AIR QUALITY ASSESSMENT AND PROJECTION
FOR SUMMIT COUNTY, COLORADO

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Air Quality Impacts on
County-wide Land Use Planning

March 1976

Final Report

Submitted to Summit County, Colorado, Planning Department

by

AMBIENT ANALYSIS, INC.
1675 Range
Boulder, Colorado 80302

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EPA Project Officer: Mr. William J. Basbagill
EPA Contract: No. 68-01-3200

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A. Introduction

Summit County is a small county in the heart of the Colorado Rockies, which has gained an importance far beyond what its size and population might imply. It lies just beyond the Continental Divide from Denver, Colorado's capitol and most populous city. It occupies the valley of the Blue River and its tributaries, and although the Blue River is a tributary of the Colorado River which flows to the Pacific, Summit County supplies a large fraction of Denver's water supply. Summit County is a land of virtually unparalleled scenic beauty. It provides a mecca for small-boat sailors, fishermen, hikers, and road-bound tourists in the summer. It contains several of the most convenient and best ski resorts in the country. Clearly, most people who visit Summit County consider it to be an unusually attractive, essentially unspoiled, mountain resort area.

The resources which make Summit County so attractive are in danger of being damaged. Further, the damage is being done by the very people who are seeking to enjoy those resources. Automobile traffic, single and multiple dwellings, roadside restaurants, inns, service stations, ski resorts--these are all ostensibly to serve the people who visit the area, but they can readily destroy the very resources which draw those people. If that happens, it will be a tragic loss for Summit County and for all those who will not be able to enjoy the recreational opportunities Summit County now affords.

The Summit County Planning Staff is seeking to make the County's resources available to the maximum number of people without loss of quality. The Planning Staff is anticipating the growth of demand on the County's resources. It is trying to understand what facilities and services will be needed to meet that demand. It is trying to determine how those facilities and services can be provided in an orderly way. It is also asking what effect providing those facilities and services and accepting the people who use and provide them will have on the basic resources of the area.

A primary concern is the direct effect which people and people-oriented activities have on the quality of the air. Sparkingly clean air is one of the area's great attractions. There is also concern for the effects that polluted air may have on water and vegetation. In a study reported by Holben and Marlatt (1974) an effort was made to use air quality models and projected pollutant emission rates to predict future concentrations of pollutants in Summit County. Those predicted concentrations were compared to statutory standards. The report by Holben and Marlatt was generally optimistic about the feasibility of maintaining satisfactory air quality in Summit County. It did, nonetheless, contain recommendations that several positive actions be taken to assure that air quality is maintained. The recommendations were all directed toward limiting the release of pollutants in the County.

As a continuing part of the efforts of Summit County to evaluate the air pollution potential of the County and to understand better the limitations that maintaining good air quality places on human activity and development, two of the most critical pollutants have been measured by Ambient Analysis, Inc. at several key points in the County. These measurements were made under disparate meteorological conditions, but at times when human activity in the County was high. One objective was to learn as much as possible in a short, low-budget study about current air quality in the County. A second purpose was to check current air quality against model predictions. The ultimate goal of the study was to advise the County Planning Staff on future development in the County.

The meteorological conditions under which measurements were to be made were those calculated to produce very good and very poor dispersion of pollutant. The places chosen to make the measurements were, with one exception, in areas where sources were numerous and concentrations were expected to be high. The exception was a rural site in the north end of the County. This site was expected to serve as an indicator of what air quality in the County can be in the absence of virtually all polluting sources.

B. Summary of Results

The sites at which measurements were made are shown in Figure I.1. The sites and the reasons for selecting them are discussed in Appendix B. Site 1 is a rural site; all others are in the vicinity of an important highway intersection or near a center of human activity. Site 3 at Breckenridge is the only urban site, except that in December Site 2 was in Silverthorne. Concentrations of particles and carbon monoxide at all the sites are summarized in Table I.1. The measurements were not made with the intent of checking current pollutant levels against statutory standards. Nonetheless, some comparisons can be made. Air flow was observed carefully during each observational period. Actual air flow was used in interpreting other measurements, and it was combined with climatological data and theory to arrive at an air flow model for Summit County. This model is described in detail in Section III. A brief description is given here.

TABLE I.1

Particle and Carbon Monoxide Summary. Particle data are given in micrograms of the Total Suspended Particulate (TSP) matter per cubic meter of air ($\mu g/m^3$). Carbon monoxide (CO) data are given in parts of CO per million (ppm) parts of air by volume.

	August 18, 1974		July 23, 1975		December 30, 1975	
SITE	TSP ($\mu g/m^3$)	CO (ppm)	TSP ($\mu g/m^3$)	CO (ppm)	TSP ($\mu g/m^3$)	CO (ppm)
1	41	0.2	14	0.5	<4	1.4
2	61	0.5	49	1.5	16	4.5
3	86	0.9	16	0.5	11	7.4
4			37	1.0	10	16.3
5			13	<0.5	12	8.0

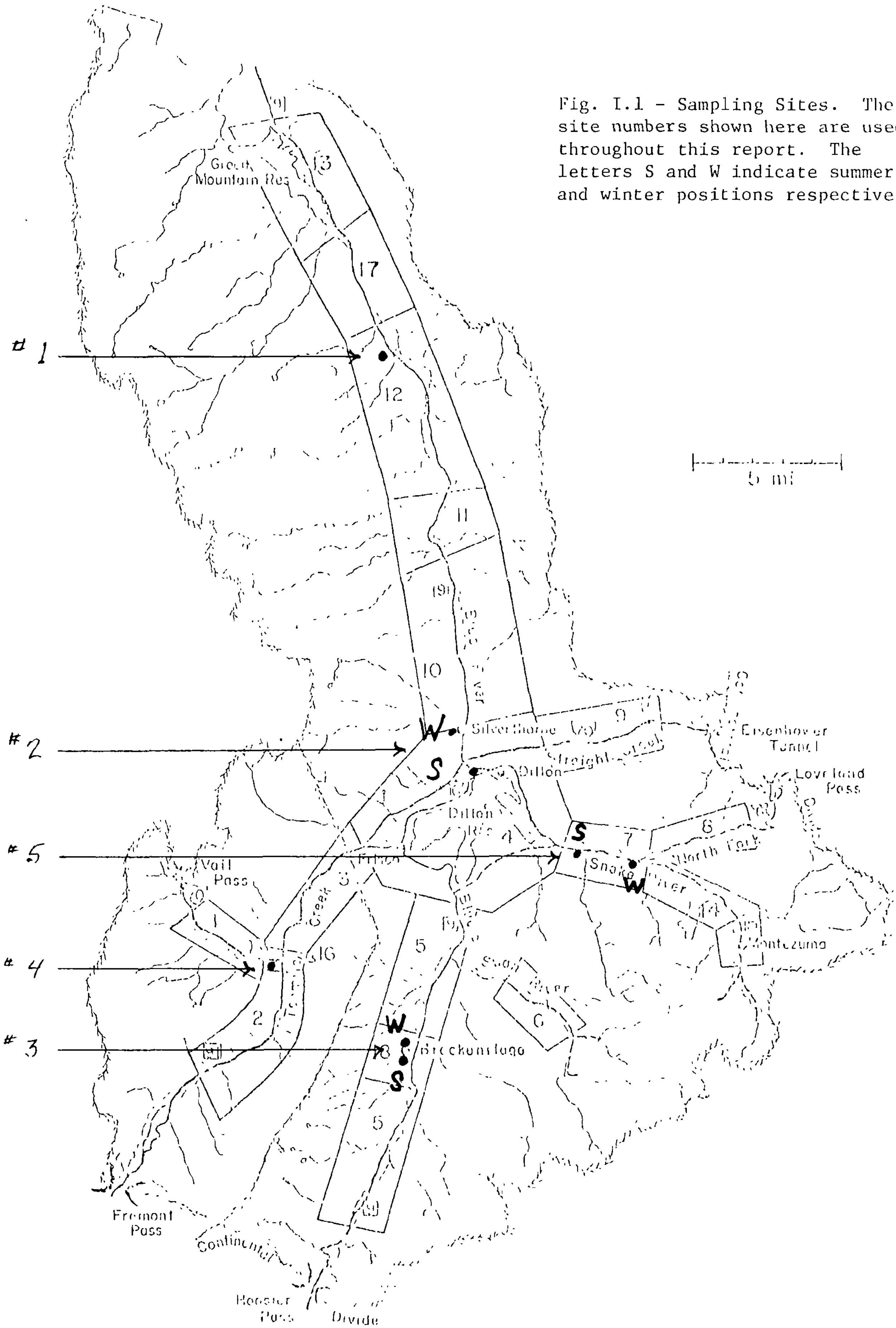

Fig. I.1 - Sampling Sites. The site numbers shown here are used throughout this report. The letters S and W indicate summer and winter positions respectively.

1. Air Flow

The flow of air in Summit County is critically important to air quality. With little air movement, any pollutants which escape into the atmosphere remain near the source and accumulate. Strong flow through the county, on the other hand, carries any pollutants away. It is important also that air from near the surface be mixed upward so that pollutants are dispersed through a deep layer.

A valley frequently has little air flow because it is protected from the strong winds which normally flow across the valley above the mountain tops. There are internal circulations in a valley, however; and in Summit County these valley winds are highly significant. They blow up the valley at day and down the valley at night.

At night when the valley is cool and the air is stable, little vertical mixing occurs. Fortunately, the air which starts down from a high level in the valley flows out over the air in the lower reaches of the valley. Thus pollutants from high altitude emission sources do not mix with pollutants from low altitude sources, and emissions do not remain near the valley floor for a great distance away from their release point. The valley floor is high enough at its southern end so that down valley flow originating there is at mountain top level when it reaches the northern end of the valley. It can then be carried out of the valley by the winds above the valley.

During the warm part of the day, air flows up the valley. It is usually unstable near the surface so that any pollutant released there is mixed through an appreciable depth above the valley floor. Air which flows up the valley walls and reaches mountain top level is carried away by the winds above the mountains, carrying its burden of pollutant with it.

The up valley winds in daytime and down valley winds at night are both flow systems which help to lift surface level pollutant emissions away from the ground surface. In Summit County which slopes steeply downward from south to north, valley winds are normally quite effective in dispersing emissions; however if they do not develop fully, pollutants may accumulate. General cloudiness can prevent valley winds from developing. Winds above the mountains flowing along instead of across a valley can also prevent valley flow from developing. Thus some side valleys such as the Snake River Valley may be stagnant when valley flow is fully developed in the Blue River Valley.

The transition periods each day when flow changes direction are essentially stagnant periods. Transition normally occurs earlier in the upper reaches of the valley than in the lower portions. The down valley to up valley change occurs shortly after sunrise high in the valley and as late as

1100 MST in the lower valley. The evening change may start as early as 1600 MST high in the valley and as late as midnight at the lower end. The transition period varies in length, but winds may be expected to be light and variable in direction for about two hours at each transition.

The morning transition is more critical insofar as air pollution is concerned. During that transition the air on the valley floor is still stable and little vertical mixing can occur. After the wind shifts and starts to blow up the valley, the air is likely to remain stable for one to two hours. Consequently pollutant which is well above the surface in the lower reaches of the valley approaches the surface as it moves up the valley. It is added to the surface emission source pollution, and concentrations increase very near the ground.

2. Carbon Monoxide

The highest one-hour average of carbon monoxide concentration measured was downwind of the parking lot at Copper Mountain. It was slightly in excess of 16 parts per million (ppm) by volume. The one-hour federal standard is 35 ppm. This measurement was made in December during a period when both I-70 traffic and traffic into the parking lot were heavy and continuous for several hours. Dispersion was poor during that period. Hence, it is quite likely that the average concentration over an eight-hour period did exceed the federal standard of 9 ppm for eight hours. This conclusion is not established conclusively but there can be no doubt that the Copper Mountain parking lot is a source which is now on the verge of exceeding federal standards. Those standards can readily be exceeded in the future when parking lot traffic and traffic on adjacent highways are high and dispersion is low.

3. Particles

The highest particle concentration found in the measurements was 86 $\mu g/m^3$. This was an average for a period of about three hours. It was observed during a period of the day when particle concentrations were expected to be high; consequently it is highly unlikely that the 24 hour average there exceeded either the Colorado Standard of 260 $\mu g/m^3$ or the Federal Standard of 150 $\mu g/m^3$ for non-designated areas. Particle concentrations, in terms of mass per unit volume of air, do not appear to present a serious limitation to development in most places in Summit County. Although no measurements were made there, it is known that blowing dust has at times been a serious problem at the sediment reservoirs in the southwest part of the county. Blowing dust can be a problem in summer anywhere in the county where the soil is disturbed. Dry conditions and gusty winds then raise dust. The duration of such blowing dust is normally short.

Another and potentially more serious problem exists. The filter which was exposed near the intersection of I-70 and State 9 in July showed asbestos-like fibers in surprisingly large numbers. A second filter exposed for short periods along I-70 between Silverthorne and the west portal of the Eisenhower Tunnel also contained many such fibers. These were identified by qualitative x-ray probe as inorganic. If subsequent tests show these to persist in Straight Creek Canyon or elsewhere in Summit County, they are cause for concern.

C. Recommendations

1. Minimize the number and strength of air pollution sources in every practical way in Summit County. This is a simple, obvious recommendation, but acting on it involves making compromises between air quality and economy, air quality and water quality, etc. This is amplified in Section I.D.

2. Maximize distribution of unavoidable pollutants in every practical way. Many things can be done. Sources can be distributed judiciously throughout the valley, placing them at many levels and preventing large clusters. (A parking lot constitutes a cluster of sources.) Chimneys and houses can be built so that downwash is minimized. Sources, including roads, placed in confined valleys will cause more severe pollution problems than comparable sources placed on hills or hillsides.

3. Monitor air quality in those places where concentrations are likely to be greatest under adverse conditions.

4. Develop and use controls. These may range from restricting fireplace burning to closing the County to all nonessential traffic.

D. Discussion

The recommendations in Section III.C are brief. Some amplification and discussion of each is given in this Section.

1. Minimize the number and strength of air pollution sources

Residences, commercial facilities, recreational facilities, lodging, and dining facilities are all stationary emissions sources. Portable emissions sources are sources which can be moved. According to the State Air Pollution Control Division, there were no large stationary sources in Summit County in February 1976. There was one portable emission source with a potential of 100 tons per year. Indirect sources are usually vehicular-related and anything such as a recreational parking lot costitutes an indirect source. One area source is identified by the State Air Pollution Control Division; it is the sedimentation reservoir complex in the southwestern part of the County.

The Colorado Air Quality Control Regulations and Ambient Air Quality Standards which became effective on February 1, 1972, provide the statutory authority for controlling air quality in Colorado. There are a number of regulations, each having limited applicability. Since these regulations constitute a legal document, no effort is made to interpret them, although attention will be called to them occasionally.

Controlling the number of sources may not be easy. Doing so limits growth and development. The current population for Summit County has been estimated as follows by Mr. David Vince of the Summit County Planning Staff:

	Total	Unincorporated Areas
Permanent	4,336	1,477
Second Home	16,533	11,572
Peak	20,869	13,049

Mr. Vince has also estimated the total potential population, based on approved zoning, as 99,900, and the potential population in unincorporated areas to be 53,400.

These figures suggest that the population may grow to four or five times its present peak level. The distribution between incorporated and unincorporated areas is not expected to change drastically. Hence population density is expected to increase everywhere with an inevitable increase in emissions sources of most of the types now existing in Summit County. An increase in source numbers must be accompanied by a decrease in source strength and better dispersion if air quality is not to deteriorate.

As a first step in exercising control, the County should require that each prospective developer submit a statement with his plan which shows that he has considered air quality maintenance in the vicinity of the development and how he plans to minimize emissions.

The strength of each emission source can be decreased. Fireplace burning can be avoided. Clean fuels can be used for space heating. Perhaps furnaces can be improved so that they produce less pollutant, although they are probably not serious offenders. Much work is being undertaken to make the automobile exhaust cleaner. Until recently the effects of altitude on automotive pollution has not been considered in setting performance standards. In the future automobiles may have to meet prescribed standards in the area in which they are sold. Because of the high volume of tourist and cross-country truck traffic in Summit County, altitude effects may continue to be a problem, however.

Any large intense source should be permitted only after a very careful study shows that it will not degrade the environment. It appears unlikely that a source such as a power plant will be acceptable anywhere in the County.

2. Maximize distribution of unavoidable pollutants

Pollutants are always present. It is only when their concentrations reach levels which have recognizably undesirable effects that they become a problem. Concentrations can be kept low by mixing those pollutants which cannot be avoided with adequate quantities of air. There are many things which can be done; there are also limitations.

In a valley dispersion from a single source is related to the broadness of the valley (particularly at the source level), to the winds blowing in the valley, and to the stability of the air in the valley. These are things over which man has little control. He is capable of understanding them, however, and he can place sources where dispersion is good and refrain from placing them where dispersion is poor. The air flow model discussed in detail in Section III.B provides general information from which some conclusions can be drawn.

Sources should be well distributed both horizontally and vertically about the valley. Intense sources should be avoided everywhere, but they should be avoided particularly in small basins. A large parking lot in a basin can become an intense source. The high concentrations can be avoided by using a series of small parking lots distributed through an appreciable valley depth. This would require that public transportation of a non-polluting type provide transportation from these small lots to the center of attraction which the large lot now serves.

A shopping center in an urban area may serve as an intense emissions source. The cluster of buildings associated with the center causes a number of sources to be located near each other and at essentially the same level. These and the autos using the parking lot can readily constitute a concentration of sources that will cause unacceptable local concentrations. Again good horizontal and vertical distribution of small shopping facilities is preferred for air quality preservation.

Even residences should be well distributed about the valley if a way can be found to permit travel to and from them without creating pollution problems and provided that they and their access roads do not create undue visual environmental problems or water problems.

Most of the land in Summit County is under jurisdiction of the Federal Government. It is assumed in the discussion of the watershed areas below that development can occur on either public or private land.

With air flow, valley dimensions, and terrain all considered qualitatively, the following statements are offered. Development in the following areas has reached a level and is of such a nature that carbon monoxide concentrations should occasionally be expected to exceed the primary Federal Standard for undesignated areas: Straight Creek Canyon, Dillon, Silverthorne, Frisco, Breckenridge, and the ski areas of Copper Mountain and Keystone. These areas in which additional development should be most carefully controlled are indicated in Figure I.2.

Figure I.3 shows the distribution of private and public lands in Summit County. It also shows the various watersheds. Some statements are made

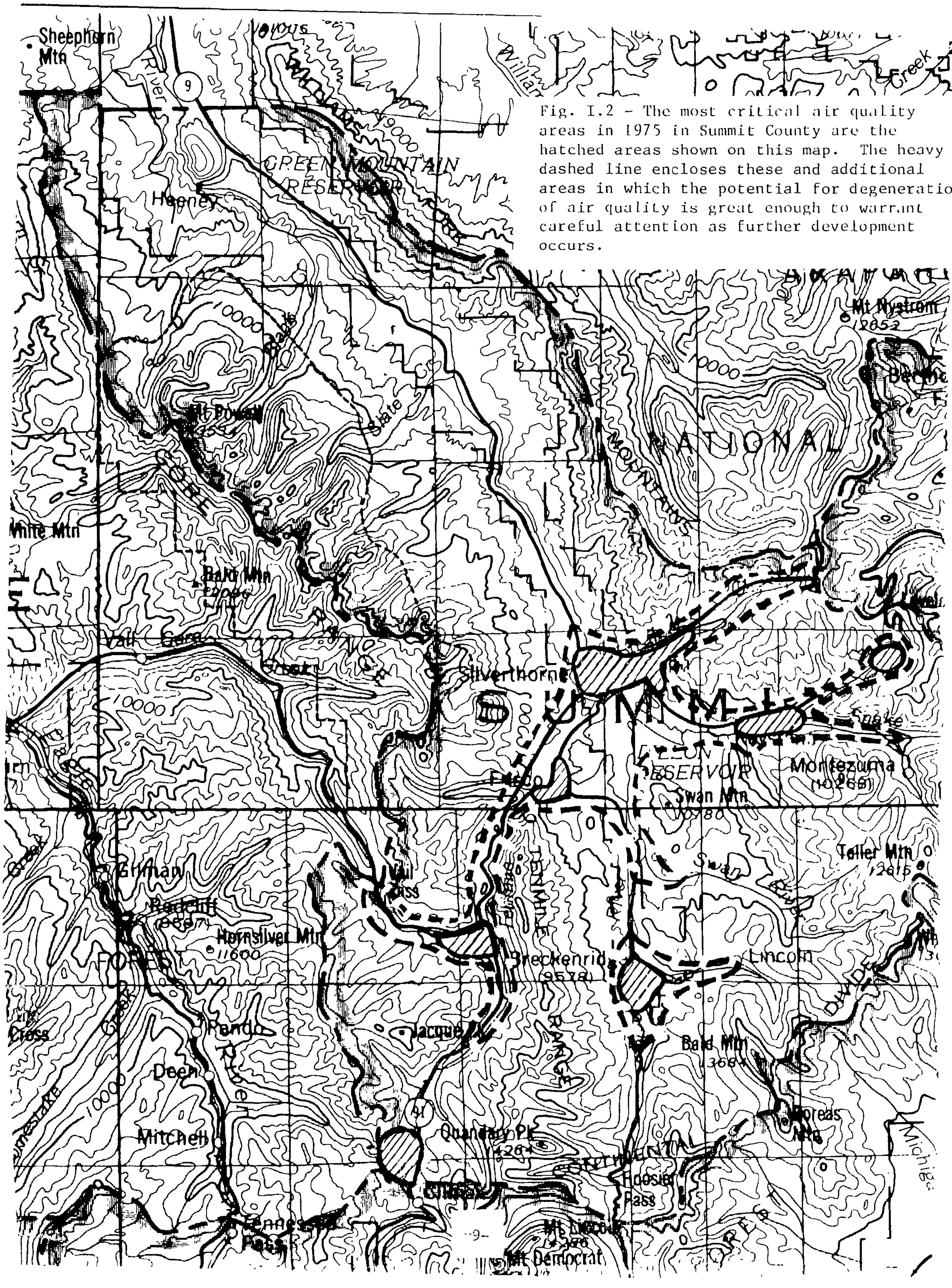

Fig. I.2 - The most critical air quality areas in 1975 in Summit County are the hatched areas shown on this map. The heavy dashed line encloses these and additional areas in which the potential for degeneration of air quality is great enough to warrant careful attention as further development occurs.

