Sonoma Technology, Inc.
Innovative Environmental Solutions

# Technical Memorandum

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To: Jason Wong, County of Marin, Department of Public Works

From: Josette E. Marrero, Paul T. Roberts

**Re: Summary of Air Quality Measurements at the San Rafael Rock Quarry During the Reclamation Monitoring Period**

## Overview

This memorandum summarizes air quality monitoring data collected in an area near the San Rafael Rock Quarry (SRRQ) between July 24 and October 2, 2018. This 10-week period marked the start of the SRRQ's Phase 1 Reclamation of their northeast quadrant. As with the background monitoring period that ran between May and July 2018, monitoring included continuous hourly measurements of particulate matter ($PM_{2.5}$ and $PM_{10}$) and black carbon (BC), as well as 24-hr discrete $PM_{10}$ filter samples to quantify crystalline silica and metals (using two separate sequential air samplers). PM measurements were made at a site in Marin Bay Park Court. Meteorological measurements (winds, temperature, and relative humidity) were conducted at the Marin Municipal Water District Tank. Data collected during the 10-week reclamation are compared with those collected during the background monitoring period, which was discussed in an interim report in September 2018.

Analysis of the data collected during reclamation activities revealed the following key findings:

- When compared to the springtime background monitoring period, hourly concentrations of BC increased by 70%, $PM_{2.5}$ increased by 36%, and $PM_{10}$ increased by 8%.
- Weekday concentrations of BC, $PM_{2.5}$, and $PM_{10}$ were greater than weekend concentrations by 78%, 30%, and 53%, respectively.
- The impact of quarry activities on the local air quality increased during reclamation, but concentrations are still within allowable state and federal air quality standards.
- Concentrations of silica and metals in $PM_{10}$ samples are below levels that are dangerous to human health.

## Data Collected

During the 10-week reclamation period, efforts were made to minimize gaps in measurements or data loss. For the 71 days spanning July 24 through October 2, hourly BC and PM data were collected at least 98% of the time (out of 1,704 hours). All hourly meteorological measurements were recorded during the reclamation period. As before, only days with 75% of possible hourly measurements were considered valid and included in analysis requiring 24-hour averages (note: 24-hour averages span between midnight and midnight daily). BC measurements were incomplete, and excluded from 24-hour averages, on three days during the reclamation monitoring period. $PM_{10}$ data were incomplete and excluded on just one day, and $PM_{2.5}$ data were included on all days. Because of instrument error, $PM_{10}$ filter samples for analysis of metals could not be collected on 15 days, or 20% of the days during reclamation. Samples designated for analysis of silica were collected every day (also midnight to midnight).

## Quality Control Checks

Automated quality control checks are still in place for data received into the data management system. PM data are marked invalid if values greater than 950 $\mu g/m^3$ are reported, since this is a default instrument code indicative of an instrument error or maintenance. Data are flagged as suspect if BC values are reported below -0.5 $\mu g/m^3$ and if PM values are below -2 $\mu g/m^3$, since they indicate that measurements are close to the instrument limits of detection. Additionally, data are flagged as suspect if the same value is reported for four or more consecutive hours. These data are then further evaluated manually by the data reviewer to ensure their validity on a daily to weekly basis. Data can be nullified if instrumental or operational conditions are the reason for the suspicious data.

## Data Interpretation

Monitoring data were analyzed to reveal typical patterns in BC and PM, including time of day or day of the week when concentrations are highest. Wind speeds and directions were used to relate PM measurements to potential sources. One of the primary goals of PM and BC monitoring during the reclamation period was to compare trends to those observed during the background period. During the reclamation period, quarry activities included grading of an area of approximately 300,000 square feet, only on weekdays. Therefore, it was expected that weekend days during this 10-week period would be similar to data collected during the background monitoring period and representative of typical local and regional sources of PM. It should be noted that in addition to quarry activities, smoke from the Mendocino Complex Wildfire impacted the area during the month of August. Those data are identified in a following section.

## *Trends in Hourly BC and PM Concentrations*

A time series plot of BC and PM measurements during the reclamation period (July 24 – October 2) is shown in **Figure 1**. As expected, concentrations of $PM_{2.5}$ and $PM_{10}$ track each other well, with peak and minimum concentrations occurring at the same time. BC measurements during the reclamation period generally follow the same trends as $PM_{2.5}$ and $PM_{10}$. For reference, the time series of PM and BC measurements observed during the background period (May 4 – July 23) are included in Figure 1. A quick glance at time series data reveals differences between the background and reclamation monitoring periods, with more spikes in BC (values >1 µg/m$^3$) and $PM_{10}$ (>100 µg/m$^3$) present.

