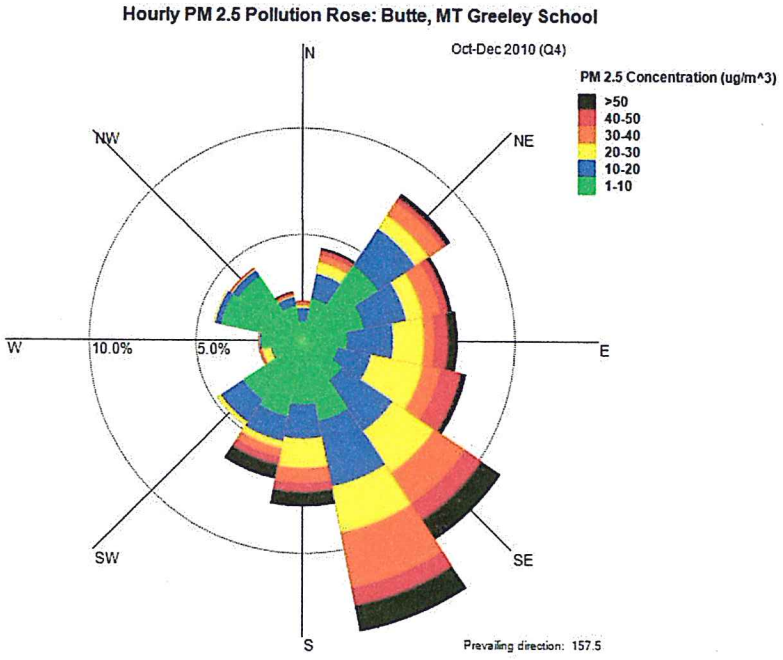
An Assessment of Ambient Particulates in Butte, Montana



Submitted to: The Air Quality Section of the Butte-Silver Bow Health Department

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EXECUTIVE SUMMARY

Particulate concentration data in Butte was evaluated to understand the trend of particulate matter less than or equal to 10 micrometer diameter size (PM_{10}) and 2.5 micrometer in diameter size ($PM_{2.5}$) with respect to wind direction at the Greely School monitoring site in Butte. In addition, $PM_{2.5}$ data from several satellite temporary monitoring sites were analyzed to understand the distribution of $PM_{2.5}$ across the Butte Valley. Also five specific metal contents in $PM_{2.5}$ were evaluated from samples collected from Greely School site. This study was funded by the Air Quality Section of the Silver Bow County Health Department in Butte, Montana.

The PM_{10} data from 1993 to 2012 was analyzed to understand the particulate trend in Butte over the years. The annual average PM_{10} levels since 1993 was steady at 20$\mu g/m^3$ until 2000. A small decline occurred in the concentration between 2001and 2004, reaching a lowest concentration of 14$\mu g/m^3$ in 2002. The PM_{10} levels showed increasing trend from 2005 peaking at 32$\mu g/m^3$ in 2007 and becoming steady between 2008 and 2012 at about 29$\mu g/m^3$. The maximum hourly concentration of 162$\mu g/m^3$ of the PM_{10} occurred on September 15, 2012. The PM_{10} trend indicated an increase of about 10 $\mu g/m^3$ or 30% during the last five years compared to the PM_{10} levels during 2000.

The $PM_{2.5}$ data for the Greely School was analyzed using different averaging times. In general, the $PM_{2.5}$ concentrations at the Greely School site were lower during the second quarter compared to the first quarter (Jan-March) and fourth quarter (Oct-Dec). However, a 24 hour (daily) maximum of 100.6$\mu g/m^3$ was observed on September 15, 2012. This event being in summer, could be attributed to contributions from sources other than residential wood burning, could be from forest fire, long range transport, and yard burning and other sources. The 24 hour $PM_{2.5}$ Design Value for 2010, 2011, and 2012 for Butte were 38$\mu g/m^3$, 38$\mu g/m^3$ and 34 $\mu g/m^3$. These Design Values can be directly compared to the NAAQS of 35$\mu g/m^3$. Thus, the 24 hour $PM_{2.5}$ levels exceeded the Federal $PM_{2.5}$ 24 hour standards in 2010 and 2011 in Butte. However, the annual average design values for these three years respectively 9.8, 9.6, and 8.9 $\mu g/m^3$, were below the annual NAAQS standard of 12$\mu g/m^3$.

Up to eight additional monitoring sites were established on a temporary basis to measure $PM_{2.5}$ levels across the Butte Valley to compare with the Greely School site $PM_{2.5}$ concentrations. In summary, it appears that during winter times the Greely School $PM_{2.5}$ levels can be twice as higher than the Butte valley $PM_{2.5}$ averaged over all sites. The $PM_{2.5}$ pollution rose also indicated that the wind direction influencing the $PM_{2.5}$ was different in each site based on the available data. During winter months the Greely School site has predominant wind and associated $PM_{2.5}$ from SE and E directions.
The metal content in the $PM_{2.5}$ samples from Greely School site for 2010-2012, was less than 0.2 ug/m3 for all five metals; arsenic, cadmium, copper, lead and nickel. The metal content was also compared to results from a background site in Sieben Flats near Helena, Montana. The results showed no major differences between two sites however, the Butte site had slightly higher levels than Helena site except nickel. Nickel values in Butte $PM_{2.5}$ were either less than or almost equal to the background nickel levels.

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1.0 Introduction

This study is sponsored by the Silver Bow County Health Department's Air Quality Division. Air quality data in Butte is evaluated to understand the trend of particulate matter less than or equal to 2.5 micrometer in diameter size ($PM_{2.5}$) with respect to wind direction. The main focus of this project is to evaluate particulate concentration levels and the distribution of $PM_{2.5}$ in Butte using the existing air monitoring data for particulates. The air monitoring site in Butte is located at the Greely School.

This study analyzed the changes in PM_{10} and $PM_{2.5}$ particulate concentration by monthly and quarterly for the past three years, 2010-2012, from the Butte particulate data. Additionally wind data for the same period is also analyzed to interpret the particulate concentrations in different seasons. The particulate concentration distribution across the Butte Valley was also evaluated using the data from eight satellite existing monitoring sites established recently to represent the Butte air shed in addition to the Greely School site. The analysis of data from these sites provided an evaluation of particulate concentration variation across Butte Valley.

2.0 Project Description

The particulate concentration in ambient air for the Butte study involved six specific tasks. The first task was to evaluate three years of PM_{10} particulate concentration for Butte. The second task was to evaluate the wind data along with the $PM_{2.5}$ data for the Greely School site with the available data for three years from 2010 to 2012. The third task was to evaluate the E-BAM data from seven to nine satellite sites in the Butte valley to compare the $PM_{2.5}$ levels with the Greely school site levels. The task four was to conduct a speciation evaluation of five metals contained in the $PM_{2.5}$ particulate matter in the Greely School site and a background site near Helena Montana. This study used the data being collected by the Montana Department of Environmental Quality and the Butte Silver Bow County Health Department.

3.0 Particulate Matter 10 Micrometer Size Data Analysis (PM10)

In 1987, EPA replaced the Total Suspended Particulate (TSP) air quality standard with a PM_{10} standard. The PM_{10} standard was focused on particles that are likely being responsible for adverse health effects because of their ability to reach the lower regions of the respiratory tract. The PM_{10} standard includes particles with a diameter of 10 micrometers or less (0.0004 inches or one-seventh the width of a human hair). EPA's health-based national ambient air quality standard for PM_{10} is 50 $\mu g/m^3$ as an annual mean and 150$\mu g/m^3$ as a 24 hour mean concentration not to be exceeded more than once per year on average over three years. However, in 2006 the PM_{10} annual average concentration standard was dropped and the PM_{10} 24 hour standard of 150$\mu g/m^3$ was continued.

Major concerns for human health from exposure to PM_{10} includes: effects on breathing and respiratory systems, damage to lung tissue, cancer, and premature death. The elderly, children,

and people with chronic lung disease, influenza, or asthma, are especially sensitive to the effects of particulate matter. Acidic PM_{10} can also damage human-made materials and is a major cause of reduced visibility in many parts of the U.S. However, fine particles (equal to or smaller than 2.5 micrometers in diameter) were known to cause serious adverse health effects by having the ability to reach deeper part of the lungs. As a result, EPA set a new standard for particulate matter less than or equal to 2.5 micrometers in diameter, $PM_{2.5}$. The $PM_{2.5}$ standard was recently revised in 2012 to reflect the serious health problems proven to be associated with $PM_{2.5}$. The new $PM_{2.5}$ primary standard for annual three year running mean value shall not exceed $12\mu g/m^3$. While the 98 percentile 24 hour average $PM_{2.5}$ for a three year running average shall not exceed $35\mu g/m^3$. The Montana Department of Environmental Quality and the Butte Silver Bow Health Department adapted the Federal US EPA standards. Therefore, the bottom line for any community is to maintain the PM_{10} and $PM_{2.5}$ particulates below these set standards. Once the PM levels exceed the standard then the local, state and federal agencies have to work together to develop plans and strategies to comply with the standard.

4.0 PM_{10} Particulate Analysis for Greely School Site

The PM_{10} data from Greely School in Butte was analyzed for three years from 2010 to 2012. The data was evaluated in a time resolution of daily (24 hours), monthly, quarterly and annual basis. In addition, PM_{10} data from year 1993 to 2012 was also analyzed to understand the trend of PM_{10} on an annual average concentration levels.

4.1 PM_{10} Analysis of Annual Average Concentration

The analysis of the annual average data from 1993 to 2000 showed that for the first eight years the concentration was steady at $20\mu g/m^3$. From 2001 to 2004 there was a small decline in PM_{10} concentration $14\mu g/m^3$ being the lowest in 2002. From 2005 onwards, the PM_{10} concentration showed increasing trend and in 2007 the peak concentration was $32\mu g/m^3$. Again the PM_{10} concentration was steady at $29\mu g/m^3$ between 2008 and 2012. There was almost an increase of $10\mu g/m^3$ of PM_{10} concentration in Butte during 2007 to 2012 compared to PM_{10} levels of 1993 to 2000. The trend indicates that in recent years there is almost a 30% increase in PM10 in Butte area. The PM_{10} annual average data for 1993 to 2012 is presented in Figure 1.

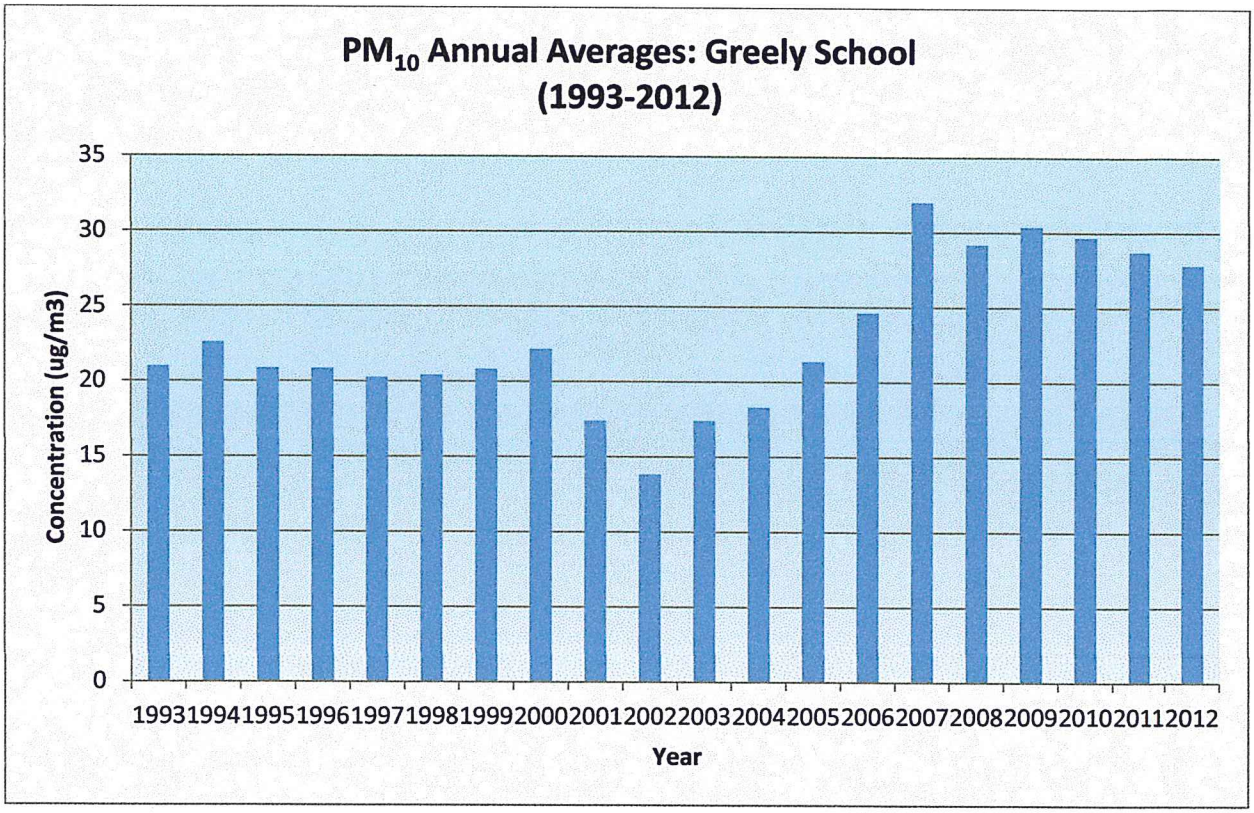


Figure 1: PM_{10} Annual Averages from Greely School Site (1993-2012)

4.2 PM_{10} Analysis of Quarterly Average Concentration

The PM_{10} data analysis (based on four quarters; January-March (1st), April-June (2nd), July – September (3rd) and October-December (4th)) showed that the second quarter has the least number of samples that exceeded the concentration of 40 $\mu g/m^3$. The 40$\mu g/m^3$ level was chosen as an arbitrary value for the purpose of relative comparison for the quarterly data. During the second quarter only 2.3% of the time the PM_{10} concentration exceeded the 40$\mu g/m^3$ but for the first quarter it exceeded 31 % and in the third quarter 39 % and in the fourth quarter 28%. That is, during the months of July to September there was maximum number of concentrations above 40$\mu g/m^3$. In year 2012 during the summer quarter (3rd quarter) the 24 hour concentration was as high as 162$\mu g/m^3$ on September 15. In summary, during the winter months, closely followed by summer months, the Greely School site showed relatively higher PM_{10} concentrations. However, a single 24 hour concentration over 150$\mu g/m^3$ will not constitute violation of the National Ambient Air Quality Standard because it is based on three year running average. A sample PM_{10} daily average data for 2012 is given in Figure 2. The 24 hour average PM_{10} data on a quarterly basis for Greely School is given in Appendix A.

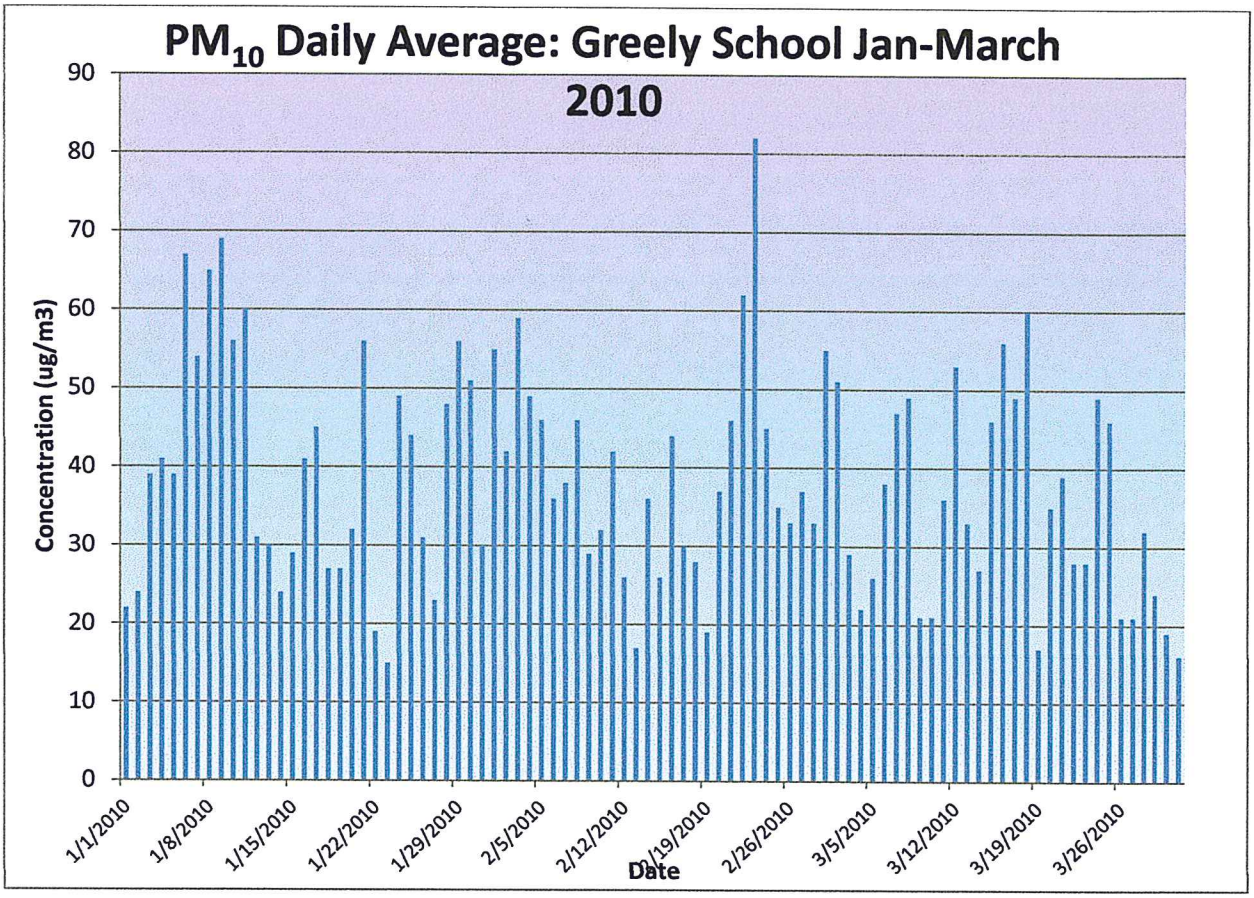


Figure 2: PM_{10} Daily Average: Jan-March 2010 at Greely School

Although, there is no standard for monthly and yearly PM_{10} concentration levels, the available data was analyzed to understand further the concentration profiles. The results showed that except in the month of September 2012, the average monthly concentration was less than $40\mu g/m^3$ for all other months. The highest monthly average was about $68\mu g/m^3$ during the month of September 2012 as shown in Figure 3.

