	1431.4	166.4	353.7	1597.8
Chipping/ Grinding	3,033,092	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Exempt Facilities	36,865	0.85	3.84	15.3	0.4	63.4	7.4	15.7	70.8
			Total	**1038.5**	**686.5**	**2149.6**	**339.8**	**1725**	**2489.4**
Totals in tons per day based on 365 days per year				**2.8**	**1.9**	**5.9**	**0.9**	**4.7**	**6.8**

Of this inventory, there are 7 co-composting and 12 greenwaste composting facilities that generate an annual VOC emissions exceeding the 10 tons per year threshold for major sources as defined in District Rule 3001. Depending on the throughput, the largest greenwaste facility is estimated to emit up to 600 tons per year of VOC, which would be considered among the top 5 VOC emitters in the SCAB.

CHAPTER III

CONTROL TECHNOLOGY ASSESSMENT

INTRODUCTION

This chapter discusses the following:

- ✓ Composting Methods;
- ✓ Emission Control System (Biofilter);
- ✓ Demonstrated Control Efficiencies; and
- ✓ Chipping and Grinding Methods.

COMPOSTING METHODS

Emissions from composting can be reduced by maintaining optimal aerobic conditions, or utilizing state-of-the art emissions control technologies, such as aeration static pile (ASP), in-vessel, and biofilters.

Optimized Practices

Maintaining optimal aerobic composting conditions can reduce some emissions and odors from composting operations. The microorganisms responsible for composting function best within a given range of parameters such as carbon to nitrogen ratio, moisture content, oxygen concentration, pH, and temperature of the compost piles. Although optimal conditions can vary based on the type of feedstock, preferred ranges are typically in the following:

Table 3-1
Optimal Composting Conditions

Characteristic	Preferred Range
Carbon:Nitrogen ratio	25:1 to 40:1
Moisture content	50% to 60%
Oxygen concentration	5% to 15%
PH	6.5 to 8.0
Temperature	130°F to 150°F

Additionally, good practices for compost mixing, curing and storage can also reduce odors, dust and emissions; however, the amount of reduction cannot be easily quantified.

Aerated Static Pile (ASP)

ASP was developed to eliminate substantial land space requirement and other problems associated with windrow composting. ASP is an established technology where forced aeration is applied to provide direct, precise control of oxygen, temperature, and moisture conditions to the pile. Currently, there are approximately 118 operational composting facilities in the U.S. utilizing the ASP technology, two of them are located in the AQMD jurisdiction. Some of the ASP facilities operate within enclosures for further control. These facilities handle a daily throughput ranging from about 0.1 dry ton to 300 dry tons. In addition, several groups in the AQMD jurisdiction also consider ASP for their facilities.

With the ASP, feedstock is piled over a base of porous materials such as wood chips, which contains perforated aeration pipes. In order to avoid short circuiting, the porous base should be smaller than the base of the pile. The perforated pipes are connected to a blower that either pulls (negative pressure or suction) or pushes (positive pressure) air through the pile. The blower should be operated intermittently to maintain the 5% to 15% oxygen range and the uniform temperature. To provide insulation and prevent escape of odors during composting, the pile is usually covered with a thick layer (12 to 18 inches) of finished compost or bulking agent.

With positive pressure aeration, contaminated air is pushed through the pile to the outer surface; therefore, is difficult to be collected for odor treatment. However, positive pressure aeration is more effective at cooling the pile because it provides better airflow.

With a suction system, air is pulled through the pile from the outer surface. Contaminated air is collected in the aeration pipes and can be directed to an odor treatment system. To avoid clogging, condensed moist air drawn from the pile must be removed before reaching the blower. Negative aeration might create uneven drying of the pile due to its airflow patterns.

A study conducted by City of Columbus, Ohio demonstrates that the weighted-average odor emissions from an outdoor negative aeration pile is approximately 67% lower than those from an outdoor positive aeration pile. However, to provide flexibility in operations, some composting facilities aerate in both positive and negative modes. Negative aeration is usually used during the beginning of the composting process to greatly reduce odors. In enclosed active composting area, negative pressure aeration also reduces moisture released into the building, and thus, reduces fogging. Positive aeration is used mostly near the end of the composting cycle for more efficient drying of the compost.

In summary, compared to traditional windrow composting, ASP provides a more precise control of oxygen and temperature conditions; therefore, it can reduce odors and emissions by promoting optimal aerobic conditions. However, currently there is no field measure available to quantify any additional emission benefit of ASP (i.e., lower pile emissions). An ASP confined in a building enclosure would capture 100% of its emissions to an emission control device that will be discussed later in this chapter. ASP also provides better flexibility to handle changes in compost feedstock quantity and quality. In addition, it requires less time to complete the active composting phase. With proper operation, active composting from an ASP might be completed within 20 to 28 days; therefore, more finished compost can be produced in a smaller footprint. Study conducted by Synagro Composting Facility indicates that, in comparison to windrows, ASP reduces the landspace requirement on the order of 60%. There are two common forms of ASP: individual piles and extended piles.

Individual Piles

Individual piles are long triangular piles that are usually constructed with a width equal to about twice the height. The aeration pipes run lengthwise beneath the ridge of each pile and serve the entire pile. Each pile contains feedstock of roughly the

same recipe and age. Individual piles are practical when feedstock is available for composting at intervals.

Extended piles
To make more effective use of available space, another pile configuration called the extended aerated pile has been developed. Studies indicate that the area required for an extended pile is about 50% less than that for an individual pile. Extended piles consist of individual cells that are stacked against each other. Cells of new feedstock are constructed in one pile, and cells of nearing mature compost are placed in other. The space between the two piles allows the removal of an old cell from one pile and adding of a new cell to the other. Cells are usually constructed with a width equals to the pile's height. Each cell contains one day's volume of feedstock. Generally, each cell is aerated by its own blower and controlled by its own timer or temperature sensor. However, cells contain feedstock of roughly the same age can share a single blower by connecting the pipes with a header. Connecting several cells to one blower minimizes the number of blowers required, but also complicates the blower control system.

Appendix A contains the list of ASP composting achieved in practice, which based mainly on the 1998 Biocycle survey.

In-Vessel Composting
In-vessel is developed to eliminate substantial land space requirement for windrow composting, as well as to overcome the deficiencies in windrow. In-vessel composting is an established technology where feedstock is confined within a building, a container, or a vessel. In-vessel methods rely on forced aeration and mechanical turning to speed up the composting. Currently, there are approximately 50 operational composting facilities in the U.S. utilizing in-vessel technology; one of them is located in the District. These facilities handle a daily throughput ranging from less than 1 dry ton to over 100 dry tons. There are different types of in-vessel, such as silos, rotating drums, transportable containers, bin composting, and agitated bed, which are designed/manufactured by about 15 companies; however, bin composting, silo, and agitated bed are considered the most popular in-vessel systems used in composting operations.

Bin Composting
Bin composting is the most basic and simple in-vessel technique, where feedstock is contained in a bin with or without roof. Essentially, bin composting operates like the ASP; it includes forced aeration in the floor of the bin and requires little or no turning of the feedstock. Besides having the advantages of an ASP, bin composting can also eliminate weather problems, provide better temperature control, and reduce odors released to the atmosphere.

Silo
In composting operations, vertical silo is the most popular system where air is provided from the base through the feedstock. Contaminated air can be collected from the top of the silo and vented to an odor or emission control equipment. Feedstock is loaded at the top of the silo, and finished compost is removed from the

base. Typical active composting time is 14 days, so one-fourteenth of the silo volume must be removed and replaced daily. Compost is often cured in a second aerated silo, which minimizes land space. However, this composting method may be difficult to operate due to compaction, temperature and air-flow problems, which are associated with this process.

Agitated Bed

Agitated bed is a system where controlled aeration and periodic turning are combined. With this system, feedstock is placed at the front end of a long, narrow channel (bed). As the turning machine moves forward, it mixes the organic materials and discharges it behind itself. With each turning, the machine moves the feedstock a set distance toward the end of the bed. The length of a bed and the turning frequency determine the composting period. If the machine moves the organic materials 10 feet at each turning and the bed is 100 feet long, the composting period is ten days. Suggested composting periods for agitated bed system ranges from two to three weeks.

Between turnings, aeration is provided through a set of aeration pipes, which locate in the floor of the bed. Since the organic materials along the bed are at different stages of composting, the bed is divided into different aeration zones. Each blower supplies air to one zone and is controlled by a temperature sensor or a time clock.

Agitated bed composting, in combination with the use of building enclosures, are capable of capturing 100% of the process of emission and odors. This method also provides better process controls. This type of process can produce consistent quality compost, reduce the composting time cycle, and reduce operational costs, which can help offset its high capital costs.

Attachment B contains the list of operational in-vessel composting facilities in the U.S. This list is compiled based on the 1998 Biocycle survey and the input from one major in-vessel designer firm.

EMISSION CONTROL SYSTEMS (BIOFILTER)

There are several types of emissions control systems that are capable of controlling ammonia and VOC emissions; however, this discussion is limited to biofilters, since it is the most economically feasible and most common type of control equipment in composting operations.

Biofiltration is a well-established emission and odor control technology in Europe where over two hundred biofilters were in use as of 1984 (Eitner, 1984). In the United States, biofilters have been mainly utilized for the treatment of odors as well as VOC in wastewater treatment plans. Biofilters have recently gained better acceptance by composting and other operations such as body repair shops, MRF/transfer stations, pharmaceuticals, beer breweries, etc. To date, AQMD has issued 17 Permits to Operate biofilters and is processing 15 additional applications.

Basically, biofilters use microorganisms that live in the biofilm; a thin layer of moisture surrounds the particles that make up the media, to adsorb and biologically

degrade contaminated air into non-harmful substances. In particular, VOC is oxidized to carbon dioxide and water, and ammonia is degraded into nitrate without creating aggravating pollution issues.

In biofilter design, the selection of a media is a critical factor. For a biofilter to operate efficiently, a media must have a good adsorption capacity and good resistance to compaction, be able to provide a suitable environment for microorganism growth and reproduction, and have high porosity for minimal back pressure. Typically, biofilter media is made up of wood waste and small portion of compost, which would provide an air-filled porosity between 40% and 60% and a pH between 6 and 8.

In order for a biofilter to perform at its best, several parameters should also be maintained:

Moisture Content
Maintaining proper and consistent moisture content in the biofilter media is essential to support microorganisms and to remove ammonia (by dissolution). Ideally, moisture levels in the media should be kept between 40% and 60% at all times; however, a range of 30% to 65% are proven acceptable. Since the media has a tendency to dry out due to the airflow, biofilters usually have a pretreatment stage that moisturizes the contaminated air before it reaches the media. However, moisture content should be carefully monitored to avoid biofilter clogging.

Temperature
The optimum operating temperature for a biofilter is between 80 °F to 100 °F. In order to avoid damaging to microorganisms, influent gas in excess of 105 °F might require cooling prior to entering the biofilter.

Backpressure
There is no absolute number for optimal backpressure (increase in pressure above normal operating gauge pressure). Backpressure varies depending upon media type, bed depth, unit airflow, media age, and may range from less than 1 inch water column to over 10 inches water column. Backpressure will rise as biofilter media ages (if there are no leaks, shortcircuits, channels, or fissures in the media.)

Maintenance
Sophisticated monitoring protocols are helpful; however, they should not take the place of regular inspection for dry spots, leaks, cracks, fissures of the media, and the presence of odors.

In composting, biofilters are usually used in conjunction with aerated static piles or in-vessel systems. Biofilters are known for their competitive capital and low operating costs compared to conventional technologies, such as carbon filtration, chemical scrubbers, or oxidation; however, it may take up a large land space. Biofilters are also known as the best systems to remove multiple odor-causing compounds at low concentration. If properly designed and operated, biofilter would achieve an overall control efficiency of 75% for ammonia and 90% for VOC (Appendix C).

There are several types of biofilters, such as single-layer open bed, multi-layer stack bed, etc. They all have two basic components: a media, and a piping system that distributes contaminated air through the biofilter.

Single-Layer Open Bed Biofilter
Single-layer open bed biofilter is the most typical biofilter used in the composting operations. With this type of biofilter, contaminated air is introduced though a distribution system, which typically contains perforated plastic pipes, embedded in a layer of gravel. Above this layer, there is a media of approximately 4-ft thick. The typical airflow rate is in the range of 3 cfm and 5cfm per ft^2 of biofilter surface. An open bed biofilter also has a sprinkler system to keep the media moist, and a drainage system to drain excess water in the event of over watering or rain.

Single-layer open bed biofilter takes up a lot of space and often causes compaction of the media, which results in an increased head loss. Depending on the usage, biofilter media might need replacement every 2 to 3 years.

Multi-Layers Stack Biofilter
Multi-layers stack biofilter is an enclosed system that can prevent compaction of the media and also minimize the space requirement. Since multiple units can be run in parallel, the biofilter will not be shut down during media replacement. This type biofilter can also minimize the risk of channeling of the contaminated air stream.

DEMONSTRATED EMISSIONS CONTROL EFFICIENCY

Biofiltration is an emission control system that has been widely used by the composting industry in the United States. The emissions control effectiveness for biofiltration is published in numerous studies. In addition, independent emissions and odors evaluations have also been conducted by facilities employing biofiltration. Appendix C – Biofilters in Operation at Composting Facilities in the United States, provide information on inlet and outlet emission rates for the biofilters systems cited. Based on these data, AQMD estimated the destruction efficiency of biofiltration to be 75 and 90 percent for ammonia and VOC, respectively.

Table 3-2 – Composting Methods, Capture and Control Efficiencies, provides a summary of methods used in the composting and related operations industry and their respective efficiencies in terms of controlling air emissions.

Table 3-2 – Composting Methods, Capture and Control Efficiencies

Composting Method	Emissions Capture Efficiency	Control Equipment Efficiency		Over-all Control Efficiency	
		Ammonia	VOC	Ammonia	VOC
Windrow	0%	n/a	n/a	0 %	0%
ASP*	25 to 33 %	75.0%	90.0%	18.8 – 24.7%	22.5 – 45.0
In-Vessel	100%	75.0%	90.0%	75.0%	90.0%

*Additional emission reduction potential from ASP cannot be quantified at this time.

CHIPPING AND GRINDING METHODS

Chipping/grinding facilities chip and grind wood/green waste, which was mostly collected from landscaping or from cities' curbside collection programs, and stockpile the processed materials until they are transferred to other facilities for different usage such as alternative daily cover (ADC), biomass fuel, mulch, or composting feedstock. Stockpiling green waste, especially those from the curbside collection where other putrescible wastes are not normally separated, for a period of time under certain moisture and temperature, will allow the organic materials to decompose anaerobically and generate odors as well as emissions. High temperature and VOC monitoring data obtained during the AQMD site visits of the chipping/grinding facilities demonstrate that those piles were in the process of decomposing.

To prevent wood/green waste from decomposing, staff recommends that certain processed and unprocessed materials to be removed from the site within certain time limit that will be determined later in the rule development process. The explicit holding times might vary by the source of unprocessed materials and by the end usage of chipped and ground materials.

Beside VOCs, chipping and grinding operations can also be sources of PM10. PM10 results from the chipping, grinding and screening of wood/green materials. It can also result when high winds entrain materials from processed material piles. To address these issues, AQMD staff is recommending consideration of the following PM10 dust controls, which are based on the Best Available Control Measures (BACM) listed in Rule 403, Fugitive Dust:

- Cover the chipped/ground material with tarps, plastic or similar covering; or
- Install a three-sided barriers equal the height of the piles; or
- Water the piles; or
- Cease all outdoor chipping/grinding activities during high winds (greater than 25 mph) or when visible plume extends more than 100 feet from the equipment.

CHAPTER IV

EMISSION REDUCTIONS AND COST EFFECTIVENESS

INTRODUCTION

This chapter discusses the following:

- ✓ Emission Reductions; and,
- ✓ Cost-Effectiveness.

EMISSIONS REDUCTIONS

AQMD staff has evaluated three control scenarios for co-composting and three for green-waste composting. Additionally, AQMD has analyzed the impact of hauling the green and sewer sludge wastes to landfills.

Co-Composting

AQMD staff analyzed the following three control scenarios for the co-composting sector of the composting industry:

Scenario 1

- Enclosure of the active and curing phase of the process and the utilization of Aerated Static Pile (ASP) system; and,
- Venting of emissions to a control device (biofilter).

Scenario 2

- Enclosure of the active phase of the process and the utilization of ASP
- Utilization of a ASP system under negative pressure for the curing phase of the process (no enclosure); and,
- Venting of emissions to a control device (biofilter).

Scenario 3

- Utilization of a ASP system under negative pressure for the active and curing phase of the process (no enclosure); and,
- Venting of emissions to a control device (biofilter).

The following assumptions were made to analyze the previously described control scenarios for co-composting:

1. The seven largest windrow facilities with a combined throughput of 894,175 tons/yr would be subject to control;
2. The ammonia emissions factor for the active phase of the process is the same as the emission factor for the curing phase of the process: 1.47 lbs/ton mix;
3. The VOC emission factor for the active phase of composting is 1.42 lbs/ ton mix;
4. The VOC emission factor for the curing phase of composting is 0.36 lbs/ton mix;
5. The windrow method of composting is assumed to be the baseline source of emissions, having no emissions capture efficiency (0%);
6. No emission reduction benefit for resting pile emissions is assumed for an ASP;
7. The capture efficiency of negative-ASP during the active phase of the process is assumed to be 33%;

8. The capture efficiency of negative-ASP during the curing phase of the process is assumed to be 25%;
9. Enclosure is assumed to mean total enclosure and therefore, having a capture efficiency of 100%;
10. The destruction efficiency of biofiltration for ammonia emissions is assumed to be 75%; and,
11. The destruction efficiency of biofiltration for VOC emissions is assumed to be 90% percent.

The following equations where used to calculate emission reductions:

Emissions (tons/yr)

[Total throughput (tons/yr) X Emissions Factor (lbs/ton)]/2000 (lbs/tons),

where,

- Total throughput is the total combined throughput of 7 composting facilities using the windrow method of composting; and,
- The emissions factor is a variable dependant on the pollutant and process phase.

Emission Reductions (tons/yr)

[Emissions (tons/yr) X Control Efficiency %]

where,

- The emissions are a variable dependant on the pollutant and process phase; and,
- Control Efficiency is the result of the capture efficiency multiplied by the destruction efficiency of the control device. Control Efficiency is a variable dependant on the pollutant and process phase.

Table 4-1 – Co-Composting Scenarios, provides a summary of the emission reductions for each of the control scenarios analyzed for co-composting.

Table 4-1 – Co-Composting Scenarios

Scenario		Composting Method	Uncontrolled Emissions (tons/yr)		Over-all Control Efficiency %		Emission Reductions (tons/yr)		Total ER (tons/yr)
	Active	Curing	Active	Curing	Active	Curing	Active	Curing	
Ammonia									
1	Enclosed ASP	Enclosed ASP	654.98	654.98	75	75	491.24	491.24	982.47
2	Enclosed ASP	Negative Pressure ASP	654.98	654.98	75	19	491.24	122.81	614.05
3	Negative Pressure ASP	Negative Pressure ASP	654.98	654.98	25	19	162.11	123.23	285.34
VOC									
1	Enclosed ASP	Enclosed ASP	636.65	159.16	90	90	572.99	143.24	716.23
2	Enclosed ASP	Negative Pressure ASP	636.65	159.16	90	23	572.99	35.81	608.80
3	Negative Pressure ASP	Negative Pressure ASP	636.65	159.16	30	23	188.70	36.21	224.92

Greenwaste-Composting

AQMD staff analyzed the following three control scenarios for the greenwaste-composting sector of the composting industry:

Scenario 1

- Enclosure of the active and curing phases of the process and the utilization of an Aerated Static Pile (ASP) system;
- Venting of emissions to a control device (biofilter).

Scenario 2

- Enclosure of the active phase of the process and the utilization of an ASP system;
- No control for the curing phase of the process; and,
- Venting of the active composting emissions to a control device (biofilter).

Scenario 3

- Utilization of an ASP system under negative pressure for the active and curing phases of the process (no enclosure); and,
- Venting of emissions to a control device (biofilter).

The following assumptions were made to analyze the previously described control scenarios for greenwaste-composting:

1. The ten largest facilities are open static piles windrow type operations and combined, these facilities have a total throughput of 819,461 tons/yr;
2. The emission factor for ammonia for the active phase of the composting process is 0.83 lbs/ton greenwaste;

3. The emission factor for ammonia for the curing phase of the composting process is 0.02 lbs/ton greenwaste;
4. The VOC emission factor for the active phase of composting is 3.44 lbs/ ton greenwaste;
5. The VOC emission factor for the curing phase of composting is 0.4 lbs/ton greenwaste;
6. The static windrow piles method of composting is assumed to be the baseline source of emissions, having no emissions capture efficiency (0%);
7. The capture efficiency of negative-ASP during the active and curing phases of the process phase of the process is assumed to be 25%;
8. Enclosure is assumed to mean total enclosure and therefore, having a capture efficiency of 100%;
9. The ammonia destruction efficiency for biofiltration is assumed to be 75%;
10. The VOC destruction efficiency for biofiltration is assumed to be 90% percent: and,
11. No emission reduction benefit for resting pile emissions is assumed for an ASP.

Emission reductions were calculated using the previously listed equations. Table 4-2 – Greenwaste-Composting Scenarios, provides a summary of the emission reduction for the three scenarios evaluated for greenwaste-composting.

Table 4-2
Greenwaste Scenarios

Ammonia									
Scenario		Composting Method	Uncontrolled Emissions (tons/yr)		Over-all Control Efficiency %		Emission Reductions (tons/yr)		Total ER (tons/yr)
	Active	Curing	Active	Curing	Active	Curing	Active	Curing	
1	Enclosed ASP	Enclosed ASP	340.50	8.23	75	75	255.4	6.2	261.60
2	Enclosed ASP	No Control	340.50	8.23	75	0	255.38	0	255.38
3	Negative Pressure ASP	Negative Pressure ASP	340.50	8.23	19	19	63.97	1.54	65.51
VOC									
1	Enclosed ASP	Enclosed ASP	1,411.22	162.55	90	90	1,270.16	147.50	1,417.66
2	Enclosed ASP	No Control	1,411.22	162.55	90	0	1,270.28	0	1,270.28
3	Negative Pressure ASP	Negative Pressure ASP	1,411.22	162.55	23	23	317.13	37.29	354.42

Summary

As illustrated in both Tables 4-1 and 4-2, full enclosure of active and curing piles would generate the greatest emission reductions with open ASP providing the least reductions. However, the emission reduction potential could be higher than the data presented in Tables 4-1 and 4-2 for all three scenarios, if additional emission reduction benefits from

ASP operations can be quantified. It may also modify the incremental difference between scenarios 2 and 3.

COST-EFFECTIVENESS

Affected Facilities

The control scenarios analyzed affect composting and chipping and grinding facilities in the AQMD jurisdiction. The affected facilities mainly belong to SIC 4952 (Sewerage System) and 4953 (Refuse System). Of these affected facilities, only 17 composting facilities are required to install control equipment, and, therefore, would incur significant additional costs. Of the 17 composting facilities, ten facilities are greenwaste-only and the remaining seven are co-composting facilities. Three composting facilities (18%) are located in Los Angeles County, three facilities (18%) in Orange County, four facilities (23%) in Riverside County, and the remaining seven facilities (41%) are located in San Bernardino County.

Small Business Impacts

The AQMD defines a "small business" in Rule 102 as one which employs ten or fewer persons and which earns less than $500,000 in gross annual receipts. In addition to the AQMD's definition of a small business, the federal Small Business Administration (SBA), the federal Clean Air Act Amendments (CAAA) of 1990, and the California Department of Health Services (DHS) also provide their own definitions of a small business.

The SBA's definition of a small business uses the criterion of either gross annual receipts (ranging from $0.5 million to $17 million, depending on industry type) or number of employees (ranging from 100 to 1,500). The SBA definitions of small businesses vary by 4-digit SIC code. The industries affected by the proposed Rule 1133 mainly belong to SIC 4952 and 4953—sanitary and refuse systems (miscellaneous processes). For the facilities affected by the proposed rule, gross annual receipts of $5 million is the criterion below which a business is considered small under the federal SBA definition. The CAAA classifies a facility as a "small business stationary source" if it: (1) employs 100 or fewer employees, (2) does not emit more than ten tons per year of either VOC or NOx, and (3) is a small business as defined by SBA. The DHS definition of a small business uses an annual gross receipt criterion (ranging from $1 million to $9.5 million, depending on industry type) for non-manufacturing industries and an employment criterion of fewer than 250 employees for manufacturing industries.

Of the 17 affected composting facilities, ten have gross annual receipts and employee information reported in the 2000 Dun & Bradstreet database acquired by the AQMD. Based on the AQMD's Rule 102 definition, only one of the ten facilities would be considered a small business. With the federal SBA's definition, three facilities would be considered small businesses. With the CAAA's, ten could be considered small businesses. Table 4-3 provides the range of the gross annual sales and number of employees for these facilities.

Table 4-3
Number of Facilities by Sales and Employees

Gross Annual Sales (millions $)	Number of Facilities		Number of Employees	Number of Facilities
Less than $0.5	1		5 to 9	2
≥ $0.5 and ≤ $1	1		10 to 19	0
>$1 and ≤ $2.5	3		20 to 49	6
> $2.5 and ≤ $5	2		50 and above	2
≥ $20 and ≤ $50	3		100 to 500	3

Cost Assumptions

Some of the control scenarios require active co-composting and greenwaste-only processes to be enclosed and to have forced aeration, either through an in-vessel or aerated static pile (ASP) system. Emissions from the enclosure must be vented to a biofilter or other control device that achieves a control efficiency of 75 percent reduction for ammonia and 90 percent reduction for VOC.

Compliance costs of the control scenarios were estimated based on the cost of the building enclosures, ASP, and biofilters. The cost of building enclosures was estimated based on the enclosure area (square feet) required relative to the total annual throughput of an affected facility. It should be noted that total throughput includes feedstock (sewer sludge/manure) and bulking agent. In addition, for the building enclosure, two different structural designs were assumed: concrete and fabric structures. For concrete and fabric structures, estimated costs of $50 and $30 per square feet were assumed, respectively. These estimates include building structure, air exchanges and fire protection systems, and were based on City of Redlands and the IEUA RP-1 conceptual design plan. For the enclosure of active and curing, 1.5 square feet per ton of annual throughput and for enclosure of active piles only, 0.75 square feet per ton of annual throughput was used. These estimated were based on Inland Empire Utility Agency (IEUA) RP-1 conceptual design, IKEA (IEUA) site design, and city of Davenport design plans.

The cost for ASP in the city of Columbus conceptual design and the city of Davenport's plan was used. The annualized cost of ASP was estimated at $6.75 per ton of throughput. This estimate includes flooring, piping, and aeration equipment.

The Biofilter estimate was derived based on biofilter surface required for emissions treatment. The biofilter cost was estimated at $12 per square feet of biofilter surface. This estimate was provided by Black and Veatch Company, and includes cost components such as biofilter fans, ducks, and biofilter media.

It is assumed that the economic life of building enclosures, ASP, and biofilters is 15 years each. Operating and maintenance cost for the total enclosure was assumed to be 10 percent of the total capital cost. For the biofilters, the cost of media change every three years is included in their operating cost. The total annual throughput of the affected facilities is estimated at 1,713,636 tons, of which 894,175 tons are from co-composting and the remaining 819,461 are from greenwaste only facilities.

Compliance Costs

Table 4-4 and 4-5 present annualized cost and cost effectiveness of the three scenarios for co-composting and greenwaste-only facilities. For co-composting facilities, cost-effectiveness ranges from $21,154 to $42,515 per ton of VOC reduction. The corresponding annualized costs of scenarios one, two, and three are estimated at $27.1 and $22 million, $19.9 and $17.3 million, and $12.9 million, respectively.

The annualized cost of each scenario includes both annualized cost of capital and annual operating and maintenance costs (10 % of total annual cost). The total capital cost includes cost of building enclosure, ASP, and biofilter. The capital cost is annualized by multiplying total capital cost by a capital recovery factor (CRF) of 0.090. The CRF 0.090 is based on a 15-year period (the assumed equipment lifetime) and with a 4 percent real interest rate.

For the purpose of illustration, the total annualized cost of a typical facility with an annual throughput of 200,000 tons is estimated at $4,497,300, as shown below:

Capital Cost

Total Building Cost:	$7,500,000
Total ASP Cost:	$14,250,000
Total Biofilter Cost:	$1,920,000
Total Capital Cost:	$23,670,000

Operating Cost

O & M Cost:	0.1 x($23,670,000) = $2,367,000
Total Annualized Cost	= Total Capital Cost x CRF (0.090) + O & M Cost
	= ($23,670,000 x 0.090) + $2,367,000 = $4,497,300

For each scenario, cost-effectiveness is calculated based on both overall emission reductions and VOC emission reductions only for both concrete and fabric structure designs. The cost-effectiveness analysis uses the Discounted Cash Flow (DCF) method to compute the present value of the proposed rule's costs over a 15-year period (the assumed equipment lifetime) with a 4 percent real interest rate, which gives the present value factor of 11.118. DCF cost effectiveness can then be calculated as:

$$Cost\ Effectiveness = \frac{Capital\ Costs + (Annual\ O\ \&\ M\ Costs \times 11.118)}{Emission\ Reductions_{tons/yr} \times 15\ years}$$

Table 4-4
Co-Composting Annualized Cost and Cost-effectiveness by Scenario ($/ton)

Scenarios	Description	Annualized Cost (Millions $)		C-E for VOC Only		C-E for VOC & Ammonia	
		Concrete	Fabric	Concrete	Fabric	Concrete	Fabric
1	Enclose* Active and Curing Piles +ASP + Biofilter	$27.1	$22	$28,052	$22,779	$11,828	$9,604
2	Enclose* Active Piles only +ASP + Biofilter	$19.9	$17.3	$24,255	$21,154	$12,076	$10,531
3	Open ASP + Biofilter		$12.9		$42,515		$18,740

*Includes Static and Tipping Piles.

As with the co-composting, three scenarios representing three different levels of control were selected to analyze the effectiveness of the proposed rule on greenwaste-only facilities.

Table 4-5 presents annualized cost and cost-effectiveness of the three scenarios for greenwaste-only facilities. Cost-effectiveness ranges from $8,929 to $24,726 per ton of VOC reduced. Cost-effectiveness ranges from $9,604 to $18,740 per ton of combined VOC and ammonia reduced. The corresponding annualized costs of scenarios one, two, and three are estimated at $24.8 and $20.1 million, $17.6 and $15.3 million, and $11.8 million, respectively. There is no building enclosure requirement for the scenario three.

Table 4-5
Greenwaste-Only Annualized Cost and Cost-effectiveness by Scenario ($/ton)

Scenarios	Description	Annualized Cost (Millions $)		C-E for VOC Only		C-E for VOC & Ammonia	
		Concrete	Fabric	Concrete	Fabric	Concrete	Fabric
1	Enclose* Active and Curing Piles +ASP + Biofilter	$24.8	$20.1	$12,988	$10,547	$10,962	$8,901
2	Enclose* Active Piles only +ASP + Biofilter no Control on Curing	$17.6	$15.3	$10,291	$8,929	$8,568	$7,434
3	Open ASP + Biofilter	$11.8		$24,726		$20,869	

*Includes Static and Tipping Piles.

Due to lack of sufficient data at this time, PM10 emission reductions and additional emission reductions from ASP technology (i.e., lower pile emissions) have not been quantified for all scenarios. As a result, it is expected that emission reductions could be larger and control process would be more cost-effective than is currently established. PM10 emissions inventory as well as emission reductions will be further evaluated.

Incremental Cost-effectiveness

H&SC Section 40920.6, requires that incremental cost effectiveness be performed whenever more than one control option is available to meet emission reduction requirements for a proposed rule or amendment relating to ozone, carbon monoxide (CO), oxides of sulfur (SO_x), oxides of nitrogen (NO_x), and their precursors. Incremental cost effectiveness is defined as the difference in costs divided by the difference in emissions between one level of control and the next more stringent control. The incremental cost-effectiveness analysis related to the VOC portion of the proposed rule will be presented in the final staff report.

Unquantified Savings

Some control scenarios require active composting process to be enclosed and to have forced aeration either through an in-vessel or aerated static pile (ASP) system. This process provides a more precise control of oxygen and temperature conditions, and can greatly reduce odors and emissions by promoting optimal aerobic conditions. Furthermore, this process requires fewer spaces for active composting and reduces time required to produce final composting product. For example, the Los Angeles County Sanitation District (LACSD) composting study shows that with the ASP technology the actual surface area required for composting could be up to 60 percent less than the footprint required for active windrow composting piles. Therefore, ASP facilities sited could reduce capital investments in land acquisition.

In addition, with proper operation, active composting from an enclosed ASP could be completed in far fewer days than the 45 to 60 days under traditional windrow composting. Therefore, the volume of finished compost product and revenue generated from selling them could possibly increase. To the extent it could occur, an enclosed ASP system could reduce even more emissions generated from this additional throughput. Since the capital cost of enclosed ASP systems would remain relatively constant during the process, more throughputs would make this process more cost-effective.

Hauling Scenarios

Staff has developed two additional scenarios to further evaluate the potential cost impact, which could incur as a result of the proposed rule. Scenario one assumes that the proposed rule would cause complete shutdown of all composting facilities in the district, and, as a result, one hundred percent of the biosolid and greenwaste materials are hauled away and dumped out of the state. This estimate was based on hauling 1,713,636 tons per year of materials to landfills out of state. This estimate includes both transportation cost and tipping fees cost. Based on both LA County Sanitation District and the AQMD's survey, hauling cost is estimated at $18 per ton. This estimate includes fuel cost, driver's salary, benefits, food and depreciation of the vehicle. The tipping fees for outside of the state is assumed to be $20 per ton. Based on these assumptions, the total annual cost of hauling scenario is estimated at $38 per ton. The annual cost of this scenario is estimated at $65.1 million.

Scenario two is similar to scenario one, but assumes that only 75 percent of the biosolids and greenwaste materials would be shipped out of the state and the remaining 25 percent would be hauled to the local landfills. The annual cost includes both transportation cost and tipping fees cost. Based on the Integrated Waste Management Board (IWMB) survey data (1995-2000), the average tipping fee at the local landfill is estimated at $35 per ton. The annual cost of this scenario is estimated at $67.5 million.

According to the recent information received by staff, the projected cost of hauling waste is estimated at $63 per ton, which includes $33 per ton for transporting materials to out of state (Arizona) and $30 per ton for tipping fees charged by the landfills located outside of California. This could significantly increase the cost of the hauling scenarios described above.

In response to stakeholders questions, AQMD staff also analyzed the transportation emissions impact from increased hauling. The [potential emissions increase from hauling scenario is estimated at 13 ton of VOC, 57 tons of CO, 290.5 tons of Nox, and 7.50 tons of PM10 (Diesel) per year. These emissions are estimated based on the ARB's EMFAC 2001 emission factors from the above pollutants. The remaining assumptions are as follows:

Total Throughput per year	1,713,636
Load per Truck	23 tons
Round trip Miles	400
Number of truck Trip per year	74,506
Total number of Miles per day	81,650
Total Number of Miles per day (District)	40,825 (Based on GIS Analysis)

Affordability Analysis

For the purpose of evaluating of the financial impacts, staff has estimated the annualized cost per ton of throughput of the most likely control scenario, Scenario 2, for selected number of affected facilities. Furthermore, due to lack of financial information from these facilities, revenues from tipping fees and product sales were estimated and used as a surrogate to a facility's total revenue.

Table 4-6 and 4-7 present both annual compliance costs and revenues per ton of throughput for the selected co-composting and greenwaste-only facilities.

Table 4-6
Potential Cost Impacts of the Proposed Rule (Scenario 2) on Selected Co-Composting Facilities

Facility	Annual Throughput	Status	Annualized Control Costs	Incremental Costs Per ton of Throughput	Surrogate Revenue From Tipping Fees and Product Sales per Year ($/ton)**
A	365,000	Private	$8,134,755	$22	$18,213,500 ($40 and $30)
B	200,500	Private	$4,468,343	$22	$10,004,501 ($40 and $30)
C	250,000	Public/ Private	$5,571,750	$22	$7,475,000 ($20 and $30)

**It was assumed that only 33% of co-composting materials would be converted to a final composting product.

Table 4-7
Potential Cost Impacts of the Proposed Rule (Scenario 2) on Selected Greenwaste-only Facilities

Facility	Annual Throughput	Status	Annualized Control Cost	Incremental Costs Per ton of Throughput	Surrogate Revenue From Tipping Fees and Product Sales per Year ($/ton)**
A	312,000	Private	$6,717,017	$22	$13,728,000 ($20 and $30)
B	187,200	Private	$4,030,210	$22	$7,675,200 ($25 and $20)
C	130,000	Private	$2,798,757	$22	$3,640,000 ($12 and $20)

** It was assumed that only 80% of greenwaste-only materials would be converted to a final composting product.

The annualized compliance costs of Scenario 2 is about 50 percent of the annual revenue received by both co-composting and greenwaste-only facilities.

Financial Incentives

The facilities affected by Proposed Rule 1133 may seek funding to help defray the cost of the proposed rule. For example, the California IWMB offers funding opportunities authorized by legislation to assist public and private entities in the safe and effective management of the waste stream. The Recycling Market Development Zone Revolving Loan Program (RMDZ) provides direct loans to businesses that use post-consumer or secondary waste materials to manufacture new products or that undertake projects to reduce the waste resulting from the manufacture of a product.

Since 1998, the RMDZ program has provided financing totaling $2,146,875 (less than 10 percent of the total funding) to five companies involved in composting and $682,000 to one company involved in mulching. The RMDZ loan program is driven by increased diversion from landfills and a development of markets for recycled or recycled content products.

In addition to the RMDZ program, there are other potential sources of financial assistance for affected facilities as follows:

- Air Resources Board: Grant or loan programs regarding air quality
- California Communities: Solid Waste/Recycling–Land, Building, and Equipment Loans
- State Treasurers Office: Various bond financing and loan guarantee programs
- California Technology, Trade and Commerce: Programs for small businesses
- U.S. Small Business Administration: Various loans guarantee programs
- AQMD Small Business Assistance: Various loans guarantee programs

CHAPTER V

RECOMMENDATIONS

INTRODUCTION

This chapter discusses the following:

- ✓ AQMD staff Recommendations

AQMD STAFF RECOMMENDATION

Based on information from this report, AQMD staff is recommending that AQMP Control Measure WST-2 – Emission Reductions from Composting and Related Operations, be implemented in two phases. The first phase would consist of an adoption of a fact-finding rule that would have the elements listed below. The first phase would also include control requirements for new co-composting facilities with total design capacity of 100,000 tons per year. The second phase would consider composting control technologies for new and existing facilities based on the results of additional technical work described below. AQMD staff proposes to bring the first phase rule to the Board for consideration in mid-year 2002.

