

# “WHEN THE DUST SETTLES” YEAR 2 – A MULTIVARIABLE STUDY OF THE PATTERNS OF NEAR AND FAR DISPERSAL OF WINDBLOWN PARTICULATE MATTER

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**ABSTRACT:** What are dispersal patterns of windblown dust into adjacent and mountain snowpack? This question arose from concern about increased aerosol particulate matter (PM) due to drought and rapid natural gas development in Wyoming.

“When the Dust Settles” continued previous research on effects of PM on snow. PM Collections used passive PM collectors to evaluate effects of distance and height on PM dispersal. Natural PM Deposits compared effects of distance from heavily used dirt roads on PM dispersal into adjacent snow and PM mass, reflectivity, and melt rate. Melt rates were compared to Modeled Ice Blocks. Mountain Snow Collections evaluated mountain snow’s PM.

Five hypotheses were evaluated. Horizontal and Vertical PM Collector data showed that at lower, upper, and ground levels, as distance from sources increased, PM mass decreased. Natural PM Deposits data showed that as distance from sources increased, PM mass deposited in adjacent snowpack decreased. Both Year 1’s Models and Natural PM Deposit samples showed that when PM was added to snow and ice, reflectivity decreased which caused melt rate to increase. Deposited material, including PM and vegetation, was found in both mountain sites; definite matches to origins of PM have not yet been confirmed.

This investigation proved that PM is dispersed in specific patterns from heavily used dirt roads. PM carried by winds at various heights above the ground is deposited into snowpack of adjacent lands. Additionally, PM was found in mountain snowpack. Increased PM was proved to cause increased melt rate of snow and ice, which will result in faster loss of snow earlier in the spring, leaving even less soil moisture for summer months.

These results emphasize the need to monitor PM sources such as highly used dirt roads and devegetated areas due to widespread dispersal patterns of PM in snowpack “When the Dust Settles.”

**KEYWORDS:** particulate matter, dispersal, snowpack, melt rate, water supply

## 1. INTRODUCTION

Air quality is a major component of environmental concerns globally. One of the important contributors to decreased air quality is haze, made up of aerosol particulate matter (PM). PM can originate from multiple sources such as chemical pollution, dry devegetated areas, and highly used dirt roads (Figure 1). Bare soils produce minute particles of soil which can become aerosols that are transported by prevailing winds into snow pack of adjacent basins and mountains.



Figure 1. PM Dispersal series taken on dirt road of Pinedale Anticline, the Mesa.

In the western United States, there is a drought which has caused many areas to become drier and dustier, with loss of vegetation and decrease in snow pack in critical areas (Figure 2). Locally, in addition to the drought conditions, there is a booming development of natural gas. There are two major gas fields, the Jonah Field and the Pinedale Anticline, also known as the Mesa. This natural gas development requires many miles of dirt roads and many acres of well pads. Both roads and well pads are devegetated and contribute to an increase of PM.



Figure 2. Sagebrush basin and high mountain snow packs are critical for soil moisture and water supply.

Throughout the world, there are multiple examples of plumes of aerosol particulate matter (dust) blowing long distances. African dust from the Sahara Desert has been found in the ice pack of both Greenland and Antarctica. Plumes of Middle Eastern dust from Iran have been photographed by satellites blowing into the Mediterranean Sea. In the Rocky Mountains, dust from western Utah has been photographed blowing to the Wasatch Range, and dust from the Colorado Plateau has been found in the San Juan Mountains.

With increasing concern about air quality in Southwest Wyoming, research about PM has been initiated, which led to more specific investigation about effects and dispersal patterns of PM.

“When the Dust Settles – Year 2” is a continuation of Year 1’s previous study on the effect of PM on reflectivity and melt rate of snow and ice. The intent of the Year 2 project was to focus on the dispersal patterns of PM from heavily used dirt roads into snow pack of adjacent lands and high mountain ranges.

## 2. QUESTIONS AND HYPOTHESES

2.1 Question 1: Does the distance from an active particulate matter source and the height above the ground affect the dispersal of particulate matter by wind?

Hypothesis 1A: For the lower level dispersal, as the distance from the source increases, the mass of the particulate matter will decrease.

Hypothesis 1B: For the upper level dispersal, as the distance increases, the mass of the particulate matter will increase.

