

HYGIENE, COLORADO

PM₁₀ RECEPTOR MODELING STUDY



**Colorado Department
of Public Health
and Environment**

Prepared for

Northern Boulder County Environmental Health Community Task Force

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September 27, 2000

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TABLE OF CONTENTS

LIST OF TABLES	iv
LIST OF FIGURES	iv
EXECUTIVE SUMMARY	1
1.0 INTRODUCTION	3
2.0 PM ₁₀ SOURCES IN HYGIENE	5
3.0 PM ₁₀ SAMPLING IN HYGIENE	7
4.0 PM ₁₀ CHEMICAL COMPOSITION	8
4.1 PM ₁₀ Receptor Composition	8
4.2 PM ₁₀ Source Composition	9
5.0 PM ₁₀ SOURCE APPORTIONMENT	12
5.1 CMB Model Background	12
5.2 CMB Source Profiles	13
5.3 CMB Source Contribution Estimates	15
5.3.1 Geological Material	16
5.3.2 Vegetative Burning	17
5.3.3 Mobile Sources	18
5.3.4 Secondary Particulate	18
6.0 BULK SAMPLE ANALYSIS	19
6.1 Background	19
6.2 Bulk Sample Analyses	20
6.3 Ambient Air Sample Analyses	24
7.0 SUMMARY OF AMBIENT PM ₁₀ VALUES	26
7.1 Measured PM ₁₀ Values	26
7.2 Estimated Contributions From Southdown	27
8.0 CONCLUSIONS	29
9.0 REFERENCES	30
Appendix A: PM ₁₀ Data Summary	
Appendix B: Analytical Reports	
Appendix C: CMB Model Runs	
Appendix D: CMB Model Diagnostics	

LIST OF TABLES

Table 1 Summary Statistics for PM₁₀ Chemical Composition, Hygiene, CO

Table 2 Typical Chemical Abundance in PM₁₀ Source Emissions

Table 3 Source Profiles Selected For Use in the Hygiene CMB Modeling

Table 4 Summary of Hygiene CMB Source Contribution Estimates

Table 5 Bulk Sample Analyses Performed by Hazen Research, Inc.

Table 6 Bulk Sample Analysis Performed Chester LabNet, Inc.

Table 7 Size and Elemental Distribution Analyses by RJ LeeGroup, Inc.

Table 8 Average and Maximum Measured Speciated PM₁₀ Concentrations From Hygiene Study Period

Table 9 Summary of Type I/II Bulk Sample Analyses and Estimated Average and Maximum Ambient Contributions at Hygiene

LIST OF FIGURES

Figure 1 Map of the Hygiene Study Area

Figure 2 Results of the 1997 Lyons PM₁₀ Emission Inventory

Figure 3 PM₁₀ Concentrations Monitored at Hygiene, CO (Dec. '98-Nov '99)

Figure 4 Average PM₁₀ Source Contribution Estimates, Hygiene, CO

Figure 5 Mass Bulk Sample Population vs. Equivalent Spherical Diameter

Figure 6 Overall Size and Elemental Distribution of Ambient PM₁₀ Samples

EXECUTIVE SUMMARY

Residents of the community of Hygiene, Colorado, in the St. Vrain Valley have expressed concern about ambient levels of respirable particulate (PM_{10}) and specifically the potential health impacts of a local commercial operation, Southdown, Inc. Lyons Cement Plant (Southdown), which produces Portland cement. Other potential PM_{10} sources in the area include windblown soil, dust from paved and unpaved roads, emissions from agricultural, industrial and commercial operations, and emissions from wood burning and motor vehicles. In order to assess the relative influence of local air pollution sources to monitored PM_{10} concentrations, the Air Pollution Control Division (APCD) initiated a special PM_{10} monitoring effort in Hygiene, beginning November 1998. The maximum PM_{10} concentration measured at Hygiene during this study period was 54 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) and the average PM_{10} concentration was $20 \mu\text{g}/\text{m}^3$. The levels of PM_{10} are relatively low for a study of this magnitude and have been well below the United States Environmental Protection Agency's (EPA) National Ambient Air Quality Standards (NAAQS) for PM_{10} . Normally, chemical mass balance (CMB) modeling and speciation of ambient filters occur when the PM_{10} concentration exceeds $110 \mu\text{g}/\text{m}^3$ for a 24-hour sample period. However, the level of concern and documented occurrences of nuisance dust warranted a study of this level. This report covers the study period from December 1998 through November 1999.

A number of ambient PM_{10} filter samples collected during the study were submitted to private laboratories for chemical analysis. The Hygiene monitoring and receptor modeling program had two main objectives. The primary goal was to determine the relative contribution of air pollution sources to PM_{10} levels in Hygiene using the EPA approved Chemical Mass Balance (CMB) receptor model. An additional goal was to estimate the relative contribution of local cement manufacturing to potential airborne particulate at the Hygiene monitoring site.

Six (6) quartz PM_{10} filters collected at Hygiene were chemically characterized and modeled for this report. The results of the CMB modeling indicated that paved and unpaved road dust material, Type I/II Portland cement, and vegetative burning emissions were the most significant sources of particulate air pollution at the monitoring site. Road dust material comprised about 53% of the PM_{10} mass, Type I/II cement material contributed about 20% of the PM_{10} mass, and vegetative burning contributed about 16% of the PM_{10} mass. The average contribution from mobile sources was approximately 6%. Secondary particulate (i.e., ammonium sulfate, ammonium bisulfate, and ammonium nitrate) contributed about 5% of PM_{10} mass. Furthermore, cement kiln dust provided a strong statistical correlation next to Type I/II Portland cement and can be considered a suspect source profile. The output files from the CMB model runs are provided in Appendix C of this report.

The five (5) bulk samples of local soil, road dust, and potential fugitive dust from Southdown in the Lyons airshed were analyzed by a private laboratory to determine elemental, ionic, RCRA metals, crystalline silica, and radiation content of these materials. Some of the bulk sample analytical results were used to estimate industry contributed upper bound ambient concentrations at Hygiene that were not measured directly. The results of these analyses are presented in this report and are provided completely in Appendix B.

The results of the CMB analyses can also be combined with the Lyons emission inventory to estimate the annual relative influence of various sources to PM_{10} concentrations monitored at Hygiene.

This analytical approach indicated that on an annual average, street sand and road dust contribute about 4% of the PM₁₀ at Hygiene, while fugitive dust from Southdown potentially accounts for about 11-15% of monitored PM₁₀, and vegetative burning accounts for about 1%.

Overall, this study provided a baseline PM₁₀ monitoring database, speciated particulate measurements, and estimated upper bound ambient contributions from cement manufacturing at the Hygiene monitoring site. It is suggested that the level of information contained within this report is sufficient for a screening level risk assessment. If further studies are warranted based on public and peer review of this report, APCD will consider conducting or supporting any feasible studies in the near future.

In an abbreviated summary, the findings of this report are as follows:

- The one year average PM₁₀ concentrations at Hygiene are well below the EPA NAAQS for PM₁₀;
- CMB results indicated a 53% road dust contribution; 20% Type I/II Portland cement contribution; 16% vegetative burning contribution; 6% mobile source contribution; and a 5% secondary particulate contribution;
- Cement kiln dust is a suspected contributor in place of Type I/II Portland cement;
- Specific CMB sample events can differ from annual average emission inventory estimates due to sample specific dates versus annual emission reports and estimates;
- Estimated upper bound ambient contributions from cement manufacturing potentially contribute four (4) species (arsenic, cadmium, chromium as Cr⁺⁶, and manganese) that are near or above EPA Integrated Risk Information System (IRIS) reference concentrations; and
- Sampler siting in hygiene may not be representative of potential fugitive dust events near the Southdown facility
- Sufficient information has been provided within this report to conduct a screening level risk assessment. The extent to which a risk assessment may be conducted will be left to the decision of the Northern Boulder County Environmental Health Community Task Force. A risk assessment is beyond the scope of this report

1.0 INTRODUCTION

Hygiene, Colorado is a community located about three miles northwest of Longmont, in Boulder County. The area is north of the St. Vrain Creek and south of State Route 66. A large portion of the land area around Hygiene is devoted to agriculture. A map of the Hygiene study area and emission inventory census tract are presented in Figure 1, and details the PM₁₀ monitoring sites and some local operations.

Residents of the community of Hygiene have expressed concern about ambient levels of respirable particulate (PM₁₀) and specifically the potential health impacts of a local commercial operation, which produces Portland cement. Other potential PM₁₀ sources in the area include windblown soil, dust from paved and unpaved roads, emissions from agricultural, industrial and commercial operations, and emissions from wood burning and motor vehicles.

There are two classes of air quality models that can be used to assess the impact of local air pollution sources: dispersion models, and receptor models. Dispersion models use detailed emission information about air pollution sources and local wind fields to estimate the impact of those sources on pollutant concentrations at a number of sites in an airshed. Dispersion models are prospective in the sense that they are extremely useful for estimating future impacts of new air pollution sources, or for evaluation of the effectiveness of proposed air pollution control strategies.

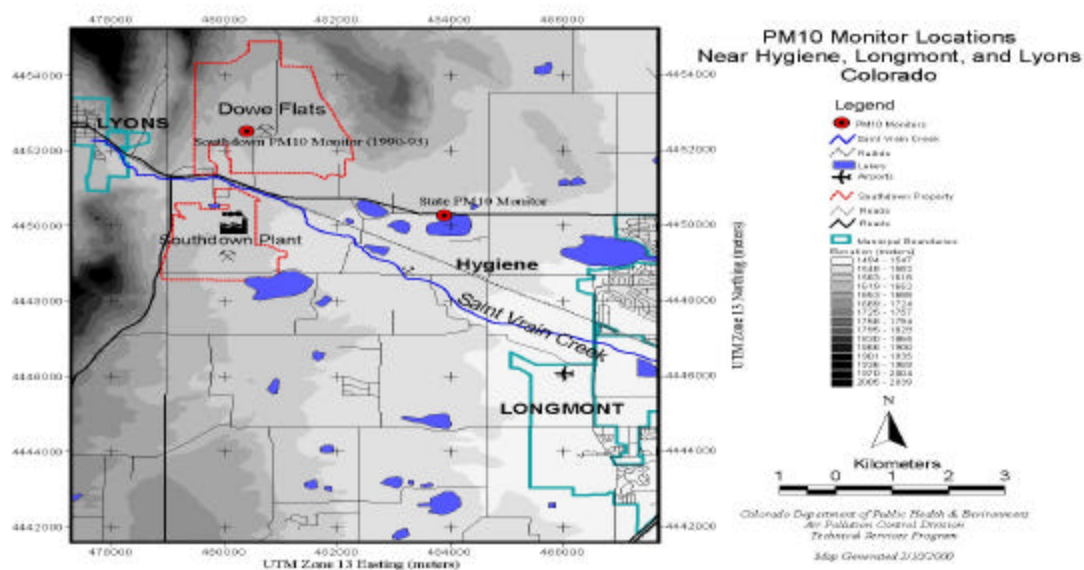
Receptor models use monitored pollutant concentrations and some information about the chemical composition of local air pollution sources to estimate the relative influence of these sources on pollutant levels at a single monitoring site. Receptor models are retrospective in that they can only assess the impacts of air pollution source categories on pollutant concentrations that have already been monitored.

The Air Pollution Control Division (APCD) is conducting a special PM₁₀ monitoring effort in Hygiene, which began in November of 1998 in order to collect filter samples suitable for chemical analysis and source receptor modeling.

