Health Consultation

Exposure Investigation

Airborne Exposures to Particulate Matter and Silica Dust in
Valley School

VALLEY SCHOOL
VALLEY, WASHINGTON

JULY 30, 2019

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Agency for Toxic Substances and Disease Registry
Division of Community Health Investigations
Atlanta, Georgia 30333

Health Consultation: A Note of Explanation

An ATSDR health consultation is a verbal or written response from ATSDR to a specific request for information about health risks related to a specific site, a chemical release, or the presence of hazardous material. In order to prevent or mitigate exposures, a health consultation may lead to specific actions such as restricting use of or replacing water supplies, intensifying environmental sampling, restricting site access, or removing the contaminated material.

In addition, health consultations may recommend additional public health actions such as conducting health surveillance activities to evaluate exposure or trends in adverse health outcomes, conducting biological indicators of exposure studies to assess exposure, or providing health education for health care providers and community members. This concludes the health consultation process for this site, unless additional information is obtained by ATSDR which, in the Agency's opinion, indicates a need to revise or append the conclusions previously issued.

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Prepared by the
U.S. Department of Health and Human Services
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Acronyms and Abbreviations

Acronym	*Definition*
AQG	Air Quality Guideline
AQI	Air Quality Index
ATSDR	Agency for Toxic Substances and Disease Registry
BAM	beta attenuation monitor
CAPCOA	California Air Pollution Control Officers Association
COV	coefficient of variation
CV	comparison value
DQO	data quality objectives
E-BAM	environmental beta attenuation monitor (MetOne)
Ecology	Washington Department of Ecology
EI	exposure investigation
EPA	(U.S.) Environmental Protection Agency
FRM	Federal Reference Method
IARC	International Agency for Research on Cancer
IBL	information by location
LMC	Lane Mountain Company
$\mu g/m^3$	micrograms per cubic meter
µm	microns
mmHg	millimeter of mercury
NAAQS	National Ambient Air Quality Standards
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NTP	National Toxicology Program
OEHHA	(California) Office of Environmental Health Hazard Assessment
PM	particulate matter
$PM_{2.5}$	particulate matter with aerodynamic diameter less than or equal to 2.5 microns
PM_4	particulate matter with aerodynamic diameter less than or equal to 4 microns
PM_{10}	particulate matter with aerodynamic diameter less than or equal to 10 microns
REL	Reference Exposure Level
SO_2	sulfur dioxide
UCL	upper confidence limit (95% upper confidence limit of the mean)
WDOH	Washington Department of Health
WHO	World Health Organization
WL&I	Washington Department of Labor and Industries
WTN	Washington Tracking Network

Executive Summary

The Valley School campus houses Valley Elementary (K-8) School, Valley Early Learning Center, Paideia High School, and Columbia Virtual Academy and is located in Valley, Washington. The school has been operational since the 1880s and has undergone several upgrades and expansions. In 1992 during an upgrade and repair of the roof, workers found a large quantity of sand in the ceiling system of one of the buildings at Valley School. Lane Mountain Company (LMC), the Northwest's largest silica sand production facility, is directly across the street from the Valley School campus (see Figure 1). LMC has been in operation at their current site since 1961 [LMC 2016].

Following the discovery of sand in the ceiling during the 1992 roof repairs, Valley School contacted the Washington State Department of Ecology (Ecology) with concerns about silica dust impacts. Since 1992, there have been additional concerns raised about health risks to children from silica dust exposure that have led to involvement of additional agencies (Northeast Tri-County Health District, the Washington State Department of Health, and the Agency for Toxic Substances and Disease Registry (ATSDR)). Multiple ambient air quality monitoring projects for particulate matter with aerodynamic diameter of 10 microns (PM_{10}) or less have been conducted at Valley School and LMC since 2008. Ecology established a permanent PM_{10} monitor on the school campus in 2010.

In 2013, ATSDR recommended that mineralogical characterization of the measured PM_{10} would be necessary to assess the potential health risk from crystalline silica [ATSDR 2013]. ATSDR provided a strategy to identify previously collected PM_{10} filters for silica analysis [ATSDR 2014]. The Washington Department of Labor and Industries (WL&I) volunteered to provide silica analysis of a subset of the Federal Reference Monitor (FRM) samples collected from LMC. However, because there were only silica data from a single location, and that location was not at the school, the WL&I samples did not provide a definitive conclusion regarding silica exposure.

The Washington Department of Health (WDOH) requested an exposure investigation from ATSDR to better characterize the school and community's exposure to silica. ATSDR designed this exposure investigation (EI) to evaluate exposure to respirable silica and particulate matter. Sulfur dioxide (SO_2) was also collected, as a measure of automobile and bus traffic, to determine its contribution to particulates in the area. From July through September 2016, ATSDR collected information from nine sites throughout the area: inside and outside at the Valley School campus, in a nearby residential area, and a location more distant in another direction from LMC. Various averaging times up to one day were used to assess acute exposures while the average over the entire EI was used to assess chronic exposures.

All pollutants were detected over the course of the EI. The measured concentrations were compared to chemical-specific, health-based comparison values (CVs) from the World Health Organization (WHO), the U.S. Environmental Protection Agency (EPA), and the California Office of Environmental Health Hazard Assessment (OEHHA). ATSDR, in an effort to ensure that the community has the best information possible to safeguard its health, has drawn four conclusions based on the air pollutants measured in Valley (see the following Conclusions Section).

Since ATSDR completed the data collection phase of the exposure investigation, Ecology and LMC have agreed to implement changes that are expected to reduce the LMC impacts on the nearby

community. At the time of the release of this health consultation, the magnitude of any exposure reductions from these actions are unknown.

Conclusions

Conclusion 1

ATSDR concludes that breathing PM_{10} on the campus of Valley School could harm some people's health. The primary concern for exposure is to sensitive populations.

Basis for Conclusion 1

The upper confidence limit (UCL) of the mean of PM_{10} concentrations at both PM_{10} monitors were above the WHO annual guideline for PM_{10} (20 microgram per cubic meter [$\mu g/m^3$]). At one location close to the school (Site 5), one of fourteen 24-hour averages of PM_{10} (57 $\mu g/m^3$) was above the WHO 24-hour air quality guideline (AQG) for PM_{10} (50 $\mu g/m^3$) but below the 24-hour National Ambient Air Quality Standard (NAAQS) of 150 $\mu g/m^3$. During the exposure investigation, the permanent PM_{10} station at Valley School had 25 of 54 days with 24-hour average concentrations over 50 $\mu g/m^3$, but no days over 150 $\mu g/m^3$.

Over the past four years (2014 – 2017) at the permanent PM_{10} station, nine days had 24-hour PM_{10} concentrations greater than 150 $\mu g/m^3$ (24-hour NAAQS for PM_{10}), and approximately 25% of days had concentrations greater than 50 $\mu g/m^3$ (WHO 24-hour AQG for PM_{10}). Applying the EPA Air Quality Index (AQI), 1 day (0.1%) was designated as unhealthy, 8 days (0.7%) were designated as unhealthy for sensitive groups, and 259 days (21.3%) were moderate. On days that are designated "moderate", a very small number of "unusually sensitive"[1] individuals may experience health effects; for those designated "unhealthy for sensitive individuals", there is an increasing likelihood of respiratory symptoms and aggravation of lung disease, such as asthma; on days designated as unhealthy, respiratory effects are expected in the general population. Only one day in four years presented a public health concern for healthy adults.

Conclusion 2

Breathing respirable crystalline silica characterized as PM_4 (particulate matter with aerodynamic diameter of 4 microns or less) on the campus of Valley School and in the surrounding area presents a potential chronic public health hazard to students, staff, and residents.

Basis for Conclusion 2

The UCL of PM_4 crystalline silica measured during the EI was greater than 3 $\mu g/m^3$ (reference exposure level [REL] developed by OEHHA) at all monitoring locations on the campus of Valley School as well as at two locations in the nearby community. ATSDR evaluated two scenarios for exposure to silica. First, a conservative (worst-case) exposure scenario assumes exposure 24-hours a day for a lifetime at the UCL concentration from Site 5 (school) during the EI (5.12 $\mu g/m^3$). The second scenario evaluates a more realistic exposure point concentration (2.71 $\mu g/m^3$) that considers the time spent away from school at lower concentrations and the fact that this EI was designed to capture the highest exposures.

[1] EPA does not formally define "unusually sensitive", but it is a qualitative designation of personal vulnerability to PM possible due to the inherent differences among individuals.

Chronic inhalation of respirable crystalline silica particles may cause silicosis and is associated with increased risk of lung cancer. The International Agency for Research on Cancer (IARC) and the U.S. National Toxicology Program (NTP) have designated respirable crystalline silica as a human carcinogen. In addition, inhalation of crystalline silica has been associated with other respiratory diseases such as chronic obstructive pulmonary disease, bronchitis and emphysema, as well as kidney and autoimmune system diseases.

Conclusion 3

Concentrations of PM_{10} and PM_4 crystalline silica measured during the EI were highest on Valley School campus when winds are from the southwest (the direction of LMC relative to the school campus). These wind conditions are more common in the spring and summer than other times of year. Concentrations of PM_4 indoors are approximately four times lower than concentrations of PM_4 outdoors.

Basis for Conclusion 3

PM_{10} and PM_4 crystalline silica are highest at monitors closest to the facility. Polar plots from all PM monitors at the school show the highest concentrations when winds are from the direction of LMC.

Conclusion 4

Breathing particulate matter with aerodynamic diameter of 2.5 microns or less ($PM_{2.5}$) on the campus of Valley School and in the surrounding area does not present a public health hazard to the general and sensitive population of students, staff, or residents. ATSDR recognizes that some individuals (e.g., asthmatics or those with other cardiopulmonary conditions) are unusually sensitive to changes in air quality, and as such, those individuals may still experience transient health effects during days with poorer air quality, regardless of whether concentrations exceed health-based values like the WHO AQGs.

Basis for Conclusion 4

All 24-hour concentrations of $PM_{2.5}$ were below the 24-hour WHO guideline for $PM_{2.5}$ (25 $\mu g/m^3$). The average $PM_{2.5}$ concentration during the entire EI was below the annual WHO AQG (10 $\mu g/m^3$) at all sites except Site 2 (10.5 $\mu g/m^3$) at the school. Since data from the permanent PM_{10} monitor show that concentrations during the EI were approximately 20% higher than the long-term average, and assuming similar relative concentrations of $PM_{2.5}$ and PM_{10}, it is likely that the concentrations measured during the EI represent a reasonable upper estimate of exposure.

Limitations

ATSDR acknowledges that this EI, like all field measuring programs, has some limitations. Those limitations include:

The measurement period for this EI was eight weeks and may not be representative of long-term exposure. Monitoring/sampling was conducted at fixed, stationary locations; however, people move around, and do not remain in one place all day long. Therefore, the data collected at the fixed locations are not directly equivalent to actual exposures that occurred.

The data were collected during this EI from July 22 to September 27, 2016. ATSDR attempted to sample during the worst conditions (based on previous data from a PM_{10} monitor in the area), and the eight weeks of data were used as a protective estimate of community exposures throughout the year. ATSDR notes that this sampling strategy may result in elevated annual estimates of contaminant concentrations.

ATSDR is unable to assess the potential for health hazard from breathing SO_2 because the air conditioning system was not functional in the school building in which the SO_2 monitor was located.

Recommendations

ATSDR makes the following recommendations to reduce exposure to PM_{10} and PM_4 crystalline silica on the campus of Valley School and in the surrounding area.

1. LMC should confirm that the efforts implemented via the 2017 Administrative Order to reduce emissions of PM_{10} and PM_4 crystalline silica from their operations have resulted in reduced exposure to particulate matter and crystalline silica in the surrounding area.

2. LMC should make permanent station PM_{10} data available to Valley School District in real-time to assist in decision-making on when to limit outdoor activity on the school campus.

3. Valley School District should limit outdoor activity when concentrations of PM_{10} are above 50 $\mu g/m^3$ in outdoor air or in the AQI moderate category.

4. If real-time data are not available, Valley School should limit outdoor activity on campus when strong winds from the southwest are present since those conditions are most likely to result in elevated concentrations of PM_{10} and PM_4 crystalline silica on school grounds. If no wind direction measurements are available from Valley School, LMC could install a windsock to inform decision makers about wind directions.

5. LMC should conduct regular calibration checks and audits of the permanent PM_{10} monitor.

Purpose of the Exposure Investigation

At the request of the Washington Department of Health (WDOH), the Agency for Toxic Substances and Disease Registry (ATSDR) conducted an exposure investigation (EI) to assess human exposure to crystalline silica dust in ambient (outdoor) and indoor air at the Valley School campus and nearby residential properties in Valley. Crystalline silica dust is of concern to parents, residents, and the Valley School District because of the proximity to Lane Mountain Company (LMC) to the Valley School campus and to residential properties in the town of Valley.

During this EI, a community-based ambient air and limited indoor air monitoring program was conducted over eight weeks during the summer and early fall of 2016 (July 27 through September 22, 2016). ATSDR conducted sampling to obtain representative community-based concentrations of crystalline silica measured in respirable particulate matter with 50% cutoff at aerodynamic diameter of 4 microns (µm) (PM_4), particulate matter with aerodynamic diameter of 10 µm or less (PM_{10}), particulate matter with aerodynamic diameter of 2.5 µm or less ($PM_{2.5}$), sulfur dioxide (SO_2), and site-specific meteorological parameters.

ATSDR designed this investigation to evaluate community exposures and the associated health effects to the selected pollutants and not to determine regulatory compliance with National Ambient Air Quality Standards (NAAQS). While this information was not collected for a regulatory purpose, the results could be used to inform potential actions.

Background and Community Concerns

LMC operates a silica processing operation in Valley, WA along the west side of Highway 231 approximately forty-five miles northwest of Spokane, WA. The facility started operating in 1961 and covers approximately 18 acres. LMC specializes in the production of high purity, low iron silica sand. Crystalline silica content of this product is 99.4%. LMC is one of the largest producers of silica sand in the Pacific Northwest. Sand from LMC is used in glass, golf courses, filtration, foundry, white cement, cement siding, roofing, traction, horse arenas, and industrial filler [LMC 2016].

The Valley School campus is situated directly across Highway 231 from LMC (Figure 1). The school campus includes an Elementary (K-8) School, Early Learning Center, Paideia High School, and Columbia Virtual Academy. The school has been operational since the 1880s and has undergone several upgrades and expansions. In 1992 during an upgrade and repair of the roof, workers found a large quantity of sand in the ceiling system of one of the buildings at Valley School.

Inhalation of respirable crystalline silica particles may cause silicosis and is associated with increased risk of lung cancer. The International Agency for Research on Cancer (IARC) and the U.S. National Toxicology Program (NTP) have designated respirable crystalline silica as a human carcinogen [IARC 1997, 2012; NTP 2016]. In addition, inhalation of crystalline silica has been associated with other respiratory diseases such as chronic obstructive pulmonary disease, bronchitis and emphysema, as well as kidney and autoimmune system diseases. Many studies have investigated the impact of respiratory exposure to crystalline silica on human health; however, these studies largely focus on workers exposed to silica in varying industries, whose cumulative and

average daily exposure levels are much higher than typical community-based ambient air levels. Moreover, none of the studies included children or other vulnerable populations, nor have there been studies of potential exacerbation of asthma, which may have a more severe impact on children than adults.