Co-Composting

As described in this report, co-composting facilities are major sources of VOC and ammonia emissions (e.g., a 100,000 ton/year total throughput facility has annual emissions of 89 tons/year VOC and 147 tons/year ammonia). Based on local community concerns and industry studies, siting of large co-composing facilities in urban areas now requires active consideration of enclosed and controlled facilities to address public health and nuisance concerns. Enclosed ASP or in-vessel systems with control equipment, while feasible and effective at significantly reducing emissions, are costly. Based on industry comment and the staff's analysis, there may be additional emission reductions associated with ASP systems that have not been quantified in this report (e.g., reduced pile emissions due to forced aeration). Additional testing of ASP systems, such as that proposed by Southern California Association of POTWS (SCAP), would allow the emission reduction potential of all control scenarios to be refined. Also, additional operational and cost information for an enclosed ASP system will be available subsequent to the opening of IEUA's'RP-1 facility in 2003. This information would allow this report's conservative cost-effectiveness analysis to be refined. PR 1133 would require that new co-composting facilities above 100,000 tons/year total throughput meet the Scenario 2 control requirements (i.e., enclosed active composting with controls) and all existing operations and new operations under 100,000 tons/year of total throughput would meet certain registration and annual reporting requirements. Specifically:

- Scenario II control requirements for new facilities with total throughput designed capacity of 100,000 tons per year;
  - ✓ Enclosure and ASP for the active phase of the process with emissions vented to a bio-filtration system;
  - ✓ Open ASP for the curing phase of the process with emission vented to a bio-filtration system;
- One-time registration with AQMD;
- Annual reporting requirements; and,

- Compliance with all applicable AQMD rules, regulations and permit conditions.

This proposal is consistent with Best Available Control Technology practices and is designed to address potential public nuisance and emission issues. AQMD staff is aware that three out of four existing facilities with designed capacities of 100,000 tons per year or more, are planning to close operations at their existing sites and move to other locations where they are expected to meet or exceed Scenario II control requirements. Furthermore, it is recommended that the AQMD staff take the following actions:

- Establish a Composting Technical Advisory Group (CTAC):

AQMD staff will continue to evaluate all source testing and other studies currently under development including, but not limited to, the SCAP study and testing conducted by the Integrated Waste Management Board. As part of this evaluation process, AQMD staff is recommending that a Composting Technical Advisory Committee (CTAC) be formed to address the technical concerns of this sector of the composting and related operations industry. The TAC would include members of the regulated community, staff from the Integrated Waste Management Board and AQMD, representatives from sanitation district and utility agencies.

- Report to the AQMD Stationary Source Committee in six months on findings from the SCAP study. The SCAP study is designed to test the effectiveness of an open ASP system and some select operating parameters and is expected to be completed by June 2002. Staff will summarize the technical findings and provide recommendations as appropriate in seeking cost-effective control opportunities.

- Provide technical assistance to local or state jurisdiction on air quality issues during permitting or the preparation of CEQA documents. During this rulemaking, the staff has obtained a great deal of information on composting air emissions and it would be beneficial to the permitting or lead agency to give adequate air quality consideration in its decision-making. It also provides an opportunity to evaluate emission reduction potential on a case-by-case basis.

Greenwaste Composting

As described in Chapters 2 and 4 of this report, the greenwastes industry represents a significant source of VOC emissions and its control options in general are considered cost-effective even without taking accounting for additional reduction potential from an ASP system. However, the affordability analysis and potential increase in tipping fees indicate that these controls are infeasible at this time without government grants to help finance controls. As a result, the staff is proposing minimal requirements on the industry at this time and the proposed requirements would primarily track its operations and emissions inventory and to claim SIP reductions should site-specific controls be implemented. The following summarizes the proposed requirements:

- One-time registration
- Annual reporting requirements
- Compliance with all applicable AQMD rules, regulations and permit conditions

In light of the fact that there are cost-effective control options for this industry that are not yet affordable, AQMD staff is recommending that, through the District's Legislative Committee, special funding from the state legislature be sought to implement state of the art composting methods, including but not limited to, enclosed ASP. AQMD staff will work with the CIWMB and CARB to seek additional funding and/or make existing funding directed more towards air quality spending.

Chipping and Grinding Requirements

- One-time registration;
- Compliance with all applicable AQMD rules, regulations and permit conditions;
- Holding time restrictions by source of unprocessed materials and by the end usage of chipped and ground materials; and
- PM10 controls to prevent visible PM10 emissions over the property line during operations and from processed material piles.

Exemptions

- Portable chipping and grinding
- Community composting
- Agricultural composting
- Nurseries
- Small Operations (throughput threshold to be determined)

Registration and Annual Reporting Requirements

The one time registration requirement will, at a minimum, require facility owners and/or operators to provide the following information:

- ✓ Facility name;
- ✓ Facility location and mailing address;
- ✓ Facility legal owner;
- ✓ Facility operator;
- ✓ Facility contact person;
- ✓ Facility IWMB identification number and contact person;
- ✓ LEA identification number and contact person;
- ✓ Facility designed capacity (throughput);
- ✓ Feedstock description;
- ✓ Composting process description;
- ✓ Products produced;
- ✓ Customers profile;
- ✓ Tipping fee schedule; and,
- ✓ Number of employees.

The annual reporting requirements would require the following information:

- ✓ Update of registration information, as pertinent;
- ✓ Annual actual throughput;
- ✓ Number of enforcement actions against the facility by enforcing agency;

Annual Status Report

The information received from the co-composting and greenwaste facilities and their emission estimates will be summarized and presented as an annual status report to the AQMD Stationary Source Committee. As part of this report, funding opportunities, composting technology, progresses in emission reductions will also be included.

CHAPTER VI

PUBLIC OUTREACH

INTRODUCTION

This chapter discusses the following:
- ✓ Public Outreach

PUBLIC OUTREACH

The public outreach efforts for Proposed Rule 1133 – Composting and Related Operations, included public meetings, focused presentations, and site visits. The meetings were well attended. In general, the average number of people in attendance for each of the meetings range from 60 to 80 people. Following is chronological listing of the public meetings.

- Public Consultation Meeting, October 5, 2000
- Proposed Rule 1133 Working Group Meeting, August 22, 2001
- Public Workshop, September 5, 2001
- Proposed Rule 1133 Working Group Meeting, September 28, 2001
- Proposed Rule 1133 Working Group Meeting, January 15, 2002
- Proposed Rule 1133 Working Group Meeting, February 19, 2002

Focused presentation on Proposed Rule 1133 where given to the following entities:

- Orange County League of Cities
- San Gabriel Valley COG Solid Waste Committee
- California League of Cities – Environmental Quality Committee
  - ✓ Membership includes all cities in the State of California
- San Bernardino County Solid Waste Advisory Task Force
- California Contract Cities Association, Legislative Committee
- SCAG Solid Waste Task Force
- Los Angeles County Solid Waste Management Committee Integrated Waste Management Task Force
- AQMD's Ethnic Community Advisory Group

- AQMD's Local Governments and Small Business Advisory roup
- AQMD's Stationary Source Committee

AQMD staff conducted site visits to the following facilities:

- Aguinaga Fertilizer
- B. P. Hauling
- California Biomass
- Community Recycling & Resource Recovery, Inc.
- Empire Utilities Agency Composting Facility
- Inland Empire Composting
- Leisure World
- Los Angeles City – Archrorage
- Los Angeles City – Griffith Park
- Los Angles City – VanNorman
- R & S Dumping Service
- Rancho Las Virgenes Composting Facility
- River Ranch Recycling Organics
- Salado Creek – Coachella Landfill Composting
- Sierra Soil Company
- Synagro
- Tierra Verde Industries
- Whittier Fertilizer

In addition to the site visits, AQMD staff has met numerous times with industry and sanitation district(s) representatives, individually and in groups, to address specific rule proposal issues and discuss research plans.

Following is a list of all the cities and governmental agencies that to date have been active in the rulemaking process for Proposed Rule 1133:

- City of Burbank
- City of Cerritos
- City of Chino
- City of Chino Hills
- City of Colton
- City of El Segundo

- City of Glendale
- City of La Canada-Flintridge
- City of Los Angeles
- City of Newport Beach
- City of Palm Springs
- City of Pasadena
- City of Pico Rivera
- City of Redlands
- City of San Diego
- City of San Marino
- City of Santa Fe Springs
- City of Upland
- City of West Covina
- City of Whittier
- Eastern Municipal Water District
- Inland Empire Utilities Agency
- Las Virgenes Municipal Water District
- Los Angeles City Dept. of Water & Power
- Los Angeles County – Dept. of Parks & Recreation
- Los Angeles County – Public Works Dept.
- Los Angeles County Arboretum & Botanical Gardens
- Los Angeles County DPW
- Los Angeles County LEA
- Los Angeles County Sanitation District
- Municipal Water District
- Orange County Council of Governments
- Orange County Integrated Waste Management
- Orange County Sanitation District
- Riverside County Environmental Health
- Riverside County Waste Management Dept.

- San Bernadino County LEA
- San Bernadino County Solid Waste Management District
- Southern California Alliance of Publicly Owned Treatment Works
- Southern California Association of Governments
- Ventura County Air Pollution Control District
- Ventura County LEA
- Western Riverside Council of Governments

REFERENCES

REFERENCES

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Appendix S

(Adopted January 10, 2003)

RULE 1133. COMPOSTING AND RELATED OPERATIONS – GENERAL ADMINISTRATIVE REQUIREMENTS

(a) Purpose

This rule sets forth administrative requirements for existing and new chipping and grinding activities and composting operations. The purpose of this rule is to create an emissions-related informational database on composting and related operations through a registration process.

(b) Applicability

This rule applies to owners or operators of chipping and grinding activities and composting operations unless otherwise exempt under subdivision (g).

(c) Definitions

For the purposes of this rule, the following definitions shall apply:

(1) AGRICULTURAL COMPOSTING is composting conducted in agricultural settings where the feedstock consists of wastes generated on-site by the production and processing of farm or agricultural products.

(2) BACKYARD COMPOSTING is composting conducted by a household including, but not limited to, single family residences, duplexes, or apartment buildings.

(3) CHIPPING AND GRINDING is any activity that mechanically reduces the size of greenwaste, woodwaste, and/or foodwaste.

(4) COMMUNITY COMPOSTING is composting conducted by a residential neighborhood association using feedstock generated within the residential neighborhood to produce compost for the neighborhood's use.

(5) COMPOST is a product resulting from the controlled biological decomposition of organic materials.

(6) COMPOSTING is a process in which solid organic waste materials are decomposed in the presence of oxygen under controlled conditions through the action of bacteria and other microorganisms.

(7) COMPOSTING OPERATIONS are facilities involved in composting organic materials including, but not limited to, greenwaste, biosolids, manure and foodwaste.

(8) FOODWASTE is any food scraps collected from the food service industry, grocery stores, or residential food scrap collection. Foodwaste also includes foodwaste that is chipped and ground. Foodwaste mixed with greenwaste is considered foodwaste.

(9) GREENWASTE is any organic waste material generated from gardening, agriculture, or landscaping activities including, but not limited to, grass clippings, leaves, tree and shrub trimmings, and plant remains.

(10) NURSERY COMPOSTING is composting conducted at a nursery to produce compost for on-site use.

(11) PORTABLE CHIPPING AND GRINDING is chipping and grinding utilizing equipment with a manufacturer's rating of 170 brake horsepower or less.

(12) RECREATIONAL FACILITIES COMPOSTING is composting conducted at parks, arboretums and other recreational facilities using feedstock generated on-site to produce compost for on-site use.

(13) WOODWASTE is lumber, and the woody material portion of mixed demolition wastes and mixed construction wastes.

(d) Requirements

Operators of chipping and grinding activities and composting operations shall meet the following requirements:

(1) No later than July 1, 2003, operators of existing chipping and grinding activities and composting operations shall register with the District by submitting the complete and applicable information required in accordance with subdivision (e) of this rule.

(2) Prior to start of operation, operators of new chipping and grinding activities and composting operations, shall register with the District by submitting the complete and applicable information required in accordance with subdivision (e) of this rule.

(3) No later than July 1, 2004, and every year thereafter, operators of chipping and grinding activities and composting operations registered with the District shall update their registration information by providing any changes to the information submitted in accordance with subdivision (e) of this rule.

(e) Registration Process

The registration and annual update required pursuant to subdivision (d) of this rule shall, at a minimum, include the following information:

(1) Facility name;

(2) Facility location address and mailing address;

(3) Facility legal owner(s), contact person, title, telephone number, and mailing address;

(4) Facility operator (s), contact person, title, telephone number, and mailing address;

(5) Number of employees at the facility;

(6) Applicable California Integrated Waste Management Board's permit number, identification number, and facility classification;

(7) Type and amount of materials received and type and amount of products produced for the preceding year;

(8) Facility design capacity (throughput) in tons per year;

(9) Facility actual throughput in tons per month for the preceding calendar year. For new facilities, projected throughput must be provided;

(10) Feedstock description;

(11) Facility process description including, process diagram and a description of chipping and grinding operations and composting methods used (if applicable);

(12) Published tipping fee schedule for the preceding calendar year by feedstock, and;

(13) Number of air quality- and odor-related enforcement actions issued in writing against the facility by any Local Enforcement Agency and the California Integrated Waste Management Board for the preceding calendar year.

(f) Fees

The operator of any activity or facility subject to registration and annual update requirements pursuant to this rule shall be subject to a one-time fee equivalent to the plan submittal fee in accordance with Rule 306 at the time of registration.

(g) Exemptions

The following types of facilities and operations are exempt from the requirements of this rule:

(1) Portable chipping and grinding;
(2) Community composting;
(3) Agricultural composting;
(4) Nursery composting;
(5) Recreational facilities composting;
(6) Backyard Composting; and
(7) Woodwaste chipping and grinding facilities.

Appendix T

(Adopted January 10, 2003)

RULE 1133.1 CHIPPING AND GRINDING ACTIVITIES

(a) Purpose

The purpose of this rule is to prevent inadvertent decomposition occurring during chipping and grinding activities.

(b) Applicability

This rule applies to operators of chipping and grinding activities, unless otherwise exempted under subdivision (f) of this rule. The requirements of Rule 403 – Fugitive Dust, also apply to these activities.

(c) Definitions

For the purposes of this rule, the following definitions shall apply:

(1) AGRICULTURAL CHIPPING AND GRINDING is any chipping and grinding activity conducted at an agricultural site where organic waste material is generated on-site by the production and/or processing of farm products, and the chipped and ground organic waste material is used on-site.

(2) CALENDAR DAYS refer to any days of the year, excluding official federal and state holidays.

(3) CHIPPING AND GRINDING is any activity that mechanically reduces the size of greenwaste, woodwaste, and/or foodwaste.

(4) COMPOSTING is a process in which solid organic waste materials are decomposed in the presence of oxygen under controlled conditions through the action of bacteria and other microorganisms.

(5) CURBSIDE GREENWASTE is greenwaste that is collected from receptacles designated for residential household greenwaste. Curbside greenwaste also includes screened curbside greenwaste containing only grass clippings, leaves, and/or twigs that is not considered non-curbside greenwaste as defined in paragraph (c)(11).

(6) FOODWASTE is any food scraps collected from the food service industry, grocery stores, or residential food scrap collection. Foodwaste also includes foodwaste that is chipped and ground. Foodwaste mixed with greenwaste is considered foodwaste.

(7) GREENWASTE is any organic waste material generated from gardening, agriculture, or landscaping activities including, but not limited to, grass clippings, leaves, tree and shrub trimmings, and plant remains.

(8) INADVERTENT DECOMPOSITION is decomposition of greenwaste and/or foodwaste associated with stockpiling greenwaste and/or foodwaste for an extended period of time, and is not considered part of normal chipping and grinding operations.

(9) LANDCLEARING is an activity where trees and plants grown at the site are cut, then chipped or ground and removed from the site to clear the site.

(10) MIXED GREENWASTE is curbside greenwaste that is mixed with non-curbside greenwaste.

(11) NON-CURBSIDE GREENWASTE is any greenwaste that is not collected from receptacles designated for residential household greenwaste. Curbside greenwaste or mixed greenwaste that is screened and contains only large woody materials (larger than 3 inches in any dimension) such as tree trimmings and branches, is also considered to be non-curbside greenwaste.

(12) PALM CHIPPING AND GRINDING is any activity that mechanically reduces the size of palm trees waste.

(13) PORTABLE CHIPPING AND GRINDING is chipping and grinding utilizing equipment with a manufacturer's rating of 170 brake horsepower or less.

(14) RAINY DAY is any day with at least 0.05 inches of rain reported by the National Weather Service or a cooperative weather reporting station for the site closest to where the chipping and grinding activity occurs.

(15) WET WEATHER CONDITIONS are weather conditions following a rainy day not to exceed 10 days.

(16) WOODWASTE is lumber, and the woody material portion of mixed demolition wastes and mixed construction wastes.

(d) Requirements

Effective July 1, 2003, the operator of a chipping and grinding activity shall:

(1) Remove foodwaste from the site or use foodwaste for on-site composting within 2 calendar days of receipt.

(2) Chip or grind, or use on-site, or remove curbside greenwaste from the site within 3 calendar days of receipt.

(3) Chip or grind or remove non-curbside greenwaste from the site within 14 calendar days of receipt.

(4) Chip or grind, or use on-site, or remove mixed greenwaste from the site within 7 calendar days of receipt.

(5) Remove chipped or ground curbside greenwaste from the site or use chipped or ground curbside greenwaste on-site within 3 calendar days of being chipped or ground.

(6) Maintain the following records on-site for two years:

(A) A copy of the facility's AQMD registration and annual updates submitted in compliance with Rule 1133; and,

(B) Records of date, type, and amount of greenwaste and/or foodwaste received; and,

(C) Records of date, type, amount of greenwaste and/or foodwaste removed from the site, and location where they are transferred to.

(D) Records of dates of rainy days and wet weather conditions and description of specific conditions that limited normal operations.

(E) Records of moisture content measurements.

(F) Records of dates and amount of curbside greenwaste chipped and ground.

(7) The time requirements specified in paragraphs (d)(1), (d)(2), (d)(3), (d)(4), and (d)(5) may be extended by the number of rainy days and wet weather conditions that impede normal chipping and grinding operations provided that records are maintained in accordance with subparagraph (d)(6)(D).

(e) Moisture Content Measurement

Moisture content shall be determined by collecting at least 10 samples of chipped and ground greenwaste from various locations of the pile at a depth of at least 12 inches below pile surface. The samples shall then be mixed thoroughly and analyzed for moisture content by ASTM method D4442, ASTM method D4444 or ASTM method E871-82.

(f) Exemptions

(1) Chipping and grinding activities of greenwaste derived from the site and used on-site shall be exempt from the requirements of paragraphs (d)(2), (d)(3), (d)(4), (d)(5), and (d)(6).

(2) Portable chipping and grinding, agricultural chipping and grinding, landclearing chipping and grinding, woodwaste chipping and grinding, and palm chipping and grinding activities shall be exempt from the requirements of paragraphs (d)(2), (d)(3), (d)(4), (d)(5), and (d)(6).

(3) Chipped and ground curbside greenwaste shall be exempt from the requirements of paragraph (d)(5) provided that the moisture content is less than 30%, measured in accordance with subdivision (e) and the moisture content measurements are maintained on-site in accordance with subparagraph (d)(6)(E).

Appendix U

(Adopted January 10, 2003)

RULE 1133.2 EMISSION REDUCTIONS FROM CO-COMPOSTING OPERATIONS

(a) Purpose

The purpose of this rule is to reduce volatile organic compounds (VOC) and ammonia (NH_3) emissions from co-composting operations.

(b) Applicability

This rule applies to all new and existing co-composting operations.

(c) Definitions

For the purposes of this rule, the following definitions shall apply:

(1) AERATION SYSTEM is a system where air is forced through organic materials being composted, through the use of fans or blowers.

(2) AGRICULTURAL COMPOSTING is composting conducted in agricultural settings where the feedstock consists of wastes generated on-site by the production and processing of farm or agricultural products.

(3) ACTIVE CO-COMPOSTING is the phase of the composting process that begins when organic materials are mixed together for composting and lasts a minimum of 22 days.

(4) BASELINE EMISSIONS FACTORS are the non-controlled emission factors for co-composting operations for VOC and ammonia.

(5) BIOFILTRATION is a pollution control technology that removes and oxidizes VOC and ammonia through the action of bacteria and other microorganisms.

(6) CO-COMPOSTING is composting where biosolids and/or manure are mixed with bulking agents to produce compost. Co-composting includes both the active and curing phases of the composting process.

(7) COMPOST is a product resulting from the controlled biological decomposition of organic materials.

(8) COMPOSTING is a process in which solid organic waste materials are decomposed in the presence of oxygen under controlled conditions through the action of bacteria and other microorganisms.

(9) CURING is the phase of the co-composting process that begins immediately after the end of the active phase of composting and lasts 40 days or until the compost has a Solvita Maturity Index of 7 or the product respiration rate is below 10 milligrams of oxygen consumed per gram of volatile solids per day as measured by direct respirometry.

(10) ENCLOSURE is a completely walled, floored, and roofed structure or vessel.

(11) EXISTING CO-COMPOSTING OPERATIONS are all co-composting operations that have begun operations on or before the date of adoption of this rule.

(12) GREENWASTE is any organic waste material generated from gardening, agriculture, or landscaping activities including, but not limited to, grass clippings, leaves, tree and shrub trimmings, and plant remains.

(13) GREENWASTE COMPOSTING is composting of greenwaste by itself or greenwaste in combination with up to 20 percent manure, by volume.

(14) NEW CO-COMPOSTING OPERATIONS are co-composting operations that have not started operations as of the date of adoption of this rule.

(15) OPERATOR is the operator of a co-composting operation.

(16) SOLVITA MATURITY INDEX is an index that defines the stage where compost exhibits resistance to further decomposition, as tested by the Solvita Maturity Test®.

(17) START-UP is the first day of active co-composting operations at the facility.

(18) THROUGHPUT is the mass of biosolids, manure, and greenwaste in tons per year as received by the facility and processed through composting excluding recycled materials.

(19) WOODWASTE is lumber, and the woody material portion of mixed demolition wastes and mixed construction wastes.

(20) WOODWASTE COMPOSTING is composting of woodwaste by itself.

(d) Requirements

(1) Operators of new co-composting operations shall:

(A) Conduct all active co-composting within the confines of an enclosure which meets the following conditions:

(i) The inward face velocity of air through each opening in which air can enter the enclosure shall be a minimum of 100

feet per minute, unless the opening is equipped with a closure device that seals the opening in the event that the airflow direction changes.

(ii) The area of all openings in the enclosure through which air can enter the enclosure shall not exceed 2% of the surface area of the enclosure's four walls, floor, and ceiling.

(iii) The enclosure may be opened for brief time periods, not to exceed a total of 30 minutes per day for purposes of access or maintenance. These time periods do not need to be included in the face velocity determination or as an opening for the two percent criteria.

(iv) No measurable increase over background levels of ammonia or hydrocarbons outside the enclosure shall occur at any enclosure opening including any opening that occurs briefly for access or maintenance. A portable ammonia or hydrocarbon analyzer shall be used for these measurements. The portable ammonia analyzer shall be operated per manufacturer's instructions and calibrated with certified zero and 10 parts per million ammonia standards. The portable hydrocarbon analyzer shall be a flame ionization detector operated per manufacturer's instructions and calibrated with certified zero and 10 parts per million methane standards.

(B) Conduct all curing using an aeration system that operates under negative pressure for no less than 90 percent of its blower(s) operating cycle; and,

(C) Vent the exhaust from the enclosure and the aeration system to an emissions control system designed and operated with a control efficiency equal to or greater than 80 percent, by weight, for VOC emissions and 80 percent, by weight, for ammonia emissions.

(2) In lieu of complying with the requirements of paragraph (d)(1), operators of new co-composting operations may submit a compliance plan, for the approval of the Executive Officer, that demonstrates an overall emission reduction of 80 percent, by weight, for VOC emissions and 80 percent, by weight, for ammonia emissions from the baseline emission factors.

(3) Operators of existing co-composting operations shall submit a compliance plan, for the approval of the Executive Officer, that demonstrates an overall emission reduction of 70 percent, by weight, for VOC emissions and 70 percent, by weight, for ammonia emissions from the baseline emission factors.

(4) The baseline emission factors to be used under paragraphs (d)(2) and (d)(3) shall be 1.78 pounds of VOC per ton of throughput and 2.93 pounds of ammonia per ton of throughput. The Executive Officer may approve the use of operation-specific baseline emission factors in lieu of the baseline emission factors, if the operator requests the use of such baseline emission factors as part of the compliance plan submittal and demonstrates that the operation specific baseline emissions factors are representative of noncontrolled operations.

(5) The operator of a co-composting operation shall submit the compliance plan required pursuant to paragraphs (d)(2) or (d)(3) at least one year prior to the start of operations for new co-composting operations and at least one year prior to the effective date of compliance for existing co-composting operations.

(6) The control efficiency required under subparagraphs (d)(1)(C) and (j)(2)(A) for new co-composting operations shall be demonstrated by a source test conducted as part of the permit application process and every two years thereafter.

(7) The control efficiency required under subparagraph (j)(2)(A) for existing co-composting operations shall be demonstrated by a source test conducted on or before January 1, 2007, and every two years thereafter.

(8) Within 180 days after the effective date of compliance and every two years thereafter, the operator of a co-composting operation shall perform all necessary tests and provide a certification of compliance report that includes all source test data and all other applicable information to demonstrate compliance with the emission reduction requirement of paragraphs (d)(2) or (d)(3).

(e) Compliance Plan

(1) Compliance plans required under paragraphs (d)(2) and (d)(3) shall contain all the following elements:

(A) The name(s), address(es), and telephone number(s) of the person(s) responsible for the preparation, submittal and implementation of the compliance plan;

(B) The name, address, and telephone number(s) of the facility for which the compliance plan is being prepared;

(C) A description and process diagram of the co-composting operation;

(D) A complete description of the control method(s) that will be used at the co-composting operation to meet the requirements under paragraphs (d)(2) or (d)(3). The description shall be in sufficient detail to demonstrate compliance with paragraphs (d)(2) or (d)(3). The acceptable control methods include, but are not limited to:

(i) enclosure design or technology;

(ii) aeration system design and operation;

(iii) biofiltration;

(iv) scrubber;

(v) feedstock component optimization;

(vi) biosolids thermal pre-treatment;

(vii) enclosed material mixing and thermal stripping;

(viii) staged active pile construction and aeration;

(ix) feedstock ratio optimization;

(x) process controls;

(xi) best management practices; or,

(xii) any combination of the methods listed above; or,

(xiii) any other method approved by the Executive Officer, California Air Resources Board, and the United States Environmental Protection Agency.

(E) All data, calculations methodology, calculations, records, manufacturer specifications and all other information necessary to determine that the composting methods and control methods proposed in subparagraph (e)(1)(D) will achieve the required emission reductions.

(F) A methodology and calculations establishing the daily and annual VOC and ammonia emissions or projected emissions;

(G) If applicable, a source test protocol developed in accordance with the requirements of subdivision (g), to establish operation-specific baseline emission factors.

(H) A source testing protocol developed in accordance with the requirements of subdivision (g) to demonstrate compliance with the overall emission reductions specified in paragraph (d)(2) or (d)(3).

(I) An identification of all equipment needing permits to construct and operate.

(2) In evaluating the plan, the Executive Officer may require tests and sampling as necessary to determine the adequacy of the plan and the likelihood of compliance with the emission reduction requirements of paragraphs (d)(2) or (d)(3).

(3) The Executive Officer may approve operation-specific baseline emissions factors provided the baseline emissions factors are substantiated with source test data obtained in accordance with subdivision (g) of this rule and the composting method(s) and mixture is representative of normal operations.

(4) The Executive Officer shall provide interim approval of the compliance plan provided the operator submits all of the information required under paragraph (e)(1) and the Executive Officer verifies that, by design, the plan will meet the requirements of paragraph (d)(2) or (d)(3), as applicable.

(5) Following the interim approval of the plan, the Executive Officer shall approve the compliance plan provided the operator submits, no later than 180 days after the effective date of compliance, a certification of compliance report that includes all source test data, and the Executive Officer verifies that the emissions from the co-composting operations comply with the requirements of paragraphs (d)(2) or (d)(3), as applicable.

(6) The Executive Officer may impose conditions necessary to ensure that the co-composting operation complies with the compliance plan and all applicable AQMD rules.

(7) The Executive Officer may require the operator to maintain records consistent with the compliance plan necessary to demonstrate compliance with the plan.

(8) Compliance with the provisions of the approved plan does not exempt an operator from complying with the requirements of the California Health and Safety Code, or any other AQMD rule.

(f) Compliance Schedule

(1) The effective dates of compliance for paragraphs (d)(1), (d)(2), and (d)(3) of this rule shall be as follows:

(A) Upon start-up for new co-composting operations.

(B) January 1, 2007 for existing co-composting operations with a facility design capacity of 100,000 tons of throughput per year or more.

(C) January 1, 2008 for existing co-composting operations with a facility design capacity greater than or equal to 10,000 but less than 100,000 tons of throughput per year.

(D) January 1, 2009 for existing co-composting operations with a facility design capacity less than 10,000 tons of throughput per year.

(2) The Executive Officer shall extend for up to three years the compliance date for an existing co-composting operation which, at the time of rule adoption and at least one year prior to the effective compliance date, has less than 3 years remaining under a non-renewable conditional use permit beyond its effective compliance date. By June 1, 2003, the operator of such an operation must submit to the Executive Officer a copy of the conditional use permit and a letter from the responsible agency verifying that the permit is non-renewable and the date when the permit is expired.

(g) Testing Protocol

(1) The operator of a co-composting operation shall conduct all required source and laboratory tests in accordance with an Executive Officer approved test protocol developed in accordance to the guidelines provided in Attachment A of this rule.

(2) The operator of the co-composting operation shall use a District approved laboratory in accordance with the Attachment A of this rule.

(3) The following methods shall be used to determine compliance with this rule:

(A) SCAQMD Method 207.1 – Determination of Ammonia Emissions from Stationary Sources.

(B) SCAQMD Method 25.3 – Determination of Low Concentration Non-Methane Non-Ethane Organic Compound Emissions from Clean Fueled Combustion Sources.

(C) SCAQMD Method 1.1 Sample and Velocity Traverses for Stationary Sources.

(D) SCAQMD Method 1.2 Sample and Velocity Traverses for Stationary Sources with Small Stacks or Ducts.

(E) SCAQMD Method 2.1 Determination of Stack Gas Velocity and Volumetric Flow Rate (S-Type Pitot Tube).

(F) SCAQMD Method 2.2 Direct Measurement of Gas Volume through Pipes and Small Ducts.

(G) SCAQMD Method 2.3 Determination of Gas Velocity and Volumetric Flow Rate From Small Stacks or Ducts.

(H) SCAQMD Method 4.1 Determination of Moisture Content in Stack Gases.

(h) Recordkeeping

The operator shall, at a minimum, maintain operation's records for a period of at least two years, or five years for facilities subject to Title V Permit Requirements, and make them available to the Executive Officer upon request.

(i) Plan Fees

Operators subject to a compliance plan submittal pursuant to paragraphs (d)(2) and (d)(3) shall be assessed, as applicable, filing and evaluation fees pursuant to Rule 306.

(j) Exemptions

(1) The provisions of subdivisions (d) through (i) of this rule shall not apply to agricultural composting operations, greenwaste composting operations, woodwaste composting operations, co-composting operations with a design capacity of less than 1,000 tons of throughput per year, and existing co-composting operations with a design capacity of less than 35,000 tons of throughput per year containing no more than 20 percent biosolids, by volume.

(2) Except for paragraphs (d)(6) and (d)(7), the provisions of subdivisions (d) through (i) shall not apply to new and existing co-composting operations that:

(A) Conduct co-composting operations using an aeration system that is vented to an emission control device with a control efficiency of

80 percent, by weight, for VOC emissions and 80 percent, by weight, for ammonia emissions; and,

(B) Are owned and operated by a municipality which composts waste generated within the jurisdiction of the municipality; and,

(C) Process less than 5,000 tons of biosolids or manure per year, combined.

ATTACHMENT A

GUIDELINES FOR THE DEVELOPMENT OF SOURCE TEST PROTOCOLS FOR VOC AND AMMONIA EMISSIONS FROM CO-COMPOSTING OPERATIONS

Source test protocols are to consist of testing plans to measure VOC and ammonia emissions due to the composting process. When used for determining the control device efficiency requirement specified for new facilities, the measurements shall consist of lb/hr measurements at the inlet and exhaust of the control device as well as a verification of the enclosure and are subject to the applicable requirements that follow. When used for determining the overall emission reduction requirements as compared to the baseline emissions factors, emissions are to be reported as % reductions for the active co-composting and curing phases in terms of pounds of emissions per ton of throughput (total raw material as received) and are subject to the applicable requirements that follow. The following are general requirements for all testing as well as specific requirements for the rule sections for each facility-specific protocol which must be prepared by the source test contractor and approved by the SCAQMD prior to testing.

1. *Alternative Test Methods*

   The reference test methods for ammonia, VOC, and flow rate cited in this guideline shall be used to determine compliance with this rule. Alternative test methods may be used if they are determined to be equivalent and approved in writing by the Executive Officer, the California Air Resources Board, and the U.S. Environmental Protection Agency. For the source test protocols, as defined as the manner in which the reference test methods are employed to obtain a measurement of the emissions, alternatives to the procedures cited in this guidelines may be used if they are determined to be equivalent and approved in writing by the Executive Officer.

2. *LAP Requirements*

   The sampling, analysis, and reporting shall be conducted by a laboratory/source test firm that has been approved under the SCAQMD Laboratory Approval Program (LAP) for the cited SCAQMD reference test methods, where LAP approval is available. For SCAQMD reference test methods for which no LAP program is available, the LAP approval requirement shall become effective one year after the date that the LAP program becomes available for that SCAQMD reference test method.

3. *Operating Conditions*

The testing must be conducted under representative operating conditions with respect to seasonal conditions, compost composition, process throughput, processing of the materials, and pile geometries. The following operating parameters shall be recorded during testing and reported with the test results:

a) A thorough description of the composting process and process diagram of each processing area and including residence times in each of the composting process areas.
b) Process throughput as determined by facility's billing scales or other calibrated measuring device that represents the tons of the material as received that is present at the facility during the time of the testing. When using the District Baseline Emission Factors, the process throughput is to include all of the raw organic materials that are composted excluding material that is recycled from previous similar processing. Several throughputs may be necessary if applicable to the different processing areas or pile ages.
c) Compost composition (percent and type of materials i.e. biosolids, manure, greenwaste, etc…).
d) Age of all piles that were tested and all piles present at the facility during testing.
e) Detailed Dimensions of all piles so that a surface area for each pile type can be calculated.

4. *Ammonia Sampling*

SCAQMD Method 207.1 shall be used to obtain the ammonia samples from each source of emissions to be tested. When sampling from a flux chamber, a sample line of minimal length should be connected to a midget sampling train consisting of; two midget impingers each filled with 15 ml of 0.1N Sulfuric Acid, an empty bubbler, and a bubbler filled with tared silica gel. The samples shall be analyzed for ammonium content as ammonia by ion chromatography or ion selective electrode.

5. *VOC Sampling*

Duplicate integrated gas samples shall be taken from each source of emissions to be tested using SCAQMD Method 25.3. The Method 25.3 apparatus should be connected to sample directly inside the flux chamber or duct as applicable. Compost emissions are considered as water soluble sources where the 50 ppm applicability limit of Method 25.3 does not apply.

6. *Specific Requirements for Testing Co-Composting Operations Control Equipment Performance*

For surface types of emissions, such as with open faced biofilter exhausts, the exhaust emission rate shall be determined as in the following Section (8).

For a control device inlet or exhaust that is vented through a testable duct, the gas velocity within the duct shall be measured according to SCAQMD Methods 1.1, 2.1, and 3.1. The flow rate shall also be corrected to dry standard conditions using the moisture content as determined by SCAQMD Method 4.1. This flow rate may then be used to determine mass emission rates.

The overall destruction efficiency is calculated as follows:

$$ODE = 100 \times (1 - (E / I)) \qquad \text{(Equation 1)}$$

Where:

ODE =	Overall Destruction Efficiency (%)
E =	Total Exhaust Emission Rate (lb/hr)
I =	Total Inlet Emission Rate to Control Device (lb/hr)

7. *Specific Requirements for Existing Co-Composting Operations and New Co-Composting Operations (Overall Emissions Reduction)*

A proposed measurement from the active and curing co-composting process, including but not limited to surface emissions of all piles where the materials are composted, and outlets (vents or surfaces) of control devices must be included in the protocol. If the emissions are vented to atmosphere from a vent stack such as from an otherwise uncontrolled aerated static pile or other vent to atmosphere, then the stack concentration, determined using methods specified in Sections (4) and (5) and flow rate measurements as specified in the previous Section (6) are required. From all surface types of emissions such as from compost piles and biofilter surfaces, the procedure for measuring surface emissions as in Section (8) is required. A measurement for fugitive emissions from aerated static pile surfaces must also be included.

Each type of pile must be tested. If the facility includes several identical piles, then only the largest pile need be tested. If the facility has more than three different age piles that are otherwise identical in processing and composition, then at a minimum three ages can be tested including newer, older, and middle aged piles. In any case, the surface area of all piles at the facility must be included in the determination of pile dimensions as recorded in Section (3).

If the facility elects to use an alternative to the District's baseline emissions factors, then a separate test must be conducted to establish this baseline on the uncontrolled composting operation (e.g., windrow method) with the same compost mix. Following the source test to determine an alternative baseline, facilities would have the option to use the District's baseline emissions factors or the alternative baseline emissions factors.

Reduction of emissions shall be calculated as follows:

$$\% \text{ Reduction} = 100 \times (1 - TE/B) \qquad \text{(Equation 2)}$$

Where:

TE = Total Active and Curing Phase Emissions (lb/ton throughput)
B = District Baseline Emissions or Alternative Baseline Emissions if Tested (lb/ton throughput)

8. *Procedure for Measuring Surface Emissions*

The procedure for measuring surface emissions such as the compost pile and biofilter surfaces that cannot be tested by conventional methods through a stack or duct, is a modified form of the procedures found in the US Environmental Protection Agency's (EPA) *Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber User's Guide* (EPA Guide). The modification to the procedures in the EPA Guide are specified in the following requirements.

The flux chamber encompasses a fixed surface area of 1.4 ft^2 and contains a sweep air system to obtain a homogeneous air sample by employing a mixing fan and sweep gas (10% He in air at 5 liters/min recommended). The sweep gas must contain a non reactive and non-present tracer such as the aforementioned 10% helium so that a correction for the contribution of the surface flow rate can be calculated.