2.2 Question 2: What are the effects of distance from an active particulate matter source on the amount of particulate matter deposited in the snow pack adjacent to the source?

Hypothesis 2: As the distance from an active particulate matter source increases, the mass of the particulate matter deposited in the snow pack will decrease.

2.3 Question 3: Are the effects of particulate matter naturally deposited in snow pack similar to those observed in controlled models?

Hypothesis 3: If particulate matter is deposited naturally in snow pack, then the reflectivity and melt rate of the snow pack will be similar to the controlled models.

2.4 Question 4: Is there particulate matter deposited in the snow pack of the Wind River Mountains?

Hypothesis 4: If snow is collected from sites along the Wind River Mountains, Southern sites will have particulate matter originating from southern sources closer to development, and Northern sites will have particulate matter originating from northern sources.

## 3. METHODS

### 3.1 Short Distance PM Dispersal Experiment

- Study sites were adjacent to heavily used dirt roads of the Mesa on public land managed and permitted by the BLM (Figure 1)
- Build PM collection apparatus: 20 cm x 28 cm plywood boards with adhesive paper, attached on PVC pipe uprights at 150 cm and 300 cm as Upper and Lower Vertical Collectors; secure to ground the 20 cm plates as Horizontal Collectors at base of each pipe (Figure 3)
- Establish 2 trials of transects, upwind and downwind of PM source, parallel to prevailing winds; set collectors at 0, 4, 8, 12, 16, 32 m, along transects; place Control site upwind 250 m (Figure 3)
- During PM collection, also measure environmental conditions every 30 minutes: wind speed (kph), humidity (%), and temperature (C)
- Remove PM collection apparatus after 278 vehicles have passed (4 hrs)
  - Seal and label each adhesive paper and plate set in separate bags
  - Measure mass; then calculate net mass of PM (Figure 3)



Figure 3. Setting up PM collection apparatus, and later measuring mass of PM collected in trials

### 3.2 Natural PM Deposit Experiment

- Study sites were adjacent to heavily used dirt roads of the Mesa on public land

managed by the BLM, with adjacent snowpack

- Establish transects, 16 m upwind and 16 m downwind from source of PM blown into adjacent snowpack, set up 4 trials
- Collect 10 cm x 10 cm x 2 cm snow block samples along each transect at 0, 4, 8, 12, and 16 m (Figure 4)
  - Combine sets 1 and 2, and freeze for Ice Blocks Experiment
  - Combine sets 3 and 4 for Evaporation Experiment
- Natural PM Deposit – Ice Blocks Experiment
  - Place ice blocks from sets 1 and 2 in baskets on clothesline
  - Measure net mass, reflectivity, and environmental conditions every 20 min until completely melted (Figure 4)
  - Calculate melt rate of blocks from increasing distances from source with varying masses of PM
- Natural PM Deposit – Evaporation Experiment
  - Melt and evaporate samples from sets 3 and 4
  - Measure mass of dry samples, to calculate net mass of PM from increasing distances from source (Figure 4)



Figure 4. Collection of Dirty and Clean Snow Blocks along road, with measurement of melt rate, and evaporated net mass of PM.

### 3.3 Deposition of PM in Mountain Snow Pack Experiment

- Collect snow samples from high mountain meadows (Figure 5)
  - Northern site: White Pine Ski Area
  - Southern site: Irish Canyon
  - Excavate snow from 0.5 m x 0.5 m snow pits, to just above ground depth into clean bags (Figure 6)
- Melt snow, decant water, evaporate, and calculate net dry mass of PM deposits (Figure 6)

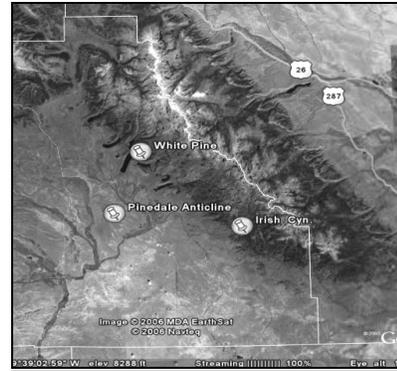


Figure 5. Study sites of Pinedale Anticline, the Mesa, just west of the Wind River Range's high mountain sites for collecting mountain snowpack.