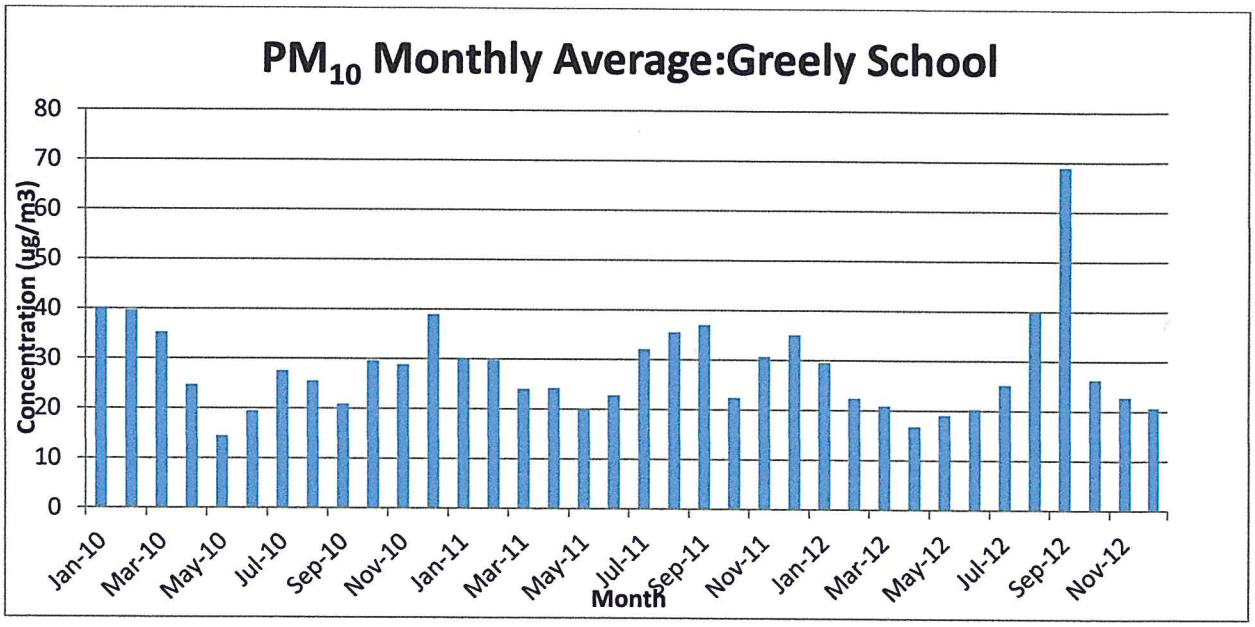


Figure 3: PM_{10} Monthly Average Concentrations for 2010, 2011, 2012 at the Greely School

5.0 $PM_{2.5}$ Analysis for the Greely School Site and Satellite Monitoring Sites in Butte

The $PM_{2.5}$ concentration at Greely School was analyzed to understand the concentration in time resolution of month, quarterly and yearly for three years, 2010-2012. In 2010 the lowest monthly average concentration of 3.3µg/m^3 was observed in June and the highest of 24.2µg/m^3 was observed in January. In 2011, the lowest concentration of 3.8µg/m^3 was observed during the month of June and the highest of 20µg/m^3 was observed in December. In 2012, the lowest monthly average of 4.0µg/m^3 was observed in June while the highest of 37.0µg/m^3 was observed in September. During the same year the concentration in December and January were 12 µg/m^3 and 10.9µg/m^3 respectively. This data is presented in Figure 4.

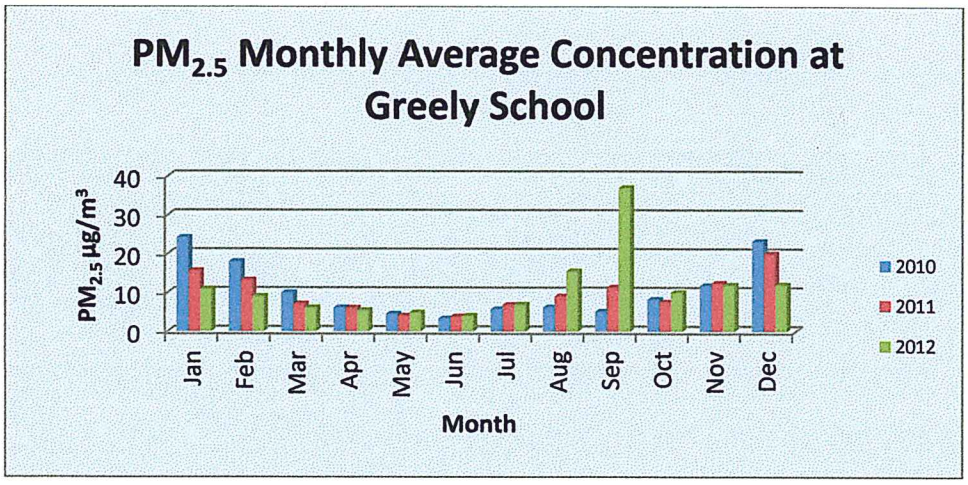


Figure 4: $PM_{2.5}$ Monthly Average Concentration for 2010, 2011, 2012 at the Greely School

The $PM_{2.5}$ data based on the four quarters indicated that the lowest concentration occurred in the second quarter while the highest concentrations occurred during the first and fourth quarters. The $PM_{2.5}$ quarterly averages for 2010, 2011, and 2012 are given in Figure 5.

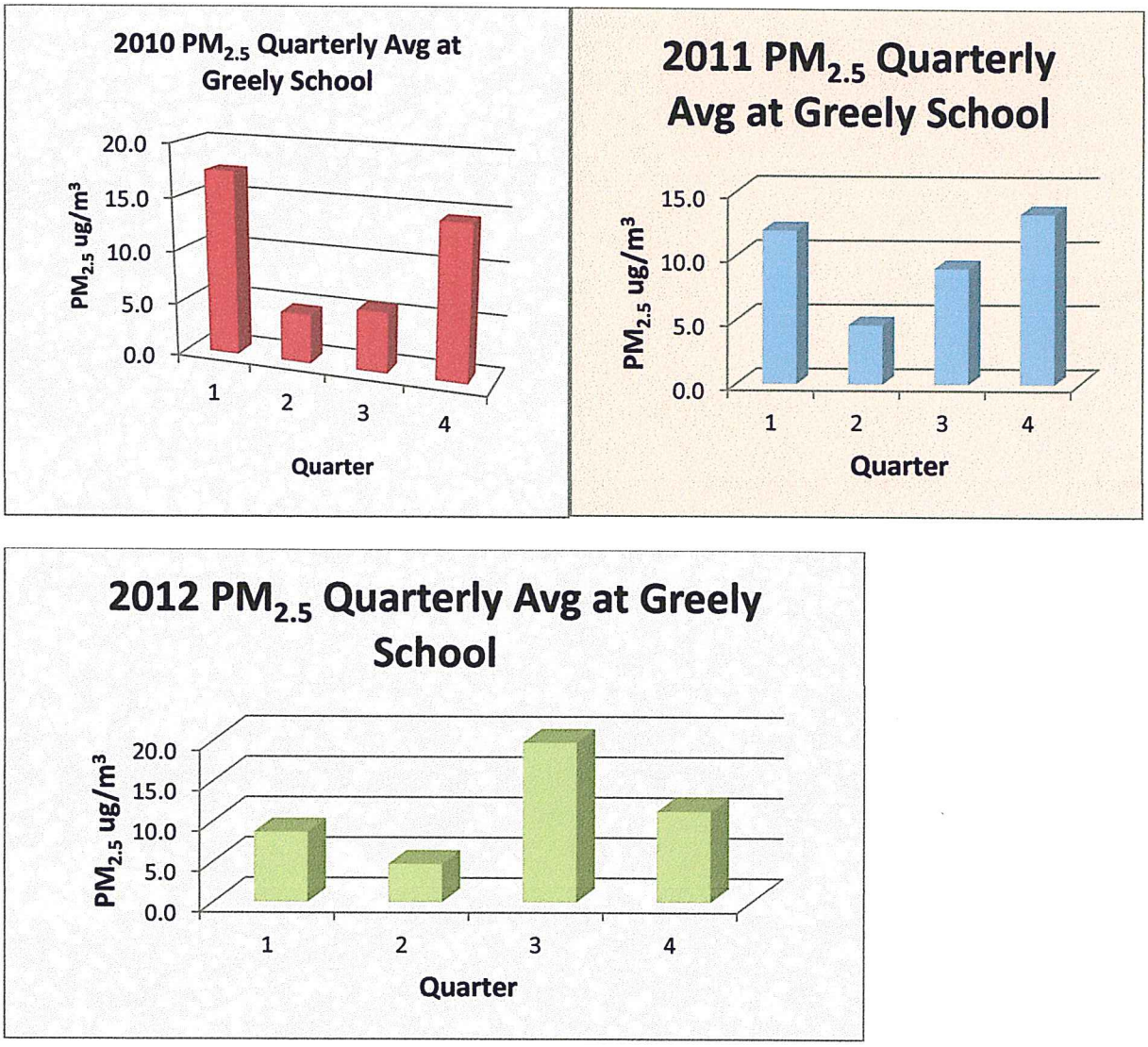


Figure 5: $PM_{2.5}$ Quarterly Average for 2010, 2011and 2012 at Greely School

A daily maximum of 100.6μg/m^3 occurred on September 15 of 2012. This event could have been mainly due to sources other than wood burning. The US Environmental Protection Agency has calculated the Design Values for $PM_{2.5}$ for Greely School site as given in the following Table 1. The National Ambient Air Quality Standards (NAAQS) dictates that the 98 percentile of $PM_{2.5}$ 24 hour average should not exceed 35μg/m^3 based on a three year rolling average, this value is considered to be the Design Value. The maximum hourly $PM_{2.5}$ concentration at Greely School for 2010, 2011, and 2012 is presented in Figure 6.

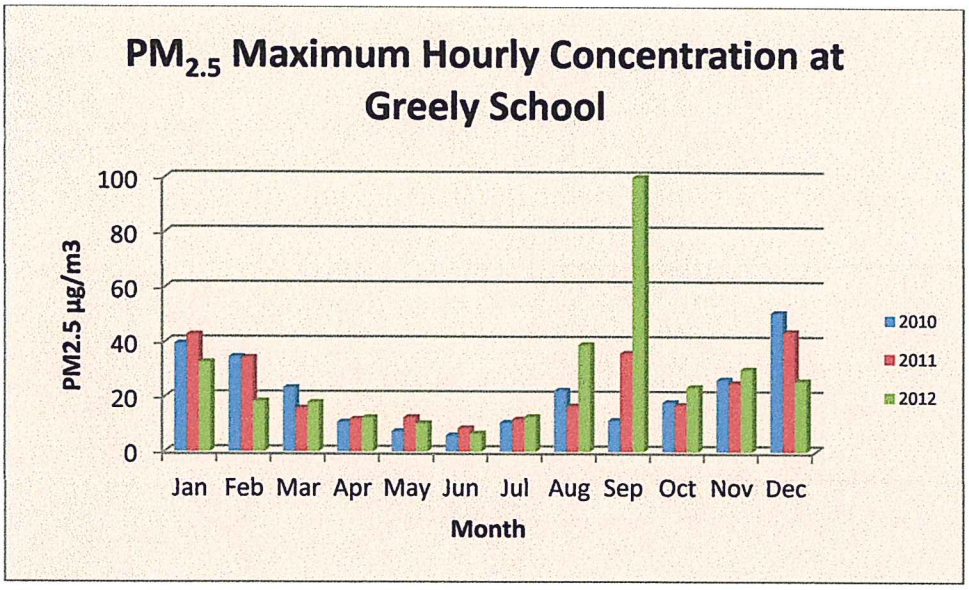


Figure 6: $PM_{2.5}$ Maximum Hourly Concentration for 2010, 2011, 2012 at Greely School

For the Greely School site the 98 percentile 24 hour $PM_{2.5}$ data for 2008, 2009, and 2010 were respectively 32.3μg/m^3, 38.5μg/m^3, and 42.1μg/m^3. The three year rolling average for this three year period was calculated to be 38μg/m^3, which was the Design Value. Similarly for the next three years, 2009 to 2011 the 98 percentile values were 38.5μg/m^3, 42.1μg/m^3, and 34.4μg/m^3 providing a Design Value of 38μg/m^3. Similarly for the next three years of 2010 to 2012 the 98 percentile 24 hour concentrations were 42.1μg/m^3, 34.4μg/m^3 and 24.5μg/m^3 yielding a Design Value of 34μg/m^3.

Table 1: The EPA Design Values for $PM_{2.5}$ for Greely School

Year	# of days	98% 24 hr $PM_{2.5}$ μg/m^3	Wt mean, $PM_{2.5}$ μg/m^3	24 hr Design Value μg/m^3	Annual Design Value, μg/m^3
2008	116	32.3	9.9		
2009	112	38.5	9.7		
2010	303	42.1	9.7	38	9.8
2011	343	34.4	9.3	38	9.6
2012	358	24.5	7.7	34	8.9

From the Design Values, at the Greely School site it appears that the $PM_{2.5}$ concentrations exceeded the National Ambient Air Quality Standard (NAAQS) of 35μg/m^3 in 2010 and 2011. However, in 2012, it was below the NAAQS. The annual average values are well below the 12μg/m^3 of new NAAQS for all three years of 2010, 2011, and 2012.

5.1 Comparison of Greely School Site $PM_{2.5}$ to the Satellite Sites in Butte

In Butte, besides the Greely School site, several satellite air quality monitoring sites were established to understand the distribution of $PM_{2.5}$ across the Butte air shed. Four months of hourly $PM_{2.5}$ data was analyzed for all the available monitoring stations and the $PM_{2.5}$ concentrations were then compared. In October 2012 the data was collected from seven sites besides the Greely School, they were: East Junior High, Health Department, High School, Stodden Park and Whittier School. In November and December of 2012 another monitoring site was added at the Butte Air Port. In January of 2013 there was one more monitoring site added at the Original Mine site in the Uptown of Butte. In order to compare, the concentrations were averaged over a month, and data is presented for October, November and December 2012 and for January 2013. Two monitoring sites, the Greely School and the East Junior High sites consistently showed higher levels of $PM_{2.5}$ relative to the other sites. Two monitoring sites consistently showed lower concentration were the Airport and the Original Mine sites. In January 2013 the $PM_{2.5}$ concentration in the Greely School was over 5 times higher than at the Airport or the Original Mine site. The East Junior high site showed almost four times the Airport or the Original Mine sites. Based on concentration averaged over all sites for January 2013, the monthly average across the valley was at 12.8μg/m^3. In comparison at the Greely School for the same month it was almost twice as the valley average value. This data indicated that the Greely School site location measures 1.3 times higher in October, 1.5 times higher in November, 1.6 times higher in December and 1.9 times higher in January than the average $PM_{2.5}$ concentration across all the sampling sites. It is likely that the $PM_{2.5}$ concentration at Greely School during the winter months may be twice higher than the $PM_{2.5}$ averaged over all sites. Therefore, the local sources around the Greely School might be influencing the higher $PM_{2.5}$ winter levels. The $PM_{2.5}$ monthly average data for October 2012, November 2012, December 2012 and January 2013 are given in Figure 7-10.