A minimum of ten (10) sample locations or a sufficient number at each pile/surface tested must be obtained in order to achieve a representative sample of the surface emissions. These locations can be composited for each pile/surface to reduce testing costs. For example, for one hour sampling, ten (10) random positions on the pile should be tested for 6 minutes each. Alternatively, a lesser number of sample locations may be sampled provided that an evaluation of spatial variation demonstrates that the number of sample locations are sufficient.

The emissions must be reported in units of lb/hr-ft^2, lb/hr and lb/ton of throughput. The following calculations shall apply to the test results:

$$\text{Surface Flow Correction Factor} = C_t / C_s \qquad \text{(Equation 3)}$$

Where:

C_t = Concentration of Tracer in Sweep Gas
C_s = Concentration of Sweep Gas in Flux Chamber Sample

Corrected Flux Chamber Results (lb/hr-ft^2) = UFC x SFCF (Equation 4)

Where:

UFC = Uncorrected Flux Chamber Results (lb/hr-ft^2)
SFCF = Surface Flow Correction Factor

lb/hr = lb/hr-ft^2 x Total Compost Surface Area in Category (Equation 5)

lb/ton throughput = lb/hr x (24 hr/day) /PT (Equation 6)

Where:

PT = Process Throughput (total ton/day as received)

Total Emissions (lb/ton throughput) = $\sum$ P (Equation 7)

Where:

P = Active and curing sources of the Facility Compost Emissions (lb/ton throughput)

For a facility where not every age of pile was tested, the surface areas from each pile in the facility must be included and sorted into appropriate age and emissions categories from those that were measured.

Appendix V

APPENDIX A – LIST OF OPERATIONAL ASP (AERATED STATIC PILES) COMPOSTING FACILITIES IN THE U.S.

LIST OF OPERATING ASP FACILITIES IN THE U.S.

Attachment A contains the list of ASP composting achieved in practice, which based mainly on the 1998 Biocycle survey.

Facility	Location	Throughput (in dry tons/day, unless noted)
	Alaska	
Golden Heart Utilities	Fairbanks	30 wet t/d
	California	
	Arcata	37 dry t/yr
Los Alisos Water Reclamation Plant	Lake Forest	0.5
Griffith Park	Los Angeles	25 (incl. zoo manure & greenwaste)*
	Colorado	
Denver Metro	Denver	3
Evergreen Metro District	Green Acres	319 dry t/yr
	Gunnison	200 - 250 dry t/yr
	Longmont	1.7
	Pitkin County	10
	Silverthorne/Dillon	0.75
Twin Landfill Corp.	Summit County	319 dry t/yr
	Tri-Lakes	1.1 - 1.4
	Upper Eagle Valley: Vail area	1 (2.5 days/wk)
	Woodland Park	1 -1.5
	Delaware	
	Seaford, Delaware	267 dry t/yr
	Florida	
Miami-Dade Water Sewer: South Plant	Miami-Dade	510 dry t/wk., Oct. - May
	Reedy Creek	10
	Idaho	
	Coeur d"Alene	1.5
EKO	Lewiston	4
	Illinois	
	DuPage County, Woodridge-Green Valley	2 to 3
	Indiana	
	Kokomo, Indiana	16
	Iowa	
	Davenport	28
	Louisiana	
Global Envir. Solutions	Columbia	300
United Soils, Inc.	Vidalia	n/a
	Maine	
	Bar Harbor	0.3
	Kennepunkport	0.4
Lincoln Sanitary District	Lincoln	0.4
Little River Turf Farms	Lisbon	1.4
	Old Orchard Beach	1.5
	Old Town & Orono	1.4
	Rumford & Mexico	0.8
	Scarborough	1.33

Facility	Location	Throughput (in dry tons/day, unless noted)
	Wilton	0.15
	Maryland	
	Aberdeen	1.2
	Elkton	2
	Havre de Grace	1.1
	Montgomery County	60
	Perryville	2.5
	Queen Anne's County	60 cy/mo
	Massachusetts	
	Barre	5 cy/wk
	Billericas	3
	Bridgewater	20 - 25 wet t/wk
	Hopedale	1
	Leicester	0.75 dry t/wk
	Mansfield	30 cy/wk
	Nantucket	0.3
	Pepperell	0.3
Otis Air National Guard	Sandwich	2 dry t/mo
	Somerset	2
	Southbridge	845 dry t/yr
	Williamstown/Hoosac	7 to 8
	Michigan	
	Mackinac Island, Michigan	1.9 (seasonal)
	Missouri	
	Nixa	100 dry t/yr
	Montana	
Glacier Gold Compost	Kalispell	6.2
EKO	Missoula	4
	New Hampshire	
	Bristol	280 cy/yr
	Claremont	3 to 5
	Dover	2
	Lebanon	1.3
	Milford	0.89
	New Jersey	
	Buena Borough	1
	Sussex County	4
	New York	
	Attica	0.5
	Cedarhurst	0.5
	Chenango	0.5
	Churchville	0.1
	Erwin	0.3
	Gowanda	0.3
LBD Enterprises	Kirkville	1
	Lawrence	0.06
	Manchester/Shortville	1
	Medina	0.5
	Mt. Morris	96 dry t/yr

Facility	Location	Throughput (in dry tons/day, unless noted)
	Oneonta	2
	Red Hook	n/a
	Rouses Point	0.5
Tri-Municipal Sewage		0.5
	Wayland	350 dry t/yr
	Weedsport	1
	North Carolina	
	Beech Mountain	0.2
	Burnsville	0.16
	Charlotte	10
Catawba River Plant	Morganton	3.25
	Rockingham	1.62
McGill Regional Composting Facility	Rose Hill	10
	Valdese	2
	Ohio	
	Columbus	27.5
Mentor WWTF	Lake County	8
	Oregon	
Winston Green WWTF	Douglas County	<0.1
	Eugene	109 dry t/yr
	Klamath Falls	0.7
	Pennsylvania	
Valley Joint Authority	Athens	1.5
	Butler	4 to 5
J.P. Mascaro	Lancaster County	40
	Philadelphia	42
	Scranton	18
	Springettsbury Twp.	14
	South Carolina	
Horse Creek WWTP	Aiken County	10 (with poultry manure)
	Florence	12
	Kiawah Island	14 dry t/yr
	Myrtle Beach	3
	Tennessee	
	Elizabethton	1
	Utah	
	Park City: Snydersville Basin	267 dry t/yr
	Tremonton	300 dry t/yr
	Vermont	
	Springfield	1
	Virginia	
Moores Creek WWTP	Charlottesville	6
	Franklin	2 to 3
	Harrisonburg/Rockingham	8
	New Market	0.2
	Washington	
	LaConner	n/a
	Lynden	1.5
	Maple Valley	Cedar Grove

Facility	Location	Throughput (in dry tons/day, unless noted)
	Pierce County	4.6 (green waste)
	Port Towsend	1
Southwest Suburban Sewer District	Miller Creek, Seattle	1.6
	Snohomish	Lost Hill Farm
South Sound Soils	Tenino	n/a
	West Virginia	
J.P. Mascaro	Brooke County	100
J.P. Mascaro	Wetzel County	n/a

Appendix W

APPENDIX C – BIOFILTERS IN OPERATION AT COMPOSTING FACILITIES IN THE UNITED STATES

Facility	Location	Compost Mix	System	Enclosure	Test Date	Control Eff. (%)		Comments
						NH3	VOC	
Burlington County Board of Chosen Freeholders	Burlington County, New Jersey	Biosolids & shredded yard/wood waste	Agitated bed in-vessel	Active composting & curing	4/99 & 7/99	not avail.	not avail.	No inlet data. Ave. outlet VOC is 8.7 ppm.
City of Columbus	Columbus, Ohio	Biosolids & amendments	ASP pilot project	Active composting	Oct-99			Odor-emissions test. 86.7% reduction with building enclosure.
City of Lockport	Lockport, New York	Biosolids, yardwate & wood chips	IPS in-vessel agitated bed	Mixing & active composting	7/20/92 - 7/22/92	86	not avail.	
Griffith Park Composting	Los Angeles, CA	Biosolids & manure & wood chips	Negative pressure ASP	No enclosure	Aug-97	98.7 - 99.8	93.2 - 97.4	Control efficiency of 2 biofilters
Joint Water Pollution Control Plant (L.A. Co. Sanitation)	Carson, CA	Biosolids & amendments	In-vessel pilot project		5 & 6/95	99.8	99.4	With venturi scrubber & activated carbon bed
Las Virgenes Municipal Water District	Calabasa, California	Biosolids & wood chips	IPS in-vessel agitated bed	Mixing & active comosting & curing & storageTotal	Aug-94	98.6 - 99.4	not avail.	
Philadelphia Water Dept. - Bioslids Recycling Center	Philadelphia	Biosolids & woodchips	Negative pressure aerated static pile (ASP)	No enclosure	Dec-00	not avail.	80 - 95	90% control efficiency achieved after improvement made to biofilter design

Facility	Location	Compost Mix	System	Enclosure	Test Date	Control Eff. (%)		Comments
						NH3	VOC	
Rockland County Solid Waste Management Authority	Rockland County, New York	Biosolids & shredded yard waste	IPS in-vessel agitated bed	Mixing & active composting & curing	4 & 5 & 6/99	97 - 99	not avail.	
Solid Waste Authority of Palm Beach County	W. Palm Beach, Florida	Biosolids & yard waste	IPS in-vessel agitated bed	Mixing & active composting		75		Verbally stated.
Synagro	Corona, CA	Biosolids & amendments	Pilot project - enclosed ASP	Mixing & active composting	Aug-99	99	not avail.	Odor test
Town of Dartmouth	S. Dartmouth, Massachusetts	Biosolids & yard waste	IPS in-vessel agitated bed		5/93 & 12/93	98 - > 99	not avail.	

Appendix X

Bay Area Air Quality Management District
939 Ellis Street
San Francisco, CA 94109
(415) 771-6000

Permit Evaluation
and
Statement of Basis
for
MAJOR FACILITY REVIEW PERMIT
SIGNIFICANT REVISION

for

Redwood Landfill, Inc.
Facility #A1179

Facility Address:
8950 Redwood Highway
Novato, CA 94948

Mailing Address:
P. O. Box 793
Novato, CA 94948

Application Engineer: Carol Allen
Site Engineer: Carol Allen

Applications: 10873 and 10874

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ENGINEERING EVALUATION and STATEMENT of BASIS

Redwood Landfill, Inc.; PLANT # 1179

APPLICATIONS # 10873 and 10874

A. BACKGROUND

Site Description:

Redwood Landfill, Inc. operates the Redwood Landfill Facility in Novato, CA. This facility includes the active landfill (S-5 with about 12 million tons of refuse in place), a 120 MM BTU/hour landfill gas flare (A-50), a 5 MM BTU/hour leachate evaporator (S-50), sludge handling and composting operations (S-2, S-25, S-28, S-34, S-35, S-37, S-38, S-39, and S-41), soil stockpiles (S-42), a non-retail gasoline dispensing facility (S-55), and five diesel engines providing portable or standby power (S-45, S-46, S-37, S-48, and S-49).

The A-50 Landfill Gas Flare is currently the sole operational device for controlling the landfill gas that is generated at this facility. Although the S-50 Leachate Evaporator is permitted to burn up to 5 MM BTU/hour of landfill gas, this equipment is not currently operating and any future operation of this unit is uncertain.

Redwood Landfill is planning to expand the design capacity of the S-5 landfill. Pursuant to Application # 11371, Redwood has proposed to increase the amount of decomposable waste that will ultimately be placed in the landfill from the current permitted limit of 17.1 million tons to 32.3 million tons. This request will generate additional landfill gas and will require additional control capacity. A new 3000 cfm enclosed landfill gas flare was requested as part of the expansion project. This request is currently under review by the District. In addition, this action is the subject of a CEQA EIR. A draft EIR was circulated for public comment in 2004. The lead agency, Marin County, is expected to respond to comments later this year.

Landfill Gas Control Issue:

In January 2005, Redwood Landfill reported that existing flare (A-50) is experiencing operational problems. It has become apparent that the flare cannot burn (in a compliant manner) the full permitted landfill gas flow rate of 4000 cfm. In fact the flare is having difficulty maintaining proper operation at the minimum landfill gas flow rates that are currently necessary to prevent surface leaks from the landfill (1600-1700 cfm). As a long-term solution to these compliance issues, Redwood Landfill has accelerated the planned installation of a second flare at this site (see Applications # 11371 and # 11757). This second flare has been sized to handle at least 3000 cfm of landfill gas and will provide sufficient control capacity for the landfill (as it is currently permitted). However, the new flare will not be delivered until early May 2005. Redwood Landfill and the District's Legal, Engineering, and Enforcement Divisions are discussing several options to improve compliance and minimize air emissions between now and June 2005, when the new flare is expected to be operating.

Due to the current operational problems with A-50, a third flare may be necessary to provide full control capacity for the expanded landfill and/or back-up control capacity. The operational capability of A-50 will be fully evaluated later this year after the 3000 cfm flare has been installed. If A-50 is found to be not repairable, the District anticipates that another application for a third flare may be submitted in late 2005.

Other Compliance Issues:

Redwood Landfill conducted their required annual compliance demonstration tests in July 2004. Test results indicated that the concentrations of total reduced sulfur (TRS) compounds and several toxic organic

compounds in the landfill gas exceeded permitted concentration levels. Condition # 19235, Part 18 requires the facility to submit a permit application to increase the permitted limits, if testing indicates that NMOC, TRS, or toxic compound concentration levels exceed the limits in Part 18. At the District's request, Redwood Landfill submitted the test results for all of the quarterly landfill gas sulfur content testing conducted to date. These results indicated that the sulfur concentration exceeded the limit of 231 ppmv of TRS in landfill gas on at least three other test dates. Consequently, Redwood Landfill submitted Application # 10874 to increase the permitted concentration levels of TRS, benzene, and methylene chloride and submitted Application # 10873 to modify the Title V permit at this facility.

The proposed condition revisions are discussed in more detail below.

Landfill Gas Concentration Limit Revisions:

Initially, Redwood Landfill proposed the following changes to the Part 18 concentration limits:
(a) to increase the landfill gas sulfur content limit from 231 ppmv to 750 ppmv,
(b) to increase the benzene limit from 340 ppbv to 1000 ppbv, and
(c) to increase the methylene chloride limit from 320 ppbv to 1000 ppbv
These changes would result in emission increases of hydrogen sulfide (and other sulfur compounds), benzene, and methylene chloride at the S-5 landfill, A-50 flare, and S-50 leachate evaporator and emission increases of sulfur dioxide at the A-50 flare and S-50 leachate evaporator.

Since the S-50 leachate evaporator is not currently operating and may be removed from this site in the future, Redwood has withdrawn their request for emission increases at S-50.

Shortly after Redwood Landfill submitted Application # 10874 to increase concentration limits for landfill gas constituents, Redwood Landfill submitted Application # 11371 to expand the landfill. Since these two projects are related, the District plans to conduct a single health risk screening analysis for this larger project. This health risk analysis will be conducted pursuant to Application # 11371. This health risk screening analysis will fully evaluate the health risks from the expanded landfill and larger landfill gas control system as well as higher concentrations of benzene and methylene chloride.

Application # 10874 will now only address the necessary increase to the landfill gas sulfur content limit. The District has discussed several alternatives for sulfur content limits and monitoring procedures with Redwood Landfill. Redwood Landfill is now requesting to increase the landfill gas sulfur content to a peak limit on any day of 1300 ppmv as H_2S and an annual average limit of 425 ppmv as H_2S. This request will result in hydrogen sulfide and carbon disulfide emission increases at the S-5 Landfill and A-50 Flare and sulfur dioxide emission increases at the A-50 Flare. Permit application fees have been adjusted pursuant to this revised request.

B. EMISSIONS

From Application # 17752, the current maximum permitted annual emission rates for toxic sulfur compounds from the landfill are 4245 pounds/year of hydrogen sulfide (H_2S) and 13.2 pounds/year of carbon disulfide (CS_2). From Application # 8501, the current maximum permitted emission rates from the flare are: 2074.6 pounds/year of H_2S, 0.6 pounds/year CS_2, 221.6 pounds/day of SO_2, and 28.661 tons/year of SO_2. Note that for Application # 8501, the proposed emission rate for H_2S was only 607.2 pounds/year, which was well below the previously permitted rate of 2074.6 pounds/year. Therefore, Application # 8501 resulted in no H_2S increases. Total permitted emissions are 6320 pounds/year of H_2S and 13.8 pounds/year of CS_2.

Hydrogen sulfide is usually the only reduced sulfur compound detected in Redwood's landfill gas. Carbon disulfide has only been detected on one test, and it was less than 0.01% of the TRS concentration. Mercaptans and thiophenes have occasionally been detected, but these compounds are not on the risk

screen trigger level list. Maximum permitted toxic sulfur compound emissions will be determined by a ratio of the proposed to current concentration. Hydrogen sulfide emissions are calculated by assuming that all TRS is H_2S. Maximum potential carbon disulfide emissions are calculated by assuming CS_2 is 1% of the TRS.

Landfill: (425 ppmv TRS/231 ppmv TRS)*(1 lb H_2S/1 lb TRS)*(4245 lbs/yr H_2S)	=	4186 lbs/yr H_2S
Flare: (425 ppmv TRS/231 ppmv TRS)*(1 lb H_2S/1 lb TRS)*(607.2 lbs/yr H_2S)	=	1117 lbs/yr H_2S
Total Proposed Hydrogen Sulfide Emissions:		5303 lbs/yr H_2S

Since the current permitted emission rate is 6320 pounds/year of H_2S, this application will not result in any H_2S emission increases.

Landfill: (4186 lbs/yr of TRS)*(0.01 lb CS_2/1 lb TRS)	=	42 lbs/yr CS_2
Flare: (1117 lbs/yr of TRS)*(0.01 lb CS_2/1 lb TRS)	=	11 lbs/yr CS_2
Total Proposed Carbon Disulfide Emissions:		53 lbs/yr CS_2

Since the risk screen trigger level for CS_2 is 14,000 pounds/year, a risk screen is not required for a proposed project emission rate of 53 pounds/year.

Maximum permitted sulfur dioxide emissions from the A-50 Flare will be determined by a ratio of the proposed to current TRS concentration limits:

Daily: (1300 ppmv TRS/231 ppmv TRS)*(221.6 pounds/day SO_2)	=	1247 pounds/day SO_2
Annual: (425 ppmv TRS/231 ppmv TRS)*(28.661 tons/year SO_2)	=	52.731 ton/year SO_2

Cumulative Emission Increases:

Total Plant CEI for SO_2:		51.206 tons/year of SO_2 *
Flare Emission Increases: 52.731 tons/year - 28.661 tons/year	=	24.070 tons/year of SO_2
New Total Plant CEI:		75.276 tons/year of SO_2

(* This CEI includes increases for several sources that have now been shut down. The database will be corrected shortly.)

Current Facility Wide Potential to Emit:	30.577 tons/year of SO_2
Flare Emission Increases:	24.070 tons/year of SO_2
New Facility Wide Potential to Emit:	54.647 tons/year of SO_2

C. STATEMENT OF COMPLIANCE

Regulation 2, Rule 1:

This application is for a change of permit conditions at the S-5 Redwood Landfill and A-50 Landfill Gas Flare. The largest emission increases are due to the abatement of landfill gas and the secondary combustion emission of sulfur dioxide from the A-50 Flare. The permitting of abatement equipment such as the A-50 Landfill Gas Flare meets the requirements of District Regulation 2-1-312.2. Therefore, the permitting of a change of conditions at A-50 is categorically exempt from CEQA review. In addition, this project will comply with the no net increase provisions of the new source review rule, because the SO_2 emission increases are not subject to offset requirements and the flare will comply with RACT for SO_2 emissions. This project will not trigger a risk screen pursuant to the District's Toxic Risk Management Policy. Therefore, this application complies with all requirements of Regulations 2-1-312.11.1-4 and is categorically exempt from CEQA review pursuant to Regulation 2-1-312.11.

The project is over 1000 feet from the nearest school and is therefore not subject to the public notification requirements of Regulation 2-1-412.

Regulation 2, Rule 2:

This project will result in both daily and annual emission increases of SO_2 at the A-50 Landfill Gas Flare. Therefore, A-50 is considered a modified device and is subject to Regulation 2, Rule 2: New Source Review (NSR). Since the A-50 Flare satisfies a BARCT requirement (Regulation 8-34-301.3) for control of NMOC emissions from the S-5 Redwood Landfill, the secondary pollutant emissions (NO_x, CO, PM_{10}, and SO_2) are exempt from BACT requirements pursuant to Regulation 2-2-112. Regulation 2-2-112 requires that Reasonably Available Control Technology (RACT) be used to control secondary pollutant emissions. This project will not increase emissions of NO_x, CO or PM_{10}. RACT for SO_2 will be discussed below.

RACT for SO_2: Landfill gas contains reduced sulfur compounds (mainly hydrogen sulfide with small percentages of mercaptans, carbon disulfide, and other sulfur compounds). Gypsum (from wallboard) decomposition and sewage sludge decomposition are the main sources of these sulfur compounds. Landfill gas combustion produces sulfur dioxide (SO_2) as a byproduct.

The only reasonable method of reducing SO_2 emissions from landfill gas combustion is to reduce the amount of sulfur compounds in the landfill gas. This can be accomplished by using pollution prevention (i.e. reducing gypsum or sewage sludge disposal) or by treating the landfill gas to remove the sulfur compounds. For Redwood Landfill, most of the H_2S in the landfill gas is coming from sewage sludge that is mixed with other materials and used as a daily cover material. In the last few years, Redwood Landfill has made significant reductions in the amount of sewage sludge accepted at the site. Much of the sludge that is used in cover materials today is coming from the on-site storage pond, which must be eliminated. Although the use of sewage sludge in cover materials will continue in the future (at a much lower rate than past years), most of the sulfur in the landfill gas now is coming from sludge that has already been placed in the landfill. Therefore, sulfur contents are expected to decline in future years from the current annual average of about 380 ppmv. Additional waste stream restrictions are not necessary at this time. This issue will be reviewed again under the landfill expansion application.

The only other available sulfur dioxide control method for the A-50 Flare is treatment of the landfill gas to remove the sulfur compounds prior to combustion. Although an internet search did find several commercially available methods for removing sulfur compounds from landfill gas (iron sponges, liquid scrubbers, and catalytic iron-redox systems), these removal systems were generally only applied to gases containing more than 500 ppmv of TRS. Searches of EPA's RACT/BACT/LAER Clearinghouse, ARB's BACT Clearinghouse, and South Coast's Major Source BACT Determinations found no cases where a sulfur removal system was required in order to meet BACT for SO_2 emissions from a landfill gas flare. Therefore, no landfill gas treatment options are considered to be BACT for controlling SO_2 emissions from a landfill gas flare.

In the Bay Area, RACT for SO_2 emissions from landfill gas fired combustion equipment is usually achieved by limiting the average landfill gas sulfur content to 150 ppmv (expressed as H_2S). This 150 ppmv sulfur limit was based on South Coast Air Quality Management District Rule 431.1, which limits the sulfur content of landfill gas to 150 ppmv, averaged on a daily basis. The staff report for this rule indicated that all landfills were expected to meet this sulfur content limit without any gas treatment and that no South Coast landfills were expected to exceed a peak sulfur content of 200 ppmv in the raw landfill gas. At one time, the South Coast rule required that all fuel gas meet a sulfur content limit of 40 ppmv. Several South Coast landfills operated under a variance from this requirement while the commercially available sulfur removal systems were evaluated for landfill gas applications. Although the sulfur removal systems proved feasible, the landfill operators experienced difficulty with the realistic operation and high operating costs of these sulfur removal systems. Ultimately, South Coast revised Rule 431.1 and established the 150 ppmv daily average limit for landfill gas with no landfill gas sulfur treatment systems required for any South Coast landfills. Although landfill gas sulfur treatment systems are available, these systems are not being used on a wide spread basis and have not been required to meet BARCT, RACT, or BACT for landfill gas combustion operations. Therefore, landfill gas sulfur treatment systems do not constitute a "reasonably"

available control measure. Instead, RACT for SO_2 emissions from landfill gas combustion operations will be compliance with reasonable landfill gas sulfur content limits.

The Regulation 9-1-302 limit of 300 ppmv of SO_2 in the exhaust gas will be used to establish a reasonable peak sulfur content limit (a limit applied to any single test for sulfur content of the landfill gas). The landfill gas contains a minimum of 45% methane with a minimum heat content of 447 BTU/scf and an F-factor of 9830 dscf of flue gas at 0% O_2 per MM BTU. Under these conditions, an exhaust concentration limit of 300 ppmv SO_2 is equivalent to an inlet TRS concentration limit of about 1300 ppmv as H_2S, as shown below.

(300 ft^3 SO_2/MM ft^3 flue)*(1 ft^3 H_2S/1 ft^3 SO_2)*(0.00983 MM ft^3 flue/MM BTU)*(447 MM BTU/MM scf LFG) = 1318 ft^3 of H_2S/MM ft^3 LFG = 1318 ppmv of TRS as H_2S

For most landfills, an average sulfur content limit of 150 ppmv is easily met and is considered RACT for the landfill gas combustion operations associated with these landfills. However, landfill gas from the S-5 Redwood Landfill has the highest sulfur content of any of the Bay Area landfills due to this site's past extensive use of dried sewage sludge in daily cover material. For the past 2 years, quarterly testing has indicated a range of 186-370 ppmv TRS plus one test at 1171 ppmv TRS. The average concentration including the one high test was 376 ppmv TRS. Considering the variability of the test data, Redwood's proposed annual average limit of 425 ppmv TRS is reasonable. Furthermore, this limit is below the 500 ppmv level normally necessary before sulfur removal controls become cost effective. For the A-50 Landfill Gas Flare, an annual average landfill gas sulfur content limit of 425 ppmv (expressed as H_2S) shall be considered RACT for SO_2 emissions.

Offsets for SO_2: The SO_2 offset requirements in Regulation 2-2-303 only apply if the facility is considered a Major Facility for that pollutant. Total facility wide emissions will be 54.64 tons/year of SO_2. Since facility-wide SO_2 emissions are less than 100 tons/year, this facility is not a Major Facility for SO_2, and Regulation 2-2-303 does not apply.

Regulation 2, Rule 2 (PSD)

Since this facility will not emit more than 100 tons/year of non-fugitive emissions of SO_2, this facility is not a Major Facility for SO_2. Consequently, the PSD requirements of Regulation 2-2-304 do not apply.

New Source Review for Toxic Air Contaminants:

This application will result in emission increases of carbon disulfide above the current permitted level. However, the proposed emission rate is less than the risk screen trigger level for CS_2. Therefore, a risk screening analysis was not required, and TBACT does not apply.

Regulation 2, Rule 6:

This facility is subject to the Operating Permit requirements of Title V of the federal Clean Air Act (40 CFR, Part 70) and BAAQMD Regulation 2, Rule 6, Major Facility Review (MFR), because it is a major facility, as defined by Regulation 2-6-212. This facility has the "potential to emit," as defined by Regulation 2-6-218, more than 100 tons per year of a regulated air pollutant, specifically more than 100 tons per year of carbon monoxide. Therefore, this facility is required to have an MFR permit pursuant to Regulation 2-6-301.

This facility is also subject to the Title V operating permit requirements and Regulation 2, Rule 6, MFR permit requirements, because it is a designated facility as defined by Regulation 2-6-204. The Standards of Performance for Municipal Solid Waste Landfills (40 CFR Part 60, Subpart WWW) require the owner or operator of a landfill that is subject to Subpart WWW and that has a design capacity of greater than or equal to 2.5 million megagrams (Mg) and 2.5 million cubic meters (m^3) to obtain an operating permit pursuant to Part 70. The landfill at this facility is subject to 40 CFR, Part 60, Subpart WWW and has

design capacities of 14.6 million m^3 and 15.5 million Mg. Therefore, this facility is a designated facility and is required to have an MFR permit pursuant to 2-6-304.

The initial MFR Permit for this facility was issued on November 10, 2003 and was revised on November 10 2004. This application will require a revision of the current MFR permit. The definition of significant revision is discussed below to determine if this application constitutes a significant MFR revision.

- Regulation 2-6-226.1 and 226.2: This application does not involve the incorporation of a change considered to be a major modification, or a modification under NSPS, NESHAPs, or Section 112 of the CAA.
- Regulation 2-6-226.3: This application does not involve the relaxation of any monitoring, record keeping or reporting requirements.
- Regulation 2-6-226.4: This application does not involve limits imposed to avoid an applicable requirement.
- Regulation 2-6-226.5: This application involves the establishment of or change to a case-by-case emission limit or standard (specifically a case-by-case RACT determination for SO_2 emissions from the Flare).
- Regulation 2-6-226.7: This application does not involve the incorporation of any requirements promulgated by the EPA.

Since this application triggers Regulation 2-6-226.5, it will be processed as a significant MFR permit revision. The proposed MFR permit revisions related to this application are described later in this document.

Regulation 8, Rule 34:

The S-5 Redwood Landfill and A-50 Landfill Gas Flare are subject to Regulation 8, Rule 34 "Solid Waste Disposal Sites". As discussed in the background section, the S-5 Landfill has been experiencing intermittent compliance problems with Regulation 8, Rule 34 due to the unexpected deterioration of the landfill gas flow rate that the A-50 Flare can properly destroy. Regulation 8-34-301.3 limits the organic emissions from landfill gas flares and requires A-50 to either achieve 98% destruction of non-methane hydrocarbons (NMHC) or to emit no more than 30 ppmv of NMHC, expressed as methane, at 3% oxygen. A July 2004 source test indicated that the A-50 Flare was complying with all applicable requirements, including the 8-34-301.3 outlet NMOC concentration limit, at an average landfill gas flow rate of 1427 dscfm (50.102% methane) and an average flare combustion temperature of 1700 °F. In order to ensure that no surface leaks will occur, Redwood Landfill needs to collect more than 1427 dscfm of landfill gas due to higher landfill gas generation rates in 2005 and future years. However the flare cannot reach higher combustion temperatures without risking irreparable damage. Redwood Landfill is currently discussing their compliance options with the District to determine the best course of action until a new flare can be installed on site, which is scheduled for June 2005.

Although the landfill and flare are currently having intermittent compliance difficulties with Regulation 8, Rule 34, this application concerns only the sulfur content of the landfill gas. Changing this sulfur content limit will have no impact on the ability of the landfill or flare to comply with Regulation 8, Rule 34.

Regulation 9, Rule 1:

Regulation 9-1-302 limits the sulfur dioxide concentration in any exhaust gas to 300 ppmv of SO_2. Note that this limit is not referenced to any particular oxygen concentration, and therefore applies to the as measured conditions of the exhaust stream. The revised condition # 19867, Part 18a will limit the landfill gas sulfur content to a maximum of 1300 ppmv of sulfur expressed as hydrogen sulfide. This limit will ensure compliance with the Regulation 9-1-302 limit and shown below (assuming the landfill gas contains a minimum of 45% methane with a minimum heat content of 447 BTU/scf and an F-factor of 9830 dscf of flue gas at 0% O_2 per MM BTU).

(1300 ft^3 H_2S/MM ft^3 LFG)*(1 ft^3 SO_2/1 ft^3 H_2S)/(447 MM BTU/MM ft^3 LFG)/(0.00983 MM ft^3 flue/MM BTU)

= 296 ft^3 of SO_2/MM ft^3 flue gas at 0% oxygen = 296 ppmv of SO_2 at 0% oxygen

The exhaust gas from the landfill gas landfill gas typically contains 10%-15% oxygen. Assuming the flare exhaust stream contains 10% oxygen, the outlet SO_2 concentration from the flare will be no more than: (296 ppmv of SO_2 at O% O_2)*(20.9-10)/(20.9-0) = 154 ppmv of SO_2

The compliance ratio with the Regulation 9-1-302 limit is about 2:1. In order to ensure compliance with the 9-1-302 limit, the District is proposing to continue the quarterly landfill gas sulfur content testing by laboratory analysis, and the District is proposing to add weekly testing of the landfill gas H_2S content using a Draeger tube. Draeger tube testing has been used by other Title V landfills to show compliance with the Regulation 9-1-302 limit and is an acceptable method of demonstrating compliance with this limit.

Although most other landfill gas sites are conducting quarterly Draeger tube analyses to determine the landfill gas hydrogen sulfide content, the District is proposing a weekly testing frequency at this site in order to better evaluate the variability of the landfill gas sulfur content at this site. A recent quarterly test found 1171 ppmv of TRS in the landfill gas at this site. Subsequent testing by both the District and an outside test firm found between 186 ppmv and 308 ppmv of TRS. The proposed weekly testing regimen will aid in determining: (a) if the sulfur content is highly variable as is indicated by the testing to date (186-1171 ppmv of TRS), or (b) if the single test showing 1171 ppmv of TRS was flawed and the sulfur content range is really 186-370 ppmv of TRS. If the latter is true, the flare's compliance ratio with the Regulation 9-1-302 limit is about 6:1 rather than 2:1 (for the proposed condition change). Since Draeger tube testing is inexpensive, the District feels that a weekly testing frequency is not overly burdensome.

Federal Requirements:

NSPS for MSW Landfills: The landfill at this facility is subject to the 40 CFR Part 60, Subpart WWW, the NSPS for Municipal Solid Waste (MSW) Landfills. The A-50 Landfill Gas Flare is subject to 40 CFR 60.752(b)(2)(iii)(B), which requires the control system to achieve either 98% removal of NMOC or emit no more than 20 ppmv of NMOC, expressed as hexane at 3% O_2. The outlet concentration limit is equivalent to a limit of 120 ppmv of NMOC expresses as methane and is less stringent than Regulation 8-34-301.3. As discussed above for Regulation 8-34-301.3, the flare is complying with the 8-34-301.3 outlet concentration limit at 1427 sdcfm and 1700 °F and is therefore complying with 40 CFR 60.752(b)(2)(iii)(B). The flare will also comply with the temperature and gas flow monitoring requirements of 40 CFR 60.756(b)(1) and 60.756(b)(2), respectively. All applicable requirements are contained in the current Title V permit. The change to the landfill gas sulfur content limit will not impact any of these applicable requirements or the landfill or flare's ability to comply with these requirements.

NESHAPs for MSW Landfills: Any landfills that are subject to the landfill gas collection and control requirements of either the NSPS for MSW Landfills or the EG for MSW Landfills are also subject to the NESHAPs for MSW Landfills (40 CFR, Part 63, Subpart AAAA). This NESHAP requires that subject facilities prepare and implement startup, shutdown, malfunction plans and additional reporting requirements. All applicable requirements are contained in the existing MFR permit, and this facility is expected to comply with these requirements.

D. MFR PERMIT MODIFICATIONS

Sections I-V:

No changes are proposed to these sections.

Section VI:

This MFR Permit revision will modify Condition # 19867, Parts 18 and 31. The landfill gas sulfur content

limit will be changed from a single limit (no averaging time specified, but based on annual emission rates) to a peak limit (applies to any single test) and an annual average limit (annual average of weekly and quarterly tests). The current quarterly laboratory analysis of the landfill gas will continue. Weekly testing using a Draeger tube will be added to gather more data about the variability of the sulfur content at this site and to improve compliance assurance with the equivalent limit to the Regulation 9-1-302 standard (300 ppmv of SO_2 in the flare exhaust).

Condition # 19867
FOR: S-5, REDWOOD LANDFILL WITH GAS COLLECTION SYSTEM; A-18, WATER SPRAYS; AND A-50, LANDFILL GAS FLARE

18. If a gas characterization test indicates that this site's landfill gas contains compounds in excess of any of the concentrations listed below, then the Permit Holder shall submit an application for a Change of Permit Conditions, within no later than 30 days from receipt of the test results.

a. Total Non-Methane Organic Compounds: 750 ppmv
(calculated as hexane equivalent)
Total Reduced Sulfur (TRS) Content: ~~231 ppmv~~
(calculated as hydrogen sulfide equivalent)
Peak TRS Limit (any single test): 1300 ppmv
Annual Average TRS Limit: 425 ppmv
(Basis: Cumulative Increase and RACT)

*b. For toxic air contaminants (TACs):

Compound	Concentration
Acrylonitrile	280 ppbv
Benzene	340 ppbv
Carbon Tetrachloride	70 ppbv
Chloroform	70 ppbv
1,4 Dichlorobenzene	400 ppbv
1,1 Dichloroethane	150 ppbv
Ethylene Dibromide	70 ppbv
Ethylene Dichloride	70 ppbv
Methylene Chloride	320 ppbv
Perchloroethylene	450 ppbv
1,1,2,2 Tetrachloroethane	70 ppbv
Trichloroethylene	250 ppbv
Vinyl Chloride	880 ppbv

(Basis: Toxic Risk Management Policy)

31. a. The Permit Holder shall conduct a characterization of the landfill gas on a quarterly basis with one test concurrent with the annual source test required by Part 30 above. The landfill gas sample shall be drawn from the main landfill gas header. Each quarterly landfill gas sample shall be analyzed for the sulfur compounds listed below. Once per year (concurrent with the Part 30 annual source test) the landfill gas shall be analyzed for all the organic and sulfur compounds listed below. All concentrations shall be reported on a dry basis. The test report shall be submitted to the Compliance and Enforcement Division and the Source Test Section within 45 days of the test date.
(Basis: Toxic Risk Management Policy and Regulations 8-34-412 and 9-1-302)

Organic Compounds	Organic Compounds	Sulfur Compounds
acrylonitrile	ethylene dibromide	carbon disulfide
benzene	fluorotrichloromethane	carbonyl sulfide
carbon tetrachloride	hexane	dimethyl sulfide
chlorobenzene	isopropyl alcohol	ethyl mercaptan
chlorodifluoromethane	methyl ethyl ketone	hydrogen sulfide

chloroethane	methylene chloride	methyl mercaptan
chloroform	perchloroethylene	
1,1 dichloroethane	toluene	
1,1 dichlorethene	1,1,1 trichloroethane	
1,2 dichlorethane	1,1,2,2 tetrachloroethane	
1,4 dichlorbenzene	trichloroethylene	
dichlorodifluoromethane	vinyl chloride	
dichlorofluoromethane	xylenes	
ethylbenzene		

b. Once per week, beginning no later than March 31, 2005, the Permit Holder shall analyze the landfill gas for hydrogen sulfide (H2S) concentration using a Draeger tube to further demonstrate compliance with Part 18 and Regulation 9-1-302. The landfill gas sample shall be drawn from the main landfill gas header. The Permit Holder shall follow the manufacturer's procedures for using the Draeger tube and interpreting the results. The total reduced sulfur (TRS) content of the landfill gas shall be calculated using the average ratio of TRS/H2S for this site according to the following equation: TRS = 1.015* H2S measured by Draeger tube. The Permit Holder shall maintain records of all Draeger tube test dates and test results and shall summarize the average H2S concentrations and the calculated TRS content of the landfill gas on a quarterly basis. Each Draeger tube test result (after conversion to TRS content) and the quarterly laboratory analysis in Part 31a shall be compared to the Peak TRS Limit in Part 18. On a rolling quarterly basis, the Permit Holder shall determine the annual average TRS content for comparison to the Annual Average TRS Limit in Part 18. (Basis: RACT and Regulation 9-1-302).