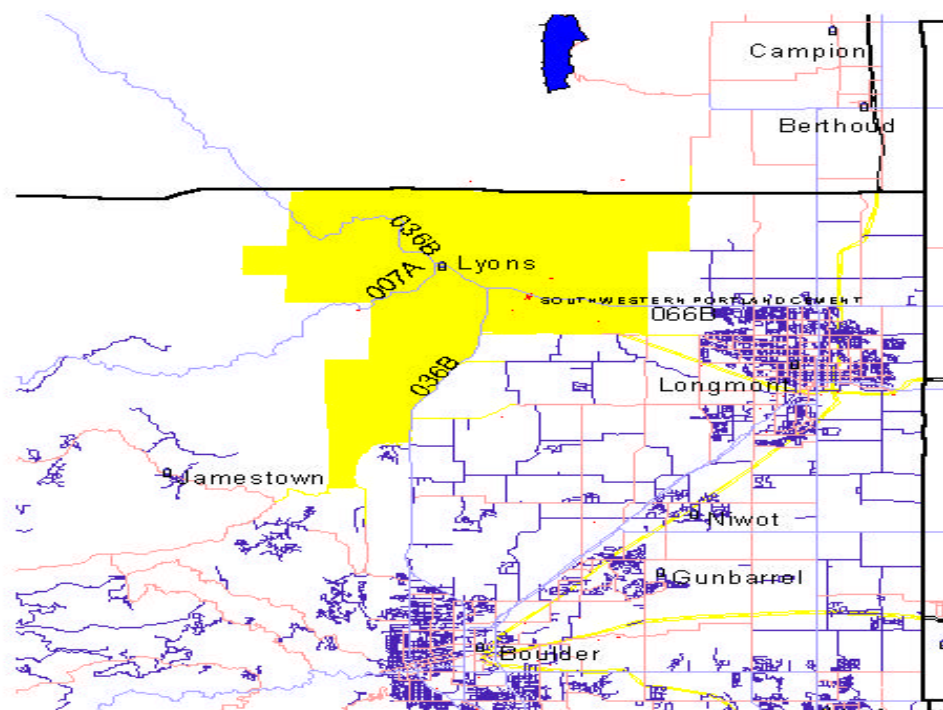
The monitoring and receptor modeling program during this initial special monitoring effort had two main objectives. The primary goal of the modeling program was to determine the relative contribution of air pollution sources to PM₁₀ levels in Hygiene using the Chemical Mass Balance (CMB) receptor model. An additional goal was to determine the relative contribution of local cement manufacturing to potential airborne particulate at the Hygiene monitoring site. This report details the results of that PM₁₀ chemical characterization and receptor modeling effort.

FIGURE 1

Map of the Hygiene-Lyons Study Area and Census Tract



Lyons Emissions Inventory Area (Census Tract 13601)



2.0 PM₁₀ SOURCES IN LYONS

A detailed inventory of PM₁₀ emissions in the Lyons airshed was prepared by the Air Pollution Control Division (APCD)⁽¹⁾ and can be found in Appendix B. An emission inventory combines existing estimates of emission factors and activity data to calculate the amount of a pollutant emitted seasonally or annually into a census tract-defined airshed. Emission factors are estimates of the rate at which a pollutant is emitted into the atmosphere by a process or activity. Activity data provide information about the frequency with which a pollutant-generating activity occurs in an airshed. Activity data typically include demographic and transportation information, as well as specific information about operations at local commercial and industrial operations, which emit pollutants. This emission inventory included the Hygiene study area.

The PM₁₀ source categories considered in the Lyons emission inventory include emissions from residential and commercial fuel combustion, aircraft, railroads, structural fires, prescribed burning, highway vehicles, non-road activities, industrial point sources, and wind blown dust from erosion and agricultural activities within the census tract. The emission inventory was based on emissions and activities, which occurred during 1997 as reported to the EPA Aerometric Information Retrieval Systems Information (AIRS) via actual facility emission reports or estimates emission values from EPA's approved emission factors in AP-42. Total annual PM₁₀ emissions in the Lyons airshed were estimated to be approximately 817 tons per year (tpy).

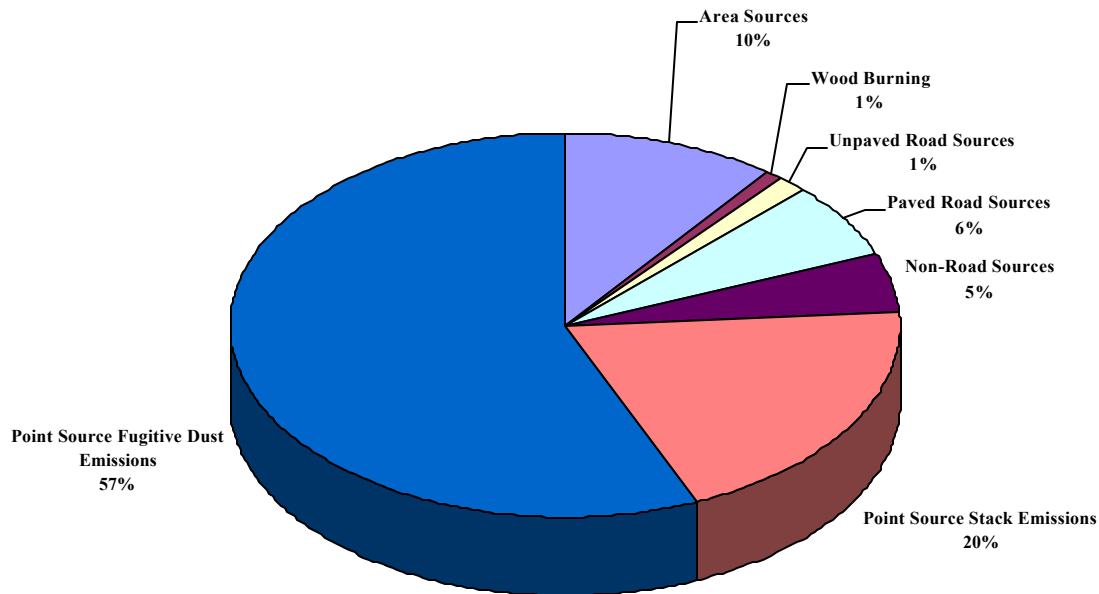
Section 2.0 of this report presents a brief summary of the results of the Lyons PM₁₀ emission inventory. These emission inventory results are graphically presented in Figure 2. When reviewing this information, it is important for the reader to consider that these emission estimates are calculated on an annual basis and may not accurately reflect actual PM₁₀ emissions on a given day. For example, annual estimates of wood burning emissions have been calculated for the Lyons airshed. Since residential wood burning is an activity which occurs almost entirely during the core winter months, the relative influence of wood burning emissions during the winter season is actually greater than would be indicated by an annual inventory.

Three (3) businesses in the Lyons airshed were considered in the industrial point source category. These businesses include Southdown, and two gravel pit operations (Western Mobile Boulder, and Goldens Gravel). The annual PM₁₀ emission estimate from these industrial sources was 622 tpy, equivalent to 76.1% of total PM₁₀ emissions in the Lyons airshed. It should be noted that the estimated annual PM₁₀ emission rate from Southdown is 584 tpy (162 tpy in stack emissions, 390 tpy in fugitive dust emissions, and 32 tpy in crushed stone operations). Overall, Southdown contributes 422 tpy in fugitive dust emissions (51.7%) and the total industrial fugitive dust rate was 460 tpy (56%).

Emissions from tilling operations wind erosion of agricultural land, commercial and institutional fuel use, and construction were also considered in the emission inventory. Since much of the land surrounding Lyons and Hygiene is used in agricultural operations and housing development is very active in the current Colorado front range economy, agricultural land use and construction are potentially significant PM₁₀ sources. The PM₁₀ emission estimate from area sources was 84.3 tons per year, equivalent to 10% of total PM₁₀ emissions in the Lyons airshed.

FIGURE 2

Results of the 1997 Lyons PM₁₀ Emission Inventory



Use of equipment for agricultural, industrial, and commercial applications was also considered. The PM₁₀ emission inventory of these non-road sources was 41 tons per year, equivalent to 5% of the total PM₁₀ emissions in the Lyons airshed.

Dust and street dirt suspended into the atmosphere from motor vehicle traffic is a significant source of PM₁₀ in most Colorado communities. Emission rates from unpaved roads depend on the fraction of fine particulate on the road surface, moisture content of the material, vehicle speed, vehicle weight, and traffic frequency. Paved roads are a significant PM₁₀ source in proportion to the amount of suspended dust on their surfaces, vehicle speed, and traffic frequency. Road dust loading can be highly variable. These deposits are derived from anti-skid sanding material, mud and dirt "carryout" from unpaved roads and construction sites, ground up litter and detritus, deposited tailpipe exhaust, and pavement wear. Primary motor vehicle emissions consist of particles emitted from incomplete fuel combustion, tire wear, and non-asbestos related brake wear. Estimates of emissions from paved roads, unpaved roads, resuspended street sand, and tail pipe emissions were developed for the Lyons airshed. Roadway vehicle (paved & unpaved sources) emissions were determined to be approximately 64 tons per year, equivalent to 7.8% of total PM₁₀ emissions in the Lyons airshed.

Residential wood burning in stoves and fireplaces is an important PM₁₀ source in most Colorado communities during the winter season. Emission rates from this source category are dependent on the type and age of the wood burning device, and the type and amount of fuel burned. The PM₁₀ emission estimate from residential wood burning was 6.1 tons per year, equivalent to 0.75% of total PM₁₀ emissions in the Lyons airshed.

3.0 PM₁₀ SAMPLING IN HYGIENE

Sampling for PM₁₀ is being conducted by the APCD in Hygiene. In response to requests from the community and the Boulder County Health Department, two PM₁₀ samplers (Sierra-Andersen Model 321) were installed by the APCD at the Wade Gaddis Water Filtration Plant at 7024 Ute Highway in Hygiene in November 1998. This site (ID# 08-013-0013) has typically been operated on an every third day sampling schedule. PM₁₀ concentrations monitored at this site have been in a range of 2-54 µg/m³. Figure 3 graphically presents the historical record of PM₁₀ concentrations monitored at the Hygiene site since the sampler was installed.

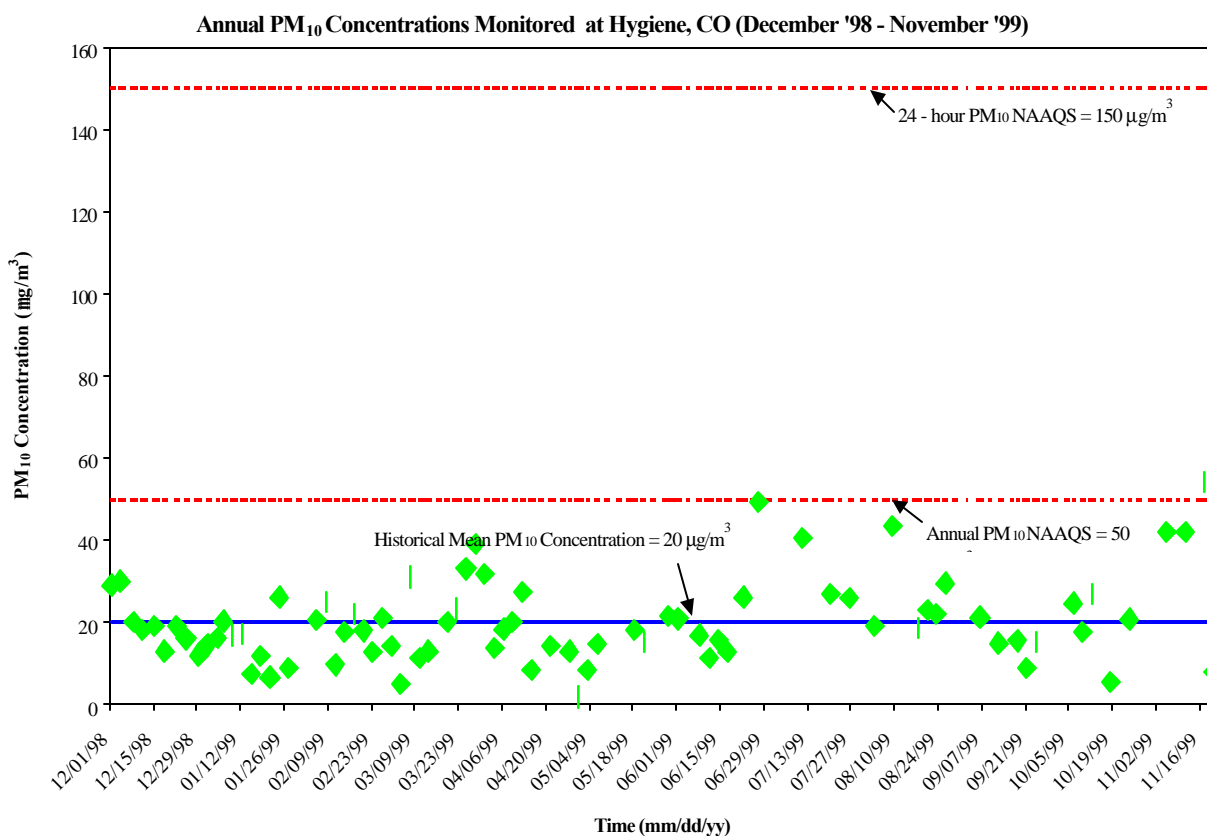
The identification numbers used to identify this site are from the Aerometric Information and Retrieval System - Air Quality Subsystem (AIRS-AQS), the national ambient air quality database operated by the EPA. All PM₁₀ data collected at Hygiene is routinely submitted by the APCD to the AIRS database. The filter substrate used in this routine PM₁₀ sampling network is a high purity quartz filter and the samples are collected over a 24-hour period from midnight to midnight.