The Valley School District contacted the Washington Department of Ecology (Ecology) in 1992 with concerns about silica dust impacts. Ecology began monitoring total suspended particulate at the site in 1992, which resulted in enforcement action to require control of particulate matter and development of a monitoring plan in early 1993. LMC conducted a study to identify additional fugitive dust controls that would minimize impacts to the school, and installed three high volume, total suspended, particulate matter samplers in 1993.

The Valley School District requested additional sampling from Ecology in July of 2008, due to concerns about health risks to children from silica dust exposure. During the process of school campus expansion planning, the Northeast Tri County Health District reviewed building plans, required the school to address the mitigation of any health hazards, and contacted WDOH with health concerns for children breathing silica sand dust at the school.

From September through November of 2008, Ecology monitored ambient air quality at Valley School. A beta attenuation monitor (BAM) measured hourly PM_{10} concentrations. A Thermo Scientific Partisol™ 2000 Federal Reference Method (FRM) PM_{10} monitor using pre-weighed 47-mm Teflon filters collected integrated 24-hour samples either every 3 days or every 6 days.

In February 2009, Ecology shared the results report with Valley School District, LMC, WDOH, and Tri County Health District. All agreed that there were not enough data to inform a health risk assessment, but the data could help with planning next steps. WDOH recommended a baseline standard of 3–5 $\mu g/m^3$ crystalline silica exposure based on the California Office of Environmental Health Hazard Assessment (OEHHA) and U.S. Environmental Protection Agency's (EPA) estimated average ambient and acceptable ambient level [OEHHA 2005; EPA 1996].

Ecology agreed that 3 $\mu g/m^3$ of respirable silica is protective of the general population. LMC collected these data as part of a settlement agreement with Ecology to control fugitive dust emissions from the facility [Washington Pollution Control Hearings Board 2011].
Collection of hourly PM_{10} data at a monitoring site located at Valley School began in 2010. Data from this site are included in this assessment as the "permanent" monitoring location. WDOH contacted ATSDR for assistance in summarizing and examining trends in hourly airborne data. The results indicated that there were significant increases in measured PM_{10} during weekdays and daylight hours, especially when the winds were strong and from the south and southwest. ATSDR analyzed BAM measurements and FRM data from October 2010 to March 2013. A seasonal pattern was observed with PM_{10} concentrations highest during the summer and lowest during the winter with spring and fall as transitional periods. ATSDR recommended that mineralogical characterization of the measured PM_{10} would be necessary to assess the potential health risk and sources [ATSDR 2013].

In February 2014, ATSDR met with Washington Department of Labor and Industries (WL&I), WDOH, Ecology, Tri County Health District, Valley School District, and LMC to discuss options to move forward in assessing potential health risks. ATSDR provided a strategy to identify

previously collected PM_{10} filters for silica analysis [ATSDR 2014]. The FRM collects particulate samples on filters with subsequent weighing in a laboratory. Washington Department of Labor and Industries (WL&I) volunteered to provide silica analysis of a subset of the FRM samples. WL&I digested the original filters provided and redeposited the particulates on silver membrane filters for analysis using X-ray diffractometry. WL&I also performed additional particle identification using scanning electron microscopy with energy dispersive X-ray spectroscopy to confirm particle size and quartz content. However, because there were only data from a single location, and that location was at the school, the WL&I samples did not provide a definitive conclusion regarding silica exposure. Based on the wind direction analysis, additional monitoring locations would be helpful in evaluating community exposure. Therefore, WDOH requested an exposure investigation from ATSDR.

Actions Implemented Since Completion of the EI Data Collection

Since ATSDR completed the data collection phase of the exposure investigation, Ecology and LMC have agreed to implement changes (via Administrative Order dated November 2017) that are expected to reduce the LMC impacts on the nearby community. Those actions are summarized as follows:

“Lane Mountain submitted a Notice of Construction application notifying Ecology Air Quality Program of their intent to replace pollution control equipment. The AQP has reviewed the application and will issue an Approval Order to cover the replacement pollution control equipment and permit the facility operations (the permitting work is currently underway and should be completed in the near future).

Lane Mountain's wet scrubbers (Number 2 and 3) are to be replaced by a single baghouse with a guaranteed grain-loading limit of 0.005 grains/dry standard cubic foot (that is a 95.49 percent reduction in particulate emissions). Lane Mountain has the new baghouse system and is working on getting the ductwork connections designed. Installation is expected to be complete in November 2019.

If Lane Mountain decides or production increases and emission calculations indicate that wet scrubber Number 1 may need replacement to verify compliance with state maximum particulate emission limits as contained in WAC 173-400-060, Lane Mountain will notify Ecology and a new Administrative Order will be issued to document the replacement of that wet scrubber.” [Ecology 2018].

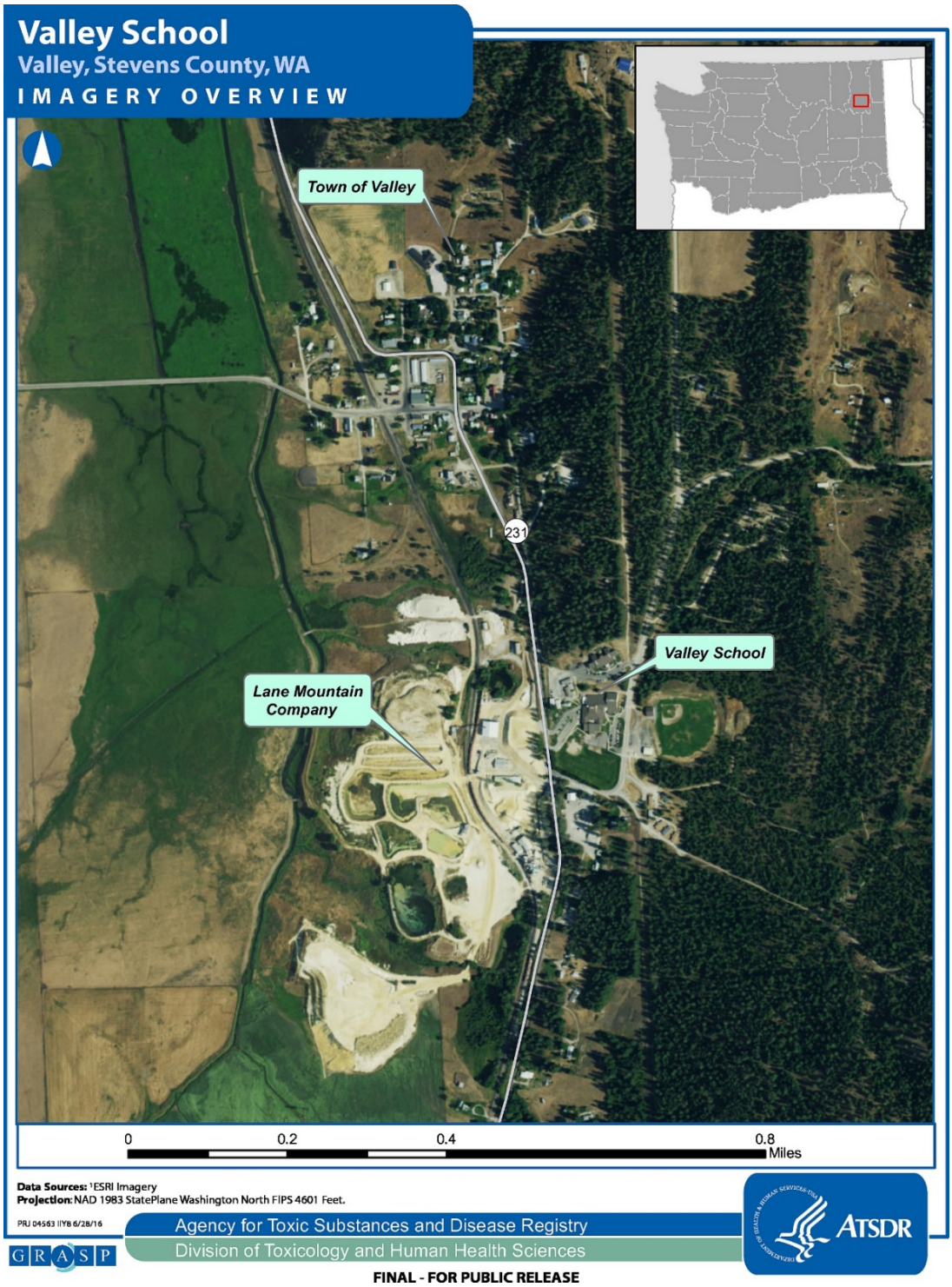


Figure 1. Aerial view of the Lane Mountain Company and surrounding area

Methods

Exposure Investigation Design

An EI protocol developed specifically for this site [ATSDR 2016] provided details on the design of this EI. The protocol included guidelines for siting of sampling locations, selecting an appropriate duration and season for the EI, and descriptions of the instrumentation to be used in the EI.

ATSDR selected locations for sampling equipment (Figure 2) where the greatest community exposures to crystalline silica, particulate matter, and sulfur dioxide were expected, or where exposure was likely to occur often. ATSDR collected samples over eight weeks from July 27 through September 22, 2016. Six sampling locations were selected to measure PM_4 mass and crystalline silica, five locations measured $PM_{2.5}$, one location measured PM_{10}, two indoor locations and one outdoor location measured PM_4 mass, and one location measured sulfur dioxide. A meteorological station collected data from one of the sampling locations. The setting and measurements collected at each site are presented in Table 1. A permanent continuous PM_{10} monitor (BAM) on the grounds of Valley School and a permanent meteorological station at LMC also provided data during the EI period. Data from these instruments supplements the data collected during this EI.

Table 1. Site Setting and Measurements

Site Number	***Setting***	***Measurements***
1	School, Outdoor	PM_4 silica
2	School, Outdoor	$PM_{2.5}$, PM_4 silica
3i	School, Indoor	PM_4
4i	School, Indoor	PM_4
4c	School, Outdoor	PM_4
5	School, Outdoor	$PM_{2.5}$, PM_{10}, PM_4 silica
6	School, Outdoor	SO_2
7	Community, Outdoor	$PM_{2.5}$, PM_4 silica
8	Community, Outdoor	$PM_{2.5}$, PM_4 silica
9	Background, Outdoor	$PM_{2.5}$, PM_4 silica
Permanent	School, Outdoor	PM_{10}

Partisol samplers collected integrated 24-hour filter samples with subsequent gravimetric analysis (for mass) and X-ray diffraction analysis (for crystalline silica). MetOne Instruments, Inc. environmental real-time beta attenuation monitors (E-BAMs) with appropriate size selective inlets and flow rates measured hourly concentrations of the different sized particles. A Thermo Scientific Model 43i Analyzer collected sulfur dioxide measurements. Additional details about the methods are included in the EI protocol [ATSDR 2016].

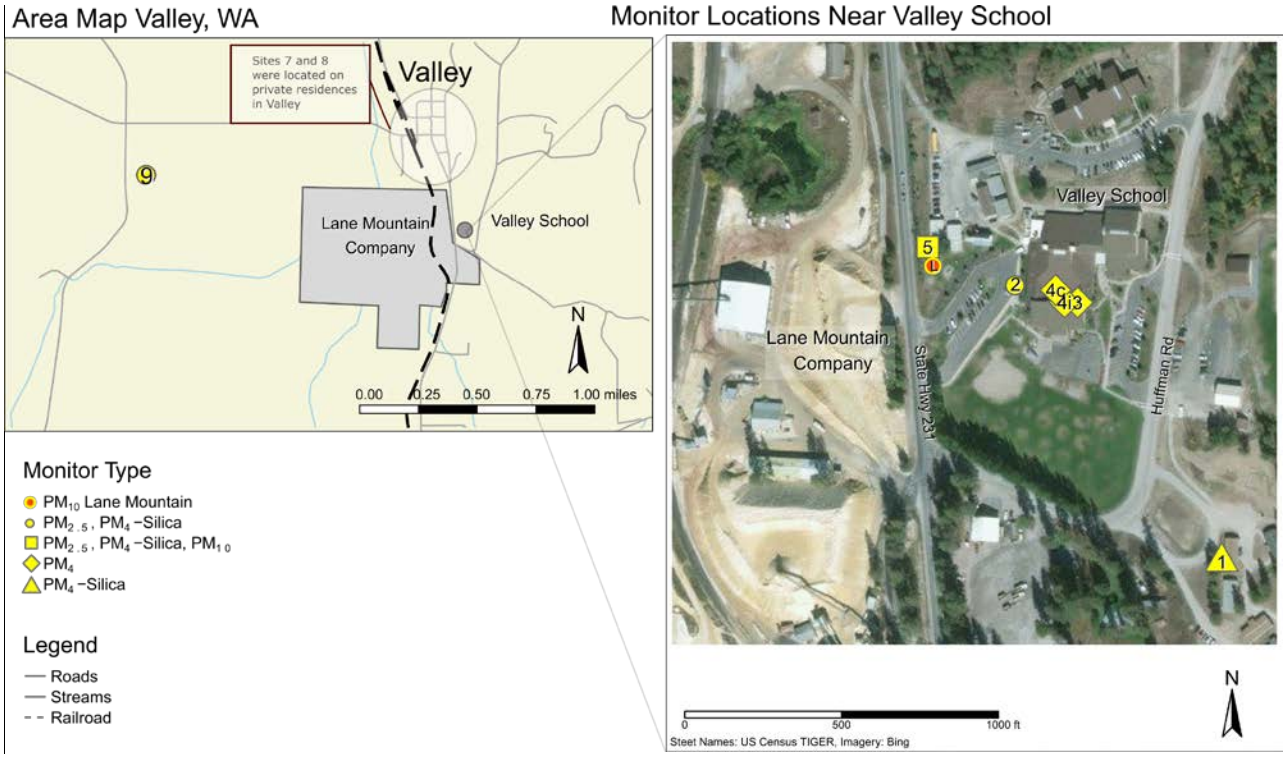


Figure 2. **Valley School area EI monitoring network map**

Data Quality Objectives

Data Quality Objectives (DQOs) are measures used to determine how good data must be in order to achieve the project goals. For this EI, there were both operational and technical DQOs specified in the EI protocol. All operational DQOs were satisfied in the design of the EI and the data collected met the technical DQOs for crystalline silica and particulate matter. The DQOs for sulfur dioxide were not met or of sufficient quality for public health decision making. Because of unforeseen site conditions related to temperature control, the equipment malfunctioned and yielded variable data output, resulting in an unreliable data set. A quantitative discussion of the DQOs is provided in Appendix A.

Data Analysis

For specific details on the analysis of data, see Appendix A. In general, ATSDR calculated 24-hour averages from the data at each site. Maximum 24-hour average concentrations were used as estimates of acute exposure. The 95% upper confidence level (UCL) of the mean, which is the 95th percent confidence limit of the average concentration, was used as an estimate of chronic exposure. Polar plots comparing measured contaminant concentrations to wind direction and speed were also developed for each monitor.

Screening of Contaminants

ATSDR compared the measured concentrations to health-based screening values (Table 2) to determine if there is a potential public health hazard due to exposure to the measured contaminants. These comparison values (CVs) are intended to protect the general public from adverse health effects for specific durations of exposure. They are used to screen out contaminants that are measured at concentrations that are generally safe (below the CV). A concentration above the CV does not necessarily mean that an adverse effect will occur, but it is an indication that the specific contaminant is a contaminant of concern and should be further investigated and compared to the health effects and doses documented in scientific literature.