Section VII:

The sulfur content limits in Table VII-B will be revised as indicated below.

Table VII – B
Applicable Limits and Compliance Monitoring Requirements
S-5 REDWOOD LANDFILL WITH GAS COLLECTION SYSTEM
AND A-50 LANDFILL GAS FLARE

Type of Limit	Citation of Limit	FE Y/N	Future Effective Date	Limit	Monitoring Requirement Citation	Monitoring Frequency (P/C/N)	Monitoring Type
...							
SO_2	BAAQMD 9-1-301	Y		Property Line Ground Level Limits: ≤ 0.5 ppm for 3 minutes and ≤ 0.25 ppm for 60 min. and ≤0.05 ppm for 24 hours (applies to A-50 Flare only)	None	N	NA
SO_2	BAAQMD 9-1-302	Y		≤ 300 ppm, dry basis (applies to A-50 Flare only)	BAAQMD Condition # 19867, Parts 18a and 31	P/W, Q	Weekly Draeger tube analysis and Quarterly ~~Landfill Gas~~ Laboratory Analysis of Landfill Gas

Table VII – B
Applicable Limits and Compliance Monitoring Requirements
S-5 REDWOOD LANDFILL WITH GAS COLLECTION SYSTEM
AND A-50 LANDFILL GAS FLARE

Type of Limit	Citation of Limit	FE Y/N	Future Effective Date	Limit	Monitoring Requirement Citation	Monitoring Frequency (P/C/N)	Monitoring Type
H_2S	BAAQMD 9-2-301	N		Property Line Ground Level Limits: $\leq$ 0.06 ppm, averaged over 3 minutes and $\leq$ 0.03 ppm, averaged over 60 minutes	None	N	NA
Total Reduced Sulfur (TRS)	BAAQMD Condition # 19867, Part 18a	Y		~~$\leq$ 231 ppmv of TRS in landfill gas, expressed as H_2S, dry basis~~ Peak TRS Limit (any single test): 1300 ppmv of TRS (expressed as H_2S) in landfill gas Annual Average TRS Limit: 425 ppmv of TRS (expressed as H_2S) in landfill gas	BAAQMD Condition # 19867, Part 31	P/W, Q	Weekly Draeger tube analysis and Quarterly ~~Landfill Gas~~ Laboratory Analysis of Landfill Gas and Records
...							

Section VIII:

The acceptable method for the Draeger tube analysis will be added to Table VIII as indicated below.

Table VIII
Test Methods

Applicable Requirement	Description of Requirement	Acceptable Test Methods
...		
BAAQMD Condition # 19867, Part 18a	Concentration of Total Reduced Sulfur (TRS) Compounds in Landfill Gas (Peak and Annual Average Limits)	Draeger tube used in accordance with manufacturer's recommendations and calculation procedures described in Condition # 19867, Part 31b; and Manual of Procedures, Volume III, Method 5 Determination of Total Mercaptans in Effluents and Method 25 Determination of Hydrogen Sulfide in Effluents, or Method 44 Determination of Reduced Sulfur Gases and Sulfur Dioxide in Effluent Samples by Gas Chromatographic Methods
...		

Sections IX:

No changes are proposed to this section.

Section X:

These above revisions are summarized in the revision history section as shown below.

X. REVISION HISTORY

Title V Permit Issuance (Application 17363): **November 10, 2003**

Significant Revision (Application 8501): **November 10, 2004**

- In Table II-B, change the capacity of the A-50 Flare from 75 MM BTU/hour to 120 MM BTU/hour.
- Add several missing sections of 40 CFR Part 60, Subpart WWW (flare operating and monitoring requirements) to Table IV-B.
- Delete future effective dates that have passed from Tables IV-B, IV-M, VII-B, VII-M and Condition # 19867, Part 22.
- Delete unnecessary requirements of Condition # 19867 (Parts 27 and 28) and delete references to these parts in Tables IV-B, VII-B, and VIII.
- Correct errors in Tables IV-B and IV-M and in Condition # 19867, Parts 16 and 30.
- Revise landfill gas throughput limits for A-50 in Condition # 19867, Part 20 and Table VII-B.
- Revise the NMOC emission limit for A-50 in Condition # 19867, Part 23 and Table VII-B.
- Revise the non-federally enforceable TAC destruction efficiency limit for A-50 in Condition # 19867, Part 24 and Table VII-B.

Minor Revision (Applications 6943 and 9565): **November 10, 2004**

- In Table II-A and Section VI, Condition # 19867, Part 17a, update collection system description to reflect gas collection system components that are operating as of August 1, 2004.
- In Section VI, Condition # 19867, Part 17b, add the description of the collection system component changes that have been authorized pursuant to Application # 9565.

Significant Revision (Applications 10873 and 10874): **[Insert Approval Date]**

- In Condition # 19867, Part 18a and Table VII-B, replace the current TRS content limit for landfill gas with a new peak TRS limit and a higher annual average TRS content limit.
- In Condition # 19867, Part 31, add a new subpart b that describes the Draeger tube hydrogen sulfide analysis

requirements, testing frequency, TRS calculation procedures, and record keeping requirements.

- Add the weekly Draeger tube monitoring requirements and TRS calculation procedures to Table VII-B and Table VIII.

Sections XI-XII:

No changes are proposed to these sections.

E. RECOMMENDATION

Issue a Change of Permit Conditions for the following equipment:

S-5 Redwood Landfill; abated by A-50 Landfill Gas Flare

Issue a proposed significant revision of the MFR Permit for the following facility:

A1179 Redwood Landfill, Inc.

By: signed by Carol S. Allen
Carol S. Allen
Senior Air Quality Engineer

February 23, 2005
Date

H:\Pub_Data\TitleV Permit Appls\01\A1179\Sig Rev – 10874\A1179C-10874SOB.doc

Appendix X

BAY AREA AIR QUALITY MANAGEMENT DISTRICT

Particulate Matter

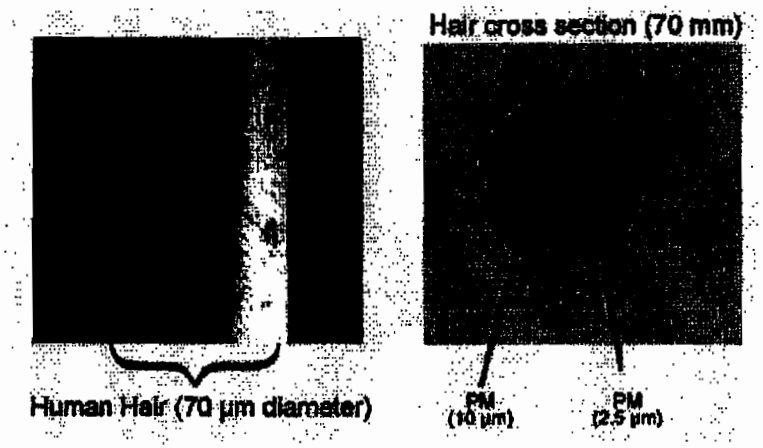
Air Quality Plans
Air Status / Technical Data
Boards/Council
Divisions/Offices
- Administration
- Clerk of the Boards
- Compliance & Enforcement
- Engineering
- Executive
- Human Resources
- Information Systems
- Public Information & Outreach
- Planning
- Technical Services

Grants & Incentives
Opportunities
Permits
Pollution Prevention
Programs
Public Notices
Rules & Regulations
Site Archives

What Is Particulate Matter (PM)?
What Kinds Of Problems Does PM Cause?
What are PM conditions in the Bay Area?
What is being done about PM in the Bay Area?
What else is being done to reduce PM pollution?
What you can do.
More information about particulate matter.

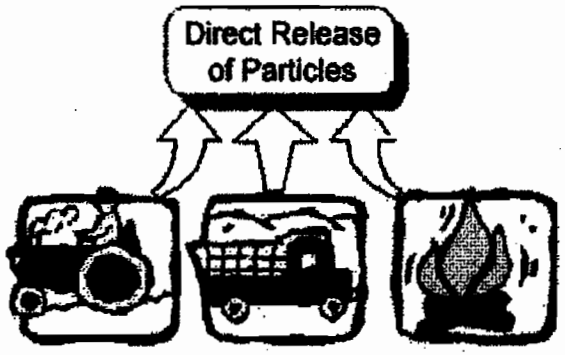
What Is Particulate Matter (PM)?

Particulate matter (referred to as PM) consists of very small liquid and solid particles suspended in the air, and includes particles smaller than 10 microns in size (PM_{10}) as well as finer particles smaller than 2.5 microns in size ($PM_{2.5}$). Particles with a size between 2.5 and 10 microns are sometimes referred to as "coarse particles". The following figures illustrate how very small these particles are.

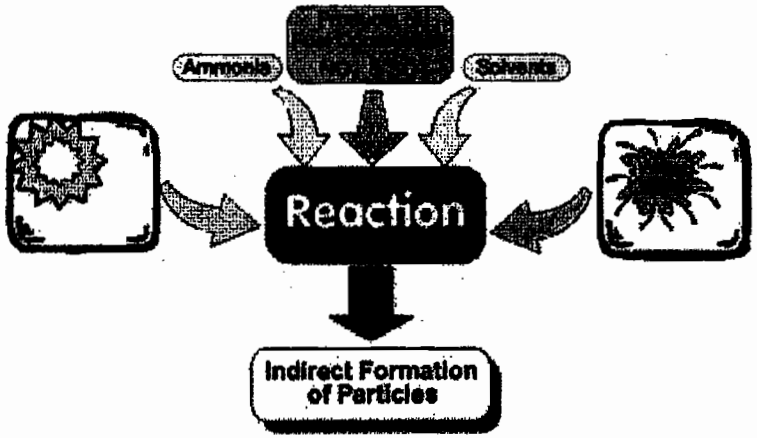


Ambient PM is made up of particles that are emitted directly, such as soot and fugitive dust, as well as secondary particles that are formed in the atmosphere from reactions involving precursor pollutants

such as oxides of nitrogen, sulfur oxides, volatile organic compounds, (NOx, SOx, and VOC), and ammonia. Secondary PM and combustion soot tend to be fine particles ($PM_{2.5}$) while fugitive dust is mostly coarse particles.



Some particles are directly emitted into the air. They come from a variety of sources such as cars, trucks, buses, industrial facilities, power plants, construction sites, tilled fields, unpaved roads, stone crushing, and burning of wood.



Other particles may be formed indirectly when gases from burning fuels react with sunlight and water vapor. These can result from fuel combustion in motor vehicles, at power plants, and in other industrial processes. Many combustion sources, such as motor vehicles and power plants, emit PM directly and also emit pollutants that form secondary PM.

What Kinds Of Problems Does PM Cause?

Human Health
Exposure to particulate pollution is linked to increased frequency and severity of asthma attacks and even premature death in people with pre-existing cardiac or respiratory disease. Those most sensitive to particulate pollution include infants and children, the elderly, and persons with heart and lung disease.

When we inhale, we breathe in air along with any particles that are in the air. The air and the particles travel into our respiratory system (the lungs and airway). Along the way the particles can stick to the sides of the airway or travel deeper into the lungs. The farther particles go, the worse the effect. Smaller particles can pass through the smaller airways.

Many scientific studies have linked breathing PM to a series of significant health problems, including:

- aggravated asthma
- increases in respiratory symptoms like coughing and difficult or painful breathing
- chronic bronchitis
- decreased lung function
- premature death

Visibility impairment
PM is the major cause of reduced visibility (haze) in the United States, including both urban and rural areas. PM reduction programs are underway in cities as well as places like the Grand Canyon and the Great Smokey Mountains National Parks where millions of tourists come every year to take in the views.

Atmospheric deposition
The smaller particles are lighter and stay in the air longer and travel farther. PM_{10} particles can stay in the air for minutes or hours while $PM_{2.5}$ particles can stay in the air for days or weeks before settling as deposition on surfaces. PM_{10} particles can travel as little as a hundred yards or as much as 30 miles. $PM_{2.5}$ particles can go even farther; many hundreds of miles before settling out. The effects of this settling include:

- making lakes and streams acidic
- changing the nutrient balance in coastal waters and large river basins
- depleting the nutrients in soil
- damaging sensitive forests and farm crops

Aesthetic damage
Certain types of PM, such as soot, can stain and damage stone and other materials, including culturally important objects such as historic buildings, monuments, and statues. Cleaning up these landmarks is expensive and time consuming.

What are PM conditions in the Bay Area?
The U.S. Environmental Protection Agency (U.S. EPA) and the California Air Resources Board (ARB) have adopted ambient air quality standards for PM_{10} and $PM_{2.5}$ (Table 1). California's standards are the most health-protective standards in the nation and are designed to provide additional protection for the most sensitive groups of people. According to ARB, attainment of California's standards is expected to result in the prevention of premature deaths, incidences of asthma among children, and over millions of lost work days per year.

	California Standard ($\mu g/m^3$)	National Standard ($\mu g/m^3$)
PM_{10} - Annual	20	50
PM_{10} - 24-hour	50	150
$PM_{2.5}$ - Annual	12	15
$PM_{2.5}$ - 24-hour	--	65

Table 1: State and National particulate patter ambient air quality standards. The levels of the standards are expressed in micrograms per cubic meter ($\mu g/m^3$).

Today, virtually all of California is considered to be in "nonattainment" for the State PM_{10} standard, with most urban areas, the Central Valley, and several other areas in nonattainment for the State $PM_{2.5}$ standard. The Bay Area is currently in attainment of the Federal PM_{10} and $PM_{2.5}$ standards but is classified as nonattainment for the more stringent State standards (Table 2).

	California Standard ($\mu g/m^3$)	National Standard ($\mu g/m^3$)
PM_{10} - Annual	Nonattainment	Attainment
PM_{10} - 24-hour	Nonattainment	Unclassified
$PM_{2.5}$ - Annual	Nonattainment	Attainment
$PM_{2.5}$ - 24-hour	--	Attainment

Table 2: Status of Bay Area Region with respect to the State and National particulate matter standards. Based on data available as of 11/23/2004.

What is being done about PM in the Bay Area?
The District implements a number of regulations and programs to reduce PM emissions. These include rules limiting direct PM emissions from open burning of agricultural and non-agricultural waste, controlling dust from earthmoving and construction/demolition operations, limiting emissions from various combustion sources such as cement kilns and furnaces, and reducing PM from composting and chipping activities. In addition, the District also enforces rules that limit indirect PM precursor emissions

such as NO x from power plants, industrial facilities, and other combustion sources, and VOCs from petroleum refineries, coatings and solvents, product manufacturing, fuel storage, transfer and dispensing activities, and many other industrial and commercial facilities.

The District also administers programs that deal specifically with emissions from wood-burning appliances such as fireplaces, wood stoves and heaters. These programs include the Spare the Air Tonight campaign that advises Bay Area residents not to burn wood on cold, stagnant winter evenings that create conditions for increased PM levels. The District has also developed a model wood burning ordinance for cities and counties, and administers incentive programs to replace older and dirtier wood-burning equipment with EPA-certified devices.

To reduce PM emissions from mobile sources, the District implements a variety of incentive programs that help fleet operators offset the cost of purchasing low-emission vehicles, re-powering old polluting heavy duty diesel engines, and installing emissions control devices that reduce particulates and NOx. These incentives are available for a wide variety of on-road and off-road equipment. In addition, one program focuses specifically on school buses while another deals specifically with refuse trucks. The District also operates a vehicle buy-back program to provide financial incentives to remove the oldest most polluting vehicles from our roadways.

What else is being done to reduce PM Pollution?

In 2003 the California Legislature enacted Senate Bill 656 (SB 656, Sher), codified as Health and Safety Code (H&SC) section 39614, to reduce public exposure to PM_{10} and $PM_{2.5}$. SB 656 requires ARB, in consultation with local air pollution control and air quality management districts (air districts), to develop and adopt, by January 1, 2005, a list of the most readily available, feasible, and cost-effective control measures that could be used by ARB and the air districts to reduce PM_{10} and $PM_{2.5}$ (collectively referred to as PM). The goal is to make progress toward attainment of State and national PM_{10} and $PM_{2.5}$ standards.

The proposed control measures are to be based on rules, regulations, and programs existing in California as of January 1, 2004 to reduce emissions from new, modified, and existing stationary, area, and mobile sources. By July 31, 2005, the bill requires the ARB and air districts to adopt implementation schedules for appropriate ARB and air district measures. Finally, no later than January 1, 2009, the ARB must prepare a report describing actions taken to fulfill the requirements of the legislation as well as recommendations for further actions to assist in achieving the State PM standards. The bill requirements sunset on January 1, 2011, unless extended.

For more information about SB 656 and to view related documents, please go to www.arb.ca.gov/pm/pmmeasures/pmmeasures.htm.

The District is currently developing a draft implementation schedule for new or expanded PM control measures. This process includes analyzing air monitoring and emissions inventory data to determine the sources of PM in the Bay Area. District staff is reviewing ARB's list of measures and comparing

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Appendix Z

4 of 7 DOCUMENTS

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*** THIS SECTION IS CURRENT THROUGH THE AUGUST 31, 2005 ISSUE OF ***
*** THE FEDERAL REGISTER ***

TITLE 40 -- PROTECTION OF ENVIRONMENT
CHAPTER I -- ENVIRONMENTAL PROTECTION AGENCY
SUBCHAPTER C -- AIR PROGRAMS
PART 51 -- REQUIREMENTS FOR PREPARATION, ADOPTION, AND SUBMITTAL OF IMPLEMENTATION PLANS
SUBPART X -- PROVISIONS FOR IMPLEMENTATION OF 8-HOUR OZONE NATIONAL AMBIENT AIR QUALITY STANDARD

Go to the CFR Archive Directory

40 CFR PART 51 ***APPENDIX W***

APPENDIX W TO PART 51 -- GUIDELINE ON AIR QUALITY MODELS

[PUBLISHER'S NOTE: Throughout the text of this section, many characters cannot be reproduced on LEXIS. For further reference, see the Federal Register for Apr. 15, 2003 *(68 FR 18440).]*

Preface

a. Industry and control agencies have long expressed a need for consistency in the application of air quality models for regulatory purposes. In the 1977 Clean Air Act, Congress mandated such consistency and encouraged the standardization of model applications. The Guideline on Air Quality Models (hereafter, Guideline) was first published in April 1978 to satisfy these requirements by specifying models and providing guidance for their use. The Guideline provides a common basis for estimating the air quality concentrations of criteria pollutants used in assessing control strategies and developing emission limits.

b. The continuing development of new air quality models in response to regulatory requirements and the expanded requirements for models to cover even more complex problems have emphasized the need for periodic review and update of guidance on these techniques. Three primary on-going activities provide direct input to revisions of the Guideline. The first is a series of annual EPA workshops conducted for the purpose of ensuring consistency and providing clarification in the application of models. The second activity is the solicitation and review of new models from the technical and user community. In the March 27, 1980 FEDERAL REGISTER, a procedure was outlined for the submittal to EPA of privately developed models. After extensive evaluation and scientific review, these models, as well as those made available by EPA, are considered for recognition in the Guideline. The third activity is the extensive on-going research efforts by EPA and others in air quality and meteorological modeling.

c. Based primarily on these three activities, new sections and topics are included as needed. EPA does not make changes to the guidance on a predetermined schedule, but rather on an as needed basis. EPA believes that revisions of the Guideline should be timely and responsive to user needs and should involve public participation to the greatest possible extent. All future changes to the guidance will be proposed and finalized in the FEDERAL REGISTER. Information on the current status of modeling guidance can always be obtained from EPA's Regional Offices.

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1.0 Introduction

a. The Guideline recommends air quality modeling techniques that should be applied to State Implementation Plan (SIP) revisions for existing sources and to new source reviews (NSR), including prevention of significant deterioration (PSD). (See Ref. 1, 2, 3). Applicable only to criteria air pollutants, it is intended for use by EPA Regional Offices in judging the adequacy of modeling analyses performed by EPA, State and local agencies and by industry. The guidance is appropriate for use by other Federal agencies and by State agencies with air quality and land management responsibilities. The Guideline serves to identify, for all interested parties, those techniques and data bases EPA considers acceptable. The Guideline is not intended to be a compendium of modeling techniques. Rather, it should serve as a common measure of acceptable technical analysis when supported by sound scientific judgement.

b. Due to limitations in the spatial and temporal coverage of air quality measurements, monitoring data normally are not sufficient as the sole basis for demonstrating the adequacy of emission limits for existing sources. Also, the impacts of new sources that do not yet exist can only be determined through modeling. Thus, models, while uniquely filling one program need, have become a primary analytical tool in most air quality assessments. Air quality measurements can be used in a complementary manner to dispersion models, with due regard for the strengths and weaknesses of both analysis techniques. Measurements are particularly useful in assessing the accuracy of model estimates. The use of air quality measurements alone however could be preferable, as detailed in a later section of this document, when models are found to be unacceptable and monitoring data with sufficient spatial and temporal coverage are available.

c. It would be advantageous to categorize the various regulatory programs and to apply a designated model to each proposed source needing analysis under a given program. However, the diversity of the nation's topography and climate, and variations in source configurations and operating characteristics dictate against a strict modeling "cookbook". There is no one model capable of properly addressing all conceivable situations even within a broad category such as point sources. Meteorological phenomena associated with threats to air quality standards are rarely amenable to a single mathematical treatment; thus, case-by-case analysis and judgement are frequently required. As modeling efforts become more complex, it is increasingly important that they be directed by highly competent individuals with a broad range of experience and knowledge in air quality meteorology. Further, they should be coordinated closely with specialists in emissions characteristics, air monitoring and data processing. The judgement of experienced meteorologists and analysts is essential.

d. The model that most accurately estimates concentrations in the area of interest is always sought. However, it is clear from the needs expressed by the States and EPA Regional Offices, by many industries and trade associations, and also by the deliberations of Congress, that consistency in the selection and application of models and data bases should also be sought, even in case-by-case analyses. Consistency ensures that air quality control agencies and the general

public have a common basis for estimating pollutant concentrations, assessing control strategies and specifying emission limits. Such consistency is not, however, promoted at the expense of model and data base accuracy. The Guideline provides a consistent basis for selection of the most accurate models and data bases for use in air quality assessments.

e. Recommendations are made in the Guideline concerning air quality models, data bases, requirements for concentration estimates, the use of measured data in lieu of model estimates, and model evaluation procedures. Models are identified for some specific applications. The guidance provided here should be followed in air quality analyses relative to State Implementation Plans and in supporting analyses required by EPA, State and local agency air programs. EPA may approve the use of another technique that can be demonstrated to be more appropriate than those recommended in this guide. This is discussed at greater length in Section 3. In all cases, the model applied to a given situation should be the one that provides the most accurate representation of atmospheric transport, dispersion, and chemical transformations in the area of interest. However, to ensure consistency, deviations from this guide should be carefully documented and fully supported.

f. From time to time situations arise requiring clarification of the intent of the guidance on a specific topic. Periodic workshops are held with the headquarters, Regional Office, State, and local agency modeling representatives to ensure consistency in modeling guidance and to promote the use of more accurate air quality models and data bases. The workshops serve to provide further explanations of Guideline requirements to the Regional Offices and workshop reports are issued with this clarifying information. In addition, findings from on-going research programs, new model submittals, or results from model evaluations and applications are continuously evaluated. Based on this information changes in the guidance may be indicated.

g. All changes to the Guideline must follow rulemaking requirements since the Guideline is codified in **Appendix W** of Part 51. EPA will promulgate proposed and final rules in the FEDERAL REGISTER to amend this Appendix. Ample opportunity for public comment will be provided for each proposed change and public hearings scheduled if requested.

h. A wide range of topics on modeling and data bases are discussed in the Guideline. Section 2 gives an overview of models and their appropriate use. Section 3 provides specific guidance on the use of "preferred" air quality models and on the selection of alternative techniques. Sections 4 through 7 provide recommendations on modeling techniques for application to simple-terrain stationary source problems, complex terrain problems, and mobile source problems. Specific modeling requirements for selected regulatory issues are also addressed. Section 8 discusses issues common to many modeling analyses, including acceptable model components. Section 9 makes recommendations for data inputs to models including source, meteorological and background air quality data. Section 10 covers the uncertainty in model estimates and how that information can be useful to the regulatory decision-maker. The last chapter summarizes how estimates and measurements of air quality are used in assessing source impact and in evaluating control strategies.

i. **Appendix W** to 40 CFR Part 51 itself contains an appendix: Appendix A. Thus, when reference is made to "Appendix A" in this document, it refers to Appendix A to **Appendix W** to 40 CFR Part 51. Appendix A contains summaries of refined air quality models that are "preferred" for specific applications; both EPA models and models developed by others are included.

2.0 Overview of Model Use

a. Before attempting to implement the guidance contained in this document, the reader should be aware of certain general information concerning air quality models and their use. Such information is provided in this section.

2.1 Suitability of Models

a. The extent to which a specific air quality model is suitable for the evaluation of source impact depends upon several factors. These include: (1) The meteorological and topographic complexities of the area; (2) the level of detail and accuracy needed for the analysis; (3) the technical competence of those undertaking such simulation modeling; (4) the resources available; and (5) the detail and accuracy of the data base, i.e., emissions inventory, meteorological data, and air quality data. Appropriate data should be available before any attempt is made to apply a model. A model that requires detailed, precise, input data should not be used when such data are unavailable. However, assuming the data are adequate, the greater the detail with which a model considers the spatial and temporal variations in emissions and meteorological conditions, the greater the ability to evaluate the source impact and to distinguish the effects of various control strategies.

b. Air quality models have been applied with the most accuracy, or the least degree of uncertainty, to simulations of long term averages in areas with relatively simple topography. Areas subject to major topographic influences

experience meteorological complexities that are extremely difficult to simulate. Although models are available for such circumstances, they are frequently site specific and resource intensive. In the absence of a model capable of simulating such complexities, only a preliminary approximation may be feasible until such time as better models and data bases become available.

c. Models are highly specialized tools. Competent and experienced personnel are an essential prerequisite to the successful application of simulation models. The need for specialists is critical when the more sophisticated models are used or the area being investigated has complicated meteorological or topographic features. A model applied improperly, or with inappropriate data, can lead to serious misjudgements regarding the source impact or the effectiveness of a control strategy.

d. The resource demands generated by use of air quality models vary widely depending on the specific application. The resources required depend on the nature of the model and its complexity, the detail of the data base, the difficulty of the application, and the amount and level of expertise required. The costs of manpower and computational facilities may also be important factors in the selection and use of a model for a specific analysis. However, it should be recognized that under some sets of physical circumstances and accuracy requirements, no present model may be appropriate. Thus, consideration of these factors should lead to selection of an appropriate model.

2.2 Levels of Sophistication of Models

a. There are two levels of sophistication of models. The first level consists of relatively simple estimation techniques that generally use preset, worst-case meteorological conditions to provide conservative estimates of the air quality impact of a specific source, or source category. These are called screening techniques or screening models. The purpose of such techniques is to eliminate the need of more detailed modeling for those sources that clearly will not cause or contribute to ambient concentrations in excess of either the National Ambient Air Quality Standards (NAAQS) (4) or the allowable prevention of significant deterioration (PSD) concentration increments. (2, 3) If a screening technique indicates that the concentration contributed by the source exceeds the PSD increment or the increment remaining to just meet the NAAQS, then the second level of more sophisticated models should be applied.

b. The second level consists of those analytical techniques that provide more detailed treatment of physical and chemical atmospheric processes, require more detailed and precise input data, and provide more specialized concentration estimates. As a result they provide a more refined and, at least theoretically, a more accurate estimate of source impact and the effectiveness of control strategies. These are referred to as refined models.

c. The use of screening techniques followed, as appropriate, by a more refined analysis is always desirable, however there are situations where the screening techniques are practically and technically the only viable option for estimating source impact. In such cases, an attempt should be made to acquire or improve the necessary data bases and to develop appropriate analytical techniques.

2.3 Availability of Models

a. For most of the screening and refined models discussed in the Guideline, codes, associated documentation and other useful information are available for download from EPA's Support Center for Regulatory Air Modeling (SCRAM) Internet Web site at http://www.epa.gov/scram001. A list of alternate models that can be used with case-by-case justification (subsection 3.2) and an example air quality analysis checklist are also posted on this Web site. This is a site with which modelers should become familiar.

3.0 Recommended Air Quality Models

a. This section recommends the approach to be taken in determining refined modeling techniques for use in regulatory air quality programs. The status of models developed by EPA, as well as those submitted to EPA for review and possible inclusion in this guidance, is discussed. The section also addresses the selection of models for individual cases and provides recommendations for situations where the preferred models are not applicable. Two additional sources of modeling guidance are the Model Clearinghouse and periodic Regional/State/Local Modelers workshops.

b. In this guidance, when approval is required for a particular modeling technique or analytical procedure, we often refer to the " appropriate reviewing authority ". In some EPA regions, authority for NSR and PSD permitting and related activities has been delegated to State and even local agencies. In these cases, such agencies are " representatives " of the respective regions. Even in these circumstances, the Regional Office retains the ultimate authority in decisions and approvals. Therefore, as discussed above and depending on the circumstances, the appropriate reviewing authority may be the Regional Office, Federal Land Manager(s), State agency(ies), or perhaps local agency(ies). In cases where review and approval comes solely from the Regional Office (sometimes stated as " Regional Administrator "), this will be

stipulated. If there is any question as to the appropriate reviewing authority, you should contact the Regional modeling contact (http://www.epa.gov/scram001/tt28.htm#regionalmodelingcontacts) in the appropriate EPA Regional Office, whose jurisdiction generally includes the physical location of the source in question and its expected impacts.

c. In all regulatory analyses, especially if other than preferred models are selected for use, early discussions among Regional Office staff, State and local control agencies, industry representatives, and where appropriate, the Federal Land Manager, are invaluable and are encouraged. Agreement on the data base(s) to be used, modeling techniques to be applied and the overall technical approach, prior to the actual analyses, helps avoid misunderstandings concerning the final results and may reduce the later need for additional analyses. The use of an air quality analysis checklist, such as is posted on EPA's Internet SCRAM Web site (subsection 2.3), and the preparation of a written protocol help to keep misunderstandings at a minimum.

d. It should not be construed that the preferred models identified here are to be permanently used to the exclusion of all others or that they are the only models available for relating emissions to air quality. The model that most accurately estimates concentrations in the area of interest is always sought. However, designation of specific models is needed to promote consistency in model selection and application.

e. The 1980 solicitation of new or different models from the technical community and the program whereby these models were evaluated, established a means by which new models are identified, reviewed and made available in the Guideline. There is a pressing need for the development of models for a wide range of regulatory applications. Refined models that more realistically simulate the physical and chemical process in the atmosphere and that more reliably estimate pollutant concentrations are needed. Thus, the solicitation of models is considered to be continuous.

3.1 Preferred Modeling Techniques

3.1.1 Discussion

a. EPA has developed models suitable for regulatory application. Other models have been submitted by private developers for possible inclusion in the Guideline. These refined models have undergone evaluation exercises (7, 8, 9, 10, 11, 12, 13, 14, 15) that include statistical measures of model performance in comparison with measured air quality data as suggested by the American Meteorological Society (16) and, where possible, peer scientific reviews. (17, 18, 19, 20, 21)

b. When a single model is found to perform better than others, it is recommended for application as a preferred model and listed in Appendix A. If no one model is found to clearly perform better through the evaluation exercise, then the preferred model listed in Appendix A is selected on the basis of other factors such as past use, public familiarity, cost or resource requirements, and availability. No further evaluation of a preferred model is required for a particular application if the EPA recommendations for regulatory use specified for the model in the Guideline are followed. Alternative models to those listed in Appendix A should generally be compared with measured air quality data when they are used for regulatory applications consistent with recommendations in subsection 3.2.

c. The solicitation of new refined models which are based on sounder scientific principles and which more reliably estimate pollutant concentrations is considered by EPA to be continuous. Models that are submitted in accordance with the established provisions will be evaluated as submitted. These requirements are:

i. The model must be computerized and functioning in a common computer code suitable for use on a variety of computer systems.

ii. The model must be documented in a user's guide which identifies the mathematics of the model, data requirements and program operating characteristics at a level of detail comparable to that available for currently recommended models.

iii. The model must be accompanied by a complete test data set including input parameters and output results. The test data must be included in the user's guide as well as provided in computer-readable form.

iv. The model must be useful to typical users, e.g., State air pollution control agencies, for specific air quality control problems. Such users should be able to operate the computer program(s) from available documentation.

v. The model documentation must include a comparison with air quality data (and/or tracer measurements) or with other well-established analytical techniques.

vi. The developer must be willing to make the model available to users at reasonable cost or make it available for public access through the Internet or National Technical Information Service: the model cannot be proprietary.

d. The evaluation process will include a determination of technical merit, in accordance with the above six items including the practicality of the model for use in ongoing regulatory programs. Each model will also be subjected to a performance evaluation for an appropriate data base and to a peer scientific review. Models for wide use (not just an isolated case) that are found to perform better will be proposed for inclusion as preferred models in future Guideline revisions.

3.1.2 Recommendations

a. Appendix A identifies refined models that are preferred for use in regulatory applications. If a model is required for a particular application, the user should select a model from that appendix. These models may be used without a formal demonstration of applicability as long as they are used as indicated in each model summary of Appendix A. Further recommendations for the application of these models to specific source problems are found in subsequent sections of the Guideline.

b. If changes are made to a preferred model without affecting the concentration estimates, the preferred status of the model is unchanged. Examples of modifications that do not affect concentrations are those made to enable use of a different computer or those that affect only the format or averaging time of the model results. However, when any changes are made, the Regional Administrator should require a test case example to demonstrate that the concentration estimates are not affected.

c. A preferred model should be operated with the options listed in Appendix A as "Recommendations for Regulatory Use." If other options are exercised, the model is no longer "preferred." Any other modification to a preferred model that would result in a change in the concentration estimates likewise alters its status as a preferred model. Use of the model must then be justified on a case-by-case basis.

3.2 Use of Alternative Models

3.2.1 Discussion

a. Selection of the best techniques for each individual air quality analysis is always encouraged, but the selection should be done in a consistent manner. A simple listing of models in this guide cannot alone achieve that consistency nor can it necessarily provide the best model for all possible situations. EPA reports (22, 23) are available to assist in developing a consistent approach when justifying the use of other than the preferred modeling techniques recommended in the Guideline. An ASTM reference (24) provides a general philosophy for developing and implementing advanced statistical evaluations of atmospheric dispersion models, and provides an example statistical technique to illustrate the application of this philosophy. An EPA reference (25) provides a statistical technique for evaluating model performance for predicting peak concentration values, as might be observed at individual monitoring locations. In many cases, this protocol should be considered preferentially to the material in Chapter 3 of reference 22. The procedures in these documents provide a general framework for objective decision-making on the acceptability of an alternative model for a given regulatory application. The documents contain procedures for conducting both the technical evaluation of the model and the field test or performance evaluation.

b. This section discusses the use of alternate modeling techniques and defines three situations when alternative models may be used.

3.2.2 Recommendations

a. Determination of acceptability of a model is a Regional Office responsibility. Where the Regional Administrator finds that an alternative model is more appropriate than a preferred model, that model may be used subject to the recommendations of this subsection. This finding will normally result from a determination that (1) a preferred air quality model is not appropriate for the particular application; or (2) a more appropriate model or analytical procedure is available and applicable.

b. An alternative model should be evaluated from both a theoretical and a performance perspective before it is selected for use. There are three separate conditions under which such a model may normally be approved for use: (1) If a demonstration can be made that the model produces concentration estimates equivalent to the estimates obtained using a preferred model; (2) if a statistical performance evaluation has been conducted using measured air quality data and the results of that evaluation indicate the alternative model performs better for the given application than a comparable model in Appendix A; or (3) if the preferred model is less appropriate for the specific application, or there is no preferred model. Any one of these three separate conditions may make use of an alternative model acceptable. Some known alternative models that are applicable for selected situations are listed on EPA's SCRAM Internet Web site

(subsection 2.3). However, inclusion there does not confer any unique status relative to other alternative models that are being or will be developed in the future.

c. Equivalency, condition (1) in paragraph (b) of this subsection, is established by demonstrating that the maximum or highest, second highest concentrations are within 2 percent of the estimates obtained from the preferred model. The option to show equivalency is intended as a simple demonstration of acceptability for an alternative model that is so nearly identical (or contains options that can make it identical) to a preferred model that it can be treated for practical purposes as the preferred model. Two percent was selected as the basis for equivalency since it is a rough approximation of the fraction that PSD Class I increments are of the NAAQS for SO<2>, i.e., the difference in concentrations that is judged to be significant. However, notwithstanding this demonstration, models that are not equivalent may be used when one of the two other conditions described in paragraphs (d) and (e) of this subsection are satisfied.

d. For condition (2) in paragraph (b) of this subsection, the procedures and techniques for determining the acceptability of a model for an individual case based on superior performance are contained in references 22-25 should be followed, as appropriate. Preparation and implementation of an evaluation protocol which is acceptable to both control agencies and regulated industry is an important element in such an evaluation.

e. Finally, for condition (3) in paragraph (b) of this subsection, an alternative refined model may be used provided that:

i. The model has received a scientific peer review;

ii. The model can be demonstrated to be applicable to the problem on a theoretical basis;

iii. The data bases which are necessary to perform the analysis are available and adequate;

iv. Appropriate performance evaluations of the model have shown that the model is not biased toward underestimates; and

v. A protocol on methods and procedures to be followed has been established.

3.3 Availability of Supplementary Modeling Guidance

a. The Regional Administrator has the authority to select models that are appropriate for use in a given situation. However, there is a need for assistance and guidance in the selection process so that fairness and consistency in modeling decisions is fostered among the various Regional Offices and the States. To satisfy that need, EPA established the Model Clearinghouse (5) and also holds periodic workshops with headquarters, Regional Office, State, and local agency modeling representatives.

b. The Regional Office should always be consulted for information and guidance concerning modeling methods and interpretations of modeling guidance, and to ensure that the air quality model user has available the latest most up-to-date policy and procedures. As appropriate, the Regional Office may request assistance from the Model Clearinghouse after an initial evaluation and decision has been reached concerning the application of a model, analytical technique or data base in a particular regulatory action.

4.0 Simple-Terrain Stationary Source Models

4.1 Discussion

a. Simple terrain, as used here, is considered to be an area where terrain features are all lower in elevation than the top of the stack of the source(s) in question. The models recommended in this section are generally used in the air quality impact analysis of stationary sources for most criteria pollutants. The averaging time of the concentration estimates produced by these models ranges from 1 hour to an annual average.

b. In the early 1980s, model evaluation exercises were conducted to determine the "best, most appropriate point source model" for use in simple terrain. (8, 17) No one model was found to be clearly superior and, based on past use, public familiarity, and availability, ISC (predecessor to ISC3 (26)) became the recommended model for a wide range of regulatory applications. Other refined models which also employed the basic Gaussian kernel, i.e., BLP, CALINE3, OCD, and EDMS, were developed for specialized applications (Appendix A). Performance evaluations were also made for these models, which are identified in Appendix A.