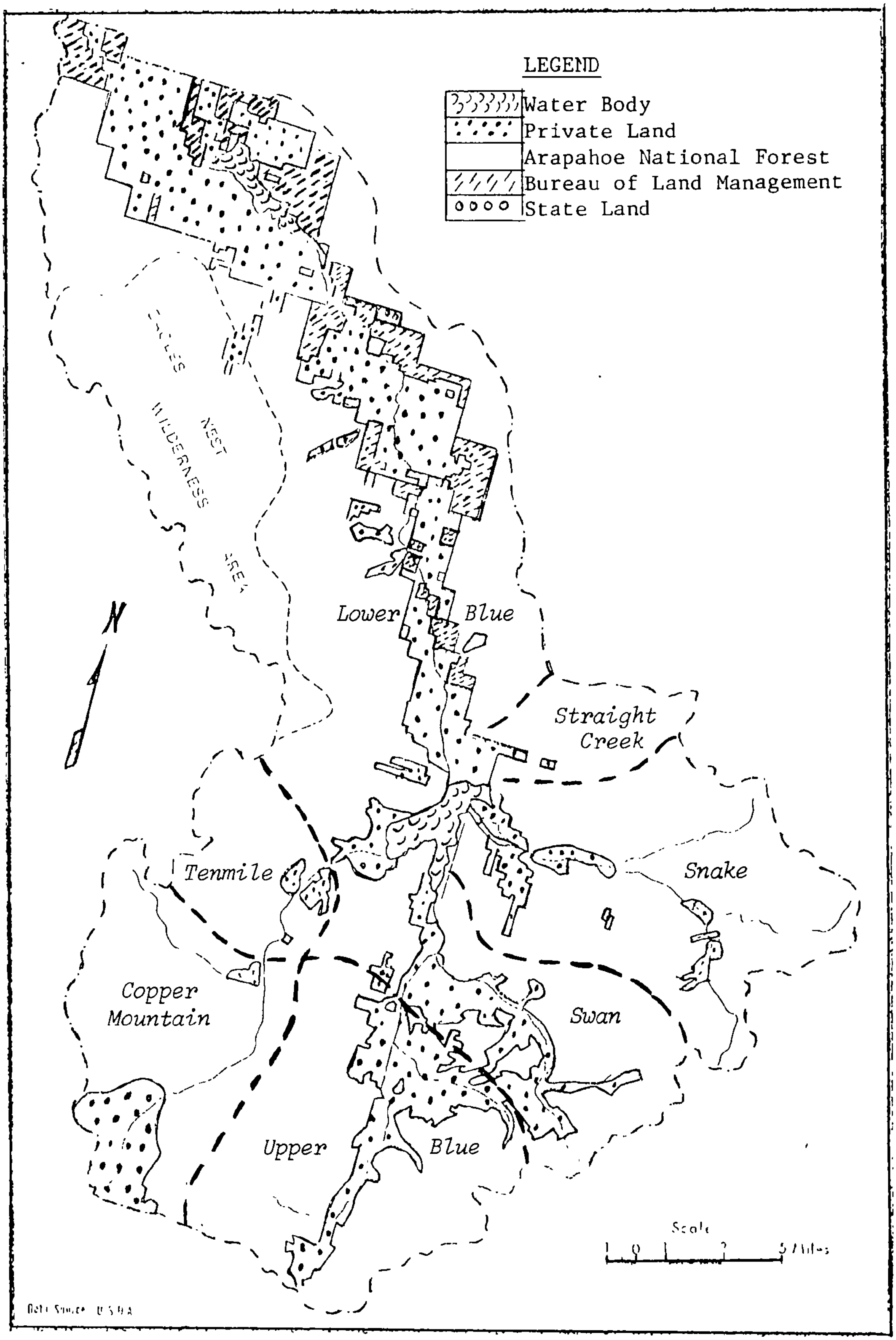

Fig. I.3 - Land ownership in Summit County below about air quality and the opportunity for development in each of these watershed areas.

Straight Creek. Any further development should be of a non-polluting kind. The air becomes stagnant frequently at night and I-70 constitutes a strong source of both carbon monoxide and particles.

Snake. Limited development is feasible, but it should be clean (i.e., pollutant contributions from both direct and indirect sources should be low) and it should be distributed horizontally and vertically. The north and east sides of Swan Mountain offer some possibilities. Stagnant, stable air is more likely in the Snake River Valley than in most other parts of Summit County. Pollution may be expected to be worse in winter than in summer.

Swan. The western part of the Swan is most subject to development, and since the region includes a large area west of the Blue River, considerable development should be practical here. The west side of Swan Mountain is suitable for development from the air quality viewpoint. Swan River itself may be expected to suffer from stagnant, stable air in winter as Straight Creek and the Snake will. Hence development should be less intensive there than on the west side of the Blue River. Winter is the worst season for pollution.

Upper Blue. Although the valley here is not broad, it is short and it is perpendicular to the prevailing winds above the mountains. Consequently, additional development appears feasible, if source strengths are kept low and the sources are well distributed horizontally and vertically. Additional development in the immediate vicinity of Breckinridge is least desirable. Winter is the season when air quality can be poorest.

Copper Mountain. Further development in the immediate vicinity of Wheeler Junction must be accompanied by actions to reduce source strengths if Federal Standards for carbon monoxide are not to be violated. Development can occur elsewhere if due regard is paid to source strength and distribution, although the narrow gorges of Tenmile Creek will tolerate very little development. Since I-70 is in the gorge below Wheeler Junction, additional pollutant sources should be avoided there. Also any development in West Tenmile Creek which includes pollutant emissions should occur well away from the highway. Particulate matter is likely to be a problem in the upper reaches of Tenmile Creek because of the sediment reservoirs there. This is a summer problem. In the valleys, particularly at Wheeler Junction, air pollution will be most serious in winter.

Tenmile. This area offers little terrain which appears suitable for development, but some development could occur without creating an air quality problem if the sources are judiciously distributed.

Lower Blue. The Lower Blue is the largest valley in Summit County. Its terrain is varied enough to permit considerable development without concentrating emission sources too greatly at any single level. It can be expected to have a well-developed valley breeze, and the air which flows from the valley at night will not often reenter the valley the following day. On those days when the winds above the mountains are from northwest, the down-valley wind at night will be disrupted and air from the Blue River as far away as Kremmling and, indeed, air from all parts of the Colorado River Valley around Kremmling may enter the Lower Blue. Thus air quality in the Lower Blue Valley will be better because of the broader Colorado River Valley to the north if emissions sources there are not excessive. Strong sources there could create a real problem for the Lower Blue, however. Again, winter is the most critical period.

Reservoir Area. This includes Dillon, Silverthorne, Frisco, and the Dillon Reservoir. The highway intersection at Silverthorne is quite important because it is a focal point for much of the automotive traffic within and through the County. This basin is relatively large and air moves through it well under most meteorological conditions; these are factors which favor good air quality. The several clusters of pollutant sources and the flatness of the terrain have an adverse effect. During stable periods pollutants released near the ground in this basin tend to remain near the ground. Thus Dillon can be exposed to its own emissions plus those of Frisco during down-valley flow, and to emissions from Dillon, I-70, State 9, and Silverthorne during up-valley flow. The area west of I-70 between Silverthorne and Frisco offers the best opportunity for further development without creating an air quality problem. The area around the junction of I-70 and State 9 at Silverthorne is one of the most critical areas in the County; further development there should be undertaken only if it has been carefully considered and fully justified. Winter is the most critical period for carbon monoxide. Particulate matter may become a problem in summer. (See Sections III and III.E.)

3. Monitor air quality

This study suggests that there are already some areas in Summit County in which statutory standards are being exceeded. The areas are small. The excesses are more likely in winter than in summer. (The area around the sediment reservoirs near Climax may be an exception.) With continued development pollutant concentrations are likely to get worse in all parts of the County in each succeeding year unless positive actions are taken to limit emissions and increase dispersion. Air quality monitoring will disclose how well these actions are working.

Although a general knowledge of air flow in the County exists, more must be known if development is to be done wisely. Hence a number of meteorological variables should be measured regularly at several places in the County. Measurements which yield hourly average wind speed, direction, and temperature, or a continuous record like that produced by the MRI mechanical weather station would be very helpful. A single station at a representative site near Dillon is most essential. Additional stations are desirable and representative sites near Keystone and Copper Mountain would be most useful. A few periods of intensive observations using tethered balloon systems and a rawinsonde should also be conducted. A concurrent study of the synoptic meteorology of the Rocky Mountain Region should be a part of such studies.

Equally important, good air quality measurements should be made regularly at several locations. A site should be set up near the intersection of I-70 and State 9. Another should be placed in an urban area like Breckenridge. As a control one should be placed in a rural area away from roads. These should all be equipped to measure carbon monoxide and particles, either continuously or at times recommended by an air pollution meteorologist who maintains an awareness of existing and expected weather in Summit County. The measurements must be done carefully and well. Measuring instruments must be kept in good operating condition and calibrated often using good calibration standards. These obvious statements cannot be given too much emphasis, because they are too often not followed.

Periodically particles should be collected along I-70 on membrane filters and tested for mineral fibers.

4. Develop and use controls

Control of development has been discussed. The Colorado Air Quality Control Regulations and Ambient Air Quality Standards provide the statutory basis for exercising control over air quality. They may not be adequate. In particular, there is no regulation applicable to indirect sources. Summit County will have to develop its own method of dealing with indirect sources. This might include urging adoption of an applicable regulation by the state.

Even if development is controlled according to a well-conceived plan which assures good air quality virtually all the time, there will be occasions when nature fails to follow her usual course. Unusual periods of intense stagnation can occur. It is reasonable to take unusual measures to control pollution in these situations, measures which would not be acceptable routinely. It is unreasonable to maintain development at such a low level that there could be no problem under the most adverse meteorological conditions. Therefore, controls which can be imposed in a short time and which will cause as little disruption of activity as possible must be considered. These can range from banning fireplace burning during a few morning hours to banning all automotive traffic in the County except that which is absolutely essential to health and welfare.

It is clear that I-70 with its high volume of traffic constitutes a major source of air pollution in Summit County. Perhaps I-70 traffic can be changed from an automotive arterial to some other form of mass transportation. If one could be found which makes use of more efficient and less polluting vehicles than private automobiles, Summit County's pollution problem would be considerably simplified. This was recommended in the public hearings of the Land Use Commission in November 1974.

SECTION II

A. Air Quality Data Base for Summit County

For the purpose of this study air quality data consist of the chemical and meteorological measurements of the type needed to state the current air quality in Summit County and to make a reasonable projection of future air quality. Data currently available have been summarized by Kahn (1974) and Holben and Marlatt (1974). Some additional data have become available since these studies were completed, however. In particular, additional Hi-Vol particle data have become available at Breckenridge and additional meteorological data covering a few months duration is available for Silverthorne, Breckenridge, and the Breckenridge waste-water disposal plant at Swan Mountain. These data and environmental impact statements FWHA-COLO-EIS-74-01-D and FHWA-COLO-EIS-74-02-F were provided by the State Highway Department.

B. Wind Flow and Dispersion Models

Wind flow in mountainous terrain is poorly understood. Wind flow in valleys is better understood, however, and a qualitative wind flow model for a valley can be quite useful. Such a model is discussed in detail in Section III.B. Success in projecting air quality depends on having an adequate wind flow model, a good dispersion model and adequate meteorolgical and pollutant emission data. Most modeling for mountain valleys is done using a single constant wind velocity and either a box or a Gaussian dispersion model. Holben and Marlatt used both of these models with a constant wind in making projections of air quality in Summit County. They also made limited use of a WINDS model designed by Fosberg, Rango and Marlatt (1974). This model employs terrain elevation, slope, aspect and surface roughness and an initial temperature field to calculate local wind flow.

C. Emission Inventory

An inventory of emissions from stationary and mobile sources was prepared by Holben and Marlatt (1974).

D. Air Quality Estimates

Air quality projections made through the use of the models and emission data discussed above are contained in the report to Summit County by Holben and Marlatt (1974). Using a box model, they estimated that the air pollution potential of five regions is high, three regions is medium, and ten regions is low. The box model is not realistic for a valley with a steeply-sloping floor, and they assumed wind and box depth data. Therefore their estimates are misleading.

E. Land Use Regulations

State and county land use regulations pertaining to air quality are at present limited to the county permit-to-construct process and the State of Colorado 100 ton stationary emission requirements. The State has laws which can be interpreted to cover developments of specific concern to the public. Statutory air quality regulations are found in the Air Pollution Control Act (66-31). The regulations from that act which are applicable in Summit County are:

Reg. 1	Fugitive dusts, fuel burning equipment.
Reg. 2	Odor control.
Reg. 3	Basic permits.
Reg. 6	Stationary sources.
Reg. 7	Hydrocarbon emissions.
Reg. 8	Hazardous substances
Reg. 9	Automotive pollution restraints.

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SECTION III

A. Topography and Climate

Topography and climate are closely related in Summit County. Holben and Marlatt (1974) provided a short summary of climate and its relation to topography. In this section those aspects of topography and climate which bear most directly on the air pollution potential of the County are reviewed.

1. Topography

Summit County occupies the valleys of the Blue River and its tributaries. The most important tributaries are Straight Creek, Snake River, Swan River, and Tenmile Creek. The Straight Creek and the West Tenmile Creek valleys are small but quite important because I-70 occupies each through its full length, and automotive traffic is heavy.

The Blue River Valley is oriented in a generally north-south direction. The valley is high; its floor ranges in height from 7,500 ft. (2,280 m) at the north end, where it opens out into the broader Colorado River Valley, to 10,000 ft (3,050 m) south of Breckenridge. The 10,000 ft contour also delineates rather well the upper reaches of the valley floor in all of the principal tributary valleys of the Blue River. The steepness of the valley floor (it drops 2,500 ft in a distance of approximately 40 miles) is important to its air quality potential.

The walls of the valley are steep nearly everywhere. Peaks in excess of 13,000 ft (3,960 m) are found in most of the ranges which form the county boundaries. The steep valley walls and height of the mountains are also important to the air pollution potential of the county. The high mountains serve to isolate the valley from the strong westerly winds which flow across it aloft. The steep walls and floor assure nearly continuous air motion in the valley. Air motion is discussed in detail in Section III-B.

The only level portions of the valley are those occupied by the Dillon Reservoir near the center of the county, the Green Mountain Reservoir in the north and the sediment reservoirs in the extreme southwest section of the county. None of these are large, but the basin-like character of the Dillon area and the relatively high population and traffic density there do make it one of the county areas which is most prone to air pollution problems. The sediment reservoirs are important because they are a source of particles, and when strong westerly winds blow, the particles get carried to great height and dispersed downwind.

The east-west orientation of most of the tributaries of the Blue River causes them to be less isolated from the prevailing west winds at mountain-top level than the Blue River. In the Snake River Valley this may frequently be quite important, but the valleys associated with the other tributaries are small and steep enough that the westerly winds aloft will have a lesser effect on the flow in them.

It is important to note that the entire valley is short and that it opens out on a much larger valley, which is subject to frequent and thorough scouring by the prevailing west winds. Because of the shortness of the Blue River, the light, diurnal, valley winds are also capable, most of the time, of carrying away pollutants originating in the valley. If the valley were longer, these same winds, blowing down the valley at night and up the valley by day, could cause pollutant to be trapped and to oscillate up and down the valley, gaining strength day by day.

2. Climate

Summit County embraces a continuing change of climate from its lowest to its greatest heights, which is much like the change one might encounter in going at sea level from the Northern U.S. to the Canadian tundra. The valley is cut off from a continuing moisture supply by high mountains and its great distance from the oceans. Therefore, cloudiness and precipitation are low, and most of precipitation is in the form of snow which falls in winter as major storms cross the area. The snow serves as a water storage mechanism, and water is also stored in reservoirs. Consequently, although the total precipitation isn't large, Summit County serves as a source of water for Denver and has water for a limited resident population and for some agriculture.

Frequent clear skies and high altitude help to assure maximum radiative heat effects. The sun warms the surface rapidly in the morning and the days are warm. Likewise, at night clear skies permit the warm surface to radiate away its heat, and nights are cold. The diurnal variation of temperature contributes to a well-organized persistent diurnal wind system in the valley. This valley flow is explained in detail in Section III.B.

In addition to having well-defined diurnal weather changes, Summit County weather also undergoes a marked annual change. Summer is warm and dry. The precipitation which falls is usually in the form of brief, light showers. These occur most frequently over the mountains in the afternoon and infrequently in the valley. Rarely does a major storm cross Summit County and cause widespread precipitation there in the summer.

In winter when a major storm crosses the area, snow falls throughout the county. The winds aloft (at mountain-top level and above) are from a southerly direction ahead of a major storm and from north to northwest behind the storm. Valley winds are disrupted by these storms, and blowing snow can occur in the valley. Following the passage of a major storm, air in the valley frequently becomes quite cold.

Minor storms pass through the Central Rockies frequently in winter. These are accompanied by small changes in wind direction aloft and little wind in the valley. These minor storms do cause snow to fall on the high mountains, however, and so contribute to the total snow pack at high altitudes.

The vertical stability of air near the surface is an important factor when air pollution is a potential problem. Stable air is generally associated with poor vertical air mixing and high pollution potential. Unstable air is associated with good mixing and good air quality. These concepts must be applied with reservations in a valley such as the Blue River Valley; the reason is explained in Section III.B. Nonetheless, stability is a useful concept. In Summit County the air near the surface becomes stable nearly every evening. It is most stable early in the morning. At sunrise the air starts to become less stable, and by noon unstable conditions generally exist near the ground throughout the County. This diurnal variation occurs in all seasons. As a rule the air is less stable at any hour of the day in summer than in winter at the corresponding hour.

During storms normal diurnal changes fail to occur. Also each storm affects the valley in its own way and air flow, temperature, precipitation, and stability are difficult to describe in a general way for stormy periods. When precipitation is falling, however, air pollution is not likely to be a concern; after a winter storm has passed and new snow covers the valley, air pollution must be considered a threat.

B. Mountain Valley Flow and Dispersion

Winds in a mountain valley are influenced by so many factors that they often defy description. On the other hand, when a valley is isolated from the flow of the atmosphere above, winds often follow a predictable diurnal pattern, flowing down the valley at night and up the valley during the day. This diurnal change is the dominant weather feature in some valleys. It is also a feature which causes much concern when air in the valley is being polluted. Since the populated portion of Summit County is in a valley which experiences a marked diurnal wind flow, the characteristics of that flow are discussed at some length here. Some attention is also devoted to the influence of the atmosphere outside the valley as it effects the valley.

The Blue River Valley is the major valley in Summit County. Being oriented nearly north-south, the prevailing westerly winds in the free atmosphere above the mountains flow over the valley, often influencing winds in the valley through only a short distance below the mountain tops. Figures III.1 through III.4 are schematic views of air flow and potential temperature in a steep-walled, narrow valley with a north-south orientation. The valley is open on the north. The top drawing in each figure depicts an east-west cross-section of the valley at a location approximately midway between the head of the valley and the point at which it opens out onto a plain or much larger valley and loses its separate identity. The lower drawing shows a longitudinal section of a part of the valley. It is a north-south section, the location where the cross-section cuts it is identified by the number 1. The valley floor slopes steeply toward the north. The vertical scale is exaggerated in all of these figures.

Figure III.1 represents a simplified view of the wind flow and the potential temperature pattern in the valley during the early morning just before dawn. The arrows represent the wind components in the plane of the paper, the length of the arrow is proportional to the wind speed. The symbol ⊙ represents wind flowing toward the viewer--that is a south wind flowing down the valley.