In the absence of ATSDR-derived CVs, health-based screening values from other authoritative/reliable sources are used. EPA's Air Quality Index (AQI) and NAAQS, and the World Health Organization's (WHO) air quality guidelines (AQG) were used to evaluate exposures to $PM_{2.5}$ and PM_{10}. ATSDR primarily relied on the WHO AQGs for supporting the public health conclusions because they are more protective of public health. The OEHHA silica Reference Exposure Level (REL) was used to evaluate exposures to PM_4 silica. See Appendix B for a more in-depth description of the CVs used in this assessment.

Table 2. Exposure Investigation Contaminants and Associated Health-based Screening Values

Chemical Measured*	***Comparison Value***	***Source***	***Was the CV exceeded at any site?***
PM_4 crystalline silica	3 µg/m^3 annual average	OEHHA chronic silica REL[†]	Yes
PM_{10}	50 µg/m^3 24-hour average	WHO 24-hour Guideline	Yes
PM_{10}	20 µg/m^3 annual average	WHO Annual Guideline	Yes
$PM_{2.5}$	25 µg/m^3 24-hour average	WHO 24-hour Guideline	No
$PM_{2.5}$	10 µg/m^3 annual average	WHO Annual Guideline	Yes (Site 2 only)

OEHHA: California Office of Environmental Health Hazard Assessment
WHO: World Health Organization
PM: Particulate matter
REL: Reference Exposure Level
µg/m^3: micrograms per cubic meter
*Sulfur dioxide was also monitored, however due to data quality concerns stemming from a lack of building air conditioning; ATSDR did not use the data for this EI.
[†]The chronic REL represents a yearly average concentration.

Measured concentrations of PM_{10}, $PM_{2.5}$, and PM_4 crystalline silica exceeded CVs at some sites during the exposure investigation. The following presents a summary of theses contaminants, the results of the pollutant screening, and comparison to health effects documented in the scientific literature.

Results

Particulate Matter

Particulate Matter (PM) is a term used in air quality that refers to particles of dust suspended in air. PM comes from industrial, manmade, and natural sources. PM_{10} is primarily produced by

mechanical processes such as construction activities, road dust resuspension and wind. $PM_{2.5}$ originates primarily from combustion sources—like wood smoke, motor vehicle exhaust, and emissions from power plants—and certain industrial processes [EPA 2009]. The size of particles is directly linked to their potential for causing health problems [EPA 2006]. Particles less than 10 microns in diameter (PM_{10},) can pass through the throat and nose to enter the lungs. Fine particles less than 2.5 microns in diameter ($PM_{2.5}$) can lead to deeper penetration of the lungs and higher toxicity [EPA 2006].

Short-term exposure to particulate matter has been associated with a range of respiratory and cardiovascular health problems. Health effects linked to exposure to ambient particulate matter include premature death, the exacerbation of asthma as well as respiratory and cardiovascular disease, acute respiratory symptoms, chronic bronchitis, decreased lung function, and increased risk of heart attack [EPA 2009].

There is also evidence that long-term exposure to PM can cause an increase in mortality (i.e., all-cause and cardiovascular), respiratory symptoms and incident asthma, reductions in birth weight, and pre-term birth [EPA 2009, EPA 2012]. Although studies on the long-term health effects from exposure to PM_{10} have been less conclusive than those of $PM_{2.5}$, they are likely to have similar impacts to the respiratory and cardiovascular systems [EPA 2009].

The current primary National Ambient Air Quality Standards (NAAQS) for PM are as follows [EPA 2013]:

- **PM_{10}**: The 24-hour average must not exceed 150 $\mu g/m^3$ more than once per year on average over three consecutive calendar years; and
- **$PM_{2.5}$**: The annual average concentrations of $PM_{2.5}$, averaged over three consecutive calendar years, should not exceed 12 $\mu g/m^3$. Further, the 98^{th} percentile of 24-hour average $PM_{2.5}$ concentrations in one year, averaged over three consecutive calendar years, must not exceed 35 $\mu g/m^3$.

ATSDR notes the World Health Organization's (WHO's) air quality guidelines (AQGs) for PM_{10} and $PM_{2.5}$ are lower than the EPA's NAAQS [WHO 2006]:

- **PM_{10}**: The WHO annual average AQG is 20 $\mu g/m^3$ and the 24-hour AQG is 50 $\mu g/m^3$; and
- **$PM_{2.5}$**: The WHO annual average AQG is 10 $\mu g/m^3$ and the 24-hour AQG is 25 $\mu g/m^3$.

Although WHO acknowledges that $PM_{2.5}$ is a better indicator of long-term health effects than PM_{10}, they maintained an annual PM_{10} AQG of 20 $\mu g/m^3$ to protect against the harmful effects of coarse particle ($PM_{2.5}$-PM_{10}) exposures [WHO 2006]. WHO considers the quantitative evidence insufficient to derive a PM_{10} guideline from chronic studies. To be protective in developing countries, WHO assumes that the ratio of $PM_{2.5}/PM_{10}$ is 0.5; thus, the chronic PM_{10} AQG (20 $\mu g/m^3$) is set at twice the WHO AQG for $PM_{2.5}$ (10 $\mu g/m^3$). Conditions on the Valley School campus are unusual because there is a nearby source of large particles that does not contribute to the burden of finer particles. The ratio of $PM_{2.5}$ to PM_{10} measured during the EI was approximately 0.25. These unusual conditions suggest that there may be a chronic health hazard related to PM_{10} exposure even though $PM_{2.5}$ concentrations are relatively low.

Particulate matter mass was measured at one location for PM_{10}, nine locations for PM_4 crystalline silica, and five locations for $PM_{2.5}$. Two PM_4 monitors measured indoor concentrations during the summer break. These two monitors were moved outdoors once schoolchildren returned to the classrooms. One of these monitors was moved to the courtyard to measure PM_4 concentrations and the other monitor was converted to measuring PM_{10} at Site 5. In addition to the measurements collected as part of the EI, there is one permanent PM_{10} monitor located on the Valley School campus. Six of the PM_4 monitoring locations were filter-based with every other day 24-hour averages collected. All other monitoring locations were continuously operating BAMs. In general, measured concentrations from monitors collecting the same contaminant simultaneously correlated well with one another. Particulate matter mass results, by site, are summarized in Table 3.

Table 3. 24-Hour Particulate Matter Mass Results by Site

Site (additional notes)	Valid days	*Concentration, in micrograms per cubic meter (µg/m³)*		
		Maximum*	Mean†	95% UCL of mean†
		PM_{10}		
5	14	**57**	**30.7**	**31.3**
Permanent (during EI)	54	**116**	**51.6**	**52.7**
Permanent (2014-2017)	1217	**274**	**39.1**	**40.6**
		$PM_{2.5}$		
2	56	**25**	**10.3**	**10.5**
5	56	15	8.3	8.4
7	54	12	6.5	6.7
8	56	13	7.2	7.3
9	53	9.6	4.8	4.9
		PM_4‡		
3i (indoor)	41	11	4.9	5.0
4i (indoor)	29	8.8	4.3	4.4
4c (outdoor)	26	30	16.6	16.9
1 (filter)	27	30	11.4	13.4
2 (filter)	28	25	13.6	15.3
5 (filter)	29	31	16.6	18.5
7 (filter)	27	19	9.9	11.2
8 (filter)	27	19	9.8	11.2
9 (filter)	27	11	5.3	6.4

Notes: UCL, upper confidence level; PM, particulate matter;

* Maximum concentrations were compared against the following comparison values:
  PM_{10}: 50 µg/m³ (World Health Organization 24-hour guideline)
  $PM_{2.5}$: 25 µg/m³ (World Health Organization 24-hour guideline)

† Mean and 95% UCL of mean concentrations were compared against the following comparison values:
  PM_{10}: 20 µg/m³ (World Health Organization annual guideline)
  $PM_{2.5}$: 10 µg/m³ (World Health Organization annual guideline)

‡ There are no ambient guidelines for PM_4 mass to compare to measured concentrations. PM_4 mass was only measured to determine concentrations of PM_4 silica that can be compared to CVs.

EPA's AQI online tool, "AIRNow AQI Calculator" was used in the evaluation of acute health effects from 24-hour averages of PM_{10} and $PM_{2.5}$ measured in Valley (see https://www.airnow.gov/index.cfm?action=airnow.calculator) [EPA 2016]. This tool offers guidance to the potential acute health effects associated with specific concentrations of PM. The AQI categorizes 24-hour PM concentrations into six categories: good, moderate, unhealthy for sensitive populations, unhealthy, very unhealthy, and hazardous. See Table 4 for the AQI designations for the concentrations of PM measured at each site.

Table 4. Percent and number of days that $PM_{2.5}$ and PM_{10} (24-hour average) falls into each category of EPA Air Quality Index, Valley, WA Exposure Investigation (µg/m^3)

Sampling Event	**Good** **PM_{10}(<55)** **$PM_{2.5}$ (<12.1)** Percent (number of days)	**Moderate** **PM_{10} (≥55 to ≤155)** **$PM_{2.5}$ (≥12.1 to ≤35.5)** Percent (number of days)	**Unhealthy for Sensitive Groups** **PM_{10}(>155 to ≤255)** **$PM_{2.5}$ (≥35.5 to ≤55.4)** Percent (number of days)	**Unhealthy** **PM_{10} (>255)** **$PM_{2.5}$ (>55.4)** Percent (number of days)
$PM_{2.5}$ (Site 2)	**60.3 (35)**	**39.7 (23)**	0(0)	0(0)
$PM_{2.5}$ (Site 5)	**86.2 (50)**	**13.8 (8)**	0(0)	0(0)
$PM_{2.5}$ (Site 7)	**100 (58)**	0 (0)	0(0)	0(0)
$PM_{2.5}$ (Site 8)	**96.6 (56)**	**3.4 (2)**	0(0)	0(0)
$PM_{2.5}$ (Site 9)	**100 (55)**	0 (0)	0(0)	0(0)
PM_{10} (Site 5)	**93.8 (15)**	**6.2 (1)**	0(0)	0(0)
Permanent PM_{10} (2014-2017)	**78.0 (949)**	**21.3 (259)**	**0.7 (8)**	**0.1 (1)**

AQI Calculator website (https://www.airnow.gov/index.cfm?action=airnow.calculator) describes categories in more detail:
Notes: AQI – air quality index from EPA AirNow Calculator; EPA – U.S. Environmental Protection Agency; µg/m^3 – micrograms per cubic meter; PM_{10} – particulate matter smaller than 10 microns; $PM_{2.5}$ – particulate matter smaller than 2.5 microns
None of the 24-hour concentrations for PM_{10} and $PM_{2.5}$ from any monitor fell into the AQI categories "Very Unhealthy" or Hazardous"

Figure 3 (PM_{10}) and Figure 4 ($PM_{2.5}$) present the 24-hour particulate matter results in boxplot form. The figures include the AQI categories (background shading) as well as the WHO 24-hour and annual guidelines. Mean concentrations of PM_{10} are above the WHO annual guideline at all sites and there are many days above the WHO 24-hour guideline. Mean concentrations of $PM_{2.5}$ are generally below the WHO annual guideline (except for Site 2, which is slightly above) and only a single 24-hour average exceeds the WHO 24-hour guideline for $PM_{2.5}$.