Figure 6. Collecting snow from pits at high mountain sites, and later decanting the melted water from the settled PM to speed evaporation.

## 4. DISCUSSION OF RESULTS

### 4.1 Summary of Results

Hypotheses 1A and 1B compared the effects of distance from the particulate matter (PM) source and height above the ground, on the mass of airborne PM settling on the collector surfaces. Hypothesis 1A was supported by both the Horizontal and Vertical PM Collector data, showing that at lower heights and ground level, as the distance from the source increased, the mass of the deposited PM decreased. Hypothesis 1B was not supported, because at the upper heights, as the distance increased, the mass of the deposited PM increased slightly, and then decreased, rather than increase, as hypothesized.

Hypothesis 2 compared the effect of distance from the source on the mass of PM settling on the snow pack. The data supported this hypothesis, showing that as the distance from the source increased, the mass of the PM deposited in adjacent snow pack decreased. In addition, the data showed that as the amount of PM that was naturally deposited in snow pack increased, reflectivity decreased, which caused melt rate to increase.

Hypothesis 3 compared the reflectivity and melt rate of snow pack with naturally deposited PM to the reflectivity and melt rate of Year 1's controlled snow and ice dust loaded models. Year 1's data proved that when PM was added to snow and ice, the reflectivity decreased, which caused the melt rate to increase. The current research followed the same patterns. The higher the mass of PM found in the evaporated snow samples, the lower the reflectivity and the higher the melt rate in the collected samples. Therefore, Hypothesis 3 was supported by the similar results of the controlled models and the naturally deposited samples.

Hypothesis 4 compared PM deposited in snowpack from sites along the Wind River Mountains. Deposited material, including PM and vegetation, was found in both mountain sites; however, definite matches to origins of PM were not confirmed. Therefore, Hypothesis 4 was neither supported nor denied.

#### 4.2 Discussion of PM Collection Experiment

The PM Collection Experiment compared the mass of airborne particulate matter (PM) deposited at increasing distances from the source and at different heights in an outdoor, natural environment, along both sides of a heavily used dirt road: a Control Site outside of PM area, Horizontal Collectors, and Upper and Lower Vertical Collectors. Data from two sites on two trial days were averaged for analysis. (Figure 7)

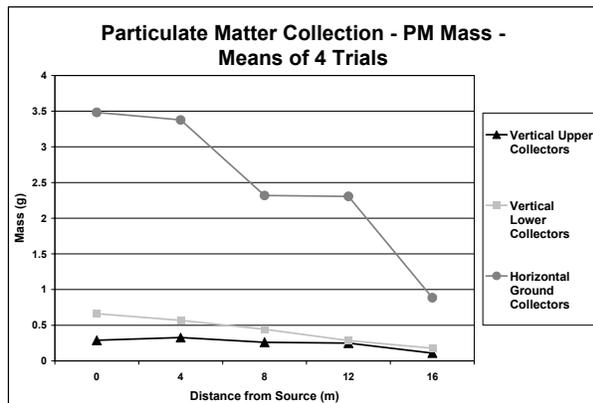


Figure 7. All Collectors showed PM deposited from 0-16 meters.

The Horizontal Collectors were flat plates attached to the ground. The trend line for the ground layer collectors showed the most PM deposited at 0 meters (m) and 4 m from the source, with slightly less deposited at 8 m, an increase at 12 m, then decrease further at 16 m and 32 m from the source. At this ground level, by 32 m from the road, the deposited PM mass was

close to the Control's mass taken outside of the PM influences.

The Vertical Collectors were vertical adhesive papers attached to upright 3.6 m pipes. There were two papers on each pipe, the Lower at 1 m and the Upper at 3 m above the ground.

The trend line for the Lower Vertical Collectors showed the most PM collected at 0 m and 4 m from the source, with a steady decrease of PM mass at 8 m, 12 m, and 16 m. Specifically, the average started at 0.65 g, and then showed a gradual decline to 0.58 g at 4 m, 0.45 g at 8 m, 0.25 at 12 m, and 0.1 g at 16 m from the source. The 16 m mass was very close to the Control of 0.0 g outside of the PM influence area.