1. Potential temperature as an aid to understanding stability and air motion

Potential temperature is an artifice which the meteorologist finds quite useful. As air in the atmosphere moves upward, its sensible (measureable) temperature drops unless the air is gaining heat. Similarly, as air moves downward its sensible temperature increases. Its potential temperature, however, does not change as it changes altitude unless it gains or loses heat. Normally, air at high altitudes has a higher potential temperature than air at low altitudes. A layer of air which has higher potential temperature at the top than at the bottom is said to be stable; it will not mix unless it is physically stirred. A layer which has lower potential

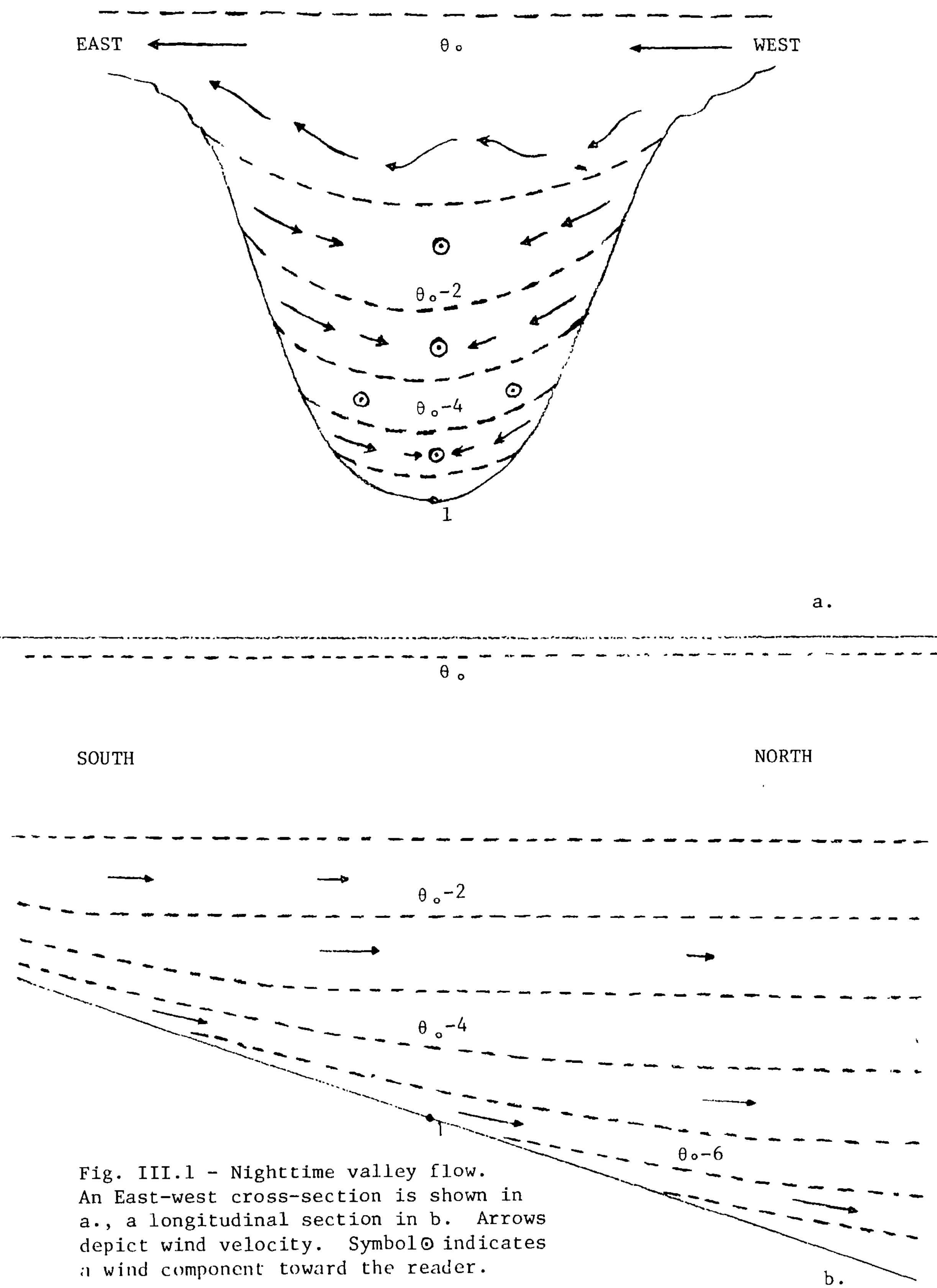


Fig. III.1 - Nighttime valley flow. An East-west cross-section is shown in a., a longitudinal section in b. Arrows depict wind velocity. Symbol ⊙ indicates a wind component toward the reader.

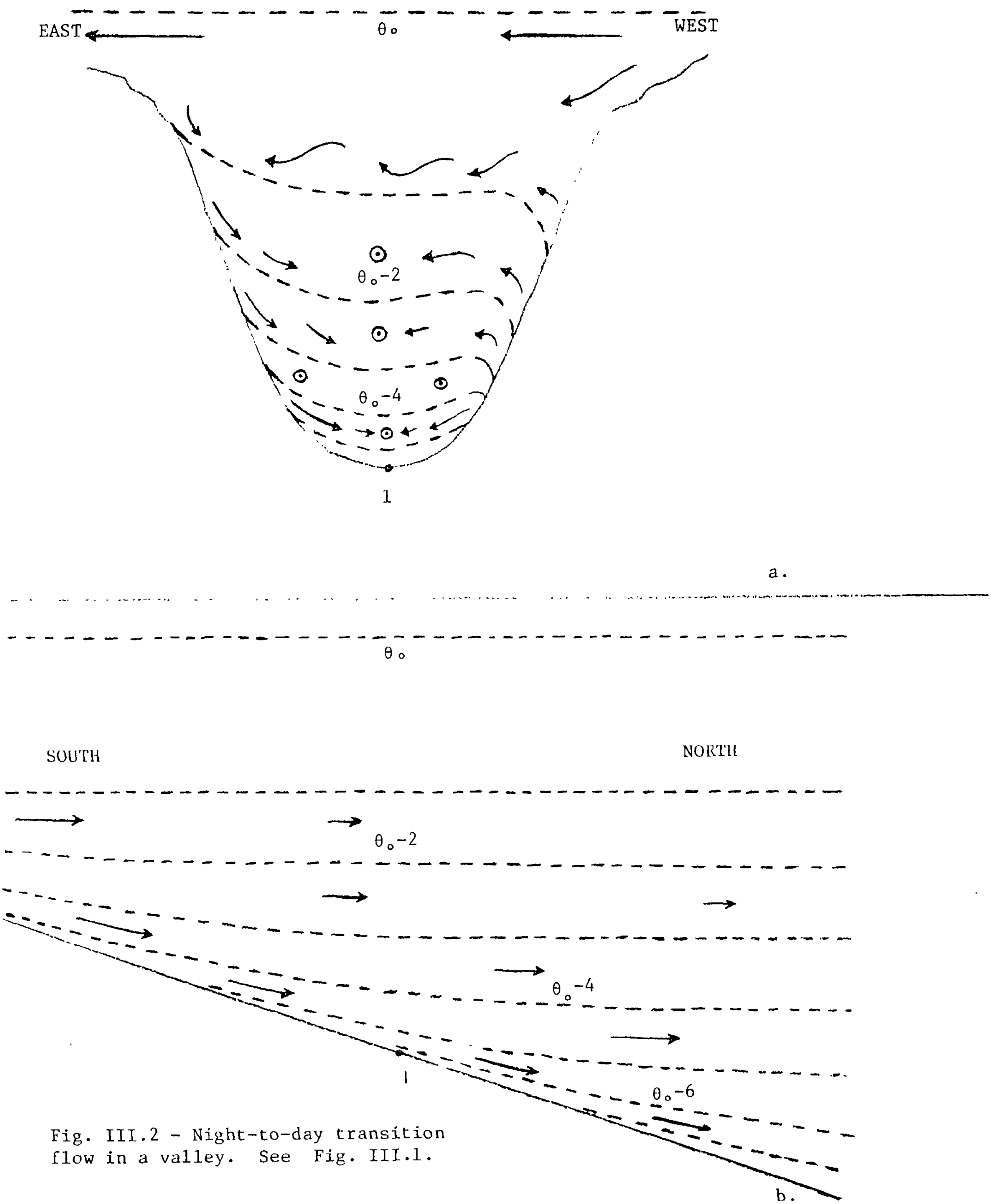


Fig. III.2 - Night-to-day transition flow in a valley. See Fig. III.1.

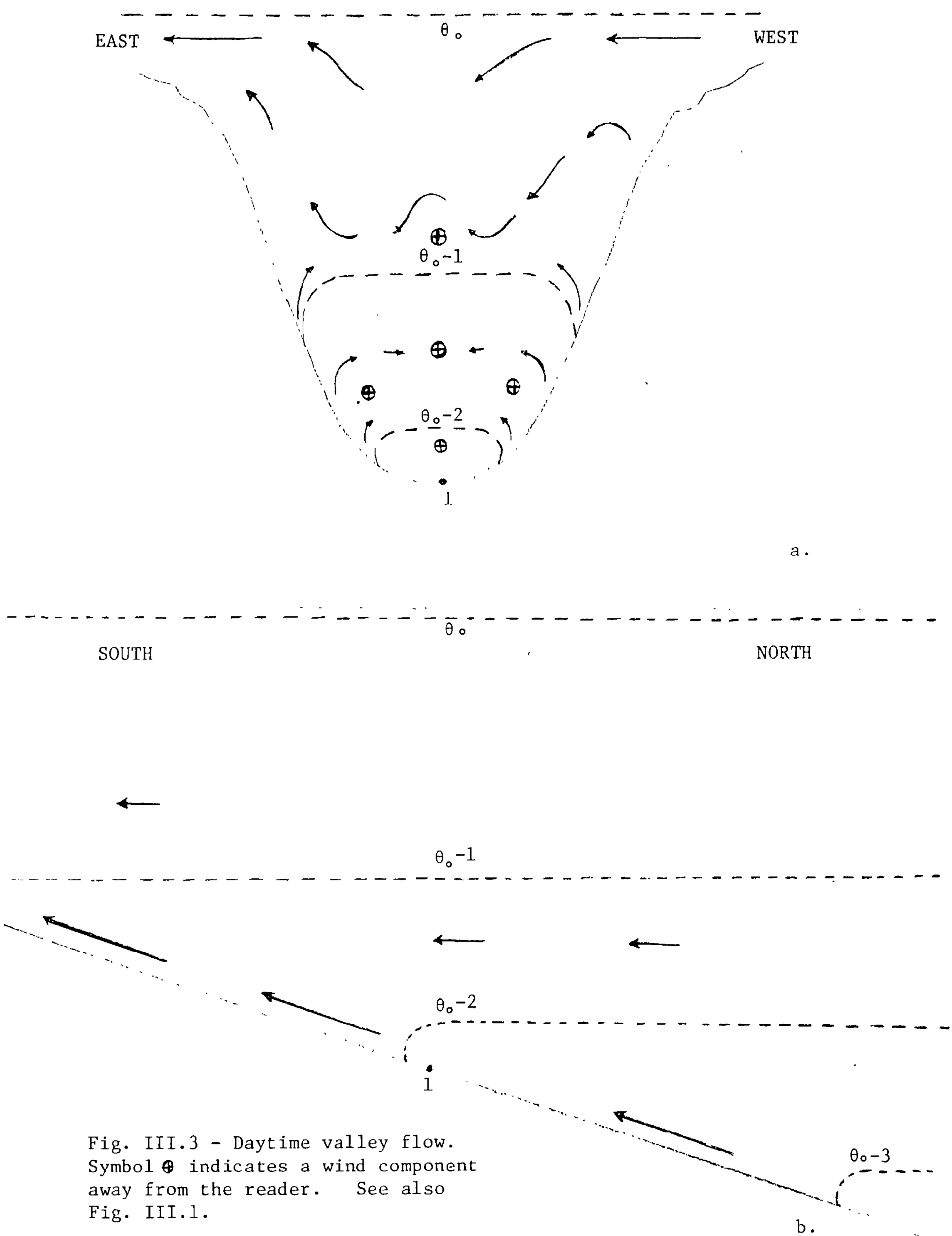


Fig. III.3 - Daytime valley flow. Symbol ⊕ indicates a wind component away from the reader. See also Fig. III.1.

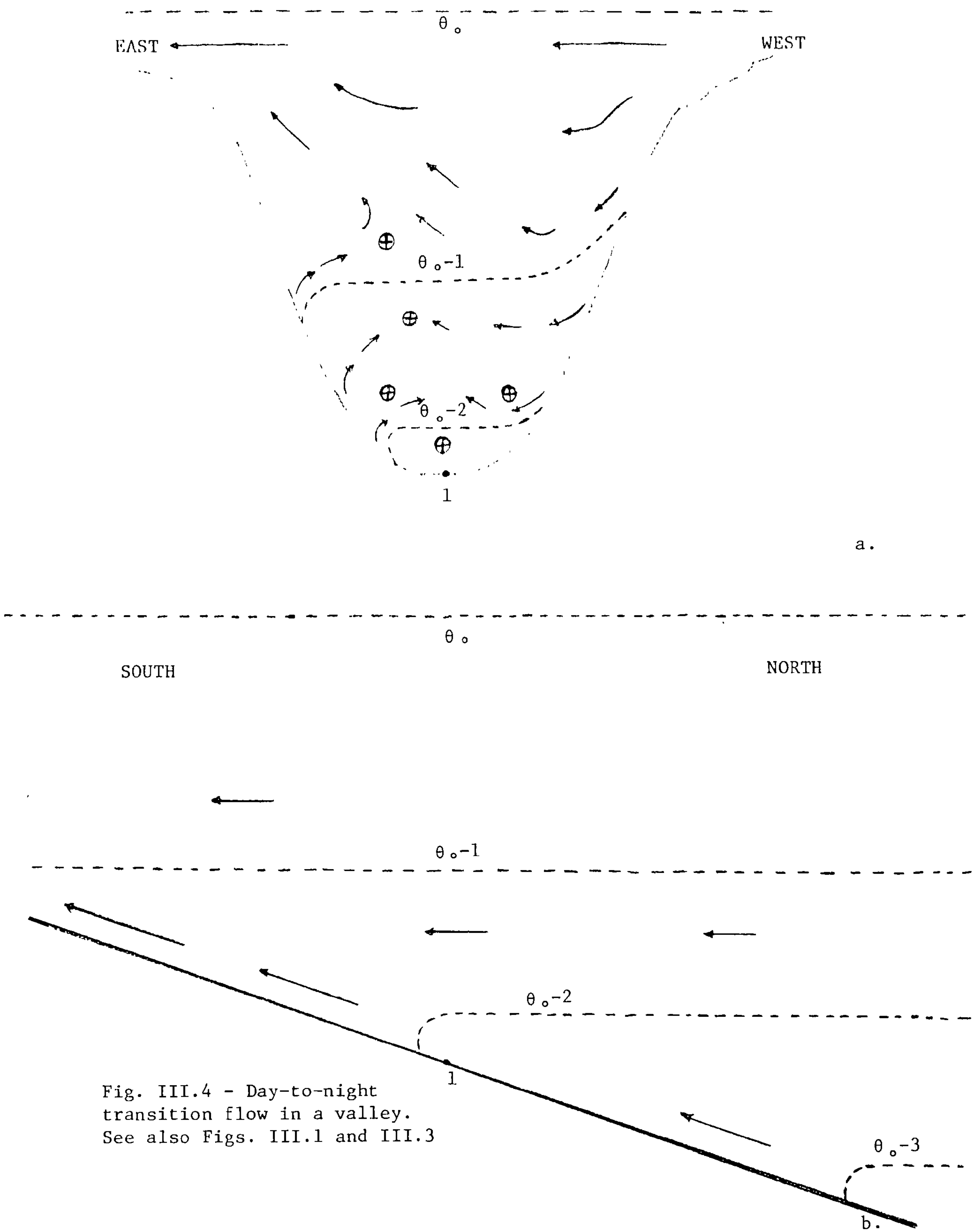


Fig. III.4 - Day-to-night transition flow in a valley. See also Figs. III.1 and III.3

temperature at the top than at the bottom is unstable. It will mix of its own accord, and as it does so the air will all come to the mean potential temperature of the entire layer. The layer will then be in neutral equilibrium. A neutral layer can easily be mixed, but air in it will not expend its own potential energy to do so as air in an unstable layer will.

Note that potential temperature is shown to have a value θ_0 above the valley in all of the Figures III.1 through III.4. It is shown to have lower values in the valley in all figures, but the distribution is different from figure to figure. If one visualizes the valley in three dimensions, it will be apparent that any given potential temperature is found on a nearly horizontal surface except when that surface comes close to the ground. Near the valley walls and floor, however, where the air is usually being warmed or cooled by the ground, the potential temperature surfaces are not horizontal. If the air is being cooled by the ground, the potential temperature surface is higher where it intersects the valley walls than it is out over the valley. Conversely, when the air is being warmed by the ground, the potential temperature surface is lower where it intersects the valley walls.

In addition to serving as an indicator of stability--and hence of the tendency of the air layer adjacent to the ground to mix--potential temperature is also important because the air flows along potential temperature surfaces. Note that the wind arrows in all the Figures III.1 through III.4 are generally shown to be parallel to the θ lines. When the arrows are not parallel to the θ lines, the air moving along the arrow is either gaining or losing heat, or the potential temperature surfaces are moving up or down. It is important to keep this in mind, and it will be recalled later. (Section III.C.2).

2. Steady state night time flow

Returning now to Figure III.1, it has been pointed out that the figure represents in an idealized way the wind flow and potential temperature patterns in the early morning. Radiation from the valley floor and walls has cooled them, and they in turn have cooled the air adjacent to them to temperatures lower than the air out over the valley at the same level. This cool air flows down the valley in much the same way water would flow during a rain, except that the air flow is much deeper. Small streams from side canyons combine as they reach the main valley, and under steady state conditions, the combined flow in the valley is just deep and strong enough to carry away all the air moving into it. Prior to reaching steady state, cold air accumulates and deepens in the valley. If the cold air supply from the valley walls and floor is not adequate to maintain steady state flow, the accumulated cold air in the valley flows out and the cold air depth increases.

In the paragraph above a similarity was drawn to the flow of air and water. That similarity is useful, but it can be deceptive. Figure III.1 shows in particular that flow originating well up on the valley wall will not reach the valley floor as long as this steady state situation exists. On the contrary, an air parcel originating on a valley wall (and any pollutant it contains which follows the air flow) will remain on its own potential surface and flow down the valley above the valley floor. The very stability which prevents mixing in this situation assures continued separation of pollutants which originate at different levels. Thus, during the night when down-valley flow is occurring, pollutants from sources which are well distributed in altitude in the valley will not concentrate on the valley floor. This is important to remember when using the box model for air quality calculations. The box model is discussed in greater detail in B.7 of this section.

It has been assumed that the flow depicted in Figure III.1 is not influenced by flow outside the valley. This is often nearly true in nature, but rarely completely true. In Figure III.1, the wind arrows near the top of the valley suggest motion in the same general westerly direction as the wind above the mountains. They also suggest up and down motion. Such motion often occurs and it disturbs the cold air in the valley. The disturbance is usually limited to a thin layer at the top of the cold valley air. Sometimes, however, it sets the entire body of air in the valley in motion like water in a pail which has been tilted and then suddenly released. Wind aloft which is blowing parallel to the valley can either aid or hinder nighttime down-valley flow. If the wind aloft is blowing in a down-valley direction, it will increase the flow. Air quality in a valley will suffer most if the nighttime down-valley flow is just barely reversed. The air will remain stable, and all pollutant will remain and accumulate near the ground as it is moved slowly up the valley.

3. Transition from night to day flow

As the rising sun starts to warm the east-facing wall of a north-south valley, the air in contact with that wall also warms. When it becomes warmer than the air over the valley at its own height, it starts to rise, thereby decreasing the supply of cold air which has been maintaining the steady state down-valley flow. The cold air already in the valley continues to flow out, however, thereby decreasing its depth in the valley. Figure III.2 shows the flow and potential temperature patterns in a valley when flow reversal on the west (east-facing) wall has progressed well down toward the valley floor. Note that the θ lines on the west wall now bend down as they approach the valley wall. Also note that the wind arrows appear to cross the θ lines. Actually, an air parcel must still remain on its own potential temperature surface as long as it neither gains nor loses heat, but as the cold air drains out of the valley, the potential temperature surfaces sink and so the air must have a downward component if it is not to change its θ value.

As the sun continues to rise and warms more of the valley, there comes a time when all cold air sources are eliminated--indeed, on the valley walls the flow is reversed. The core of cold air in the valley will continue to flow outward for a time, deriving kinetic energy from its potential energy as it moves to a lower position outside the valley and spreads out. Concurrently, the organized kinetic energy is being converted into turbulent energy by friction at the ground. Soon organized down valley flow ceases and is replaced by up-valley flow, which develops until it reaches an essentially steady state conditon like that shown in Figure III.3.

The transition period is a very important one insofar as air pollution is concerned. As the cold air in the valley shrinks in depth, the potential temperature surfaces move closer together and migrate toward the ground. Pollutants which were distributed through a large vertical depth are now spread through a much smaller vertical depth near the ground. The area covered is larger; hence concentrations in terms of mass per unit volume are not changed. More important, immediately after flow has changed to an up-valley wind, the air stratum on the valley floor is likely to be stable. Now flow up the valley from surface sources does follow along the ground, warming as it goes. Even flows from elevated sources approach the ground as they move up the valley. During this period, pollutant injected at many levels during the period leading up to the wind reversal can move back up the valley near the surface. It is added to that pollutant which is being injected concurrently.

No figure has been prepared to show the late phases of the night-to-day transition. Figure III.3 illustrates the situation which exists then except that in Figure III.3, the θ lines are hooked where they touch the ground. Without this hook, the air adjacent to the earth's surface is stable and mixing is quite restricted.

Although this transition starts at sunrise on the highest portion of the valley wall, the wind on the valley floor may not reverse until mid-morning or perhaps later. The reversal occurs first in the high end of the valley and last in the low end. Wind data for the period May 24 through July 8, 1974, were available simultaneously at the Breckenridge wastewater treatment plant near the upper end of Dillon Lake and at the Silverthorne maintenance yard. At the Breckenridge plant the mean time for onset of the up-valley winds was 0905 MST. At Silverthorne the mean time was 1106 MST. On four days during that period the wind failed to reverse at the Breckenridge plant; failure occurred on six days at Silverthorne. Some wind data exist also for an earlier period at the city of Breckenridge. During the winter of 1974-75, the transition at Breckenridge occurred at an average time of 0800 MST. These few data help to illustrate the point that Summit County is a valley in which valley winds are important, and they show that the night-to-day reversal occurs early in the morning high in the valley and much later at lower altitudes.

4. <u>Daytime flow</u>

Figure III.3 illustrates flow during a day when only the air immediately adjacent to the surface is unstable. Above that, the air is slightly on the stable side of neutral. In this conditon, thermals probably form frequently along the higher reaches of the valley walls. A thermal is a stream of air moving nearly vertically upward over a relatively small area. It is usually warmer than the air around it and it is this characteristic which gives it its name. Occasionally a thermal may form over the valley. Also, winds from mountain-top level frequently dip well into the valley. This is indicated by the lack of organization of the wind arrows between the θ_o and θ_o-1 potential temperature lines in Figure III.3.a. On a more stable day, pollutants would tend to collect in the valley; on a less stable day they would be lifted rapidly into the westerly flow above the mountains and be carried away. On a day like that shown, cleansing would be sporadic and not complete.