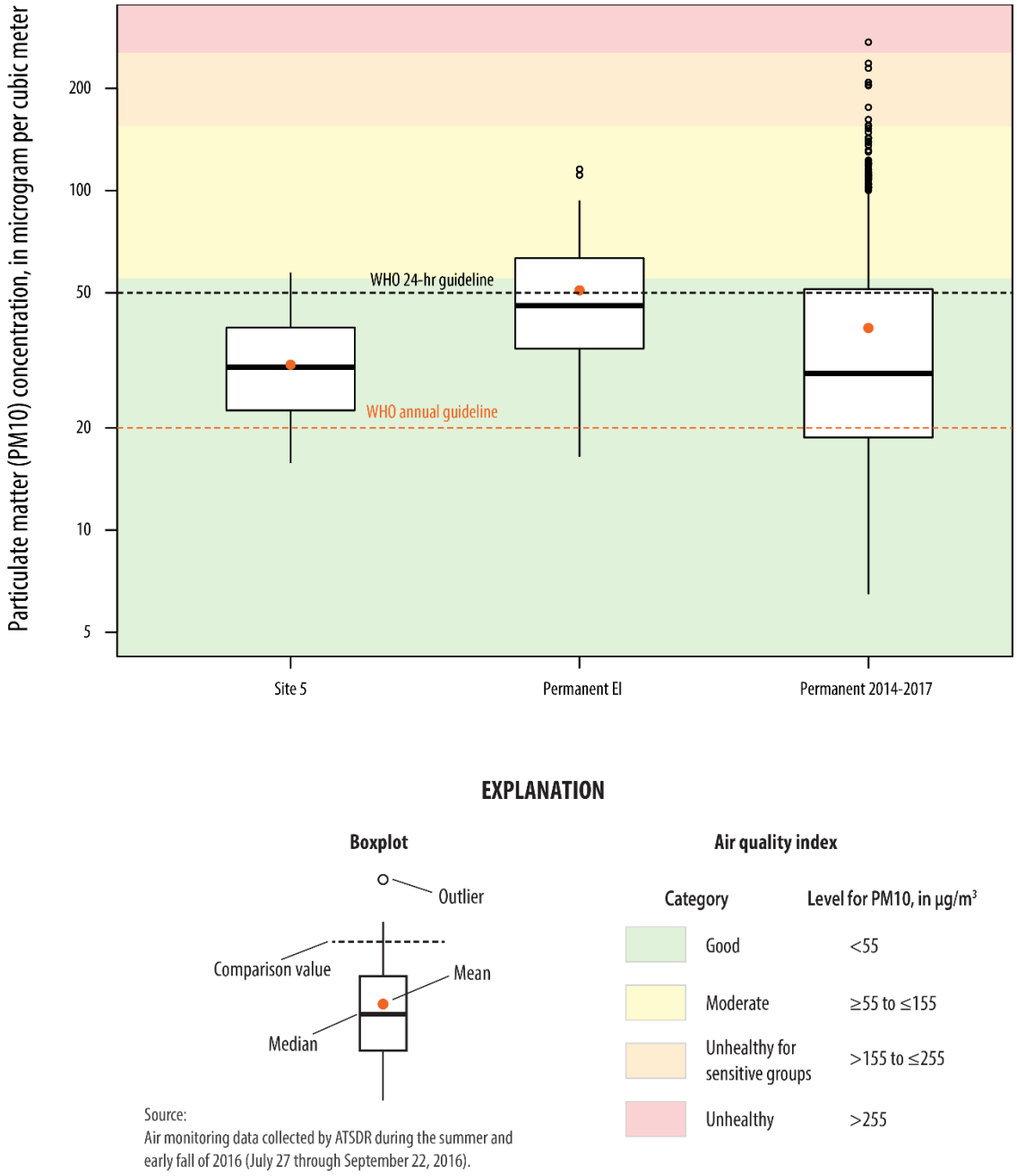


Figure 3. Boxplot of 24-hour PM_{10} concentrations at Valley School

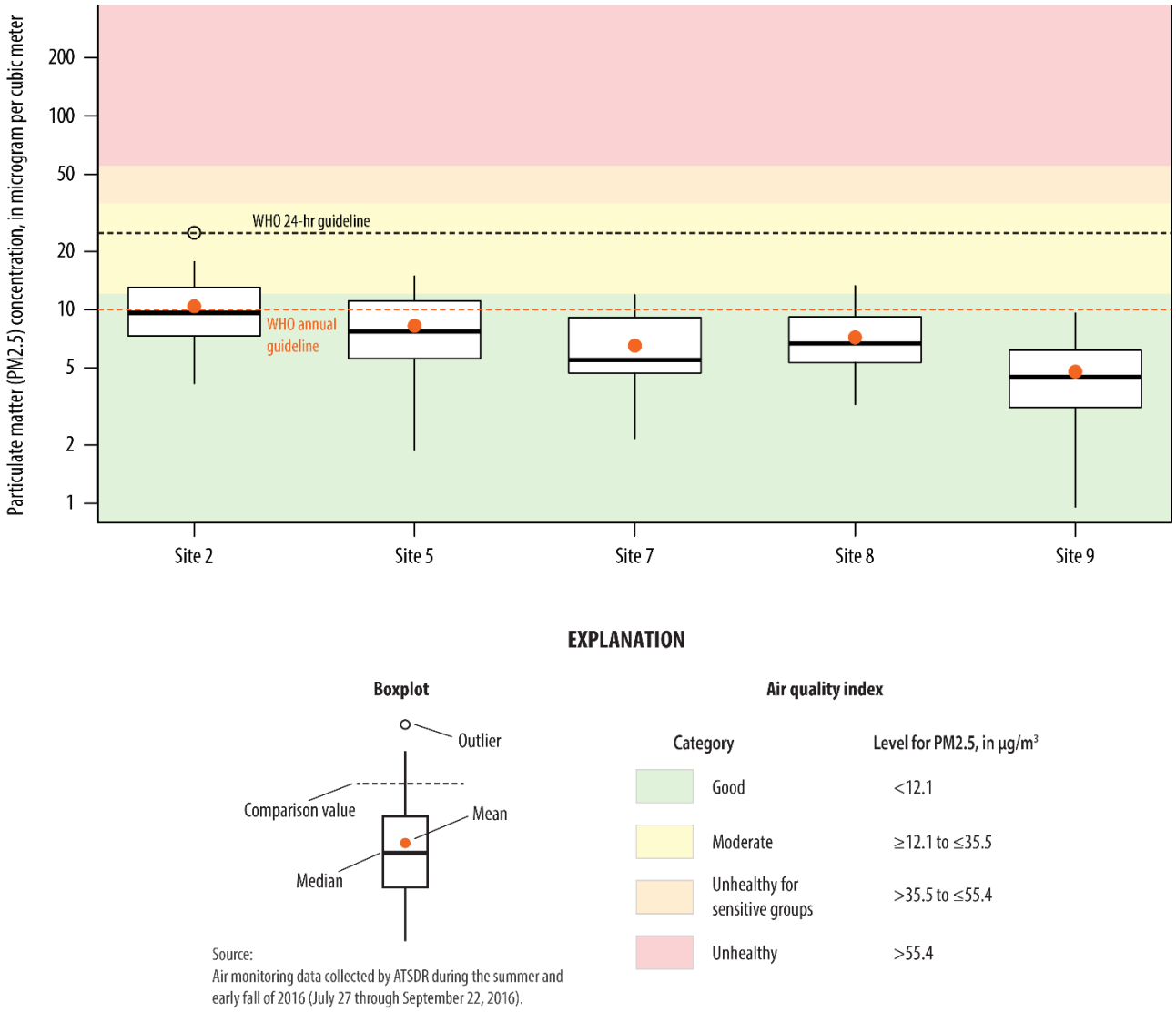


Figure 4. Boxplot of 24-hour $PM_{2.5}$ concentrations at Valley School

PM_{10}

Acute short-term exposures –The maximum PM_{10} concentrations during the EI at Site 5 and at the permanent PM_{10} monitor (both on school grounds) exceeded the WHO 24-hour AQG (50 $\mu g/m^3$) but were below the 24-hour NAAQS (150 $\mu g/m^3$). Based on the EPA AQI calculator, the highest measured 24-hour concentration of PM_{10} at Valley was categorized as moderate, which is associated with increasing likelihood of respiratory symptoms in sensitive groups including older adults, children, and people of lower socioeconomic status; and the aggravation of heart or lung disease and premature mortality in people with heart or lung disease. To reduce the risk of health effects, unusually sensitive individuals with heart or lung disease, older adults, children, and people of lower socioeconomic status should reduce prolonged or heavy exertion outdoors. Only one day out of the 14 measured at Site 5 fell into this category, all other 24-hour samples were designated as good.

ATSDR also reviewed data from the permanent PM_{10} monitor in Valley from 2014-2017, 1217 valid measurements were made. Of these measured concentrations, 1 day (0.1%) was designated as unhealthy, 8 days (0.7%) were designated as unhealthy for sensitive groups, and 259 days (21.3%) were moderate. On days that are unhealthy for sensitive individuals, there is an increasing likelihood of respiratory symptoms and aggravation of lung disease, such as asthma. People with respiratory disease, such as asthma, should limit outdoor exertion. On days that are unhealthy, respiratory effects are expected in the general population.

Maximum 24-hour concentrations during the EI were not as high as the maximum concentrations observed from 2014-2017. Data from the permanent monitor indicate that there are some days (approximately 1%) with PM_{10} concentrations greater than the NAAQS (150 $\mu g/m^3$) and approximately 25% of days with concentrations greater than the AQG (50 $\mu g/m^3$). These data indicate that there is the potential for sensitive individuals (children and the elderly with advanced heart or lung disease) to experience respiratory effects and/or aggravation of heart or lung disease. The highest concentrations measured over four years could cause respiratory effects in the general population.

Chronic long-term exposures – The PM_{10} UCL was above the WHO annual AQG for PM_{10} (20 $\mu g/m^3$) at Site 5 and the permanent station. Evaluating only days where both sites had valid measurements, concentrations at the permanent station were approximately 13 $\mu g/m^3$ (40%) higher than at Site 5 (See Figure 5). This difference could be due to differences in monitor calibration or spatial differences in air concentrations of PM. Collocated PM monitors should agree within 15-20%. Since these monitors were not collocated (but were separated by approximately 75 feet), it is possible that the observed difference is due to spatial gradients in PM_{10}. Large particles are more likely to settle out of the air and are not transported as far as smaller particles. Alternatively, it is possible that the two PM monitors at these locations had different sensitivity to PM. The monitor at Site 5 passed all quality assurance checks performed during the EI.

When four years of data (2014-2017) from the permanent PM_{10} station are considered, the mean and UCL of the mean are lower than during the EI. The average PM_{10} concentration during the EI was about 20% higher than the four-year average. ATSDR chose the dates of the EI to correspond to the highest daily permanent PM_{10} averages measured in the past. Concentrations measured during this EI likely represent a worst-case scenario. While, on average, the measured concentrations from (2014-2017) were lower than those in this EI, more extreme values were measured from 2014-2017, during which several days had concentrations exceeding the 24-hour NAAQS (150 $\mu g/m^3$).

Frequency of short-term exposures can help to understand long-term exposures. At Site 5 (school), one 24-hour average (of 14 total samples) of PM_{10} (57 $\mu g/m^3$) was above the WHO 24-hour guideline for PM_{10} (50 $\mu g/m^3$) but below the 24-hour NAAQS of 150 $\mu g/m^3$. The permanent PM_{10} station at Valley School had 25 days (46%) with 24-hour average concentrations over 50 $\mu g/m^3$, but no days over 150 $\mu g/m^3$. Over four years (2014-2017) at the permanent PM_{10} station, nine days (0.7%) had 24-hour PM_{10} concentrations greater than 150 $\mu g/m^3$ (24-hour NAAQS for PM_{10}), and approximately 25% of days had concentrations greater than 50 $\mu g/m^3$ (WHO 24-hour AQG for PM_{10}).

The measured concentrations during this EI have shown the potential to exceed the annual guidelines from the WHO, and measurements over the last four years show the potential to exceed both the AQGs and the NAAQS. Although the evidence is not as clear for the implications of exposure in PM_{10} as in $PM_{2.5}$ health outcome studies, short-term exposure to PM_{10} has been associated with increases in mortality, cardiovascular, and respiratory effects in areas with mean 24-hour average concentrations as low as 6.1 µg/m^3, 7.4 µg/m^3, and 5.6 µg/m^3, respectively [EPA 2009]. The 2014-2017 95% UCL of the mean PM_{10} concentration was 40.6 µg/m^3 at the permanent monitoring station at Valley School. For comparison, the 2014-2017 mean PM_{10} concentrations were 20.4 µg/m^3 at a monitoring location in Spokane (approximately 40 miles south of Valley) and 22.3 µg/m^3 at a monitoring location in Colville (approximately 30 miles north of Valley). The 24-hour concentrations of PM_{10} measured at both the permanent monitor and Site 5 (both at the school) were frequently above levels associated with health effects. Thus, ATSDR concludes that chronic and acute exposure to PM_{10} on the campus of Valley School could cause adverse health effects.

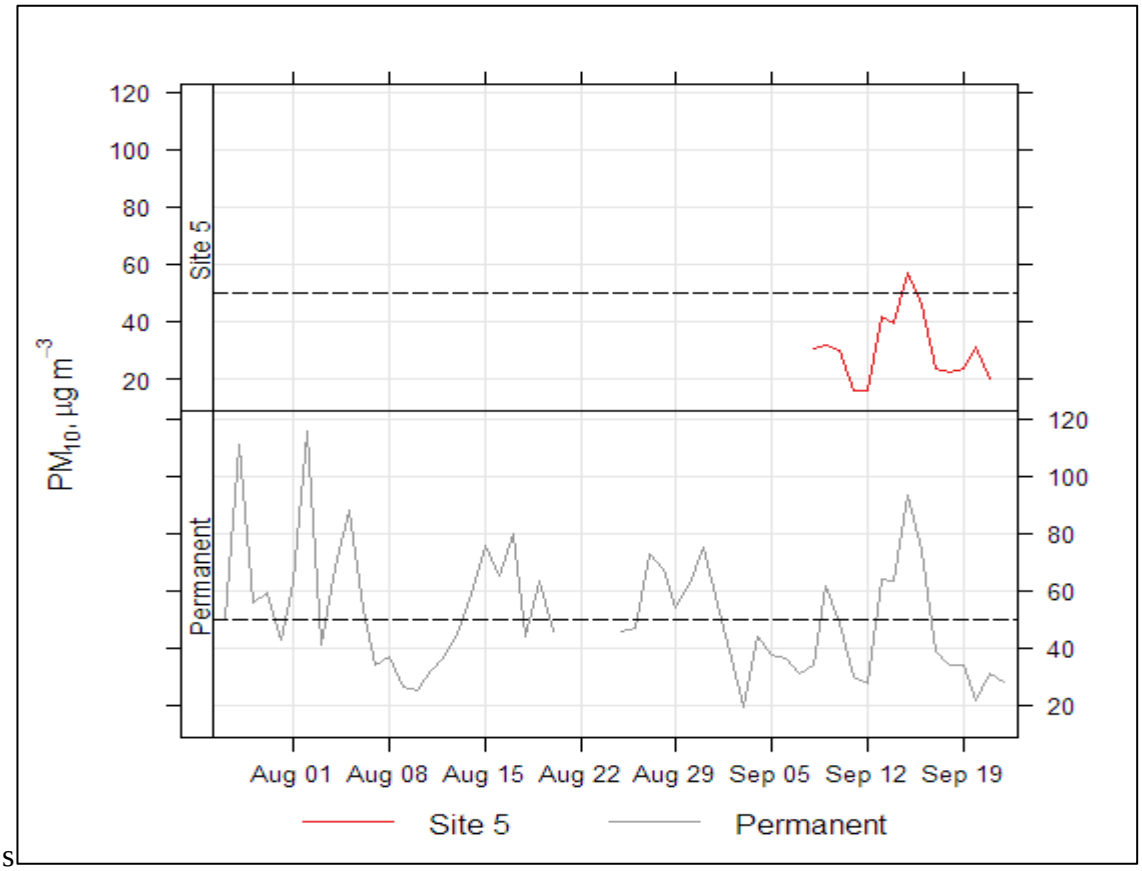


Figure 5. Time series of 24-hour average PM_{10} measurements

Dashed line denotes World Health Organization 24-Hour Guideline for PM_{10} of 50 µg/m^3

$PM_{2.5}$

Acute short-term exposures- Excluding one day at Site 2, all measured 24-hour concentrations of $PM_{2.5}$ were below both the WHO 24-hour guideline for $PM_{2.5}$ (25 µg/m^3) and the 24-hour $PM_{2.5}$ NAAQS of 35 µg/m^3. The maximum concentration of $PM_{2.5}$ measured at Site 2 (on school grounds)

was equal to the WHO AQG. Based on the EPA AQI calculator, the highest measured concentrations of $PM_{2.5}$ fall into the moderate category, which is associated with increasing likelihood of respiratory symptoms in sensitive groups including older adults, children, and people of lower socioeconomic status; and the aggravation of heart or lung disease and premature mortality in people with heart or lung disease. To reduce the risk of health effects, unusually sensitive individuals with heart or lung disease, older adults, children, and people of lower socioeconomic status should reduce prolonged or heavy exertion outdoors.

In all, 34 of 287 valid 24-hour samples (11.8%) fell into the moderate category for $PM_{2.5}$. The majority of moderate days (23) were measured at Site 2, where roughly 40% of the samples were designated as moderate. ATSDR does not expect that short-term exposures to $PM_{2.5}$ would result in harmful health effects in the general population; however, some sensitive individuals (children and the elderly with advanced heart or lung disease) may experience respiratory effects and/or aggravation of heart or lung disease during days with poorer air quality, regardless of whether concentrations exceed health-based values like the WHO AQGs or the NAAQS values.

Chronic long-term exposure- The UCL 24-hour $PM_{2.5}$ concentrations during the entire EI were below the annual WHO AQG (10 $\mu g/m^3$) at all sites except Site 2 (10.5 $\mu g/m^3$), and the UCLs at each site were below the annual $PM_{2.5}$ NAAQS. Since data from the permanent PM_{10} monitor show that concentrations during the EI were approximately 20% higher than the long-term average, and assuming similar relative concentrations of $PM_{2.5}$ and PM_{10}, it is likely that the concentrations measured during the EI represent a reasonable upper end exposure. Based on the measured concentrations of $PM_{2.5}$ and other available information, it is unlikely that exposure to $PM_{2.5}$ at Valley School or in the surrounding area presents a health hazard for students, staff, or residents.

PM_4

Occupational settings are interested in respirable crystalline silica particles, those that get into the lower lung, which are approximated by PM4. Since silica dust is largely an occupational hazard, guidelines for silica only apply to the concentration in the PM_4 fraction of particulates. There are no ambient guidelines for PM_4 mass to compare to measured concentrations. PM_4 mass data are summarized in Table 3 for each site. PM_4 mass was only measured to determine concentrations of PM_4 silica that can be compared to CVs. There were 11 days with both indoor and outdoor PM_4 measurements (Site 3i – inside the school, and Site 4c – just outside the school). These data indicate that indoor concentrations are lower than outdoor concentrations for PM_4 (range of 2.3 to 7.9 times lower indoor compared to outdoor).