The samplers operate by continuously drawing a known volume of ambient air through a pre-weighed filter. After sampling, the filter is reweighed and a particulate pollutant concentration can be calculated. Particulate samplers in the APCD monitoring network operate on a 24-hour schedule, from midnight to midnight.

The mean annual PM₁₀ concentration in Hygiene is 20 µg/m³ from December '98 – November '99. The highest monitored PM₁₀ concentration in Hygiene during this study period was a PM₁₀ value of 54 µg/m³ measured November 17, 1999. This value can be compared to the applicable PM₁₀ NAAQS, a 24-hour average concentration of 150 µg/m³. The PM₁₀ sampler collects all suspended particulate matter with an aerodynamic diameter of 10 µm and smaller.

A general comparison of the one-year Hygiene PM₁₀ data set from December '98–November '99 demonstrates that the PM₁₀ air quality at Hygiene (mean = 20 µg/m³, max = 54 µg/m³) is comparable to the surrounding areas of downtown Boulder (1999 mean = 22 µg/m³, 1999 max = 46 µg/m³) and Longmont (1999 mean = 19 µg/m³, 1999 max = 58 µg/m³).

FIGURE 3



4.0 PM₁₀ CHEMICAL COMPOSITION

4.1 PM₁₀ Receptor Composition

A total of five (5) quartz high volume PM₁₀ filters, collected at the Hygiene monitoring site, were submitted to two private analytical laboratories (Chester LabNet and Hazen Research) for a complete suite of chemical analyses. One (1) subsequent filter was submitted to Chester LabNet as a follow-up to the final report. The sample selection was based on monitored PM₁₀ concentrations. Filters collected at Hygiene on six (6) sample days with relatively high PM₁₀ concentrations (29-54 µg/m³) during the special study were selected, including the highest PM₁₀ concentration.

Elemental analysis was performed on each filter for approximately 36 elements, ranging from aluminum (Al) to lead (Pb), by x-ray fluorescence (XRF). Additional chemical analyses were conducted for several ionic species; sulfate (SO₄²⁻), nitrate (NO₃⁻), ammonium (NH₄⁺), and water-soluble potassium (K⁺). These ionic species were analyzed by ion chromatography. The filters were analyzed for organic carbon (OC) and elemental carbon (EC) using a thermal/optical carbon analyzer.

The results from the chemical determinations made on each filter type were compiled and

reported in terms of concentration ($\mu\text{g}/\text{m}^3$) along with an associated uncertainty which is estimated based on the precision of the analytical technique used in the chemical determination and the volumetric uncertainty in the fine particle sampling. The chemical analyses were conducted by Chester LabNet, Inc. of Tigard, OR. The contractor's data transmittal letter detailing the results of these analyses is presented in Appendix B.

A statistical summary of the chemical composition data collected at the Hygiene monitoring site is presented in Table 1. This table provides an opportunity to review the chemical composition of the PM_{10} . Table 1 shows the chemical composition of the particulate matter collected at Hygiene is dominated by organic carbon (OC), accounting for about 12% of the PM_{10} mass on average. The constituents of this organic carbon fraction include a wide range of semi-volatile organic compounds typically derived from motor vehicle and wood burning sources.

Calcium (Ca), silicon (Si), and aluminum (Al) comprise about 6%, 5%, and 4% of the PM_{10} mass, respectively. These elements are a strong indicator of geologic sources (e.g., mining, unpaved road dust, and agricultural activity).

Elemental carbon (EC) comprises about 7% of the PM_{10} mass. In most Colorado communities, elemental carbon (soot) is primarily derived from wood burning and diesel motor vehicle emissions. Elemental carbon is the only particulate species which efficiently absorbs light, causing it to have a more significant impact on visual air quality than any other component of particulate matter.

Two ionic species (sulfate and nitrate) are the next most significant constituents of the collected PM_{10} . Along with ammonium, these species are often referred to as "secondary particulate" since they are predominantly formed by the gas-to-particle conversion of precursor gases (SO_2 , NO_x , and NH_3 respectively) in the atmosphere. In contrast, primary particulate matter is emitted from a source as a solid. These secondary particulate species, as a group, account for about 9% of the PM_{10} mass. Potassium (K) and iron (Fe), which are components of geological material such as street sand or soil, are also present in concentrations of approximately $1.0 \mu\text{g}/\text{m}^3$.

4.2 PM_{10} Source Composition

Before submitting the chemical analysis data to the CMB model, it is often useful to look directly at the chemical composition data for indications of potential source categories affecting ambient particulate concentrations. Although there are rarely unique ambient chemical tracers for any given air pollution source, many chemical species are predominantly derived from a few source categories. Table 2 lists some air pollution source categories likely to influence PM_{10} levels in Boulder County and the chemical species found in emissions from those sources.

TABLE 1

Summary Statistics For PM₁₀ Chemical Composition
Hvgiene. CO - PM₁₀ Samples

Species	Average* ($\mu\text{g}/\text{m}^3$)	\pm Std. Error** ($\mu\text{g}/\text{m}^3$)
Total PM ₁₀ Mass	39	4.0
Aluminum (Al)	1.4742	0.5586
Antimony (Sb)	0.0028	0.0098
Arsenic (As)	0.0004	0.0039
Barium (Ba)	0.3170	0.0649
Bromine (Br)	0.0025	0.0023
Cadmium (Cd)	0.0012	0.0062
Calcium (Ca)	2.4259	0.4746
Chlorine (Cl)	0.0095	0.0112
Chromium (Cr)	0.0027	0.0016
Cobalt (Co)	0.0001	0.0026
Copper (Cu)	0.0384	0.0049
Gallium (Ga)	0.0000	0.0036
Germanium (Ge)	0.0010	0.0031
Indium (In)	0.0021	0.0069
Iron (Fe)	1.0034	0.1628
Lanthanum (La)	0.0163	0.0513
Lead (Pb)	0.0071	0.0067
Manganese (Mn)	0.0209	0.0045
Mercury (Hg)	0.0014	0.0055
Molybdenum (Mo)	0.0321	0.0076
Nickel (Ni)	0.0001	0.0015
Palladium (Pd)	0.0009	0.0059
Phosphorous (P)	0.0000	0.1321
Potassium (K)	0.8527	0.1576
Rubidium (Rb)	0.0056	0.0027
Selenium (Se)	0.0008	0.0024
Silicon (Si)	1.9770	0.1977
Silver (Ag)	0.0042	0.0060
Strontium (Sr)	0.0126	0.0036
Sulfur (S)	0.4270	0.0881
Tin (Sn)	0.0091	0.0083
Titanium (Ti)	0.0943	0.0166
Vanadium (V)	0.0012	0.0025
Yttrium (Y)	0.0052	0.0036
Zinc (Zn)	0.0155	0.0030
Zirconium (Zr)	0.0264	0.0065
Ammonium (NH ₄ ⁺)	0.5147	0.0728
Nitrate (NO ₃ ⁻)	1.6307	0.2312
Sulfate (SO ₄ ⁼)	1.9108	0.2719
Soluble Pottasium (K ⁺)	0.1642	0.0232
Elemental Carbon (EC)	2.7166	0.3329
Organic Carbon (OC)	4.5624	0.5816

Note:

* Average of six (6) filters

** Standard error is a measure of precision.

- $\mu\text{g}/\text{m}^3$: micrograms per cubic meter

TABLE 2

Typical Chemical Abundances in PM₁₀ Source Emissions

Source Type	Dominant Particle Size	Chemical Abundances
Geological Material	Coarse ≥ 2.5 μm	>10% : Si 1-10% : OC, EC, Al, Fe 0.1-1.0% : Cl ⁻ , NO ₃ ⁻ , SO ₄ ⁼ , NH ₄ ⁺ , P, S, Cl, Ti, Mn, Ba, La
Motor Vehicle	Fine ≤ 2.5 μm	>10% : OC, EC 1-10% : S, Cl ⁻ , NO ₃ ⁻ , SO ₄ ⁼ , NH ₄ ⁺ 0.1-1.0% : Al, Si, Cl, P, Ca, Mn, Fe, Zn, Br, Pb
Vegetative Burning	Fine ≤ 2.5 μm	>10% : OC, EC 1-10% : K ⁺ , K, Cl ⁻ , Cl 0.1-1.0% : NO ₃ ⁻ , SO ₄ ⁼ , NH ₄ ⁺ , Na ⁺
Coal Fired Power Plant	Fine ≤ 2.5 μm	>10% : Si 1-10% : SO ₄ ⁼ , OC, EC, Al, S, Ca, Fe 0.1-1.0% : NH ₄ ⁺ , P, K, Ti, V, Ni, Zn, Sr, Ba, Pb

Note:

- OC: Organic Carbon; EC: Elemental Carbon

- Information presented in this table is excerpted from the *Guidelines For PM10*

Sampling and Analysis Applicable to Receptor Modeling.⁽²⁾

The source categories listed in Table 2 will be discussed in greater detail in Section 5.2 of this report. Several chemical species aluminum (Al), silicon (Si), potassium (K), calcium (Ca), titanium (Ti) and iron (Fe) are common to all of the geological sources; soil, paved road dust, and street sanding material. Paved road dust tends to be somewhat enriched in organic carbon (OC) and elemental carbon (EC) due to deposited automobile emissions. Street sanding material often contains substantial concentrations of chlorine (Cl) from salt (NaCl or MgCl) added to the material.

Motor vehicle sources emit substantial amounts of organic and elemental carbon in addition to trace amounts of lead, bromine, and manganese derived from gasoline fuel additives. Diesel motor vehicles can emit significant trace amounts of sulfate as well as organic and elemental carbon. Wood burning emissions are dominated by organic and elemental carbon, along with trace amounts of minerals from entrained ash. The most significant trace mineral emitted by wood burning is water soluble potassium (K⁺), while potassium derived from geological materials (K) is usually water-insoluble.

5.0 PM₁₀ SOURCE APPORTIONMENT

5.1 CMB Model Background

The chemical composition data for each filter were submitted to a Chemical Mass Balance (CMB) analysis using EPA-approved CMB Version 8.0 software ^(3, 4). The CMB model uses a least-squares solution to a set of linear equations which expresses each receptor concentration of a chemical species as a linear sum of products of source profile species and source contributions. The source profile species (i.e. the fractional amount of the species in each source type) and the receptor species concentrations, with appropriate uncertainty estimates, serve as inputs to the model.