5. Transition from day to night flow

Figure III.4 illustrates the beginning of the day-to-night transition. Again the transition starts on the west (east-facing) wall of the valley because the effect of the loss of the sun's radiation is felt there first. The surface cools, cooling the adjacent air. This cooling lifts the potential temperature surfaces adjacent to the shaded valley face, and the cool air starts to flow downward and out over the valley. At first, flow from the western valley wall gets caught up in the main flow up the valley, and so any pollutant injected into the air along the west wall during this period may start to move downward toward the valley and then turn and move up the valley. During this early phase of the transition, pollutant from a higher point on the west wall may reach a receptor at a lower level but up the valley from the source.

As the east wall of the valley becomes shaded, cool air flows downward from all sides and starts to accumulate. The cold air accumulating in the valley raises the air above. This lifting is portrayed in Figure III.4 by showing the wind arrows crossing the θ lines from lower to higher values. Again, as in the morning transitions, this indicates upward migration of the potential temperature surfaces. Continued cooling of the air in the valley also has the effect of adding additional potential temperature surfaces as the surfaces present during the day are lifted. At some time after solar heating has ceased and radiational cooling of the ground has become predominant, down-valley flow becomes organized throughout the valley.

The onset of down-valley flow appears earliest in the high reaches of the valley and latest at the lower end of the valley. It is not usually as well defined an event as the onset of up-valley winds in the morning. The data for Breckenridge, the Breckenridge wastewater treatment plant, and the Silverthorne maintenance yard showed mean times of 1836, 1933 and 2116 MST respectively for the onset of down-valley winds. There were 6 days out of the 46 days when no well-defined change could be identified at the Breckenridge plant, and 8 days when no change was clearly identifiable at Silverthorne. At the Breckenridge plant, 90% of the changes in the morning occurred over a three-hour period, while at night it required an eight-hour period to encompass 90% of the changes. At Silverthorne, changes in the morning were also well grouped about the mean, but evening changes were even more scattered than at the Breckenridge plant.

This transition period does not appear to present as great a pollution problem as the morning period, given equal source strengths. Unfortunately, there is a long period during which the wind may be light and variable, and it occurs at the time during which many people are using fireplaces, driving to dinner, or leaving a day of skiing to drive home.

6. Complicating factors

Some of the factors which complicate wind flow in a simple, steep, north-south valley have been mentioned. The wind above the valley is one factor, and some of its effects have been discussed. Cloudiness can also change the circulation. Low cloudiness setting in late in the afternoon after a warm day can greatly delay or perhaps prevent the onset of the down-valley wind. Similarly, low cloudiness forming near sunrise after a cold night can delay or prevent an up-valley wind on that day. The nature of the ground cover also is important. New-fallen snow which covers trees as well as the ground is an excellent radiator at its temperature and a poor absorber of sunlight. Such a new snow cover can become extremely cold at night and contribute to the nighttime down-valley wind. By reflecting most of the sunlight the following day, it can delay or prevent the up-valley wind.

Topography is also important. Canyons entering the valley from the side participate in the valley flow and complicate it. Broad, relatively level sections in an otherwise uniform, steep valley change the flow. A deep narrow gorge in an otherwise uniform valley obstructs flow in both directions. In particular, the walls of the gorge may act as a dam and back up a deep pool of cold air at night. Summit County has all of these topographic features in some measure. For example, the Straight Creek Valley opens into the Blue River Valley at Silverthorne. The air flowing down Straight Creek will usually arrive at Silverthorne with a different potential temperature than the air arriving from the southeast after having crossed Dillon Reservoir. Consequently, the Straight Creek air will flow under the air from the southeast, if its potential temperature is lower, or over if its potential temperature is higher. If the two flows have the same potential temperature, the flow from Straight Creek will cause large eddies in the larger flow from across Dillon Reservoir, but the two flows will move along down the canyon mixing as they go. Just above Silverthorne the Dillon Reservoir is a large flat area in what is otherwise a sloping valley floor. The water in the reservoir serves as a heat source in late fall and early winter--at least until it freezes and is covered by a deep coat of insulating snow. From spring when the ice thaws until fall, the water is a heat sink which cools air in contact with it. In its role as a heat source and sink, its influence is quite different from the land around it. Clearly, the simple valley flow model which has been discussed is not realistic for the Silverthorne area. The model may provide some useful answers for Silverthorne, nonetheless, if its limitations are kept in mind. Meteorological sounding data for Silverthorne are discussed in Section III.C.

7. Applying the valley circulation model to air pollution problems

A number of air pollution models are in use, and most are misused at times by applying them under circumstances in which they have little chance of yielding reliable results. The box model is an acceptable model in valleys in which the sources of the pollutant are uniformly distributed over a nearly level floor and the air is well mixed from the surface up to the base of some well-defined inversion. It was used by Holben and Marlatt (1974) to make estimates of the mean concentrations in some rather large boxes, using an assumed set of wind data and an assumed set of mixing heights. They recognized the limitations of the model, and they state that available meteorological data are woefully inadequate. There is some confusion in their use of "mixing height" and "top of the inversion." In the box model, as they used it, the vertical dimension of the box should be the distance from the earth's surface to the top of the mixed stratum adjacent to the surface. The top of the mixed stratum is the base of a stable stratum, either an actual temperature inversion or a well-defined inversion of potential temperature. The base (not the top) of the inversion is the lid of the box. In a down-valley (katabatic) wind such as they assumed in their use of the box model, the base of the temperature inversion is at the earth's surface, in most instances; the box then has a volume of zero and the box model is not tenable as they used it. See Section III-C, Figure III.5 for examples of an inversion at the surface and a shallow mixed layer.

A different kind of box model is more realistic under down-valley wind conditions. It differs from the model used by Holben and Marlatt only in that it is assumed that pollutant from each source remains on the potential surface on which it was released. The potential temperature surface which passes through the highest source is then the top of the box. Concentration varies with potential temperature and is a function of the strength of the sources on each potential temperature surface. If source strength is fairly evenly distributed with height, this model can be simplified by letting the height of the highest sources be the depth of the box and using the model in the usual way.

The Gaussian model is often used for point sources. In its various modifications it is also used for multiple point sources, for line sources and for area sources. In a steep valley such as the Blue River Valley, it can be applied in its basic form and most of its modified forms, if proper precautions are taken. For example, when a down-valley wind is blowing, a plume from a single source can be expected to diffuse up and down from the potential temperature surface on which it comes to equilibrium. Since the floor of the valley falls away from that potential temperature surface down the valley, the ground cannot act as a reflector in the way it is usually assumed to act. When an up-valley flow is still stable above a shallow mixed stratum at the ground, an elevated plume will approach the ground bodily as it moves away from the source, and as it approaches the ground it will mix nearly uniformly through the shallow mixed stratum at the ground. Horizontal dispersion in a valley may be treated as it is normally in the Gaussian model until the plume width approaches the width of the valley. Beyond that point, reflection by the valley walls can be used, but the results may not be particularly satisfactory.

The stability categories normally used (e.g. Turner 1969) are often not satisfactory in a valley. On a bright sunny day in the period immediately following the onset of an up-valley wind, an unstable category would be chosen if one followed instructions found in Turner (1969). A stable category should be chosen in most cases for one to two hours following onset of the up-valley wind. In some cases, the stable category will be applicable throughout the day.

Some specialized models have been mentioned in the discussion of Gaussian models. Specifically, models such as HIWAY, PTMAX, etc. must be used with great care to avoid misleading results. These are EPA computer models which are widely used by engineers, they are well documented, and they are quite useful when properly applied. One basic assumption in most of these is that the ground is nearly level and relatively smooth. Clearly, this is not a valid assumption when the model is used in a steep valley. For example, PTMAX is designed to determine the maximum ground level concentration and the point at which this maximum occurs, when one or more individual stacks are the polluting sources. If applied for a single stack without modifications in a nighttime situation in a steep valley, PTMAS would predict a single maximum on the ground downwind of the stack. The actual maximum would more likely be on one of the valley walls and both walls might receive higher concentrations than the valley floor. These models can sometimes be used in a valley under very restrictive conditions and provide useful information.

C. Sampling Days--Criteria, Weather and Traffic

1. Sampling criteria

The places and times at which air samples should be collected were determined only after careful study. The goal was to sample on a day when human activity was high and dispersion was good and on a day when activity was high and dispersion was poor. Air flow patterns and stability in the valley vary with season, time of day, and past and present meteorological conditions over the entire Rocky Mountain region. These had to be taken into account. The distribution of roads, parking lots, urban areas, dwelling complexes and rural areas, and the topographical setting in which these were found were all important. Seasonal tourist activity was also considered. Each sampling site is discussed in Appendix B. The criteria for selecting both summer and winter sites and sampling times are summarized briefly here.

a. Summer

Because the plan was to sample in summer when the air in the valley was well mixed sampling was done in the afternoon. To be downwind of a source in the afternoon, each site must normally be up the valley from its source. Each site had to be far enough from all intense, small sources, that samples were not unduly influenced by any one such source. For example, sites in the vicinity of parking lots were located far enough downwind from the lots so that the sample was indicative of the general environment of the lot and not of the exhaust at the rear of one automobile. Likewise, sites located near highways were located far enough from the roadway to avoid peak concentrations from individual vehicles and to approximate the concentrations to which roadside residences and businesses would be exposed.

b. Winter

Sampling in winter was to be done when dispersion was poor and source strengths were high. Preliminary analyses suggested that dispersion was poor throughout the nighttime hours when the air stratum near the ground was stable, and that it would be worst early in the morning. It was also anticipated that source strengths would be strongest early in the morning when space heating and traffic to ski resort areas both were high. Consequently, a cold early morning period when winter sports activity was expected to be great was selected for the winter sampling. At that time the air would be flowing down the valleys, if meteorological conditions were favorable for valley flow. Consequently, sites were expected to be down the valley from the source areas to be sampled.

c. Meteorology

It was important in both summer and winter that meteorlogical conditions in the Rocky Mountain area be taken into account. The ideal condition would be a situation in which skies were nearly cloudless in the morning, wind at mountain-top levels and above was from a westerly direction and wind speed was low. This would permit valley flow to prevail. In summer, cloudless skies permit strong solar heating in the valley and assure good vertical mixing and dispersion in the afternoon. In winter, clear skies permit the ground to radiate to space and cool, thereby assuring the cold surface temperatures and stable conditions needed for low dispersion. In winter, a fresh snow fall within the last few days was desirable. This would encourage skiers to come to Summit County and it would enhance the radiational cooling at the surface. The actual day of sampling was selected by reviewing the weather map each day on the several days leading up to the sampling day. Thus the meteorological history of the county over the week preceding the day selected, as well as the forecast for the day, were both important in selecting the day for sampling.

2. Weather

a. Summer

The weather on July 23, 1975, when sampling was conducted at all five sites is described in Appendix A. Weather on August 18, 1974, when samples were taken at three sites was very similar to that of July 23, 1975. Dispersion was excellent and the flow was up the valley during both sampling periods. The primary difference in the weather was that gusts were stronger on August 18 than on July 23, and more dust was raised by the wind.

b. Winter

A storm had passed over the Rockies during the weekend following Christmas and left some new snow in Summit County. Following the passage of the storm, cold air settled over the Colorado Rockies. This was the ideal situation for the winter sampling which had been planned, except that the winds above the mountain tops were from the north. These strong northerly winds aloft were causing north winds throughout the Blue River Valley; at times they were strong enough to cause blowing snow on the floor of the valley.

On Sunday, December 28, 1975, it appeared that by Tuesday morning the winds above the mountain tops would have shifted to a northwesterly direction. On Monday, the situation appeared doubtful. Winds aloft were still northerly, and snow was falling in some mountain areas about Summit County. The winds were diminishing and starting to back, however, and the weather did appear promising enough to warrant starting preparations to sample the following morning.

At 0400 MST on December 30, skies were clear over the mountains east of Summit County, but low thin clouds covered parts of the valley. Under these clouds, very light snow fell occasionally. The air flow at Silverthorne varied from the south to east, however, indicating that the down-valley wind was blowing.

Surface meteorological data at the sampling sites are shown in Table III.1 for the morning of December 30. Soundings were taken in Silverthorne (Site 2) by means of a tethered balloon sounding system (The Tethersonde™). The soundings are shown in Figures III.5 through III.7.

In general, the anticipated down-valley wind existed at all sites. At Site 1 which was the lowest site, winds were variable from south or southeast. At Site 2, the influence of Straight Creek Canyon can be seen vividly in the lower levels of the Tethersonde soundings. The winds near the surface coming down the Straight Creek Canyon were from east or eastnortheast. At higher levels the soundings show wind from southeast to south. At Breckenridge (Site 3) winds were generally southerly until after 0900 MST. They shifted to northerly sometime before 1000 MST. At Site 4, flow was generally from a westerly direction. The flow aloft aided the down-valley flow so that the strongest surface winds observed at any site were observed here. Site 5, located in the east-west oriented Snake River Canyon shows light, down-canyon winds early. The northwest winds aloft were impeding the down-valley flow here; hence direction was variable throughout most of the sampling period.

Turbulence was quite evident at the Wheeler Junction during much of the morning as the flows from West Tenmile Creek and Tenmile Creek joined. A small cloud with its base at about 50 to 100 m and its top at 200 m formed in Tenmile Creek across the mouth of West Tenmile Creek. Individual cloud elements formed at the southern end of this cloud, moved downstream (northward), and dissipated a short distance downstream of the junction. Clearly, the air was nearly saturated and lifting of one or both canyon flows as they joined caused saturation.

The Tethersonde soundings made at Silverthorne are shown in Figures III.5 through III.7. They show a number of interesting aspects of valley flow. First, they disclose a temperature inversion at the surface which lasted throughout the morning until the descent of the final sounding. Even then a strong inversion overlaid the shallow unstable layer caused by solar heating at the surface. They show increasing temperature and drying of the air as time passed at all levels. All temperature increases, except for those immediately above the surface, were caused by the subsiding of the cold air as it flowed out of the valley after its source had been cut off (Figures III.5 and III.6). Note that the temperature increased at the top of the sounding slowly early in the morning and then more rapidly as the cold air source dwindled.

Turbulence in the upper portions of the soundings was absent in the early morning. It showed up above 375 m (1,200 ft) in the 0808 soundings which reached 475 m (1,500 ft) above the valley floor (Figure III.7). Turbulence probably in the form of waves on the upper surface of the cold air caused the repeated changes of altitude of the balloon. In this set of soundings neither short period wind speed nor direction changes were great (Figure III.6).

Table III.1

Summary of Surface Meteorological Data in Summit County
Morning of December 30, 1975

TIME (MST)	0510	0610	0710	0730	0740	0815	0900	0915	0930	1015	1030	1045
Site 1												
Wind Dir.	112	180	180	158	160	130	140	-	175	-	140	-
Wind Speed (m/s)	<1	1	-	1.8	1.8	1.3	<1	-	1	--	<1	-
Temp. (°C)	-9.3	-10.6	-	-12.5	-13.9	-13.9	-12.2	-	-10.0	-	-	-
Wet Bulb (°C)	-9.4	-10.6	-	-12.8	-14.6	-13.9	-12.2	-	-10.0	-	-	-
R.H. (%)	89	100	-	80	78	100	100	-	100	-	-	-
Site 2												
Wind Dir.	270	120	-	120	-	120	-	120	-	120	-	-
Wind Speed (m/s)	<1	<1	-	1.3	-	1.1	-	1.8	-	1.8	-	-
Temp. (°C)	-	-9.3	-9.4	-	-	-10.8	-	-9.8	-	-7.6	-	-4.8
Wet Bulb (°C)	-	-9.5	-9.8	-	-	-11.1	-	-10.8	-	-8.8	-	-6.8
R.H. (%)	-	95	82	-	-	82	-	67	-	67	-	58
Site 3												
Wind Dir.	180	-	135	135	-	180	-	180	-	045	-	Var.
Wind Speed (m/s)	1	-	1.3	1.8	-	1.8	-	1	-	1	-	1
Temp. (°C)	-7.8	-8.3	-8.3	-8.3	-	-12.2	-	-8.3	-	-8.3	-	-5.6
Site 4												
Wind Dir.	040	030	Var.	270	-	240	-	240	-	270	-	240
Wind Speed (m/s)	<1	1.8	<1	2.2	-	2.7	-	1	-	<1	-	1
Site 5												
Wind Dir.	135	135	-	Var.	-	Var.	-	Var.	-	022	-	-
Wind Speed (m/s)	1.6	1	-	1	-	1	-	1	-	1.3	-	-

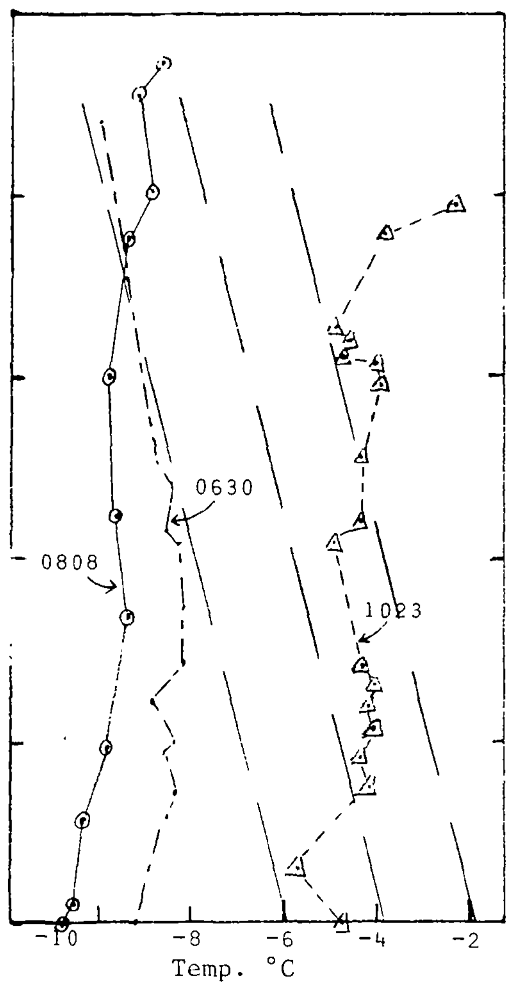


Fig. III.5 - Temperature vs. height at Silverthorne, Dec. 30, 1975. Times are MST.

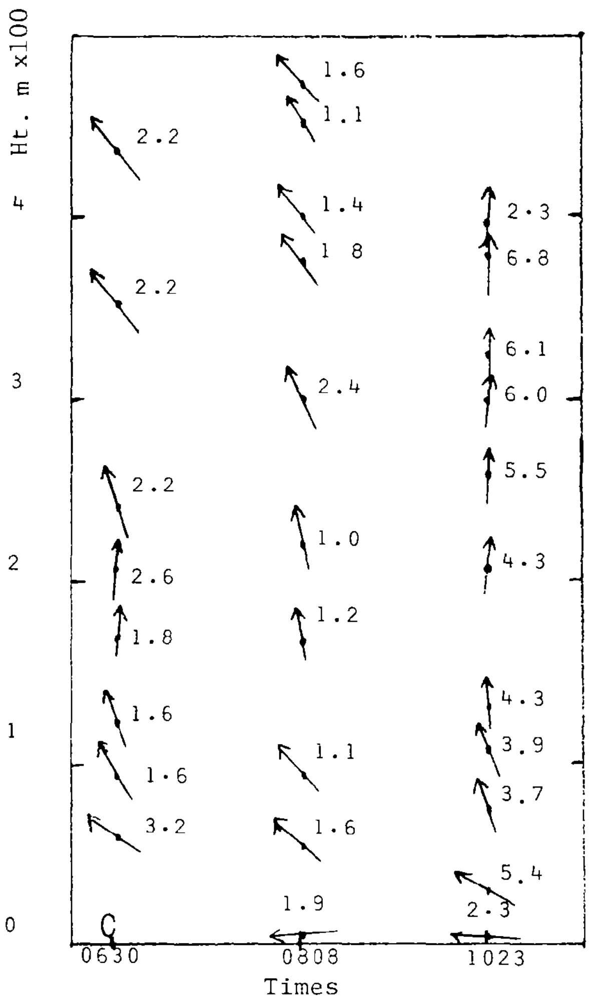


Fig. III.6 - Wind velocity vs. height at Silverthorne, Dec. 30, 1975. Speeds are m/s.

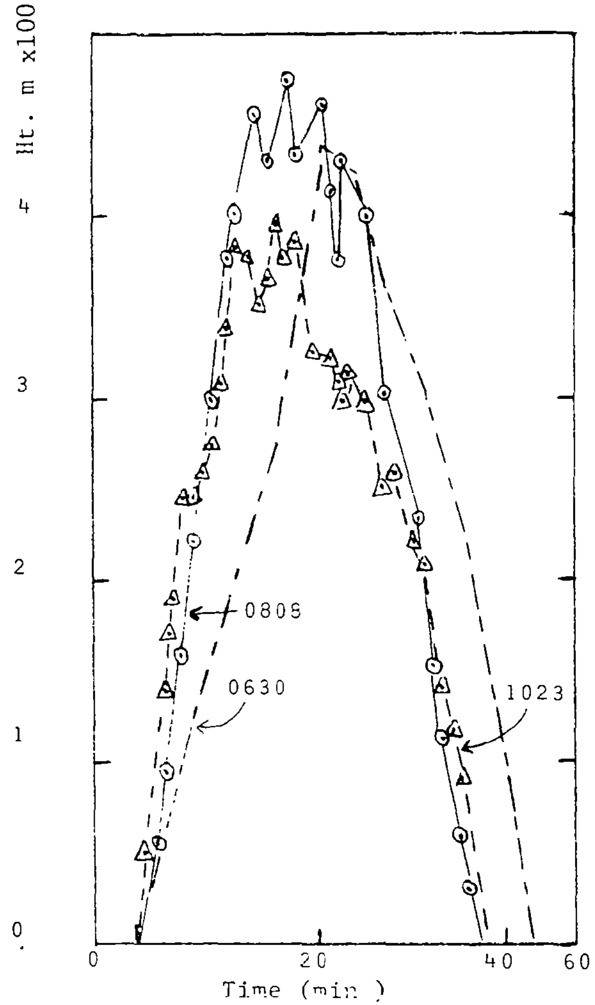


Fig. III.7 - Time in minutes into flight vs. height at Silverthorne, Dec. 30, 1975

By 1023 MST when the last set of soundings was being made, turbulence was evident as low as about 200 m. It is shown by balloon height changes, wind speed changes, and temperature changes. The wind from above mountain-top level was evidently stirring the air above flight level, mixing parcels of air with warmer potential temperature down well into the valley. This mixing from above, warming from below, and flow of the cold air out of the valley probably continued until the air in the valley was much warmer and was well mixed throughout or until cooling in the late afternoon started replenishing the cold air again. It is not known whether an up-valley wind occurred at Silverthorne on the afternoon of December 30, but it probably did as soon as subsidence and warming destroyed the near-surface inversion.