4.2 Recommendations

4.2.1 Screening Techniques

a. Where a preliminary or conservative estimate is desired, point source screening techniques are an acceptable approach to air quality analyses. EPA has published guidance for screening procedures, (27) and a computerized version of the recommended screening technique, SCREEN3, is available. (28)

b. All screening procedures should be adjusted to the site and problem at hand. Close attention should be paid to whether the area should be classified urban or rural in accordance with subsection 8.2.3. The climatology of the area should be studied to help define the worst-case meteorological conditions. Agreement should be reached between the model user and the appropriate reviewing authority (paragraph 3.0(b)) on the choice of the screening model for each analysis, and on the input data as well as the ultimate use of the results.

4.2.2 Refined Analytical Techniques

a. A brief description of preferred models for refined applications is found in Appendix A. Also listed in that appendix are the model input requirements, the standard options that should be selected when running the program, and output options.

b. When modeling for compliance with short term NAAQS and PSD increments is of primary concern, a short term model may be used to provide long term concentration estimates. The conversion from long term to short term concentration averages by any transformation technique is not acceptable in regulatory applications.

c. The state-of-the-science for modeling atmospheric deposition is evolving and the best techniques are currently being assessed and their results are being compared with observations. Consequently, the approach taken for any purpose should be coordinated with the appropriate reviewing authority (paragraph 3.0(b)).

5.0 Model Use in Complex Terrain

5.1 Discussion

a. For the purpose of the Guideline, complex terrain is defined as terrain exceeding the height of the stack being modeled. Complex terrain dispersion models are normally applied to stationary sources of pollutants such as SO[2] and particulates.

b. A major outcome from the EPA Complex Terrain Model Development project has been the publication of a refined dispersion model (CTDM) suitable for regulatory application to plume impaction assessments in complex terrain. (29) Although CTDM as originally produced was only applicable to those hours characterized as neutral or stable, a computer code for all stability conditions -- CTDMPLUS -- together with a user's guide, (30) and site specific meteorological and terrain data processors (31, 32) is available. Moreover, CTSCREEN, (33) a version of CTDMPLUS that does not require site specific meteorological data inputs, is also available as a screening technique.

c. The methods discussed in this section should be considered in two categories: (1) Screening techniques, and (2) the refined dispersion model, CTDMPLUS, discussed in this subsection and listed in Appendix A.

d. Continued improvements in ability to accurately model plume dispersion in complex terrain situations can be expected, e.g., from research on lee side effects due to terrain obstacles. New approaches to improve the ability of models to realistically simulate atmospheric physics, e.g., hybrid models which incorporate an accurate wind field analysis, will ultimately provide more appropriate tools for analyses. Such hybrid modeling techniques are also acceptable for regulatory applications after the appropriate demonstration and evaluation.(22)

5.2 Recommendations

a. Recommendations in this section apply primarily to those situations where the impaction of plumes on terrain at elevations equal to or greater than the plume centerline during stable atmospheric conditions are determined to be the problem. If a violation of any NAAQS or the controlling increment is indicated by using any of the preferred screening techniques, then a refined complex terrain model may be used. Phenomena such as fumigation, wind direction shear, lee-side effects, building wake- or terrain-induced downwash, deposition, chemical transformation, variable plume trajectories, and long range transport are not addressed by the recommendations in this section.

b. Where site specific data are used for either screening or refined complex terrain models, a data base of at least 1 full-year of meteorological data is preferred. If more data are available, they should be used. Meteorological data used in the analysis should be reviewed for both spatial and temporal representativeness.

c. Placement of receptors requires very careful attention when modeling in complex terrain. Often the highest concentrations are predicted to occur under very stable conditions, when the plume is near, or impinges on, the terrain.

The plume under such conditions may be quite narrow in the vertical, so that even relatively small changes in a receptor's location may substantially affect the predicted concentration. Receptors within about a kilometer of the source may be even more sensitive to location. Thus, a dense array of receptors may be required in some cases. In order to avoid excessively large computer runs due to such a large array of receptors, it is often desirable to model the area twice. The first model run would use a moderate number of receptors carefully located over the area of interest. The second model run would use a more dense array of receptors in areas showing potential for high concentrations, as indicated by the results of the first model run.

d. When CTSCREEN or CTDMPLUS is used, digitized contour data must be first processed by the CTDM Terrain Processor (32) to provide hill shape parameters in a format suitable for direct input to CTDMPLUS. Then the user supplies receptors either through an interactive program that is part of the model or directly, by using a text editor; using both methods to select receptors will generally be necessary to assure that the maximum concentrations are estimated by either model. In cases where a terrain feature may "appear to the plume" as smaller, multiple hills, it may be necessary to model the terrain both as a single feature and as multiple hills to determine design concentrations.

e. The user is encouraged to confer with the Regional Office if any unresolvable problems are encountered with any screening or refined analytical procedures, e.g., meteorological data, receptor siting, or terrain contour processing issues.

5.2.1 Screening Techniques

a. CTSCREEN (33) can be used to obtain conservative, yet realistic, worst-case estimates for receptors located on terrain above stack height. CTSCREEN accounts for the three-dimensional nature of plume and terrain interaction and requires detailed terrain data representative of the modeling domain. The model description and user's instructions are contained in the user's guide. (33) The terrain data must be digitized in the same manner as for CTDMPLUS and a terrain processor is available. (32) A discussion of the model's performance characteristics is provided in a technical paper. (34) CTSCREEN is designed to execute a fixed matrix of meteorological values for wind speed (u), standard deviation of horizontal and vertical wind speeds ([sigma][v], [sigma][w]), vertical potential temperature gradient (d[thetas]/dz), friction velocity (u[*]), Monin-Obukhov length (L), mixing height (z[i]) as a function of terrain height, and wind directions for both neutral/stable conditions and unstable convective conditions. Table 5-1 contains the matrix of meteorological variables that is used for each CTSCREEN analysis. There are 96 combinations, including exceptions, for each wind direction for the neutral/stable case, and 108 combinations for the unstable case. The specification of wind direction, however, is handled internally, based on the source and terrain geometry. Although CTSCREEN is designed to address a single source scenario, there are a number of options that can be selected on a case-by-case basis to address multi-source situations. However, the appropriate reviewing authority (paragraph 3.0(b)) should be consulted, and concurrence obtained, on the protocol for modeling multiple sources with CTSCREEN to ensure that the worst case is identified and assessed. The maximum concentration output from CTSCREEN represents a worst-case 1-hour concentration. Time-scaling factors of 0.7 for 3-hour, 0.15 for 24-hour and 0.03 for annual concentration averages are applied internally by CTSCREEN to the highest 1-hour concentration calculated by the model.

b. Placement of receptors requires very careful attention when modeling in complex terrain. Often the highest concentrations are predicted to occur under very stable conditions, when the plume is near, or impinges on, the terrain. The plume under such conditions may be quite narrow in the vertical, so that even relatively small changes in a receptor's location may substantially affect the predicted concentration. Receptors within about a kilometer of the source may be even more sensitive to location. Thus, a dense array of receptors may be required in some cases. In order to avoid excessively large computer runs due to such a large array of receptors, it is often desirable to model the area twice. The first model run would use a moderate number of receptors carefully located over the area of interest. The second model run would use a more dense array of receptors in areas showing potential for high concentrations, as indicated by the results of the first model run.

c. As mentioned above, digitized contour data must be preprocessed (32) to provide hill shape parameters in suitable input format. The user then supplies receptors either through an interactive program that is part of the model or directly, by using a text editor; using both methods to select receptors will generally be necessary to assure that the maximum concentrations are estimated by either model. In cases where a terrain feature may "appear to the plume" as smaller, multiple hills, it may be necessary to model the terrain both as a single feature and as multiple hills to determine design concentrations.

d. Other screening techniques, e.g., Valley (as implemented in SCREEN3 (28)), COMPLEX I (as implemented in ISC3 (26)), SHORTZ/LONGZ (35), and RTDM (36) may be acceptable for complex terrain cases where established procedures are used. The user is encouraged to confer with the appropriate reviewing authority (paragraph 3.0(b)) if any

unresolvable problems are encountered, e.g., applicability, meteorological data, receptor siting, or terrain contour processing issues.

5.2.2 Refined Analytical Techniques

a. When the results of the screening analysis demonstrate a possible violation of NAAQS or the controlling PSD increments, a more refined analysis may need to be conducted.

b. The Complex Terrain Dispersion Model PLus Algorithms for Unstable Situations (CTDMPLUS) is a refined air quality model that is preferred for use in all stability conditions for complex terrain applications. CTDMPLUS is a sequential model that requires five input files: (1) General program specifications; (2) a terrain data file; (3) a receptor file; (4) a surface meteorological data file; and (5) a user created meteorological profile data file. Two optional input files consist of hourly emissions parameters and a file containing upper air data from rawinsonde data files, e.g., a National Climatic Data Center TD-6201 file, unless there are no hours categorized as unstable in the record. The model description and user instructions are contained in Volume 1 of the User's Guide.(30) Separate publications (32, 31) describe the terrain preprocessor system and the meteorological preprocessor program. In Part I of a technical article (37) is a discussion of the model and its preprocessors; the model's performance characteristics are discussed in Part II of the same article. (38) The size of the CTDMPLUS executable file on a personal computer is approximately 360K bytes. The model produces hourly average concentrations of stable pollutants, i.e., chemical transformation or decay of species and settling/deposition are not simulated. To obtain concentration averages corresponding to the NAAQS, e.g., 3- or 24-hour, or annual averages, the user must execute a postprocessor program such as CHAVG. CTDMPLUS is applicable to all receptors on terrain elevations above stack top. However, the model contains no algorithms for simulating building downwash or the mixing or recirculation found in cavity zones in the lee of a hill. The path taken by a plume through an array of hills cannot be simulated. CTDMPLUS does not explicitly simulate calm meteorological periods, and for those situations the user should follow the guidance in subsection 9.3.4. The user should follow the recommendations in the User's Guide under General Program Specifications for: (1) Selecting mixed layer heights, (2) setting minimum scalar wind speed to 1 m/s, and (3) scaling wind direction with height. Close coordination with the Regional Office is essential to insure a consistent, technically sound application of this model.

c. The performance of CTDMPLUS is greatly improved by the use of meteorological data from several levels up to plume height. However, due to the vast range of source-plume-hill geometries possible in complex terrain, detailed requirements for meteorological monitoring in support of refined analyses using CTDMPLUS should be determined on a case-by-case basis. The following general guidance should be considered in the development of a meteorological monitoring protocol for regulatory applications of CTDMPLUS and reviewed in detail by the Regional Office before initiating any monitoring. As appropriate, EPA guidance (see reference 100) should be consulted for specific guidance on siting requirements for meteorological towers, selection and exposure of sensors, etc. As more experience is gained with the model in a variety of circumstances, more specific guidance may be developed.

d. Site specific meteorological data are critical to dispersion modeling in complex terrain and, consequently, the meteorological requirements are more demanding than for simple terrain. Generally, three different meteorological files (referred to as surface, profile, and rawin files) are needed to run CTDMPLUS in a regulatory mode.

e. The surface file is created by the meteorological preprocessor (METPRO) (31) based on site specific measurements or estimates of solar and/or net radiation, cloud cover and ceiling, and the mixed layer height. These data are used in METPRO to calculate the various surface layer scaling parameters (roughness length, friction velocity, and Monin-Obukhov length) which are needed to run the model. All of the user inputs required for the surface file are based either on surface observations or on measurements at or below 10m.

f. The profile data file is prepared by the user with site specific measurements (from at least three levels) of wind speed, wind direction, turbulence, and potential temperature. These measurements should be obtained up to the representative plume height(s) of interest (i.e., the plume height(s) under those conditions important to the determination of the design concentration). The representative plume height(s) of interest should be determined using an appropriate complex terrain screening procedure (e.g., CTSCREEN) and should be documented in the monitoring/modeling protocol. The necessary meteorological measurements should be obtained from an appropriately sited meteorological tower augmented by SODAR if the representative plume height(s) of interest exceed 100m. The meteorological tower need not exceed the lesser of the representative plume height of interest (the highest plume height if there is more than one plume height of interest) or 100m.

g. Locating towers on nearby terrain to obtain stack height or plume height measurements for use in profiles by CTDMPLUS should be avoided unless it can clearly be demonstrated that such measurements would be representative of conditions affecting the plume.

h. The rawin file is created by a second meteorological preprocessor (READ62) (31) based on NWS (National Weather Service) upper air data. The rawin file is used in CTDMPLUS to calculate vertical potential temperature gradients for use in estimating plume penetration in unstable conditions. The representativeness of the off-site NWS upper air data should be evaluated on a case-by-case basis.

i. In the absence of an appropriate refined model, screening results may need to be used to determine air quality impact and/or emission limits.

Table 5-1a. -- Neutral/Stable Meteorological Matrix for CTSCREEN

Variable	Specific values				
U (m/s)	1.0	2.0	3.0	4.0	5.0
[sigma][v] (m/s)	0.3	0.75			
[sigma][w] (m/s)	0.08	0.15	0.30	0.75	
[DELTA][thetas]/ [DELTA]z (K/m)	0.01	0.02	0.035		
WD	(Wind direction optimized internaly for each meteorological combination)				

Exceptions:

(1) If U [</=] 2 m/s and [sigma][v] [</=] 0.3 m/s, then include [sigma][w] = 0.04 m/s.

(2) If [sigma][w] = 0.75 m/s and U [>/=] 3.0 m/s, then [DELTA][thetas]/[DELTA]z is limited to [</=] 0.01 K/m.

(3) If U [>/=] 4 m/s, then [sigma]w [>/=] 0.15 m/s.

(4) [sigma][w] [</=] [sigma][v]

Table 5-1b. -- Unstable/Convective Meteorological Matrix for CTSCREEN

Variable	Specific values				
U (m/s)	1.0	2.0	3.0	4.0	5.0
u[*] (m/s)	0.1	0.3	0.5		
L (m)	-10	-50	-90		
[Delta][sigma]/ [Delta]z (K/m)	0.030 (potential temperature gradient above z[i])				
z[i] (m)	0.5h	1.0h	1.5h		
	(where h = terrain height)				

6.0 Models for Ozone, Particulate Matter, Carbon Monoxide, Nitrogen Dioxide, and Lead

6.1 Discussion

a. This section identifies modeling approaches or models appropriate for addressing ozone (O[3]) (1), carbon monoxide (CO), nitrogen dioxide (NO[2]), particulates (PM-2.5 <a> and PM-10), and lead. These pollutants are often associated with emissions from numerous sources. Generally, mobile sources contribute significantly to emissions of these pollutants or their precursors. For cases where it is of interest to estimate concentrations of CO or NO[2] near a single or small group of stationary sources, refer to Section 4. (Modeling approaches for SO[2] are discussed in Section 4.)

fn1 Modeling for attainment demonstrations for O[3] and PM-2.5 should be conducted in time to meet required SIP submission dates as provided for in the respective implementation rules. Information on implementation of the 8-hr O[3] and PM-2.5 standards is available at: http://www.epa.gov/ttn aaqs/.

b. Several of the pollutants mentioned in the preceding paragraph are closely related to each other in that they share common sources of emissions and/or are subject to chemical transformations of similar precursors. (39, 40) For

example, strategies designed to reduce ozone could have an effect on the secondary component of PM-2.5 and vice versa. Thus, it makes sense to use models which take into account the chemical coupling between O[3] and PM-2.5, when feasible. This should promote consistency among methods used to evaluate strategies for reducing different pollutants as well as consistency among the strategies themselves. Regulatory requirements for the different pollutants are likely to be due at different times. Thus, the following paragraphs identify appropriate modeling approaches for pollutants individually.

c. The NAAQS for ozone was revised on July 18, 1997 and is now based on an 8-hour averaging period. Models for ozone are needed primarily to guide choice of strategies to correct an observed ozone problem in an area not attaining the NAAQS for ozone. Use of photochemical grid models is the recommended means for identifying strategies needed to correct high ozone concentrations in such areas. Such models need to consider emissions of volatile organic compounds (VOC), nitrogen oxides (NO[X]) and carbon monoxide (CO), as well as means for generating meteorological data governing transport and dispersion of ozone and its precursors. Other approaches, such as Lagrangian or observational models may be used to guide choice of appropriate strategies to consider with a photochemical grid model. These other approaches may be sufficient to address ozone in an area where observed concentrations are near the NAAQS or only slightly above it. Such a decision needs to be made on a case-by-case basis in concert with the Regional Office.

d. A control agency with jurisdiction over one or more areas with significant ozone problems should review available ambient air quality data to assess whether the problem is likely to be significantly impacted by regional transport. (41) Choice of a modeling approach depends on the outcome of this review. In cases where transport is considered significant, use of a nested regional model may be the preferred approach. If the observed problem is believed to be primarily of local origin, use of a model with a single horizontal grid resolution and geographical coverage that is less than that of a regional model may suffice.

e. The fine particulate matter NAAQS, promulgated on July 18, 1997, includes particles with an aerodynamic diameter nominally less than or equal to 2.5 micrometers (PM-2.5). Models for PM-2.5 are needed to assess adequacy of a proposed strategy for meeting annual and/or 24-hour NAAQS for PM-2.5. PM-2.5 is a mixture consisting of several diverse components. Because chemical/physical properties and origins of each component differ, it may be appropriate to use either a single model capable of addressing several of the important components or to model primary and secondary components using different models. Effects of a control strategy on PM-2.5 is estimated from the sum of the effects on the components composing PM-2.5. Model users may refer to guidance (42) for further details concerning appropriate modeling approaches.

f. A control agency with jurisdiction over one or more areas with PM-2.5 problems should review available ambient air quality data to assess which components of PM-2.5 are likely to be major contributors to the problem. If it is determined that regional transport of secondary particulates, such as sulfates or nitrates, is likely to contribute significantly to the problem, use of a regional model may be the preferred approach. Otherwise, coverage may be limited to a domain that is urban scale or less. Special care should be taken to select appropriate geographical coverage for a modeling application. (42)

g. The NAAQS for PM-10 was promulgated in July 1987. A SIP development guide (43) is available to assist in PM-10 analyses and control strategy development. EPA promulgated regulations for PSD increments measured as PM-10 in a notice published on June 3, 1993. As an aid to assessing the impact on ambient air quality of particulate matter generated from prescribed burning activities, a reference (44) is available.

h. Models for assessing the impacts of particulate matter may involve dispersion models or receptor models, or a combination (depending on the circumstances). Receptor models focus on the behavior of the ambient environment at the point of impact as opposed to source-oriented dispersion models, which focus on the transport, diffusion, and transformation that begin at the source and continue to the receptor site. Receptor models attempt to identify and apportion sources by relating known sample compositions at receptors to measured or inferred compositions of source emissions. When complete and accurate emission inventories or meteorological characterization are unavailable, or unknown pollutant sources exist, receptor modeling may be necessary.

i. Models for assessing the impact of CO emissions are needed for a number of different purposes. Examples include evaluating effects of point sources, congested intersections and highways, as well as the cumulative effect of numerous sources of CO in an urban area.

j. Models for assessing the impact of sources on ambient NO[2] concentrations are primarily needed to meet new source review requirements, such as addressing the effect of a proposed source on PSD increments for annual

concentrations of NO[2]. Impact of an individual source on ambient NO[2] depends, in part, on the chemical environment into which the source's plume is to be emitted. There are several approaches for estimating effects of an individual source on ambient NO[2]. One approach is through use of a plume-in-grid algorithm imbedded within a photochemical grid model. However, because of the rigor and complexity involved, and because this approach may not be capable of defining sub-grid concentration gradients, the plume-in-grid approach may be impractical for estimating effects on an annual PSD increment. A second approach is to develop site specific conversion factors based on measurements. If it is not possible to develop site specific conversion factors and use of the plume-in-grid algorithm is also not feasible, other screening procedures may be considered.

k. In January 1999 (40 CFR part 58, Appendix D), EPA gave notice that concern about ambient lead impacts was being shifted away from roadways and toward a focus on stationary point sources. EPA has also issued guidance on siting ambient monitors in the vicinity of such sources. (45) For lead, the SIP should contain an air quality analysis to determine the maximum quarterly lead concentration resulting from major lead point sources, such as smelters, gasoline additive plants, etc. General guidance for lead SIP development is also available. (46)

6.2 Recommendations

6.2.1 Models for Ozone

a. Choice of Models for Multi-source Applications. Simulation of ozone formation and transport is a highly complex and resource intensive exercise. Control agencies with jurisdiction over areas with ozone problems are encouraged to use photochemical grid models, such as the Models-3/Community Multi-scale Air Quality (CMAQ) modeling system (47), to evaluate the relationship between precursor species and ozone. Judgement on the suitability of a model for a given application should consider factors that include use of the model in an attainment test, development of emissions and meteorological inputs to the model and choice of episodes to model. (41) Similar models for the 8-hour NAAQS and for the 1-hour NAAQS are appropriate.

b. Choice of Models to Complement Photochemical Grid Models. As previously noted, observational models, Lagrangian models, or the Empirical Kinetics Modeling Approach (EKMA) (48, 49) may be used to help guide choice of strategies to simulate with a photochemical grid model and to corroborate results obtained with a grid model. Receptor models have also been used to apportion sources of ozone precursors (e.g., VOC) in urban domains. EPA has issued guidance (41) in selecting appropriate techniques.

c. Estimating the Impact of Individual Sources. Choice of methods used to assess the impact of an individual source depends on the nature of the source and its emissions. Thus, model users should consult with the Regional Office to determine the most suitable approach on a case-by-case basis (subsection 3.2.2).

6.2.2 Models for Particulate Matter

6.2.2.1 PM-2.5

a. Choice of Models for Multi-source Applications. Simulation of phenomena resulting in high ambient PM-2.5 can be a multi-faceted and complex problem resulting from PM-2.5's existence as an aerosol mixture. Treating secondary components of PM-2.5, such as sulfates and nitrates, can be a highly complex and resource-intensive exercise. Control agencies with jurisdiction over areas with secondary PM-2.5 problems are encouraged to use models which integrate chemical and physical processes important in the formation, decay and transport of these species (e.g., Models-3/CMAQ (47) or REMSAD (50)). Primary components can be simulated using less resource-intensive techniques. Suitability of a modeling approach or mix of modeling approaches for a given application requires technical judgement (42), as well as professional experience in choice of models, use of the model(s) in an attainment test, development of emissions and meteorological inputs to the model and selection of days to model.

b. Choice of Analysis Techniques to Complement Air Quality Simulation Models. Receptor models may be used to corroborate predictions obtained with one or more air quality simulation models. They may also be potentially useful in helping to define specific source categories contributing to major components of PM-2.5. (42)

c. Estimating the Impact of Individual Sources. Choice of methods used to assess the impact of an individual source depends on the nature of the source and its emissions. Thus, model users should consult with the Regional Office to determine the most suitable approach on a case-by-case basis (subsection 3.2.2).

6.2.2.2 PM-10

a. Screening techniques like those identified in subsection 4.2.1 are applicable to PM-10. Conservative assumptions which do not allow removal or transformation are suggested for screening. Thus, it is recommended that subjectively

determined values for "half-life" or pollutant decay not be used as a surrogate for particle removal. Proportional models (rollback/forward) may not be applied for screening analysis, unless such techniques are used in conjunction with receptor modeling. (43)

b. Refined models such as those discussed in subsection 4.2.2 are recommended for PM-10. However, where possible, particle size, gas-to-particle formation, and their effect on ambient concentrations may be considered. For point sources of small particles and for source-specific analyses of complicated sources, use the appropriate recommended steady-state plume dispersion model (subsection 4.2.2). For guidance on determination of design concentrations, see paragraph 8.2.1.1(e).

c. Receptor models have proven useful for helping validate emission inventories and for corroborating source-specific impacts estimated by dispersion models. The Chemical Mass Balance (CMB) model is useful for apportioning impacts from localized sources. (51, 52, 53) Other receptor models, e.g., the Positive Matrix Factorization (PMF) model (54) and Unmix (55), which don't share some of CMB's constraints, have also been applied. In regulatory applications, dispersion models have been used in conjunction with receptor models to attribute source (or source category) contributions. Guidance is available for PM-10 sampling and analysis applicable to receptor modeling. (56)

d. Under certain conditions, recommended dispersion models may not be reliable. In such circumstances, the modeling approach should be approved by the Regional Office on a case-by-case basis. Analyses involving model calculations for stagnation conditions should also be justified on a case-by-case basis (subsection 8.2.8).

e. Fugitive dust usually refers to dust put into the atmosphere by the wind blowing over plowed fields, dirt roads or desert or sandy areas with little or no vegetation. Reentrained dust is that which is put into the air by reason of vehicles driving over dirt roads (or dirty roads) and dusty areas. Such sources can be characterized as line, area or volume sources. Emission rates may be based on site specific data or values from the general literature. Fugitive emissions include the emissions resulting from the industrial process that are not captured and vented through a stack but may be released from various locations within the complex. In some unique cases a model developed specifically for the situation may be needed. Due to the difficult nature of characterizing and modeling fugitive dust and fugitive emissions, it is recommended that the proposed procedure be cleared by the Regional Office for each specific situation before the modeling exercise is begun.

6.2.3 Models for Carbon Monoxide

a. Guidance is available for analyzing CO impacts at roadway intersections. (57) The recommended screening model for such analyses is CAL3QHC. (58, 59) This model combines CALINE3 (listed in Appendix A) with a traffic model to calculate delays and queues that occur at signalized intersections. The screening approach is described in reference 57; a refined approach may be considered on a case-by-case basis with CAL3QHCR. (60) The latest version of the MOBILE (mobile source emission factor) model should be used for emissions input to intersection models.

b. For analyses of highways characterized by uninterrupted traffic flows, CALINE3 is recommended, with emissions input from the latest version of the MOBILE model.

c. For urban area wide analyses of CO, an Eulerian grid model should be used. Information on SIP development and requirements for using such models can be found in several references. (57, 61, 62, 63)

d. Where point sources of CO are of concern, they should be treated using the screening and refined techniques described in Section 4.

6.2.4 Models for Nitrogen Dioxide (Annual Average)

a. A tiered screening approach is recommended to obtain annual average estimates of NO[2] from point sources for New Source Review analysis, including PSD, and for SIP planning purposes. This multi-tiered approach is conceptually shown in Figure 6-1 and described in paragraphs b through d of this subsection:

Display Image

b. For Tier 1 (the initial screen), use an appropriate model in subsection 4.2.2 to estimate the maximum annual average concentration and assume a total conversion of NO to NO[2]. If the concentration exceeds the NAAQS and/or PSD increments for NO[2], proceed to the 2nd level screen.

c. For Tier 2 (2nd level) screening analysis, multiply the Tier 1 estimate(s) by an empirically derived NO[2]/NO[X] value of 0.75 (annual national default). (64) The reviewing agency may establish an alternative default NO[2]/NO[X] ratio based on ambient annual average NO[2] and annual average NO[X] data representative of area wide quasi-

equilibrium conditions. Alternative default NO[2]/NO[X] ratios should be based on data satisfying quality assurance procedures that ensure data accuracy for both NO[2] and NO[X] within the typical range of measured values. In areas with relatively low NO[X] concentrations, the quality assurance procedures used to determine compliance with the NO[2] national ambient air quality standard may not be adequate. In addition, default NO[2]/NO[X] ratios, including the 0.75 national default value, can underestimate long range NO[2] impacts and should be used with caution in long range transport scenarios.

d. For Tier 3 (3rd level) analysis, a detailed screening method may be selected on a case-by-case basis. For point source modeling, other refined screening methods, such as the ozone limiting method, (65) may also be considered. Also, a site specific NO[2]/NO[X] ratio may be used as a detailed screening method if it meets the same restrictions as described for alternative default NO[2]/NO[X] ratios. Ambient NO[X] monitors used to develop a site specific ratio should be sited to obtain the NO[2] and NO[X] concentrations under quasi-equilibrium conditions. Data obtained from monitors sited at the maximum NO[X] impact site, as may be required in a PSD pre-construction monitoring program, likely reflect transitional NO[X] conditions. Therefore, NO[X] data from maximum impact sites may not be suitable for determining a site specific NO[2]/NO[X] ratio that is applicable for the entire modeling analysis. A site specific ratio derived from maximum impact data can only be used to estimate NO[2] impacts at receptors located within the same distance of the source as the source-to-monitor distance.

e. In urban areas (subsection 8.2.3), a proportional model may be used as a preliminary assessment to evaluate control strategies to meet the NAAQS for multiple minor sources, i.e., minor point, area and mobile sources of NO[X]; concentrations resulting from major point sources should be estimated separately as discussed above, then added to the impact of the minor sources. An acceptable screening technique for urban complexes is to assume that all NO[X] is emitted in the form of NO[2] and to use a model from Appendix A for nonreactive pollutants to estimate NO[2] concentrations. A more accurate estimate can be obtained by: (1) Calculating the annual average concentrations of NO[X] with an urban model, and (2) converting these estimates to NO[2] concentrations using an empirically derived annual NO[2]/NO[X] ratio. A value of 0.75 is recommended for this ratio. However, a spatially averaged alternative default annual NO[2]/NO[X] ratio may be determined from an existing air quality monitoring network and used in lieu of the 0.75 value if it is determined to be representative of prevailing ratios in the urban area by the reviewing agency. To ensure use of appropriate locally derived annual average NO[2] / NO[X] ratios, monitoring data under consideration should be limited to those collected at monitors meeting siting criteria defined in 40 CFR Part 58, Appendix D as representative of "neighborhood", "urban", or "regional" scales. Furthermore, the highest annual spatially averaged NO[2]/NO[X] ratio from the most recent 3 years of complete data should be used to foster conservatism in estimated impacts.

f. To demonstrate compliance with NO[2] PSD increments in urban areas, emissions from major and minor sources should be included in the modeling analysis. Point and area source emissions should be modeled as discussed above. If mobile source emissions do not contribute to localized areas of high ambient NO[2] concentrations, they should be modeled as area sources. When modeled as area sources, mobile source emissions should be assumed uniform over the entire highway link and allocated to each area source grid square based on the portion of highway link within each grid square. If localized areas of high concentrations are likely, then mobile sources should be modeled as line sources using an appropriate steady-state plume dispersion model (e.g., CAL3QHCR; subsection 6.2.3).

g. More refined techniques to handle special circumstances may be considered on a case-by-case basis and agreement with the appropriate reviewing authority (paragraph 3.0(b)) should be obtained. Such techniques should consider individual quantities of NO and NO[2] emissions, atmospheric transport and dispersion, and atmospheric transformation of NO to NO[2]. Where they are available, site specific data on the conversion of NO to NO[2] may be used. Photochemical dispersion models, if used for other pollutants in the area, may also be applied to the NO[X] problem.

6.2.5 Models for Lead

a. For major lead point sources, such as smelters, which contribute fugitive emissions and for which deposition is important, professional judgement should be used, and there should be coordination with the appropriate reviewing authority (paragraph 3.0(b)). To model an entire major urban area or to model areas without significant sources of lead emissions, as a minimum a proportional (rollback) model may be used for air quality analysis. The rollback philosophy assumes that measured pollutant concentrations are proportional to emissions. However, urban or other dispersion models are encouraged in these circumstances where the use of such models is feasible.

b. In modeling the effect of traditional line sources (such as a specific roadway or highway) on lead air quality, dispersion models applied for other pollutants can be used. Dispersion models such as CALINE3 and CAL3QHCR have

been used for modeling carbon monoxide emissions from highways and intersections (subsection 6.2.3). Where there is a point source in the middle of a substantial road network, the lead concentrations that result from the road network should be treated as background (subsection 9.2); the point source and any nearby major roadways should be modeled separately using the appropriate recommended steady-state plume dispersion model (subsection 4.2.2).

7.0 Other Model Requirements

7.1 Discussion

a. This section covers those cases where specific techniques have been developed for special regulatory programs. Most of the programs have, or will have when fully developed, separate guidance documents that cover the program and a discussion of the tools that are needed. The following paragraphs reference those guidance documents, when they are available. No attempt has been made to provide a comprehensive discussion of each topic since the reference documents were designed to do that. This section will undergo periodic revision as new programs are added and new techniques are developed.

b. Other Federal agencies have also developed specific modeling approaches for their own regulatory or other requirements. (66) Although such regulatory requirements and manuals may have come about because of EPA rules or standards, the implementation of such regulations and the use of the modeling techniques is under the jurisdiction of the agency issuing the manual or directive.

c. The need to estimate impacts at distances greater than 50km (the nominal distance to which EPA considers most steady-state Gaussian plume models are applicable) is an important one especially when considering the effects from secondary pollutants. Unfortunately, models originally available to EPA had not undergone sufficient field evaluation to be recommended for general use. Data bases from field studies at mesoscale and long range transport distances were limited in detail. This limitation was a result of the expense to perform the field studies required to verify and improve mesoscale and long range transport models. Meteorological data adequate for generating three-dimensional wind fields were particularly sparse. Application of models to complicated terrain compounds the difficulty of making good assessments of long range transport impacts. EPA completed limited evaluation of several long range transport (LRT) models against two sets of field data and evaluated results. (13) Based on the results, EPA concluded that long range and mesoscale transport models were limited for regulatory use to a case-by-case basis. However a more recent series of comparisons has been completed for a new model, CALPUFF (Section A.3). Several of these field studies involved three-to-four hour releases of tracer gas sampled along arcs of receptors at distances greater than 50km downwind. In some cases, short-term concentration sampling was available, such that the transport of the tracer puff as it passed the arc could be monitored. Differences on the order of 10 to 20 degrees were found between the location of the simulated and observed center of mass of the tracer puff. Most of the simulated centerline concentration maxima along each arc were within a factor of two of those observed. It was concluded from these case studies that the CALPUFF dispersion model had performed in a reasonable manner, and had no apparent bias toward over or under prediction, so long as the transport distance was limited to less than 300km. (67)

7.2 Recommendations

7.2.1 Visibility

a. Visibility in important natural areas (e.g., Federal Class I areas) is protected under a number of provisions of the Clean Air Act, including Sections 169A and 169B (addressing impacts primarily from existing sources) and Section 165 (new source review). Visibility impairment is caused by light scattering and light absorption associated with particles and gases in the atmosphere. In most areas of the country, light scattering by PM-2.5 is the most significant component of visibility impairment. The key components of PM-2.5 contributing to visibility impairment include sulfates, nitrates, organic carbon, elemental carbon, and crustal material.

b. The visibility regulations as promulgated in December 1980 (40 CFR 51.300-307) require States to mitigate visibility impairment, in any of the 156 mandatory Federal Class I areas, that is found to be "reasonably attributable" to a single source or a small group of sources. In 1985, EPA promulgated Federal Implementation Plans (FIPs) for several States without approved visibility provisions in their SIPs. The IMPROVE (Interagency Monitoring for Protected Visual Environments) monitoring network, a cooperative effort between EPA, the States, and Federal land management agencies, was established to implement the monitoring requirements in these FIPs. Data has been collected by the IMPROVE network since 1988.

c. In 1999, EPA issued revisions to the 1980 regulations to address visibility impairment in the form of regional haze, which is caused by numerous, diverse sources (e.g., stationary, mobile, and area sources) located across a broad

region (40 CFR 51.308-309). The state of relevant scientific knowledge has expanded significantly since the Clean Air Act Amendments of 1977. A number of studies and reports (68, 69) have concluded that long range transport (e.g., up to hundreds of kilometers) of fine particulate matter plays a significant role in visibility impairment across the country. Section 169A of the Act requires states to develop SIPs containing long-term strategies for remedying existing and preventing future visibility impairment in 156 mandatory Class I federal areas. In order to develop long-term strategies to address regional haze, many States will need to conduct regional-scale modeling of fine particulate concentrations and associated visibility impairment (e.g., light extinction and deciview metrics).

d. To calculate the potential impact of a plume of specified emissions for specific transport and dispersion conditions ("plume blight"), a screening model, VISCREEN, and guidance are available. (70) If a more comprehensive analysis is required, a refined model should be selected. The model selection (VISCREEN vs. PLUVUE II or some other refined model), procedures, and analyses should be determined in consultation with the appropriate reviewing authority (paragraph 3.0(b)) and the affected Federal Land Manager (FLM). FLMs are responsible for determining whether there is an adverse effect by a plume on a Class I area.

e. CALPUFF (Section A.3) may be applied when assessment is needed of reasonably attributable haze impairment or atmospheric deposition due to one or a small group of sources. This situation may involve more sources and larger modeling domains than that to which VISCREEN ideally may be applied. The procedures and analyses should be determined in consultation with the appropriate reviewing authority (paragraph 3.0(b)) and the affected FLM(s).

f. Regional scale models are used by EPA to develop and evaluate national policy and assist State and local control agencies. Two such models which can be used to assess visibility impacts from source emissions are Models-3/CMAQ (47) and REMSAD. (50) Model users should consult with the appropriate reviewing authority (paragraph 3.0(b)), which in this instance would include FLMs.

7.2.2 Good Engineering Practice Stack Height

a. The use of stack height credit in excess of Good Engineering Practice (GEP) stack height or credit resulting from any other dispersion technique is prohibited in the development of emission limitations by *40 CFR 51.118* and *40 CFR 51.164*. The definitions of GEP stack height and dispersion technique are contained in *40 CFR 51.100*. Methods and procedures for making the appropriate stack height calculations, determining stack height credits and an example of applying those techniques are found in several references (71, 72, 73, 74), which provide a great deal of additional information for evaluating and describing building cavity and wake effects.

b. If stacks for new or existing major sources are found to be less than the height defined by EPA's refined formula for determining GEP height, then air quality impacts associated with cavity or wake effects due to the nearby building structures should be determined. The EPA refined formula height is defined as $H + 1.5L$ (see reference 73). Detailed downwash screening procedures (27) for both the cavity and wake regions should be followed. If more refined concentration estimates are required, the recommended steady-state plume dispersion model in subsection 4.2.2 contains algorithms for building wake calculations and should be used.