The CMB model algorithm consists of the following set of equations:

$$C_i = \sum (F_{i1}S_1 + F_{i2}S_2 + \dots + F_{ij}S_j)_{i=1..I, j=1..J}$$

where

- C_i = Concentration of species i measured at a receptor site
- F_{ij} = Fraction of species i in emissions from source j
- S_j = Estimate of the contribution of source j
- I = Number of chemical species
- J = Number of source types

The model calculates values for contributions from each source and estimates the uncertainties of those source contributions. It is important to consider that the CMB model identifies chemically distinct source types, not individual emission sources, and provides source contribution estimates only for the day of sampling. For example, many geological sources are so chemically similar that although an unpaved road dust profile might provide the best model fit for a given sample, the source contribution estimate represents all geological sources, not just emissions from unpaved roads. A series of model runs are necessary for a comprehensive source-receptor analysis.

The CMB model can be applied with three sequential levels of complexity, each level being more costly, but providing more accurate and precise information than the previous level. The basic level, Level 1, uses existing data, or data that can be readily obtained from analysis of existing sources. A Level 2 CMB analysis involves the collection of either new ambient filter samples or source profiles. A Level 3 analysis involves the collection of both ambient filter samples and the development of new source profiles from local air pollution sources.

The CMB modeling effort detailed in this report is a combined Level 2-Level 3 analysis, which included collection and analysis of bulk samples of local geological material. Because of the prohibitive expense, no effort was made to characterize other local emission source categories such as emissions from wood burning devices, restaurant emissions, or motor vehicle emissions. This PM₁₀ modeling effort benefits from the 1987-88 Metro Denver Brown Cloud Study (DBCS), which included a CMB source apportionment of Denver's fine-fraction (PM_{2.5}) particles. A number of PM_{2.5} and PM₁₀ source profiles of industrial emissions, motor vehicle emissions, wood burning emissions, and area sources were developed for the DBCS and available for use in the PM₁₀ receptor modeling effort.⁽⁵⁾

Application of the CMB model requires several underlying assumptions about the quality of the input data and the behavior of particles in the atmosphere. These assumptions include; 1) compositions of source emissions are constant from source to receptor, 2) chemical species do not react with each other during transport or sampling, 3) all potential sources have been identified, 4) the number of source categories is less than or equal to the number of species in the receptor and source profiles, 5) the source profiles are independent of one another, and 6) measurement uncertainties are random, uncorrelated, and normally distributed.

Application of the CMB model requires 1) identification of contributing source types, 2) selection of chemical "fitting species", 3) estimation of the source composition, 4) estimation of the uncertainty in ambient concentrations and source compositions, and 5) solution of the chemical mass balance equations.

The Lyons PM₁₀ emission inventory, summarized in Section 2.0 of this report, identified potentially significant air pollution sources for consideration in the CMB modeling. The "fitting species" (e.g., elements, ions, and carbon) selected for use in the analysis must be present above detection limits on the ambient PM₁₀ filters and be present in significant amounts in the air pollutant source profiles. Generally, all chemical species present in concentrations at least twice their associated uncertainty were used as fitting species in the analysis. About 19 fitting species; ammonium (NH₄⁺), nitrate (NO₃⁻), sulfate (SO₄⁻), organic carbon (OC), elemental carbon (EC), aluminum (Al), silicon (Si), sulfur (S), chlorine (Cl), potassium (K), calcium (Ca), titanium (Ti), chromium (Cr), manganese (Mn), iron (Fe), zinc (Zn), rubidium (Rb), strontium (Sr), and zirconium (Zr) were used in CMB analyses. Uncertainty estimates of both source and receptor profile concentrations were provided by the analytical laboratory (Chester LabNet, Inc.) as detailed in Section 4.0 of this report.

5.2 CMB Source Profiles

A brief description of the PM₁₀ source profiles selected for possible use in this analysis is presented in Table 3. These profiles include examples from five broad source categories which are likely to be present in the Lyons air shed; geological material, vegetative burning emissions, motor vehicle emissions, and secondary particles of ammonium sulfate and ammonium nitrate.

TABLE 3

Source Profiles Selected For Use in the Hygiene CMB Modeling

Source code	Source category	Description
PAVED*	Geological material	Composite of PM10 paved street dirt samples collected in the Denver area.
UNPAVED*	Geological material	Composite of PM10 unpaved street dirt samples collected in the Denver area.
LEUKPST	Geological material	Lekonen's Pasture, west of Southdown
59THSTR	Geological material	59th Street Unpaved Road Source in Hygiene
STHDNKF	Geological material	Southdown, Kiln Feed sample
CEMKLNDS	Geological material	Southdown, Cement Kiln Dust sample
TP12CMNT*	Geological material	Southdown, Portland Cement Product sample
UNLP2&3	Mobile source	Composite of emissions data from unleaded fuel vehicles operated in Phase 2 & 3, cold stabilized and hot transient conditions.
DIESP2&3	Mobile source	Composite of emissions data from diesel fuel vehicles operated in Phase 2 & 3, cold stabilized and hot transient conditions.
MD7515US	Mobile source	Composite of emissions data weighted to a 75% diesel, 15% leaded, and 10% unleaded fuel mix.
MD8510US*	Mobile source	Composite of emissions data weighted to a 85% diesel, 10% leaded, and 5% unleaded fuel mix.
FIREP*	Vegetative burning	Composite of PM10 emissions from fireplace testing.
WSTOVE	Vegetative burning	Composite of PM10 emissions from woodstove testing.
WOODBURN	Vegetative burning	Composite of PM10 emissions from woodstove and fireplace testing.
BURNING*	Vegetative burning	Composite of PM10 emissions from field/grass burning emissions.
NH4NO3*	Secondary particulate	Ammonium nitrate profile.
(NH4)2SO4*	Secondary particulate	Ammonium sulfate profile.
NH4HSO4*	Secondary particulate	Ammonium bisulfate profile.

Note:

* Profiles were included in at least one of the final CMB model source apportionments.

The geological category may include material derived from paved and unpaved roads, fugitive dust from commercial operations, or street sanding material. Other chemically similar sources which would be included in the geological source category are dust from agricultural operations, windblown soil, and particulate emissions from coal-fired power plants. Five local fugitive dust profiles were developed for the Hygiene receptor modeling effort. These profiles include wind blown/soil erosion sample collected from a pasture (Luekonen's pasture) west of Southdown (LEUKPST), an unpaved road dust sample collected east of Southdown (59THSTR), and three (3) samples collected from Southdown storage piles (STHDKF, CEMKLNDS, and TP12CMNT) from the kiln feed operation, dust from the cement kiln, and Portland cement product classified as Type I/II Portland. Bulk samples of these materials were dried, sieved, aspirated into a suspension chamber, and then collected on filters using a PM₁₀ sampler. The filters were then chemically analyzed using methods identical to those used to analyze the Hygiene ambient air samples. The bulk sample processing and chemical analysis was performed by Chester LabNet, Inc. of Tigard, OR and Hazen Research, Inc. of Golden, CO.

The vegetative burning source in Hygiene could include residential wood burning, emissions from restaurant grills and char broilers, or agricultural or silvicultural burning. Although agricultural burning source profiles are available, they were not considered to be significant sources during the winter season in Boulder County and were not included in this analysis. Restaurant grill or char broiler PM₁₀ source profiles are represented by the residential wood burning source profiles developed from stove testing in Denver.

Several motor vehicle source profiles were taken from dynamometer testing done in Denver

using a number of motor vehicle classes and fuels.

Single constituent source profiles of ammonium sulfate $(\text{NH}_4)_2\text{SO}_4$, ammonium bisulfate $(\text{NH}_4\text{HSO}_4)$ and ammonium nitrate (NH_4NO_3) were also included in these analyses.

5.3 CMB Source Contribution Estimates

Application of the CMB model is an iterative procedure during which the analyst selects different combinations of CMB source profiles in an effort to best apportion the chemical composition of the material collected on the PM_{10} filter. The CMB model output includes a number of statistical measures which are used to assess the accuracy and representativeness of the model run. The final model runs selected for characterization of the Hygiene samples are presented in Appendix C. A brief description of the CMB model diagnostic criteria used in selection of the optimum CMB model runs is presented in Appendix D. All filters modeled for this report met the CMB diagnostic criteria.

The results of the CMB analyses performed on filters collected at the Hygiene monitoring site are presented in Table 4. This table shows the PM_{10} source contribution estimate for six (6) air pollution source categories; mobile sources, vegetative burning, ammonium nitrate, ammonium sulfate, paved/unpaved road dust, and Type I/II cement. In some cases, the CMB model can predict a lower mass concentration than what is actually measured on the filter. This "under-apportionment" is indicated in Table 4 by an average 96.8% PM_{10} value associated with the unknown mass concentration.

The source contribution estimates in Table 4 are presented both in terms of concentration ($\mu\text{g}/\text{m}^3$) as well as percent of PM_{10} mass collected on the filter. Furthermore, the percent apportionment has been normalized to 100% for an accurate graphical representation, and maximum percent apportionment per category has been included.

The results of the individual CMB analyses can be averaged to provide an indication of the average contribution of the listed sources. As in most Colorado communities where winter-season PM_{10} receptor modeling has been done, the contributions from geological and wood burning sources were by far the most significant sources of particulate air pollution. Geological material comprised about 73% (~53% road dust, ~20% Type I/II contribution) of the PM_{10} mass, while vegetative burning contributed about 16% of the PM_{10} mass. Secondary particulate species contributed about 5% of PM_{10} mass, while the average contribution from mobile sources was 6%.

TABLE 4

Summary of Hygiene CMB Source Contribution Estimates

Source ID:	PM ₁₀ ³	Mobile Sources	Vegetative Burning	Ammonium Nitrate	Ammonium Sulfate/bisulfate	Paved/Unpaved	Type I/II Cement
Date	(µg/m ³)	(µg/m ³)	(µg/m ³)	(µg/m ³)	(µg/m ³)	(µg/m ³)	(µg/m ³)
12/1/98	29	1.6391	4.1540	0.0000	0.2346	17.2931	5.7843
12/4/98	30	2.2986	4.3731	0.0000	0.3228	18.0756	5.7115
3/25/99	33	1.3930	5.2939	2.2736	2.0535	18.5621	6.1058
3/28/99	39	0.0000	11.0874	1.4659	0.6985	15.3779	10.7007
3/31/99	32	0.5018	7.9515	1.4379	0.7615	15.2456	6.6392
11/17/99	54	7.0035	1.2429	0.8358	0.0000	26.3732	7.1782
Avg. (µg/m ³)	36.2	2.1	5.7	1.0	0.7	18.5	7.0
Avg. (%)	96.8	5.9	15.7	2.8	1.9	51.1	19.4
Normalized	100.0	6.1	16.2	2.9	1.9	52.8	20.1
Max. (%)	---	13.0	28.4	6.9	6.2	60.3	27.4

Note:

PM₁₀: particulate matter with an aerodynamic diameter of 10 microns or less.

µg/m³: micrograms per cubic meter

* Relative percentage values were normalized to 100% to provide an appropriate graphical representation in Figure 4.

5.3.1 Geological Material

Geologic material may be derived from windblown soil, or dust from commercial or agricultural operations, street sanding material, and roadway dust from paved and unpaved roads. For this CMB modeling exercise, the general geological source apportionment was separated into two source categories: paved/unpaved and Type I/II cement. The Type I/II cement (Southdown Portland cement) provided the best model fit on all of the Hygiene CMB model runs. Attempts were made for each model run to include, or substitute, other source profiles from collected bulk samples and from other generic EPA library sources. However, this local source profile proved to be the best fit consistently.

A Denver paved road dust source profile (PAVED) provided the best model fit on most of the CMB model runs. This profile is rich in organic carbon and some of the trace metals associated with deposited automobile exhaust, making it suitable for use at the Hygiene monitoring site, that has relatively high mobile source activity along State Route 66. Certainly a small fraction of the PM₁₀ attributed to this geologic source category is derived from motor vehicle exhaust.

It is also to be noted that, because a specific source profile provides the best model statistics, does not mean that other sources do not contribute to PM₁₀ monitored at the Hygiene monitoring site. Other emission sources could potentially have similar constituents. An estimate of the contribution from source categories to Hygiene PM₁₀ can be made based on these CMB results for source profiles and the emission inventory results.