During the period 0610 to 0730 MST the temperature of Breckenridge (Site 3) remained constant at -8.3°C or 264.8°K. The potential temperature at the surface was determined to be 292°K. In a similar way, the potential temperature was calculated at various heights above Silverthorne, using the 0620-0703 MST soundings. During ascent, the potential temperature at the surface was 288°K, and a potential temperature of 292°K was found at 241 m. The difference in altitude of the two sites is 246 m. Hence, the potential temperature surface passing through the Breckenridge site was virtually level at that time. Later (from the 1023 sounding) after the cold air source was cut off and the cold air was emptying into the Colorado River Valley to the north, the 292°K surface had lowered to about 50 m at Silverthorne.

3. Traffic volume at Site 2, Silverthorne

Traffic volumes for three different periods on the days when sampling was done are shown in Tables III.2, III.3, III.4.

TABLE III.2

Traffic Count Tabulation*
Final Composite

Week 34 beginning August 18, 1974--SH 9 North of Silverthorne

Day	Sunday	Thursday	Friday	Saturday
Date	18	22	23	24
Hour				
09-10	160	164	178	226
10-11	283	213	201	266
11-12	274	169	187	228
12-13	359	185	210	261
13-14	372	176	202	240
14-15	356	209	231	237
15-16	369	185	232	257
16-17	388	218	244	267

Peak Hours - 388, 16-17 Sunday, August 18, 1974

Week 34 beginning August 18, 1975--I-70 East of Dillon

Day	Sunday	Thursday	Friday	Saturday
Date	18	22	23	24
Hour				
09-10	760	745	734	996
10-11	1161	868	890	1181
11-12	1316	882	975	1312
12-13	1620	1002	930	1212
13-14	1649	805	966	1230
14-15	1727	961	1141	1200
15-16	1823	970	1145	1225
16-17	1832	866	1196	1222

Peak Hours - 1832, 16-17 Sunday, August 18, 1974

*Source - Department of Highways, State of Colorado, Planning and Research Division. This is a count of vehicle passages past a given point in both directions.

TABLE III.3

Traffic Count Tabulation*

Week 30 beginning July 20, 1975--SH 9 North of Silverthorne

Day	Sunday	Monday	Tuesday	Wednesday
Date	20	21	22	23
Hour				
09-10	182	174	193	186
10-11	252	193	159	193
11-12	282	192	148	198
12-13	288	163	177	197
13-14	309	185	156	199
14-15	389	202	192	230
15-16	328	181	196	181

Peak Hour - 389, 14-15, Sunday, July 20, 1975

Week 30 beginning July 20, 1975--I-70 East of Dillon

Day	Sunday	Monday	Tuesday	Wednesday
Date	20	21	22	23
Hour				
09-10	819	720	819	702
10-11	1074	941	642	800
11-12	1297	942	811	908
12-13	1659	828	752	848
13-14	1607	817	744	741
14-15	1711	935	846	900
15-16	1745	878	837	904

Peak Hour - 1745, 15-16, Sunday, July 20, 1975

*Source - Department of Highways, State of Colorado, Planning and Research Division.

TABLE III.4

Traffic Count Tabulation*

Week 53 beginning December 28, 1975--SH 9 North of Silverthorne

Day	Sunday	Monday	Tuesday	Wednesday
Date	28	29	30	31
Hour				
05-06	2	95	68	63
06-07	27	168	161	156
07-08	21	63	54	41
08-09	69	72	81	44
09-10	67	69	78	50
10-11	111	96	97	60
11-12	119	102	118	95

Peak Hour - 168, 06-07, Monday, December 29, 1975

Week 53 beginning December 28, 1975--I-70 East of Dillon

Day	Sunday	Monday	Tuesday	Wednesday
Date	28	29	30	31
Hour				
05-06	50	164	97	62
06-07	132	211	181	136
07-08	447	442	525	291
08-09	1174	1239	1255	572
09-10	1080	1397	1284	557
10-11	1028	961	1076	708
11-12	1073	916	963	599

Peak Hour - 1397, 09-10, Monday, December 29, 1975

*Source - Department of Highways, State of Colorado, Planning and Research Division.

D. Carbon Monoxide and Particle Measurements

Carbon monixide and particles were measured at three sites on August 18, 1974, at five sites on July 23, 1975, and again at the same five sites on December 30, 1975. See Figure I.1 for site locations. The general approach was to sample under preplanned conditions and to preserve and analyze the samples in such a way that the integrity of each sample was assured. The criteria for selecting sampling sites and times are given in Section III.C.

1. Carbon monoxide (CO)

Carbon monoxide sampling was done by collecting an air sample in mylar bags conditioned to the atmosphere of each site. Each sample was collected at a uniform rate over a one-hour period. A description of calibration and sampling methods appear in Appendix A.

Analysis of the one-hour samples were performed within two hours of collection. Results are summarized in Table III.5. The standard reference material used for calibration of the CO analyses in the 1975 summer test was a secondary standard. A primary NBS reference was used for the winter analyses and hence greater precision was possible.

Table III.5 also includes results taken in August 1974 by a grab sample technique and analyzed by high-sensitivity gas chromatograph. These are highly accurate measurements of spot concentrations of carbon monoxide. Although the 1974 data are virtually instantaneous values, they are considered to be representative because the samples were collected with great care under specified conditions. Note that the 0.23 ppm value shown for Site 1 (a rural site) is consistent with background concentrations measured in other places in the Rocky Mountain area (about 0.2 ppm).

a. Summer vs.winter-1975 data

Comparison of the samples taken in the winter period with those taken in summer show much higher concentrations of carbon monoxide in the winter period. Site-by-site comparison reveals the combined effect of sources and atmospheric dispersion. Site 1 on the Knorr Ranch in the northern part of the county shows carbon monoxide concentrations characteristic of air parcels not overly influenced by emissions from combustion. The concentration of the winter sample is three times that of summer, however, primarily because of lower winter dispersion. The Silverthorne winter sample (Site 2) is also three times the average summer sample level. At Breckenridge (Site 3), Copper Mountain (Site 4), and Keystone (Site 5), concentrations are all approximately 15 times as great in the winter samples as in the summer. These are all sites near busy ski areas, and increased traffic,increased space heating, and lower dispersion are all instrumental in causing the higher values in winter.

TABLE III.5

Carbon Monoxide Concentrations in Summit County

The first column lists concentrations in ppm. The second column lists the precision of measurements.

SITE†	August 18, 1974*		July 23, 1975		December 30, 1975	
	ppm		ppm		ppm	
1	0.23	±0.08	0.5	±0.25	1.4	±0.08
2	0.52	±0.08	1.5	±0.25	4.5	±0.12
3	0.92	±0.07	0.5	±0.25	7.4	±0.05
4			1.0	±0.25	16.3	±0.11
5			<0.5	±0.25	8.0	±0.04

*Analysis done by gas chromatography.
†Site locations are shown in Figure I.1 and described in Appendix B.

Among the goals of Summit County in undertaking this study was the measurement of concentrations under conditions when air quality should approach both good and bad extremes. The comparisons between samples of summer and winter carbon monoxide concentrations show that the temporal range of concentrations can be large. On the summer day when vertical mixing was great, the concentrations were well below Federal and State statutory standards everywhere. On the winter morning when little vertical mixing was occurring, concentrations were high enough at all sites, except Site 1, to suggest that current statutory standards might be exceeded under certain winter conditions.

b. Continuous CO measurements

Continuous CO concentrations were observed at Silverthorne (Site 2) near the junction of SH 9 and I-70. Hourly averages from these data are shown in Table III.6.

Summer data were collected approximately 300 meters south of the junction (See Figure I.1) so that they represent the cumulative emissions from Silverthorne and the two highways during upslope air flow conditions.

Winter data were collected at the Silverthorne Town Hall and are representative of downslope air flow near the junction of I-70 and SH 9 and a part of the community of Silverthorne. Data are presented for the winter condition to document worst dispersion conditions more completely at Site 2.

There was a combined total of 6,299 vehicle passages for SH 9 and I-70 at Silverthorne during the period 1000 to 1600 MST on July 23, 1975. (Table III.3). Air flow was upslope, dispersion was good, and the average carbon monoxide level for the six-hour period was 1.3 ppm.

The combined traffic total for the period 0500 to 1100 MST on December 30, 1975 at Silverthorne was 5,873 vehicles. (See Table III.4). During this period air flow was downslope and the average six-hour CO concentration was 4.4 ppm. Thus the CO concentration was approximately three times as great in the winter period as in the summer period and the automotive traffic was less. Some winter pollution was caused by space heating, but part of the difference in the concentrations noted above was undoubtedly caused by poorer dispersion in the winter period.

2. Total suspended particles (TSP)

Particle samples were collected by drawing air through membrane filters at a measured rate. The average exposure time was 170 minutes. Particle data are shown in Table III.7 and III.8. Great care was taken to assure that the exposed membranes and the field blanks were carefully preserved until the particulate material on them could be analyzed. Following analysis, the filters were stored for safekeeping at Ambient Analysis, Inc. and are available for further reference.

TABLE III.6

One Hour Continuous CO Concentrations Measured at Silverthorne (Site 2)

	North of Junction I-70 & SH 9				South of Junction I-70 & SH 9		
	Date	Time	ppm CO		Date	Time	ppm CO
	Dec. 29, 1975	16-17	2.5				
		20-21	2.3				
		21-22	4.0				
*D		22-23	2.7	*U			
O		23-24	2.0	P			
W	Dec. 30, 1975	00-01	2.1	S			
N		01-02	2.6	L			
S		02-03	2.7	O			
L		03-04	2.7	P			
O		04-05	3.2	E			
P		05-06	2.1		July 23, 1975	†10-11	2.2
E		06-07	2.8			11-12	0.9
		†07-08	5.2			12-13	0.8
		08-09	8.5			13-14	1.9
		09-10	4.2			14-15	1.4
		10-11	3.6			15-16	0.8
	4.4 ppm CO mean for downslope organized flow				1.3 ppm CO mean for upslope organized flow		
	†Max. five minute mean: 21.8 ppm				†Max. five minute mean: 11.7 ppm		

*The data chosen for comparison are enclosed in boxes. Air flow was persistently downslope in winter and upslope in summer during the times for which the data are compared.

Analysis was done in three ways. The 47-mm filters were weighed on a Cahn microbalance before and after exposure to determine the total mass of particulate material collected on them. Dividing this mass by the volume of air drawn through the filter yields the concentration of particulate mass per unit volume of air. The units are expressed in micrograms per cubic meter, which is abbreviated $\mu gm/m^3$. The filters were also analyzed by electron microscope to determine particle appearance (morphology) and size distribution. Finally, particle type was determined by qualitative x-ray examination. Morphological and x-ray analyses were both used to determine the general origin and composition of the particles. Qualitative x-ray identification of single particles was done for the asbestos-like particles collected at Site 2 in the summer.

a. Comparisons of summer and winter particle mass concentrations

A comparison of winter and summer gravimetric (weight) data for particles shows a generally lower concentration of TSP for the winter samples. Data from four of the five sampling stations are indicative of particle mass concentrations in those county areas where human activity is concentrated. Gravimetric data for August 18, 1974, and for the two sampling periods in 1975 are shown in Table III.7.

Gravimetric data at Site 1 show particle concentrations which are typical of background or baseline values in rural areas. These usually range from 0 to 40 micrograms per cubic meter, Hoffman, et.al. (1975). Background, baseline and benchmark are generally used interchangeably; they are relative terms and background varies from season to season, region to region, etc. For example, the data in Table III.7 for Site 1 show that TSP can vary considerably in summer at a single rural location. Concentrations at this site are considered to be close to the background values for the valley during the sampling periods. Particle samples at Sites 1, 2, and 3 collected in August of 1974 show typical concentrations when dry and windy conditions contribute to entrainment of particles.

TABLE III.7

Total Suspended Particles Data

Concentrations in $\mu gm/m^3$ are given in the first column. The difference between other sites and Site 1 is shown as "Excess" over background in the second column. The percent of TSP at each site which is excess is given in the third column.

	August 18, 1974			July 23, 1975			December 30, 1975		
Site	Conc.	Excess	(%)	Conc.	Excess	(%)	Conc.	Excess	(%)
1	41			14			< 4		
2	61	20	33	49	35	71	16	>12	>75
3	86	45	52	16	2	13	11	> 7	>64
4				37	23	62	10	> 6	>60
5				13			12	> 8	>67

TABLE III.8

Particle Size Data for 1975

The number of particles collected on each filter and the number per unit volume in the size range indicated are given in Columns 2 through 5. The mass per unit volume (concentration) of all particles collected is given in Column 6.

	Site	Particles/filter	Range of Particle Diameters <1.0μm	1-10μm	>10μm	All	TSP $\mu g/m^3$
	1	$3.3x10^{6}$	$3.0x10^{5}$	$3.8x10^{5}$	$1.8x10^{4}$	$0.7x10^{6}$	14
	2	$8.7x10^{6}$	$1.3x10^{6}$	$5.1x10^{5}$	$3.6x10^{4}$	$1.9x10^{6}$	49
July 23	3	$5.0x10^{6}$	$7.5x10^{5}$	$5.3x10^{5}$	$5.1x10^{4}$	$1.3x10^{6}$	16
	4	$4.4x10^{6}$	$8.1x10^{5}$	$4.1x10^{4}$	$6.9x10^{4}$	$0.9x10^{6}$	37
	5	$2.5x10^{6}$	$3.1x10^{5}$	$2.6x10^{5}$	$1.6x10^{4}$	$0.6x10^{6}$	13
	1	*	*	*	*	*	<4
	2	$1.0x10^{6}$	$5.5x10^{4}$	$2.7x10^{5}$	$1.5x10^{4}$	$0.3x10^{6}$	16
Dec. 30	3	$1.8x10^{6}$	$1.9x10^{4}$	$2.3x10^{5}$	$1.3x10^{4}$	$0.3x10^{6}$	11
	4	$2.9x10^{6}$	$5.1x10^{4}$	$6.2x10^{5}$	$3.1x10^{4}$	$0.7x10^{6}$	10
	5	$1.2x10^{6}$	$4.3x10^{4}$	$2.5x10^{5}$	$1.2x10^{4}$	$0.3x10^{6}$	12

* Too few particles to yield a statistically reliable count.

< A symbol indicating that the actual value is "less than" the number following the symbol.

> A symbol indicating "greater than."

The effects of human activity on total suspended particulate (TSP) concentrations in Summit County can be inferred from the data. The difference between the TSP at each site and Site 1 is assumed to be the excess of TSP caused by human activity. Since some of the TSP at Site 1 is human-related, the excesses shown are probably low or conservative.

Traffic volume for the period 1100 to 1700 MST on August 18, 1974, was higher than during any other sampling period (See III-C) with 8,891 vehicles counted on Highways 9 and I-70 near Site 2. Thus, heavy traffic contibuted to the TSP on that day. Gusty winds also contributed by raising dust. It is noted that dispersion was excellent and that CO values were not particularly high at Site 2 despite the heavy traffic. Air quality was more affected by high particle concentrations on that day than it was on all the other sampling days.

A number of other observations can be made about the particle data. The variability from site to site is much greater in summer than in winter. In summer, Site 5 was virtually a rural (background) site, whereas in winter when skiing drew large crowds, it was affected almost as much by human activity as Sites 2 through 4. Then at non-rural sites (2 through 4 in summer), the average fraction of TSP which can be ascribed to human activity is 46%. In winter the average is 66%. Thus, although the summer values are larger at all sites than the winter values, a much higher fraction of the winter particulate matter is contributed by human activity. Excluding Site 1, the winter concentrations are quite comparable at all sites, suggesting similar sources and similar levels of activity. In summer the concentrations and the fraction contributed by human activity vary greatly from site to site, indicating dissimilar sources or levels of activity, and different land use as affecting air quality.

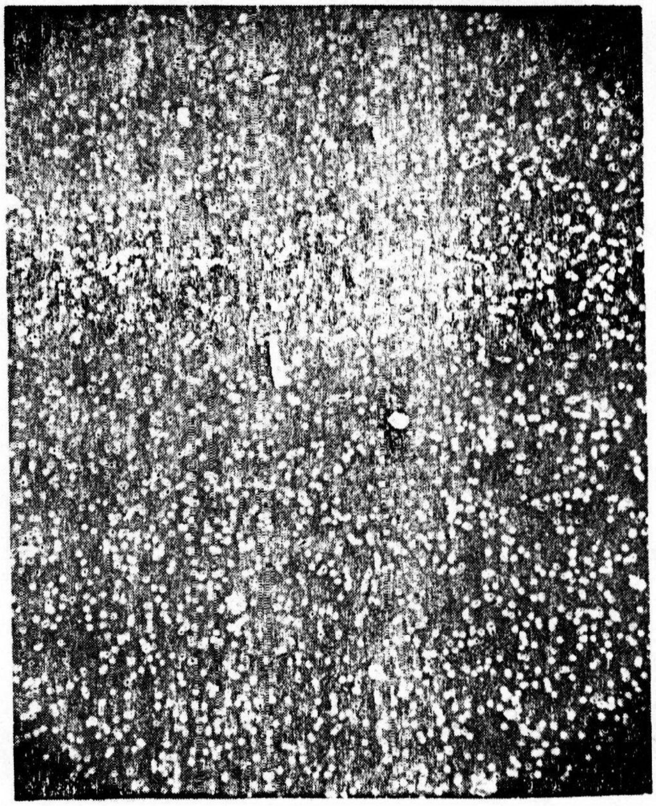
b. Particle size distribution

The particle size data in Table III.8 show that the number of particles per unit volume was lower in most size categories at most sites in December than in July. The most marked difference is in small particles, however. Microphotographs are shown in Figures III.8 through III.12.

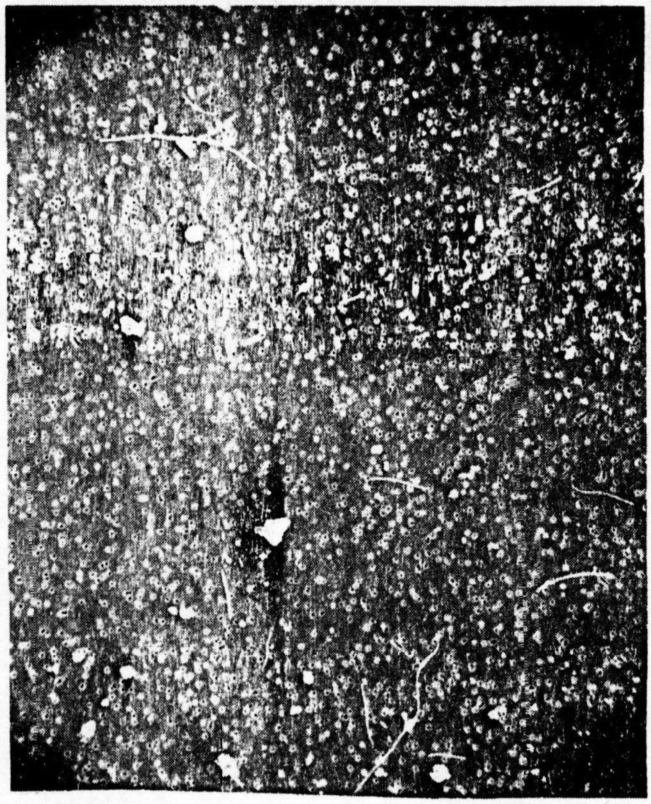
The morphological appearance of the particles shows the winter samples (Figures III.10, III.11 and III.12) to have the characteristics of combustion particles. Fly ash and combustion nuclei predominate at Sites 2 through 5. The micrograph for Site 1 shows the exposed filter to be so clean that its appearance was essentially the same as the field blanks--see Appendix A.

Snow cover changes the character of the airborne particles. In the summer with no snow cover, particles were mixtures of inorganic and organic substances. Wintertime particles were less dense and were almost wholly organic. They probably have characteristics like liquid aerosols due to temperature conditions during emission. Qualitative x-ray analyses of the particles collected at Sites 2 and 4 indicate that the material was predominately organic.