The trend for the Upper Vertical Collectors showed 0 m collecting less PM than 4 m, and then 8 m, 12 m, and 16 m steadily decreasing in PM collection. At the individual collection sites, these Upper Collectors showed only a slightly arching trajectory pattern of the wind blown PM as it left the source and arched upward. In more detail, at 0 m the average started at 0.25 g, and increased in a slightly arching trajectory pattern to 0.38 g at 4 m. The Upper Collectors' trajectories then decreased from 4 m to 8 m at 0.25 g. At 12 m from the source the collection remained at 0.25 g, and then dropped to near 0.1 g at 16 m., very near the Control of 0.0 g.

The Upper and Lower Vertical collectors proved there was a difference in PM dispersal patterns at different heights. The more massive particles were not able to become highly airborne, and therefore they were deposited more on the Ground Horizontal and the Lower Vertical collectors, as shown by the larger PM masses found at 0 m and 4 m from the source. In contrast, the Upper Verticals collected less than half that mass at 0 m and 4 m.

Hypothesis 1A was supported by both the Horizontal and Vertical Collector data, showing that at lower heights and ground level, as the distance from the source increased, the mass of the deposited PM decreased. Hypothesis 1B was not supported, because at the upper height, as the distance increased, the mass of the deposited PM increased slightly, and then decreased, rather than increase, as hypothesized.

#### 4.3 Discussion of Natural PM Deposit Experiment

The Natural PM Deposit Experiment compared the effect of distance from the source, a heavily used dirt road adjacent to snow covered sagebrush, on the snow samples' PM mass, reflectivity, and melt rate. The four trial sets of snow that were collected included samples (200

square centimeters each) at 0 m, 4 m, 8 m, 12 m, and 16 m from both the prevailing downwind and upwind sides of the road. The downwind side's snow was visually much dirtier with more PM, so was titled the "Dirty Snow Samples", while the upwind side's visually cleaner snow was titled the "Clean Snow Samples". Two trial sets of snow collections were evaporated, and the net mass of PM was measured. This mass data for two sets was averaged for analysis of mass differences. The other two sets of snow collections were used in the Reflectivity and Melt Rate Experiment.

When evaporated for net dry mass of PM, the Dirty Snow PM showed similar results as the PM dispersal in the Lower Vertical and Horizontal PM Collectors Experiments. As the distance from the source increased, the PM mass decreased. At 0 m on the Dirty side from the source, the PM mass in the snow plot was 13.12 g. The next Dirty snow plot at 4 m had a large decrease in mass to 3.48 g, and continued to decrease gradually over the next 2 plots. However at 16 m from the source there was a slight increase in mass. The calculated trend line showed a strongly negative slope from 0 m to 16 m from the source.

In contrast, the Clean Snow PM net dry mass had a low starting mass at 0.57 g at 0 m, and continued to have low PM masses from 0 m to 16 m. The Control was the cleanest sample available, at 16 m from the source on the clean side, with a PM mass of 0.06 g. The calculated trend line showed a much more gradual, slightly negative slope from 0 m to 16 m from the source.

The reflectivity data was taken over the 4-hour melting period, and was averaged for each sample. In Year 1, reflectivity was shown to typically decrease as PM mass increased, because the darker PM material absorbed the light, rather than reflect it back. In contrast, the cleaner samples have less PM, so more light is reflected because there is less dark material for absorption of light.

The Dirty Snow at 0 m from the source, with a PM mass of 13.12 g, averaged 161 foot candles (fc). At 4 m from the source the mass decreased to 3.48 g and the reflectivity increased to 171 fc. As the distance increased from the source to 8 m, 12 m, and 16 m, the PM masses decreased and the reflectivities increased, ending at 0.74 g and 188 fc.

The reflectivity of the Clean Snow at 0 m, with a PM mass of 0.57 g, averaged 191 fc. At 4 m from the source the Clean Snow PM mass decreased to 0.27 g and the reflectivity atypically decreased to 190 fc. However, then as the distance increased from the source to 8 m, 12 m,

and 16 m, the PM masses decreased and the reflectivity more typically increased, ending at 0.06 g and 199 fc.