Crystalline Silica

Long-term Exposure to PM_4 Crystalline Silica- Crystalline silica compounds are odorless solids composed of silicon and oxygen atoms. Silica is abundant in the environment and has many uses. Over 95% of the earth's crust is made of silica-containing minerals and crystalline silica. Silica sand and gravel are used for building and construction, hydraulic fracturing, ceramics, and abrasives. Quartz, one form of crystalline silica commonly found in the environment, is the major component (90–95%) of all sand and silt fractions in soil. Silica sand has been used throughout history to make glass. Crystal quartz forms of silica are used in jewelry, electronics, and the optical component industry [ATSDR 2017].

Silica compounds can be released into the environment by natural, industrial, and agricultural activities. Crystalline silica is emitted as a component of particulate matter into the environment. Local meteorological conditions, such as wind and rain, can influence the transport of silica-containing dust. People may be exposed to silica compounds from the air, indoor dust, food, water, soil, and various consumer products. Human exposures to crystalline silica that have the potential to impact human health occur mainly in industrial and occupational settings, and people who work where silica is mined or used are exposed to higher levels of these substances than the general population. In addition, residents living near quarries, sand and gravel operations, or drilling involving hydraulic fracturing may be exposed to elevated levels of respirable crystalline silica [ATSDR 2017].

Tissues within the respiratory system are the most exposed and the most sensitive to the effects of inhaled respirable crystalline silica. The most serious effects being the development of silicosis, a progressive, fibrotic lung disease that may result in death due to respiratory failure, and lung cancer. Various studies of occupational exposures to respirable crystalline silica have demonstrated exposure-response relationships for incidence and mortality due to silicosis. Respirable crystalline silica exposure is also associated with increased risk of chronic obstructive pulmonary disease, pulmonary tuberculosis, renal and autoimmune diseases [NIOSH 2002; ATSDR 2017].

Crystalline silica has also been associated with cause lung cancer. The NTP 14th Report on Carcinogens listed respirable crystalline silica, primarily quartz dusts occurring in industrial and occupational settings, as *known to be a human carcinogen* based on sufficient evidence of carcinogencity from studies in humans [NTP 2016]. Also, IARC has classified respirable crystalline silica in the form of quartz or cristobalite dust as *carcinogenic to humans* (Group 1), based on sufficient evidence in humans for the carcinogenicity of crystalline silica in the form of quartz or cristobalite and sufficient evidence in experimental animals for carcinogencity of quartz dust [IARC 1997, 2012]. EPA has no cancer slope factor for evaluating potential cancer risk for crystalline silica. In absence of other CVs, ATSDR compared the measured concentrations of silica in Valley to lung? cancer effect levels found in literature.

Although neither ATSDR nor EPA have derived non-cancer CVs for any route or duration of exposure to crystalline silica, the agencies agree on the following:

- Health effects on the respiratory system (i.e., silicosis) are the most sensitive non-cancer effects of inhaled crystalline silica;

- Identification of a no-effect or threshold level for silicosis is highly uncertain due to varying evidence from chronic occupational studies; and

- Silicosis is a serious adverse effect that has the potential to cause death due to respiratory failure.

ATSDR did not identify acute or intermediate exposure screening levels at this time. OEHHA derived a chronic inhalation REL of 3 µg/m^3, based on silicosis as the critical health endpoint. A chronic REL is an airborne level of a chemical at or below which no adverse health effects are

anticipated in individuals indefinatelyexposed to that level. The REL was based on a study of gold miners exposed to respirable dust with 30% crystalline silica – alpha quartz that observed an increase in silicosis with continuous lifetime exposure at a human equivalent concentration of 9.8 µg/m^3 [OEHHA 2005].

ATSDR compared the maximum and 95% UCL 24-hour concentrations to the OEHHA chronic inhalation REL (3 µg/m^3) to assess the potential for chronic noncancer effects. To assess the potential for silica concentrations in Valley to cause cancer, ATSDR compared the measured concentrations to cancer effect levels found in literature.

PM_4 crystalline silica results are summarized by site in Table 5 and depicted graphically in Figure 6. The 95% UCL for PM_4 crystalline silica was above OEHHA's 3 µg/m^3 REL at each site (except Site 9 – the furthest from LMC) during the EI with a maximum of 5.12 µg/m^3 at the school (Site 5). Maximum measured 24-hour PM_4 crystalline silica concentrations were greater than 3 µg/m^3 at all of the six monitoring locations. Site 9 had only two of 27 samples (7.4%) exceed the PM_4 crystalline silica screening value of 3 µg/m^3; all other sites had nine or more exceedances of this value. Since there were no collocated measurements of PM_4 crystalline silica at any site, it is not possible to assess the precision of the measurements. Note that one sample from Site 5 (August 16) had a very low silica content (below detection limit). This sample is unusual as the other samples from the school grounds (Site 1 and Site 2) on that day had silica concentrations of 2.8 and 3.0 µg/m^3. This pattern was not consistent with other days during the EI.

Table 5. 24-hour PM_4 Crystalline Silica Results by Site

Site	Samples	Samples >3 µg/m^{3*}	Samples Below Detection Limit	Maximum	Mean	95% UCL of Mean
				Micrograms per cubic meter (µg/m^3)		
1	27	16	0	5.89	3.27	3.59
2	28	20	0	11.3	4.10	4.70
5	29	24	1	9.72	4.56	5.12
7	27	9	3	5.59	2.77	3.09
8	27	10	3	5.34	2.71	3.02
9	27	2	15	3.47	1.37	1.65

Detection limit is 0.5125 µg/m^3

* 3 µg/m^3 is the California Office of Health Hazard and Evaluation Recommended Exposure Limit for PM_4 silica

UCL: upper confidence limit

PM_4: particulate matter with aerodynamic diameter less than or equal to 4 microns

µg/m^3: micrograms per cubic meter

Individual sample results for PM_4 crystalline silica are shown in Figure 4. There was some on-site construction on the Valley School campus (near Site 1) for a greenhouse and fishpond that generated visible airborne dust from August 22 through August 26. This construction could have impacted measurements at Site 1 but was not occurring on the day with the non-detect silica sample from Site 5, so it is unlikely to be the cause of a discrepancy among the Valley School campus sites on that day.

The silica concentrations across sites were statistically different (Kruskal-Wallis Rank Sum Test $p < 0.001$). Pairwise comparisons of sites using the Wilcoxon Rank Sum test with Holm's multiple comparison adjustment showed that the concentration at Site 9 (background) was lower than all the other sites ($p < 0.001$), and the concentrations at Site 2 and Site 5 (both at the school) were higher than at Site 7 and Site 8 ($p < 0.01$). Sites 1 (school), 7 (community), and 8 (community) were statistically indistinguishable from each other.

The median percent silica (based on total PM_4 mass) at every site (excluding Site 9) was between 28 and 31%. At Site 9, the median silica concentration was below the detection limit, so no median silica fraction was calculated. ATSDR used robust regression on order statistics as implemented in the R package "NADA version 1.6-1" to impute samples below the detection limit and calculate statistics [Lee and Helsel 2005].

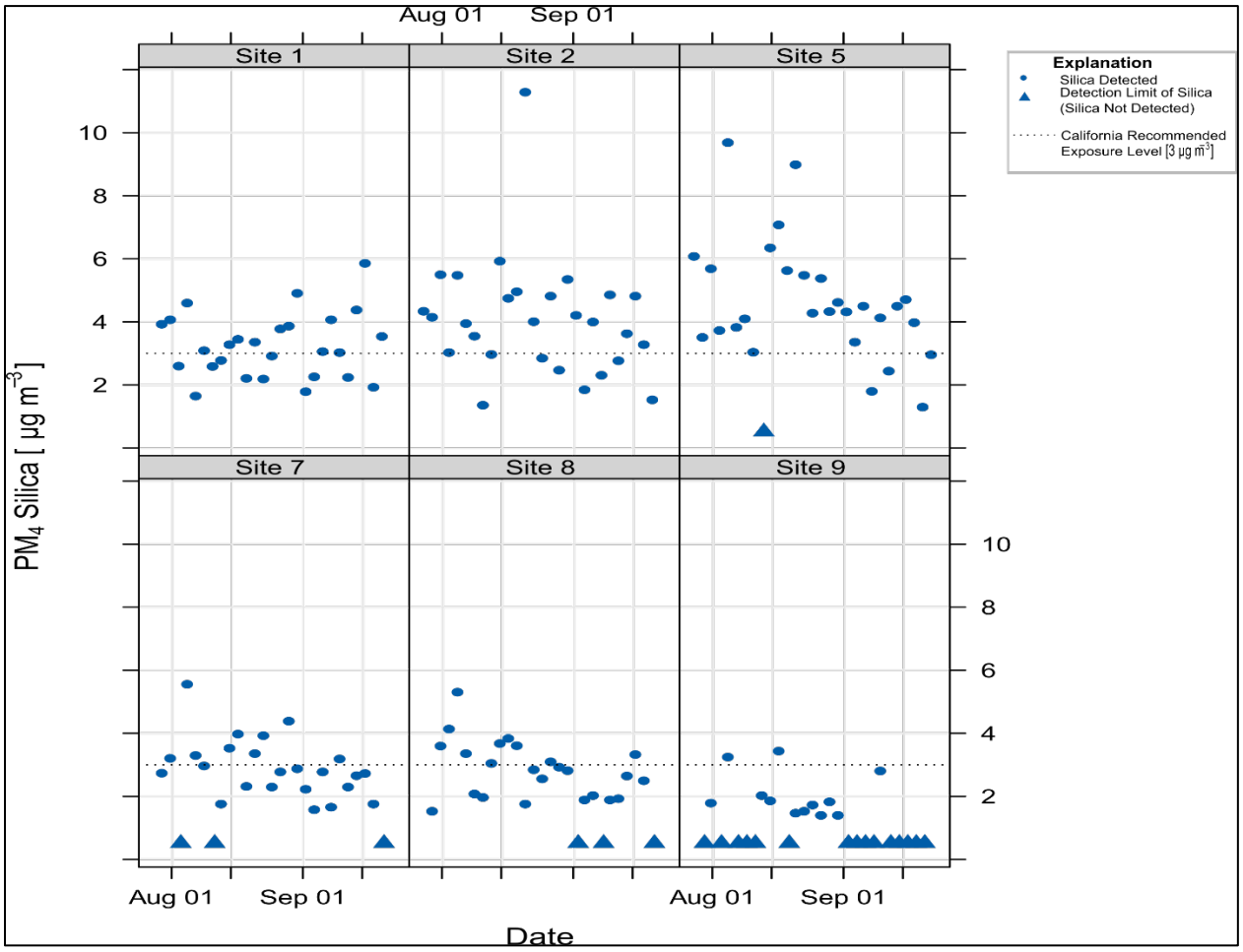


Figure 6. Time series of PM_4 crystalline silica measurements
µg/m³, microgram per cubic meter

Chronic long-term exposure

ATSDR evaluated the 95% UCL of the mean 24-hour concentration at each monitor to estimate the potential for chronic effects. The 95% UCL of the mean at five of the six PM_4 silica monitors exceeded the REL of 3 $\mu g/m^3$ for long-term exposures. The highest 95% UCL was 5.12 $\mu g/m^3$ measured at Site 5 (on the Valley School campus). This level is above the REL, which is considered the safe level for silicosis, but below the human equivalent lowest observable adverse effect level ($LOAEL_{HEC}$) of 9.8 $\mu g/m^3$ from the literature.

The 95% UCL of PM_4 crystalline silica measured during the EI was greater than 3 $\mu g/m^3$ (REL) at all monitoring locations on the campus of Valley School as well as at two locations in the nearby community. ATSDR evaluated two scenarios for exposure to silica. First, a conservative (worst-case) exposure scenario assumes exposure 24-hours a day for a lifetime at the 95% UCL concentration from Site 5 (school) during the EI (5.12 $\mu g/m^3$). The second scenario evaluates a more realistic exposure point concentration using the following assumptions:

- Exposure at school for 6.7 hours/day, 5 days/week, 39 weeks/year [ATSDR 2018] (Site 5 95% UCL of 5.12 $\mu g/m^3$);
- Exposure at home for remainder of time (Site 7, highest residential monitoring location, 95% UCL of 3.09 $\mu g/m^3$;
- Assumes exposure to outdoor PM_4 silica concentrations 24-hours a day. Available data indicate that indoor concentrations of total PM_4 mass are lower than outdoor concentrations. If the same relationship holds for the silica fraction, this assumption will result in an overestimation of exposure to PM_4 silic; and
- The final concentration was reduced by 20% to account for the long-term average PM_{10} concentration from the permanent monitor from 2014-2017, which was 20% lower than the concentrations measured during this EI. (Sampling a worst-case scenario resulted in a roughly 20% increase in the average based on the permanent PM_{10} monitor). This 20% reduction assumes that PM_4 silica fluctuates proportionally with PM_{10}.

With these assumptions, using measured data (95% UCL) from Site 5 for school exposure and from Site 7 for home exposure, the exposure point concentration is 2.71 $\mu g/m^3$.

For comparison to occupational studies, ATSDR conservatively calculated cumulative exposures to a constant concentration of 5.12 $\mu g/m^3$ and the exposure point concentration of 2.71 $\mu g/m^3$. A cumulative exposure to 5.12 $\mu g/m^3$ for 45 years (the maximum years worked for occupational studies) is 0.2304 mg-years/m^3; at 2.71 $\mu g/m^3$ the cumulative exposure is 0.1220 mg-years/m^3 (Table 6). Rice and Stayner [1995] reviewed results from exposure-response models reported in epidemiologic studies of Ontario hardrock miners and South African gold miners to compare their risk of silicosis to that estimated from cumulative exposure to the NIOSH recommended exposure limit of 50 $\mu g/m^3$ for a 45-year worklife. In one model, an exposure of 2.0 milligrams per cubic meter per year (mg/m^3-year) resulted in a cumulative risk of between 0.0009 and 0.0062 (9 in

10,000 and 62 in 10,000, respectively). In the second, an exposure of 2.25 mg-years/m^3 led to a cumulative silicosis risk of 0.127 (almost 13%). The highest estimated cumulative exposure in Valley is roughly one tenth of that at estimated by Rice and Stayner in an occupational setting, so the risk of silicosis would expected to be much lower.

Table 6: Estimated cumulative exposure to respirable crystalline silica over time in Valley

Exposure Scenario	Exposure Duration (years)				
	30	35	40	45	70
Cumulative exposure (mg-years/m^3) from 5.12 μg/m^3 highest 95% UCL (school campus exposure)	0.15	0.18	0.20	0.23	0.36
Cumulative exposure (mg-years/m^3) from 3 μg/m^3 (REL value from OEHHA)	0.09	0.10	0.12	0.14	0.21
Cumulative exposure (mg-years/m^3) at 2.71 μg/m^3 (exposure point concentration)	0.08	0.09	0.11	0.12	0.19

PM_4 crystalline silica at Site 5 (school) was measured concurrently with PM_{10} on eight days during the EI. At the Site 5 monitor, the mean PM_4 silica was 11.1% of the mean PM_{10} mass. The ratio of PM_4 silica to PM_{10} mass ranged from 4.3% to 17.8% of PM_{10} mass. Using the mean ratio, PM_{10} measurements less than 27 μg/m^3 from the permanent station would result in PM_4 crystalline silica less than 3 μg/m^3. Using the maximum PM_4 silica to PM_{10} mass ratio (17.8%), PM_{10} concentrations greater than 17 μg/m^3 would result in PM_4 crystalline silica concentrations greater than 3 μg/m^3.