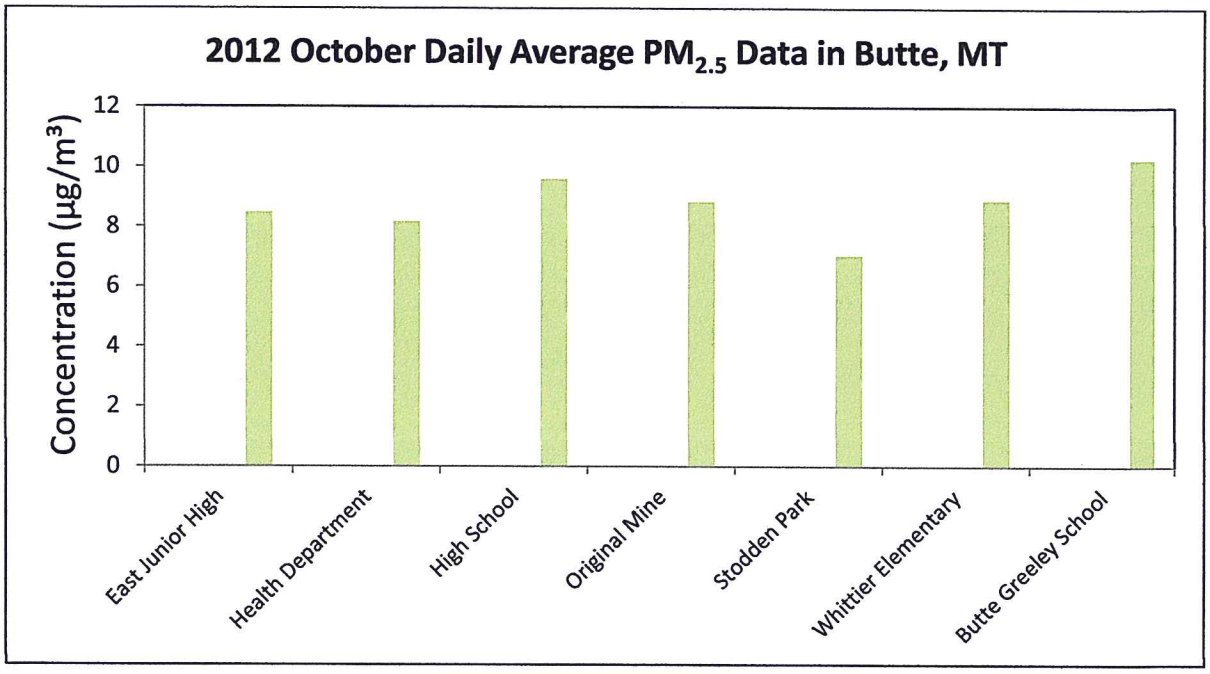


Figure 7: 2012 October Daily Average $PM_{2.5}$ Data in Butte, MT

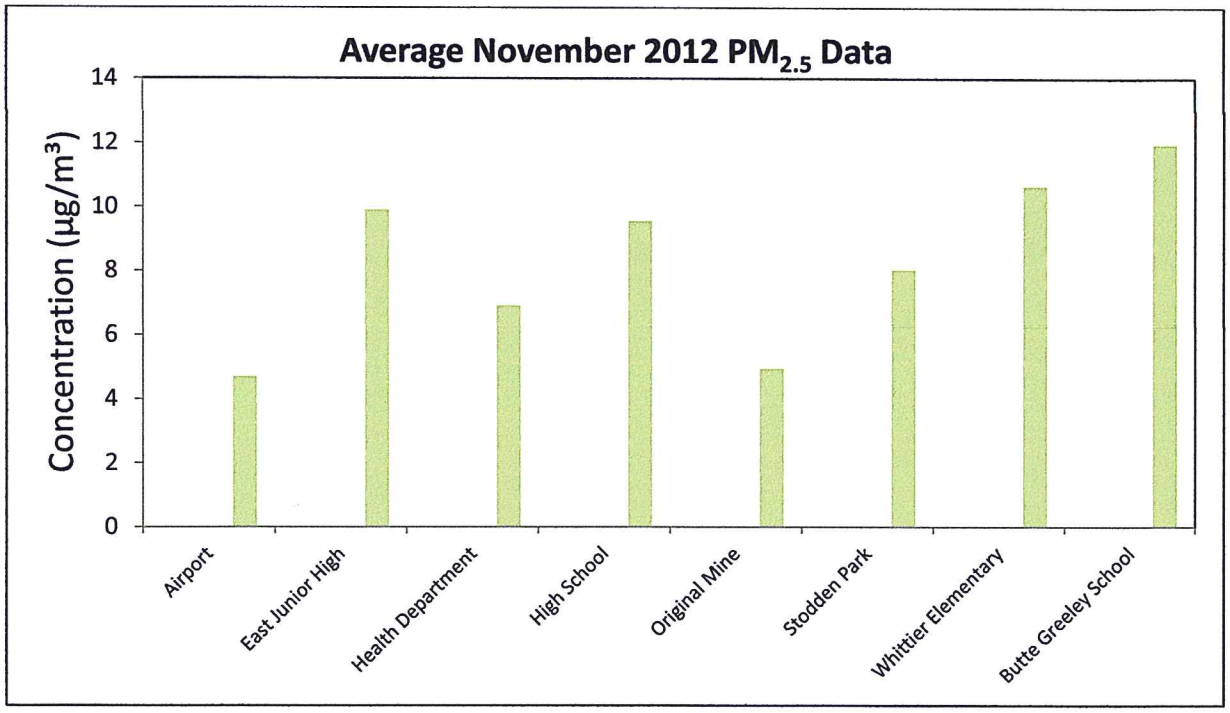


Figure 8: 2012 November Average $PM_{2.5}$ Data

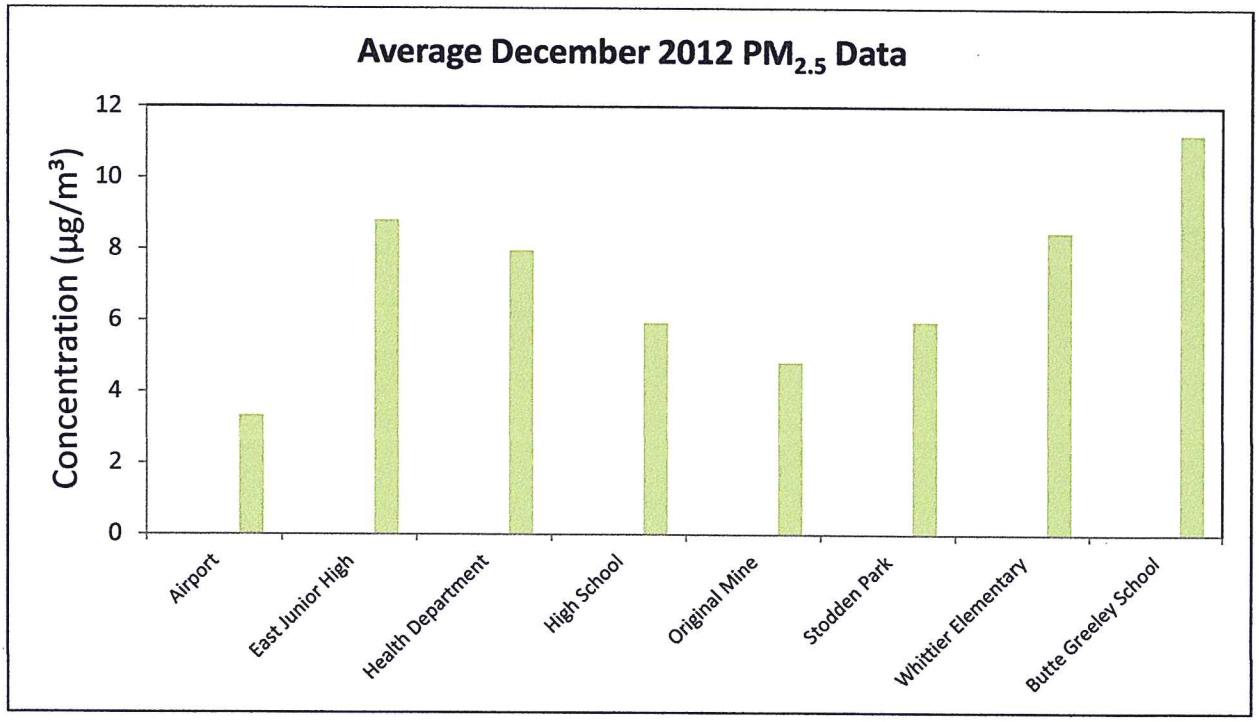


Figure 9: Average December 2012 $PM_{2.5}$ Data

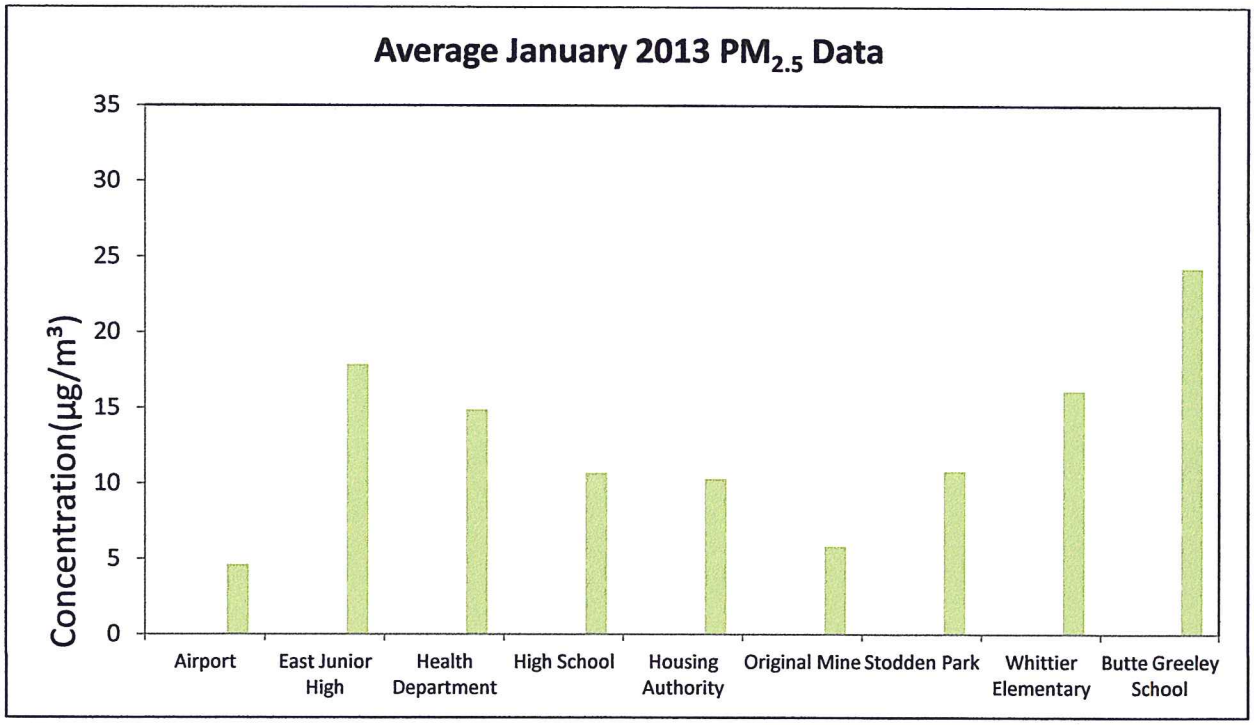


Figure 10: Average January 2013 $PM_{2.5}$ Data

5.2 Wind Rose and $PM_{2.5}$ Pollution Rose

The wind direction for the Greely School, the Original Mine, the Health Department, the Stodden Park, and the Butte High were imposed on the $PM_{2.5}$ data to show the influence of wind direction on the particulate concentration. The data for the 4 the quarter of 2012 that is for the months of October, November and December were analyzed and compared to each site. All five sites showed different wind patterns during this quarter. Greely School showed more east of SE wind with relatively higher particulate concentration, while the Original Mine site showed mainly N wind with much lower particulate concentrations. The Stodden Park and the Health Department sites had some similarities in that wind was mostly from W and west of SW directions. Both of these sites had also winds from SE direction. The Health Department site had wind and particulates coming from east of NE direction. The Butte High School site had winds and particulates mainly coming from south of SE and S and SW directions with smaller frequency of wind from almost all directions. These data are presented in Figure 11-15.

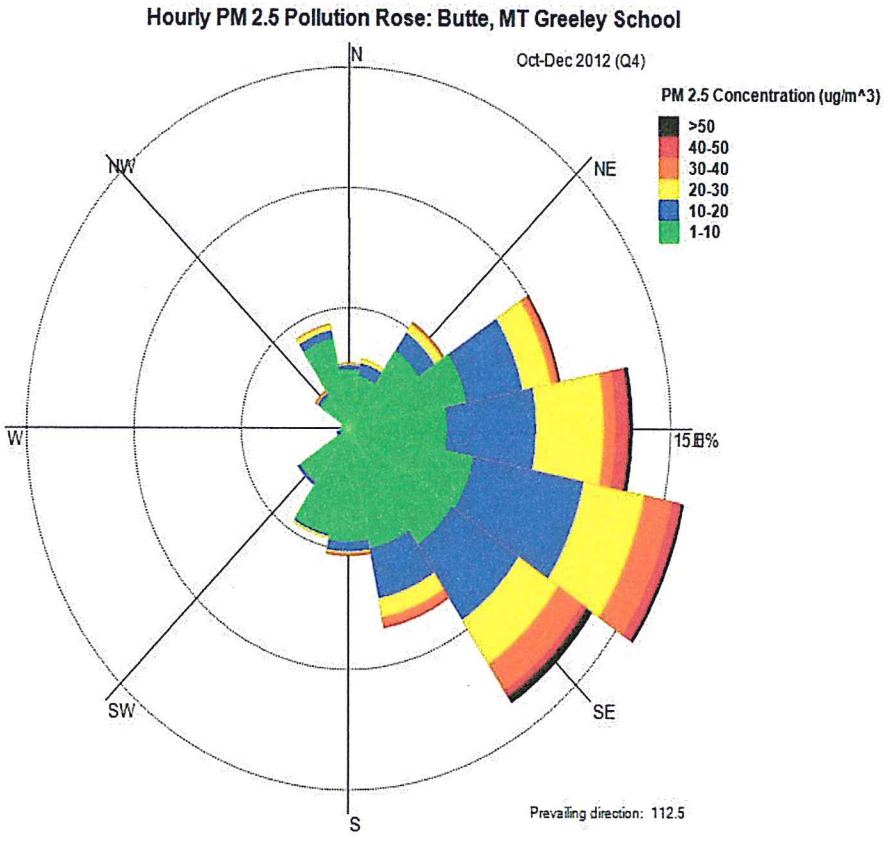


Figure 11: Hourly $PM_{2.5}$ Pollution Rose at the Greely School

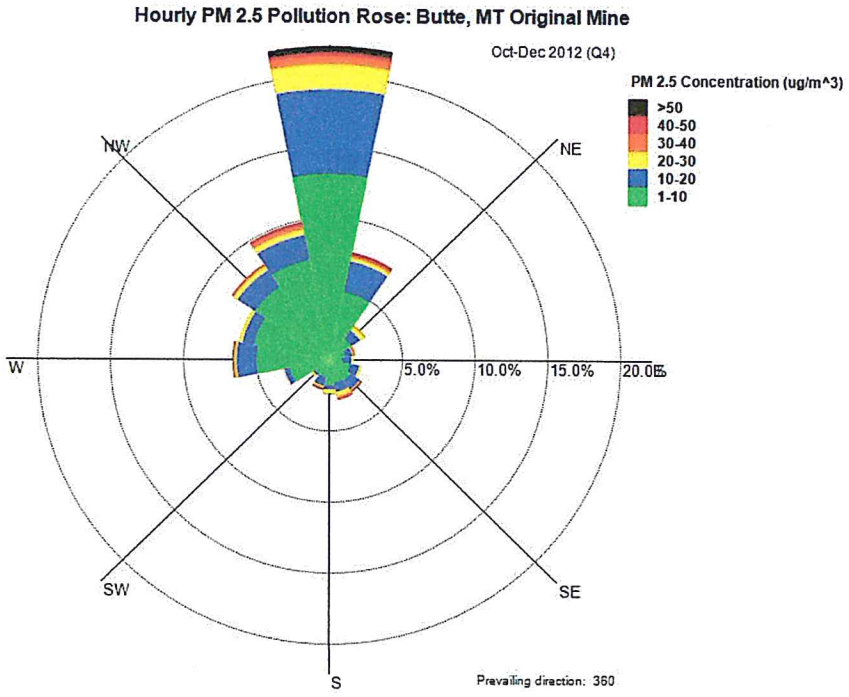


Figure 12: Hourly $PM_{2.5}$ Pollution Raised at the Original Mine

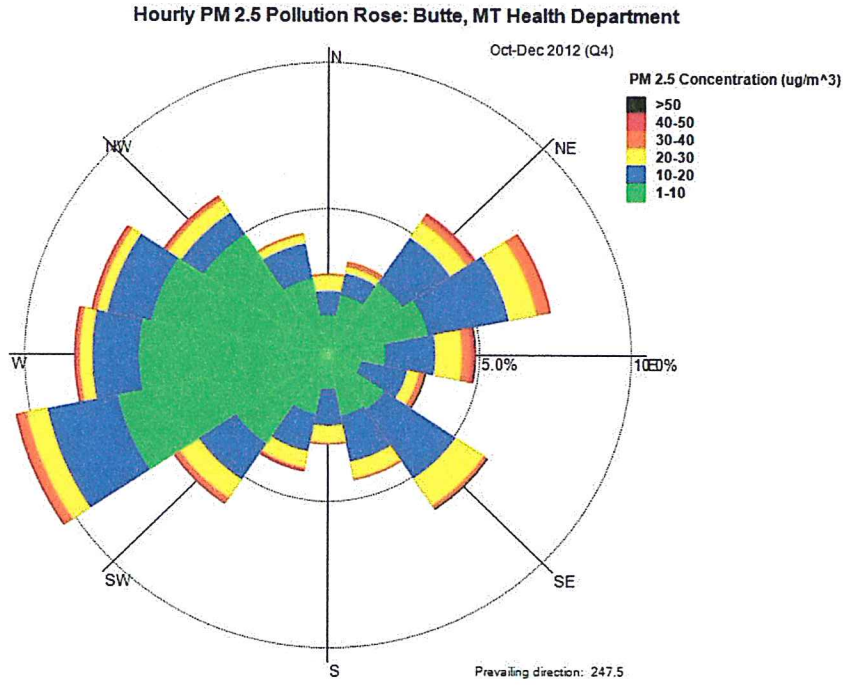


Figure 13: Hourly $PM_{2.5}$ Pollution Rose at the Health Department

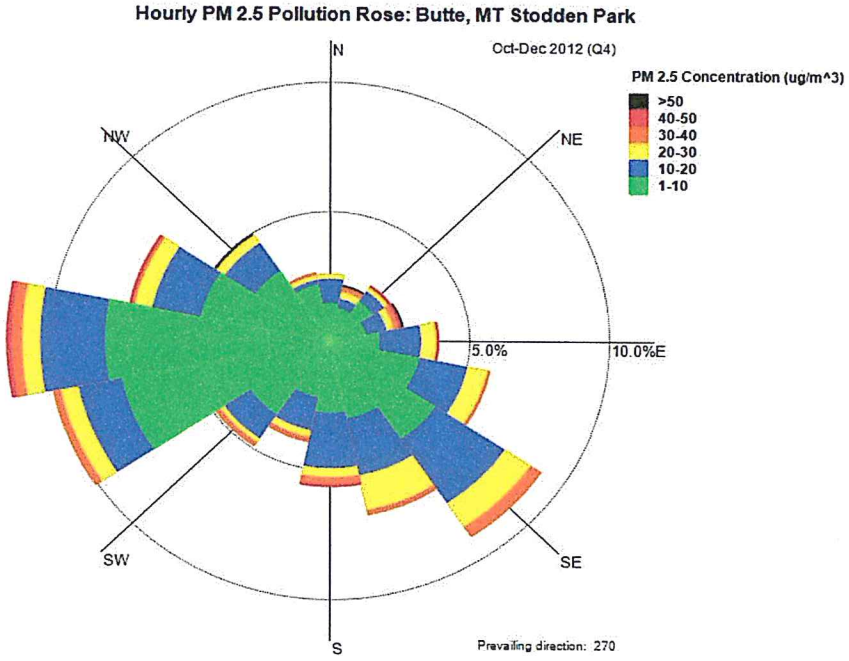


Figure 14: Hourly $PM2_{2.5}$ Pollution Rose at the Stodden Park

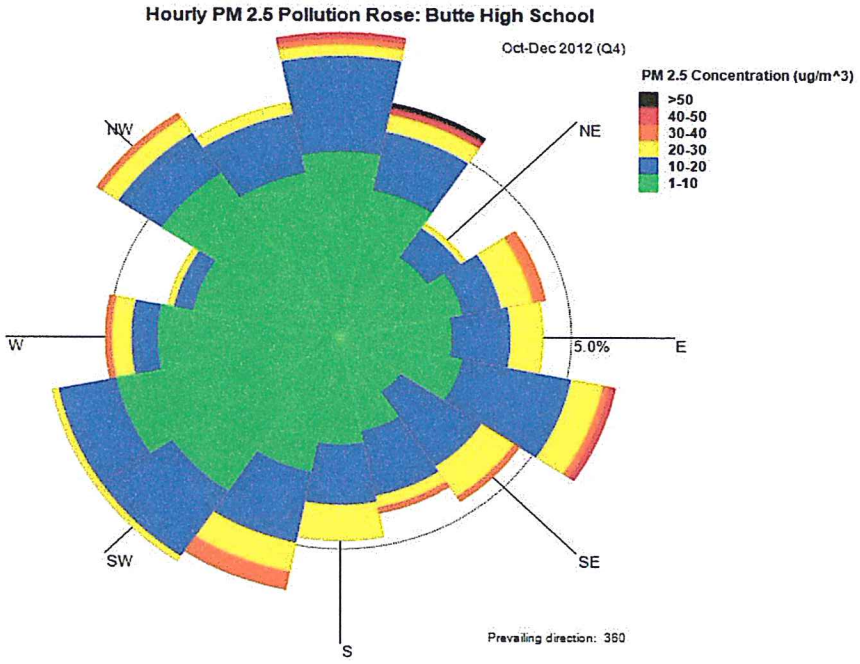


Figure 15: Hourly $PM_{2.5}$ Pollution Rose at the Butte High School

From the pollution rose data it is clear that the Butte valley has varied wind patterns from site to site even though the monitoring sites are not too far from each other. The farthest is the Air Port site which is 3.9 miles from the Greely School site. All the other sites are within 2 miles from the Greely School site. The site locations are given in Table 2.0. It should be noticed that these are temporary meteorological sites and therefore some of the wind data may be influenced by the location, height of the tower and other related factors.

Table 2.0: Particulate Sampling Site Location

Site Description	Greeley School	East Junior High	Whittier	Housing Authority	Butte High School	Health Dept.	Stodden Park	Original Mine	Airport
Elevation (Ft)	5519	5526	5510	5673	5673	5494	5480	5810	5577
Decrease in Elevation (highest to lowest) in feet	7	51	9	137	137	16	14		96
Difference in Elevation from Greeley School in feet	0	7	-9	154	154	-25	-39	291	58
Approximate Distance from Greeley School Site in Miles	0	0.3	1	1.5	1.7	1.7	1.8	2	3.9

5.3 Greely School $PM_{2.5}$ Pollution Rose

The $PM_{2.5}$ concentration was super imposed on the frequency of wind direction for the Greely School site during part of 2010, 2011, and 2012. This $PM_{2.5}$ pollution rose provided information on the influence of wind direction on the $PM_{2.5}$ concentration in a specific site for the duration. For this report, the $PM_{2.5}$ pollution roses were developed on a quarterly basis for the above mentioned three years.

Combining the three years, during the first quarter $PM_{2.5}$ pollution rose at Greely School indicated that the predominant directions were E, south of SE and north of SE. During the second quarter the winds were mainly from SE direction and with lower frequency from north of NW. However, during the second quarter, the particulate concentrations were relatively lower or lowest of the four quarters. The pollution rose for the third quarter indicated that the main directional $PM_{2.5}$ pollution was coming from SE and east of SE and south of SE. There was also a small amount of wind flowing from north of NW and N. The fourth quarter wind and pollution patterns were very similar to the third quarter except the contribution of particulates from east of SE and SE were relatively higher than the third quarter.

In specific for 2012 during the first quarter the predominant wind and the particulates were from E and east of SE. Although there were winds from S and NW the amount of particulate it carried was much lower in concentration than when the winds were from E and SE directions. During the second quarter the wind pattern was from SE and north of NW, but the relative amount of particulates it carried was lower compared to the other three quarters. During the third quarter the predominant winds and the particulates were from SE, south of SE and east of SE. The Greely School has much less Westerly wind in the third quarter. The north and north of NW winds brought particulates to Greely School site in a relatively smaller scale. During the fourth quarter the wind was mainly from the east of SE, SE and E directions with relatively higher particulates concentrations. Thus, it is clear that the Greely School $PM_{2.5}$ particulate concentrations are more influenced by the SE, S and E winds while much less influence from the N or NW directions. The 2012 $PM_{2.5}$ pollution rose for the Greely School for January-March, April-June, and July-September are given in Figures 16-18, and the Oct-Dec $PM_{2.5}$ pollution rose is given earlier in Figure 13. Additional $PM_{2.5}$ pollution rose for the year 2010 and 2011 are provided in Appendix B.