Mass change of the melting blocks was measured every 20 minutes over the time of melting. The slope of each line showing mass changes over time was calculated. These lines' slopes were then compared to show the differences in melt rate of sites at varying distances, and thus varying PM masses, from the PM source. The samples from the Dirty Snow at 0 and 4 m from the PM source showed the steepest slope (fastest mass change), while the Clean at 12 and 16 m showed the flattest slope or slowest mass change. All of the samples slopes are compared in Figure 8.

Melt rate was calculated as grams of the ice and PM block lost per minute (gpm) over the 4-hour test period. As the volume of each sample was the same (200 sq cm), the mass differences were due to varying amounts of PM in each sample. Figure 9 shows the melt rate averages.

The melt rate of Dirty Snow from the 0 m sample, with PM mass of 13.12 g, was 0.62 gpm. At 4 m from the source the mass decreased to 3.48 g and melt rate decreased to 0.54 gpm. As the distance increased from the source to 8 m, 12 m, and 16 m, the PM masses decreased and melt rates decreased, ending at 0.74 g and 0.35 gpm.

The melt rate of the Clean Snow from the 0 m sample, with PM mass of 0.57 g, was 0.42 gpm. At 4 m from the source the mass decreased to 0.27 g and melt rate decreased to 0.29 gpm. As the distance increased from the source to 8 m, 12 m, and 16 m, the PM masses decreased and melt rates decreased, ending at 0.06 g and 0.27 gpm. On the Clean Snow sampling sites, it is evident that the smaller masses of PM did not cause as much change in the reflectivity, mass change, and melt rate over the 4-hour test period.

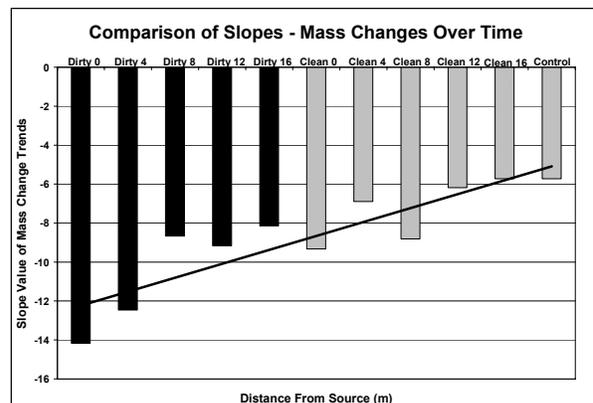


Figure 8. Comparison of melt rate slopes.

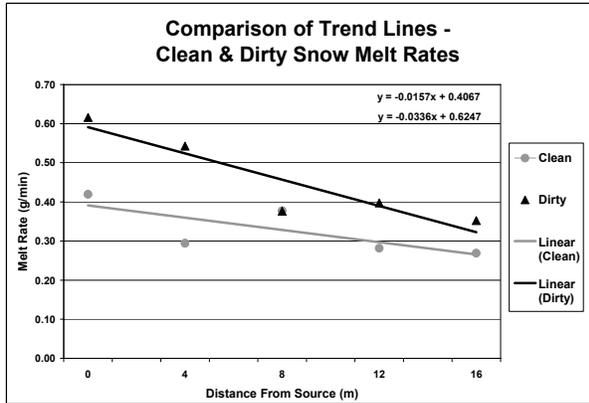


Figure 9. Melt rate data from clean and dirty snow, showing an increase in melt rate when PM mass deposits increased closer to the road.

Hypothesis 2 compared the effect of distance from the source on the mass of airborne particulate matter settling on the snow pack. The data from both Clean and Dirty Snow samples supported this hypothesis, showing that as distance from the source increased, the mass of PM deposited in adjacent snow pack decreased. In addition, the data showed that as increasing amounts of PM was deposited in snow pack, the reflectivity decreased, causing the melt rates to increase. (Figure 10)

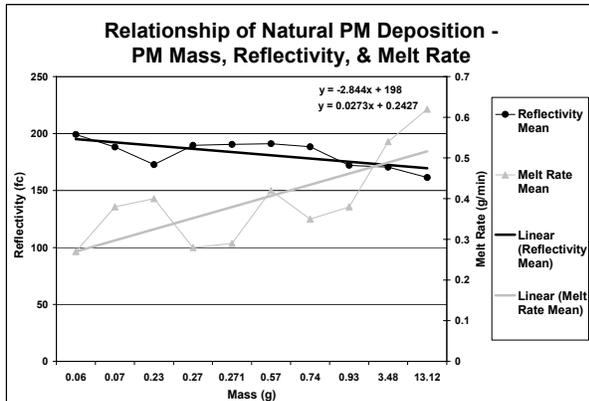


Figure 10. Naturally deposited PM had enough mass at 0-16 m from the road to lower reflectivity and consequently raise snow melt rate.