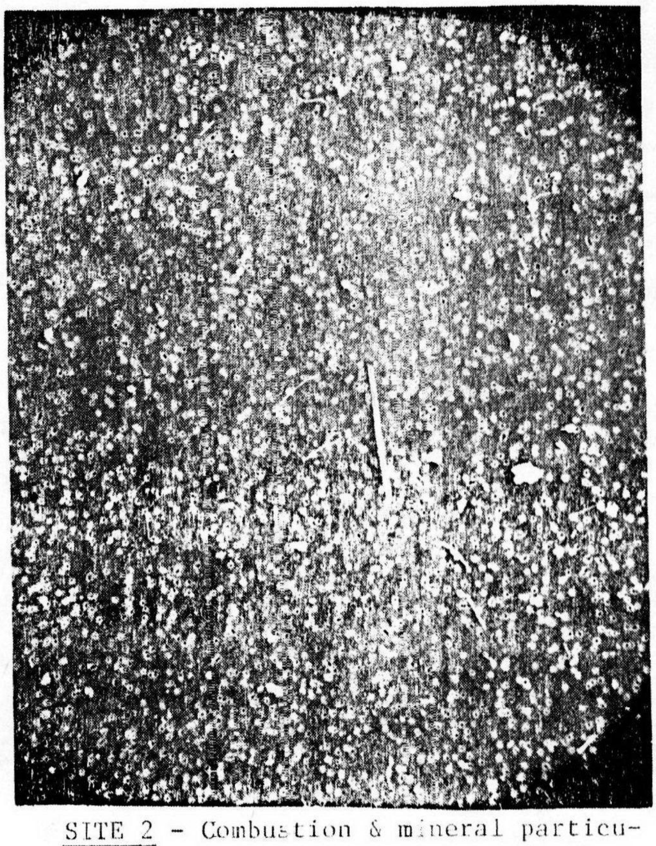
Fig. III.8-EM Micrographs, 210X, July 23, 1975



SITE 1 - Biological & mineral background particulate - relatively clean



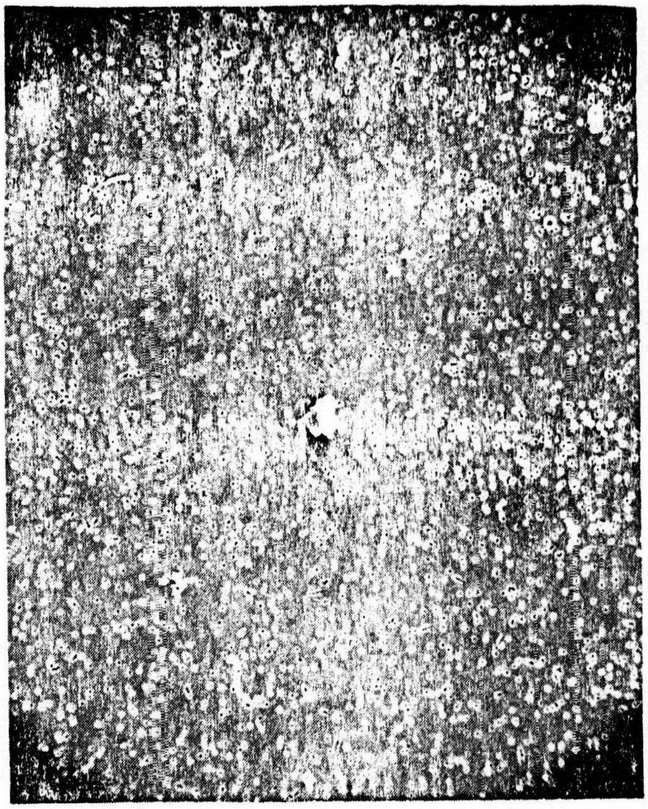
SITE 2 - Combustion & mineral particulate containing significant percentage of asbestos-like particles



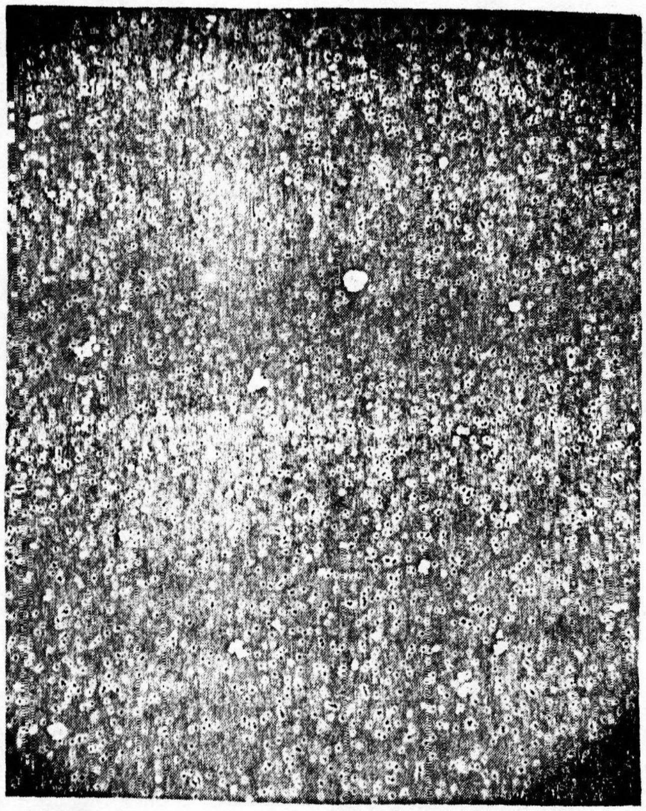
SITE 2 - Combustion & mineral particulate, contains a large fiber of asbestos-like material

SITE 3 - Predominant mineral, some carbon aggregates

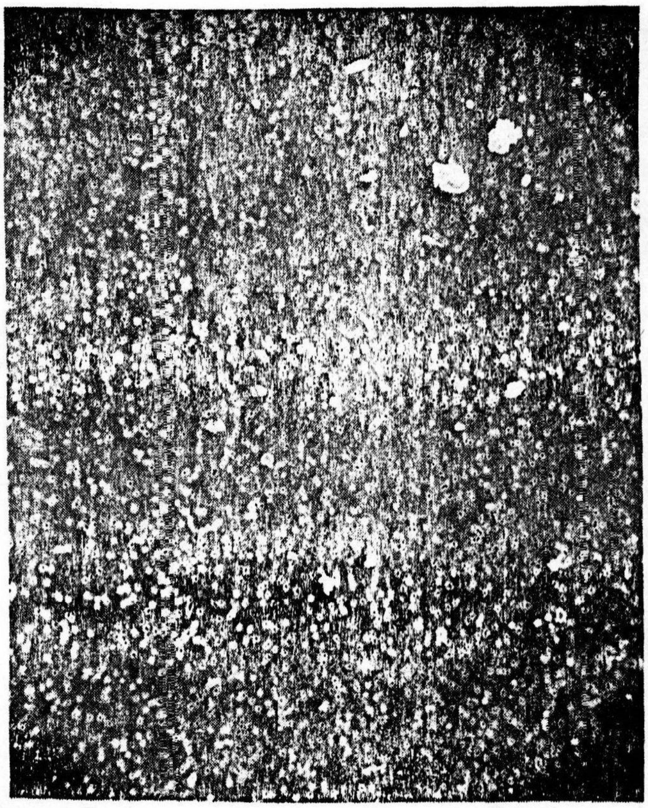
Fig. III.9-EM Micrographs, 210X, July 23, 1975



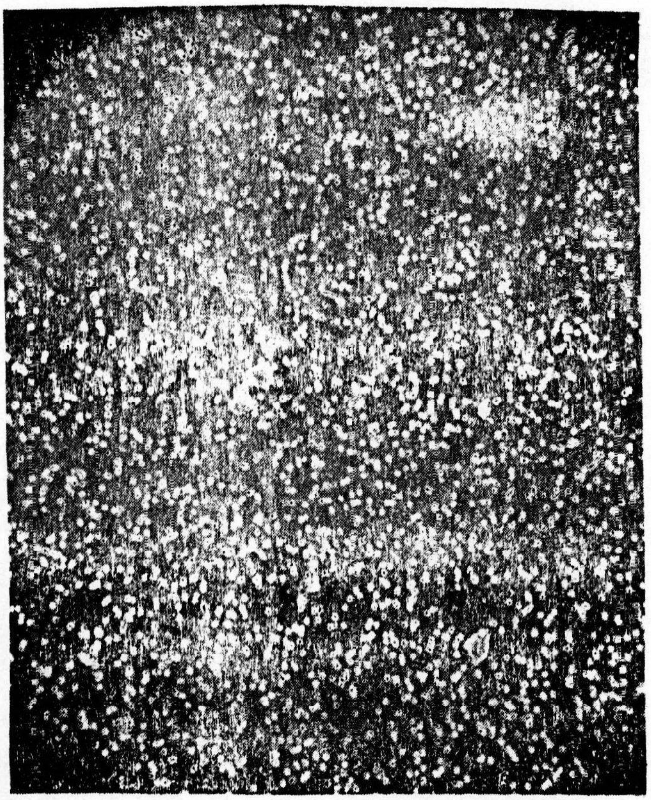
SITE 4 - Predominant mineral with carbon (fly ash) & biological particles



SITE 5 - Clean light mass loading, representative of natural particulate, mineral and biological particles.

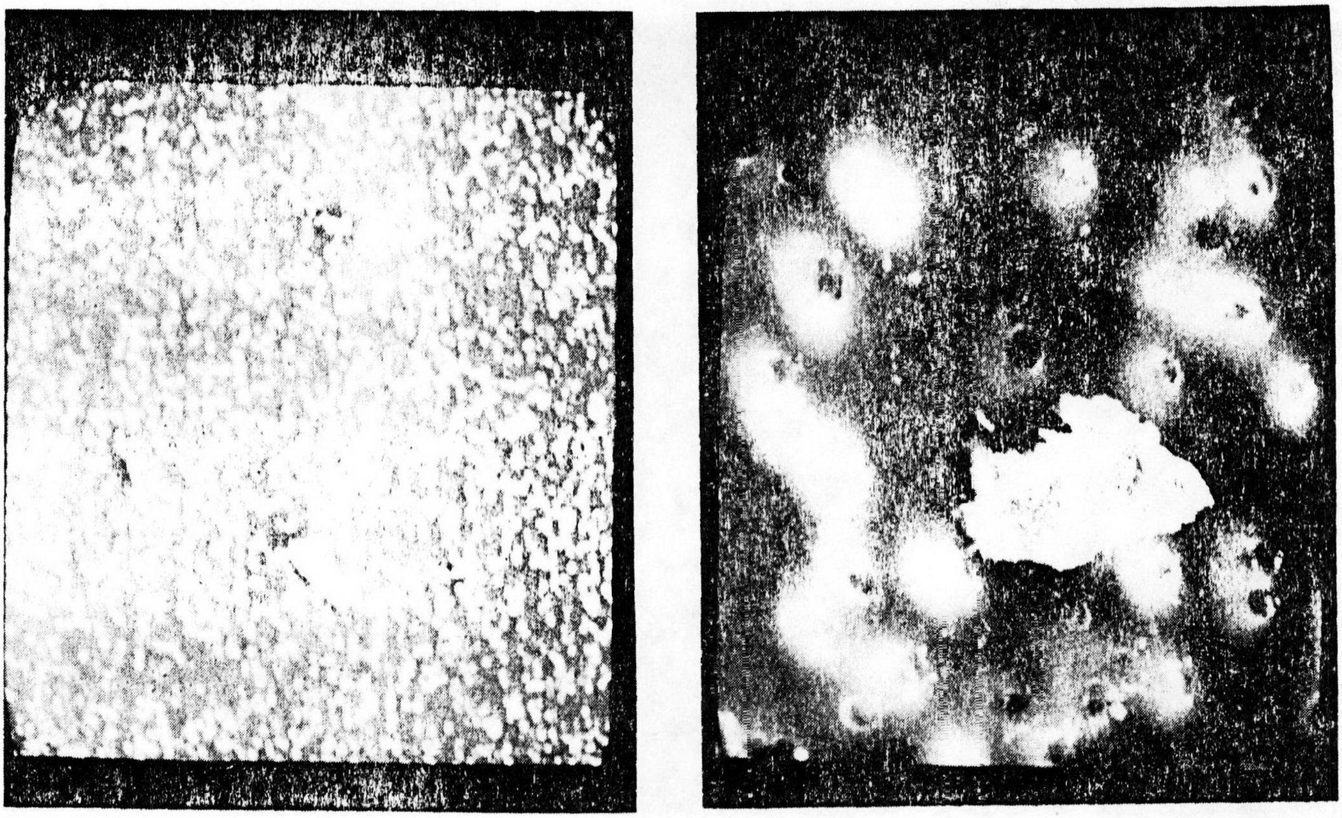


I-70 - Straight Creek, combustion particulate, asbestos-like fiber and biological particle.

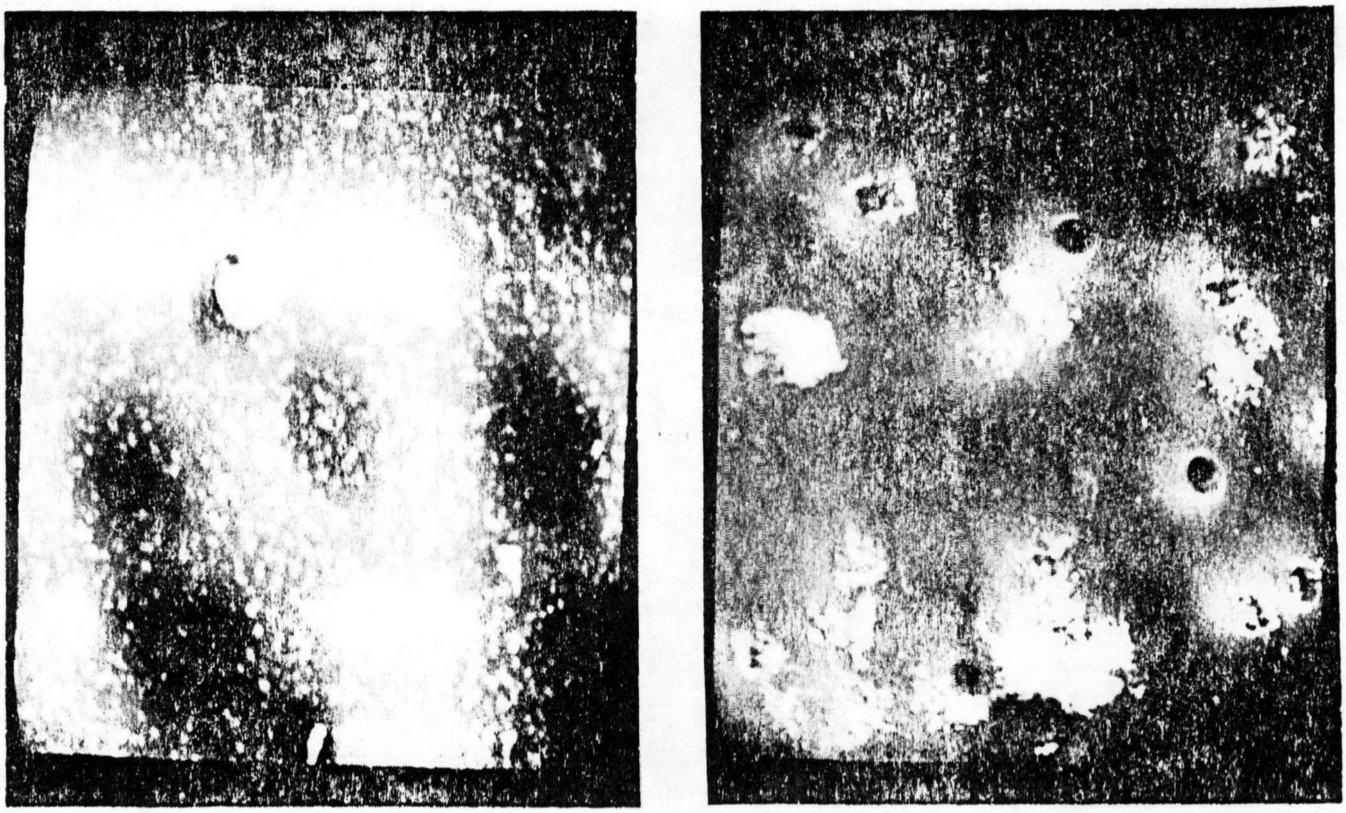


FIELD BLANK - note absence of mineral and carbon particles. Shows light contamination from handling.

Fig. III.10-EM Micrographs, Dec. 30, 1975

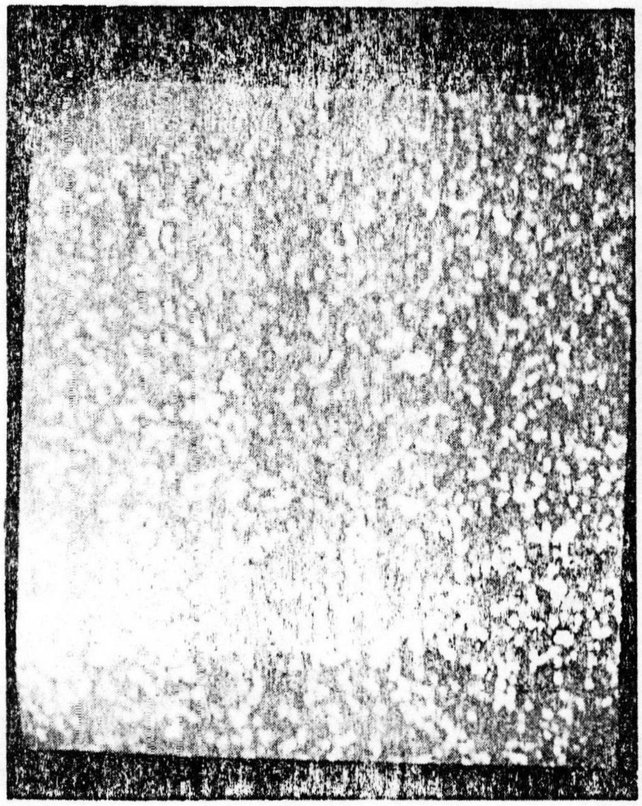


SITE 2 - Silverthorne - left 250x - right 2500x
Predominately organic; note large number of particles around holes and aggregate. Large fly ash particle on right.



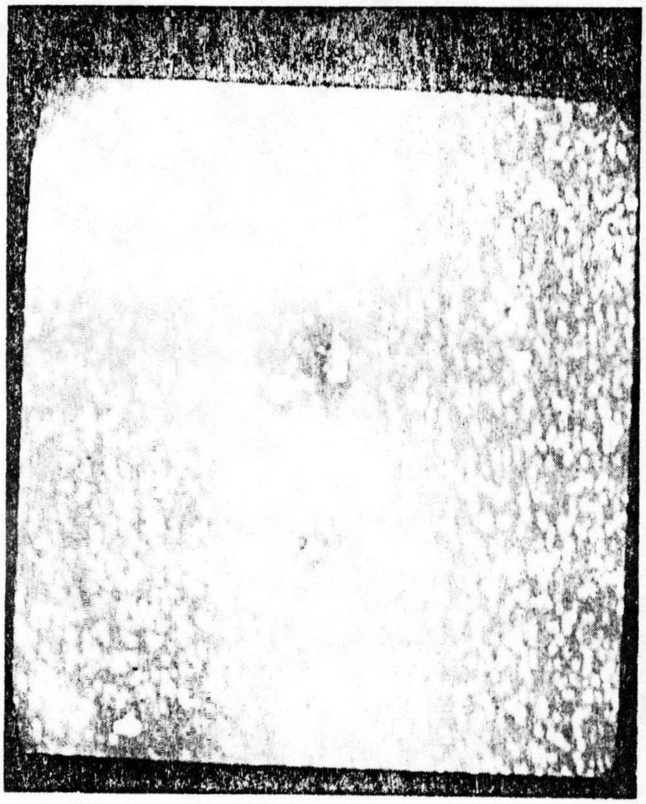
SITE 3 - Breckenridge - left 250 x - right 2500x
Predominately organic, note large particle on left that appears to be aggregate of many small particles.

Fig. III.11-EM Micrographs, Dec. 30, 1975



SITE 4 - Copper Mountain
250x Predominately organic with some fly ash

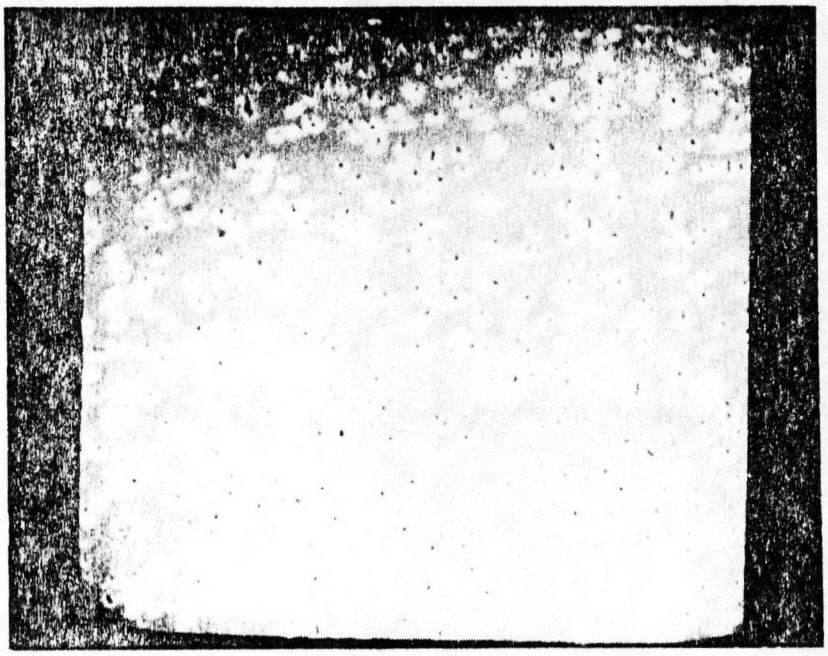
SITE 4 - Copper Mountain
2500 x Clustered aggregate around holes



SITE 5 - Keystone
250x Predominately organic more fly ash than Site 4 small combustion

SITE 5 - Keystone
2500x Predominately organic more fly ash than Site 4 small combustion

Fig. III.12-EM Micrographs, Dec. 30, 1975



SITE 1 - Knorr Ranch
Note absence of particles, some very small particles appear between holes or pores of filter. Compare to field blanks in Figure III.9 at lower magnification.

Micrographs from the winter samples disclose a general tendency for the smaller particles to clump together so that many of the larger particles seen in Figures III.10 through III.12 can be seen to be aggregates of smaller particles. Irregular angular shapes are the rule for summer particles, while rounded (almost spherical) shapes are characteristic of the winter particles. Excluding Site 1, there were on the average 3.4 times as many particles per unit volume in the summer samples as in winter and 2.4 times as much particulate mass per unit volume.

c. Significance of particle data

The data of July 23, 1975, suggest that vehicular traffic is a major contributor of particles along highways in Summit County in summer, since the greatest mass concentrations occurred at sites along I-70, where traffic was heavy. Sites 1, 3 and 5 (all sites away from the major transportation routes have air which is freer of particles than Site 2 at the Junction of SH 9 and I-70 and Site 4 at the junction of I-70 and SH 91.