The emission inventory estimated that Southdown operation contributed about 584 tpy, while the combined contribution of road dust, commercial and industrial sources, wood burning, and agricultural operations totaled approximately 817 tons per year. Based on the emission inventory, Southdown

contributes about 71% (584/817) of PM₁₀ within the Lyons airshed. Based on the CMB model, Type I/II Portland cement material comprises about 20% of PM₁₀ mass at Hygiene. Therefore, Southdown on average contributes less than 14% (71% x 20%) of PM₁₀ mass at the Hygiene monitoring site. Additionally, by further refining the 71% Southdown contribution down to 52%, to separate the probable fugitive dust emissions from the stack emissions, Southdown on average would contribute less than 10% (52% x 20%) of PM₁₀ mass at the Hygiene monitoring site.

A similar procedure can be used to estimate the contribution of paved/unpaved road dust to PM₁₀ levels at the Hygiene monitoring site. The emission inventory estimated that road sources contributed about 64 tons per year, while the combined contribution of street dust, commercial and industrial sources, and agricultural operations totaled approximately 817 tons per year. Based on the emission inventory, paved/unpaved road dust contributes about 8% (64/817) of geological material within the Lyons air shed. Based on the CMB model, paved/unpaved road sources comprise about 52% of PM₁₀ mass at Hygiene. Therefore, road sources contributes about 4% (8% x 52%) of PM₁₀ mass at the Hygiene monitoring site.

As discussed earlier in Section 2.0 of this report, the emission inventory estimate is based on annual emissions, and the actual impacts from any given source can vary depending on actual air pollution source emission strength, proximity of the source to the monitoring site, atmospheric dispersion, and seasonal variations. Additionally, the Hygiene PM₁₀ monitoring site is located within the southeastern area of the Lyons air shed. Possibly the Lyons emission inventory, or a Longmont inventory (if available) may not accurately describe the rural area of Hygiene. Therefore, the above approach, while sometimes useful for permitted sources, may not be representative in this study.

5.3.2 Vegetative Burning

The PM₁₀ source contribution estimates for vegetative burning ranged from 14% to 28% of total mass on individual sample days, and averaged about 16% at the Hygiene monitoring site. A composite source profile developed from Denver fireplace sampling (FIREP) provided the best model fit on most of the final CMB model runs. The fireplace source contribution estimate includes all residential wood burning devices as well as restaurant grill and char broiler emissions.

This estimate of the relative influence of the vegetative burning source category (~16%) is substantially different than that suggested by the local PM₁₀ emission inventory which showed that residential wood burning accounted for only about 1% of the Hygiene PM₁₀. This discrepancy is consistent with APCD experience in other Colorado communities (Denver, Telluride, Steamboat Springs) where CMB modeling and PM₁₀ emission inventories have been developed. The cause of this systematic difference is still under investigation. Potential causes could include seasonal variations, uncertainties in wood burning emission factors and activity patterns, sampling artifacts associated with condensation of organic vapors on the quartz sampling substrate, and potential errors related to the quantified impact of emissions from other carbon-rich PM₁₀ sources such as restaurant grilles and char broilers.

5.3.3 Mobile Sources

The contribution estimates for emissions from mobile sources were low, ranging from 0-14%. The MD8510US profile, which is a fleet mix composite profile developed from Denver emission testing, provided the best model fit for the mobile source category.

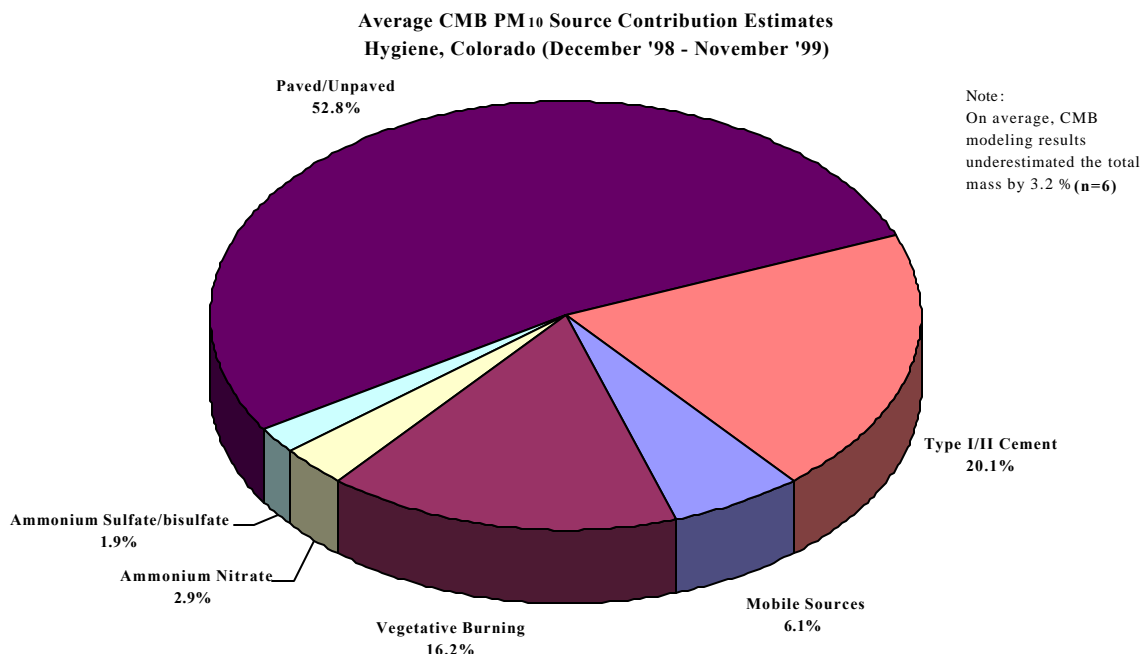
As noted earlier, this profile is enriched in organic carbon and trace elements associated with automobile exhaust. The mobile source PM₁₀ source contribution estimates include only direct tailpipe emissions, they do not include roadway material disturbed by passing traffic. As detailed in the Lyons emission inventory report, much of the actual impact of motor vehicle traffic on PM₁₀ levels is apportioned in the geological material source category.

5.3.4 Secondary Particulate

Ammonium nitrate contributions ranged from 0% to 7% of total mass, and averaged only about 3%. Ammonium sulfate/bisulfate contributions were similarly low, ranging from 0% to 6% of total mass, and also averaged about 2% of PM₁₀ mass. Because of the nonlinear processes by which these particles form, the CMB model cannot directly apportion these secondary particles to their sources. It is possible to make some estimate of sources of these particles based on emission of the precursor gases. All combustion processes (motor vehicles, space heating, wood burning, utility boilers) emit NO_x gases which can be converted in the atmosphere to nitrate particles. Diesel motor vehicles and utility coal burning are the most probable sources of SO₂ gas, the precursor to particulate sulfate. These secondary particles are very fine and can be transported long distances. It is possible that a significant fraction of the secondary species measured in this study is transported into Boulder County from distant sources. However, the local traffic on State Route 66 is influenced by diesel trucks and the coal-fired (~90% coal, ~10% gas) cement kiln at Southdown are also a possible contributor to local secondary particulate formation.

The CMB source contribution estimates determined for the samples collected during the winter 1999 special monitoring effort is presented graphically in Figure 4.

FIGURE 4



6.0 BULK SAMPLE AND PM₁₀ FILTER ANALYSES

6.1 Background

One of the primary goals of this study was to determine the relative contribution of local air pollution sources to PM₁₀ levels at the Hygiene monitoring site. Local concern about hazardous air pollutants has been elevated by the presence of the Southdown cement production facility in Lyons. Southdown processes locally mined raw materials from the Dowe Flats with other imported materials to manufacture Portland cement, a product that is used extensively in construction as a binding agent in mortar and concrete.

Portland cement (CAS# 65997-15-1) is a fine, gray, alkaline powder solid which is a mixture of tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tertacalcium aluminoferrite. It is formed from the firing of limestone, clay, silica, and iron oxide. It also contains gypsum and free calcium oxide. The gray color of Portland cement comes from the iron oxide and magnesium oxide content.

The effects of chronic exposure to Portland cement dust can include both irritant and allergic contact dermatitis, and respiratory irritation. Silicosis was an initial concern at the start of this study, due to potentially high crystalline silica content. Generally, it is accepted that pure Portland cement does not cause silicosis. However, elevated crystalline silica content ($\geq 5\%$) within Portland cement may lead to this disease. Additionally, chronic exposure to pure Portland cement can cause a benign pneumoconiosis. While Portland cement is generally regarded as a nuisance dust, it is hypothesized to be a suspect carcinogen, which may be linked to hexavalent chromium (Cr^{VI}) content. The alkali constituents of Portland are primarily calcium oxide and potassium and sodium oxides.

Since there has been emphasis on the silica content, it is important to decipher which form of silica should be analyzed for. Silica (SiO_2) is a colorless, odorless, noncombustible solid that is insoluble in water. Crystalline silica refers to oxygen and silica atoms arranged in a three-dimensional repeating pattern and should not be confused with the naturally occurring amorphous form. The heating of quartz can produce tridymite (CAS# 15468-32-3) or cristobalite (CAS# 14464-46-1). Crystalline transformations of quartz to tridymite occurs at $\sim 1,600^\circ\text{F}$, and further transformation to cristobalite will occur at $\sim 2,700^\circ\text{F}$. From a review of the Southdown operations, the formation of both forms of crystalline silica is possible. Therefore, analysis of bulk samples was approved by APCD for all three (3) species.

Other concerns of the residents of Hygiene were for the heavy metal and radiation (α , β , and γ) content of the bulk samples. Therefore, analysis of the collected bulk samples included the standard list of RCRA metals and a radiation analysis.

To enhance the suite of analyses, APCD chose to also have the bulk samples analyzed for the elemental and ionic species necessary to conduct a chemical mass balance modeling exercise. Further analyses were performed on the ambient PM_{10} filters for a particle and elemental size distribution.

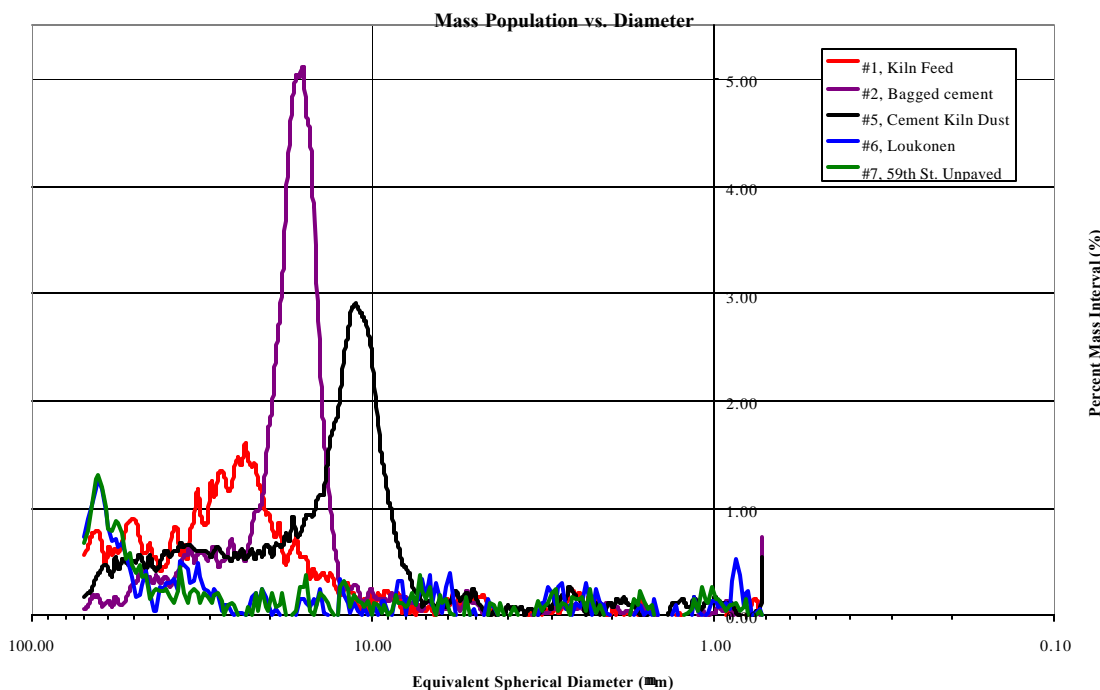
6.2 Bulk Sample Analyses

Bulk samples of local soil, unpaved road material, and material that may potentially contribute to measured PM_{10} levels at the Hygiene monitoring site were collected by the Boulder County Health Department and submitted to APCD for storage and analysis. Due to cost constraints, only two of seven collected samples were submitted for analysis by APCD, and three more samples were subsequently submitted by APCD, and financed by Southdown, Inc.