#### 4.4 Discussion of Natural PM Deposits versus Controlled Models Experiment

The Natural PM Deposits versus Controlled Models Experiment compared the reflectivity and melt rates of Year 1's Controlled Models of PM Loaded Ice Blocks with this year's Naturally Deposited PM in Snow Pack Samples. Two sets of Dirty and Clean Snow collections were melted and refrozen into ice blocks with their naturally occurring amounts of water and PM. These

blocks were placed into the same baskets and outdoor location as Year 1's Ice Blocks Experiment. As in the previous research, the reflectivity, mass change, and environmental conditions were measured at even time intervals until the blocks melted to 0 g.

For this comparison, one Clean Natural and one Dirty Natural sample were chosen to compare to the Models. The Clean Model was compared with the Cleanest Natural Deposit at 16 m from the source. The Dirty Model was compared with the Dirtiest Natural Deposit at 0 m from the source. Year 1's Models' melt rate was calculated from mass change and time, and then compared to this year's Natural Deposits' melt rate. (Figure 11)

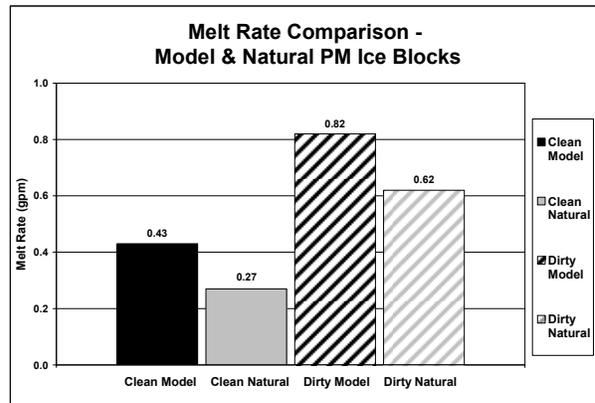


Figure 11. The models and natural showed similar melt rate patterns.

The Clean Model reflectivity was 307 fc, while the Dirty Model was lower at 120 fc. The Clean Natural reflectivity was 199 fc, and the Dirty Natural reflectivity was also lower at 161 fc. In general, the reflectivity of models and natural occurrences were similar. There was a wider span of difference between the Models than the Naturals, because the Clean Model was pure tap water, and the Dirty Model was heavily loaded with 66 g of PM.

The Clean Model melt rate was 0.43 gpm, and the Dirty Model melt rate was 0.82 gpm. The Clean Natural melt rate was 0.27 gpm. The Dirty Natural melt rate was 0.62 gpm, again approximately twice the melt rate of the Clean. The Models and Natural Deposits were closely matched in this doubling of rate of Dirty samples over Clean.

Hypothesis 3 compared the reflectivity and melt rate of snow pack with naturally deposited PM to the reflectivity and melt rate of Year 1's controlled snow and ice dust loaded models. Both Models and Natural PM Deposit Samples showed that

when PM was added to snow and ice, the reflectivity decreased, which caused the melt rate to increase. Therefore, Hypothesis 3 was supported by the similar results of the Controlled Models and the Natural Deposit samples of Clean and Dirty Snow.

#### 4.5 Discussion of Mountain Snow Pack Deposition Experiment

Collections of snowpack were made at locations along the Wind River Mountains. Four snow pits (0.5 m x 0.5 m x down to just above ground level) were excavated. Both Northern (White Pine) and Southern (Irish Canyon) high mountain locations at approximately 8,400 feet elevation were sampled. After melting the snow and decanting the clear water, PM from the four collections was put together for analysis (Figure 12 and Figure 13).