7.2.3 Long Range Transport (LRT) (i.e., Beyond 50km)

a. Section 165(d) of the Clean Air Act requires that suspected adverse impacts on PSD Class I areas be determined. However, 50km is the useful distance to which most steady-state Gaussian plume models are considered accurate for setting emission limits. Since in many cases PSD analyses show that Class I areas may be threatened at distances greater than 50km from new sources, some procedure is needed to (1) determine if an adverse impact will occur, and (2) identify the model to be used in setting an emission limit if the Class I increments are threatened. In addition to the situations just described, there are certain applications containing a mixture of both long range and short range source-receptor relationships in a large modeled domain (e.g., several industrialized areas located along a river or valley). Historically, these applications have presented considerable difficulty to an analyst if impacts from sources having transport distances greater than 50km significantly contributed to the design concentrations. To properly analyze applications of this type, a modeling approach is needed which has the capability of combining, in a consistent manner, impacts involving both short and long range transport. The CALPUFF modeling system, listed in Appendix A, has been designed to accommodate both the Class I area LRT situation and the large modeling domain situation. Given the judgement and refinement involved, conducting a LRT modeling assessment will require significant consultation with the appropriate reviewing authority (paragraph 3.0(b)) and the affected FLM(s). The FLM has an affirmative responsibility to protect air quality related values (AQRVs) that may be affected, and to provide the appropriate procedures and analysis techniques. Where there is no increment violation, the ultimate decision on whether a Class I area is adversely affected is the responsibility of the appropriate reviewing authority (Section 165(d)(2)(C)(ii) of the

Clean Air Act), taking into consideration any information on the impacts on AQRVs provided by the FLM. According to Section 165(d)(2)(C)(iii) of the Clean Air Act, if there is a Class I increment violation, the source must demonstrate to the satisfaction of the FLM that the emissions from the source will have no adverse impact on the AQRVs.

b. If LRT is determined to be important, then refined estimates utilizing the CALPUFF modeling system should be obtained. A screening approach (67, 75) is also available for use on a case-by-case basis that generally provides concentrations that are higher than those obtained using refined characterizations of the meteorological conditions. The meteorological input data requirements for developing the time and space varying three-dimensional winds and dispersion meteorology for refined analyses are discussed in paragraph 9.3.1.2(d). Additional information on applying this model is contained in Appendix A. To facilitate use of complex air quality and meteorological modeling systems, a written protocol approved by the appropriate reviewing authority (paragraph 3.0(b)) and the affected FLM(s) may be considered for developing consensus in the methods and procedures to be followed.

7.2.4 Modeling Guidance for Other Governmental Programs

a. When using the models recommended or discussed in the Guideline in support of programmatic requirements not specifically covered by EPA regulations, the model user should consult the appropriate Federal or State agency to ensure the proper application and use of the models. For modeling associated with PSD permit applications that involve a Class I area, the appropriate Federal Land Manager should be consulted on all modeling questions.

b. The Offshore and Coastal Dispersion (OCD) model, described in Appendix A, was developed by the Minerals Management Service and is recommended for estimating air quality impact from offshore sources on onshore, flat terrain areas. The OCD model is not recommended for use in air quality impact assessments for onshore sources. Sources located on or just inland of a shoreline where fumigation is expected should be treated in accordance with subsection 8.2.8.

c. The Emissions and Dispersion Modeling System (EDMS), described in Appendix A, was developed by the Federal Aviation Administration and the United States Air Force and is recommended for air quality assessment of primary pollutant impacts at airports or air bases. Regulatory application of EDMS is intended for estimating the cumulative effect of changes in aircraft operations, point source, and mobile source emissions on pollutant concentrations. It is not intended for PSD, SIP, or other regulatory air quality analyses of point or mobile sources at or peripheral to airport property that are independent of changes in aircraft operations. If changes in other than aircraft operations are associated with analyses, a model recommended in Chapter 4 or 5 should be used.

8.0 General Modeling Considerations

8.1 Discussion

a. This section contains recommendations concerning a number of different issues not explicitly covered in other sections of this guide. The topics covered here are not specific to any one program or modeling area but are common to nearly all modeling analyses for criteria pollutants.

8.2 Recommendations

8.2.1 Design Concentrations (see also subsection 11.2.3.1)

8.2.1.1 Design Concentrations for SO[2], PM-10, CO, Pb, and NO[2]

a. An air quality analysis for SO[2], PM-10, CO, Pb, and NO[2] is required to determine if the source will (1) cause a violation of the NAAQS, or (2) cause or contribute to air quality deterioration greater than the specified allowable PSD increment. For the former, background concentration (subsection 9.2) should be added to the estimated impact of the source to determine the design concentration. For the latter, the design concentration includes impact from all increment consuming sources.

b. If the air quality analyses are conducted using the period of meteorological input data recommended in subsection 9.3.1.2 (e.g., 5 years of National Weather Service (NWS) data or at least 1 year of site specific data; subsection 9.3.3), then the design concentration based on the highest, second-highest short term concentration or the highest long term average, whichever is controlling, should be used to determine emission limitations to assess compliance with the NAAQS and PSD increments.

c. When sufficient and representative data exist for less than a 5-year period from a nearby NWS site, or when site specific data have been collected for less than a full continuous year, or when it has been determined that the site specific data may not be temporally representative (subsection 9.3.3), then the highest concentration estimate should be

considered the design value. This is because the length of the data record may be too short to assure that the conditions producing worst-case estimates have been adequately sampled. The highest value is then a surrogate for the concentration that is not to be exceeded more than once per year (the wording of the deterministic standards). Also, the highest concentration should be used whenever selected worst-case conditions are input to a screening technique, as described in EPA guidance. (27)

d. If the controlling concentration is an annual average value and multiple years of data (site specific or NWS) are used, then the design value is the highest of the annual averages calculated for the individual years. If the controlling concentration is a quarterly average and multiple years are used, then the highest individual quarterly average should be considered the design value.

e. As long a period of record as possible should be used in making estimates to determine design values and PSD increments. If more than 1 year of site specific data is available, it should be used.

8.2.1.2 Design Concentrations for O[3] and PM-2.5

a. Guidance and specific instructions for the determination of the 1-hr and 8-hr design concentrations for ozone are provided in Appendix H and I (respectively) of reference 4. Appendix H explains how to determine when the expected number of days per calendar year with maximum hourly concentrations above the NAAQS is equal to or less than 1. Appendix I explains the data handling conventions and computations necessary for determining whether the 8-hour primary and secondary NAAQS are met at an ambient monitoring site. For PM-2.5, Appendix N of reference 4, and supplementary guidance (76), explain the data handling conventions and computations necessary for determining when the annual and 24-hour primary and secondary NAAQS are met. For all SIP revisions the user should check with the Regional Office to obtain the most recent guidance documents and policy memoranda concerning the pollutant in question. There are currently no PSD increments for O[3] and PM-2.5.

8.2.2 Critical Receptor Sites

a. Receptor sites for refined modeling should be utilized in sufficient detail to estimate the highest concentrations and possible violations of a NAAQS or a PSD increment. In designing a receptor network, the emphasis should be placed on receptor resolution and location, not total number of receptors. The selection of receptor sites should be a case-by-case determination taking into consideration the topography, the climatology, monitor sites, and the results of the initial screening procedure. For large sources (those equivalent to a 500MW power plant) and where violations of the NAAQS or PSD increment are likely, 360 receptors for a polar coordinate grid system and 400 receptors for a rectangular grid system, where the distance from the source to the farthest receptor is 10km, are usually adequate to identify areas of high concentration. Additional receptors may be needed in the high concentration location if greater resolution is indicated by terrain or source factors.

8.2.3 Dispersion Coefficients

a. Steady-state Gaussian plume models used in most applications should employ dispersion coefficients consistent with those contained in the preferred models in Appendix A. Factors such as averaging time, urban/rural surroundings (see paragraphs (b)-(f) of this subsection), and type of source (point vs. line) may dictate the selection of specific coefficients. Coefficients used in some Appendix A models are identical to, or at least based on, Pasquill-Gifford coefficients (77) in rural areas and McElroy-Pooler (78) coefficients in urban areas. (79)

b. The selection of either rural or urban dispersion coefficients in a specific application should follow one of the procedures suggested by Irwin (80) and briefly described in paragraphs (c)-(f) of this subsection. These include a land use classification procedure or a population based procedure to determine whether the character of an area is primarily urban or rural.

c. Land Use Procedure: (1) Classify the land use within the total area, A[o], circumscribed by a 3km radius circle about the source using the meteorological land use typing scheme proposed by Auer (81); (2) if land use types I1, I2, C1, R2, and R3 account for 50 percent or more of A[o], use urban dispersion coefficients; otherwise, use appropriate rural dispersion coefficients.

d. Population Density Procedure: (1) Compute the average population density, p per square kilometer with A[o] as defined above; (2) If p is greater than 750 people/km<2>, use urban dispersion coefficients; otherwise use appropriate rural dispersion coefficients.

e. Of the two methods, the land use procedure is considered more definitive. Population density should be used with caution and should not be applied to highly industrialized areas where the population density may be low and thus

a rural classification would be indicated, but the area is sufficiently built-up so that the urban land use criteria would be satisfied. In this case, the classification should already be "urban" and urban dispersion parameters should be used.

f. Sources located in an area defined as urban should be modeled using urban dispersion parameters. Sources located in areas defined as rural should be modeled using the rural dispersion parameters. For analyses of whole urban complexes, the entire area should be modeled as an urban region if most of the sources are located in areas classified as urban.

g. Buoyancy-induced dispersion (BID), as identified by Pasquill(82), is included in the preferred models and should be used where buoyant sources, e.g., those involving fuel combustion, are involved.

8.2.4 Stability Categories

a. The Pasquill approach to classifying stability is commonly used in preferred models (Appendix A). The Pasquill method, as modified by Turner (83), was developed for use with commonly observed meteorological data from the National Weather Service and is based on cloud cover, insolation and wind speed.

b. Procedures to determine Pasquill stability categories from other than NWS data are found in subsection 9.3. Any other method to determine Pasquill stability categories must be justified on a case-by-case basis.

c. For a given model application where stability categories are the basis for selecting dispersion coefficients, both [sigma][y] and [sigma][z] should be determined from the same stability category. "Split sigmas" in that instance are not recommended. Sector averaging, which eliminates the [sigma][y] term, is commonly acceptable in complex terrain screening methods.

8.2.5 Plume Rise

a. The plume rise methods of Briggs (84, 85) are incorporated in many of the preferred models and are recommended for use in many modeling applications. In the convective boundary layer, plume rise is superposed on the displacements by random convective velocities. (86) No explicit provisions in these models are made for multistack plume rise enhancement or the handling of such special plumes as flares; these problems should be considered on a case-by-case basis.

b. Gradual plume rise is generally recommended where its use is appropriate: (1) In complex terrain screening procedures to determine close-in impacts and (2) when calculating the effects of building wakes. If the building wake is calculated to affect the plume for any hour, gradual plume rise is also used in downwind dispersion calculations to the distance of final plume rise, after which final plume rise is used. Plumes captured by the near wake are re-emitted to the far wake as a ground-level volume source.

c. Stack tip downwash generally occurs with poorly constructed stacks and when the ratio of the stack exit velocity to wind speed is small. An algorithm developed by Briggs (85) is the recommended technique for this situation and is found in the point source preferred models.

8.2.6 Chemical Transformation

a. The chemical transformation of SO[2] emitted from point sources or single industrial plants in rural areas is generally assumed to be relatively unimportant to the estimation of maximum concentrations when travel time is limited to a few hours. However, in urban areas, where synergistic effects among pollutants are of considerable consequence, chemical transformation rates may be of concern. In urban area applications, a half-life of 4 hours (83) may be applied to the analysis of SO[2] emissions. Calculations of transformation coefficients from site specific studies can be used to define a "half-life" to be used in a steady-state Gaussian plume model with any travel time, or in any application, if appropriate documentation is provided. Such conversion factors for pollutant half-life should not be used with screening analyses.

b. Use of models incorporating complex chemical mechanisms should be considered only on a case-by-case basis with proper demonstration of applicability. These are generally regional models not designed for the evaluation of individual sources but used primarily for region-wide evaluations. Visibility models also incorporate chemical transformation mechanisms which are an integral part of the visibility model itself and should be used in visibility assessments.

8.2.7 Gravitational Settling and Deposition

a. An "infinite half-life" should be used for estimates of particle concentrations when steady-state Gaussian plume models containing only exponential decay terms for treating settling and deposition are used.

b. Gravitational settling and deposition may be directly included in a model if either is a significant factor. When particulate matter sources can be quantified and settling and dry deposition are problems, professional judgement should be used, and there should be coordination with the appropriate reviewing authority (paragraph 3.0(b)).

8.2.8 Complex Winds

a. Inhomogeneous Local Winds. In many parts of the United States, the ground is neither flat nor is the ground cover (or land use) uniform. These geographical variations can generate local winds and circulations, and modify the prevailing ambient winds and circulations. Geographic effects are most apparent when the ambient winds are light or calm. (87) In general these geographically induced wind circulation effects are named after the source location of the winds, e.g., lake and sea breezes, and mountain and valley winds. In very rugged hilly or mountainous terrain, along coastlines, or near large land use variations, the characterization of the winds is a balance of various forces, such that the assumptions of steady-state straight-line transport both in time and space are inappropriate. In the special cases described, the CALPUFF modeling system (described in Appendix A) may be applied on a case-by-case basis for air quality estimates in such complex non-steady-state meteorological conditions. The purpose of choosing a modeling system like CALPUFF is to fully treat the time and space variations of meteorology effects on transport and dispersion. The setup and application of the model should be determined in consultation with the appropriate reviewing authority (paragraph 3.0(b)) consistent with limitations of paragraph 3.2.2(e). The meteorological input data requirements for developing the time and space varying three-dimensional winds and dispersion meteorology for these situations are discussed in paragraph 9.3.1.2(d). Examples of inhomogeneous winds include, but aren't limited to, situations described in the following paragraphs (i)-(iii):

i. Inversion Breakup Fumigation. Inversion breakup fumigation occurs when a plume (or multiple plumes) is emitted into a stable layer of air and that layer is subsequently mixed to the ground through convective transfer of heat from the surface or because of advection to less stable surroundings. Fumigation may cause excessively high concentrations but is usually rather short-lived at a given receptor. There are no recommended refined techniques to model this phenomenon. There are, however, screening procedures 27 that may be used to approximate the concentrations. Considerable care should be exercised in using the results obtained from the screening techniques.

ii. Shoreline Fumigation. Fumigation can be an important phenomenon on and near the shoreline of bodies of water. This can affect both individual plumes and area-wide emissions. When fumigation conditions are expected to occur from a source or sources with tall stacks located on or just inland of a shoreline, this should be addressed in the air quality modeling analysis. The Shoreline Dispersion Model (SDM) listed on EPA's Internet SCRAM Web site (subsection 2.3) may be applied on a case-by-case basis when air quality estimates under shoreline fumigation conditions are needed. (88) Information on the results of EPA's evaluation of this model together with other coastal fumigation models is available. (89) Selection of the appropriate model for applications where shoreline fumigation is of concern should be determined in consultation with the appropriate reviewing authority (paragraph 3.0(b)).

iii. Stagnation. Stagnation conditions are characterized by calm or very low wind speeds, and variable wind directions. These stagnant meteorological conditions may persist for several hours to several days. During stagnation conditions, the dispersion of air pollutants, especially those from low-level emissions sources, tends to be minimized, potentially leading to relatively high ground-level concentrations. If point sources are of interest, users should note the guidance provided for CALPUFF in paragraph (a) of this subsection. Selection of the appropriate model for applications where stagnation is of concern should be determined in consultation with the appropriate reviewing authority (paragraph 3.0(b)).

8.2.9 Calibration of Models

a. Calibration of models is not common practice and is subject to much error and misunderstanding. There have been attempts by some to compare model estimates and measurements on an event-by-event basis and then to calibrate a model with results of that comparison. This approach is severely limited by uncertainties in both source and meteorological data and therefore it is difficult to precisely estimate the concentration at an exact location for a specific increment of time. Such uncertainties make calibration of models of questionable benefit. Therefore, model calibration is unacceptable.

9.0 Model Input Data

a. Data bases and related procedures for estimating input parameters are an integral part of the modeling procedure. The most appropriate data available should always be selected for use in modeling analyses. Concentrations can vary widely depending on the source data or meteorological data used. Input data are a major source of uncertainties in any

modeling analysis. This section attempts to minimize the uncertainty associated with data base selection and use by identifying requirements for data used in modeling. A checklist of input data requirements for modeling analyses is posted on EPA's Internet SCRAM Web site (subsection 2.3). More specific data requirements and the format required for the individual models are described in detail in the users' guide for each model.

9.1 Source Data

9.1.1 Discussion

a. Sources of pollutants can be classified as point, line and area/volume sources. Point sources are defined in terms of size and may vary between regulatory programs. The line sources most frequently considered are roadways and streets along which there are well-defined movements of motor vehicles, but they may be lines of roof vents or stacks such as in aluminum refineries. Area and volume sources are often collections of a multitude of minor sources with individually small emissions that are impractical to consider as separate point or line sources. Large area sources are typically treated as a grid network of square areas, with pollutant emissions distributed uniformly within each grid square.

b. Emission factors are compiled in an EPA publication commonly known as AP-42 (90); an indication of the quality and amount of data on which many of the factors are based is also provided. Other information concerning emissions is available in EPA publications relating to specific source categories. The appropriate reviewing authority (paragraph 3.0(b)) should be consulted to determine appropriate source definitions and for guidance concerning the determination of emissions from and techniques for modeling the various source types.

9.1.2 Recommendations

a. For point source applications the load or operating condition that causes maximum ground-level concentrations should be established. As a minimum, the source should be modeled using the design capacity (100 percent load). If a source operates at greater than design capacity for periods that could result in violations of the standards or PSD increments, this load (2) should be modeled. Where the source operates at substantially less than design capacity, and the changes in the stack parameters associated with the operating conditions could lead to higher ground level concentrations, loads such as 50 percent and 75 percent of capacity should also be modeled. A range of operating conditions should be considered in screening analyses; the load causing the highest concentration, in addition to the design load, should be included in refined modeling. For a steam power plant, the following (b-h) is typical of the kind of data on source characteristics and operating conditions that may be needed. Generally, input data requirements for air quality models necessitate the use of metric units; where English units are common for engineering usage, a conversion to metric is required.

fn2 Malfunctions which may result in excess emissions are not considered to be a normal operating condition. They generally should not be considered in determining allowable emissions. However, if the excess emissions are the result of poor maintenance, careless operation, or other preventable conditions, it may be necessary to consider them in determining source impact.

b. Plant layout. The connection scheme between boilers and stacks, and the distance and direction between stacks, building parameters (length, width, height, location and orientation relative to stacks) for plant structures which house boilers, control equipment, and surrounding buildings within a distance of approximately five stack heights.

c. Stack parameters. For all stacks, the stack height and inside diameter (meters), and the temperature (K) and volume flow rate (actual cubic meters per second) or exit gas velocity (meters per second) for operation at 100 percent, 75 percent and 50 percent load.

d. Boiler size. For all boilers, the associated megawatts, 10<6> BTU/hr, and pounds of steam per hour, and the design and/or actual fuel consumption rate for 100 percent load for coal (tons/hour), oil (barrels/hour), and natural gas (thousand cubic feet/hour).

e. Boiler parameters. For all boilers, the percent excess air used, the boiler type (e.g., wet bottom, cyclone, etc.), and the type of firing (e.g., pulverized coal, front firing, etc.).

f. Operating conditions. For all boilers, the type, amount and pollutant contents of fuel, the total hours of boiler operation and the boiler capacity factor during the year, and the percent load for peak conditions.

g. Pollution control equipment parameters. For each boiler served and each pollutant affected, the type of emission control equipment, the year of its installation, its design efficiency and mass emission rate, the date of the last test and

the tested efficiency, the number of hours of operation during the latest year, and the best engineering estimate of its projected efficiency if used in conjunction with coal combustion; data for any anticipated modifications or additions.

h. Data for new boilers or stacks. For all new boilers and stacks under construction and for all planned modifications to existing boilers or stacks, the scheduled date of completion, and the data or best estimates available for items (b) through (g) of this subsection following completion of construction or modification.

i. In stationary point source applications for compliance with short term ambient standards, SIP control strategies should be tested using the emission input shown on Table 9-1. When using a refined model, sources should be modeled sequentially with these loads for every hour of the year. To evaluate SIPs for compliance with quarterly and annual standards, emission input data shown in Table 9-1 should again be used. Emissions from area sources should generally be based on annual average conditions. The source input information in each model user's guide should be carefully consulted and the checklist (paragraph 9.0(a)) should also be consulted for other possible emission data that could be helpful. PSD and NAAQS compliance demonstrations should follow the emission input data shown in Table 9-2. For purposes of emissions trading, new source review and demonstrations, refer to current EPA policy and guidance to establish input data.

j. Line source modeling of streets and highways requires data on the width of the roadway and the median strip, the types and amounts of pollutant emissions, the number of lanes, the emissions from each lane and the height of emissions. The location of the ends of the straight roadway segments should be specified by appropriate grid coordinates. Detailed information and data requirements for modeling mobile sources of pollution are provided in the user's manuals for each of the models applicable to mobile sources.

k. The impact of growth on emissions should be considered in all modeling analyses covering existing sources. Increases in emissions due to planned expansion or planned fuel switches should be identified. Increases in emissions at individual sources that may be associated with a general industrial/commercial/residential expansion in multi-source urban areas should also be treated. For new sources the impact of growth on emissions should generally be considered for the period prior to the start-up date for the source. Such changes in emissions should treat increased area source emissions, changes in existing point source emissions which were not subject to preconstruction review, and emissions due to sources with permits to construct that have not yet started operation.

Table 9-1. -- Model Emission Input Data for Point Sources fn1

Averaging time	Emission limit (#/MMBtu) fn2	x	Operating level (MMBtu/hr) fn2	x	Operating factor (e.g., hr/yr, hr/day)
	Stationary Point Source(s) Subject to SIP Emission Limit(s) Evaluation for Compliance With Ambient Standards (Including Areawide Demonstrations)				
Annual & quarterly	Maximum allowable emission limit or federally enforceable permit limit.		Actual or design capacity (whichever is greater), or federally enforceable permit condition.		Actual operating factor averaged over most recent 2 years. fn3
Short term	Maximum allowable emission limit or federally enforceable permit limit.		Actual or design capacity (whichever is greater), or federally enforceable permit		Continuous operation, i.e., all hours of each time period under consideration (for all hours

Table 9-1. -- Model Emission Input Data for Point Sources fn1

Averaging time	Emission limit (#/MMBtu) fn2	x	Operating level (MMBtu/hr) fn2	x	Operating factor (e.g., hr/yr, hr/day)
			condition. fn4		of the meteorological data base). fn5

Nearby Source(s) fn6, fn7

Same input requirements as for stationary point source(s) above.

OtherSources fn7

If modeled (subsection 9.2.3), input data requirements are defined below.

Annual & quarterly	Maximum allowable emission limit or federally enforceable permit limit. fn6	Annual level when actually operating, averaged over the most recent 2 years. fn3	Actual operating factor averaged over the most recent 2 years. fn3
Short term	Maximum allowable emission limit or federally enforceable permit limit. fn6	Annual level when actually operating, averaged over the most recent 2 years. fn3	Continuous operation, i.e., all hours of each time period under consideration (for all hours of the meteorological data base). fn5

fn1 The model input data requirements shown on this table apply to stationary source control strategies for STATE IMPLEMENTATION PLANS. For purposes of emissions trading, new source review, or prevention of significant deterioration, other model input criteria may apply. Refer to the policy and guidance for these programs to establish the input data.

fn2 Terminology applicable to fuel burning sources; analogous terminology (e.g., #/throughput) may be used for other types of sources.

fn3 Unless it is determined that this period is not representative.

fn4 Operating levels such as 50 percent and 75 percent of capacity should also be modeled to determine the load causing the highest concentration.

fn5 If operation does not occur for all hours of the time period of consideration (e.g., 3 or 24 hours) and the source operation is constrained by a federally enforceable permit condition, an appropriate adjustment to the modeled emission rate may be made (e.g., if operation is only 8 a.m. to 4 p.m. each day, only these hours will be modeled with emissions from the source. Modeled emissions should not be averaged across non-operating time periods.)

fn6 See paragraph 9.2.3(c).

fn7 See paragraph 9.2.3(d).

Table 9-2. -- Point Source Model Input Data (Emissions) for PSD NAAQS Compliance Demonstrations

Averaging time	Emission limit (#/MMBtu) fn1	x	Operating level (MMBtu/hr) fn1	x	Operating factor (e.g., hr/yr,hr/day)
			Proposed Major New or Modified Source		
Annual & quarterly	Maximum allowable emission limit or federally enforceable permit limit.		Design capacity or federally enforceable permit condition.		Continuous operation (i.e., 8760 hours). fn2
Short term (<= 24 hours)	Maximum allowable emission limit or federally enforceable permit limit.		Design capacity or federally enforceable permit condition. fn3		Continuous operation (i.e., all hours of each time period under consideration) (for all hours of the meteorological data base). fn2
			Nearby Source(s) fn4, fn6		
Annual & quarterly	Maximum allowable emission limit or federally enforceable permit limit. fn5		Actual or design capacity (whichever is greater), or federally enforceable permit condition.		Actual operating factor averaged over the most recent 2 years. fn7, fn8
Short term (<= 24 hours)	Maximum allowable emission limit or federally enforceable permit limit. fn5		Actual or design capacity (whichever is greater), or federally enforceable permit condition. fn3		Continuous operation (i.e., all hours of each time period under consideration) (for all hours of the meteorological data base). fn2
			OtherSource(s) fn6, fn9		
Annual &	Maximum		Annual level		Actual

Table 9-2. -- Point Source Model Input Data (Emissions)
for PSD NAAQS Compliance Demonstrations

Averaging time	Emission limit (#/MMBtu) fn1	x	Operating level (MMBtu/hr) fn1	x	Operating factor (e.g., hr/yr,hr/day)
quarterly	allowable emission limit or federally enforceable permit limit. fn5		when actually operating, averaged over the most recent 2 years. fn7		operating factor averaged over the most recent 2 years. fn7, fn8
Short term (<= 24 hours)	Maximum allowable emission limit or federally enforceable permit limit. fn5		Annual level when actually operating, averaged over the most recent 2 years. fn7		Continuous operation (i.e., all hours of each time period under consideration) (for all hours of the meteorological data base). fn2

fn1 Terminology applicable to fuel burning sources; analogous terminology (e.g., #/throughput) may be used for other types of sources.

fn2 If operation does not occur for all hours of the time period of consideration (e.g., 3 or 24 hours) and the source operation is constrained by a federally enforceable permit condition, an appropriate adjustment to the modeled emission rate may be made (e.g., if operation is only 8 a.m. to 4 p.m. each day, only these hours will be modeled with emissions from the source. Modeled emissions should not be averaged across non-operating time periods.

fn3 Operating levels such as 50 percent and 75 percent of capacity should also be modeled to determine the load causing the highest concentration.

fn4 Includes existing facility to which modification is proposed if the emissions from the existing facility will not be affected by the modification. Otherwise use the same parameters as for major modification.

fn5 See paragraph 9.2.3(c).

fn6 See paragraph 9.2.3(d).

fn7 Unless it is determined that this period is not representative.

fn8 For those permitted sources not in operation or that have not established an appropriate factor, continuous operation (i.e., 8760) should be used.

fn9 Generally, the ambient impacts from non-nearby (background) sources can be represented by air quality data unless adequate data do not exist.

9.2 Background Concentrations

9.2.1 Discussion

a. Background concentrations are an essential part of the total air quality concentration to be considered in determining source impacts. Background air quality includes pollutant concentrations due to: (1) Natural sources; (2) nearby sources other than the one(s) currently under consideration; and (3) unidentified sources.

b. Typically, air quality data should be used to establish background concentrations in the vicinity of the source(s) under consideration. The monitoring network used for background determinations should conform to the same quality

assurance and other requirements as those networks established for PSD purposes. (91) An appropriate data validation procedure should be applied to the data prior to use.

c. If the source is not isolated, it may be necessary to use a multi-source model to establish the impact of nearby sources. Since sources don't typically operate at their maximum allowable capacity (which may include the use of "dirtier" fuels), modeling is necessary to express the potential contribution of background sources, and this impact would not be captured via monitoring. Background concentrations should be determined for each critical (concentration) averaging time.

9.2.2 Recommendations (Isolated Single Source)

a. Two options (paragraph (b) or (c) of this section) are available to determine the background concentration near isolated sources.

b. Use air quality data collected in the vicinity of the source to determine the background concentration for the averaging times of concern. Determine the mean background concentration at each monitor by excluding values when the source in question is impacting the monitor. The mean annual background is the average of the annual concentrations so determined at each monitor. For shorter averaging periods, the meteorological conditions accompanying the concentrations of concern should be identified. Concentrations for meteorological conditions of concern, at monitors not impacted by the source in question, should be averaged for each separate averaging time to determine the average background value. Monitoring sites inside a 90[degrees] sector downwind of the source may be used to determine the area of impact. One hour concentrations may be added and averaged to determine longer averaging periods.

c. If there are no monitors located in the vicinity of the source, a "regional site" may be used to determine background. A "regional site" is one that is located away from the area of interest but is impacted by similar natural and distant man-made sources.

9.2.3 Recommendations (Multi-Source Areas)

a. In multi-source areas, two components of background should be determined: Contributions from nearby sources and contributions from other sources.

b. Nearby Sources: All sources expected to cause a significant concentration gradient in the vicinity of the source or sources under consideration for emission limit(s) should be explicitly modeled. The number of such sources is expected to be small except in unusual situations. Owing to both the uniqueness of each modeling situation and the large number of variables involved in identifying nearby sources, no attempt is made here to comprehensively define this term. Rather, identification of nearby sources calls for the exercise of professional judgement by the appropriate reviewing authority (paragraph 3.0(b)). This guidance is not intended to alter the exercise of that judgement or to comprehensively define which sources are nearby sources.

c. For compliance with the short-term and annual ambient standards, the nearby sources as well as the primary source(s) should be evaluated using an appropriate Appendix A model with the emission input data shown in Table 9-1 or 9-2. When modeling a nearby source that does not have a permit and the emission limit contained in the SIP for a particular source category is greater than the emissions possible given the source's maximum physical capacity to emit, the "maximum allowable emission limit" for such a nearby source may be calculated as the emission rate representative of the nearby source's maximum physical capacity to emit, considering its design specifications and allowable fuels and process materials. However, the burden is on the permit applicant to sufficiently document what the maximum physical capacity to emit is for such a nearby source.

d. It is appropriate to model nearby sources only during those times when they, by their nature, operate at the same time as the primary source(s) being modeled. Where a primary source believes that a nearby source does not, by its nature, operate at the same time as the primary source being modeled, the burden is on the primary source to demonstrate to the satisfaction of the appropriate reviewing authority (paragraph 3.0(b)) that this is, in fact, the case. Whether or not the primary source has adequately demonstrated that fact is a matter of professional judgement left to the discretion of the appropriate reviewing authority. The following examples illustrate two cases in which a nearby source may be shown not to operate at the same time as the primary source(s) being modeled. Some sources are only used during certain seasons of the year. Those sources would not be modeled as nearby sources during times in which they do not operate. Similarly, emergency backup generators that never operate simultaneously with the sources that they back up would not be modeled as nearby sources. To reiterate, in these examples and other appropriate cases, the burden is on

the primary source being modeled to make the appropriate demonstration to the satisfaction of the appropriate reviewing authority.

e. The impact of the nearby sources should be examined at locations where interactions between the plume of the point source under consideration and those of nearby sources (plus natural background) can occur. Significant locations include: (1) The area of maximum impact of the point source; (2) the area of maximum impact of nearby sources; and (3) the area where all sources combine to cause maximum impact. These locations may be identified through trial and error analyses.

f. Other Sources: That portion of the background attributable to all other sources (e.g., natural sources, minor sources and distant major sources) should be determined by the procedures found in subsection 9.2.2 or by application of a model using Table 9-1 or 9-2.

9.3 Meteorological Input Data

a. The meteorological data used as input to a dispersion model should be selected on the basis of spatial and climatological (temporal) representativeness as well as the ability of the individual parameters selected to characterize the transport and dispersion conditions in the area of concern. The representativeness of the data is dependent on: (1) The proximity of the meteorological monitoring site to the area under consideration; (2) the complexity of the terrain; (3) the exposure of the meteorological monitoring site; and (4) the period of time during which data are collected. The spatial representativeness of the data can be adversely affected by large distances between the source and receptors of interest and the complex topographic characteristics of the area. Temporal representativeness is a function of the year-to-year variations in weather conditions. Where appropriate, data representativeness should be viewed in terms of the appropriateness of the data for constructing realistic boundary layer profiles and three dimensional meteorological fields, as described in paragraphs (c) and (d) below.

b. Model input data are normally obtained either from the National Weather Service or as part of a site specific measurement program. Local universities, Federal Aviation Administration (FAA), military stations, industry and pollution control agencies may also be sources of such data. Some recommendations for the use of each type of data are included in this subsection.

c. For long range transport modeling assessments (subsection 7.2.3) or for assessments where the transport winds are complex and the application involves a non-steady-state dispersion model (subsection 8.2.8), use of output from prognostic mesoscale meteorological models is encouraged. (92, 93, 94) Some diagnostic meteorological processors are designed to appropriately blend available NWS comparable meteorological observations, local site specific meteorological observations, and prognostic mesoscale meteorological data, using empirical relationships, to diagnostically adjust the wind field for mesoscale and local-scale effects. These diagnostic adjustments can sometimes be improved through the use of strategically placed site specific meteorological observations. The placement of these special meteorological observations (often more than one location is needed) involves expert judgement, and is specific to the terrain and land use of the modeling domain. Acceptance for use of output from prognostic mesoscale meteorological models is contingent on concurrence by the appropriate reviewing authorities (paragraph 3.0(b)) that the data are of acceptable quality, which can be demonstrated through statistical comparisons with observations of winds aloft and at the surface at several appropriate locations.

9.3.1 Length of Record of Meteorological Data

9.3.1.1 Discussion

a. The model user should acquire enough meteorological data to ensure that worst-case meteorological conditions are adequately represented in the model results. The trend toward statistically based standards suggests a need for all meteorological conditions to be adequately represented in the data set selected for model input. The number of years of record needed to obtain a stable distribution of conditions depends on the variable being measured and has been estimated by Landsberg and Jacobs (95) for various parameters. Although that study indicates in excess of 10 years may be required to achieve stability in the frequency distributions of some meteorological variables, such long-periods are not reasonable for model input data. This is due in part to the fact that hourly data in model input format are frequently not available for such periods and that hourly calculations of concentration for long periods may be prohibitively expensive. Another study (96) compared various periods from a 17-year data set to determine the minimum number of years of data needed to approximate the concentrations modeled with a 17-year period of meteorological data from one station. This study indicated that the variability of model estimates due to the meteorological data input was adequately reduced if a 5-year period of record of meteorological input was used.

9.3.1.2 Recommendations

a. Five years of representative meteorological data should be used when estimating concentrations with an air quality model. Consecutive years from the most recent, readily available 5-year period are preferred. The meteorological data should be adequately representative, and may be site specific or from a nearby NWS station. Where professional judgment indicates NWS-collected ASOS (automated surface observing stations) data are inadequate for cloud cover observations, the most recent 5 years of NWS data that are observer-based may be considered for use.

b. The use of 5 years of NWS meteorological data or at least 1 year of site specific data is required. If one year or more (including partial years), up to five years, of site specific data is available, these data are preferred for use in air quality analyses. Such data should have been subjected to quality assurance procedures as described in subsection 9.3.3.2.

c. For permitted sources whose emission limitations are based on a specific year of meteorological data, that year should be added to any longer period being used (e.g., 5 years of NWS data) when modeling the facility at a later time.

d. For LRT situations (subsection 7.2.3) and for complex wind situations (paragraph 8.2.8(a)), if only NWS or comparable standard meteorological observations are employed, five years of meteorological data (within and near the modeling domain) should be used. Consecutive years from the most recent, readily available 5-year period are preferred. Less than five, but at least three, years of meteorological data (need not be consecutive) may be used if mesoscale meteorological fields are available, as discussed in paragraph 9.3(c). These mesoscale meteorological fields should be used in conjunction with available standard NWS or comparable meteorological observations within and near the modeling domain. If site specific meteorological data are available, these data may be especially helpful for local-scale complex wind situations, when appropriately blended together with standard NWS or comparable observations and mesoscale meteorological fields.

9.3.2 National Weather Service Data

9.3.2.1 Discussion

a. The NWS meteorological data are routinely available and familiar to most model users. Although the NWS does not provide direct measurements of all the needed dispersion model input variables, methods have been developed and successfully used to translate the basic NWS data to the needed model input. Site specific measurements of model input parameters have been made for many modeling studies, and those methods and techniques are becoming more widely applied, especially in situations such as complex terrain applications, where available NWS data are not adequately representative. However, there are many model applications where NWS data are adequately representative, and the applications still rely heavily on the NWS data.

b. Many models use the standard hourly weather observations available from the National Climatic Data Center (NCDC). These observations are then preprocessed before they can be used in the models.

9.3.2.2 Recommendations

a. The preferred models listed in Appendix A all accept as input the NWS meteorological data preprocessed into model compatible form. If NWS data are judged to be adequately representative for a particular modeling application, they may be used. NCDC makes available surface (97, 98) and upper air (99) meteorological data in CD-ROM format.

b. Although most NWS measurements are made at a standard height of 10 meters, the actual anemometer height should be used as input to the preferred model.

c. Wind directions observed by the National Weather Service are reported to the nearest 10 degrees. A specific set of randomly generated numbers has been developed for use with the preferred EPA models and should be used with NWS data to ensure a lack of bias in wind direction assignments within the models.

d. Data from universities, FAA, military stations, industry and pollution control agencies may be used if such data are equivalent in accuracy and detail to the NWS data, and they are judged to be adequately representative for the particular application.

9.3.3 Site Specific Data

9.3.3.1 Discussion

a. Spatial or geographical representativeness is best achieved by collection of all of the needed model input data in close proximity to the actual site of the source(s). Site specific measured data are therefore preferred as model input,

provided that appropriate instrumentation and quality assurance procedures are followed and that the data collected are adequately representative (free from inappropriate local or microscale influences) and compatible with the input requirements of the model to be used. It should be noted that, while site specific measurements are frequently made "on-property" (i.e., on the source's premises), acquisition of adequately representative site specific data does not preclude collection of data from a location off property. Conversely, collection of meteorological data on a source's property does not of itself guarantee adequate representativeness. For help in determining representativeness of site specific measurements, technical guidance (100) is available. Site specific data should always be reviewed for representativeness and consistency by a qualified meteorologist.