Particle mass data, microscopic analyses, and x-ray analyses all suggest that the sources of particles in winter at Sites 2, 3, 4, and 5 are of similar strengths and that they are principally combustion processes. Particles in the July 23, 1975, samples have been identified as being asbestos-like fibers. (See Figure III.8.)

Airborne particles are characterisically organic in winter when snow covers the ground. Winter TSP levels, when compared to State and Federal standards in areas of great human activity have reached about 25% of the standard. The organic particle and its relation to health are discussed in Section III.E.

E. Effects of Carbon Monoxide and Particles on Health

1. Carbon Monoxide

Carbon monoxide (CO) is a toxic gas which is produced by incomplete combustion of carbonaceous materials. The best understood biological effect is its combination with hemoglobin (Hb) to form carboxyhemoglobin (COHb), thereby rendering the blood less capable of carrying an adequate supply of oxygen to the body cells, National Research Council (1970). This action results in acute poisoning of more people each year than any other single toxic agent except alcohol, Rose (1969). Further damage to nerve cells caused by oxygen starvation, including brain cells, is permanent, since those cells cannot repair themselves.

When a person is exposed to an increased concentration of CO in the air, the carboxyhemoglobin level in the blood increases. If the ratio of carboxyhemoglobin to hemoglobin reaches a level of 2 to 5 percent, the person becomes detectably affected, although he or she may not be aware of either the CO or its effects, Cobb (1974) and Shulte (1973). Medical authorities are not in agreement on what constitutes a dangerous level, but when a level of 5 percent is reached, it is generally agreed that a persons judgement is impaired and that visual acuity is reduced, Cobb (1974).

For a person suffering from oxygen deficiency because of physical exertion or high altitude, the effects of exposure to CO may occur at lower levels of COHb in the blood or be more severe at a given level. Thus people exercising in Summit County are especially vulnerable to CO exposure. Hence, adhering to statutory standards provides less assurance of protection in Summit County than at sea level. This was verified by the Eisenhower Tunnel Carbon Monoxide Standards Advisory Committee (1974).

2. Particles

Airborne particles vary greatly in size and composition. Particles larger than 5 micrometers (μm) in diameter are less significant physiologically than smaller particles because the lungs are capable of ridding themselves of large particles. Smaller particles are not so readily discharged, however, and it has been shown that tissues extract toxic materials more readily from these, Natusch (1974). These include particles less than 1.0 (μm), all of which are present in some degree in most atmospheric aerosols. Carcinogens, sometimes found among airborne particles, include organic as well as asbestos and glass like substances.

Unless they are inhaled in high concentrations or over a protracted period of time, the probability of ill effects from breathing airborne particles is low. When inhaled in high concentrations, however, particles can cause immediate reactions such as coughing.

3. Air Pollution

In general, health effects of air pollution are not dramatic and usually do not occur after short exposure. Some indicators are: sputum increase associated with respiratory discomfort, pulmonary edema and emphysema, headache and eye irritation. Any of these taken singly may not be perceived by most people, and many are so desensitized from exposure in smoke-filled rooms and dirty, urban environments that they can not detect these physiological warning signs if they encounter them in unexpected places, such as a ski area parking lot.

Air is highly mobile. Consequently, a pollutant entering the atmosphere at one point can spread rapidly and soon envelop a large area. Fortunately it usually becomes diluted as it does so. The dilution process for a valley is discussed in detail in Section III B. Any area which contains pollutant sources and does not have adequate ventilation may experience high pollutant concentrations at times. The most likely such areas in Summit County are those areas along busy highways, particularly those which are in basins. People working in service stations and other roadside businesses and attendants at ski area parking lots are subject to the highest pollution concentrations normally occurring in Summit County. These people should be aware that there are some health hazards associated with the locations where they work.

Concentrations of particles and carbon monoxide in Summit County on two days when human activity was high are given in Table I.1 and in Section III-D. The highest particle concentrations measured were 86 and 49 $\mu gm/m^3$. These occurred in Breckenridge and near the intersection of highways I-70 and State 9 respectively. This three-hour average value is clearly below both the 24 hour Federal and State standards which are listed in Table III 9. Unless particles themselves are particularly hazardous, particle concentration is not now a limiting factor to growth and activity in Summit County. The presence of asbestos-like particles in the summer sample taken at this site and along I-70 are cause for concern, however. If future tests prove that these are commonly found in the air anywhere in the County, the potential for growth and activity in that area should be reassessed.

The highest carbon monoxide concentrations were measured downwind from parking lots at ski resorts on December 30th. An hourly average value of 16.3 ppm was measured at one site. Because traffic in and out of these lots was high for a period of several hours, and because dispersion was poor during that period, it is highly likely that the average for an eight-hour period reached or perhaps exceeded the 8 hour Federal Standard of 9 ppm. Carbon monoxide concentrations were high enough to suggest strongly that CO emissions are already a limiting factor in winter in parts of Summit County. It is probable that parking lot attendants at the ski areas are affected adversely by the CO they inhale on a busy day.

4. Federal and State Air Pollution Standards

Federal and State standards are given in Table III 9. Primary standards are intended to protect public health. Secondary standards are intended to protect the public welfare from any known or anticipated adverse effects of a pollutant. The 1, 8, and 24 hour average values are not to be exceeded more than once per year.

TABLE III. 9

Federal and Colorado Standards for

Carbon Monoxide and Particles

	FEDERAL			COLORADO
	Averaging Time	Primary Standard	Secondary Standard	
Carbon Monoxide	8 hour	9 ppm	Same as	Same as
	1 hour	35 ppm	primary	Federal
Suspended Particles	Annual	75 $\mu g/m^3$	60 $\mu g/m^3$	45 $\mu g/m^3$
	24 hour	260 $\mu g/m^3$	150 $\mu g/m^3$	150 $\mu g/m^3$

SECTION IV

A. Conclusions

Summit County as a whole has good air quality almost all the time. There are a few small areas, however, in which pollutants do accumulate and reach concentrations approaching the statutory limits for undesignated areas. The areas in which this is most likely are associated with ski resorts, urban concentrations, and I-70.

Air pollution is not now a serious problem even in the areas noted above except during periods when atmospheric conditions do not disperse pollutants adequately. These conditions are most likely in winter. They are usually of short duration, occurring during the late night and early morning hours. Occasionally after a major storm has passed through the Rocky Mountain area and winds above the mountain tops are from the north, a long-term, serious pollution episode could develop. Such an episode could involve much larger areas of the County than those few suggested in the last paragraph.

Long-term pollution can be controlled at whatever level is desired by controlling growth and development in the County. Development can reach a higher level if pollutant emissions from all sources are kept as low as possible and if sources are carefully distributed both vertically and horizontally.

During poor dispersion episodes pollution may occasionally have to be controlled for short periods by controlling emissions. Banning fireplace burning for a few hours may be enough in some instances; under extreme conditions it may be necessary to ban all automotive traffic in the County except that essential to health and welfare. The periods during which controls need be used can be anticipated a few hours or perhaps a day in advance by an air pollution meteorologist. They can be identified when they occur by monitoring air quality as suggested in Section 1.D.3.

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APPENDIX A

SAMPLING CO AND PARTICLES IN SUMMIT COUNTY, COLORADO

Calibration Methods, and Interim
Results of Sampling--Summer 1975

October 1975

Interim Report

Submitted to Summit County, Colorado Planning Department

by

AMBIENT ANALYSIS, INC.
1675 Range
Boulder, Colorado 80302

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INTERIM REPORT - SUMMER SAMPLING IN SUMMIT COUNTY

1.0 INTRODUCTION

This report is an update on activities by AMBIENT ANALYSIS, INC. (AAI) for EPA contract number 68-01-3200, Air Quality Impact Statement for Summit County, Colorado. In this document, the results of the summer sampling episode are covered along with a short discussion of plans for remaining work.

2.0 DISCUSSION OF SUMMER SAMPLING

Two major criteria were set up to designate the day on which concentrated sampling would be performed. The first called for a general upslope wind condition near the surface with vertical mixing in the air adjacent to the surface due to convective and mechanical turbulence. This condition was expected on days with temperatures in excess of about 50°F. See section for atmospheric sounding data.

The second criteria called for recreational, weekday traffic density. This was expected to occur on any day that the weather encouraged tourist travel.

The day chosen was Wednesday, July 23, 1975. On this day, a five member team from AAI proceeded to five sampling sites in Summit County. These site locations are shown in Fig. 2.1. Appendix A contains a discription of these sites. Appendix B is an outline of the operational plan utilized on July 23.

Prior to July 23, two members of AAI visited Summit County and made spot checks of CO at various sites. On September 30, another two member team visited Summit County to correlate suspended particulate samples taken by AAI with those of the State of Colorado Hi-volume Air Sampler. Spot CO measurement were also made during this visit.

2.1 Summit County - Weather

July 23 had been chosen for sampling because it was anticipated that the air in the valley would be well mixed and hence that any pollutant released near the surface would soon mix through a deep layer. Weather maps for July 23 show that there was little large scale motion over Colorado and suggest that local circulations dominated.

The day started out nearly cloudless, and visibility was good. The wind in the vicinity of Dillon Reservoir was blowing down the valley during the early morning. By 1100 MDT it was blowing consistently up the valley at Dillon Reservoir. This was the local circulation anticipated. See Table 2.2.

FOR FIG. 2.1, SEE PAGE 3 OF THE REPORT

TABLE 2.2

Meteorological Data by Site - July 23, 1975

SITE 1*

	1040	1055	1125	1220	1300	1315	1340	1415	1445	1500	1515
WD	NNW	NNW	NW	NWW	NW	NW	NW	NWW	NW	NW	NW
WS	4	4	5+	7.5	4	4	4	2	2	4	8-10
T_d	18.9	19.2	21.1	21.7	20.8	-	19.4	-	21.1	-	17.8
T_w	13.1	13.6	13.9	14.3	12.8	-	12.2	-	12.8	-	13.6
%RH	51	53	44	44	38	-	41	-	36	-	63

SITE 2

	1010	1030	1100	1140	1210	1225	1320	1340	1415	1540
WD	W	W	NW	WNW	NW	WNW	WNW	NW	-	WNW
WS	6	7	9	9	8	8	4	7	-	5
T_d	18.9	19.4	20.0	-	20.6	19.4	21.7	22.2	20.6	21.7
T_w	11.1	11.7	11.1	-	10.6	11.1	12.2	11.7	12.2	11.7
%RH	36	37	31	-	24	33	30	24	35	27

SITE 3

	1110	1120	1200	1210	1220	1225	1230	1315	1330	1410	1450	1500	1510	1525
WD	NW	NW	N	NNE	N	-	NNW	NW	NNW	N	NNW	NNW	NNW	W
WS	4	4.5	7	3.5	7	-	7	4	5	6	10	5	3	2
T_d	17.7	-	-	19.3	-	18.2	-	18.9	-	18.4	-	-	16.1	-
T_w	9.4	-	-	10.3	-	9.8	-	9.4	-	9.3	-	-	7.8	-
%RH	30	-	-	30	-	31	-	25	-	25	-	-	27	-

SITE 4

	1050	1100	1150	1220	1225	1315	1330	1345	1355	1415	1455	1500	1520
WD	W	W	W	W	WNW	W	W	W	-	-	W	W	W
WS	9	9	4	7	8	10	11	15	0	0	10	7	10

SITE 5

	1030	1040	1050	1150	1200	1210	1220	1230	1245	1250	1300	1330	1350	1410
WD	SSW	SW	SW	W	W	NW	N	W	WSW	W	SW	W	-	W
WS	7.5	4.5	6.5	8	2.5	5.5	9	9	8.5	4	2.5	5.5	0	6

	1440	1500	1510	1550
WD	SW	NW	-	SW
WS	6	10	0	6

*See Figure 2.1 and Appendix A for site location and description

As the valley floor grew warmer, small cumulus clouds with bases higher than the mountain tops, started appearing over the mountain slopes around the valley. Occasionally one would appear over the valley itself. These cumuli grew in size and number. By mid-afternoon rain was falling from some of them. Occasionally light showers reached the ground here and there, but in many places none fell. Surface winds became gusty in the vicinity of the showers; the wind shifted direction frequently; and dust was carried into the air in places momentarily.

The air in the valley was being mixed about as thoroughly as it ever is. Visibility was excellent throughout the day except in the occasional brief showers. A question arises nonetheless about the mixing mechanism when one attempts to understand the distribution of pollutants in a valley. The following appears to explain the observed circulation in the Blue River Valley on that day.

As the air warmed near the ground, it started moving up the slopes including the valley floor. That motion became well organized by noon. Lapse rates in places became superadiabatic. Vertical air motions were then accelerated and the upward flow formed cumulus clouds. This was most general above the steep slopes near the mountain tops. Although the flow up the valley fed these cumuli continously, they did not appear to interfere with the nearly steady flow along the valley floor. A return flow may have developed over the valley at high levels, but such a flow was not obvious. It seems more likely that the air flowing out of the valley via the cumuli was replaced by inflow at the lower end of the valley. In other words, the valley did not contain a closed circulation on that day, although such closed circulations may occur under some circumstances.

In those places where cumuli formed over the valley itself, the air flowing upward into the cloud had to be replaced by air flowing inward toward the updraft at low levels. That inflow was fed either by generally increased flow up the valley below the cumulus and decreased flow up the valley above it or by general subsidence of the air around the updraft. In either event, the updrafts over the valley (away from the steep mountain slopes) were of fairly limited extent surrounded by nearly horizontal flow of much greater extent.

Although the presence of cumuli and gusty winds indicates vertical air motion and mixing, surface air containing pollutants may move nearly horizontally for long distances before being lifted off the surface. Occasionally, however, the air at a pollutant source may be swept up in a cumulus updraft virtually immediately. Thus, even on a day when mixing is obviously occurring, air in the valley is not homogeneous. Pollutants released near the surface may remain near the surface for many minutes; they are not likely to accumulate in the valley, however.

3.0 SAMPLING AND ANALYSIS

Two chemical parameters were sampled and from two to five meteorological parameters were sampled at each site. (See Table 3.1)

3.1 CO Sampling Techniques

Carbon monoxide (CO) was sampled by two different methods. Mylar bags were used at all five sites to collect grab samples. At sites 2 and 4 real time instruments were also used.

3.1.1 Mylar Bags

Each Mylar bag had an approximate filled volume of 80 liters and was housed in a rigid, air tight container. Evacuation of the bags was accomplished by connecting them directly to a vacuum pump. Filling the bag was accomplished by connecting a vacuum pump to the box and evacuating it which caused the bag to fill with outside air.

Prior to collecting the sample for analysis, the bags were filled and evacuated twice at their respective sites to insure removal of any contamination the bags might have retained from their last use. This procedure also conditioned the interior surface of the bags to the ambient relative humidity, aerosol loading and approximate gas concentrations.

The analytical sample was collected by connecting the box to the vacuum pump with a hypodermic needle.[1] This regulated the flow so that the bag was filled uniformly over a time period of 25 minutes to an hour, providing a time-integrated sample.

The procedures used in the bag sampling were developed at the National Center for Atmospheric Research in Boulder, Colorado.

After all sampling had been completed, each team member proceeded to Site 2 where each bag was analyzed by attaching it to an "Ecolyzer". The bags were again analyzed with the same "Ecolyzer" the next day in AAI's Boulder laboratory where calibration could be carried out under carefully controlled conditions.

3.1.2 "Ecolyzer"

A Model 2800 "Ecolyzer" was used for spot checks on July 11 and September 30 and at Sites 2 and 4 (two instruments) on July 23, it was also used to analyze the bag samples. This instrument operates on the electrochemical oxidation principle for CO detection. For detailed information of its operation and sensitivity refer to references - 2,3,4 and 5.

CO data were recorded on July 23 at Site 2 on a strip chart recorder. Readings at Site 4 were made intermittently by the site operator.

TABLE 3.1

Parameters According to Sampling Sites

Site	Parameter	Method	Duration
1	Carbon monoxide	Mylar bag	59 min.
	Particulates	Nuclepore filters	190 min.
	Condensation Nuclei		Intermittant
	Barometric Pressure		Intermittant
	Temperature	Sling psychrometer	Intermittent
	Relative Humidity	Sling psychrometer	Intermittent
	Wind Speed	"Dwyer wind meter"	Intermittent
	Wind Direction	Magnetic compass	Intermittent
2	Carbon monoxide	Mylar bag	57 min.
	Carbon monoxide	"Ecolyzer"	Continuous
	Particulates	Nuclepore filter	184 min.
	Temperature	Sling psychrometer	Intermittent
	Relative Humidity	Sling psychrometer	Intermittent
	Wind Speed	"Dwyer wind meter"	Intermittent
	Wind Direction	Magnetic compass	Intermittent
	Vertical Wind-temp. Profile	"Tethersonde"	30 min.
3	Carbon monoxide	Mylar bag	53 min.
	Particulates	Nuclepore filter	180 min.
	Temperature	Sling psychrometer	Intermittent
	Relative Humidity	Sling psychrometer	Intermittent
	Wind Speed	"Dwyer wind meter"	Intermittent
	Wind Direction	Magnetic compass	Intermittent
4	Carbon monoxide	Mylar bag	40 min.
	Carbon monoxide	"Ecolyzer"	Intermittent
	Particulates	Nuclepore filter	180 min.
	Wind Speed	"Dwyer wind meters"	Intermittent
	Wind Direction	Magnetic compass	Intermittent
5	Carbon monoxide	Mylar bags	25 min.
	Particulates	Nuclepore filter	180 min.
	Wind Speed	"Dwyer wind meter"	Intermittent
	Wind Direction	Magnetic compass	Intermittent

3.2 Particulate Sampling Techniques

Suspended particulates were sampled by drawing the ambient air through a 3μ pore diameter Nuclepore filter. These filters were tared* and installed in their filter holders prior to departure from Boulder. The open face of the filter holders were sealed during transport and equipment set-up to prevent contamination. (See Fig. 3.2)

To collect the samples, air was drawn through the filters by connecting them directly to the vacuum side of a 12 VDC pump. On July 23 the sampling period for the filters was interrupted at preset times to spread the collection time over a longer, more representative period. The sampling period on September 30 was a little over five hours without interuption.

In addition, to the sample collection filter, a field blank filter was taken to each site for reference. The filters (sample and field blank) were reweighed after returning to Boulder to measure total suspended particles collected. After reweighing, the filters were sent to an independent laboratory to have electron microscope pictures taken. These pictures allow qualitative identification of particle orgin.

3.3 Calibration Procedures

3.3.1 Needle Flowrates (CO)

The flow rates of the needles for CO sampling were checked in Boulder prior to leaving for Summit County. The absolute flowrate was not significant because of the analytical technique employed. That is, we were interested in flow rate only to obtain a uniformly integrated sample over the sampling period. The samples were then analyzed for the mixing ratio of CO to air.

3.3.2 Filter Flowrates

Calculation of particle concentrations required knowledge of the air volume flowing through the Nuclepore filters. These volumes were checked indirectly by measuring ΔP, the pressure drop across the filters at programmed times throughout sampling. (See Appendix B, Sampling Schedules). Volume vs. ΔP was measured as follows after leaving the post-sampling rendevous at Site 2: When an altitude was reached corresponding to the one at which the sample was collected, a duplicate filter and filter holder were hooked to the same pump and battery that were used to collect the sample. The flowrate was then measured using a dry test meter and stop-watch.

3.3.3 "Ecolyzer"

The two "Ecolyzers" were calibrated using a 48 ppm, certified secondary CO standard. Each instrument was calibrated prior to use at the two sites and calibrations were checked after the approximately four hour and forty minute sampling period was concluded. The instrument used to analyze the bags were calibrated prior to each of the two bag analysis periods. A check was also made after analyzing the bags to insure that the instrument span had not drifted.