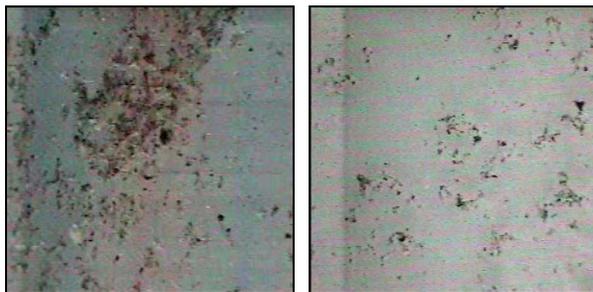


Figure 12. Evaporated snow pit samples from mountain snow pack showed PM photographed through a microscope. Left: Southern site at Irish Canyon. Right: Northern site at White Pine.

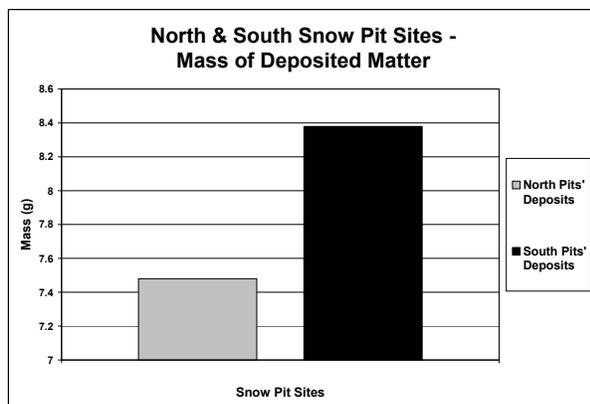


Figure 13. The Southern snow pit site showed a higher mass of PM than the Northern site.

Hypothesis 4 was neither supported nor denied. Deposited material, including PM and vegetation, was found in both mountain sites' four pits, which evaluated a total of 5 m<sup>3</sup> of snow. The Southern site had more total deposited material at

31.2 g, than the Northern site at 30.3 g. Definite matches to the origin of specific types of the PM were not yet confirmed by geochemical analysis.

#### 5. CONCLUSION

Air quality is a major component of environmental concerns globally. Aerosol PM is a contributor to haze, decreasing air quality, and secondary effects when it is deposited in snow pack. Locally in addition to drought, there is a booming natural gas development. This development requires many miles of highly used dirt roads and many acres of well pads, which add to an increased amount of aerosol PM.

This investigation proved that PM is dispersed in specific patterns from heavily used dirt roads. The PM is being carried by winds at various heights above the ground, and then deposited into snow pack of adjacent lands. Additionally, the results showed the presence of PM in mountain snow pack. Increased PM was proven to cause increased melt rate of snow and ice, which will result in faster loss of snow earlier in the spring leaving even less soil moisture for the summer season.

The results also prove likelihood of faster loss of snow in sagebrush areas of the Mesa and Jonah Field, due to dust concentrations proven to be settling in snow pack. This could multiply the drought problem because dust loaded snow melts at an increased rate and earlier in the spring, leaving less soil moisture for the summer season. There is potential for decreases in the grass type vegetation between the sagebrush that requires more soil moisture, which in turn will affect forage in wildlife habitat.

The results prove potential for faster loss in the spring of winter snow pack from the mountains due to particulate matter found in high mountain snow pack.

These results emphasize the need to use dust control on highly used dirt roads and devegetated areas because of the widespread dispersal patterns of PM that occur "When the Dust Settles."

#### 6. IMPROVEMENTS AND EXTENSIONS

The main problem occurred with the PM Collection Experiment. The adhesive paper did not continue to collect PM throughout the whole experiment due to the environmental conditions which dried out the paper. This could be improved by investigating alternative adhesives, or sources for vacuum air filters to enhance accuracy of PM collection and mass analysis.

An improvement to the Mountain Snow Pack Deposition Experiment would be to increase the number and geographic spread of snow pits excavated, melted, and evaluated. This could display PM from a larger variety of sources, and show more of a dispersal pattern in mountain snow pack.

We would like to extend and continue the project:

1. Investigate funding sources for vacuum air filters to enhance accuracy of PM collection and mass analysis.
2. Conduct an analysis of particle sizes deposited at distances from source.
3. Conduct geochemical analysis on the PM found in mountain snow pack to analyze the origin of PM.
4. Test PM in the mountain snow pack during different time periods; fall, winter, spring and compare PM amounts and origin.

#### 7. ACKNOWLEDGEMENTS

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