RCRA Metals, Crystalline Silica, Radiation, and Miscellaneous Chemistry

Hazen Research, Inc. of Golden, CO was contracted to analyze the five (5) bulk samples for heavy metal content, crystalline silica content, radiation content, carbonate, pH, alkalinity, specific gravity, and mass distribution by particle aerodynamic diameter. The bulk samples were comprised of three (3) samples from Southdown stockpiles (kiln feed, Type I/II bagged cement, and cement kiln dust) and two (2) sieved samples from the surrounding area (Leukonen's pasture and the 59th Street unpaved road) that were sieved to a 65 mesh size fraction. Two other samples that had been submitted (third ridge shale and limestone) were excluded from the analysis due to the low probability to create a fugitive dust emission. The results from the bulk sample analysis are presented in Table 5, and the mass distribution is presented in Figure 5. Note the high peaks for the bagged cement and cement kiln dust in Figure 5. This 7-20 μm range of equivalent spherical diameter supports a higher probability of source contributions from these samples. Furthermore, these two samples had provided the two best statistical CMB model fits consistently, as noted in Section 5.0.

FIGURE 5



The results of the RCRA metals analysis have been compared to the analysis conducted through Chester LabNet's elemental analysis and the two separate analyses generally agree. Of the RCRA metals analyzed for, six (6) metals (As, Ba, Cd, Cr, Pb, and Se) were detected in one or more samples. Except for selenium, all concentrations were within an order of magnitude of each other, relative to each sample.

Within the silica analysis, analyzed by x-ray diffraction, quartz was detected in each sample with the highest quartz levels being detected in the samples collected outside the Southdown facility. Cristobalite was not detected in any sample. However, tridymite was detected in the Type I/II Portland bagged cement from Southdown, at a level of less than, or equal to, 3%. The " \leq " is applied to the value since the analyst provided a range of certainty of 2-3%. Thus, an upper bound conservative value of 3% is applied here.

The results of the radiation analyses show all values being represented as " \leq " indicating less than or equal to the given value. Again, due to the uncertainty of the laboratory analysis, an upper bound conservative value was applied to each reported concentration. The upper bound value comes from the upper range of uncertainty associated with the analytical method used by laboratory.

TABLE 5

Bulk Sample Analyses Performed By Hazen Research, Inc.

Parameter (units) / Sample ID	(units)	#1, Kiln Feed	#2, Bagged Cement	#5, Cement Kiln Dust	#6, Leukonen Pasture	#7, 59th St Unpaved
RCRA METALS						
Arsenic	%	0.001	0.00178	0.00162	0.00061	0.00043
Barium	%	0.029	0.051	0.044	0.051	0.059
Cadmium	%	<0.001	<0.001	0.003	<0.001	<0.001
Chromium	%	0.004	<0.001	<0.001	0.006	0.005
Lead	%	<0.001	0.002	0.006	0.002	0.002
Mercury	%	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Selenium	%	0.0004	0.0002	0.0064	0.0002	0.0002
Silver	%	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
CRYSTALLINE SILICA ANALYSIS						
Quartz	%	9.0	<=0.2	4.3	38	37
Cristobalite	%	<0.2	<0.3	<0.05	<0.2	<0.2
Tridymite	%	<0.3	<=3.0	<0.2	<0.3	<0.3
RADIATION ANALYSIS						
Gross Alpha	pCi/g	<=17.1	<=28.0	<=41.0	<=27.0	<=22.0
Gross Beta	pCi/g	<=18.0	<=16.4	<=35.0	<=41.0	<=36.0
Gross Gamma (Ra-226 Equiv.)	pCi/g	<=1.3	<=4.5	<=6.9	<=7.7	<=9.4
MISCELLANEOUS CHEMISTRY						
Bicarbonate (as HCO ₃)	%	<0.05	<0.05	<0.05	0.05	<0.05
Carbonate	%	<0.05	<0.05	<0.05	<0.05	<0.05
Hydroxide (as OH)	%	<0.01	0.38	0.33	<0.01	<0.01
Specific Gravity		2.75	3.21	2.54	2.46	2.71
pH		10.2	12.1	12.1	8.34	9.19
INITIAL SIEVE RESULTS						
+65 mesh	%	---	---	---	92.6	92.5
-65 mesh	%	---	---	---	7.4	7.5

Note:

- A less than sign "<" indicates that the sample was not detected via the analytical method and therefore is below (less than) the lower quantitation limit.
- A less than or equal to sign "<=" indicates that the sample has been detected and a conservative value has been applied for screening purposes.

The miscellaneous chemistry that was performed on the samples confirms an approximate specific gravity of the Portland cement analyzed, compared to a text book value. Additionally, the pH of the samples confirms a greater alkaline product from Southdown, compared to local soil samples.

RCRA metals, silica, and radiation fractional values will be applied from the Type I/II bagged Portland cement to CMB apportioned PM₁₀ levels from Southdown, to develop an estimated source contribution of specific ambient species in Section 7.

Elemental and Ionic Species

Portions of the same five (5) bulk samples were sent to Chester LabNet for elemental and ionic specie content analysis. The purpose of this was to enhance the CMB modeling exercise by submitting probable fugitive dust samples for analysis to develop a source profile that was compatible with the CMB model. A summary of this analysis is presented in Table 6.

TABLE 6

Bulk Sample Analysis Performed by Chester Lab Net

Sample Profile ID:	STHDNKE	LEUKPST	59THSTR	CEMKLNDS	TP12CMNT
Specie	(fraction)	(fraction)	(fraction)	(fraction)	(fraction)
Aluminum (Al)	0.019430	0.094020	0.095220	0.017980	0.017950
Antimony (Sb)	0.000029	0.000078	0.000042	0.000007	
Arsenic (As)		0.000057		0.000040	0.000011
Barium (Ba)	0.000384	0.001258	0.001060	0.000752	0.000639
Bromine (Br)	0.000006	0.000021		0.000013	
Cadmium (Cd)			0.000042	0.000108	
Calcium (Ca)	0.333800	0.023140	0.022090	0.314600	0.376300
Chlorine (Cl)				0.000634	
Chromium (Cr)	0.000086	0.000076	0.000118	0.000059	0.000120
Cobalt (Co)					
Copper (Cu)		0.000081	0.000093		
Gallium (Ga)	0.000024	0.000039	0.000027	0.000006	0.000014
Germanium (Ge)	0.000008	0.000013	0.000013		0.000015
Indium (In)	0.000041				
Iron (Fe)	0.010620	0.045330	0.044590	0.011090	0.020790
Lanthanum (La)		0.000388	0.000231		0.000277
Lead (Pb)	0.000044	0.000043	0.000115	0.000028	0.000015
Manganese (Mn)	0.000575	0.000642	0.000795	0.000586	0.000687
Mercury (Hg)	0.000007		0.000018		0.000033
Molybdenum (Mo)	0.000009	0.000013	0.000010		0.000033
Nickel (Ni)	0.000033	0.000066	0.000045	0.000034	0.000044
Palladium (Pd)	0.000008		0.000035		
Phosphorous (P)		0.000564	0.000135		
Potassium (K)	0.003188	0.023390	0.028540	0.011740	0.011850
Rubidium (Rb)	0.000019	0.000149	0.000230	0.000069	0.000051
Selenium (Se)	0.000006			0.000075	0.000008
Silicon (Si)	0.043360	0.186800	0.184100	0.037320	0.056850
Silver (Ag)		0.000011	0.000024	0.000058	
Strontium (Sr)	0.001290	0.000186	0.000302	0.001667	0.001669
Sulfur (S)	0.003287	0.000894	0.000306	0.012110	0.018070
Tin (Sn)	0.000004	0.000092	0.000120	0.000081	0.000017
Titanium (Ti)	0.000649	0.003242	0.003476	0.000646	0.000736
Vanadium (V)	0.000184	0.000091	0.000063	0.000180	0.000071
Yttrium (Y)	0.000015	0.000056	0.000050	0.000008	0.000029
Zinc (Zn)	0.000058	0.000127	0.000121	0.000082	0.000092
Zirconium (Zr)	0.000047	0.000147	0.000111	0.000055	0.000088
Ammonium (NH ₄ ⁺)					
Nitrate (NO ₃ ⁻)				0.000425	0.000603
Sulfate (SO ₄ ⁼)	0.002544			0.034550	0.083270
Soluble Pottasium (K ⁺)		0.001580	0.000294	0.008760	0.011410
Elemental Carbon (EC)	0.017230				0.003210
Organic Carbon (OC)	0.130200	0.054350	0.016650	0.073270	0.012070

Note:

- Blank values indicate the sample was below the detection limits.

The mass distribution by particle aerodynamic diameter was conducted on each of the five bulk samples. Both samples from Leukonen's pasture and the 59th Street unpaved road were sieved to a 65 mesh and the remaining content was subjected to size distribution. The results of this analysis are presented in Figure 5. It is noted that two of the five (5) samples, Type I/II Portland cement, and cement kiln dust (CKD), have the highest potential for contributing as a fugitive dust source. This is supported by large peaks from each size distribution profile within Figure 5, and by the CMB modeling results, whereas Type I/II was the consistent fugitive dust source profile, with a strong second profile seen within the model when using CKD. Although the peaks occur just above ten microns (μm), further particle size reduction of these products can occur on the paved and unpaved surfaces within the Southdown facility increasing the potential for particle suspension into the air shed.

6.3 Ambient Air Sample Analyses

Prior to sending the five (5) of six (6) PM_{10} samples out for analysis, the filters were cut in half. One half of the filter was sent to Chester LabNet for elemental, ionic, and carbon analysis. The results of this analysis have been presented in Section 4.1.

The second half of each PM_{10} filter was sent to RJ LeeGroup, Inc., of Monroeville, PA for computer controlled scanning electron microcopy (CCSEM). This analysis provided a size distribution analysis, coupled with elemental data abundance. The results of the size and elemental distribution analyses are presented in Table 7 and graphically presented in Figure 6. These results depict a consistent geologic influence on the sample PM_{10} filters and a variable carbon content. Of added value, the silicon rich values were able to be extracted from this analysis and included in the CMB sample profile. This lead to an increased percent mass recovery during the CMB modeling exercise. Normally, silicon is excluded from the CMB modeling due to interference from the quartz-fiber filter which is silicon based.

Figure 6 further supports the probability of larger particles entering the PM_{10} sampler, compared to the size distribution profiles shown in Figure 5. This is supported by the 10-20 μm range in Figure 6. The sixth (6th) sample was subsequently analyzed by Chester LabNet in June 2000.