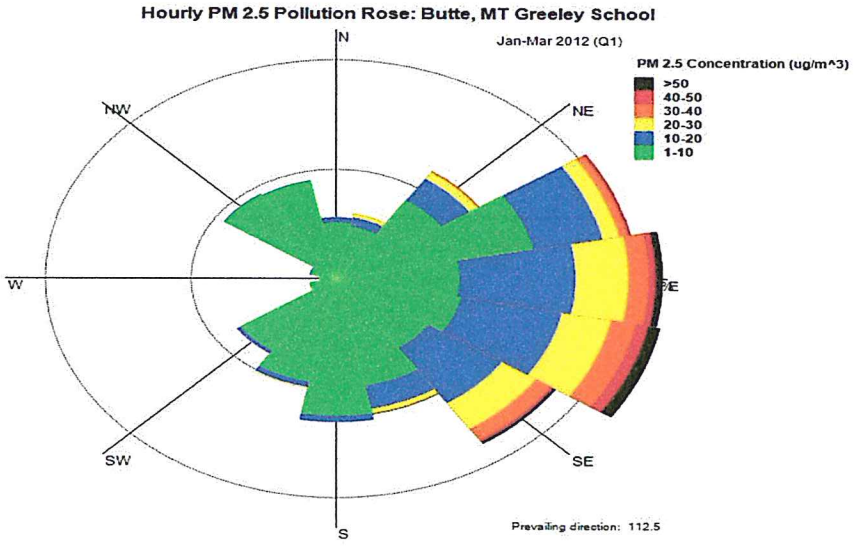


Figure16: Hourly $PM_{2.5}$ Pollution Rose at the Greely School January-March 2012

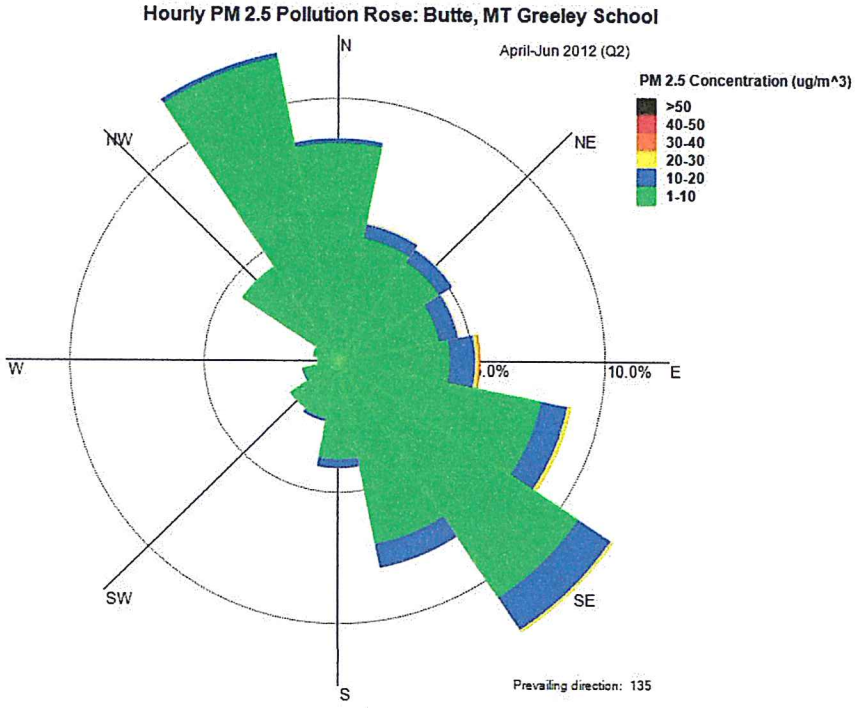


Figure 17: Hourly $PM_{2.5}$ Pollution Rose at the Greely School April-June 2012

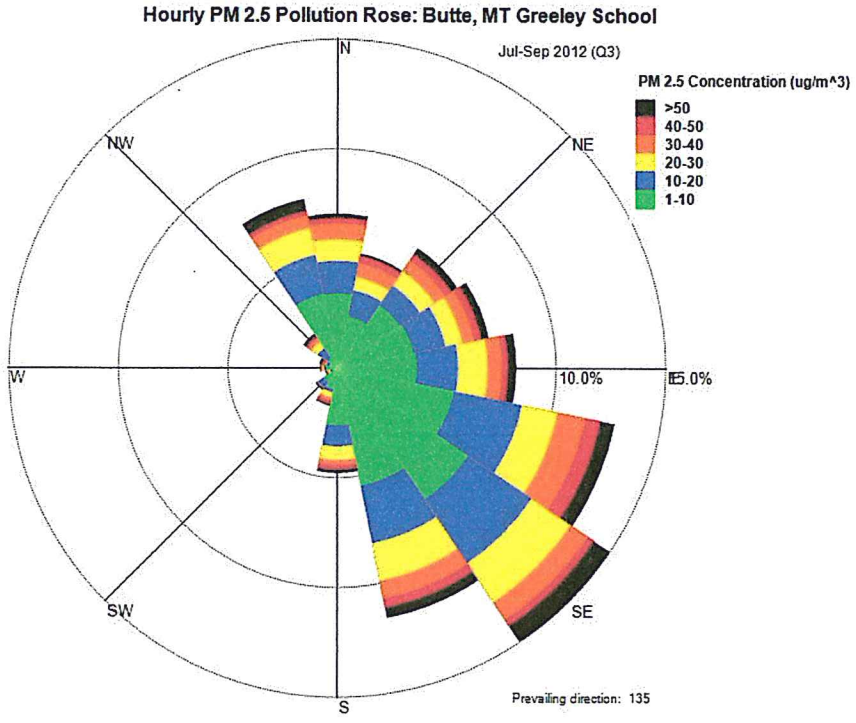


Figure 18 Hourly $PM_{2.5}$ Pollution Rose at the Greely School July-September 2012

6.0 Metals Content in $PM_{2.5}$ for the Greely School Site and the Sieben Flats

The $PM_{2.5}$ data was analyzed for five specific metals, arsenic, cadmium, copper, lead and nickel. The $PM_{2.5}$ particulates collected on the filters by the Montana Department of Environmental Quality and were sent to a certified laboratory to analyze for metal constituents in the samples. For this study five metals as mentioned above were selected for the analysis of $PM_{2.5}$ samples from the Greely School site data. The data indicated that the metal concentrations were lower than $0.2\mu g/m^3$ on 24 hour average samples for all five metals. About 10 out of 40 arsenic samples showed levels above $0.001\mu g/m^3$. About 14 samples out of 42 cadmium samples showed above $0.01\mu g/m^3$. Similarly, 17 samples out of 176 copper samples showed concentrations above $0.01\mu g/m^3$. Lead levels were above $0.003\mu g/m^3$ in 13 samples out of 58 samples. The nickel showed above $0.001\mu g/m^3$ in 5 samples out of the 23 samples that showed above detection levels. Again, none of the metal concentrations were higher than $0.2\mu g/m^3$.

The highest arsenic concentration was $0.0035\mu g/m^3$ in February, the highest cadmium was $0.03\mu g/m^3$ in February 2012, the highest copper was $0.033\mu g/m^3$ occurred in February 2012 as well as in October 2011, the highest lead was $0.007\mu g/m^3$ in December 2010, and the highest nickel concentration of $0.002\ \mu g/m^3$ was occurred in December 2012. Thus, the occurrence of highest metal concentrations in $PM_{2.5}$ does not follow a pattern of particular month or year based on the analysis of the available metal speciation data.

On a quarterly basis arsenic, copper and cadmium were relatively higher during third quarter, July to September. However, lead levels were higher during the first and second quarter, Jan-June. Copper was the only metal occurred consistently in all quarters, followed by cadmium that occurred in the first three quarters in 2012. Similar trends were noticed in 2011 except lead level was about $0.002\mu g/m^3$ in the fourth quarter. Very similar trend in 2010 was observed except lead concentrations in the fourth and first quarters were 0.0014 and $0.001\mu g/m^3$ respectively.

On yearly basis there was a small increasing trend in the annual average of copper from 0.003, 0.004 and 0.006 $\mu g/m^3$ respectively in 2010, 2011 and 2012. Cadmium followed a similar but smaller increase during these three year period from 0.0018 to $0.0023\mu g/m^3$.

The speciation data for metals in Butte were compared for two years (2011 and 2012) to a background site, the Sieben Flats near Helena, Montana. In general, as expected, the metal concentrations in Butte were higher than the background except nickel, where nickel concentrations in Butte were lower than the background levels. On a monthly basis arsenic levels were almost twice the background levels in Butte in December in 2011 at $0.0008\mu g/m^3$ while the background level was $0.0004\mu g/m^3$. In 2012 the arsenic levels in Butte was relatively higher in the month of August ($0.001\mu g/m^3$) while the highest background level was $0.0005\mu g/m^3$ in the month of April.

The cadmium monthly average level was lower than the background in 2011, while the 2012 data showed slightly higher than the background levels in Butte. The copper levels in Butte were consistently higher than the background site in 2011 and 2012. The monthly average in Butte in 2011 was 0.015μg/m^3 when the background level was around 0.001μg/m^3. The lead levels were very similar in pattern except the Butte levels were 0.0009μg/m^3 and the background levels were as high as 0.0007μg/m^3. However, nickel concentrations in Butte were consistently lower than the background levels in 2011 and 2012. The monthly and quarterly average metal values are given in Figures 19 and 20. Additional $PM_{2.5}$ metal concentration data are presented in Appendix C. However a sample data analysis is given in Figure 19 for the year 2012.

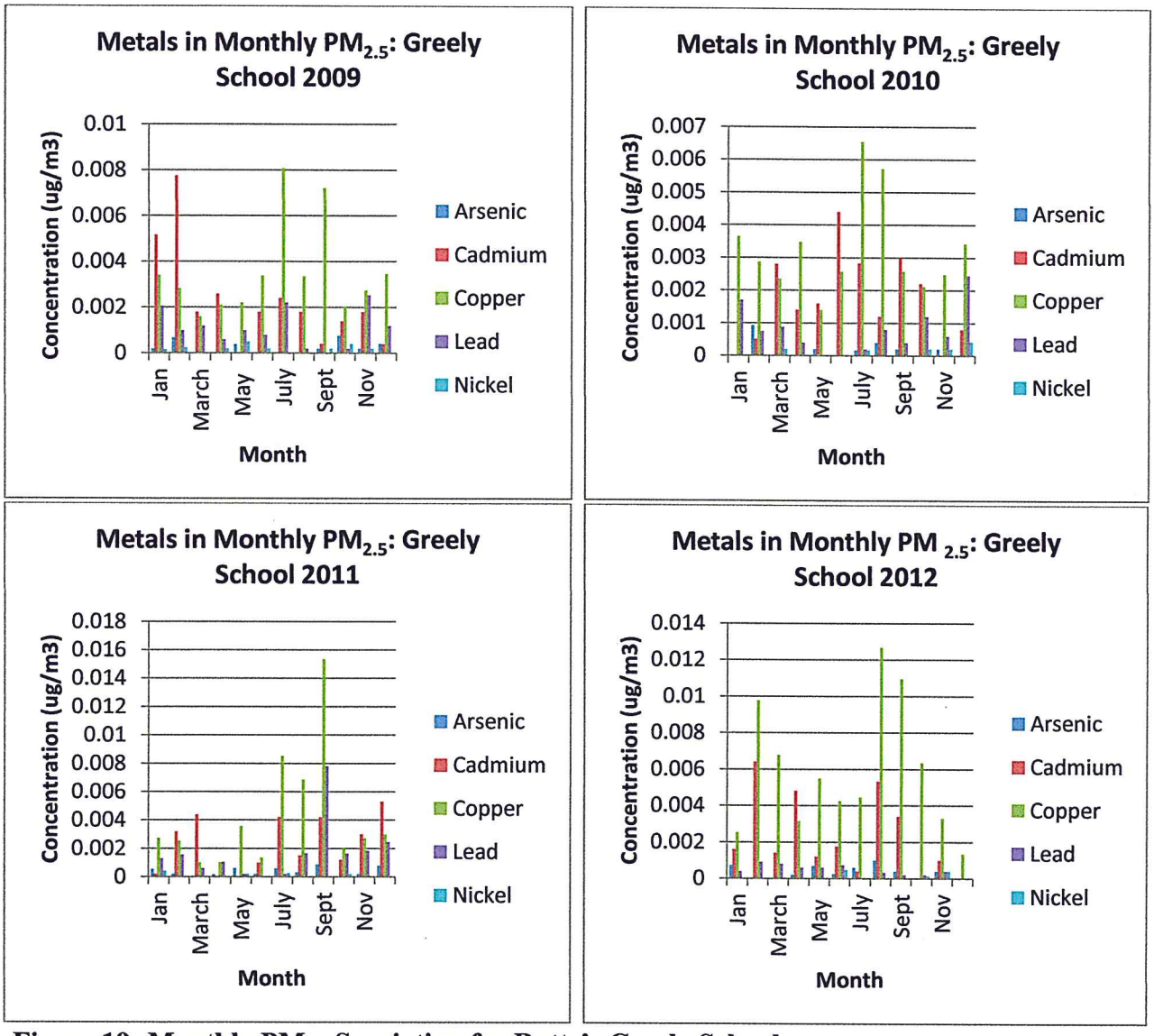
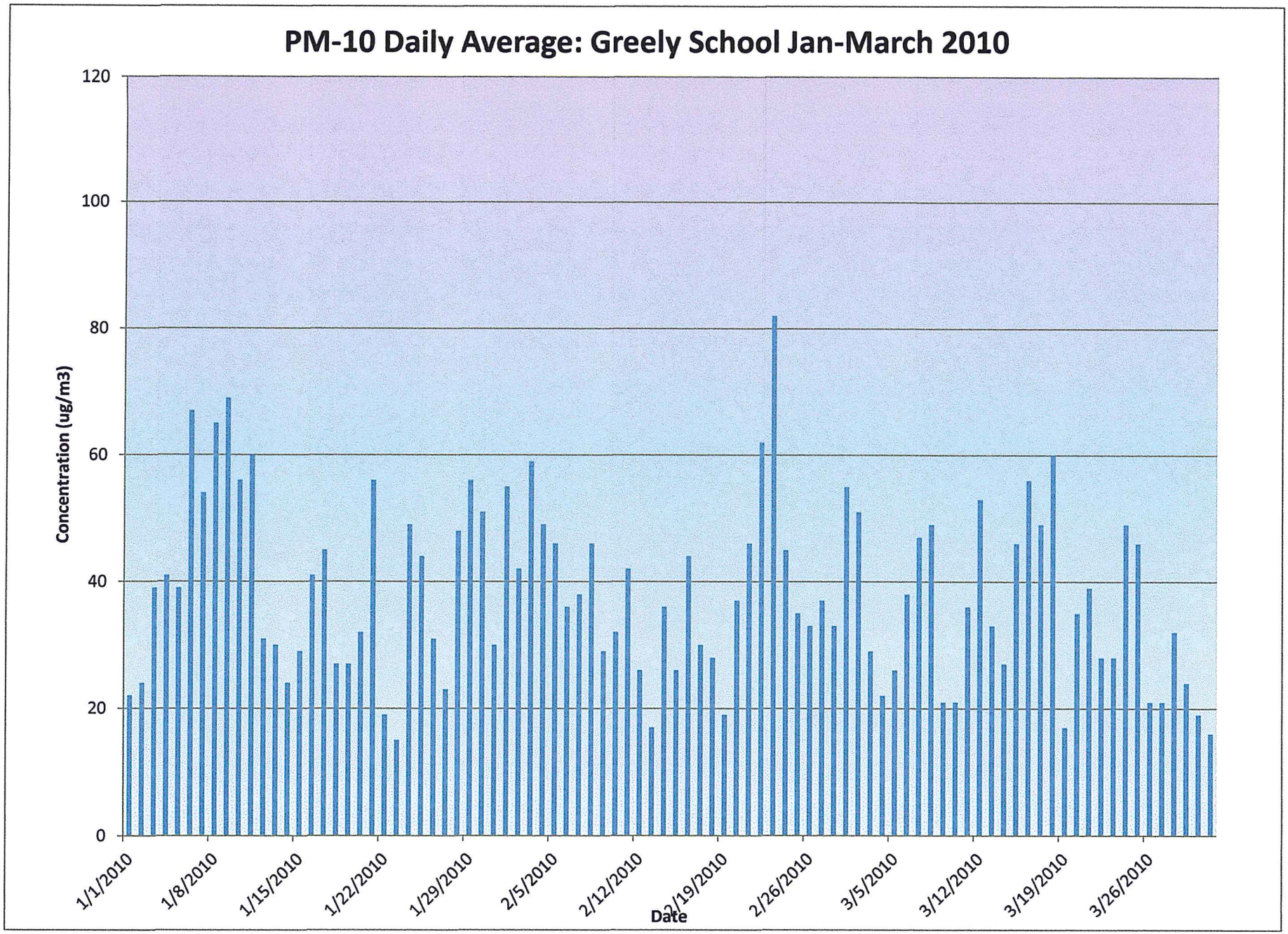


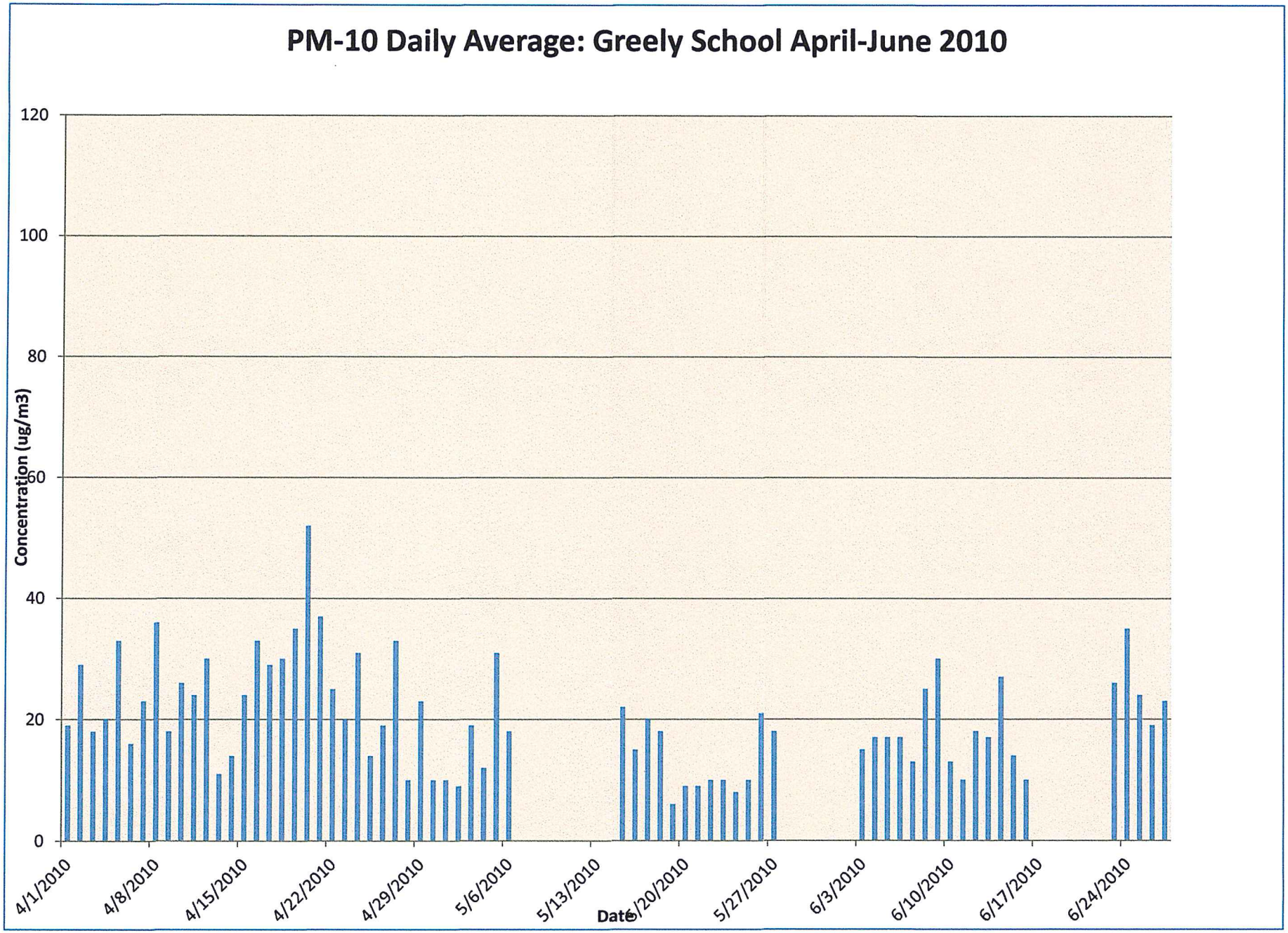
Figure 19: Monthly $PM_{2.5}$ Speciation for Butte's Greely School