9.3.3.2 Recommendations

a. EPA guidance (100) provides recommendations on the collection and use of site specific meteorological data. Recommendations on characteristics, siting, and exposure of meteorological instruments and on data recording, processing, completeness requirements, reporting, and archiving are also included. This publication should be used as a supplement to other limited guidance on these subjects. (91, 101, 102) Detailed information on quality assurance is also available. (103) As a minimum, site specific measurements of ambient air temperature, transport wind speed and direction, and the variables necessary to estimate atmospheric dispersion should be available in meteorological data sets to be used in modeling. Care should be taken to ensure that meteorological instruments are located to provide representative characterization of pollutant transport between sources and receptors of interest. The appropriate reviewing authority (paragraph 3.0(b)) is available to help determine the appropriateness of the measurement locations.

b. All site specific data should be reduced to hourly averages. Table 9-3 lists the wind related parameters and the averaging time requirements.

c. Missing Data Substitution. After valid data retrieval requirements have been met (100), hours in the record having missing data should be treated according to an established data substitution protocol provided that data from an adequately representative alternative site are available. Such protocols are usually part of the approved monitoring program plan. Data substitution guidance is provided in Section 5.3 of reference 100. If no representative alternative data are available for substitution, the absent data should be coded as missing using missing data codes appropriate to the applicable meteorological pre-processor. Appropriate model options for treating missing data, if available in the model, should be employed.

d. Solar Radiation Measurements. Total solar radiation or net radiation should be measured with a reliable pyranometer or net radiometer, sited and operated in accordance with established site specific meteorological guidance. (100, 103)

e. Temperature Measurements. Temperature measurements should be made at standard shelter height (2m) in accordance with established site specific meteorological guidance. (100)

f. Temperature Difference Measurements. Temperature difference ([delta]T) measurements should be obtained using matched thermometers or a reliable thermocouple system to achieve adequate accuracy. Siting, probe placement, and operation of [delta]T systems should be based on guidance found in Chapter 3 of reference 100, and such guidance should be followed when obtaining vertical temperature gradient data.

g. Winds Aloft. For simulation of plume rise and dispersion of a plume emitted from a stack, characterization of the wind profile up through the layer in which the plume disperses is required. This is especially important in complex terrain and/or complex wind situations where wind measurements at heights up to hundreds of meters above stack base may be required in some circumstances. For tall stacks when site specific data are needed, these winds have been obtained traditionally using meteorological sensors mounted on tall towers. A feasible alternative to tall towers is the use of meteorological remote sensing instruments (e.g., acoustic sounders or radar wind profilers) to provide winds aloft, coupled with 10-meter towers to provide the near-surface winds. (For specific requirements for CTDMPLUS, see Appendix A.) Specifications for wind measuring instruments and systems are contained in reference 100.

h. Turbulence. There are several dispersion models that are capable of using direct measurements of turbulence (wind fluctuations) in the characterization of the vertical and lateral dispersion (e.g., CTDMPLUS and CALPUFF). For specific requirements for CTDMPLUS and CALPUFF, see Appendix A. For technical guidance on measurement and processing of turbulence parameters, see reference 100. When turbulence data are used in this manner to directly characterize the vertical and lateral dispersion, the averaging time for the turbulence measurements should be one hour (Table 9-3). There are other dispersion models (e.g., BLP, and CALINE3) that employ P-G stability categories for the characterization of the vertical and lateral dispersion. Methods for using site specific turbulence data for the

characterization of P-G stability categories are discussed in reference 100. When turbulence data are used in this manner to determine the P-G stability category, the averaging time for the turbulence measurements should be 15 minutes.

i. Stability Categories. For dispersion models that employ P-G stability categories for the characterization of the vertical and lateral dispersion (e.g., ISC3), the P-G stability categories, as originally defined, couple near-surface measurements of wind speed with subjectively determined insolation assessments based on hourly cloud cover and ceiling height observations. The wind speed measurements are made at or near 10m. The insolation rate is typically assessed using observations of cloud cover and ceiling height based on criteria outlined by Turner. (77) It is recommended that the P-G stability category be estimated using the Turner method with site specific wind speed measured at or near 10m and representative cloud cover and ceiling height. Implementation of the Turner method, as well as considerations in determining representativeness of cloud cover and ceiling height in cases for which site specific cloud observations are unavailable, may be found in Section 6 of reference 100. In the absence of requisite data to implement the Turner method, the SRDT method or wind fluctuation statistics (i.e., the [sigma][E] and [sigma][A] methods) may be used.

j. The SRDT method, described in Section 6.4.4.2 of reference 100, is modified slightly from that published from earlier work(104) and has been evaluated with three site specific data bases. (105) The two methods of stability classification which use wind fluctuation statistics, the [sigma][E] and [sigma][A] methods, are also described in detail in Section 6.4.4 of reference 100 (note applicable tables in Section 6). For additional information on the wind fluctuation methods, several references are available. (106, 107, 108, 109)

k. Meteorological Data Preprocessors. The following meteorological preprocessors are recommended by EPA: PCRAMMET,(110) MPRM, (111) METPRO, (112) and CALMET. (113) PCRAMMET is the recommended meteorological preprocessor for use in applications employing hourly NWS data. MPRM is a general purpose meteorological data preprocessor which supports regulatory models requiring PCRAMMET formatted (NWS) data. MPRM is available for use in applications employing site specific meteorological data. The latest version (MPRM 1.3) has been configured to implement the SRDT method for estimating P-G stability categories. METPRO is the required meteorological data preprocessor for use with CTDMPLUS. CALMET is available for use with applications of CALPUFF. All of the above mentioned data preprocessors are available for downloading from EPA's Internet SCRAM Web site (subsection 2.3).

Table 9-3. -- Averaging Times for Site Specific Wind and Turbulence Measurements

Parameter	Averaging time (in hours)
Surface wind speed (for use in stability determinations)	1
Transport direction	1
Dilution wind speed	1
Turbulence measurements ([sigma][E] and [sigma][A]) for use in stability determinations	fn1 1
Turbulence Measurements for direct input to dispersion models	1

fn1 To minimize meander effects in [sigma][A] when wind conditions are light and/or variable, determine the hourly average [sigma] value from four sequential 15-minute [sigma]'s according to the following formula:

Display Image

9.3.4 Treatment of Near-calms and Calms

9.3.4.1 Discussion

a. Treatment of calm or light and variable wind poses a special problem in model applications since steady-state Gaussian plume models assume that concentration is inversely proportional to wind speed. Furthermore, concentrations may become unrealistically large when wind speeds less than 1 m/s are input to the model. Procedures have been developed to prevent the occurrence of overly conservative concentration estimates during periods of calms. These procedures acknowledge that a steady-state Gaussian plume model does not apply during calm conditions, and that our knowledge of wind patterns and plume behavior during these conditions does not, at present, permit the development of

a better technique. Therefore, the procedures disregard hours which are identified as calm. The hour is treated as missing and a convention for handling missing hours is recommended.

9.3.4.2 Recommendations

a. Hourly concentrations calculated with steady-state Gaussian plume models using calms should not be considered valid; the wind and concentration estimates for these hours should be disregarded and considered to be missing. Critical concentrations for 3-, 8-, and 24-hour averages should be calculated by dividing the sum of the hourly concentrations for the period by the number of valid or non-missing hours. If the total number of valid hours is less than 18 for 24-hour averages, less than 6 for 8-hour averages or less than 3 for 3-hour averages, the total concentration should be divided by 18 for the 24-hour average, 6 for the 8-hour average and 3 for the 3-hour average. For annual averages, the sum of all valid hourly concentrations is divided by the number of non-calm hours during the year. For models listed in Appendix A, a post-processor computer program, CALMPRO (114) has been prepared, is available on the SCRAM Internet Web site (subsection 2.3), and should be used.

b. Stagnant conditions that include extended periods of calms often produce high concentrations over wide areas for relatively long averaging periods. The standard steady-state Gaussian plume models are often not applicable to such situations. When stagnation conditions are of concern, other modeling techniques should be considered on a case-by-case basis (see also subsection 8.2.8).

c. When used in steady-state Gaussian plume models, measured site specific wind speeds of less than 1 m/s but higher than the response threshold of the instrument should be input as 1 m/s; the corresponding wind direction should also be input. Wind observations below the response threshold of the instrument should be set to zero, with the input file in ASCII format. In all cases involving steady-state.Gaussian plume models, calm hours should be treated as missing, and concentrations should be calculated as in paragraph (a) of this subsection.

10.0 Accuracy and Uncertainty of Models

10.1 Discussion

a. Increasing reliance has been placed on concentration estimates from models as the primary basis for regulatory decisions concerning source permits and emission control requirements. In many situations, such as review of a proposed source, no practical alternative exists. Therefore, there is an obvious need to know how accurate models really are and how any uncertainty in the estimates affects regulatory decisions. During the 1980's, attempts were made to encourage development of standardized evaluation methods. (16, 115) EPA recognized the need for incorporating such information and has sponsored workshops (116) on model accuracy, the possible ways to quantify accuracy, and on considerations in the incorporation of model accuracy and uncertainty in the regulatory process. The Second (EPA) Conference on Air Quality Modeling, August 1982, (117) was devoted to that subject.

b. To better deduce the statistical significance of differences seen in model performance in the face of unaccounted for uncertainties and variations, investigators have more recently explored the use of bootstrap techniques. (118, 119) Work is underway to develop a new generation of evaluation metrics (24) that takes into account the statistical differences (in error distributions) between model predictions and observations. (120) Even though the procedures and measures are still evolving to describe performance of models that characterize atmospheric fate, transport and diffusion (121, 122, 123) there has been general acceptance of a need to address the uncertainties inherent in atmospheric processes.

10.1.1 Overview of Model Uncertainty

a. Dispersion models generally attempt to estimate concentrations at specific sites that really represent an ensemble average of numerous repetitions of the same event. (24) The event is characterized by measured or "known" conditions that are input to the models, e.g., wind speed, mixed layer height, surface heat flux, emission characteristics, etc. However, in addition to the known conditions, there are unmeasured or unknown variations in the conditions of this event, e.g., unresolved details of the atmospheric flow such as the turbulent velocity field. These unknown conditions, may vary among repetitions of the event. As a result, deviations in observed concentrations from their ensemble average, and from the concentrations estimated by the model, are likely to occur even though the known conditions are fixed. Even with a perfect model that predicts the correct ensemble average, there are likely to be deviations from the observed concentrations in individual repetitions of the event, due to variations in the unknown conditions. The statistics of these concentration residuals are termed "inherent" uncertainty. Available evidence suggests that this source of uncertainty alone may be responsible for a typical range of variation in concentrations of as much as [+/-]50 percent. (124)

b. Moreover, there is "reducible" uncertainty (115) associated with the model and its input conditions; neither models nor data bases are perfect. Reducible uncertainties are caused by: (1) Uncertainties in the input values of the known conditions (i.e., emission characteristics and meteorological data); (2) errors in the measured concentrations which are used to compute the concentration residuals; and (3) inadequate model physics and formulation. The "reducible" uncertainties can be minimized through better (more accurate and more representative) measurements and better model physics.

c. To use the terminology correctly, reference to model accuracy should be limited to that portion of reducible uncertainty which deals with the physics and the formulation of the model. The accuracy of the model is normally determined by an evaluation procedure which involves the comparison of model concentration estimates with measured air quality data. (125) The statement of accuracy is based on statistical tests or performance measures such as bias, noise, correlation, etc. (16) However, information that allows a distinction between contributions of the various elements of inherent and reducible uncertainty is only now beginning to emerge. (24) As a result most discussions of the accuracy of models make no quantitative distinction between (1) limitations of the model versus (2) limitations of the data base and of knowledge concerning atmospheric variability. The reader should be aware that statements on model accuracy and uncertainty may imply the need for improvements in model performance that even the "perfect" model could not satisfy.

10.1.2 Studies of Model Accuracy

a. A number of studies (126, 127) have been conducted to examine model accuracy, particularly with respect to the reliability of short-term concentrations required for ambient standard and increment evaluations. The results of these studies are not surprising. Basically, they confirm what expert atmospheric scientists have said for some time: (1) Models are more reliable for estimating longer time-averaged concentrations than for estimating short-term concentrations at specific locations; and (2) the models are reasonably reliable in estimating the magnitude of highest concentrations occurring sometime, somewhere within an area. For example, errors in highest estimated concentrations of [+/-]10 to 40 percent are found to be typical (128, 129), i.e., certainly well within the often quoted factor-of-two accuracy that has long been recognized for these models. However, estimates of concentrations that occur at a specific time and site, are poorly correlated with actually observed concentrations and are much less reliable.

b. As noted above, poor correlations between paired concentrations at fixed stations may be due to "reducible" uncertainties in knowledge of the precise plume location and to unquantified inherent uncertainties. For example, Pasquill (130) estimates that, apart from data input errors, maximum ground-level concentrations at a given hour for a point source in flat terrain could be in error by 50 percent due to these uncertainties. Uncertainty of five to 10 degrees in the measured wind direction, which transports the plume, can result in concentration errors of 20 to 70 percent for a particular time and location, depending on stability and station location. Such uncertainties do not indicate that an estimated concentration does not occur, only that the precise time and locations are in doubt.

10.1.3 Use of Uncertainty in Decision-Making

a. The accuracy of model estimates varies with the model used, the type of application, and site specific characteristics. Thus, it is desirable to quantify the accuracy or uncertainty associated with concentration estimates used in decision-making. Communications between modelers and decision-makers must be fostered and further developed. Communications concerning concentration estimates currently exist in most cases, but the communications dealing with the accuracy of models and its meaning to the decision-maker are limited by the lack of a technical basis for quantifying and directly including uncertainty in decisions. Procedures for quantifying and interpreting uncertainty in the practical application of such concepts are only beginning to evolve; much study is still required. (115, 116, 117, 131, 132)

b. In all applications of models an effort is encouraged to identify the reliability of the model estimates for that particular area and to determine the magnitude and sources of error associated with the use of the model. The analyst is responsible for recognizing and quantifying limitations in the accuracy, precision and sensitivity of the procedure. Information that might be useful to the decision-maker in recognizing the seriousness of potential air quality violations includes such model accuracy estimates as accuracy of peak predictions, bias, noise, correlation, frequency distribution, spatial extent of high concentration, etc. Both space/time pairing of estimates and measurements and unpaired comparisons are recommended. Emphasis should be on the highest concentrations and the averaging times of the standards or increments of concern. Where possible, confidence intervals about the statistical values should be provided. However, while such information can be provided by the modeler to the decision-maker, it is unclear how this information should be used to make an air pollution control decision. Given a range of possible outcomes, it is easiest and tends to ensure consistency if the decision-maker confines his judgement to use of the "best estimate" provided by

the modeler (i.e., the design concentration estimated by a model recommended in the Guideline or an alternate model of known accuracy). This is an indication of the practical limitations imposed by current abilities of the technical community.

c. To improve the basis for decision-making, EPA has developed and is continuing to study procedures for determining the accuracy of models, quantifying the uncertainty, and expressing confidence levels in decisions that are made concerning emissions controls. (133, 134) However, work in this area involves "breaking new ground" with slow and sporadic progress likely. As a result, it may be necessary to continue using the "best estimate" until sufficient technical progress has been made to meaningfully implement such concepts dealing with uncertainty.

10.1.4 Evaluation of Models

a. A number of actions have been taken to ensure that the best model is used correctly for each regulatory application and that a model is not arbitrarily imposed. First, the Guideline clearly recommends the most appropriate model be used in each case. Preferred models, based on a number of factors, are identified for many uses. General guidance on using alternatives to the preferred models is also provided. Second, the models have been subjected to a systematic performance evaluation and a peer scientific review. Statistical performance measures, including measures of difference (or residuals) such as bias, variance of difference and gross variability of the difference, and measures of correlation such as time, space, and time and space combined as recommended by the AMS Woods Hole Workshop (16), were generally followed. Third, more specific information has been provided for justifying the site specific use of alternative models in previously cited EPA guidance (22, 25) and new models are under consideration and review. (24) Together these documents provide methods that allow a judgement to be made as to what models are most appropriate for a specific application. For the present, performance and the theoretical evaluation of models are being used as an indirect means to quantify one element of uncertainty in air pollution regulatory decisions.

b. EPA has participated in a series of conferences entitled, "Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes." (135) for the purpose of promoting the development of improved methods for the characterization of model performance. There is a consensus developing on what should be considered in the evaluation of air quality models (136), namely quality assurance planning, documentation and scrutiny should be consistent with the intended use, and should include:

. Scientific peer review;

. Supportive analyses (diagnostic evaluations, code verification, sensitivity and uncertainty analyses);

. Diagnostic and performance evaluations with data obtained in trial locations, and

. Statistical performance evaluations in the circumstances of the intended applications.

Performance evaluations and diagnostic evaluations assess different qualities of how well a model is performing, and both are needed to establish credibility within the client and scientific community. Performance evaluations allow us to decide how well the model simulates the average temporal and spatial patterns seen in the observations, and employ large spatial/temporal scale data sets (e.g., national data sets). Performance evaluations also allow determination of relative performance of a model in comparison with alternative modeling systems. Diagnostic evaluations allow determination of a model capability to simulate individual processes that affect the results, and usually employ smaller spatial/temporal scale date sets (e.g., field studies). Diagnostic evaluations allow us to decide if we get the right answer for the right reason. The objective comparison of modeled concentrations with observed field data provides only a partial means for assessing model performance. Due to the limited supply of evaluation data sets, there are severe practical limits in assessing model performance. For this reason, the conclusions reached in the science peer reviews and the supportive analyses have particular relevance in deciding whether a model will be useful for its intended purposes.

c. To extend information from diagnostic and performance evaluations, sensitivity and uncertainty analyses are encouraged since they can provide additional information on the effect of inaccuracies in the data bases and on the uncertainty in model estimates. Sensitivity analyses can aid in determining the effect of inaccuracies of variations or uncertainties in the data bases on the range of likely concentrations. Uncertainty analyses can aid in determining the range of likely concentration values, resulting from uncertainties in the model inputs, the model formulations, and parameterizations. Such information may be used to determine source impact and to evaluate control strategies. Where possible, information from such sensitivity analyses should be made available to the decision-maker with an appropriate interpretation of the effect on the critical concentrations.

10.2 Recommendations

a. No specific guidance on the quantification of model uncertainty for use in decision-making is being given at this time. As procedures for considering uncertainty develop and become implementable, this guidance will be changed and expanded. For the present, continued use of the "best estimate" is acceptable; however, in specific circumstances for O[3,] PM-2.5 and regional haze, additional information and/or procedures may be appropriate. (41, 42)

11.0 Regulatory Application of Models

11.1 Discussion

a. Procedures with respect to the review and analysis of air quality modeling and data analyses in support of SIP revisions, PSD permitting or other regulatory requirements need a certain amount of standardization to ensure consistency in the depth and comprehensiveness of both the review and the analysis itself. This section recommends procedures that permit some degree of standardization while at the same time allowing the flexibility needed to assure the technically best analysis for each regulatory application.

b. Dispersion model estimates, especially with the support of measured air quality data, are the preferred basis for air quality demonstrations. Nevertheless, there are instances where the performance of recommended dispersion modeling techniques, by comparison with observed air quality data, may be shown to be less than acceptable. Also, there may be no recommended modeling procedure suitable for the situation. In these instances, emission limitations may be established solely on the basis of observed air quality data as would be applied to a modeling analysis. The same care should be given to the analyses of the air quality data as would be applied to a modeling analysis.

c. The current NAAQS for SO[2] and CO are both stated in terms of a concentration not to be exceeded more than once a year. There is only an annual standard for NO[2] and a quarterly standard for Pb. Standards for fine particulate matter (PM-2.5) are expressed in terms of both long-term (annual) and short-term (daily) averages. The long-term standard is calculated using the three year average of the annual averages while the short-term standard is calculated using the three year average of the 98th percentile of the daily average concentration. For PM-10, the convention is to compare the arithmetic mean, averaged over 3 consecutive years, with the concentration specified in the NAAQS (50 [mu]g/m<3>). The 24-hour NAAQS (150 [mu]g/m<3>) is met if, over a 3-year period, there is (on average) no more than one exceedance per year. For ozone the short term 1-hour standard is expressed in terms of an expected exceedance limit while the short term 8-hour standard is expressed in terms of a three year average of the annual fourth highest daily maximum 8-hour value. The NAAQS are subjected to extensive review and possible revision every 5 years.

d. This section discusses general requirements for concentration estimates and identifies the relationship to emission limits. The following recommendations apply to: (1) Revisions of State Implementation Plans and (2) the review of new sources and the prevention of significant deterioration (PSD).

11.2 Recommendations

11.2.1 Analysis Requirements

a. Every effort should be made by the Regional Office to meet with all parties involved in either a SIP revision or a PSD permit application prior to the start of any work on such a project. During this meeting, a protocol should be established between the preparing and reviewing parties to define the procedures to be followed, the data to be collected, the model to be used, and the analysis of the source and concentration data. An example of requirements for such an effort is contained in the Air Quality Analysis Checklist posted on EPA's Internet SCRAM Web site (subsection 2.3). This checklist suggests the level of detail required to assess the air quality resulting from the proposed action. Special cases may require additional data collection or analysis and this should be determined and agreed upon at this preapplication meeting. The protocol should be written and agreed upon by the parties concerned, although a formal legal document is not intended. Changes in such a protocol are often required as the data collection and analysis progresses. However, the protocol establishes a common understanding of the requirements.

b. An air quality analysis should begin with a screening model to determine the potential of the proposed source or control strategy to violate the PSD increment or NAAQS. For traditional stationary sources, EPA guidance (27) should be followed. Guidance is also available for mobile sources. (57)

c. If the concentration estimates from screening techniques indicate that the PSD increment or NAAQS may be approached or exceeded, then a more refined modeling analysis is appropriate and the model user should select a model according to recommendations in Sections 4-8. In some instances, no refined technique may be specified in this guide for the situation. The model user is then encouraged to submit a model developed specifically for the case at hand. If that is not possible, a screening technique may supply the needed results.

d. Regional Offices should require permit applicants to incorporate the pollutant contributions of all sources into their analysis. Where necessary this may include emissions associated with growth in the area of impact of the new or modified source. PSD air quality assessments should consider the amount of the allowable air quality increment that has already been consumed by other sources. Therefore, the most recent source applicant should model the existing or permitted sources in addition to the one currently under consideration. This would permit the use of newly acquired data or improved modeling techniques if such have become available since the last source was permitted. When remodeling, the worst case used in the previous modeling analysis should be one set of conditions modeled in the new analysis. All sources should be modeled for each set of meteorological conditions selected.

11.2.2 Use of Measured Data in Lieu of Model Estimates

a. Modeling is the preferred method for determining emission limitations for both new and existing sources. When a preferred model is available, model results alone (including background) are sufficient. Monitoring will normally not be accepted as the sole basis for emission limitation. In some instances when the modeling technique available is only a screening technique, the addition of air quality data to the analysis may lend credence to model results.

b. There are circumstances where there is no applicable model, and measured data may need to be used. However, only in the case of an existing source should monitoring data alone be a basis for emission limits. In addition, the following items (i-vi) should be considered prior to the acceptance of the measured data:

i. Does a monitoring network exist for the pollutants and averaging times of concern?

ii. Has the monitoring network been designed to locate points of maximum concentration?

iii. Do the monitoring network and the data reduction and storage procedures meet EPA monitoring and quality assurance requirements?

iv. Do the data set and the analysis allow impact of the most important individual sources to be identified if more than one source or emission point is involved?

v. Is at least one full year of valid ambient data available?

vi. Can it be demonstrated through the comparison of monitored data with model results that available models are not applicable?

c. The number of monitors required is a function of the problem being considered. The source configuration, terrain configuration, and meteorological variations all have an impact on number and placement of monitors. Decisions can only be made on a case-by-case basis. Guidance is available for establishing criteria for demonstrating that a model is not applicable. (22)

d. Sources should obtain approval from the appropriate reviewing authority (paragraph 3.0(b)) for the monitoring network prior to the start of monitoring. A monitoring protocol agreed to by all concerned parties is highly desirable. The design of the network, the number, type and location of the monitors, the sampling period, averaging time as well as the need for meteorological monitoring or the use of mobile sampling or plume tracking techniques, should all be specified in the protocol and agreed upon prior to start-up of the network.

11.2.3 Emission Limits

11.2.3.1 Design Concentrations

a. Emission limits should be based on concentration estimates for the averaging time that results in the most stringent control requirements. The concentration used in specifying emission limits is called the design value or design concentration and is a sum of the concentration contributed by the source and the background concentration.

b. To determine the averaging time for the design value, the most restrictive NAAQS should be identified by calculating, for each averaging time, the ratio of the difference between the applicable NAAQS (S) and the background concentration (B) to the (model) predicted concentration (P) (i.e., (S-B)/P). The averaging time with the lowest ratio identifies the most restrictive standard. If the annual average is the most restrictive, the highest estimated annual average concentration from one or a number of years of data is the design value. When short term standards are most restrictive, it may be necessary to consider a broader range of concentrations than the highest value. For example, for pollutants such as SO[2], the highest, second-highest concentration is the design value. For pollutants with statistically based NAAQS, the design value is found by determining the more restrictive of: (1) The short-term concentration over the

period specified in the standard, or (2) the long-term concentration that is not expected to exceed the long-term NAAQS. Determination of design values for PM-10 is presented in more detail in EPA guidance. (43)

11.2.3.2 NAAQS Analyses for New or Modified Sources

a. For new or modified sources predicted to have a significant ambient impact (91) and to be located in areas designated attainment or unclassifiable for the SO[2], Pb, NO[2], or CO NAAQS, the demonstration as to whether the source will cause or contribute to an air quality violation should be based on: (1) The highest estimated annual average concentration determined from annual averages of individual years; or (2) the highest, second-highest estimated concentration for averaging times of 24-hours or less; and (3) the significance of the spatial and temporal contribution to any modeled violation. For Pb, the highest estimated concentration based on an individual calendar quarter averaging period should be used. Background concentrations should be added to the estimated impact of the source. The most restrictive standard should be used in all cases to assess the threat of an air quality violation. For new or modified sources predicted to have a significant ambient impact (91) in areas designated attainment or unclassifiable for the PM-10 NAAQS, the demonstration of whether or not the source will cause or contribute to an air quality violation should be based on sufficient data to show whether: (1) The projected 24-hour average concentrations will exceed the 24-hour NAAQS more than 1 percent of the time, on average; (2) the expected (i.e., average) annual mean concentration will exceed the annual NAAQS; and (3) the source contributes significantly, in a temporal and spatial sense, to any modeled violation.

11.2.3.3 PSD Air Quality Increments and Impacts

a. The allowable PSD increments for criteria pollutants are established by regulation and cited in *40 CFR 51.166*. These maximum allowable increases in pollutant concentrations may be exceeded once per year at each site, except for the annual increment that may not be exceeded. The highest, second-highest increase in estimated concentrations for the short term averages as determined by a model should be less than or equal to the permitted increment. The modeled annual averages should not exceed the increment.

b. Screening techniques defined in subsection 4.1 can sometimes be used to estimate short term incremental concentrations for the first new source that triggers the baseline in a given area. However, when multiple increment-consuming sources are involved in the calculation, the use of a refined model with at least 1 year of site specific or 5 years of (off-site) NWS data is normally required (subsection 9.3.1.2). In such cases, sequential modeling must demonstrate that the allowable increments are not exceeded temporally and spatially, i.e., for all receptors for each time period throughout the year(s) (time period means the appropriate PSD averaging time, e.g., 3-hour, 24-hour, etc.).

c. The PSD regulations require an estimation of the SO[2], particulate matter (PM-10), and NO[2] impact on any Class I area. Normally, steady-state Gaussian plume models should not be applied at distances greater than can be accommodated by the steady state assumptions inherent in such models. The maximum distance for refined steady-state Gaussian plume model application for regulatory purposes is generally considered to be 50km. Beyond the 50km range, screening techniques may be used to determine if more refined modeling is needed. If refined models are needed, long range transport models should be considered in accordance with subsection 7.2.3. As previously noted in Sections 3 and 7, the need to involve the Federal Land Manager in decisions on potential air quality impacts, particularly in relation to PSD Class I areas, cannot be overemphasized.

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Appendix A to **Appendix W** of Part 51 -- Summaries of Preferred Air Quality Models

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A.6 Industrial Source Complex Model (ISC3)

A.7 Offshore and Coastal Dispersion (OCD)

A. Ref References

A.0 Introduction and Availability

(1) This appendix summarizes key features of refined air quality models preferred for specific regulatory applications. For each model, information is provided on availability, approximate cost (where applicable), regulatory

use, data input, output format and options, simulation of atmospheric physics, and accuracy. These models may be used without a formal demonstration of applicability provided they satisfy the recommendations for regulatory use; not all options in the models are necessarily recommended for regulatory use.

(2) Many of these models have been subjected to a performance evaluation using comparisons with observed air quality data. Where possible, several of the models contained herein have been subjected to evaluation exercises, including (1) statistical performance tests recommended by the American Meteorological Society and (2) peer scientific reviews. The models in this appendix have been selected on the basis of the results of the model evaluations, experience with previous use, familiarity of the model to various air quality programs, and the costs and resource requirements for use.

(3) With the exception of EDMS, codes and documentation for all models listed in this appendix are available from EPA's Support Center for Regulatory Air Models (SCRAM) Web site at http://www.epa.gov/scram001. Documentation is also available from the National Technical Information Service (NTIS), http://www.ntis.gov or U.S. Department of Commerce, Springfield, VA 22161; phone: (800) 553-6847. Where possible, accession numbers are provided.

A.1 Buoyant Line and Point Source Dispersion Model (BLP)

Reference

Schulman, Lloyd L. and Joseph S. Scire, 1980. Buoyant Line and Point Source (BLP) Dispersion Model User's Guide. Document P-7304B. Environmental Research and Technology, Inc., Concord, MA. (NTIS No. PB 81-164642)

Availability

The computer code is available on EPA's Internet SCRAM website and also on diskette (as PB 2002-500051) from the National Technical Information Service (see Section A.0).

Abstract

BLP is a Gaussian plume dispersion model designed to handle unique modeling problems associated with aluminum reduction plants, and other industrial sources where plume rise and downwash effects from stationary line sources are important.

a. Recommendations for Regulatory Use

(1) The BLP model is appropriate for the following applications:

. Aluminum reduction plants which contain buoyant, elevated line sources;

. Rural areas;

. Transport distances less than 50 kilometers;

. Simple terrain; and

. One hour to one year averaging times.

(2) The following options should be selected for regulatory applications:

(i) Rural (IRU=1) mixing height option;

(ii) Default (no selection) for plume rise wind shear (LSHEAR), transitional point source plume rise (LTRANS), vertical potential temperature gradient (DTHTA), vertical wind speed power law profile exponents (PEXP), maximum variation in number of stability classes per hour (IDELS), pollutant decay (DECFAC), the constant in Briggs' stable plume rise equation (CONST2), constant in Briggs' neutral plume rise equation (CONST3), convergence criterion for the line source calculations (CRIT), and maximum iterations allowed for line source calculations (MAXIT); and

(iii) Terrain option (TERAN) set equal to 0.0, 0.0, 0.0, 0.0, 0.0, 0.0

(3) For other applications, BLP can be used if it can be demonstrated to give the same estimates as a recommended model for the same application, and will subsequently be executed in that mode.

(4) BLP can be used on a case-by-case basis with specific options not available in a recommended model if it can be demonstrated, using the criteria in Section 3.2, that the model is more appropriate for a specific application.

b. Input Requirements

(1) Source data: point sources require stack location, elevation of stack base, physical stack height, stack inside diameter, stack gas exit velocity, stack gas exit temperature, and pollutant emission rate. Line sources require coordinates of the end points of the line, release height, emission rate, average line source width, average building width, average spacing between buildings, and average line source buoyancy parameter.

(2) Meteorological data: Hourly surface weather data from punched cards or from the preprocessor program PCRAMMET which provides hourly stability class, wind direction, wind speed, temperature, and mixing height.

(3) Receptor data: Locations and elevations of receptors, or location and size of receptor grid or request automatically generated receptor grid.

c. Output

(1) Printed output (from a separate post-processor program) includes:

(2) Total concentration or, optionally, source contribution analysis; monthly and annual frequency distributions for 1-, 3-, and 24-hour average concentrations; tables of 1-, 3-, and 24-hour average concentrations at each receptor; table of the annual (or length of run) average concentrations at each receptor;

(3) Five highest 1-, 3-, and 24-hour average concentrations at each receptor; and

(4) Fifty highest 1-, 3-, and 24-hour concentrations over the receptor field.

d. Type of Model

BLP is a gaussian plume model.

e. Pollutant Types

BLP may be used to model primary pollutants. This model does not treat settling and deposition.

f. Source-Receptor Relationship

(1) BLP treats up to 50 point sources, 10 parallel line sources, and 100 receptors arbitrarily located.

(2) User-input topographic elevation is applied for each stack and each receptor.

g. Plume Behavior

(1) BLP uses plume rise formulas of Schulman and Scire (1980).

(2) Vertical potential temperature gradients of 0.02 Kelvin per meter for E stability and 0.035 Kelvin per meter are used for stable plume rise calculations. An option for user input values is included.

(3) Transitional rise is used for line sources.

(4) Option to suppress the use of transitional plume rise for point sources is included.

(5) The building downwash algorithm of Schulman and Scire (1980) is used.

h. Horizontal Winds

(1) Constant, uniform (steady-state) wind is assumed for an hour.

Straight line plume transport is assumed to all downwind distances.

(2) Wind speeds profile exponents of 0.10, 0.15, 0.20, 0.25, 0.30, and 0.30 are used for stability classes A through F, respectively. An option for user -- defined values and an option to suppress the use of the wind speed profile feature are included.

i. Vertical Wind Speed

Vertical wind speed is assumed equal to zero.

j. Horizontal Dispersion

(1) Rural dispersion coefficients are from Turner (1969), with no adjustment made for variations in surface roughness or averaging time.

(2) Six stability classes are used.

k. Vertical Dispersion

(1) Rural dispersion coefficients are from Turner (1969), with no adjustment made for variations in surface roughness.

(2) Six stability classes are used.

(3) Mixing height is accounted for with multiple reflections until the vertical plume standard deviation equals 1.6 times the mixing height; uniform mixing is assumed beyond that point.

(4) Perfect reflection at the ground is assumed.

l. Chemical Transformation

Chemical transformations are treated using linear decay. Decay rate is input by the user.

m. Physical Removal

Physical removal is not explicitly treated.

n. Evaluation Studies

Schulman, L.L. and J.S. Scire, 1980. Buoyant Line and Point Source (BLP) Dispersion Model User's Guide, P-7304B. Environmental Research and Technology, Inc., Concord, MA.

Scire, J.S. and L.L. Schulman, 1981. Evaluation of the BLP and ISC Models with SF[6] Tracer Data and SO[2] Measurements at Aluminum Reduction Plants. APCA Specialty Conference on Dispersion Modeling for Complex Sources, St. Louis, MO.

A.2 CALINE3

Reference

Benson, Paul E, 1979. CALINE3 -- A Versatile Dispersion Model for Predicting Air Pollutant Levels Near Highways and Arterial Streets. Interim Report, Report Number FHWA/CA/TL-79/23. Federal Highway Administration, Washington, DC. (NTIS No. PB 80-220841)

Availability

The CALINE3 model is available on diskette (as PB 95-502712) from NTIS. The source code and user's guide are also available on EPA's Internet SCRAM Web site (Section A.0).

Abstract

CALINE3 can be used to estimate the concentrations of nonreactive pollutants from highway traffic. This steady-state Gaussian model can be applied to determine air pollution concentrations at receptor locations downwind of "at-grade," "fill," "bridge," and "cut section" highways located in relatively uncomplicated terrain. The model is applicable for any wind direction, highway orientation, and receptor location. The model has adjustments for averaging time and surface roughness, and can handle up to 20 links and 20 receptors. It also contains an algorithm for deposition and settling velocity so that particulate concentrations can be predicted.

a. Recommendations for Regulatory Use

CALINE-3 is appropriate for the following applications:

. Highway (line) sources;

. Urban or rural areas;

. Simple terrain;

. Transport distances less than 50 kilometers; and

. One-hour to 24-hour averaging times.

b. Input Requirements

(1) Source data: Up to 20 highway links classed as "at-grade," "fill" "bridge," or "depressed"; coordinates of link end points; traffic volume; emission factor; source height; and mixing zone width.

(2) Meteorological data: Wind speed, wind angle (measured in degrees clockwise from the Y axis), stability class, mixing height, ambient (background to the highway) concentration of pollutant.

(3) Receptor data: Coordinates and height above ground for each receptor.

c. Output

Printed output includes concentration at each receptor for the specified meteorological condition.

d. Type of Model

CALINE-3 is a Gaussian plume model.

e. Pollutant Types

CALINE-3 may be used to model primary pollutants.

f. Source-Receptor Relationship

(1) Up to 20 highway links are treated.

(2) CALINE-3 applies user input location and emission rate for each link. User-input receptor locations are applied.

g. Plume Behavior

Plume rise is not treated.

h. Horizontal Winds

(1) User-input hourly wind speed and direction are applied.

(2) Constant, uniform (steady-state) wind is assumed for an hour.

i. Vertical Wind Speed

Vertical wind speed is assumed equal to zero.

j. Horizontal Dispersion

(1) Six stability classes are used.

(2) Rural dispersion coefficients from Turner (1969) are used, with adjustment for roughness length and averaging time.

(3) Initial traffic-induced dispersion is handled implicitly by plume size parameters.

k. Vertical Dispersion

(1) Six stability classes are used.

(2) Empirical dispersion coefficients from Benson (1979) are used including an adjustment for roughness length.

(3) Initial traffic-induced dispersion is handled implicitly by plume size parameters.

(4) Adjustment for averaging time is included.

l. Chemical Transformation

Not treated.

m. Physical Removal

Optional deposition calculations are included.

n. Evaluation Studies

Bemis, G.R. et al., 1977. Air Pollution and Roadway Location, Design, and Operation -- Project Overview. FHWA-CA-TL-7080-77-25, Federal Highway Administration, Washington, D.C.

Cadle, S.H. et al., 1976. Results of the General Motors Sulfate Dispersion Experiment, GMR-2107. General Motors Research Laboratories, Warren, MI.

Dabberdt, W.F., 1975. Studies of Air Quality on and Near Highways, Project 2761. Stanford Research Institute, Menlo Park, CA.

A.3 CALPUFF

References

Scire, J.S., D.G. Strimaitis and R.J. Yamartino, 2000. A User's Guide for the CALPUFF Dispersion Model (Version 5.0). Earth Tech, Inc., Concord, MA.

Scire J.S., F.R. Robe, M.E. Fernau and R.J. Yamartino, 2000. A User's Guide for the CALMET Meteorological Model (Version 5.0). Earth Tech, Inc., Concord, MA.

Availability

The model code and its documentation are available at no cost for download from the model developers' Internet Web site: http://www.src.com/calpuff/calpuff1.htm. You may also contact Joseph Scire, Earth Tech, Inc., 196 Baker Avenue, Concord, MA 01742; Telephone: (978) 371-4200, Fax: (978) 371-2468, e-mail: jss@src.com.