An EPA health risk assessment of crystalline silica concluded that for healthy individuals not compromised by other respiratory ailments, the former PM_{10} NAAQS (50 μg/m^3) offers adequate protection against silicotic effects from environmental dust containing 10% or less crystalline silica in the PM_{10} fraction [EPA 1996]. While the annual PM_{10} NAAQS is no longer in effect, that concentration (50 μg/m^3) of PM_{10} can still be used to evaluate protection from silicotic effects. The crystalline silica fraction in PM_{10} mass measured in Valley has the potential to be higher than 10% (up to 17.8%), which can increase the risk of silicotic effects. Data from the permanent PM_{10} monitor from (2014-2017) indicate that approximately 25% of days have PM_{10} concentrations greater than the former PM_{10} NAAQS (50 μg/m^3).

Quantitative Carcinogenicity Assessment

In the absence of a cancer comparison value, ATSDR compared the concentrations measured in Valley (Table 6) with cancer effect levels documented in literature. NTP, NIOSH and IARC have independently reviewed and published summaries of lung cancer studies [ATSDR 2017; NTP 2016; NIOSH 2002; IARC 2012].

In its review of literature, ATSDR identified two studies, also cited by IARC, that characterize the lower end of silica exposures associated with lung cancer mortality. Effect levels in these studies were compared to the concentrations measured in the EI. The first [Hughes et al. 2001] observed an increase in lung cancer (90 cases in 2,670 workers) in industrial sand workers exposed to 160-260 μg/m^3 silica dust for a duration of employment between 2.4 and 41.1 years. The highest site average

concentration, measured at site 5 (5.12 μg/m^3), was 32 times lower than that associated with an increase in lung cancer mortality in this occupational study.

The second study [Steenland et al. 2001] also reported an increase in lung cancer mortality in a pooled study of industrial sand workers (1,072 lung cancer deaths in 65,980 workers). This study incorporated 10 cohorts with a range of median cumulative exposure concentrations (0.13–11.37 mg /m^3-years) and durations (3.7-26.8 years). Statistically significant increases in lung cancer were observed in the 3rd quintile of cumulative exposure (2-5.4 mg /m^3-years). Using the highest measured site average from Valley of 5.12 μg/m^3 and assuming continuous exposure (over a similar duration, Table 6) would yield exposures more than an order of magnitude lower than the lowest exposure (2 mg /m^3-years) associated with lung cancer in the Steenland et al. 2001 study.

Although there may not be a threshold for the onset of lung cancer, exposure levels measured in Valley were more than an order of magnitude lower than those associated with an increase in lung cancer mortality.

Analysis of Health Outcome Data

To identify potential health issues in Valley that could be related to the measured PM_{10} (which showed the potential to exceed regulatory values), ATSDR analyzed health outcome data from the Washington State Department of Health's Washington Tracking Network (WTN). Although these data can give us an overall understanding of the health status in the community, they cannot provide any information on the cause of the health outcomes. The health outcomes related to PM_{10} exposures on the WTN (asthma hospitalizations and mortality due to cardiovascular disease [EPA 2009]) are associated with various other factors that can occur over a person's lifetime, and ATSDR cannot determine if PM_{10} was the cause of any specific health outcome.

The WTN is a public website, developed by the Washington State Department of Health, where users can find data and information about environmental health hazards, population characteristics, and health outcomes. Health statistics were obtained from the WTN for Stevens County as well as some more site-specific statistics for the zip code 99181 and Census tract 53065951100, all of which contain the town of Valley. WTN maintains statistics on asthma hospitalizations and mortality from cardiovascular disease which are both associated with PM. Asthma hospitalizations were available by county and zip code; measurements of mortality due to cardiovascular disease were available by county and census tract. Depending on the population size, zip code and census tract may be suppressed to protect confidentiality, and some statistics are only available in five-year intervals and/or designated as "not reliable" by the WTN. All data from the WTN are adjusted for age but not for race.

Asthma Hospitalizations

The asthma rates in WTN are collected from hospital discharge data [WDOH 2016a]. The latest available data from WTN (for the year 2014) show that the asthma hospitalizations in Stevens County (8.95 per 10,000) were statistically significantly higher than that of the state as a whole (5.36 per 10,000). From the older data from 2000 to 2013 the rate of asthma hospitalizations was elevated, but not to a level of statistical significance. Data for the zip code 99181 was labeled by the WTN as "Not Reliable".

Hospitalization data are based on number of events not the number of admitted patients (e.g., one patient may have experienced multiple events). WTN data includes some transfers between hospitals for the same individual for the same event. An individual hospitalized more than once will be counted more than once, even if hospitalized for the same condition. In addition, admission and subsequent discharge from a hospital may suggest a complication or aggravation of the underlying chronic condition and cannot be used to determine the prevalence of the disease in the community. Hospital admissions for asthma may reflect issues related to access to care, compliance, appropriate treatment plan, uncontrollable exposure to triggers, or other factors.

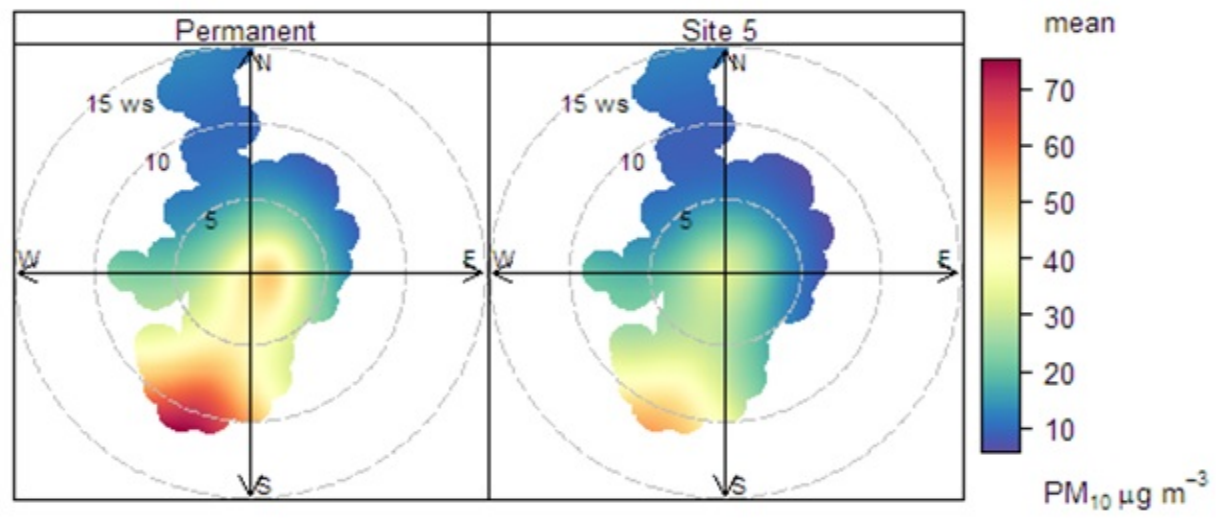
Measures of Cardiovascular Mortality

The WTN has derived an Information by Location (IBL) ranking for mortality from cardiovascular disease [WDOH 2016b]. The IBL is a mapping tool that provides information about communities using relative rankings. The IBL compares each census tract with others in the state by presenting a community's rank between 1 (lowest) and 10 (highest). Each number represents 10% of the communities. For example, if your community is ranked a 7 for health disparities, it means that 60% of the communities in Washington State have a lower level of health disparity and 30% have a greater level of disparity. ATSDR notes that IBL rankings are calculated separate from 95% confidence limits offered by the WTN, and do not always reflect a statistically significant difference between the state and the census tract. The most recent data on mortality due to cardiovascular disease show slightly elevated risk near Valley, but the difference from the state average is not statistically significant.

Meteorological, Temporal, and Spatial Analysis

ATSDR reviewed all meteorological data collected during the EI period from both the Site 9 meteorological station located furthest from LMC and the permanent meteorological station at LMC. Wind speed and direction data between these sites were substantially different. Approximately one mile separated the two meteorological stations. ATSDR chose to use the wind data from the permanent meteorological station for the data analysis presented here. We made this choice after looking at the two data sets and evaluating the potential for local terrain effects on wind speed and direction. We selected the permanent meteorological station data for this analysis because of its proximity to the majority of the monitoring locations. All analyses and figures presented in this section use wind data from the permanent meteorological station rather than the station operated during the EI at Site 9.

Polar plots show relationships between measured concentrations of a pollutant, wind speed, and wind direction. Polar plots of PM_{10} from the permanent BAM and Site 5 are shown in Figure 7. The highest PM_{10} concentrations at each location are when there are strong winds from the southwest. Concentrations of PM_{10} are higher at the permanent BAM site than Site 5.



**NOTE: This plot represents 14 days of concurrent sampling at both locations.*

Figure 7. Polar plots of PM_{10} mass

Polar plots of $PM_{2.5}$ are shown in Figure 8. Concentrations of $PM_{2.5}$ are highest when winds are from the southwest at Site 2 and Site 5. This could be due to a local source, regional transport, or a combination of the two. Concentrations of $PM_{2.5}$ at Site 7 and Site 8 increase both when winds are from the southwest, and with light winds from the east. The concentrations at these two sites never get as high as at Site 2 and Site 5. Concentrations of $PM_{2.5}$ at Site 9 are generally low, with the highest concentrations observed with calm winds.

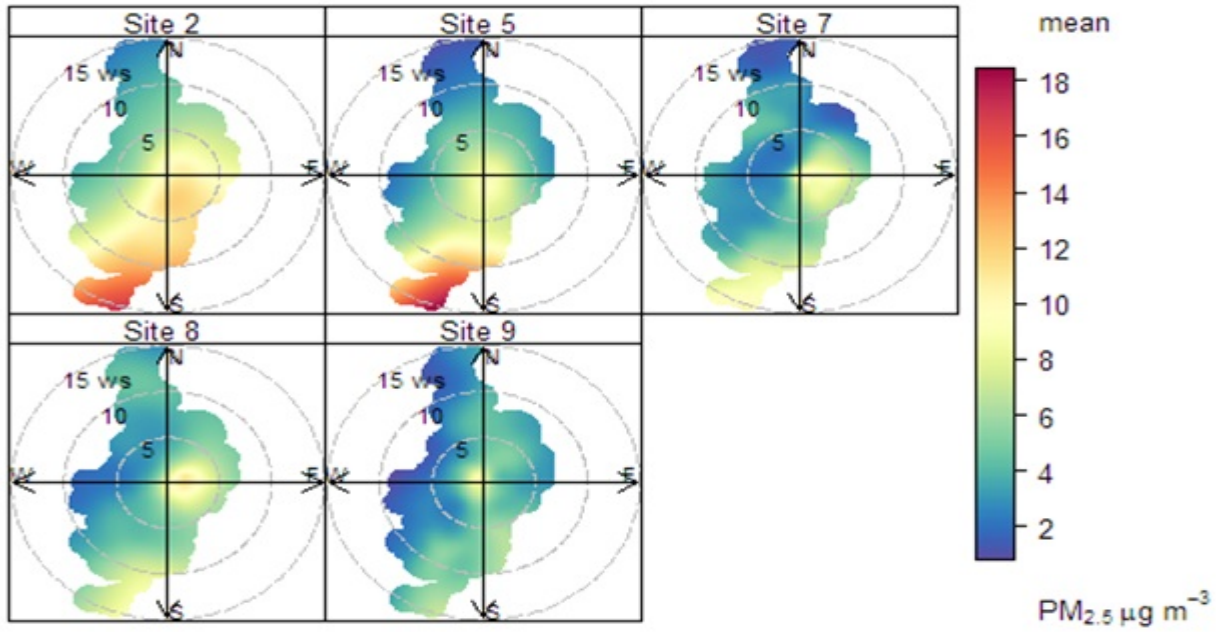


Figure 8. Polar plots of $PM_{2.5}$ mass

Polar plots of PM_4 crystalline silica are shown in Figure 9. The highest measured PM_4 crystalline silica concentrations were from Site 2 when winds were from the southwest. A similar pattern is

present in data from Site 5 and Site 1, but with lower absolute concentrations. Concentrations at Site 7 are slightly elevated with winds from the south. Concentrations at Site 8 are highest with calm winds or winds from the east or west. Concentrations at Site 9 are low under all meteorological conditions.

The polar plots for all of the particulate sizes (and the silica fraction) show that measured concentrations are highest when there are strong winds that blow from LMC to the monitoring locations. These relationships are most pronounced for the monitors located at the school. The background location does not show any relationship between measured concentrations and wind direction.

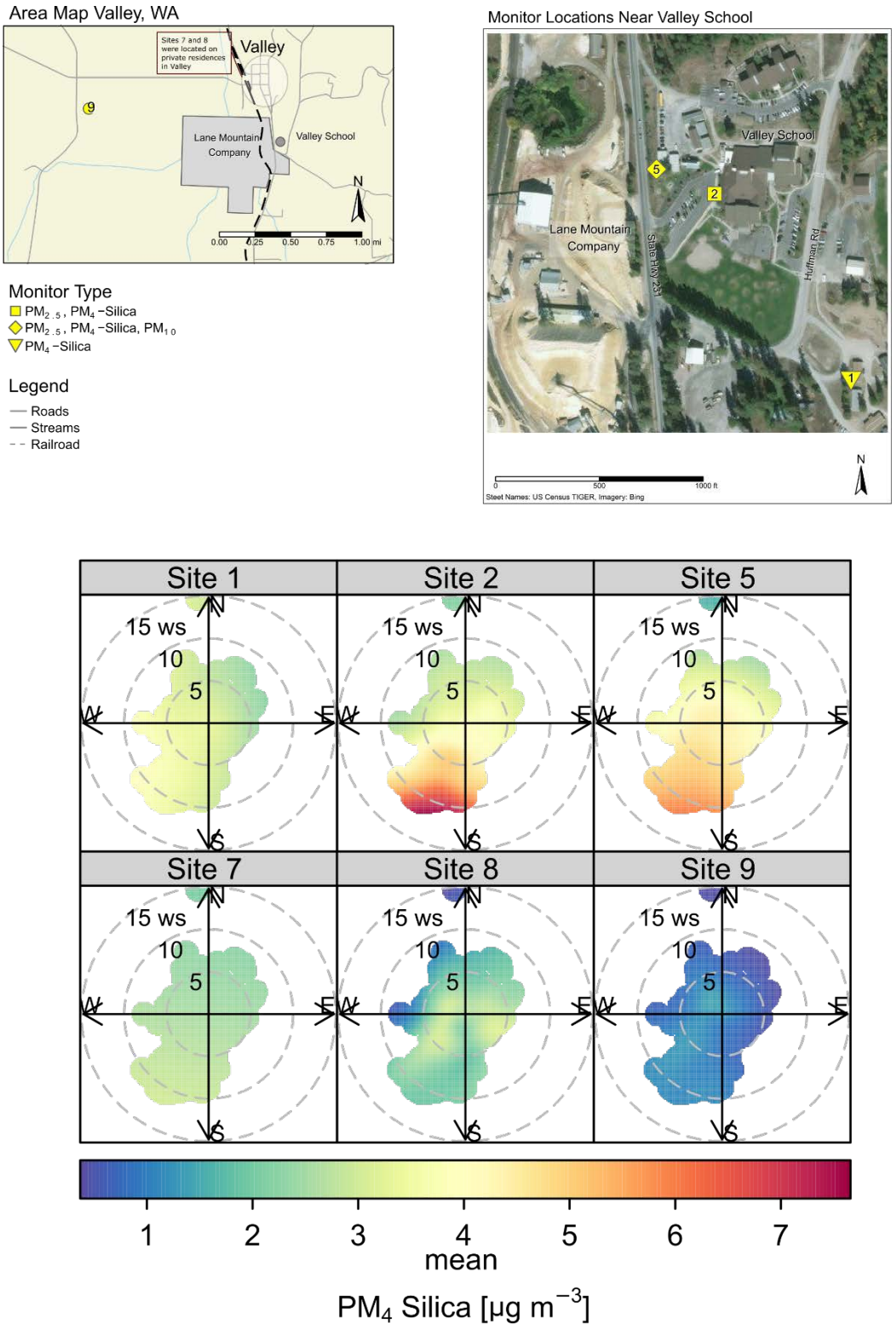


Figure 9. Valley School Area Polar plots showing meteorological distribution of PM_4 silica mass and the monitoring network map

Child Health Considerations

Since there is a school (where much of the EI environmental monitoring was conducted) directly across the street from LMC, it is relevant to consider child health in this evaluation. Because of their size, physiology, behavior, and activity level, the inhalation rates of children differ from those of adults. Factors that might contribute to enhanced lung deposition in children include higher ventilation rates, less contribution from nasal breathing, less efficient uptake of particles in the nasal airways, and greater deposition efficiency of particle and some vapor phase chemicals in the lower respiratory tract. In addition, children spend 3 times as much time outdoors as adults and engage in three times as much time playing sports and other vigorous activities [EPA 2011]. Based on these parameters, children are more likely to be exposed to more outdoor air pollution than adults are. Further, a child's lower body weight and higher intake rate results in a greater dose of hazardous substance per unit of body weight.