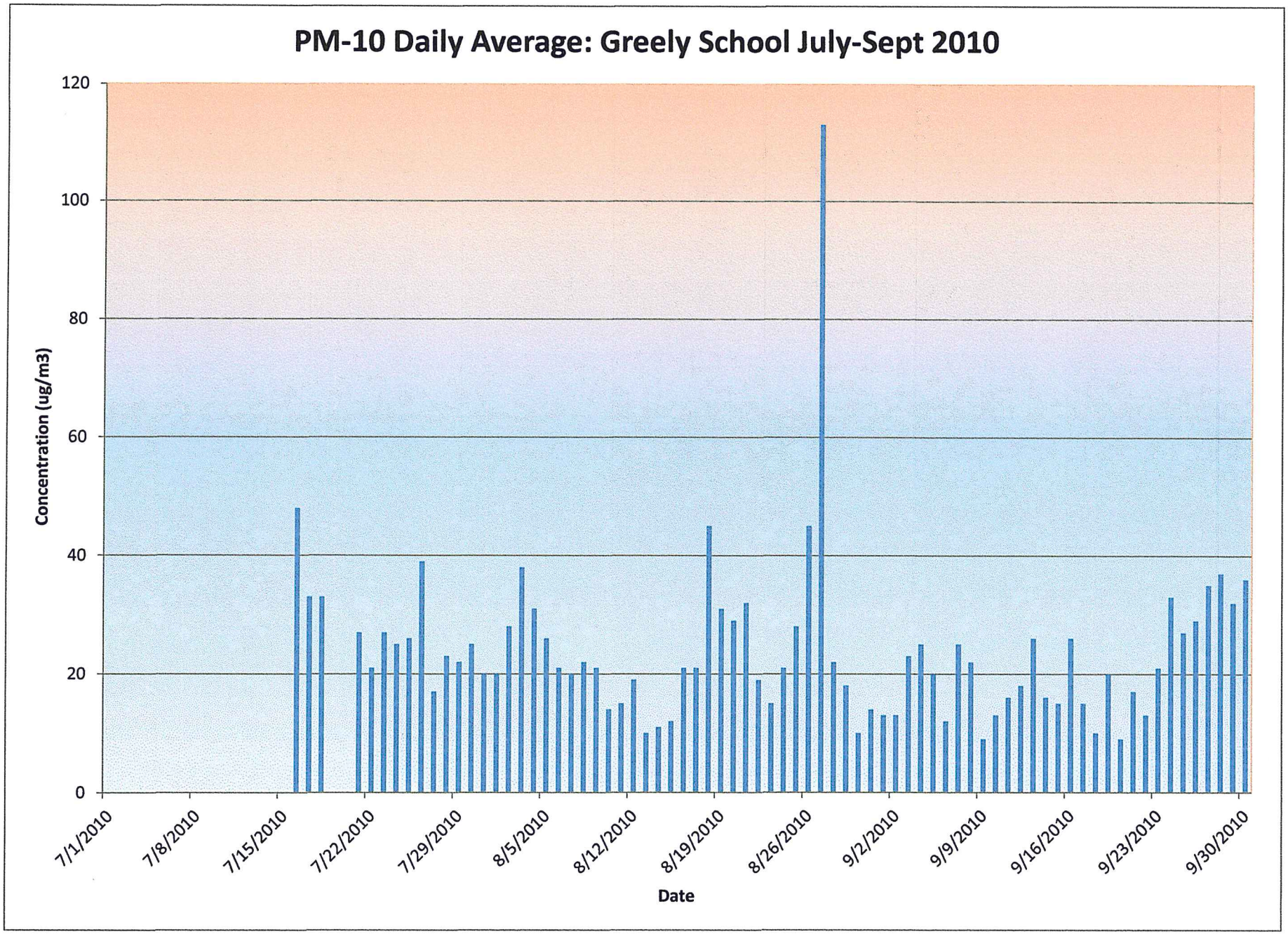
Appendix A

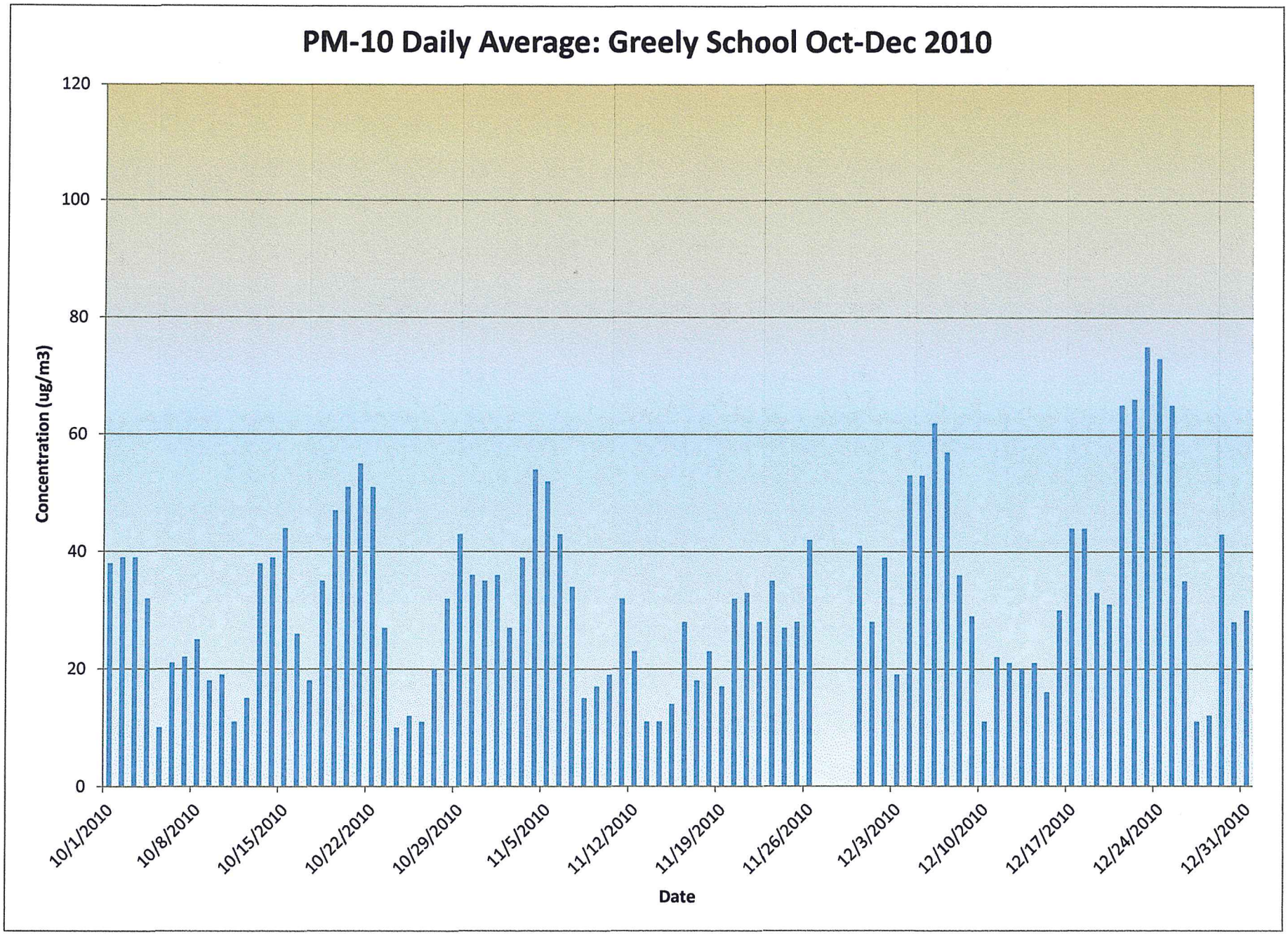
Greely School PM_{10}

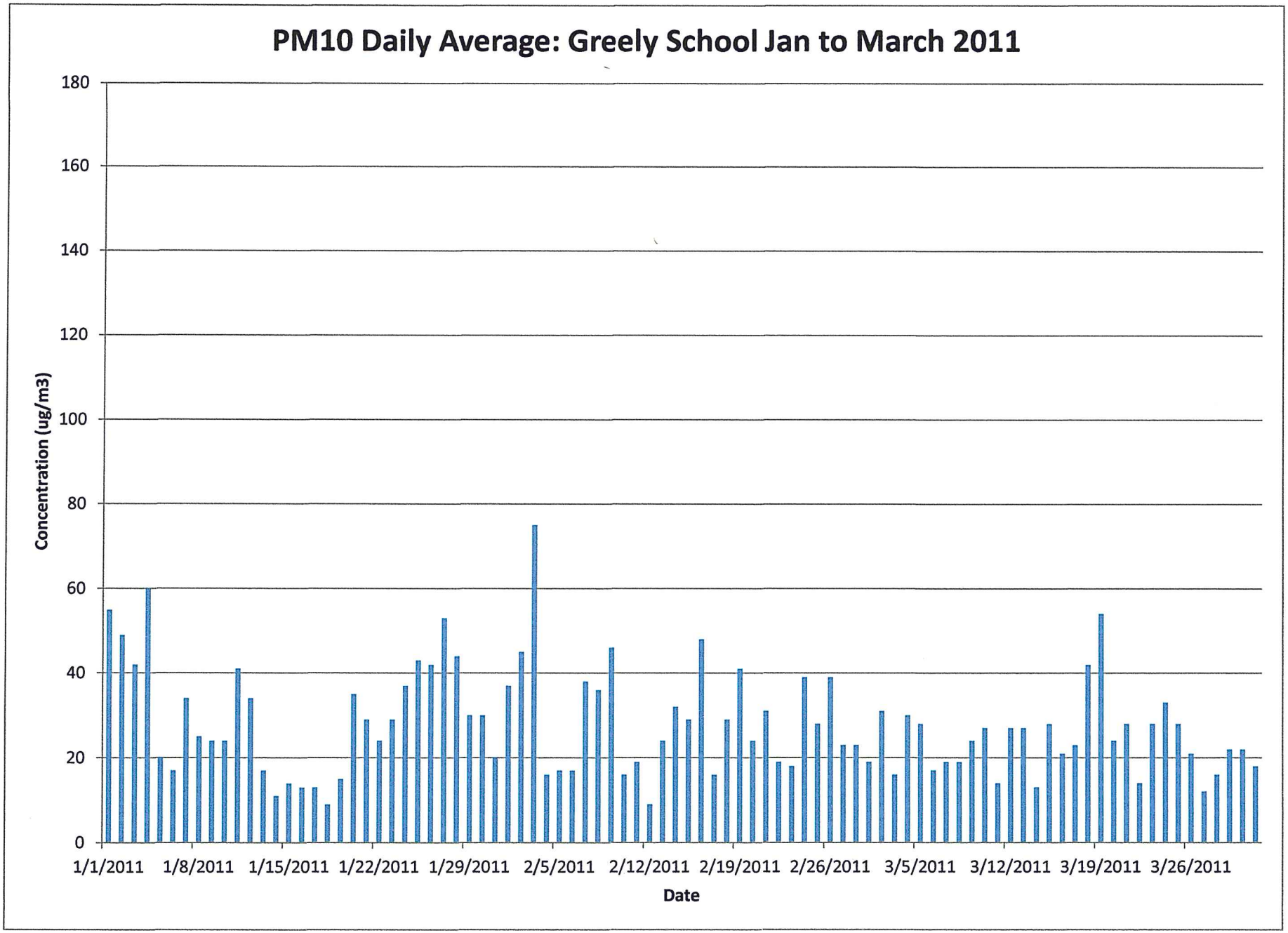
Concentration Figures

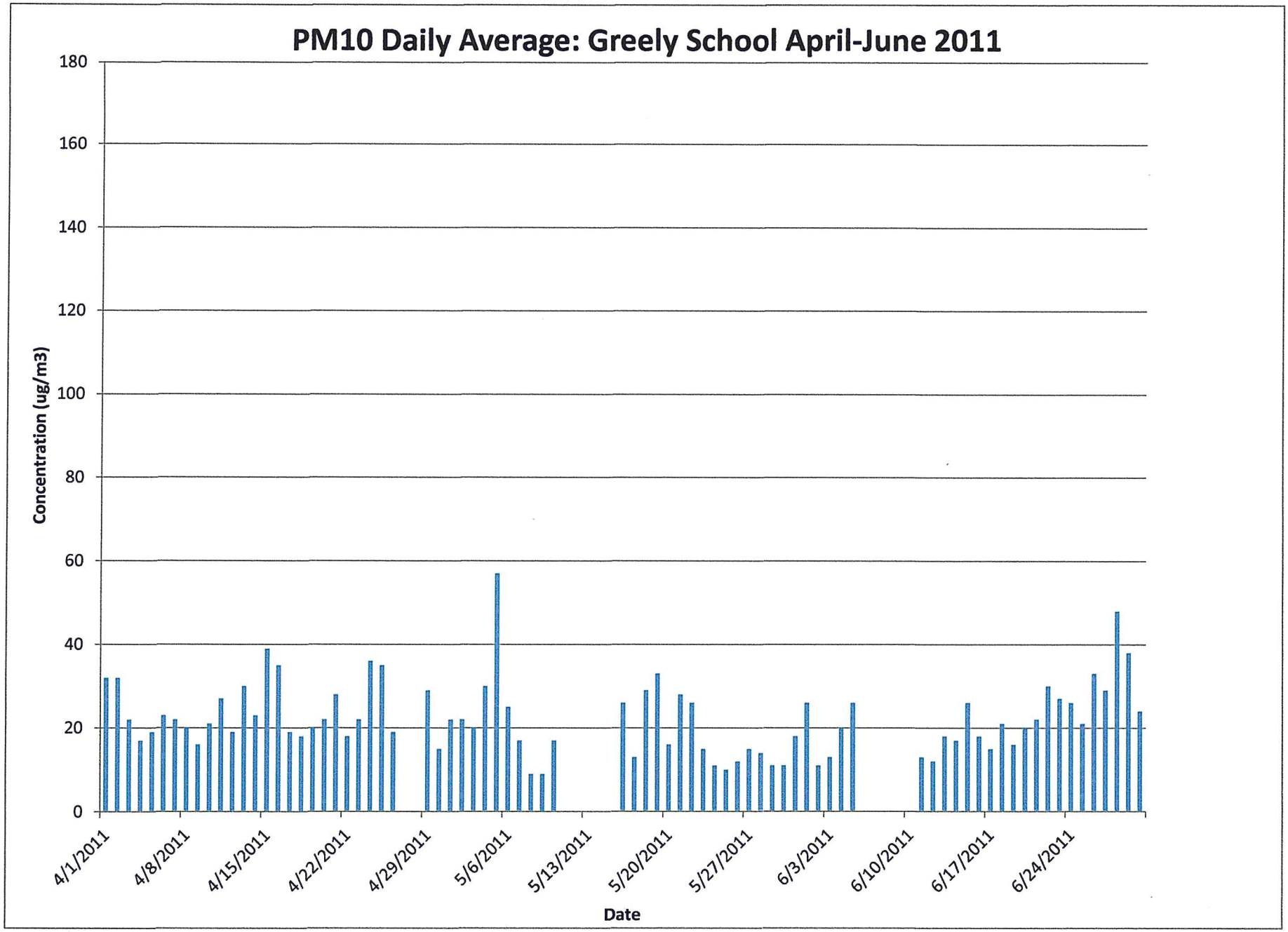

PM-10 Daily Average: Greely School Jan-March 2010
120
100
80
60
40
20
0
Concentration (ug/m3)
1/1/2010
1/8/2010
1/15/2010
1/22/2010
1/29/2010
2/5/2010
2/12/2010
2/19/2010
2/26/2010
3/5/2010
3/12/2010
3/19/2010
3/26/2010
Date

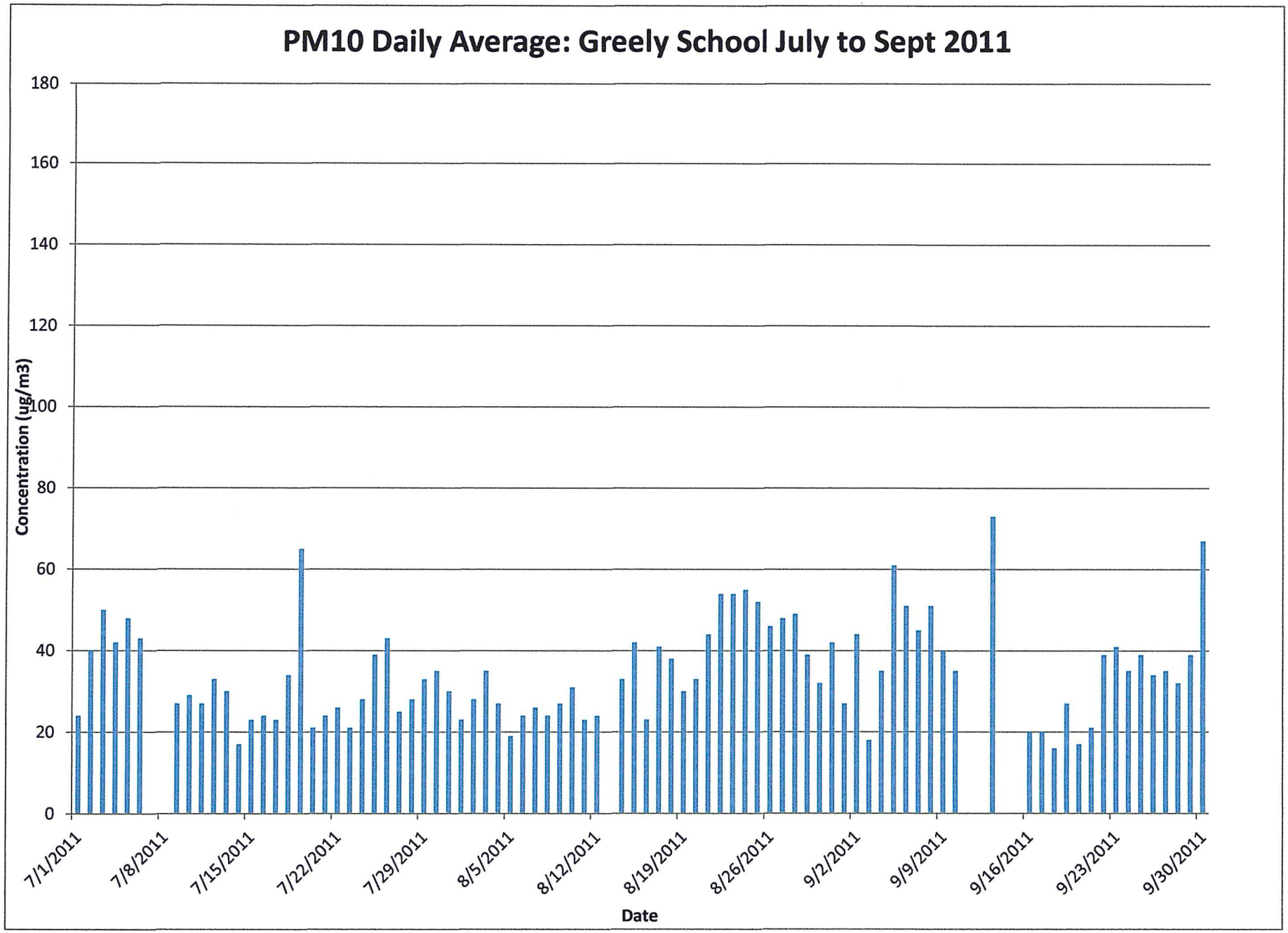

PM-10 Daily Average: Greely School April-June 2010
120
100
80
60
40
20
0
Concentration (ug/m3)
4/1/2010
4/8/2010
4/15/2010
4/22/2010
4/29/2010
5/6/2010
5/13/2010
5/20/2010
5/27/2010
6/3/2010
6/10/2010
6/17/2010
6/24/2010
Date