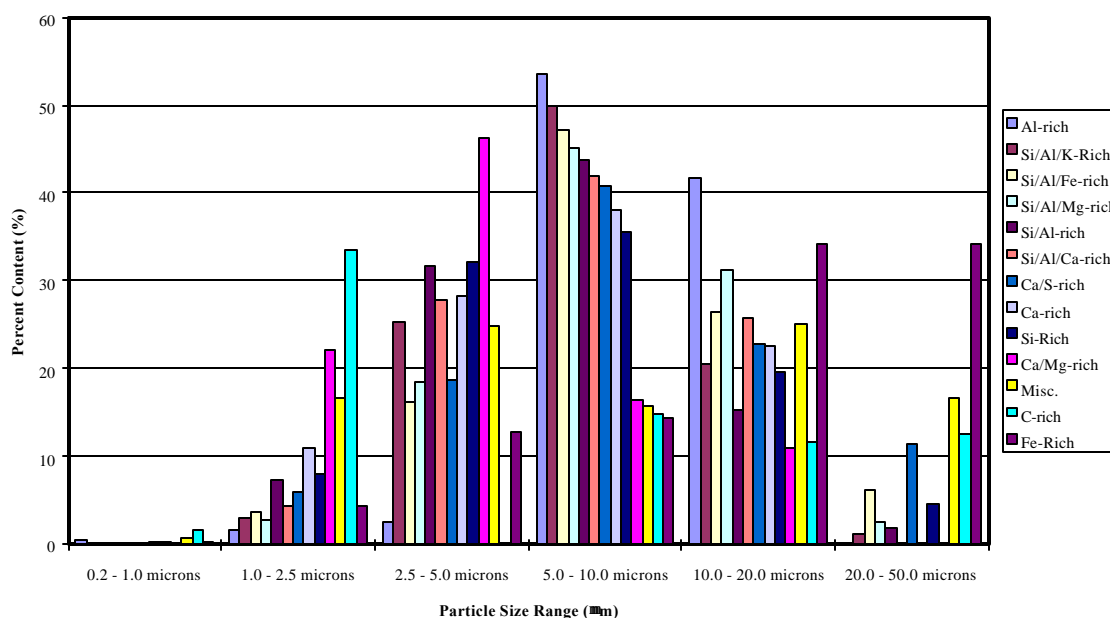
TABLE 7

Size and Elemental Distribution Analyses by R.J. LeeGroun, Inc.

Particle Count - Number													
Sample date	Si/Al/K-Rich	Si/Al-rich	Si/Al/Mg-rich	Si-Rich	Fe-Rich	Si/Al/Ca-rich	Si/Al/Fe-rich	C-rich	Ca-rich	Misc.	Ca/S-rich	Al-rich	Ca/Mg-rich
12/1/1998	215	269	106	120	46	49	23	38	67	46	8	10	
12/4/1998	218	252	122	143	18	72	24	45	58	29	6	7	3
3/25/1998	262	215	186	147	45	48	34	2	16	19	16	3	5
3/28/1998	206	199	290	91	30	50	27	0	46	17	27	2	13
3/31/1998	219	183	254	115	34	40	37	0	35	19	8	2	4
Particle Count - % Number													
Sample date	Si/Al/K-Rich	Si/Al-rich	Si/Al/Mg-rich	Si-Rich	Fe-Rich	Si/Al/Ca-rich	Si/Al/Fe-rich	C-rich	Ca-rich	Misc.	Ca/S-rich	Al-rich	Ca/Mg-rich
12/1/1998	18.67	32.46	7.96	11.87	6.15	2.95	1.46	2.07	8.78	6.27	0.43	0.93	
12/4/1998	14.3	29.01	6.54	20.7	2.69	4.02	1.69	7.8	8.27	3.85	0.21	0.4	0.53
3/25/1998	20.7	24.37	15.19	17.54	6.11	4.39	2.84	0.36	1.49	3.56	2.87	0.19	0.38
3/28/1998	11.61	25.9	24.98	10.41	1.98	4.59	2.53		7.39	3.55	4.39	0.19	2.47
3/31/1998	19.71	22.98	23.19	12.13	3.1	4.09	3.37		4.98	4.62	1.1	0.19	0.55
Percent Weight within Sample - Mass %													
Sample date	Si/Al/K-Rich	Si/Al-rich	Si/Al/Mg-rich	Si-Rich	Fe-Rich	Si/Al/Ca-rich	Si/Al/Fe-rich	C-rich	Ca-rich	Misc.	Ca/S-rich	Al-rich	Ca/Mg-rich
12/1/1998	23.48	19.7	14.56	12.6	6.51	5.58	4.21	4.1	3.13	2.61	2.09	1.44	
12/4/1998	24.16	20.03	18.72	13.12	1.49	9.16	3.13	1.28	4.46	1.12	1.84	1.13	0.36
3/25/1998	26.71	23.27	19.45	10.43	7.5	5.91	2.6	0	0.98	0.93	1.23	0.2	0.78
3/28/1998	16.62	16.06	34.46	6.42	13	3.58	1.65		3.48	0.87	2.45	0.1	1.32
3/31/1998	24.63	14.46	29.6	7.15	8.54	4.29	6.34		2.97	0.4	1.35	0.05	0.21
0.2 - 1.0 microns (% per classification per sample)													
Sample date	Si/Al/K-Rich	Si/Al-rich	Si/Al/Mg-rich	Si-Rich	Fe-Rich	Si/Al/Ca-rich	Si/Al/Fe-rich	C-rich	Ca-rich	Misc.	Ca/S-rich	Al-rich	Ca/Mg-rich
12/1/1998	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.0	0.2	0.0	0.0	
12/4/1998	0.0	0.2	0.0	0.4	0.4	0.0	0.1	1.7	0.4	0.9	0.0	0.0	0.0
3/25/1998	0.0	0.1	0.0	0.2	0.2	0.1	0.1	3.3	0.1	0.5	0.0	0.0	0.0
3/28/1998	0.0	0.1	0.0	0.1	0.1	0.0	0.1	---	0.1	0.6	0.0	0.0	0.2
3/31/1998	0.0	0.1	0.0	0.2	0.1	0.0	0.1	---	0.2	1.8	0.0	2.3	0.0
1.0 - 2.5 microns (% per classification per sample)													
Sample date	Si/Al/K-Rich	Si/Al-rich	Si/Al/Mg-rich	Si-Rich	Fe-Rich	Si/Al/Ca-rich	Si/Al/Fe-rich	C-rich	Ca-rich	Misc.	Ca/S-rich	Al-rich	Ca/Mg-rich
12/1/1998	2.7	4.0	1.4	3.7	3.2	1.0	0.6	0.2	11.4	4.8	0.0	0.0	
12/4/1998	3.1	9.5	2.0	5.5	13.7	2.0	2.4	3.3	9.5	15.6	0.0	0.0	3.7
3/25/1998	3.4	3.4	3.4	5.9	2.9	3.5	7.6	96.7	12.8	13.0	8.0	1.5	0.0
3/28/1998	3.4	9.7	4.5	14.0	0.4	7.3	6.8		14.8	15.5	16.3	7.2	9.0
3/31/1998	2.9	10.0	2.7	11.5	1.4	8.6	0.7		6.4	34.9	5.7	0.0	75.9
2.5 - 5.0 microns (% per classification per sample)													
Sample date	Si/Al/K-Rich	Si/Al-rich	Si/Al/Mg-rich	Si-Rich	Fe-Rich	Si/Al/Ca-rich	Si/Al/Fe-rich	C-rich	Ca-rich	Misc.	Ca/S-rich	Al-rich	Ca/Mg-rich
12/1/1998	19.5	23.3	15.4	18.0	5.1	10.1	0.7	0.0	14.6	12.2	8.5	12.8	
12/4/1998	25.5	20.8	13.5	23.8	43.1	33.0	13.0	0.0	55.4	10.1	0.0	0.0	96.3
3/25/1998	26.7	25.7	20.5	31.1	7.6	15.4	37.8	0.0	9.9	38.3	42.0	0.0	47.8
3/28/1998	28.4	43.7	28.4	44.9	3.8	37.0	8.8		34.7	0.0	22.4	0.0	40.9
3/31/1998	26.0	44.4	14.2	42.4	4.5	43.2	21.1		26.2	63.3	21.1	0.0	0.0
5.0 - 10.0 microns (% per classification per sample)													
Sample date	Si/Al/K-Rich	Si/Al-rich	Si/Al/Mg-rich	Si-Rich	Fe-Rich	Si/Al/Ca-rich	Si/Al/Fe-rich	C-rich	Ca-rich	Misc.	Ca/S-rich	Al-rich	Ca/Mg-rich
12/1/1998	44.6	48.7	39.9	32.7	17.1	36.0	30.3	29.0	36.5	60.9	27.9	64.2	0.0
12/4/1998	41.5	37.2	42.5	35.3	4.6	44.6	50.5	44.7	24.9	18.4	27.8	82.2	0.0
3/25/1998	55.6	58.0	37.1	58.7	46.2	48.7	42.2	0.0	35.8	0.0	32.6	23.5	8.2
3/28/1998	50.1	37.6	46.3	20.2	0.0	41.4	80.6	0.0	26.0	0.0	56.4	0.0	49.9
3/31/1998	57.8	37.7	59.3	30.6	3.8	38.9	32.7	0.0	67.2	0.0	59.9	97.7	24.1
10.0 - 20.0 microns (% per classification per sample)													
Sample date	Si/Al/K-Rich	Si/Al-rich	Si/Al/Mg-rich	Si-Rich	Fe-Rich	Si/Al/Ca-rich	Si/Al/Fe-rich	C-rich	Ca-rich	Misc.	Ca/S-rich	Al-rich	Ca/Mg-rich
12/1/1998	27.0	23.9	35.3	45.5	30.0	52.9	68.4	8.4	37.5	21.9	63.6	23.0	
12/4/1998	29.9	22.5	42.0	12.3	38.3	20.4	33.9	50.3	9.8	54.9	14.7	17.8	0.0
3/25/1998	14.3	12.8	39.0	4.1	43.1	32.4	12.3	0.0	41.4	48.3	17.4	75.0	44.1
3/28/1998	18.1	8.9	18.3	20.8	17.3	14.3	3.7	0.0	24.4	0.0	4.9	92.8	0.0
3/31/1998	13.3	7.8	21.7	15.4	42.7	9.3	14.2	0.0	0.0	0.0	13.4	0.0	0.0

FIGURE 6

Overall Size and Elemental Distribution of Ambient PM₁₀ Samples



7.0 SUMMARY OF AMBIENT PM₁₀ VALUES

This section of the report provides a summary of direct and indirect ambient PM₁₀ values.

7.1 Measured PM₁₀ Values

The results of a PM₁₀ filter pad analysis for elemental, ionic, and carbon content, are summarized in Table 8. Table 8 provides the average and maximum measured speciated PM₁₀ concentrations from the Hygiene study period. The purpose of providing this information in this format is essentially for reference purposes. Typically, average concentrations are compared to long-term (e.g., annual) air quality standards or guidelines, and maximum concentrations are compared to short-term (e.g., hourly) air quality guidelines or standards. Threshold values from EPA's IRIS database have been provided for reference. However, such a comparison (i.e., risk assessment) is beyond the scope of this report.