Abstract

CALPUFF is a multi-layer, multi-species non-steady-state puff dispersion modeling system that simulates the effects of time- and space-varying meteorological conditions on pollutant transport, transformation, and removal. CALPUFF is intended for use on scales from tens of meters from a source to hundreds of kilometers. It includes algorithms for near-field effects such as building downwash, transitional buoyant and momentum plume rise, partial plume penetration, subgrid scale terrain and coastal interactions effects, and terrain impingement as well as longer range effects such as pollutant removal due to wet scavenging and dry deposition, chemical transformation, vertical wind shear, overwater transport, plume fumigation, and visibility effects of particulate matter concentrations.

a. Recommendations for Regulatory Use

(1) CALPUFF is appropriate for long range transport (source-receptor distances of 50 to several hundred kilometers) of emissions from point, volume, area, and line sources. The meteorological input data should be fully characterized with time-and-space-varying three dimensional wind and meteorological conditions using CALMET, as discussed in paragraphs 9.3(c) and 9.3.1.2(d) of **Appendix W.**

(2) CALPUFF may also be used on a case-by-case basis if it can be demonstrated using the criteria in Section 3.2 that the model is more appropriate for the specific application. The purpose of choosing a modeling system like CALPUFF is to fully treat stagnation, wind reversals, and time and space variations of meteorology effects on transport and dispersion, as discussed in paragraph 8.2.8(a).

(3) For regulatory applications of CALMET and CALPUFF, the regulatory default option should be used. Inevitably, some of the model control options will have to be set specific for the application using expert judgement and in consultation with the relevant reviewing authorities.

b. Input Requirements

Source Data:

1. Point sources: Source location, stack height, diameter, exit velocity, exit temperature, base elevation, wind direction specific building dimensions (for building downwash calculations), and emission rates for each pollutant. Particle size distributions may be entered for particulate matter. Temporal emission factors (diurnal cycle, monthly cycle, hour/season, wind speed/stability class, or temperature-dependent emission factors) may also be entered. Arbitrarily-varying point source parameters may be entered from an external file.

2. Area sources: Source location and shape, release height, base elevation, initial vertical distribution ([sigma][z]) and emission rates for each pollutant. Particle size distributions may be entered for particulate matter. Temporal emission factors (diurnal cycle, monthly cycle, hour/season, wind speed/stability class, or temperature-dependent emission factors) may also be entered. Arbitrarily-varying area source parameters may be entered from an external file. Area sources specified in the external file are allowed to be buoyant and their location, size, shape, and other source characteristics are allowed to change in time.

3. Volume sources: Source location, release height, base elevation, initial horizontal and vertical distributions ([sigma][y], [sigma][z]) and emission rates for each pollutant. Particle size distributions may be entered for particulate

matter. Temporal emission factors (diurnal cycle, monthly cycle, hour/season, wind speed/stability class, or temperature-dependent emission factors) may also be entered. Arbitrarily-varying volume source parameters may be entered from an external file. Volume sources with buoyancy can be simulated by treating the source as a point source and entering initial plume size parameters -- initial ([sigma][y], [sigma][z]) -- to define the initial size of the volume source.

4. Line sources: Source location, release height, base elevation, average buoyancy parameter, and emission rates for each pollutant. Building data may be entered for line source emissions experiencing building downwash effects. Particle size distributions may be entered for particulate matter. Temporal emission factors (diurnal cycle, monthly cycle, hour/season, wind speed/stability class, or temperature-dependent emission factors) may also be entered. Arbitrarily-varying line source parameters may be entered from an external file.

Meteorological Data (different forms of meteorological input can be used by CALPUFF):

1. Time-dependent three-dimensional meteorological fields generated by CALMET. This is the preferred mode for running CALPUFF. Inputs into CALMET include surface observations of wind speed, wind direction, temperature, cloud cover, ceiling height, relative humidity, surface pressure, and precipitation (type and amount), and upper air sounding data (wind speed, wind direction, temperature, and height). Optional large-scale model output (e.g., from MM5) can be used by CALMET as well (paragraph 9.3.1.2(d)).

2. Single station surface and upper air meteorological data in CTDMPLUS data file formats (SURFACE.DAT and PROFILE.DAT files). This allows a vertical variation in the meteorological parameters but no spatial variability.

3. Single station meteorological data in ISCST3 data file format. This option does not account for variability of the meteorological parameters in the horizontal or vertical, except as provided for by the use of stability-dependent wind shear exponents and average temperature lapse rates.

Gridded terrain and land use data are required as input into CALMET when Option 1 is used. Geophysical processor programs are provided that interface the modeling system to standard terrain and land use data bases provided by the U.S. Geological Survey (USGS).

Receptor Data:

CALPUFF includes options for gridded and non-gridded (discrete) receptors. Special subgrid-scale receptors are used with the subgrid-scale complex terrain option. An option is provided for discrete receptors to be placed at ground-level or above the local ground level (i.e., flagpole receptors). Gridded and subgrid-scale receptors are placed at the local ground level only.

Other Input:

CALPUFF accepts hourly observations of ozone concentrations for use in its chemical transformation algorithm. Subgrid-scale coastlines can be specified in its coastal boundary file. Optional, user-specified deposition velocities and chemical transformation rates can also be entered. CALPUFF accepts the CTDMPLUS terrain and receptor files for use in its subgrid-scale terrain algorithm. Inflow boundary conditions of modeled pollutants can be specified in a boundary condition file.

c. Output

CALPUFF produces files of hourly concentrations of ambient concentrations for each modeled species, wet deposition fluxes, dry deposition fluxes, and for visibility applications, extinction coefficients. Postprocessing programs (PRTMET and CALPOST) provide options for analysis and display of the modeling results.

d. Type of Model

(1) CALPUFF is a non-steady-state time- and space-dependent Gaussian puff model. CALPUFF includes parameterized gas phase chemical transformation of SO[2], SO[4]=, NO, NO[2], HNO[3], NO[3]-, and organic aerosols. CALPUFF can treat primary pollutants such as PM-10, toxic pollutants, ammonia, and other passive pollutants. The model includes a resistance-based dry deposition model for both gaseous pollutants and particulate matter. Wet deposition is treated using a scavenging coefficient approach. The model has detailed parameterizations of complex terrain effects, including terrain impingement, side-wall scrapping, and steep-walled terrain influences on lateral plume growth. A subgrid-scale complex terrain module based on a dividing streamline concept divides the flow into a lift component traveling over the obstacle and a wrap component deflected around the obstacle.

(2) The meteorological fields used by CALPUFF are produced by the CALMET meteorological model. CALMET includes a diagnostic wind field model containing objective analysis and parameterized treatments of slope flows, valley flows, terrain blocking effects, and kinematic terrain effects, lake and sea breeze circulations, and a divergence minimization procedure. An energy-balance scheme is used to compute sensible and latent heat fluxes and turbulence parameters over land surfaces. A profile method is used over water. CALMET contains interfaces to prognostic meteorological models such as the Penn State/NCAR Mesoscale Model (e.g., MM5; Section 13.0, ref. 94), as well as the RAMS and Eta models.

e. Pollutant Types

CALPUFF may be used to model gaseous pollutants or particulate matter that are inert or undergo linear chemical reactions, such as SO[2], SO[4]=, NO, NO[2], HNO[3], NO[3]-, NH[3], PM-10, and toxic pollutants. For regional haze analyses, sulfate and nitrate particulate components are explicitly treated.

f. Source-Receptor Relationships

CALPUFF contains no fundamental limitations on the number of sources or receptors. Parameter files are provided that allow the user to specify the maximum number of sources, receptors, puffs, species, grid cells, vertical layers, and other model parameters. Its algorithms are designed to be suitable for source-receptor distances from tens of meters to hundreds of kilometers.

g. Plume Behavior

Momentum and buoyant plume rise is treated according to the plume rise equations of Briggs (1974, 1975) for non-downwashing point sources, Schulman and Scire (1980) for line sources and point sources subject to building downwash effects, and Zhang (1993) for buoyant area sources. Stack tip downwash effects and partial plume penetration into elevated temperature inversions are included.

h. Horizontal Winds

A three-dimensional wind field is computed by the CALMET meteorological model. CALMET combines an objective analysis procedure using wind observations with parameterized treatments of slope flows, valley flows, terrain kinematic effects, terrain blocking effects, and sea/lake breeze circulations. CALPUFF may optionally use single station (horizontally-constant) wind fields in the CTDMPLUS data format.

i. Vertical Wind Speed

Vertical wind speeds are not used explicitly by CALPUFF. Vertical winds are used in the development of the horizontal wind components by CALMET.

j. Horizontal Dispersion

Turbulence-based dispersion coefficients provide estimates of horizontal plume dispersion based on measured or computed values of [sigma][v]. The effects of building downwash and buoyancy-induced dispersion are included. The effects of vertical wind shear are included through the puff splitting algorithm. Options are provided to use Pasquill-Gifford (rural) and McElroy-Pooler (urban) dispersion coefficients. Initial plume size from area or volume sources is allowed.

k. Vertical Dispersion

Turbulence-based dispersion coefficients provide estimates of vertical plume dispersion based on measured or computed values of [sigma][w]. The effects of building downwash and buoyancy-induced dispersion are included. Vertical dispersion during convective conditions is simulated with a probability density function (pdf) model based on Weil et al. (1997). Options are provided to use Pasquill-Gifford (rural) and McElroy-Pooler (urban) dispersion coefficients. Initial plume size from area or volume sources is allowed.

l. Chemical Transformation

Gas phase chemical transformations are treated using parameterized models of SO[2] conversion to SO[4]= and NO conversion to NO[2], HNO[3], and SO[4]=. Organic aerosol formation is treated.

m. Physical Removal

Dry deposition of gaseous pollutants and particulate matter is parameterized in terms of a resistance-based deposition model. Gravitational settling, inertial impaction, and Brownian motion effects on deposition of particulate

matter is included. Wet deposition of gases and particulate matter is parameterized in terms of a scavenging coefficient approach.

n. Evaluation Studies

Berman, S., J.Y. Ku, J. Zhang and S.T. Rao, 1977: Uncertainties in estimating the mixing depth -- Comparing three mixing depth models with profiler measurements, Atmospheric Environment, 31: 3023-3039.

Environmental Protection Agency, 1998. Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 Summary Report and Recommendations for Modeling Long-Range Transport Impacts. EPA Publication No. EPA-454/R-98-019. Office of Air Quality Planning & Standards, Research Triangle Park, NC.

Irwin, J.S. 1997. A Comparison of CALPUFF Modeling Results with 1997 INEL Field Data Results. In Air Pollution Modeling and its Application, XII. Edited by S.E. Gyrning and N. Chaumerliac. Plenum Press, New York, NY.

Irwin, J.S., J.S. Scire and D.G. Strimaitis, 1996. A Comparison of CALPUFF Modeling Results with CAPTEX Field Data Results. In Air Pollution Modeling and its Application, XI. Edited by S.E. Gyrning and F.A. Schiermeier. Plenum Press, New York, NY.

Strimaitis, D.G., J.S. Scire and J.C. Chang. 1998. Evaluation of the CALPUFF Dispersion Model with Two Power Plant Data Sets. Tenth Joint Conference on the Application of Air Pollution Meteorology, Phoenix, Arizona. American Meteorological Society, Boston, MA. January 11-16, 1998.

A.4 Complex Terrain Dispersion Model Plus Algorithms for Unstable Situations (CTDMPLUS)

Reference

Perry, S.G., D.J. Burns, L.H. Adams, R.J. Paine, M.G. Dennis, M.T. Mills, D.G. Strimaitis, R.J. Yamartino and E.M. Insley, 1989. User's Guide to the Complex Terrain Dispersion Model Plus Algorithms for Unstable Situations (CTDMPLUS). Volume 1: Model Descriptions and User Instructions. EPA Publication No. EPA-600/8-89-041. Environmental Protection Agency, Research Triangle Park, NC. (NTIS No. PB 89-181424)

Perry, S.G., 1992. CTDMPLUS: A Dispersion Model for Sources near Complex Topography. Part I: Technical Formulations. Journal of Applied Meteorology, 31(7): 633-645.

Availability

This model code is available on EPA's Internet SCRAM Web site and also on diskette (as PB 90-504119) from the National Technical Information Service (Section A.0).

Abstract

CTDMPLUS is a refined point source Gaussian air quality model for use in all stability conditions for complex terrain applications. The model contains, in its entirety, the technology of CTDM for stable and neutral conditions. However, CTDMPLUS can also simulate daytime, unstable conditions, and has a number of additional capabilities for improved user friendliness. Its use of meteorological data and terrain information is different from other EPA models; considerable detail for both types of input data is required and is supplied by preprocessors specifically designed for CTDMPLUS. CTDMPLUS requires the parameterization of individual hill shapes using the terrain preprocessor and the association of each model receptor with a particular hill.

a. Recommendation for Regulatory Use

CTDMPLUS is appropriate for the following applications:

. Elevated point sources;

. Terrain elevations above stack top;

. Rural or urban areas;

. Transport distances less than 50 kilometers; and

. One hour to annual averaging times when used with a post-processor program such as CHAVG.

b. Input Requirements

(1) Source data: For each source, user supplies source location, height, stack diameter, stack exit velocity, stack exit temperature, and emission rate; if variable emissions are appropriate, the user supplies hourly values for emission rate, stack exit velocity, and stack exit temperature.

(2) Meteorological data: For applications of CTDMPLUS, multiple level (typically three or more) measurements of wind speed and direction, temperature and turbulence (wind fluctuation statistics) are required to create the basic meteorological data file ("PROFILE"). Such measurements should be obtained up to the representative plume height(s) of interest (i.e., the plume height(s) under those conditions important to the determination of the design concentration). The representative plume height(s) of interest should be determined using an appropriate complex terrain screening procedure (e.g., CTSCREEN) and should be documented in the monitoring/modeling protocol. The necessary meteorological measurements should be obtained from an appropriately sited meteorological tower augmented by SODAR and/or RASS if the representative plume height(s) of interest is above the levels represented by the tower measurements. Meteorological preprocessors then create a SURFACE data file (hourly values of mixed layer heights, surface friction velocity, Monin-Obukhov length and surface roughness length) and a RAWINsonde data file (upper air measurements of pressure, temperature, wind direction, and wind speed).

(3) Receptor data: Receptor names (up to 400) and coordinates, and hill number (each receptor must have a hill number assigned).

(4) Terrain data: User inputs digitized contour information to the terrain preprocessor which creates the TERRAIN data file (for up to 25 hills).

c. Output

(1) When CTDMPLUS is run, it produces a concentration file, in either binary or text format (user's choice), and a list file containing a verification of model inputs, i.e.,

. Input meteorological data from "SURFACE" and "PROFILE"

. Stack data for each source

. Terrain information

. Receptor information

. Source-receptor location (line printer map).

(2) In addition, if the case-study option is selected, the listing includes:

. Meteorological variables at plume height

. Geometrical relationships between the source and the hill

. Plume characteristics at each receptor, i.e.,

-- Distance in along-flow and cross flow direction

-- Effective plume-receptor height difference

-- Effective [sigma][y] [sigma][z] values, both flat terrain and hill induced (the difference shows the effect of the hill)

-- Concentration components due to WRAP, LIFT and FLAT.

(3) If the user selects the TOPN option, a summary table of the top 4 concentrations at each receptor is given. If the ISOR option is selected, a source contribution table for every hour will be printed.

(4) A separate disk file of predicted (1-hour only) concentrations ("CONC") is written if the user chooses this option. Three forms of output are possible:

(i) A binary file of concentrations, one value for each receptor in the hourly sequence as run;

(ii) A text file of concentrations, one value for each receptor in the hourly sequence as run; or

(iii) A text file as described above, but with a listing of receptor information (names, positions, hill number) at the beginning of the file.

(3) Hourly information provided to these files besides the concentrations themselves includes the year, month, day, and hour information as well as the receptor number with the highest concentration.

d. Type of Model

CTDMPLUS is a refined steady-state, point source plume model for use in all stability conditions for complex terrain applications.

e. Pollutant Types

CTDMPLUS may be used to model non-reactive, primary pollutants.

f. Source-Receptor Relationship

Up to 40 point sources, 400 receptors and 25 hills may be used. Receptors and sources are allowed at any location. Hill slopes are assumed not to exceed 15[degrees], so that the linearized equation of motion for Boussinesq flow are applicable. Receptors upwind of the impingement point, or those associated with any of the hills in the modeling domain, require separate treatment.

g. Plume Behavior

(1) As in CTDM, the basic plume rise algorithms are based on Briggs' (1975) recommendations.

(2) A central feature of CTDMPLUS for neutral/stable conditions is its use of a critical dividing-streamline height (H[c]) to separate the flow in the vicinity of a hill into two separate layers. The plume component in the upper layer has sufficient kinetic energy to pass over the top of the hill while streamlines in the lower portion are constrained to flow in a horizontal plane around the hill. Two separate components of CTDMPLUS compute ground-level concentrations resulting from plume material in each of these flows.

(3) The model calculates on an hourly (or appropriate steady averaging period) basis how the plume trajectory (and, in stable eutral conditions, the shape) is deformed by each hill. Hourly profiles of wind and temperature measurements are used by CTDMPLUS to compute plume rise, plume penetration (a formulation is included to handle penetration into elevated stable layers, based on Briggs (1984)), convective scaling parameters, the value of H[c,] and the Froude number above H[c.]

h. Horizontal Winds

CTDMPLUS does not simulate calm meteorological conditions. Both scalar and vector wind speed observations can be read by the model. If vector wind speed is unavailable, it is calculated from the scalar wind speed. The assignment of wind speed (either vector or scalar) at plume height is done by either:

. Interpolating between observations above and below the plume height, or

. Extrapolating (within the surface layer) from the nearest measurement height to the plume height.

i. Vertical Wind Speed

Vertical flow is treated for the plume component above the critical dividing streamline height (H[c]); see "Plume Behavior".

j. Horizontal Dispersion

Horizontal dispersion for stable eutral conditions is related to the turbulence velocity scale for lateral fluctuations, [sigma][v], for which a minimum value of 0.2 m/s is used. Convective scaling formulations are used to estimate horizontal dispersion for unstable conditions.

k. Vertical Dispersion

Direct estimates of vertical dispersion for stable eutral conditions are based on observed vertical turbulence intensity, e.g., [sigma][w] (standard deviation of the vertical velocity fluctuation). In simulating unstable (convective) conditions, CTDMPLUS relies on a skewed, bi-Gaussian probability density function (pdf) description of the vertical velocities to estimate the vertical distribution of pollutant concentration.

l. Chemical Transformation

Chemical transformation is not treated by CTDMPLUS.

m. Physical Removal

Physical removal is not treated by CTDMPLUS (complete reflection at the ground/hill surface is assumed).

n. Evaluation Studies

Burns, D.J., L.H. Adams and S.G. Perry, 1990. Testing and Evaluation of the CTDMPLUS Dispersion Model: Daytime Convective Conditions. Environmental Protection Agency, Research Triangle Park, NC.

Paumier, J.O., S.G. Perry and D.J. Burns, 1990. An Analysis of CTDMPLUS Model Predictions with the Lovett Power Plant Data Base. Environmental Protection Agency, Research Triangle Park, NC.

Paumier, J.O., S.G. Perry and D.J. Burns, 1992. CTDMPLUS: A Dispersion Model for Sources near Complex Topography. Part II: Performance Characteristics. Journal of Applied Meteorology, 31(7): 646-660.

A.6 Emissions and Dispersion Modeling System (EDMS) 3.1

Reference

Benson, Paul E., 1979. CALINE3 -- A Versatile Dispersion Model for Predicting Air Pollutant Levels Near Highways and Arterial Streets. Interim Report, Report Number FHWA/CA/TL-79/23. Federal Highway Administration, Washington, DC. (NTIS No. PB 80-220841)

Federal Aviation Administration, 1997. Emissions and Dispersion Modeling System (EDMS) Reference Manual. FAA Report No. FAA-AEE-97-01, USAF Report No. AL/EQ-TR-1997-0010, Federal Aviation Administration, Washington, DC 20591. SEE Availability below. (Note: this manual includes supplements that are available on the EDMS Internet Web site: http://www.aee.faa.gov/aee-100/aee-120/edms/banner.htm)

Petersen, W.B. and E.D. Rumsey, 1987. User's Guide for PAL 2.0-A Gaussian-Plume Algorithm for Point, Area, and Line Sources. EPA Publication No. EPA-600/8-87-009. Office of Research and Development, Research Triangle Park, NC. (NTIS No. PB 87-168 787/AS)

Availability

EDMS is available for $ 45 ($ 55 for users outside of the United States). The order form is available from: http://www.aee.faa.gov. Click the EDMS button on the left side of the page, and then click on the "EDMS Order Form" link. The $ 45 cost covers the distribution of the EDMS package: A CD ROM containing the executable installation file, the user manual, and the model changes document. This EDMS package does not include the source code, which is available only through special request and FAA approval. Upon installation the user will have on their computer an executable file for the model and supporting data and program files. Official contact at Federal Aviation Administration: Ms. Julie Draper, AEE, 800 Independence Avenue, SW., Washington, DC 20591, Phone: (202) 267-3494.

Abstract

EDMS is a combined emissions/dispersion model for assessing pollution at civilian airports and military air bases. This model, which was jointly developed by the Federal Aviation Administration (FAA) and the United States Air Force (USAF), produces an emission inventory of all airport sources and calculates concentrations produced by these sources at specified receptors. The system stores emission factors for fixed sources such as fuel storage tanks and incinerators and also for mobile sources such as aircraft or automobiles. The EDMS emissions inventory module incorporates methodologies described in AP-42 for calculating aircraft emissions, on-road and off-road vehicle emissions, and stationary source emissions. The dispersion modeling module incorporates PAL2 and CALINE3 (Section A.3) for the various emission source types. Both of these components interact with the database to retrieve and store data. The dispersion module, which processes point, area, and line sources, also incorporates a special meteorological preprocessor for processing up to one year of National Climatic Data Center (NCDC) hourly data.

a. Recommendations for Regulatory Use

EDMS is appropriate for the following applications:

. Cumulative effect of changes in aircraft operations, point source and mobile source emissions at airports or air bases;

. Simple terrain;

. Non-reactive pollutants;

. Transport distances less than 50 kilometers; and

. 1-hour to annual averaging times.

b. Input Requirements

(1) All data are entered through the EDMS graphical user interface. Typical entry items are annual and hourly source activity, source and receptor coordinates, etc. Some point sources, such as heating plants, require stack height, stack diameter, and effluent temperature inputs.

(2) Wind speed, wind direction, hourly temperature, and Pasquill-Gifford stability category (P-G) are the meteorological inputs. They can be entered manually through the EDMS data entry screens or automatically through the processing of previously loaded NCDC hourly data.

c. Output

Printed outputs consist of:

. A summary emission inventory report with pollutant totals by source category and detailed emission inventory reports for each source category; and

. A concentration summary report for up to 8760 hours (one year) of meteorological data that lists the number of sources, receptors, and the five highest concentrations for applicable averaging periods for the respective primary NAAQS.

d. Type of Model

For its emissions inventory calculations, EDMS uses algorithms consistent with the EPA Compilation of Air Pollutant Emission Factors, AP-42 (Section 11.0, ref. 96). For its dispersion calculations, EDMS uses the Point Area & Line (PAL2) model and the CALifornia LINE source (CALINE3) model, both of which use Gaussian algorithms.

e. Pollutant Types

EDMS includes emission factors for carbon monoxide, nitrogen oxides, sulfur oxides, hydrocarbons, and suspended particles and calculates the dispersion for all except hydrocarbons.

f. Source-Receptor Relationship

(1) Within hardware and memory constraints, there is no upper limit to the number of sources and receptors that can be modeled simultaneously.

(2) The Gaussian point source equation estimates concentrations from point sources after determining the effective height of emission and the upwind and crosswind distance of the source from the receptor. Numerical integration of the Gaussian point source equation is used to determine concentrations from line sources (runways). Integration over area sources (parking lots), which includes edge effects from the source region, is done by considering finite line sources perpendicular to the wind at intervals upwind from the receptor. The crosswind integration is done analytically; integration upwind is done numerically by successive approximations. Terrain elevation differences between sources and receptors are neglected.

(3) A reasonable height above ground level may be specified for each receptor.

g. Plume Behavior

(1) Briggs final plume rise equations are used. If plume height exceeds mixing height, concentrations are assumed equal to zero. Surface concentrations are set to zero when the plume centerline exceeds mixing height.

(2) For roadways, plume rise is not treated.

(3) Building and stack tip downwash effects are not treated.

h. Horizontal Winds

(1) Steady state winds are assumed for each hour. Winds are assumed to be constant with altitude.

(2) Winds are entered manually by the user or automatically by reading previously loaded NCDC annual data files.

i. Vertical Wind Speed

Vertical wind speed is assumed to be zero.

j. Horizontal Dispersion

(1) Six stability classes are used (P-G classes A through F).

(2) Aircraft runways, vehicle parking lots, stationary sources, and training fires are modeled using PAL2. Either rural (Pasquill-Gifford) or urban (Briggs) dispersion settings may be specified globally for these sources.

(3) Vehicle roadways, aircraft taxiways, and aircraft queues are modeled using CALINE3. CALINE3 assumes urban dispersion curves. The user specifies terrain roughness.

k. Vertical Dispersion

(1) Six stability classes are used (P-G classes A through F).

(2) Aircraft runways, vehicle parking lots, stationary sources, and training fires are modeled using PAL2. Either rural (Pasquill-Gifford) or urban (Briggs) dispersion settings may be specified globally for these sources.

(3) Vehicle roadways, aircraft taxiways, and aircraft queues are modeled using CALINE3. CALINE3 assumes urban dispersion curves. The user specifies terrain roughness.

l. Chemical Transformation

Chemical transformations are not accounted for.

m. Physical Removal

Deposition is not treated.

n. Evaluation Studies

None cited.

A.5 Industrial Source Complex Model (ISC3)

Reference

Environmental Protection Agency, 1995. User's Guide for the Industrial Source Complex (ISC3) Dispersion Models, Volumes 1 and 2. EPA Publication Nos. EPA-454/B-95-003a & b. Environmental Protection Agency, Research Triangle Park, NC. (NTIS Nos. PB 95-222741 and PB 95-222758, respectively)

Availability

The model code is available on the EPA's Internet SCRAM website. ISCST3 (as PB 2002-500055) is also available on diskette from the National Technical Information Service (see Section A.0).

Abstract

The ISC3 model is a steady-state Gaussian plume model which can be used to assess pollutant concentrations from a wide variety of sources associated with an industrial source complex. This model can account for the following: Settling and dry deposition of particles; downwash; area, line and volume sources; plume rise as a function of downwind distance; separation of point sources; and limited terrain adjustment. ISC3 operates in both long-term and short-term modes.

a. Recommendations for Regulatory Use

ISC3 is appropriate for the following applications:

. Industrial source complexes;

. Rural or urban areas;

. Flat or rolling terrain;

. Transport distances less than 50 kilometers;

. 1-hour to annual averaging times; and

. Continuous toxic air emissions.

The following options should be selected for regulatory applications: For short term or long term modeling, set the regulatory "default option"; i.e., use the keyword DFAULT, which automatically selects stack tip downwash, final plume rise, buoyancy induced dispersion (BID), the vertical potential temperature gradient, a treatment for calms, the appropriate wind profile exponents, the appropriate value for pollutant half-life, and a revised building wake effects algorithm; set the "rural option" (use the keyword RURAL) or "urban option" (use the keyword URBAN); and set the "concentration option" (use the keyword CONC).

b. Input Requirements

Source data: Location, emission rate, physical stack height, stack gas exit velocity, stack inside diameter, and stack gas temperature. Optional inputs include source elevation, building dimensions, particle size distribution with corresponding settling velocities, and surface reflection coefficients.

Meteorological data: ISCST3 requires hourly surface weather data from the preprocessor program RAMMET, which provides hourly stability class, wind direction, wind speed, temperature, and mixing height. For ISCLT3, input includes stability wind rose (STAR deck), average afternoon mixing height, average morning mixing height, and average air temperature.

Receptor data: Coordinates and optional ground elevation for each receptor.

c. Output

Printed output options include:

. Program control parameters, source data, and receptor data;

. Tables of hourly meteorological data for each specified day;

. "N"-day average concentration or total deposition calculated at each receptor for any desired source combinations;

. Concentration or deposition values calculated for any desired source combinations at all receptors for any specified day or time period within the day;

. Tables of highest and second highest concentration or deposition values calculated at each receptor for each specified time period during a(n) "N"-day period for any desired source combinations, and tables of the maximum 50 concentration or deposition values calculated for any desired source combinations for each specified time period.

d. Type of Model

ISC3 is a Gaussian plume model. It has been revised to perform a double integration of the Gaussian plume kernel for area sources.

e. Pollutant Types

ISC3 may be used to model primary pollutants and continuous releases of toxic and hazardous waste pollutants. Settling and deposition are treated.

f. Source-Receptor Relationships

ISC3 applies user-specified locations for point, line, area and volume sources, and user-specified receptor locations or receptor rings.

User input topographic evaluation for each receptor is used. Elevations above stack top are reduced to the stack top elevation, i.e., "terrain chopping".

User input height above ground level may be used when necessary to simulate impact at elevated or "flag pole" receptors, e.g., on buildings.

Actual separation between each source-receptor pair is used.

g. Plume Behavior

ISC3 uses Briggs (1969, 1971, 1975) plume rise equations for final rise.

Stack tip downwash equation from Briggs (1974) is used.

Revised building wake effects algorithm is used. For stacks higher than building height plus one-half the lesser of the building height or building width, the building wake algorithm of Huber and Snyder (1976) is used. For lower stacks, the building wake algorithm of Schulman and Scire (Schulman and Hanna, 1986) is used, but stack tip downwash and BID are not used.

For rolling terrain (terrain not above stack height), plume centerline is horizontal at height of final rise above source.

Fumigation is not treated.

h. Horizontal Winds

Constant, uniform (steady-state) wind is assumed for each hour.

Straight line plume transport is assumed to all downwind distances.

Separate wind speed profile exponents (Irwin, 1979; EPA, 1980) for both rural and urban cases are used.

An optional treatment for calm winds is included for short term modeling.

i. Vertical Wind Speed

Vertical wind speed is assumed equal to zero.

j. Horizontal Dispersion

Rural dispersion coefficients from Turner (1969) are used, with no adjustments for surface roughness or averaging time.

Urban dispersion coefficients from Briggs (Gifford, 1976) are used.

Buoyancy induced dispersion (Pasquill, 1976) is included.

Six stability classes are used.

k. Vertical Dispersion

Rural dispersion coefficients from Turner (1969) are used, with no adjustments for surface roughness.

Urban dispersion coefficients from Briggs (Gifford, 1976) are used.

Buoyancy induced dispersion (Pasquill, 1976) is included.

Six stability classes are used.

Mixing height is accounted for with multiple reflections until the vertical plume standard deviation equals 1.6 times the mixing height; uniform vertical mixing is assumed beyond that point.

Perfect reflection is assumed at the ground.

l. Chemical Transformation

Chemical transformations are treated using exponential decay. Time constant is input by the user.

m. Physical Removal

Dry deposition effects for particles are treated using a resistance formulation in which the deposition velocity is the sum of the resistances to pollutant transfer within the surface layer of the atmosphere, plus a gravitational settling term (EPA, 1994), based on the modified surface depletion scheme of Horst (1983).

n. Evaluation Studies

Bowers, J.F. and A.J. Anderson, 1981. An Evaluation Study for the Industrial Source Complex (ISC) Dispersion Model, EPA Publication No. EPA-450/4-81-002. Office of Air Quality Planning & Standards, Research Triangle Park, NC.

Bowers, J.F., A.J. Anderson and W.R. Hargraves, 1982. Tests of the Industrial Source Complex (ISC) Dispersion Model at the Armco Middletown, Ohio Steel Mill. EPA Publication No. EPA-450/4-82-006. Office of Air Quality Planning & Standards, Research Triangle Park, NC.

Environmental Protection Agency, 1992. Comparison of a Revised Area Source Algorithm for the Industrial Source Complex Short Term Model and Wind Tunnel Data. EPA Publication No. EPA-454/R-92-014. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 93-226751)

Environmental Protection Agency, 1992. Sensitivity Analysis of a Revised Area Source Algorithm for the Industrial Source Complex Short Term Model. EPA Publication No. EPA-454/R-92-015. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 93-226769)

Environmental Protection Agency, 1992. Development and Evaluation of a Revised Area Source Algorithm for the Industrial Source Complex Long Term Model. EPA Publication No. EPA-454/R-92-016. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 93-226777)

Environmental Protection Agency, 1994. Development and Testing of a Dry Deposition Algorithm (Revised). EPA Publication No. EPA-454/R-94-015. Office of Air Quality Planning & Standards, Research Triangle Park, NC. (NTIS No. PB 94-183100)

Scire, J.S. and L.L. Schulman, 1981. Evaluation of the BLP and ISC Models with SF[6] Tracer Data and SO[2] Measurements at Aluminum Reduction Plants. Air Pollution Control Association Specialty Conference on Dispersion Modeling for Complex Sources, St. Louis, MO.

Schulman, L.L. and S.R. Hanna, 1986. Evaluation of Downwash Modification to the Industrial Source Complex Model. Journal of the Air Pollution Control Association, 36: 258-264.

A.7 Offshore and Coastal Dispersion Model (OCD)

Reference

DiCristofaro, D.C. and S.R. Hanna, 1989. OCD: The Offshore and Coastal Dispersion Model, Version 4. Volume I: User's Guide, and Volume II: Appendices. Sigma Research Corporation, Westford, MA. (NTIS Nos. PB 93-144384 and PB 93-144392)

Availability

This model code is available on the EPA's Internet SCRAM Web site and also on diskette (as PB 91-505230) from the National Technical Information Service (see Section A.0). Official contact at Minerals Management Service: Mr. Dirk Herkhof, Parkway Atrium Building, 381 Elden Street, Herndon, VA 20170, Phone: (703) 787-1735.

Abstract

(1) OCD is a straight-line Gaussian model developed to determine the impact of offshore emissions from point, area or line sources on the air quality of coastal regions. OCD incorporates overwater plume transport and dispersion as well as changes that occur as the plume crosses the shoreline. Hourly meteorological data are needed from both offshore and onshore locations. These include water surface temperature, overwater air temperature, mixing height, and relative humidity.

(2) Some of the key features include platform building downwash, partial plume penetration into elevated inversions, direct use of turbulence intensities for plume dispersion, interaction with the overland internal boundary layer, and continuous shoreline fumigation.

a. Recommendations for Regulatory Use

OCD has been recommended for use by the Minerals Management Service for emissions located on the Outer Continental Shelf. OCD is applicable for overwater sources where onshore receptors are below the lowest source height. Where onshore receptors are above the lowest source height, offshore plume transport and dispersion may be modeled on a case-by-case basis in consultation with the appropriate reviewing authority (paragraph 3.0(b)).

b. Input Requirements

(1) Source data: Point, area or line source location, pollutant emission rate, building height, stack height, stack gas temperature, stack inside diameter, stack gas exit velocity, stack angle from vertical, elevation of stack base above water surface and gridded specification of the land/water surfaces. As an option, emission rate, stack gas exit velocity and temperature can be varied hourly.

(2) Meteorological data (over water): Wind direction, wind speed, mixing height, relative humidity, air temperature, water surface temperature, vertical wind direction shear (optional), vertical temperature gradient (optional), turbulence intensities (optional).

(3) Meteorological data (over land): Wind direction, wind speed, temperature, stability class, mixing height.

(4) Receptor data: Location, height above local ground-level, ground-level elevation above the water surface.

c. Output

(1) All input options, specification of sources, receptors and land/water map including locations of sources and receptors.

(2) Summary tables of five highest concentrations at each receptor for each averaging period, and average concentration for entire run period at each receptor.

(3) Optional case study printout with hourly plume and receptor characteristics. Optional table of annual impact assessment from non-permanent activities.

(4) Concentration files written to disk or tape can be used by ANALYSIS postprocessor to produce the highest concentrations for each receptor, the cumulative frequency distributions for each receptor, the tabulation of all concentrations exceeding a given threshold, and the manipulation of hourly concentration files.

d. Type of Model

OCD is a Gaussian plume model constructed on the framework of the MPTER model.

e. Pollutant Types

OCD may be used to model primary pollutants. Settling and deposition are not treated.

f. Source-Receptor Relationship

(1) Up to 250 point sources, 5 area sources, or 1 line source and 180 receptors may be used.

(2) Receptors and sources are allowed at any location.

(3) The coastal configuration is determined by a grid of up to 3600 rectangles. Each element of the grid is designated as either land or water to identify the coastline.

g. Plume Behavior

(1) As in ISC, the basic plume rise algorithms are based on Briggs' recommendations.

(2) Momentum rise includes consideration of the stack angle from the vertical.

(3) The effect of drilling platforms, ships, or any overwater obstructions near the source are used to decrease plume rise using a revised platform downwash algorithm based on laboratory experiments.

(4) Partial plume penetration of elevated inversions is included using the suggestions of Briggs (1975) and Weil and Brower (1984).

(5) Continuous shoreline fumigation is parameterized using the Turner method where complete vertical mixing through the thermal internal boundary layer (TIBL) occurs as soon as the plume intercepts the TIBL.

h. Horizontal Winds

(1) Constant, uniform wind is assumed for each hour.

(2) Overwater wind speed can be estimated from overland wind speed using relationship of Hsu (1981).

(3) Wind speed profiles are estimated using similarity theory (Businger, 1973). Surface layer fluxes for these formulas are calculated from bulk aerodynamic methods.

i. Vertical Wind Speed

Vertical wind speed is assumed equal to zero.

j. Horizontal Dispersion

(1) Lateral turbulence intensity is recommended as a direct estimate of horizontal dispersion. If lateral turbulence intensity is not available, it is estimated from boundary layer theory. For wind speeds less than 8 m/s, lateral turbulence intensity is assumed inversely proportional to wind speed.

(2) Horizontal dispersion may be enhanced because of obstructions near the source. A virtual source technique is used to simulate the initial plume dilution due to downwash.

(3) Formulas recommended by Pasquill (1976) are used to calculate buoyant plume enhancement and wind direction shear enhancement.

(4) At the water/land interface, the change to overland dispersion rates is modeled using a virtual source. The overland dispersion rates can be calculated from either lateral turbulence intensity or Pasquill-Gifford curves. The change is implemented where the plume intercepts the rising internal boundary layer.

k. Vertical Dispersion

(1) Observed vertical turbulence intensity is not recommended as a direct estimate of vertical dispersion. Turbulence intensity should be estimated from boundary layer theory as default in the model. For very stable conditions, vertical dispersion is also a function of lapse rate.

(2) Vertical dispersion may be enhanced because of obstructions near the source. A virtual source technique is used to simulate the initial plume dilution due to downwash.

(3) Formulas recommended by Pasquill (1976) are used to calculate buoyant plume enhancement.

(4) At the water/land interface, the change to overland dispersion rates is modeled using a virtual source. The overland dispersion rates can be calculated from either vertical turbulence intensity or the Pasquill-Gifford coefficients. The change is implemented where the plume intercepts the rising internal boundary layer.

l. Chemical Transformation

Chemical transformations are treated using exponential decay. Different rates can be specified by month and by day or night.

m. Physical Removal

Physical removal is also treated using exponential decay.

n. Evaluation Studies

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