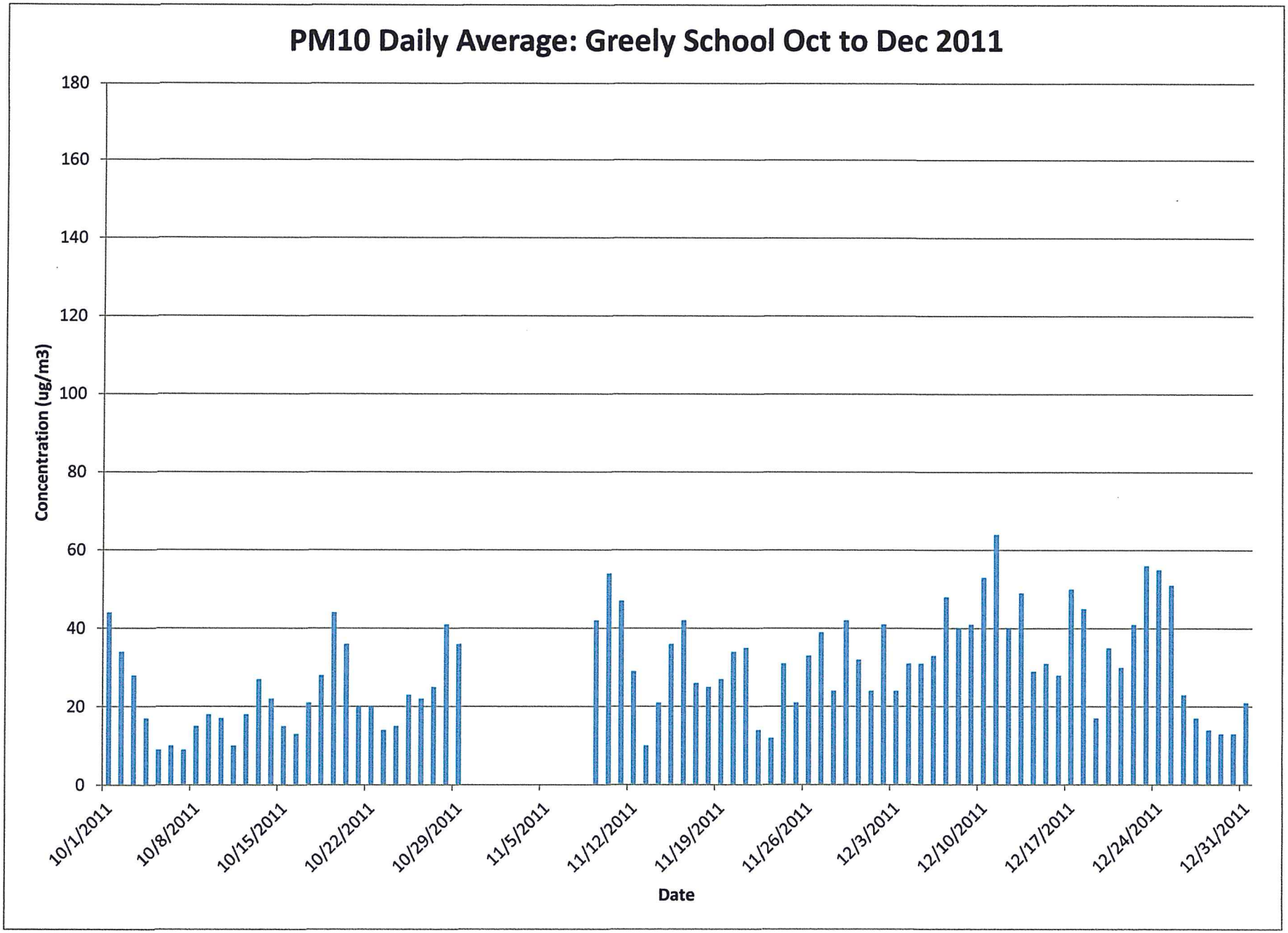

PM-10 Daily Average: Greely School July-Sept 2010
120
100
80
60
40
20
0
Concentration (ug/m3)
7/1/2010
7/8/2010
7/15/2010
7/22/2010
7/29/2010
8/5/2010
8/12/2010
8/19/2010
8/26/2010
9/2/2010
9/9/2010
9/16/2010
9/23/2010
9/30/2010
Date

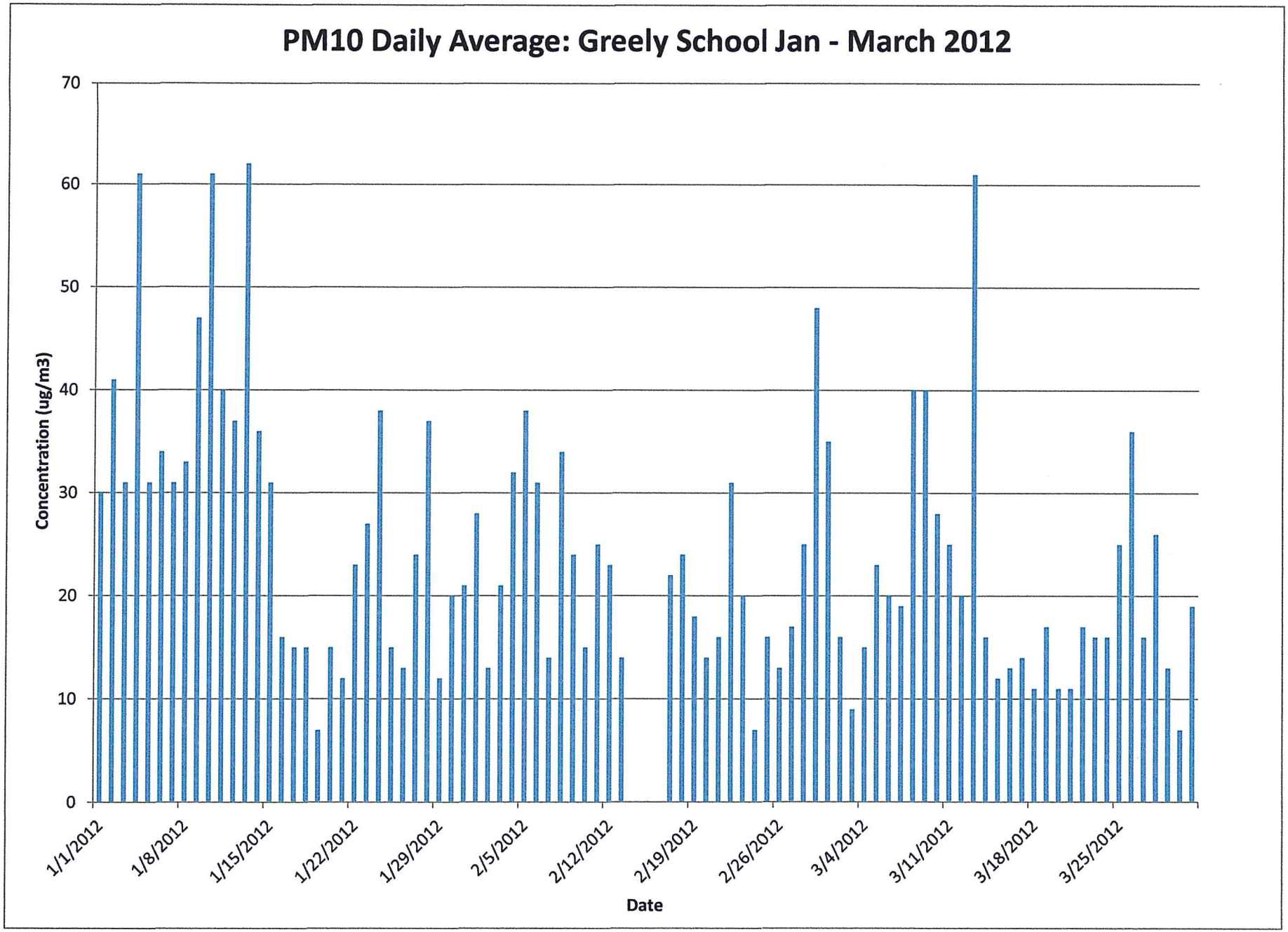

PM-10 Daily Average: Greely School Oct-Dec 2010
120
100
80
60
40
20
0
Concentration (ug/m3)
10/1/2010
10/8/2010
10/15/2010
10/22/2010
10/29/2010
11/5/2010
11/12/2010
11/19/2010
11/26/2010
12/3/2010
12/10/2010
12/17/2010
12/24/2010
12/31/2010
Date

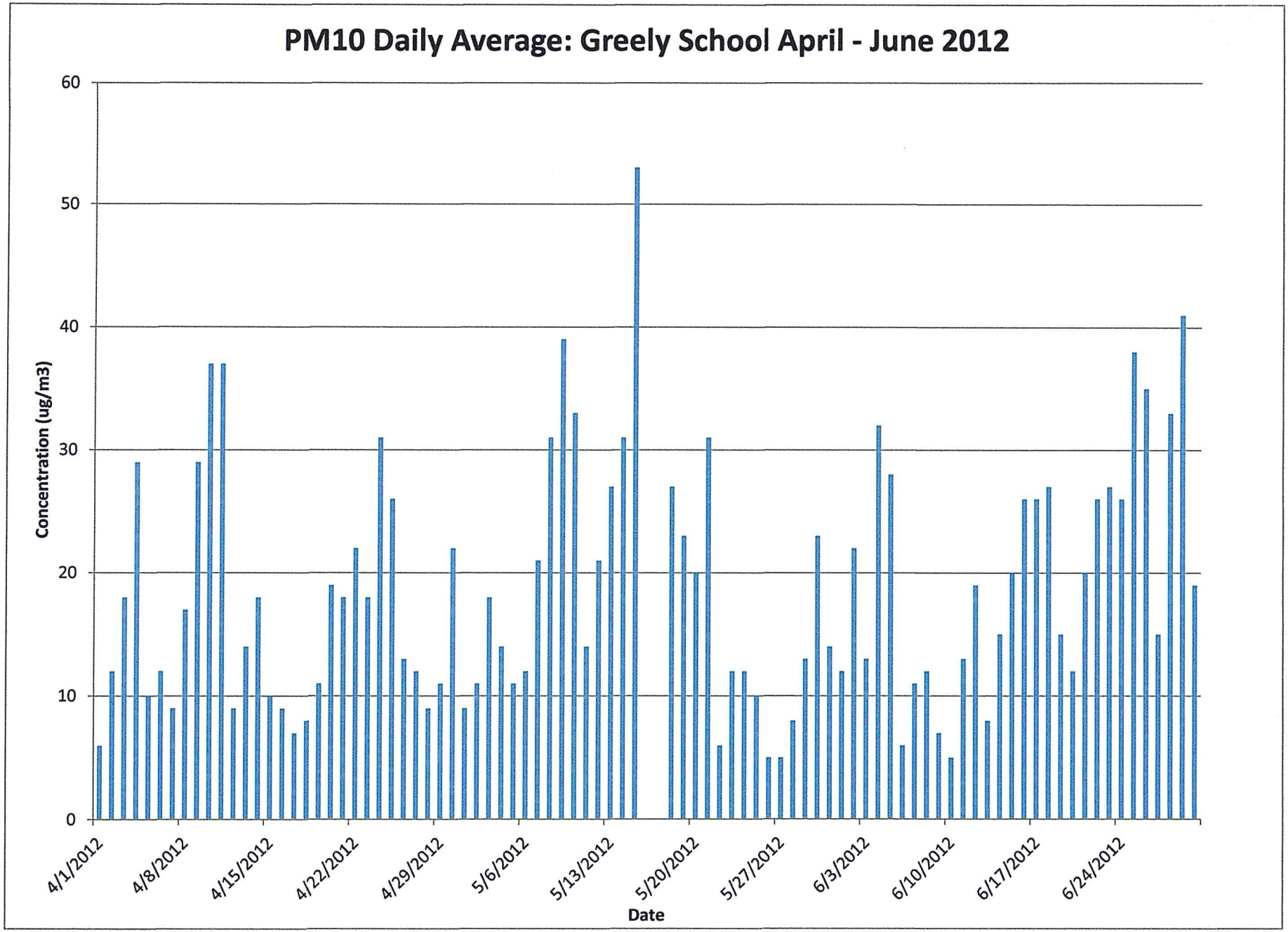

PM10 Daily Average: Greely School Jan to March 2011
Concentration (ug/m3)
180
160
140
120
100
80
60
40
20
0
1/1/2011
1/8/2011
1/15/2011
1/22/2011
1/29/2011
2/5/2011
2/12/2011
2/19/2011
2/26/2011
3/5/2011
3/12/2011
3/19/2011
3/26/2011
Date


PM10 Daily Average: Greely School April-June 2011
Concentration (ug/m3)
180
160
140
120
100
80
60
40
20
0
4/1/2011
4/8/2011
4/15/2011
4/22/2011
4/29/2011
5/6/2011
5/13/2011
5/20/2011
5/27/2011
6/3/2011
6/10/2011
6/17/2011
6/24/2011
Date


PM10 Daily Average: Greely School July to Sept 2011
Concentration (ug/m3)
180
160
140
120
100
80
60
40
20
0
7/1/2011
7/8/2011
7/15/2011
7/22/2011
7/29/2011
8/5/2011
8/12/2011
8/19/2011
8/26/2011
9/2/2011
9/9/2011
9/16/2011
9/23/2011
9/30/2011
Date


PM10 Daily Average: Greely School Oct to Dec 2011
Concentration (ug/m3)
180
160
140
120
100
80
60
40
20
0
10/1/2011
10/8/2011
10/15/2011
10/22/2011
10/29/2011
11/5/2011
11/12/2011
11/19/2011
11/26/2011
12/3/2011
12/10/2011
12/17/2011
12/24/2011
12/31/2011
Date


PM10 Daily Average: Greely School Jan - March 2012
70
60
50
40
30
20
10
0
Concentration (ug/m3)
1/1/2012
1/8/2012
1/15/2012
1/22/2012
1/29/2012
2/5/2012
2/12/2012
2/19/2012
2/26/2012
3/4/2012
3/11/2012
3/18/2012
3/25/2012
Date


PM10 Daily Average: Greely School April - June 2012
Concentration (ug/m3)
60
50
40
30
20
10
0
4/1/2012
4/8/2012
4/15/2012
4/22/2012
4/29/2012
5/6/2012
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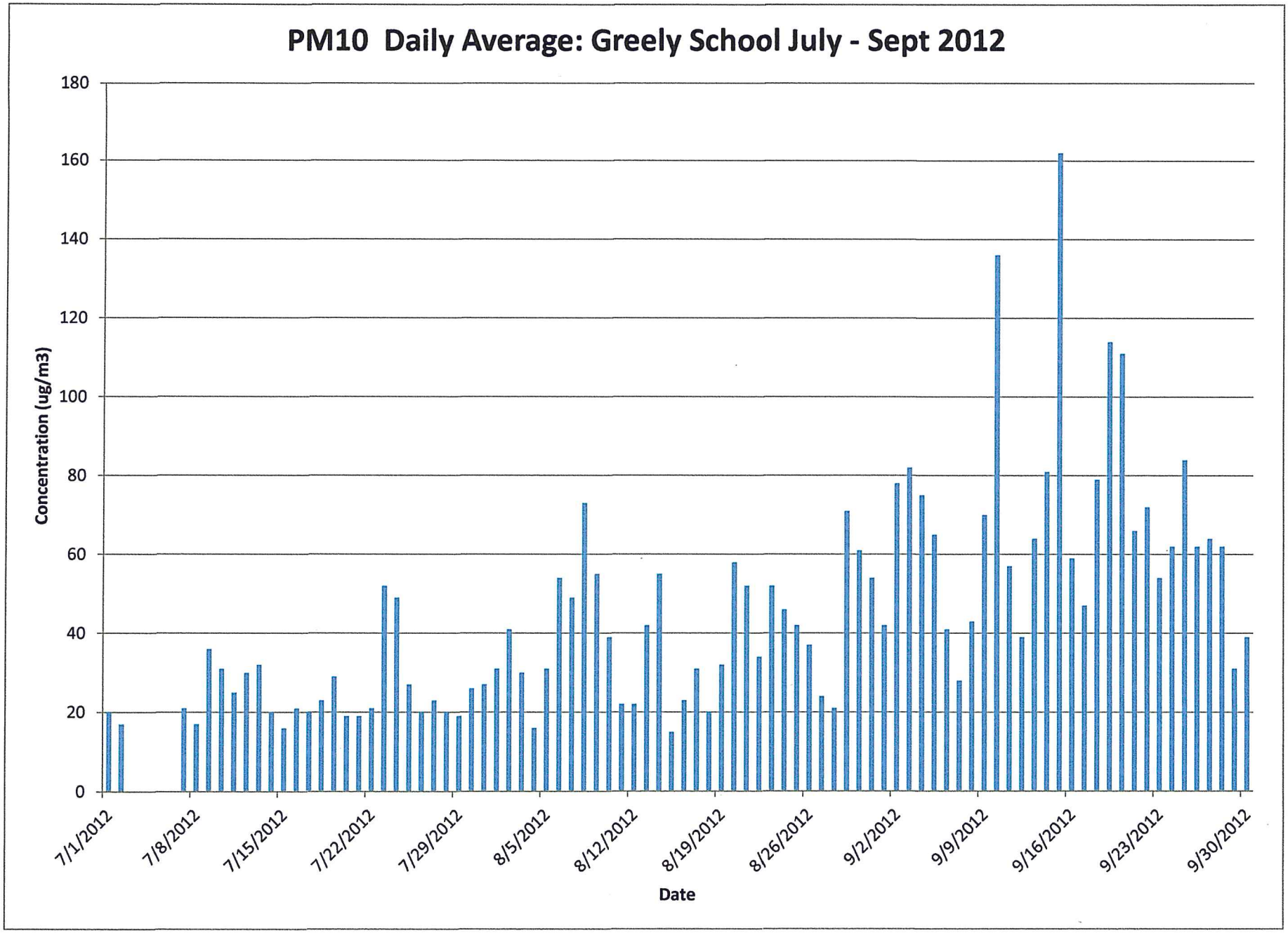
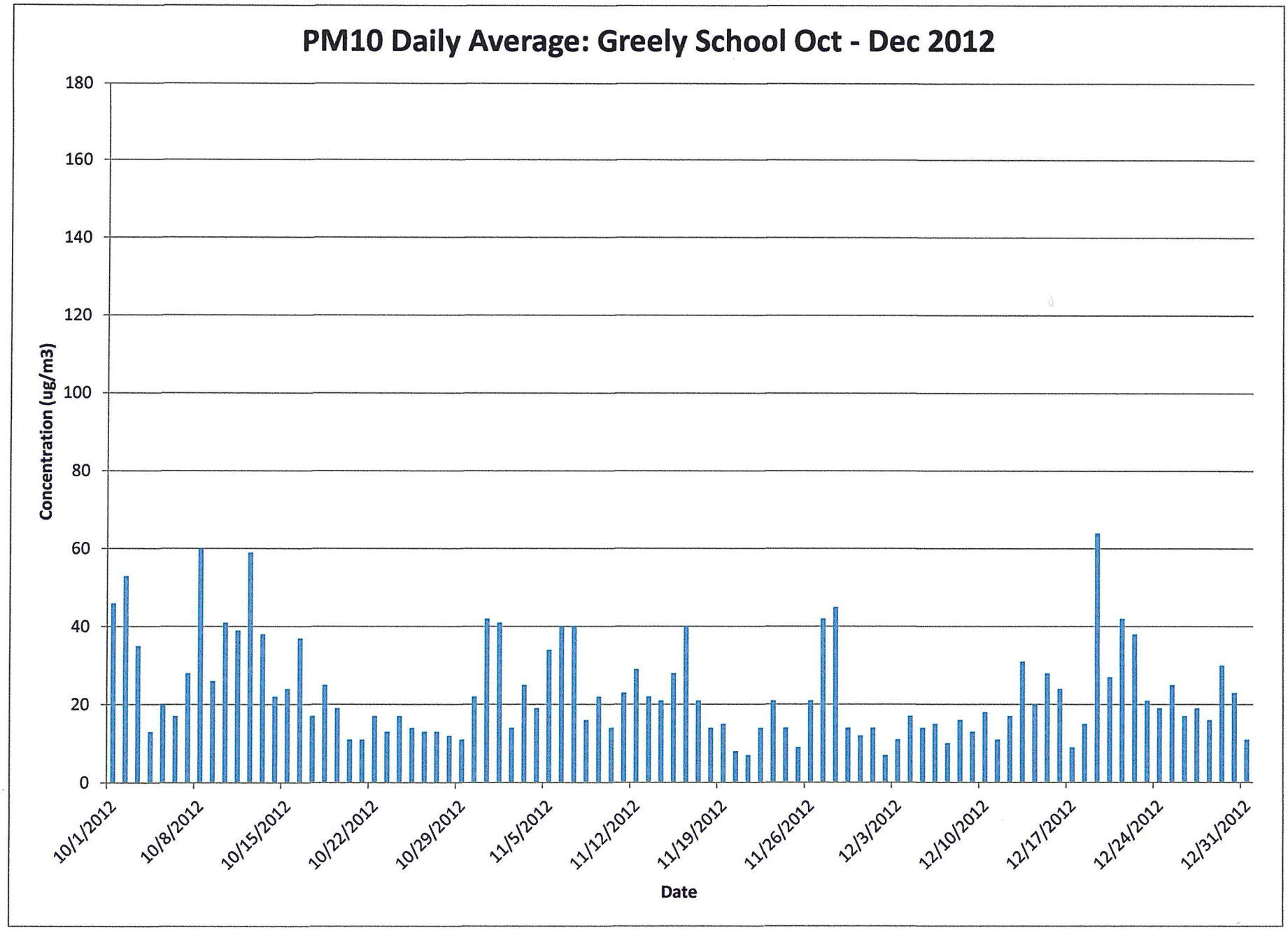
6/10/2012
6/17/2012
6/24/2012
Date