*Taring (weighing) and reweighing were done on a "Cahn" electro balance

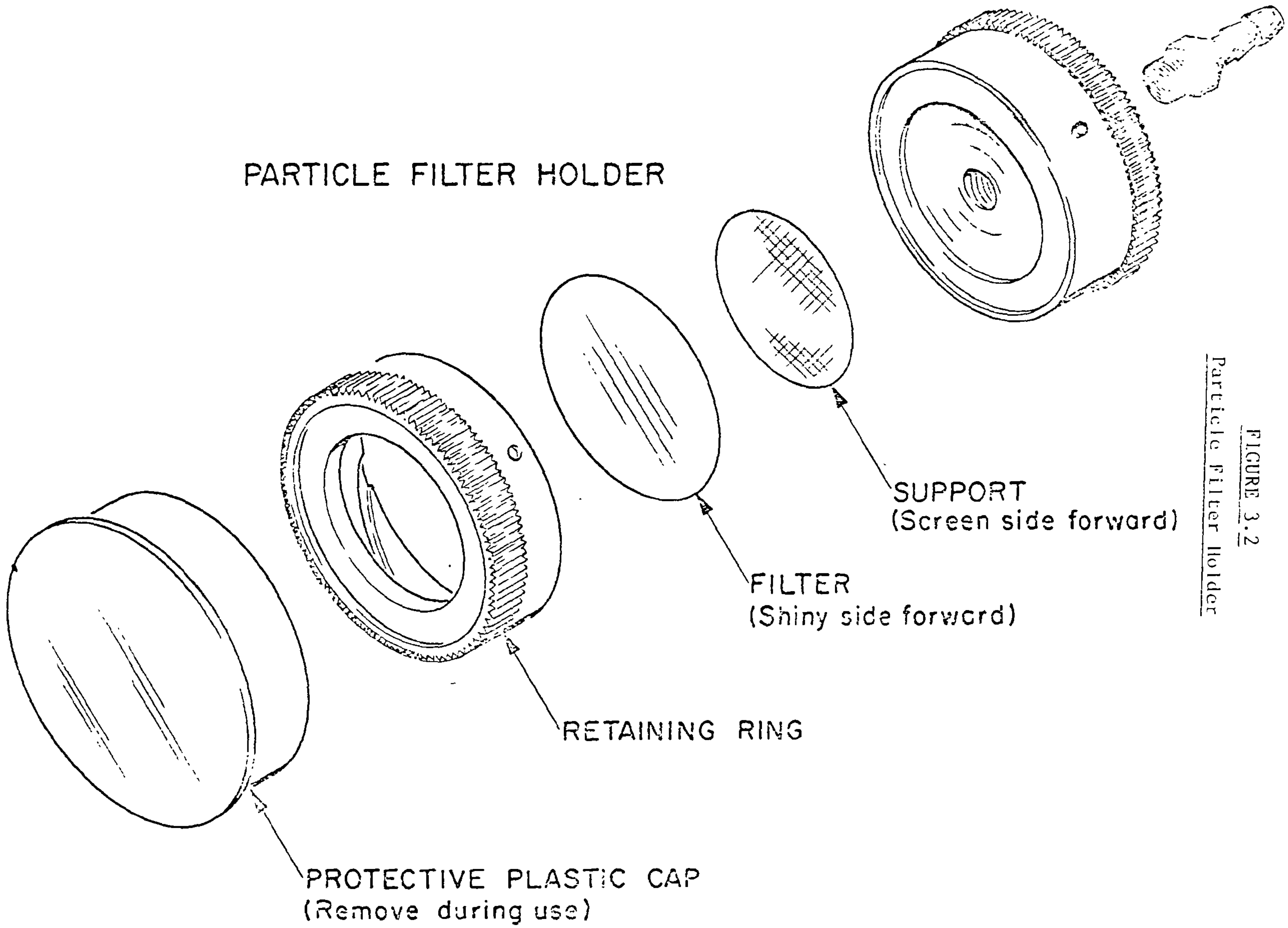


FIGURE 3.2
Particle Filter Holder

3.3.4 Meteorological Equipment

The thermometers, Dwyer Wind Meters, and compasses were not calibrated.

The "TETHERSONDE" sensors were calibrated in a chamber by the manufacturer. They were also checked against ground based sensors to insure proper operation immediately prior to launch.[6]

4.0 RESULTS

The results acquired from the sampling are presented in the following tables and figures:

Table 4.1 - gives the location, time and concentration of CO found at various points in Summit County on July 11, 1975.

Table 4.2 - presents the results of the concentrated sampling effort performed on July 23, 1975.

Figure 4.1 - Tethersonde data of July 23.

Table 4.3 - gives the CO results obtained from a moving car on December 12, 1974 and on September 30, 1975.

Table 4.4 - gives the size distribution of the total suspended particles (TSP) for July 23 and spot measurements of condensation nuclei particles (CN).

Figure 4.2 - scanning electron microscope pictures of Summit County particles.

4.1 Discussion of Table 4.1 and Sampling July 11

These data were gathered with the "Ecolyzer" in the car. The intake tube was extended out of the window.

During the stay at the Copper Mountain parking lot, two Mylar bags were filled with ambient air samples and later analyzed by NDIR at Coors laboratories. The results from Coors for each of the bags stated that CO concentrations were less than 10 ppm.

4.2 Discussion of Table 4.2

Carbon monoxide and total suspended particulate results are shown in Table 4.2. The data are consistent with other baseline data already collected in Summit County. (See Site Location Report 1975)

Baseline mass loading for non-urban continental U.S. has been estimated at 37 micrograms per cubic meter ($\mu g/m^3$). The measurements from which this average mass loading was dveloped were made with High Volume filter devices most of which are located near urban centers. It is possible that results are skewed toward higher mass loading because of the sampling locations. There is also a possibility of bias due to location (on top of building) and the method of determining mass loading.

TABLE 4.1

Spot Carbon Monoxide (CO) Concentrations Found at Various Points
Summit County, Colorado - July 11, 1975

Site	Time	ppm CO*
Driving west on I-70, East side of tunnel at 10,000 ft.	0900	9-10
Just entering east end of tunnel		30
Center of tunnel		50
About to leave west end of tunnel		45
3/4 mile west of tunnel		10
Holiday Center (Frisco)	0915	4
Frisco Town Hall	0922	3
Summit County health offices (outside)	0930	2 - 3
Highway west of Frisco	1300	4 - 8
Parked by road west of Frisco - traffic heavy and fast	1313	2-10
Following a string of slow moving cars in Ten Mile Canyon	1320	40-55
Following a string of cars - road wider, traffic faster (alt. 9711)	1322	6
Copper Mountain	1326	<2
Copper Mountain parking lot	1415	<2
Silverthorne Interchange and Dillon Straight-Creek	1530	20-75
Entering tunnel heading east	1540	55-70

*ppm CO - parts per million by volume of CO

TABLE 4.2

Carbon Monoxide (CO and Total Suspended Particles (TSP) Concentrations found at Five Sampling Sites in Summit County, July 23, 1975

Site*	ppm CO	TSP (μg/m3)
1-(Knorr Ranch)	0.5	14
2-(Intersection I-70 and Highways 9 and 6)	1.5	49
3-(Breckenridge)	0.5	16
4-(Copper Mountain)	1.0	37
5-(Keystone)	<0.5	13

Continuous CO Concentrations taken at Site 2 (Hourly Averages)

	Time	ppm CO
Site 2 (Intersection I-70 and Highways 9 and 6)	1000+	2.2
	1100	0.9
	1200	0.8
	1300	1.9
	1400	1.4
	1500	0.8
	Mean	1.34
	Standard Deviation	1.98

*See Figure 2.1 and Appendix A - sampling period approximately 1 hour each site.

+The maximum observed five minute mean value was 11.7 ppm CO.

TABLE 4.3

CO Concentrations found at various points in Summit County, Colorado

December 12, 1974*

Place	Time	ppm CO Avg.	ppm CO Max.
Silver Plume	-	<2	-
Tunnel	1040	25	50
Straight Creek	-	<2	7
Ten Mile & Copper Mountain	-	3	5
Vail Pass	-	3	5
West Vail	1150	3	18
Vail Covered Parking	1200	6	-
West Vail	-	7.5	-
Vail Pass (Trailing Traffic)	-	15	40
Copper Mountain	1230	3	-
Frisco	1242	5	15
Enroute Breckenridge	-	<2	-
Breckenridge	-	3	10

*Cloudy, cold and snow showers

September 30, 1975*

Place	Time	ppm CO Avg.	ppm CO Max.
Silver Plume	0930	2	40
Tunnel	0940	40	55
Straight Creek	-	<2	30
Dillon Interchange	-	<2	-
Frisco	-	2	-
Ten Mile (Heavy Traffic)	1410	25	50
Vail Pass (Heavy slow traffic)	1434	10	35
West Vail Pass (In construction traffic stop and start)	-	5	150
Straight Creek	-	5	-
Tunnel	1915	40	75

*Well ventilated sunny day

TABLE 4.4

Size Distribution of TSP by Site (Particles/Filter)

Site	Sample Volume (m^3)	<1.0 μm	1-10 μm	>10 μm	Total Particles
1	4.62	1.4×10^6	1.8×10^6	8.3×10^4	3.3×10^6
2	4.67	6.1×10^6	2.4×10^6	1.7×10^5	8.7×10^6
3	3.74	2.8×10^6	2.0×10^6	1.9×10^5	5.0×10^6
4	3.47	2.8×10^6	1.4×10^5	2.4×10^5	4.4×10^6
5	4.23	1.3×10^6	1.1×10^6	6.9×10^4	2.5×10^6

Spot Measurements of Condensation Nuclei (CN)/cm^3

Place	7/11/75	7/23/75	9/30/75
Eisenhower Tunnel	$>10^6$cn/cm^3	$>10^6$cn/cm^3	$>10^6$cn/cm^3
Dillon/Silverthorne	1.10^5cn/cm^3	3.10^5cn/cm^3	6.10^4cn/cm^3
Vail Pass	1.10^4cn/cm^3	---	$>10^6$cn/cm^3
Knorr Ranch (Site 1)	---	*4.10^3cn/cm^3	---

*average from 1100 to 1500 hours

On any given day in Colorado, the wind will usually blow strongly enough for some period to cause larger particles with more mass to become entrained in the air flow. Hi-Vol data are the result of extended sampling times and will therefore include high mass loading periods. Authors of aerosol studies in northern Colorado have remarked at the absence of large numbers of particles in the size range >0.15μ in comparison to aerosol studies near urban centers.[7] The data from Table 4.3 can be contrasted with those collected in August, 1975. Differing conditions may account for the lower mass seen on the samples in July 1975 compared with August 1974. Harvest and haying had taken place in August 1974 and not in July 1975. Wind was generally stronger in 1974 than in 1975 and visible dust was observed then, in contrast to sampling on July 23.

4.2.1 Gravimetric Analysis

Analytical precision for the filter weights on this study (1975) was about ± 20 μg in contrast to ± 10 μg in (1974). This can be explained by the different instrument being used for gravimetric analysis. Flow was calibrated carefully and volume measurement should be considered accurate. These data are characteristic of a very clean day in Summit County and should serve to contrast with worst dispersion characteristics to be sampled this winter.

4.2.2 Site Specific Interpretations

Size distribution was fairly uniform for all sites except number two. Site 2 was representative of average downwind characteristics to be expected from a large highway intersection. This site also had the only asbestos-like particles observed for this sampling period.[8] Site 4 also shows the effect of mixed downwind flow from a major highway and the size distribution show a greater distribution in particles greater than 10 microns that the other site. Site 5 was relatively clean, indicative of the low vehicle traffic near the site. See Fig. 4.2 for photomicrographs of particles collected at some sites.

4.3 Interpretation of Boundary Layer Data from the Tethersonde Sounding

The Tethersonde sounding data in Fig. 4.1 illustrates clearly that the air was well mixed--

The lapse rates during both ascent and descent were nearly adiabatic.

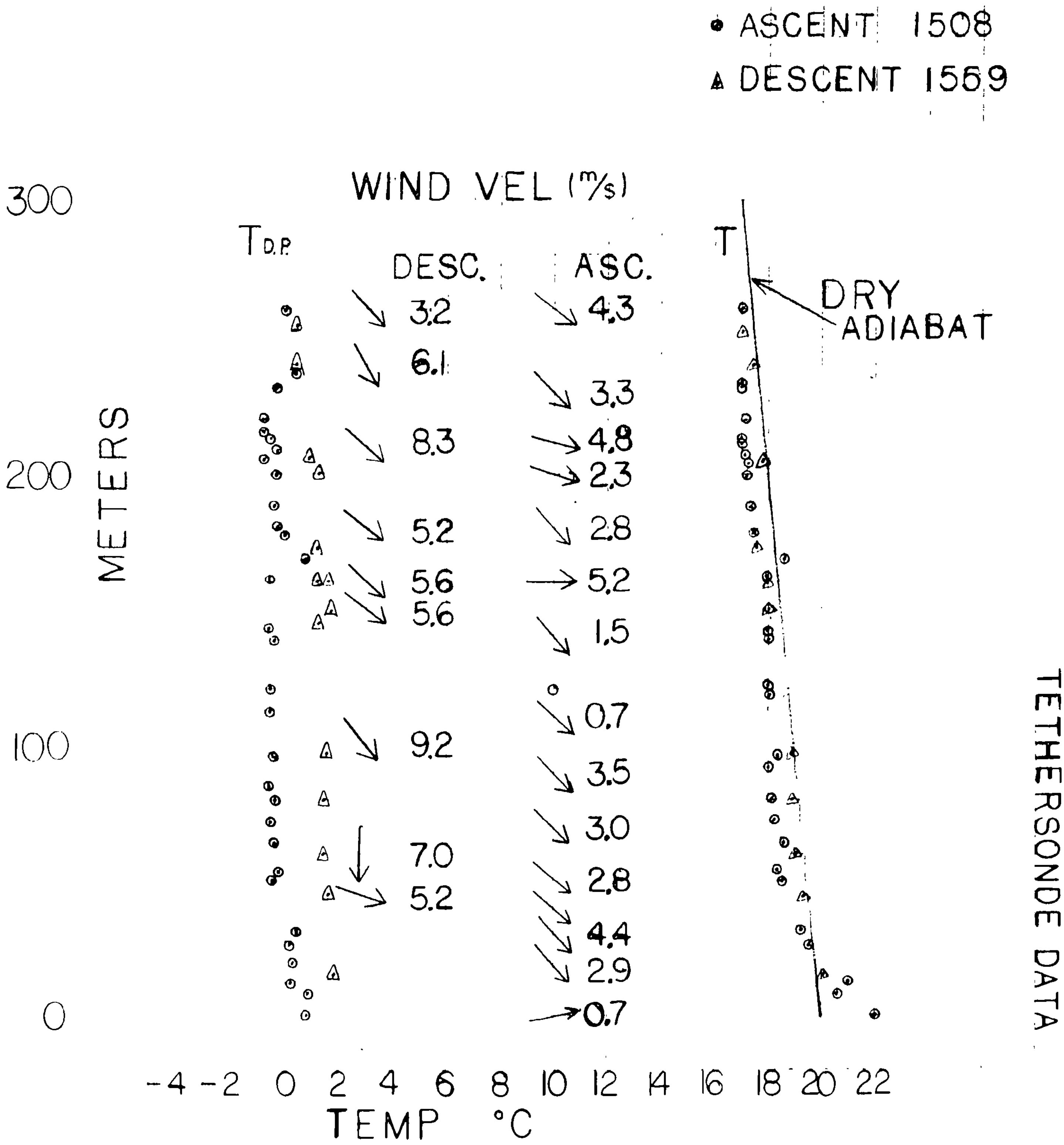
The dewpoint lapse rate was nearly zero during both ascent and descent.

The winds showed no systematic increase in speed with height, suggesting that the normally stronger winds from aloft were mixing downward.

The air was in general dry--the difference between temperature and dewpoint temperature being about 20°C near the surface. This suggests that with thorough mixing the clouds bases should have been found at about 2000 m above the surface. That would place the cloud bases at about 6,500 ft. above the site or about 2,000 ft. above the surrounding mountain tops. They were indeed observed to have been well above mountain top level.

FIGURE 4.1

Vertical Profiles of Dewpoint, Temperature, Wind Direction and Velocity



Pages 16 and 17 are included in the body of the report as pages 48 and 49.

4.4 Discussion of Tables 4.1, 4.2 and 4.3

These Carbon monoxide values were determined in the same manner as was used on July 11 (Table 4.1). That is, the "Ecolyzer" was in the car with the intake tube outside the window.

Data from July 11 were characteristic of highway concentrations encountered in December 1974 except for the measurements from Silverthorne up Straight Creek to the Eisenhower Tunnel. The atmospheric dispersion was relatively good on this day and though traffic was heavy around 1500 an average 40 ppm was unexpectedly high in route to the tunnel. Presumably, the organized flow up the creek was serving to concentrate emissions from the highway as well as any pollutant entrained throughout the county.

Table 4.2 shows a correlation between total particle mass loading and carbon monoxide concentrations. These values are comparable to data collected in August 1974. They will serve as ample reference to compare to winter data.

Table 4.3 documents concentrations taken in two different seasons and adds to the data baseline for later reference. Comparison of these data may be difficult because of inadequate VMT data. Liaison with the State Highway Department is ongoing in order to develope traffic documentation to correlate to the meteorological and chemical data.

5.0 FUTURE WORK

AAI has one major task yet to accomplish to complete the work called for in this contract for Summit County.

This is the winter sampling operation scheduled to take place sometime in November or December 1975. During this operation, sampling comparable to that performed during the summer at the same sites (if appropriate) will be done.

Any site location change recommendation will be communicated to Summit County and the EPA Project officer.

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APPENDIX B

Air Quality Study, Site Location Report
Summit County - June 1975

SITE 1

A site 350 meters south of Highway 9 on the Knorr Ranch in the northern part of Summit County has been selected. It is situated in a hayfield between Squaw Creek on the east and Brush Creek on the west. The terrain slopes gently toward the north at the site, which is located in a nearly horizontal basin approximately three miles in diameter. In upslope flow, air from the north will flow over Green Mountain Reservoir and through an appreciable depth. Well-organized downslope flow will carry air from most of the county over the site if the flow endures long enough. This flow will occur when the air is hydrostatically stable, and although air motion near the surface will be slightly turbulent, motion at higher levels is likely to be very nearly laminar. In general emissions from a high source will pass over the site at a higher level than emissions from a lower source.

The net effect at this site could be an elevated stratum containing a relatively high concentration of carbon monoxide. Localized motion down the sides of mountain ranges, i.e., the Continental Divide to the northwest and Gore Range to the southwest, is not expected to "wash" the site with cleaner air from higher elevations.

SITE 2

This site was selected to show general emissions from the major transportation arteries. It is located near the intersection of I-70 and Highways 9 and 6. The site will be placed south of I-70 for upslope or good dispersion measurements and north to be downwind for the poor dispersion analysis. The site will be about 300 meters from the highway to avoid short-term concentrations associated with traffic bursts and local turbulence which might obviate a representative test. The ground slopes downward to the northwest to the Blue River below Dillon Dam, and then the terrain climbs steeply to the Gore Range. This is one of the broadest valley areas in Summit County. To the south the dominant topographic feature is Dillon Dam and Reservoir. To the east I-70 alters the Straight Creek drainage with a sharp grade to the Eisenhower Tunnel. The terrain slopes upward from the Blue River to the west and southwest toward Frisco and Ten Mile Canyon. During downslope, air will include pollutants that are emitted in every part of the county from Wheeler Junction to the southwest, Breckenridge to the south, Keystone and Swan Mountain developments along the Snake including Dillon, and Straight Creek to the east. Elevation at the upslope site is 8790 feet ASL.

The major pollutant source will be automobile and truck traffic and associated dust-producing activities in the summer. Winter air pollutants are expected to contain the by-products of space heating, in addition to the sources mentioned above. Upslope air motion over this area should be fairly clean, containing some emissions from a relatively small number of dwellings and rural ranching activity to the north. A power plant near Green Mountain Reservoir and Heeney did not unduly influence sulfur dioxide concentrations during an upslope condition analyzed in August 1974. Cumulative effects from energy-related activities to the northwest of Summit County are not expected to influence carbon monoxide and particle concentrations materially at this location.

SITE 3

Site 3 is located near the south end of the county at an elevation of 9,578 in Breckenridge. The site is located at the north end of the tennis courts, across a street south from a parking lot which serves a small supermarket and some other shops. The Blue River flows northward about 50 meters to the east of the site. The valley is not wide here and the terrain slopes steeply upward both east and west of the river. Since the valley is deep and relatively narrow here and is oriented in a north-south direction, it will frequently be isolated from the westerly flow which prevails above the mountain tops.

This site was selected to obtain data representative of a typical urban community. Sites 1, 2 and 3 were all used for measurements under good dispersion in August of 1974, when samples were collected simultaneously under upslope, turbulent flow. Carbon monoxide concentrations at Breckenridge were about four times the concentrations at Site 1. An interpretation of this is that the approximate 1 ppm in Breckenridge constitutes a cumulative addition from combustion emissions four times that of background or baseline, as represented at Site 1. Analysis of other pollutants support the observation that Site 1 was indeed at or near background levels, especially when compared to other data of near geochemical background concentrations. Data collected support the concept of selecting a site near the south end of Summit County to provide a measurement of carbon monoxide accumulated in organized air movement up the valley during upslope flow. Downslope conditions will require a site north of town to be representative of the community. If the objective should be one of obtaining clean air to serve as reference, however, the site should be located south of town so that clean air from higher reaches is sampled before emissions are accumulated. Coose Pasture Tarn at a height of 10,000 feet might be an acceptable site. Summit County planning and project management personnel will be consulted on these potential Site 3 locations before fall and winter sampling. No decision is needed for the summer sampling operation.

SITE 4

A survey has been conducted for Site 4 in the vicinity of the Copper Mountain ski area. While a representative downslope flow in Ten Mile Canyon must include contributions from both Ten Mile Creek and West Ten Mile Creek, the recommended site will be west of Wheeler Junction, far enough to avoid the confluence of the two flows. A site in a major parking lot about one-half to one mile west of Wheeler Junction seems most appropriate for both upslope and downslope conditions. The terrain slopes steeply upward to the ski slopes to the south; the rise to the west is more gradual. The valley floor has a modest slope downward to the north and east toward the creeks. Beyond the creek to the north it rises slowly to the level of U.S. 6, beyond which the canyon wall rises precipitously.

Major influences on carbon monoxide and particle concentration are expected to be the highway and the automotive activity, fireplaces, etc. in the immediate vicinity. Westerly flow (downslope) will be more prevalent at this site than at any of the other sites because the valley is oriented in an east-west direction, down which the prevailing westerlies will flow. When flow is from the west the highway construction on Vail Pass and at the eastern end of Eagle County will serve as a pollutant source due to localized controlled burning and a high level of vehicle traffic. When flow is not from the west, the major source of carbon monoxide and particles will be from local recreational activity and highway traffic. Wintertime flow will be predominately downslope.

SITE 5

Air quality measurements on the eastern side of the county will be made near the Keystone Ski area, probably in a parking lot. This area adjacent to Highway 6 and the Snake River is in a large valley bordered on the east by the Continental Divide. Torreys and Grays Peaks, with elevations in excess of 14,000 feet, are at the head of the valley. In this east-west oriented valley, the prevailing synoptic westerly winds enhance upslope winds on the valley floor and oppose downslope flow. Also upslope flow along the Blue River will almost always be accompanied by upslope in this area. Downslope from adjacent slopes will occasionally influence the results in the winter season for Site 5.

Pollutant concentrations will be greatest at this site on a cold winter night when winter sports activity is great and the synoptic westerly winds are just sufficient to overcome the local valley wind.