TABLE 8

Average and Maximum Measured Speciated PM₁₀ Concentrations from Study Period

Measured	Avg. Conc.	Max. Conc.	Measured	Avg. Conc.	Max. Conc.
Specie	(µg/m ³)	(µg/m ³)	Specie	(µg/m ³)	(µg/m ³)
Aluminum (Al)	1.47E+00	2.68E+00	Palladium (Pd)	9.00E-04	5.61E-03
Antimony (Sb)	2.80E-03	1.01E-02	Phosphorous (P)	0.00E+00	0.00E+00
Arsenic (As)	4.00E-04	2.40E-03	Potassium (K)	8.53E-01	1.33E+00
Barium (Ba)	3.17E-01	6.31E-01	Rubidium (Rb)	5.60E-03	1.71E-02
Bromine (Br)	2.50E-03	5.80E-03	Selenium (Se)	8.00E-04	4.71E-03
Cadmium (Cd)	1.20E-03	4.21E-03	Silicon (Si)	1.98E+00	3.93E+00
Calcium (Ca)	2.43E+00	3.68E+00	Silver (Ag)	4.20E-03	1.22E-02
Chlorine (Cl)	9.50E-03	4.01E-02	Strontium (Sr)	1.26E-02	2.94E-02
Chromium (Cr)	2.70E-03	6.00E-03	Sulfur (S)	4.27E-01	8.17E-01
Cobalt (Co)	1.00E-04	5.05E-04	Tin (Sn)	9.10E-03	2.62E-02
Copper (Cu)	3.84E-02	5.54E-02	Titanium (Ti)	9.43E-02	1.57E-01
Gallium (Ga)	0.00E+00	0.00E+00	Vanadium (V)	1.20E-03	4.00E-03
Germanium (Ge)	1.00E-03	3.40E-03	Yttrium (Y)	5.20E-03	1.05E-02
Indium (In)	2.10E-03	6.33E-03	Zinc (Zn)	1.55E-02	2.08E-02
Iron (Fe)	1.00E+00	1.91E+00	Zirconium (Zr)	2.64E-02	3.90E-02
Lanthanum (La)	1.63E-02	7.25E-02	Ammonium (NH ₄ ⁺)	5.15E-01	1.64E+00
Lead (Pb)	7.10E-03	2.71E-02	Nitrate (NO ₃ ⁻)	1.63E+00	2.31E+00
Manganese (Mn)	2.09E-02	3.93E-02	Sulfate (SO ₄ ⁼)	1.91E+00	3.47E+00
Mercury (Hg)	1.40E-03	4.40E-03	Soluble Pottasium (K ⁺)	1.64E-01	2.27E-01
Molybdenum (Mo)	3.21E-02	6.16E-02	Elemental Carbon (EC)	2.72E+00	6.04E+00
Nickel (Ni)	1.00E-04	3.80E-04	Organic Carbon (OC)	4.56E+00	5.59E+00

Note:

- Speciated ambient values were measured by Chester LabNet from the ambient PM₁₀ filters, and the average and maximum of these values are presented here.
- The average values are considered conservative, since they are based on an average filter PM₁₀ concentration of 39.4 µg/m³, compared to the annual study period average PM₁₀ concentration of 20 µg/m³.
- µg/m³: micrograms per cubic meter
- Inorganic arsenic, cadmium, hexavalent chromium, manganese, Inorganic mercury, and nickel as subsulfide have IRIS related lifetime threshold values of 2E-4 µg/m³, 6E-4 µg/m³, 8E-5 µg/m³, 5E-2 µg/m³, 0.3 µg/m³, and 2E-3 µg/m³, respectively, where As, Cd, Cr as Cr+6, and Mn are potentially near or above these threshold values.

7.2 Estimated Contribution of PM₁₀ From Southdown

The results of the bulk sample analysis were considered a good source of empirical data. These analytical results were applied to a modeled mass balance approach to arrive at potential upper bound values measured at Hygiene and could prove to be useful in a screening level-risk assessment.

It has been discussed in this report and shown through a consistent modeling application, that the Type I/II Portland cement source profile was the dominant industry-geologic source profile. Therefore, from the results presented in Table 5, those detected values for the Type I/II bulk sample

have been transposed to Table 9. From these fractional or pCi/g values, estimated upper bound average and maximum ambient concentrations were calculated. The study average concentration was based on an average PM₁₀ concentration of 39.4 µg/m³ from the six (6) highest PM₁₀ filters and an average normalized CMB modeled source contribution of 20.1%. The study maximum concentration was based on a maximum study PM₁₀ concentration of 54 µg/m³ and a maximum modeled source contribution of 27.4%. Concentrations are presented in Table 9 in units of micrograms per cubic meter (µg/m³) and picocuries per cubic meter (pCi/m³). Please note that these calculated values are to be considered potential ambient contributions from Southdown and not total site concentrations (i.e., source contributions plus background values) at Hygiene.

TABLE 9

**Hazen Research Type I/II Bulk Sample Analyses and
Estimated Average & Maximum Ambient Contributions at Hygiene**

Species of Concern	Measured Bulk Value	Study Average* Concentration	Max. Value** Concentration	IRIS Value***
Arsenic (As)	1.78E-05	1.26E-04 ug/m3	2.63E-04 ug/m3	2.00E-04 ug/m3
Barium (Ba)	5.10E-04	3.62E-03 ug/m3	7.55E-03 ug/m3	---
Lead (Pb)	2.00E-05	1.42E-04 ug/m3	2.96E-04 ug/m3	---
Selenium (Se)	2.00E-06	1.42E-05 ug/m3	2.96E-05 ug/m3	---
Quartz	2.00E-03	1.42E-02 ug/m3	2.96E-02 ug/m3	---
Tridymite	3.00E-02	2.13E-01 ug/m3	4.44E-01 ug/m3	---
Alpha (α)	28 pCi/g	2.22E-04 pCi/m3	4.14E-04 pCi/m3	---
Beta (β)	16.4 pCi/g	1.30E-04 pCi/m3	2.43E-04 pCi/m3	---
Gamma (γ)	4.5 pCi/g	3.56E-05 pCi/m3	6.66E-05 pCi/m3	---

Note:

* Study Avg. Conc. for arsenic - tridymite was calculated by multiplying the measured bulk value by the average PM₁₀ concentration (39.4 µg/m³), then by the average Type I/II source contribution fraction (0.201). The same was conducted for α – γ however these values were further multiplied by 10⁻⁶ to convert from grams to micrograms.

** Max. Value Conc. for arsenic - tridymite was calculated by multiplying the measured bulk value by the maximum PM₁₀ concentration (54 µg/m³), then by the maximum Type I/II source contribution fraction (0.274). The same was conducted for α – γ however these values were further multiplied by 10⁻⁶ to convert from grams to micrograms.

*** EPA IRIS value is provided for reference only.

- Gamma (γ) is in equivalent units of Ra-226.

- Measured bulk values are either fractional, or in units of pCi/g for radiation analysis, and analyses were performed by Hazen Research.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The special purpose monitoring program has thus far shown PM₁₀ levels at Hygiene are consistently well below the applicable 24-hour NAAQS of 150 µg/m³, and the annual average NAAQS of 50 µg/m³.

CMB receptor modeling indicates that during periods of relatively elevated PM₁₀ concentrations (29-54 µg/m³), the particulate is comprised of 53% road dust, 20% Type I/II Portland cement, 16% vegetative burning, 5% secondary particulate, and 6% mobile emissions.

The Lyons emission inventory can be used as an alternative means to estimate relative influences of several air pollution sources. However, differences may exist between air shed inventory values and site specific measurements.

Sufficient information has been provided within this report to conduct a screening level risk assessment. The extent to which a risk assessment may be conducted will be left to the decision of the Northern Boulder County Environmental Health Community Task Force. A risk assessment is beyond the scope of this report.

Monitored PM₁₀ levels may be low due to the location of the sampling site or the short duration of a fugitive dust plume, relative to the 24-hour duration of the each sample period. It is recommended that sampler siting be revisited with the Northern Boulder County Environmental Health Community Task Force, as well as any needs for technical support.

REFERENCES

- 1) Lyons PM₁₀ Emission Inventory. February, 2000.
- 2) Desert Research Institute, University of Nevada System, Guidelines For PM₁₀ Sampling and Analysis Applicable To Receptor Modeling, DRI Document No. 2625.1F, 1994.
- 3) Environmental Protection Agency, Office of Air Quality Planning and Standards, Receptor Model Technical Series Volume II, Chemical Mass Balance. EPA-450/4-81-016b, January 1981.
- 4) Environmental Protection Agency, Office of Air Quality Planning and Standards, Receptor Model Technical Series Volume III, CMB7 User's Manual. EPA-450/4-90-004, January 1990.
- 5) Desert Research Institute, University of Nevada System, The 1987-88 Metro Denver Brown Cloud Study, Volume III, DRI Document No.8810 1F3, 1988.

Appendix A

PM₁₀ Data Summary

Appendix B

Analytical Reports

Appendix C

CMB Model Runs

Appendix D

CMB Model Diagnostics

CMB Model Diagnostics

There are a large number of possible source profile combinations which can be used to "explain" the chemical composition of any ambient filter. These possible source combinations are evaluated in an iterative process as the analyst adds and deletes sources from the model in an effort to find an optimum solution. The selection of the optimum model is subjective and is based on statistical diagnostics provided with the model output. In order to aid interpretation of the CMB model outputs, several useful model performance measures are discussed briefly below. These CMB statistical diagnostics are discussed in greater detail in the CMB8 User's Manual. The optimum CMB runs prepared for this analysis are presented as Appendix B to this report.

- Source Contribution Estimate (SCE). This is the contribution of each source type to the apportioned PM₁₀ in units of $\mu\text{g}/\text{m}^3$.
- Standard Error (STDERR). This is an indication of the precision or certainty of the SCE in units of $\mu\text{g}/\text{m}^3$. The STDERR is estimated by propagating the precision of the receptor data and source profiles through the CMB model least squares calculations. Ideally, STDERR will be much less than the SCE.
- t-Statistic (TSTAT). This is the ratio of the source contribution estimate to the standard error. A TSTAT value of 2.0 or greater indicates that the relative contribution of the source contribution estimate is high and that the contribution is significant. In this analysis, all of the source contribution estimates had acceptable TSTAT values.
- R-Square (R SQUARE). The R-square measures the amount of variance in the receptor concentrations which is explained by the calculated species concentrations. It is determined by a linear regression of measured versus calculated values for the fitting species. An R SQUARE of less than 0.80 indicates that the selected source profiles have not adequately accounted for the variance in the receptor concentrations. All of the model runs met this diagnostic criterion.
- Chi-square (CHISQUARE). The Chi-square is the weighted sum of squares of the differences between the calculated and measured fitting species concentrations. The weighting is inversely proportional to the squares of the precision in the source profiles and ambient data. This means that analysis of quartz filters (with larger precision estimates for most species) should tend to result in lower model Chi-square values. Chi-square values greater than 4.0 indicate that one or more species concentrations are not well explained by the source contribution estimates.

Several factors can cause the values of both the R-square and Chi-square statistics to exceed their targets: (1) contributing sources have been omitted from the CMB calculation, (2) one or more unrepresentative source profiles have been selected, (3) precisions of receptor or source profiles have been underestimated, (4) source or receptor data are inadequate. All of the model runs in this analysis met the Chi-square diagnostic criterion.

- Percent of Mass Accounted For (PERCENT MASS). This is the ratio of the sum of the source contributions to the measured mass. The target value is 100%, with an acceptable range of 20%.

Potential causes of percent mass values outside this range include (1) use of unrepresentative source profiles, (2) omission of significant source profiles, and (3) inaccurate or incomplete mass or chemical concentration determinations. All of the model runs in this analysis had acceptable percent mass statistics.

- Uncertainty/Similarity Clusters (U/S CLUSTERS). This display shows the result of a singular value decomposition analysis of collinearity. When source profiles are very similar in chemical composition, the CMB model doesn't accurately apportion species to the source types which they represent. There were no uncertainty/similarity clusters in the model runs presented in this report.
- Sum of Combined Sources (SUM OF CLUSTER SOURCES). This value is the sum of the source contributions in the cluster coupled with the standard error of that sum. In some cases it may be possible to use this value as an SCE for a source category.
- Ratio of Residual to Its Standard Error (RATIO R/U). This column contains the ratio of the signed difference between the calculated and the measured concentration (the residual) divided by the uncertainty of that residual. The model goal is a R/U values near zero for all species. As in the TSTAT, a RATIO R/U with an absolute value greater than 2 indicates a significant residual for that specie. A large positive residual indicates that one or more of the sources is contributing too much of that specie. A large negative R/U may indicate that a significant source is missing.

To a certain extent, these residuals are inevitable, and are present at levels greater than 2.0 for several species on nearly every model run. The reviewer should consider the relative importance of that chemical specie where a large R/U ratio is present on a given model run. For example, the R/U values for organic and elemental carbon, which are the predominant chemical species, are within acceptable limits on every model run. On the other hand, the R/U values for ammonium are always greater than 2.0 when ammonium data are available, indicating a significant loss of ammonia from the filters before analysis.

- Ratio of Calculated to Measured Species (RATIO C/M). This value is the ratio of the calculated to measured species concentration and the standard error of that ratio. Ideally, the RATIO C/M should be near unity.