While it is not clear that children are more toxicologically sensitive to the specific exposures of silica, they are likely more vulnerable due to their increased exposure. In terms of PM, children (and the elderly) have increased susceptibility to PM-related respiratory effects, and the health effects observed in children could be initiated by pre and/or postnatal exposures to PM [EPA 2009].

Limitations

ATSDR acknowledges that this EI, like all field measuring programs, has some limitations. Those limitations include:

The measurement period for this EI was eight weeks and may not be representative of long-term exposure. The data were collected during this EI from July 22 to September 27, 2016. ATSDR attempted to sample during the worst conditions (based on previous data from a PM_{10} monitor in the area), and the eight weeks of data was used as a conservative estimate of community exposures throughout the year. ATSDR does note that this sampling strategy may result in elevated annual estimates of contaminant concentrations.

Monitoring/sampling was conducted at fixed, stationary locations; however, people move around and do not remain in one place all day long. Therefore, the data collected at the fixed locations are not directly equivalent to actual exposures that may have occurred.

ATSDR is unable to assess the potential for health hazard from breathing SO_2 because the air conditioning system was not functional in the school building in which the SO_2 monitor was located. The lack of a temperature-controlled environment resulted in data quality concerns with the measured SO_2 data.

Conclusions

Conclusion 1

ATSDR concludes that breathing PM_{10} on the campus of Valley School could harm some people's health. The primary concern for exposure is to sensitive populations.

Basis for Conclusion 1

The UCL of the mean of PM_{10} concentrations at both PM_{10} monitors were above the WHO annual guideline for PM_{10} (20 $\mu g/m^3$). At one location close to the school (Site 5), one of fourteen 24-hour averages of PM_{10} (57 $\mu g/m^3$) was above the WHO 24-hour AQG for PM_{10} (50 $\mu g/m^3$) but below the 24-hour NAAQS of 150 $\mu g/m^3$. During the exposure investigation, the permanent PM_{10} station at Valley School had 25 of 54 days with 24-hour average concentrations over 50 $\mu g/m^3$, but no days over 150 $\mu g/m^3$.

Over the past four years (2014-2017) at the permanent PM_{10} station, nine days had 24-hour PM_{10} concentrations greater than 150 $\mu g/m^3$ (24-hour NAAQS for PM_{10}), and approximately 25% of days had concentrations greater than 50 $\mu g/m^3$ (WHO 24-hour AQG for PM_{10}). Applying the EPA Air AQI, 1 day (0.1%) was designated as unhealthy, 8 days (0.7%) were designated as unhealthy for sensitive groups, and 259 days (21.3%) were moderate. On days that are designated "moderate", a very small number of "unusually sensitive"[2] individuals may experience health effects; for those designated "unhealthy for sensitive individuals", there is an increasing likelihood of respiratory symptoms and aggravation of lung disease, such as asthma; on days designated as unhealthy, respiratory effects are expected in the general population. Only one day in four years presented a public health concern for healthy adults.

Conclusion 2

Breathing PM_4 crystalline silica on the campus of Valley School and in the surrounding area presents a potential chronic public health hazard to students, staff, and residents.

Basis for Conclusion 2

The UCL of PM_4 crystalline silica measured during the EI was greater than 3 $\mu g/m^3$ (REL developed by OEHHA) at all monitoring locations on the campus of Valley School as well as at two locations in the nearby community. ATSDR evaluated two scenarios for exposure to silica. First, a conservative (worst-case) exposure scenario assumes exposure 24-hours a day for a lifetime at the UCL concentration from Site 5 (school) during the EI (5.12 $\mu g/m^3$). The second scenario evaluates a more realistic exposure point concentration (2.71 $\mu g/m^3$) that considers the time spent away from school at lower concentrations and the fact that this EI was designed to capture the highest exposures.

Chronic inhalation of respirable crystalline silica particles may cause silicosis and is associated with increased risk of lung cancer. The IARC and the U.S. NTP have designated respirable crystalline silica as a human carcinogen. In addition, inhalation of crystalline silica has been associated with other respiratory diseases such as chronic obstructive pulmonary disease, bronchitis and emphysema, as well as kidney and immune system diseases.

Conclusion 3

Concentrations of PM_{10} and PM_4 crystalline silica measured during the EI were highest on Valley School campus when winds are from the southwest (the direction of LMC relative to the school campus). These wind conditions are more common in the spring and summer than other times of

[2] EPA does not formally define "unusually sensitive", but it is a qualitative designation of personal vulnerability to PM possible due to the inherent differences among individuals.

year. Concentrations of PM_4 indoors are approximately four times lower than concentrations of PM_4 outdoors.

Basis for Conclusion 3

PM_{10} and PM_4 crystalline silica are highest at monitors closest to the facility. Polar plots from all PM monitors at the school show the highest concentrations when winds are from the direction of LMC.

Conclusion 4

Breathing $PM_{2.5}$ on the campus of Valley School and in the surrounding area does not present a public health hazard to the general healthy (and most sensitive) population of students, staff, or residents. ATSDR recognizes that some individuals (e.g., asthmatics or those with other cardiopulmonary conditions) are unusually sensitive to changes in air quality, and as such, those individuals may still experience transient health effects during days with poorer air quality, regardless of whether concentrations exceed health-based values like the WHO AQGs.

Basis for Conclusion 4

All 24-hour concentrations of $PM_{2.5}$ were below the 24-hour WHO guideline for $PM_{2.5}$ (25 $\mu g/m^3$). The average $PM_{2.5}$ concentration during the entire EI was below the annual WHO AQG (10 $\mu g/m^3$) at all sites except Site 2 (10.5 $\mu g/m^3$) at the school. Since data from the permanent PM_{10} monitor show that concentrations during the EI were approximately 20% higher than the long-term average, and assuming similar relative concentrations of $PM_{2.5}$ and PM_{10}, it is likely that the concentrations measured during the EI represent a reasonable upper estimate of exposure.

Recommendations

ATSDR makes the following recommendations to reduce exposure to PM_{10} and PM_4 crystalline silica on the campus of Valley School and in the surrounding area.

1. LMC should confirm that the efforts implemented via the 2017 Administrative Order to reduce emissions of PM_{10} and PM_4 crystalline silica from their operations have resulted in reduced exposure to particulate matter and crystalline silica in the surrounding area.

2. LMC should make permanent station PM_{10} data available to Valley School District in real-time to assist in decision-making on when to limit outdoor activity on the school campus.

3. Valley School District should limit outdoor activity when concentrations of PM_{10} are above 50 $\mu g/m^3$ in outdoor air or in the AQI moderate category.

4. If real-time data are not available, Valley School should limit outdoor activity on campus when strong winds from the southwest are present since those conditions are most likely to result in elevated concentrations of PM_{10} and PM_4 crystalline silica on school grounds. If no wind direction measurements are available from Valley School, LMC could install a windsock to inform decision makers about wind directions.

5. LMC should conduct regular calibration checks and audits of the permanent PM_{10} monitor.

Public Health Action Plan

To facilitate the above Recommendations, ATSDR will do the following:

- ATSDR will provide a copy of this report to the Valley School District, the EPA, the WA Department of Ecology, EI Participants, and other community members as requested;

- ATSDR will offer to meet individually with EI participants to discuss the information provided in this report and to specifically discuss the data collected on their respective properties;

- ATSDR will meet with interested stakeholders to discuss the information provided in this report;

- ATSDR and the WA Department of Ecology will meet with the Valley School District to discuss changes implemented through the Administrative Order issued November 2017 by the WA Department of Ecology to Lane Mountain Company; and

- If requested, ATSDR will work with the Valley School District, the WA Department of Ecology, and the EPA to consider options to reduce exposures in the Valley, WA.

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Appendix A: Data Analysis and Quality Assurance

Data analysis

For silica results that were below the reported detection limit, ATSDR used robust regression on order statistics (ROS) [Lee and Helsel 2005; Helsel 2012] as implemented in the R package "NADA version 1.6-1". ATSDR computed means with upper 95% confidence limits using the regression on order statistics imputed values and nonparametric percentile bootstrap intervals. In the bootstrap, ATSDR used percentile methods recommended by Helsel [2012] and used 1,999 sample replicates [Helsel 2012]. To compare silica concentrations across stations, ATSDR used ordinary least squares regression of the log-transformed concentration.

For PM_{10} and $PM_{2.5}$ data, ATSDR first averaged the data to 24-hour values, and then used maximum entropy bootstrapping to calculate 95 percent confidence intervals of the mean as implemented in R package "meboot 1.4-7" [Vinod and López-de-Lacalle 2009]. Maximum entropy bootstrapping creates bootstrap replicates of the time series, which preserves the data's autocorrelation structure and the seasonality. As maximum entropy bootstraps do not assume stationarity, they are resistant to structural changes in the air quality of the air shed (e.g., implementation of pollution control devices, reductions in emissions from lowered production). Maximum entropy bootstrapping does not impose any parametric assumptions on the data.

To explore the relationship between wind direction, wind speed and concentration, ATSDR generated polar plots of PM_4 silica, PM_{10}, and $PM_{2.5}$ using the R package, "openair 2.1-5" [Carslaw and Ropkins 2012]. These plots display the relationship of wind direction and wind speed on pollutant concentration. The output is scaled to a polar coordinate system, which is essentially a circular axis. Wind direction data are placed in bins on the polar axis that correspond to the direction in degrees from which the wind originated, with north at 0 degrees, south at 180 degrees, east at 90 degrees and west at 270 degrees. Polar plots show wind speeds for any given direction in bins or compartments that are a proportional distance from the center of the plot, with higher wind speeds occurring further from the center. These plots will indicate the direction and the wind speed where contaminant concentrations are higher (the redder the area) or lower (the bluer the area) and can indicate the direction to potential sources.

Data Quality Objectives

Data Quality Objectives (DQOs) are measures used to determine how good data must be to achieve the project goals. DQOs are used to develop the criteria that a data collection design should satisfy including where to conduct monitoring, when to conduct monitoring, measurement frequency, and acceptable measurement precision and accuracy. Considering the targeted compounds, information obtained during the site visits to date, and specifications associated with the monitoring and sample collection systems that will be used, DQOs for this EI are presented in Table A-1. All DQOs for crystalline silica, PM, and meteorological data were met during the EI. Technical DQOs for SO_2 were not met and thus, SO_2 data were invalidated and not considered in developing public health conclusions from the EI data.

Table A-1. Data Quality Objectives

	Element	*Objective*
Operational DQOs	Where to Conduct Monitoring	All monitoring/sampling locations must be close to the potentially impacted population.
	Number of Monitoring Locations Required	A total of six to nine sites will provide a representative and direct relationship to the potentially impacted population (schools, public buildings, private residences, businesses).
	When to Conduct Monitoring	Daily from 00:00 to 23:59 hours across 8 continuous weeks.
	Frequency of Monitoring	•Continuous for $PM_{2.5}$, PM_4, PM_{10}, and SO_2 to allow assessment of short duration excursions and calculations of hourly and daily average concentrations. •24-hour integrated samples collected on 1 of every 2 days for PM_4 crystalline silica samples to allow assessment of daily average concentrations. •Continuous for meteorological parameters.
Technical DQOs	Overall Completeness	80% data capture or greater
	Acceptable laboratory measurement accuracy for PM_4 silica (NIOSH 7500)	Per NIOSH Method 7500
	Acceptable laboratory measurement accuracy for PM_4 silica (NIOSH 0600)	Per NIOSH Method 0600
	Acceptable field measurement accuracy for PM_4 silica using Thermo Scientific™ Partisol™ Samplers	•Flow ±4% of 11.1 liters per minute (LPM) •Temperature sensors ±2°C •Ambient pressure ±10 millimeter of mercury (mmHg) •External/internal leak check = pass •Sample flow variability <2% coefficient of variation •Total collection time within 10% of 1,440 minutes (24 hours)
	PM measurement accuracy for $PM_{2.5}$, PM_4, and PM_{10} using E-BAMs*	•Flow ±2% of set point •Temperature sensors ±2°C •Ambient pressure ±10 mmHg •Leak check ≤1.5 LPM drop •Self-test = pass •Span (membrane) test = pass
	Acceptable measurement accuracy for Thermo Scientific™ Partisol™ 43*i* SO_2 Analyzer	•≤±3% error for zero check at full scale •≤±10% error for span check at 80% of full scale

Operational DQOs

The Valley School EI met all specified operational DQOs. Detailed operational DQO performance information is presented below.

- Siting: All monitoring/sampling locations were at or near the Valley School area. As outlined in the DQO, ATSDR initially planned to have six to nine sampling/monitoring sites. This was met, with having a total of nine locations included in the EI that directly represent the potentially impacted population.
- Duration: The monitoring/sampling event began on July 27, 2016 and ended on September 22, 2016. The EI had a total duration of 8 weeks. E-BAM monitoring at some individual sites was conducted over less than 8 weeks.
- Measurement intervals: Measurements of $PM_{2.5}$, PM_4, PM_{10}, and SO_2 occurred continuously throughout the day. Measurements of PM_4 crystalline silica were 24-hour integrated samples collected on a 1 every 2-day basis.

Measurement Completeness

For this EI, completeness was defined as the number of valid measurements collected, compared to the number of possible measurements. Monitoring/sampling programs that consistently generate valid results tend to have higher measurement completeness than programs that consistently invalidate samples. Therefore, the completeness of an air-monitoring program is a qualitative measure of the reliability of air sampling and laboratory analytical equipment and the efficiency with which the field program and laboratory analysis was managed.

Measurements of PM_4 total gravimetric mass and PM_4 crystalline silica were collected using Partisol Air Samplers at Sites 1, 2, 5, 7, 8, and 9. In total for this site, there were 183 samples analyzed, including primary samples and field blanks. Specifically, the 183 Partisol samples analyzed included 165 primary field samples and 18 field blanks. All 183 of these were valid samples, yielding 100% measurement completeness. The measurement completeness DQO was satisfied for PM_4 total gravimetric mass and PM_4 crystalline silica.