PM10 Daily Average: Greely School July - Sept 2012
Concentration (ug/m3)
180
160
140
120
100
80
60
40
20
0
7/1/2012
7/8/2012
7/15/2012
7/22/2012
7/29/2012
8/5/2012
8/12/2012
8/19/2012
8/26/2012
9/2/2012
9/9/2012
9/16/2012
9/23/2012
9/30/2012
Date

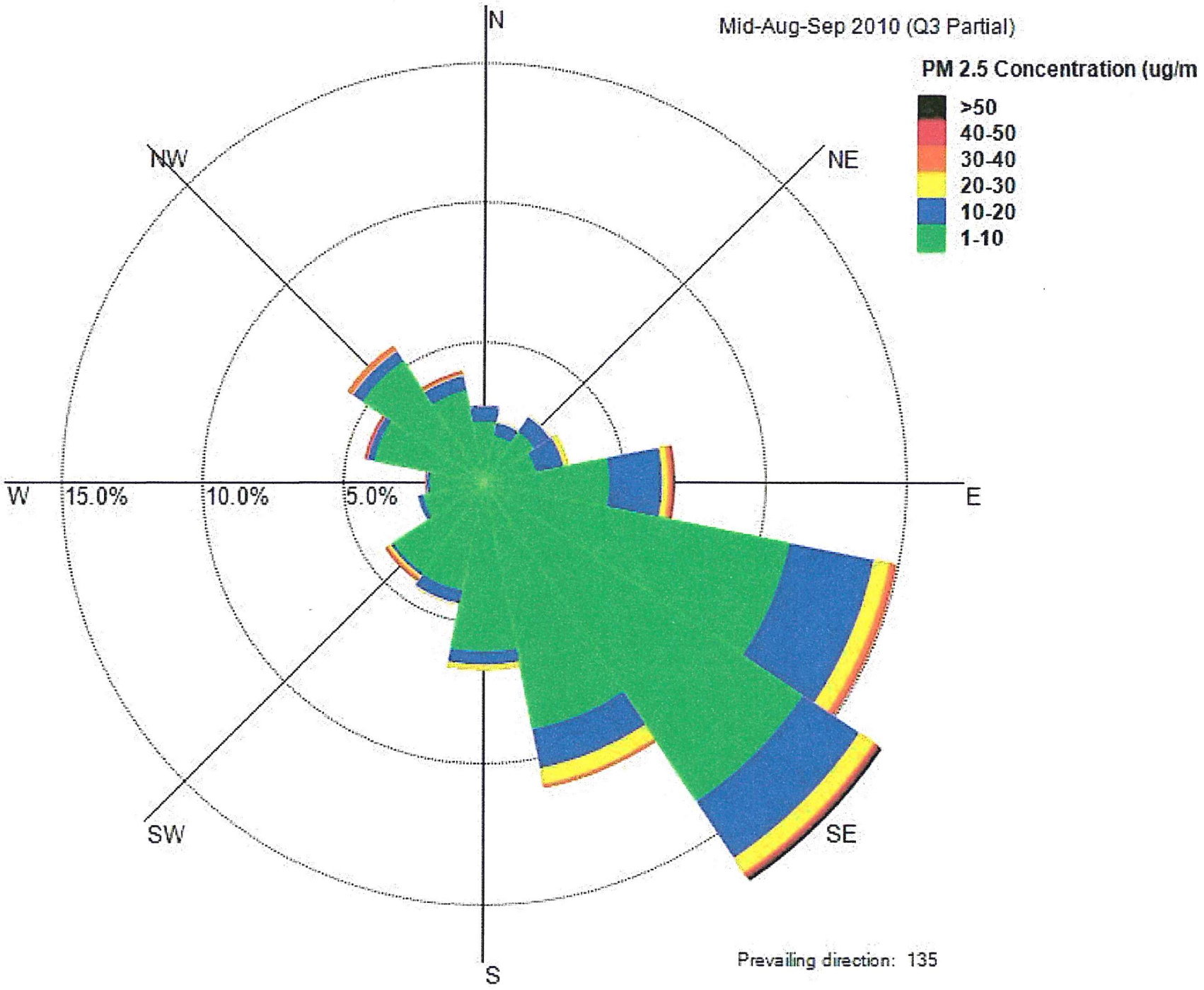

PM10 Daily Average: Greely School Oct - Dec 2012
Concentration (ug/m3)
180
160
140
120
100
80
60
40
20
0
10/1/2012
10/8/2012
10/15/2012
10/22/2012
10/29/2012
11/5/2012
11/12/2012
11/19/2012
11/26/2012
12/3/2012
12/10/2012
12/17/2012
12/24/2012
12/31/2012
Date

Appendix B

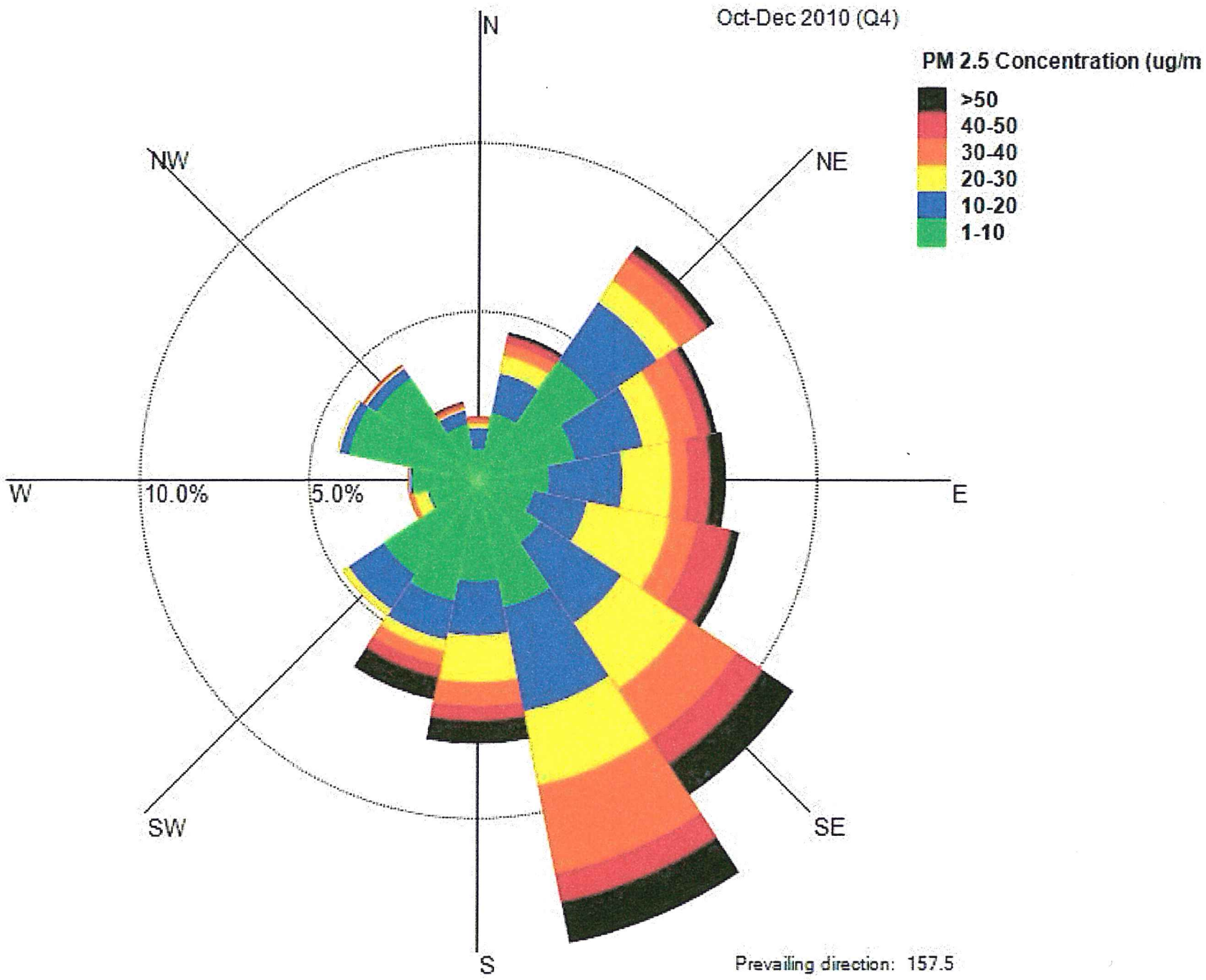
$PM_{2.5}$ Pollution Roses

For Greely School

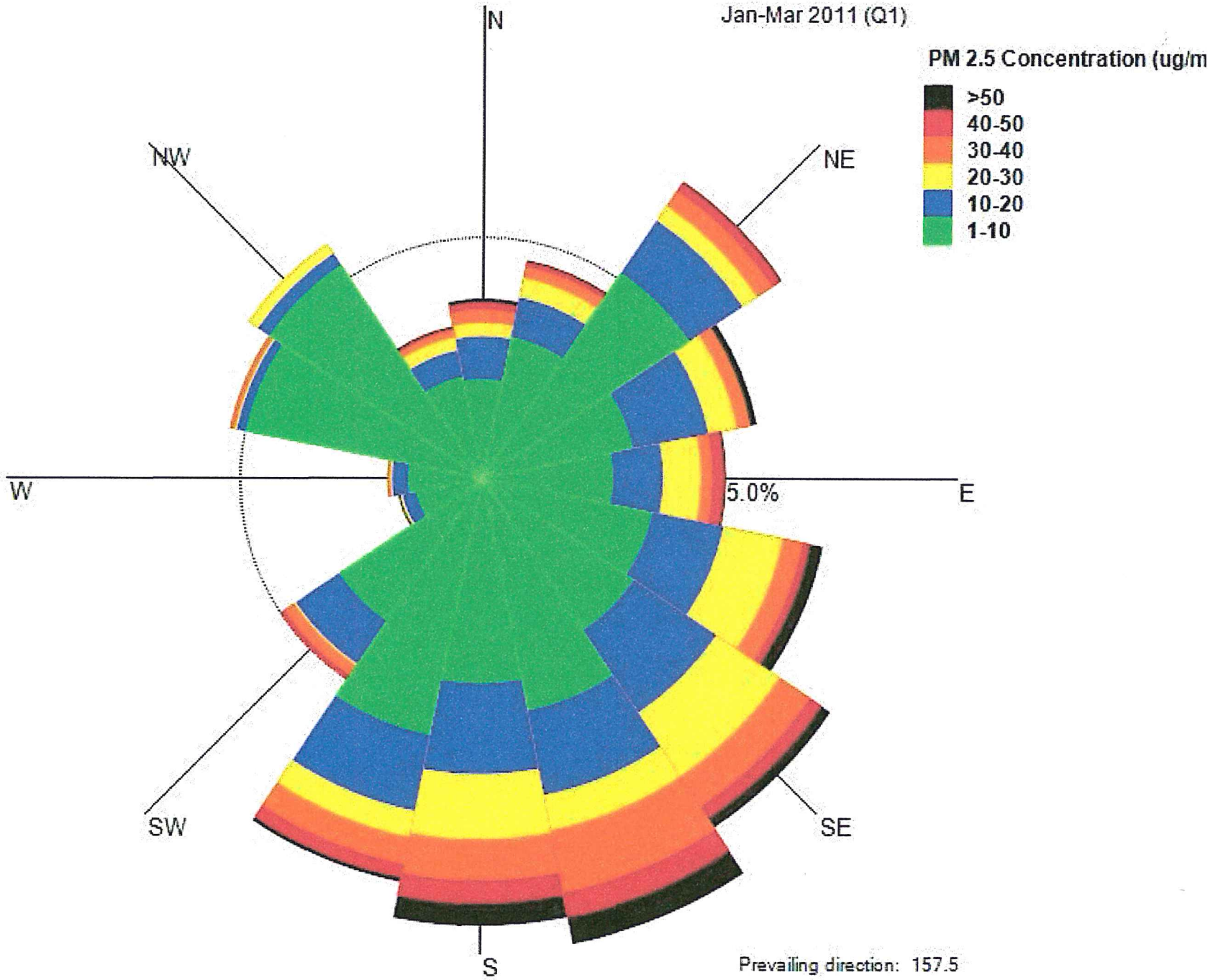
Hourly PM 2.5 Pollution Rose: Butte, MT Greeley School



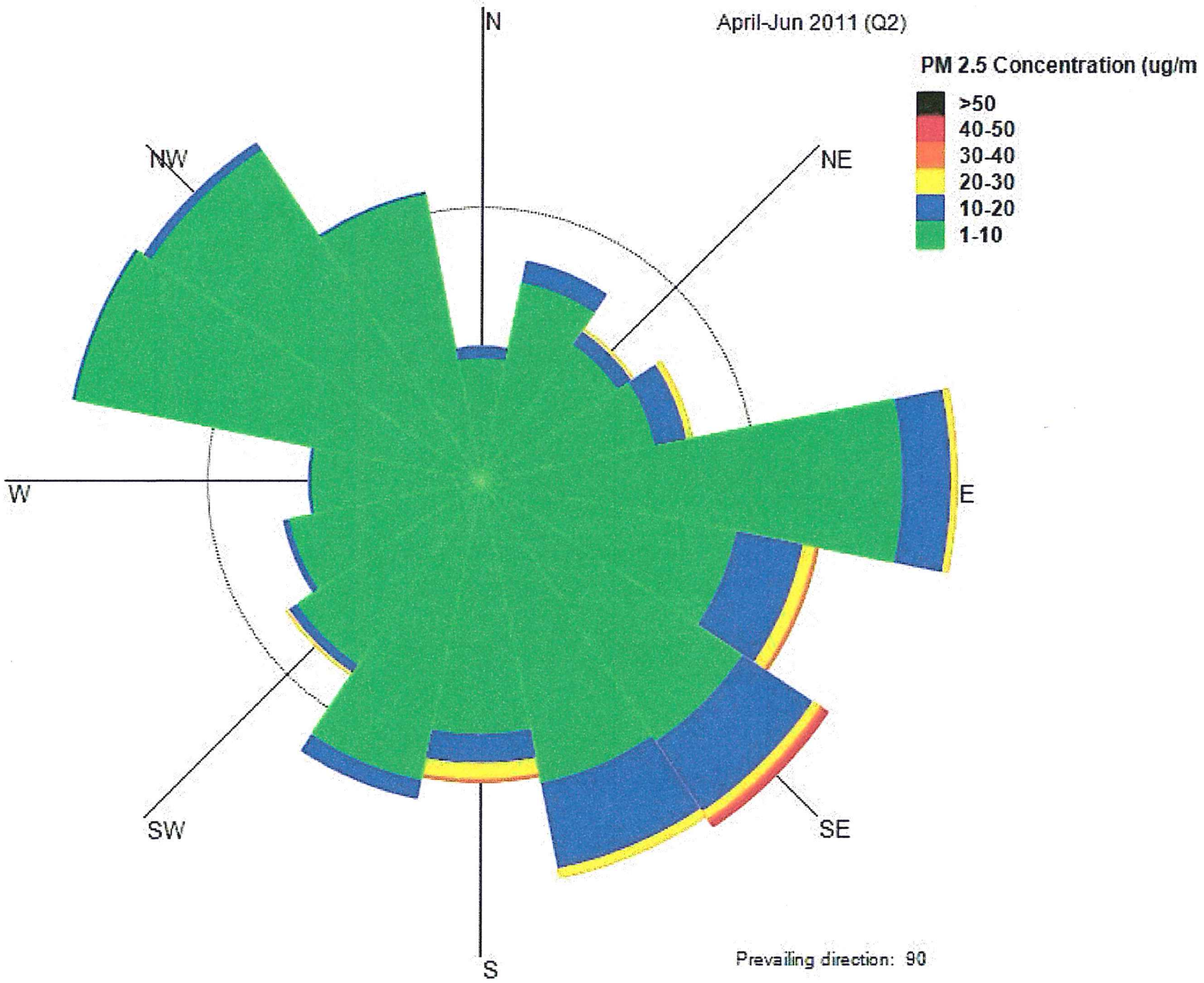
Hourly PM 2.5 Pollution Rose: Butte, MT Greeley School