Measurement completeness for E-BAM data was assessed based on valid 1-hour measurements. E-BAM completeness statistics are presented in Table A-2. Percent completeness was greater than 97% for all E-BAMs. Missing data were due to power outages or hours with flow outside of the acceptable range. The measurement completeness DQO was satisfied for all E-BAMs.

Table A-2. Data Completeness

Site ID	*Total Possible Measurements*	*Total Valid Measurements*	*Total Invalid Measurements*	*Completeness (%)*
Site 2 ($PM_{2.5}$)	1,369	1,365	4	99.71
Site 5 (PM2.5)	1,370	1,362	8	99.42
Site 7 (PM2.5)	1,366	1,335	31	97.73
Site 8 (PM2.5)	1,362	1,357	5	99.63
Site 9 (PM2.5)	1,296	1,293	3	99.77
Site 3i (PM4)	1,010	1,007	3	99.71
Site 4i (PM4)	722	717	5	99.31
Site 4c (PM4)	646	644	2	99.69
Site 5 (PM10)	358	356	2	99.44

The SO_2 instrument reported data 99.22% of the time during the EI. Data validation, however, showed that the data were not acceptable for use in public health decision making due to the lack of a temperature-controlled enclosure. No valid data were collected for SO_2, resulting in 0% measurement completeness. The measurement completeness DQO for SO_2 was not satisfied. Measurement completeness was 99.98% for the meteorological parameters measured at Site 9 during the EI. The few missed measurements were during data download. The measurement completeness DQO for meteorological data was satisfied.

Measurement Accuracy

Measurement accuracy for PM_4 crystalline silica was determined by evaluating laboratory measurement accuracy and field measurement accuracy.

For *laboratory accuracy*, analysis of PM_4 silica was performed by RTI, a laboratory accredited with the American Industrial Hygiene Association. The laboratory provided pre-weighted filters with respective cassette holders. Samples sent to the laboratory were collected, shipped, and analyzed under a chain of custody. Per the EI DQOs, RTI met the laboratory accuracy requirements by adhering to the analytical methods outlined in NIOSH Method 0600 and NIOSH Method 7500.

Field measurement accuracy associated with the Thermo Scientific™ Partisol™ samplers was assessed using a series of manufacturer- and method-specified audits. Performance audits were performed during staging (July 6, 2016), after deployment (July 28, 2016), during the fourth week of sampling (August 24, 2016), and again during recovery (September 19, 2016).

- Flow rates of the Partisol samplers were measured, and acceptable if within ±5% of the audit value. All flow rates were deemed acceptable, with a percent difference ranging from to 0.00% to 2.12%.
- Partisol temperature sensor readings were measured and checked to ensure they were within ±2° C of the audit values collected using the BGI deltaCal calibrator. Values met the requirements, with ambient temperature ranging from a difference of 0.00 °C to 1.70 °C, and filter temperature ranging from a difference of 0.00 °C to 2.00 °C.
- Ambient pressure sensor readings were collected and assessed to ensure pressure was within ±10 mmHg of the audit value. All values met the requirements, ranging from 0.00 mmHg to 1.50 mmHg difference between the readings and audit values.
- Automated external and internal leak checks were conducted. The samplers were determined to "pass" or "fail" when the checks automatically finished. For the external leak check, a pressure drop of ≤25 mmHg over 60 seconds was required to yield a "pass" designation. For the internal leak check, a pressure drop of ≤140 mmHg over 60 seconds was required to yield a "pass" designation. All of the external and internal leak checks passed the requirements.
  In addition to the performance audits, the field team also conducted accuracy checks related to individual sample controls.
- Sample flow rate variability was evaluated throughout the period of sampling to determine that coefficient of variation (COV) values were less than 2% (i.e., the flow rate deviated by less than 2% of 11.1 LPM throughout the sampling period). Based on the COV data collected throughout the EI program, the COVs (excluding field blanks) ranged from 0.01% to 0.21%, meeting the requirement for accuracy.

Sampling time was examined to ensure total sampling time for each 24-hour integrated sample was within 10% of 1,440 minutes (24 hours). Out of 165 field samples, only one sample deviated from the expected total sampling time of 1,440 minutes, likely because of a power issue, with a total time of 1,393 minutes (47 minutes less than the total expected time, or about 3%). Thus, all samples were within 10% of 1,440 minutes.

All particulate monitoring devices were operated according to the manufacturer specifications. The primary quantifiable quality control measure typically used is to assess sample flow rates prior to deployment and compare these to manufacturer specifications.

The EI field team performed various accuracy tests on the E-BAM devices at all the $PM_{2.5}$ sites (Sites 2, 5, 7, 8, and 9), the PM_4 sites (Sites 3, 4i, and 4c), and the PM_{10} site (Site 5). This effort involved performing six different types of tests, which all indicate the E-BAMs were functioning

properly during the EI: a self-test, a span test, a leak check, a flow test, a pressure sensor audit, and a temperature sensor audit. Specifically,

- The span test and self-test were internal audits programmed into the E-BAMs, which the machines run on themselves. The E-BAMs ran the programmed audits and provided a "pass" or "fail" when the audits finished. All E-BAMs passed on all days tested.
- The leak check involved plugging the inlet of the sampler and ensuring the pump pulled the sampler to a vacuum with no leaks for several minutes. E-BAMs passed if test results were ≤1.5 LPM; all E-BAMs passed on all days tested.
- The flow test involved averaging several flow readings taken with a National Institute of Standards and Technology (NIST) traceable primary flow standard. E-BAMs passed if test results were ±2% of the flow set point of 16.7 LPM (less than 17.034 LPM and greater than 16.366 LPM). All E-BAMs passed the flow tests.
- Ambient pressure sensor audits involved reading the E-BAMs ambient pressure and comparing the levels to a NIST standard ambient pressure. The E-BAMs passed if pressure levels were ≤ ±10 mmHg of the NIST standard. The E-BAMs passed the pressure sensor audits on all tested days.
- Ambient temperature sensor audits involved reading the E-BAMs ambient temperature and comparing the levels to a NIST standard ambient temperature. The E-BAMs passed if temperature levels were ≤ ±2°C of the NIST standard. The E-BAMs passed these audits on all tested days.

Sulfur Dioxide

The instrument used to collect sulfur dioxide measurements needed a temperature-controlled shelter to provide valid data. One of the buildings on the Valley School campus was identified as an indoor, sheltered location for the SO_2 monitoring system. However, the air conditioning system in the building was not functional during the monitoring period. The instrument was still deployed, but after reviewing the collected data, it was determined that the collected data were not of sufficient quality to draw public health conclusions. All measured concentrations of sulfur dioxide were very low, but a large portion of the measurements were reported as large negative values and the instrument exhibited large step changes in response after instrument maintenance. Due to these data quality concerns, ATSDR cannot determine community exposure to sulfur dioxide and we are unable to make any public health conclusions regarding sulfur dioxide on the Valley school campus.

Appendix B: Health based Comparison Values (CVs)

The purpose of this appendix is to provide information about the CVs used for screening purposes in the EI. For further information on ATSDR's public health evaluation process and comparison values, please refer to the ATSDR guidance manual available at http://www.atsdr.cdc.gov/hac/PHAManual/toc.html [ATSDR 2005].

CVs are intended to protect the general public from adverse health effects for specific durations of exposure. They are used to screen out contaminants that are measured at concentrations that are generally safe (below the CV). A concentration above the CV does not necessarily mean that an adverse effect will occur, but it is an indication that the specific contaminant should be further investigated and compared to the health effects and doses documented in scientific literature.

This appendix provides a description of comparison values (CV) available for Particulate Matter and silica: EPA National Ambient Air Quality Standards NAAQS, WHO air quality guidelines (AQGs), and the OEHHA Reference Exposure Level (REL). The EPA Air Quality Index Calculator was also used for the health assessment of PM concentration and is discussed below. All of these CVs except the NAAQS are non-enforceable health-based guidelines used for screening contaminants. For each guideline discussed, a definition and description of the derivation and applicability or intended use are provided. When available, a website reference is also provided.

California Office of Environmental Health and Hazard Assessment (OEHHA) Reference Exposure Levels (RELs)

The OEHHA develops chemical-specific reference exposure levels for acute, 8-hour, and chronic exposure durations. Inhalation RELs are air concentrations or doses at or below which adverse noncancer health effects are not expected even in sensitive members of the general population under specified exposure scenarios. RELs are based on the most sensitive relevant adverse health effect reported in the medical and toxicological literature, and they are designed to protect the most sensitive individuals in the population by the inclusion of margins of safety.

ATSDR used the OEHHA chronic REL to assess silica concentrations in Valley. The chronic RELs apply to continuous exposures for a significant fraction of a lifetime, defined as about 8 years (≥12 percent of a 70-year lifespan). A central assumption is that a population threshold exists below which adverse effects will not occur in a population; however, such a threshold is not observable and can only be estimated. Areas of uncertainty in estimating effects among a diverse human population exposed continuously over a lifetime are addressed using extrapolation and uncertainty factors [OEHHA 2015]

EPA National Ambient Air Quality Standard (NAAQS)

The Clean Air Act, last amended in 1990, requires EPA to set NAAQS for widespread pollutants from numerous and diverse sources considered harmful to public health and the environment.

The EPA has set NAAQS for six principal "criteria" pollutants: carbon monoxide, lead, nitrogen oxides, ozone, particulate matter, and sulfur dioxide. The Clean Air Act requires periodic review of

the science on which the standards are based and the standards themselves. For technical information related to setting the national air quality standards, see EPA's Web site available at http://ofmpub.epa.gov/eims/eimscomm.getfile?p_download_id=508978 [EPA 2012]. EPA has the following NAAQSs for PM:

PM_{10}: The 24-hour average must not exceed 150 $\mu g/m^3$ more than once per year on average over three consecutive calendar years.

$PM_{2.5}$: The annual average concentrations of $PM_{2.5}$, averaged over three consecutive calendar years, should not exceed 12 $\mu g/m^3$. Further, the 98^{th} percentile of 24-hour average $PM_{2.5}$ concentrations in one year, averaged over three consecutive calendar years, must not exceed 35 $\mu g/m^3$.

WHO Air Quality Guidelines (AQGs)

The World Health Organization (WHO) develops air quality guidelines (AQGs) to offer guidance in reducing the health impacts of air pollution. First produced in 1987, these guidelines are based on expert evaluation of current scientific evidence. The new information included in the 2005 update relates to four common air pollutants: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide [WHO 2006].

WHO has the following AQGs for PM:

PM_{10}: The WHO annual average AQG is 20 $\mu g/m^3$ and the 24-hour AQG is 50 $\mu g/m^3$.

$PM_{2.5}$: The WHO annual average AQG is 10 $\mu g/m^3$ and the 24-hour AQG is 25 $\mu g/m^3$.

EPA Air Quality Index

EPA's Air Quality Index (AQI) online tool, "AIRNow AQI Calculator" (AQI) was used to estimate potential health effects from 24-hour averages of PM_{10} and $PM_{2.5}$ measured in Valley (see http://airnow.gov/index.cfm?action=resources.conc_aqi_calc) [EPA 2016]. This tool offers guidance to the potential acute health effects associated with specific concentrations of PM measured throughout the (See Table B1). The AQI categorizes 24-hour PM concentrations into six categories: good, moderate, unhealthy for sensitive populations, unhealthy, very unhealthy, and hazardous. The concentration ranges for each category, the associated public health statements, and relevant CVs are given in Table A1 below.

Table B-1. EPA Air Quality Index (AQI) categories with particulate matter ranges and associated health statement compared to ambient air standards and guidelines.

AQI Category	Air Quality Index Ranges 24-hr Average Concentration (µg/m^3)		Health Messages*		Ambient Air Average Standards (EPA NAAQS) and Guidelines (WHO AQG) (µg/m^3)
	PM_{10}	$PM_{2.5}$	Health Effects Statement	Cautionary Statement	
Good	0 – 54	0 – 12.0	None.	None.	**50 (PM_{10} 24-hr AQG)** 20 (PM_{10} Annual AQG) -- 10 ($PM_{2.5}$ Annual AQG) 12 ($PM_{2.5}$ Annual NAAQS)
Moderate	55 – 154	12.1 – 35.4	Respiratory symptoms possible in unusually sensitive individuals; possible aggravation of heart or lung disease in people with cardiopulmonary disease and older adults.	Unusually sensitive people should consider reducing prolonged or heavy exertion.	**150 (PM_{10} 24-hr NAAQS)** -- **25 ($PM_{2.5}$ 24-hr AQG)** **35 ($PM_{2.5}$ 24-hr NAAQS)**
Unhealthy for Sensitive Groups	155 – 254	35.5 – 55.4	Increasing likelihood of respiratory symptoms in sensitive groups including older adults, children, and people of lower socioeconomic status; aggravation of heart or lung disease and premature mortality in people with heart or lung disease.	People with heart or lung disease, older adults, children, and people of lower socioeconomic status should reduce prolonged or heavy exertion.	NA
Unhealthy	255 – 354	55.5 – 150.4	Increased aggravation of respiratory symptoms in sensitive groups including older adults, children, and people of lower socioeconomic status; increased aggravation of heart or lung disease and premature mortality in people with heart or lung disease; increased respiratory effects in general population.	People with heart or lung disease, older adults, children, and people of lower socioeconomic status should avoid prolonged or heavy exertion; everyone else should reduce prolonged or heavy exertion.	NA
Very Unhealthy	355 – 424	150.5 – 250.4	Significant aggravation of respiratory symptoms in sensitive groups including older adults, children, and people of lower socioeconomic status; significant aggravation of heart or lung disease and premature mortality in people with heart or lung disease; significant increase in respiratory effects in general population.	People with heart or lung disease, older adults, children, and people of lower socioeconomic status should avoid all physical activity outdoors. Everyone else should avoid prolonged or heavy exertion.	

AQI Category	Air Quality Index Ranges 24-hr Average Concentration (µg/m^3)		Health Messages*		Ambient Air Average Standards (EPA NAAQS) and Guidelines (WHO AQG) (µg/m^3)
	PM_{10}	$PM_{2.5}$	Health Effects Statement	Cautionary Statement	
Hazardous	425 – 604	250.5 – 500.4	Serious aggravation of respiratory symptoms in sensitive groups including older adults, children, and people of lower socioeconomic status; serious aggravation of heart or lung disease and premature mortality in people with heart or lung disease; serious risk of respiratory effects in general population.	Everyone should avoid all physical activity outdoors; people with heart or lung disease, older adults, children, and people of lower socioeconomic status should remain indoors and keep activity levels low.	NA

Source: Adapted from [EPA 2016]: https://nepis.epa.gov/Exe/ZyPDF.cgi/P100P29X.PDF?Dockey=P100P29X.PDF

Notes: AQG – World Health Organization (WHO) Air Quality Guidelines, AQI – EPA's Air Quality Index, CV – comparison value used for screening particulate matter data, EPA – U.S. Environmental Protection Agency, hr – hour; NA – not applicable, NAAQS – EPA National Ambient Air Quality Standards, PM – particulate matter for particulates smaller than 10 microns (PM_{10}) or 2.5 microns ($PM_{2.5}$); µg/m^3 – micrograms per meter cubed

*Sensitive Groups for All AQI Categories: People with heart or lung disease, older adult, children, and people of lower socioeconomic status are the most at risk.

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