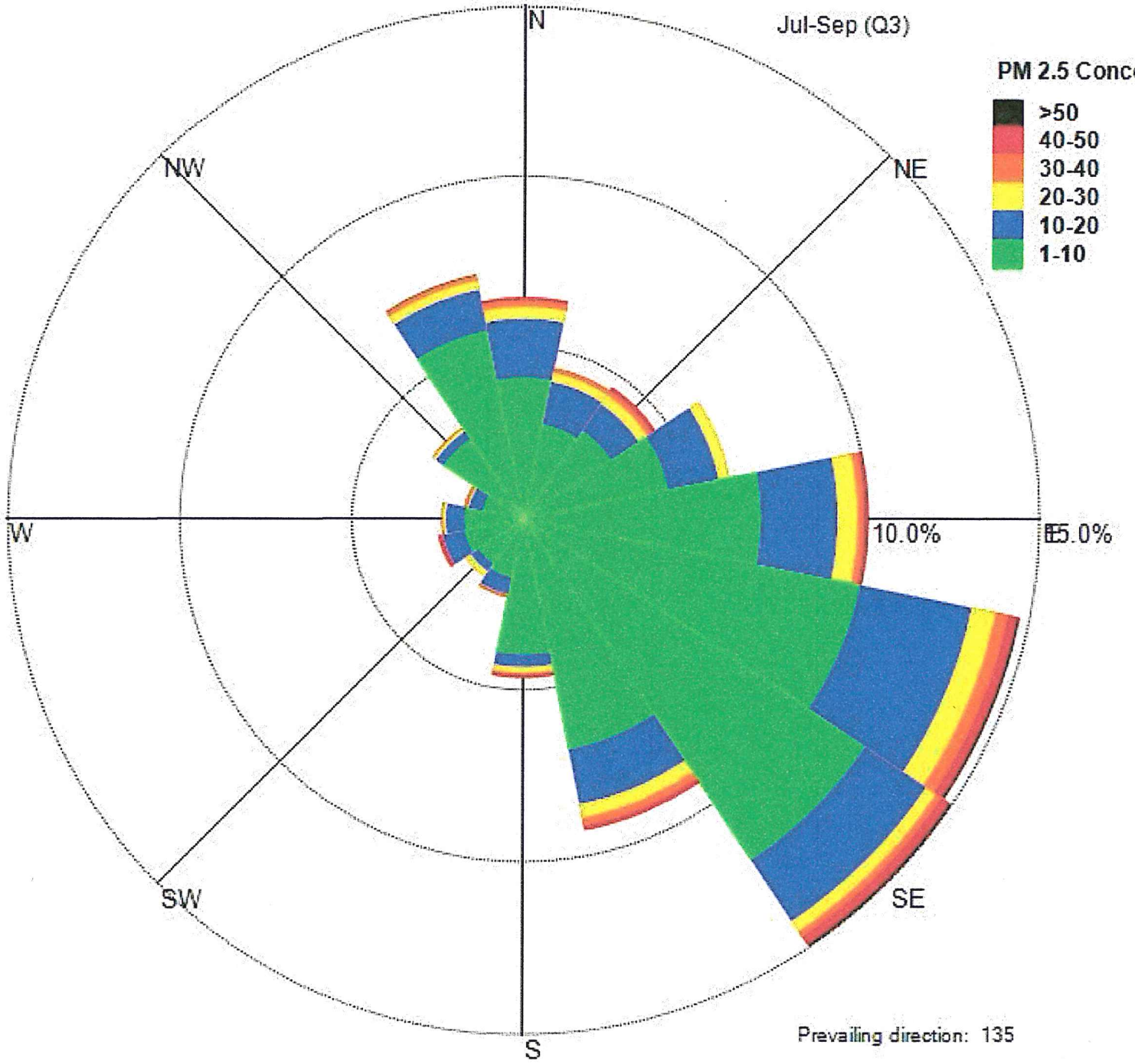
Hourly PM 2.5 Pollution Rose: Butte, MT Greeley School



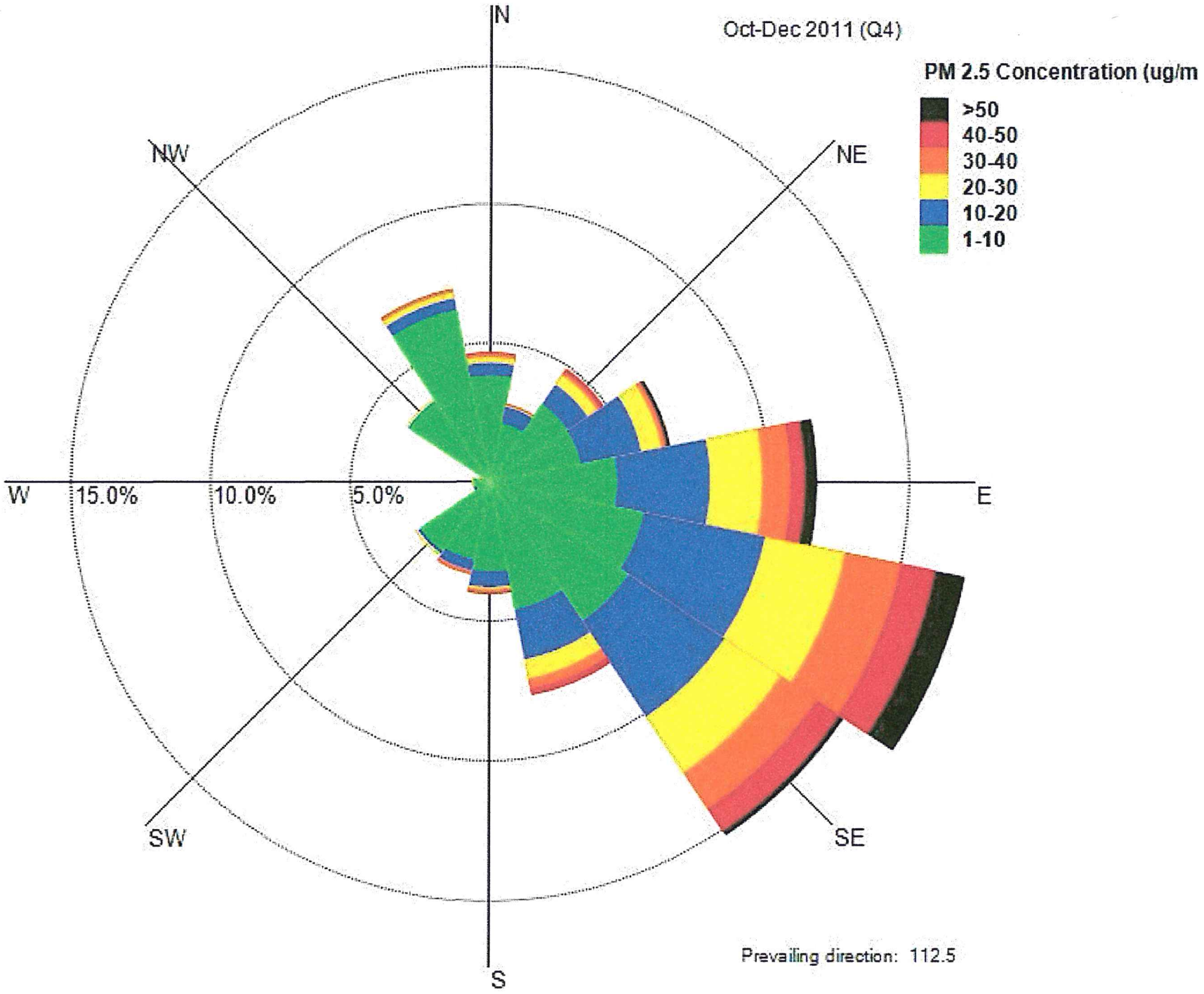
Hourly PM 2.5 Pollution Rose: Butte, MT Greeley School



Hourly PM 2.5 Pollution Rose: Butte, MT Greeley School



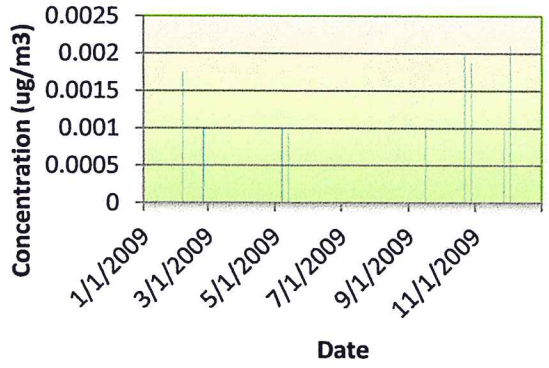
Hourly PM 2.5 Pollution Rose: Butte, MT Greeley School



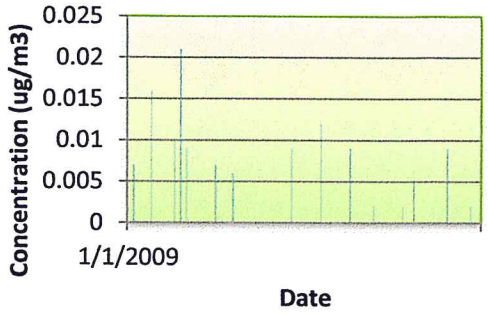
Appendix C

$PM_{2.5}$ Metal Concentrations For Greely School

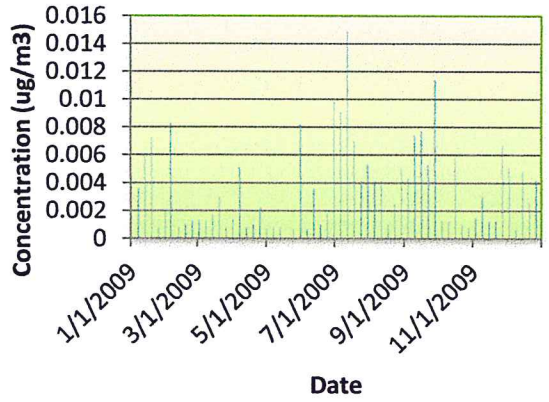
Arsenic in 24 Hour PM2.5: Greely School 2009



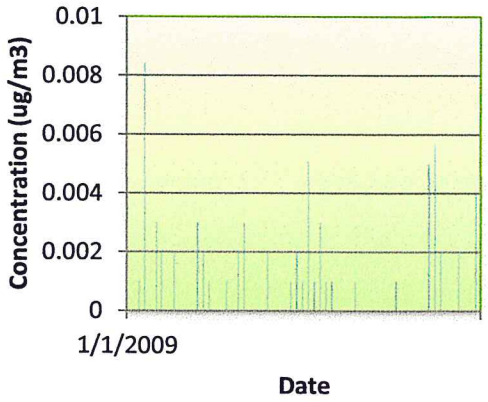
Cadmium in 24 Hour PM2.5: Greely School 2009



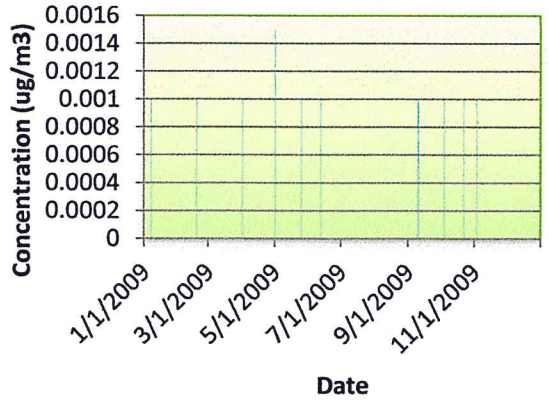
Copper in 24 Hour PM2.5: Greely School 2009



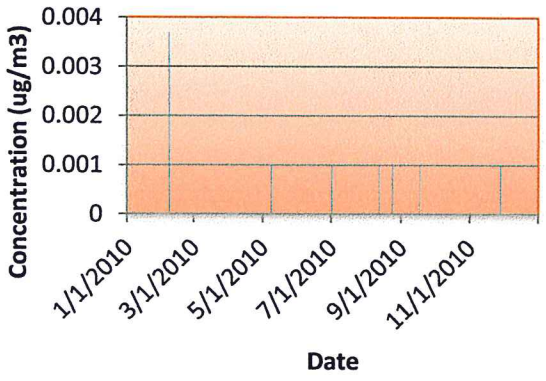
Lead in 24 Hour PM2.5: Greely School 2009



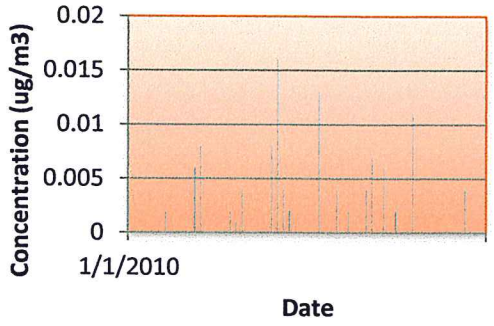
Nickel in 24 Hour PM2.5:Greely School 2009



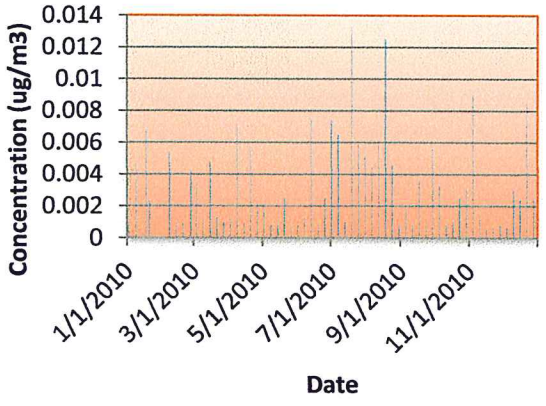
Arsenic in 24 Hour PM2.5:Greely School 2010



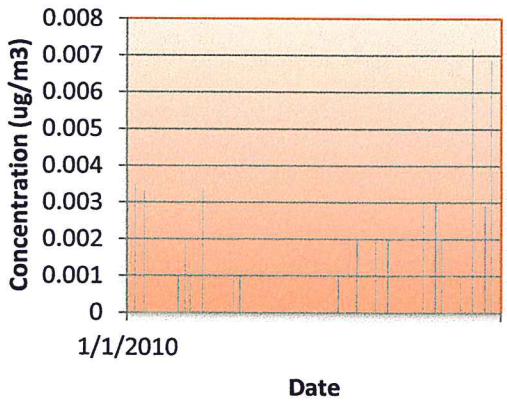
Cadmium in 24 Hour PM2.5:Greely School 2010



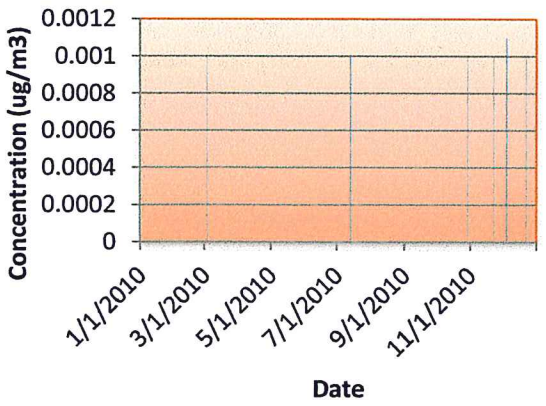
Copper in 24 Hour PM2.5: Greely School 2010



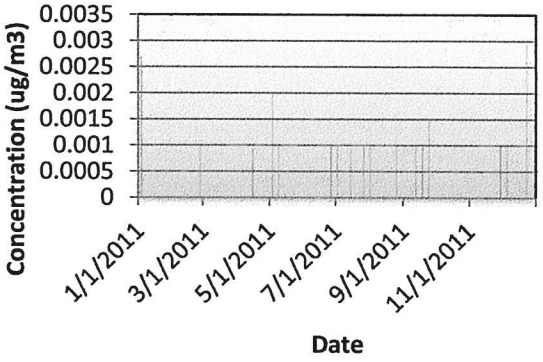
Lead in 24 Hour PM2.5: Greely School 2010



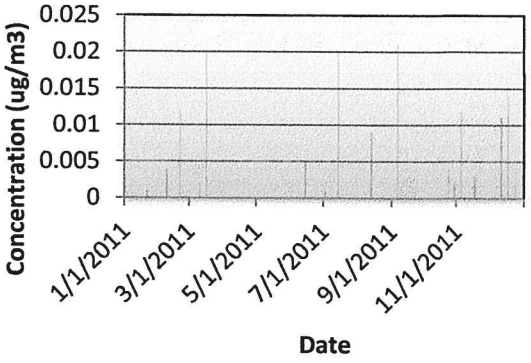
Nickel in 24 Hour PM2.5: Greely School 2010



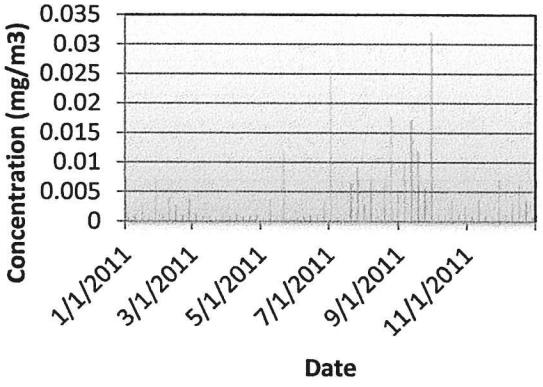
Arsenic in 24 Hour PM2.5:Greely School 2011



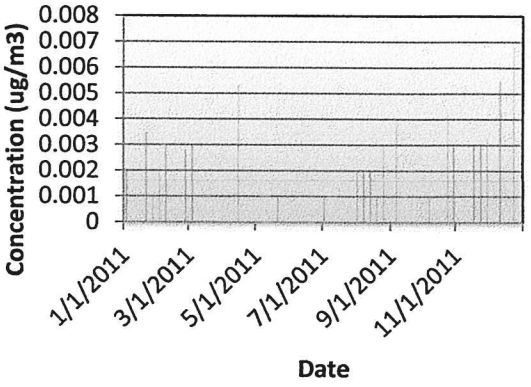
Cadmium in 24 Hour PM2.5: Greely School 2011



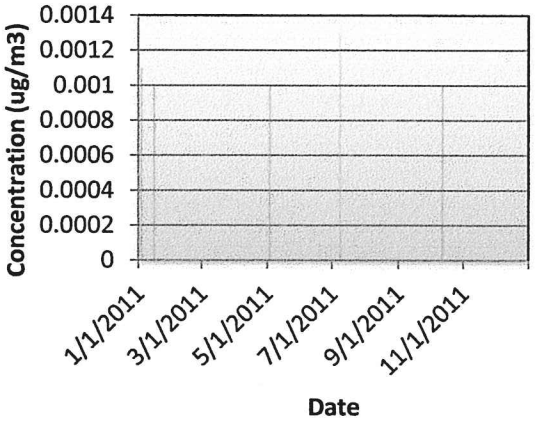
Copper in 24 Hour PM2.5: Greely School 2011



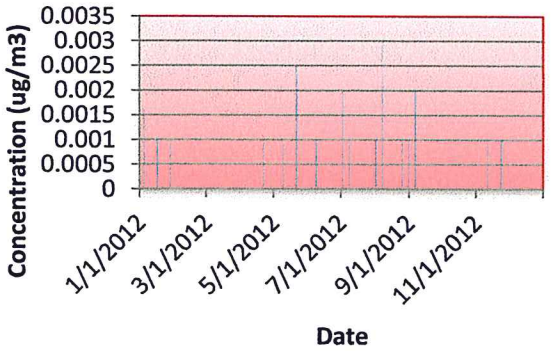
Lead in 24 Hour PM2.5:Greely School 2011



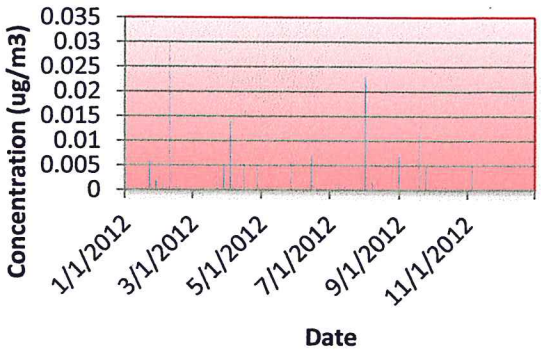
Nickel in 24 Hour PM2.5: Greely School



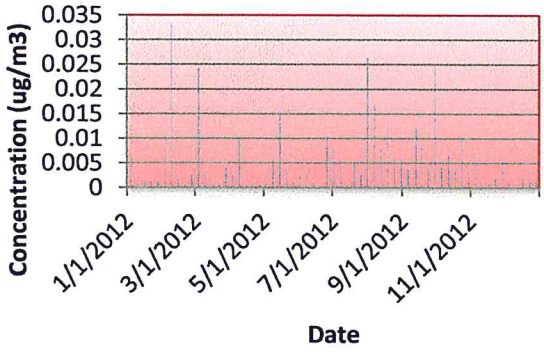
Aresenic in 24 hour PM2.5: Greely School 2012



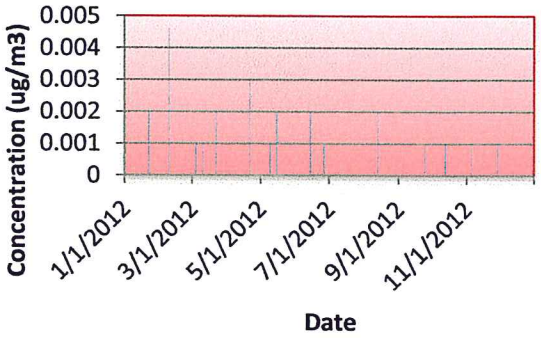
Cadmium in 24 Hour PM2.5:Greely School 2012



Copper in 24 Hour PM2.5:Greely School 2012



Lead in 24 Hour PM2.5: Greely School 2012



Nickel in 24 Hour PM2.5: Greely School 2012