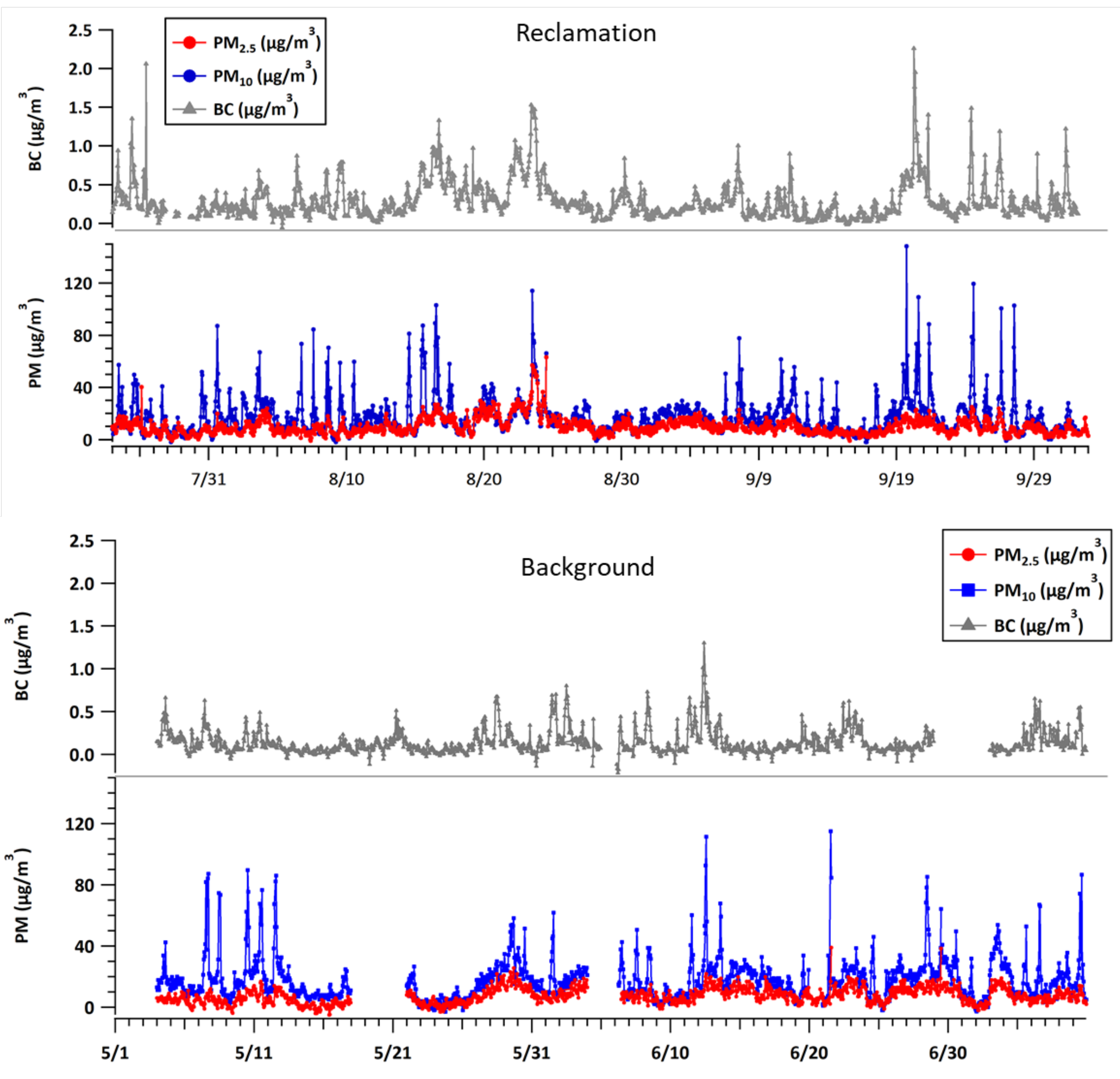


**Figure 1.** Hourly black carbon (gray), $PM_{2.5}$ (red), and $PM_{10}$ (blue) measurements collected during the reclamation period of July 24, 2018 – October 3, 2018 (top panel), and background period of May 4, 2018 – July 23, 2018 (bottom panel), at the Marin Bay Park monitoring site.

Typical winds measured during reclamation are represented in Figure 2. Winds were similar to those during the background monitoring period, and were typically from the south and southwest. Winds ranged from calm (<1.5 m/s) to a maximum speed of 6.8 m/s. Calm winds were observed approximately 28% of the time, similar to 26% during the springtime background period. Pollution roses also included in Figure 2 show typical wind directions for the various concentrations measured.

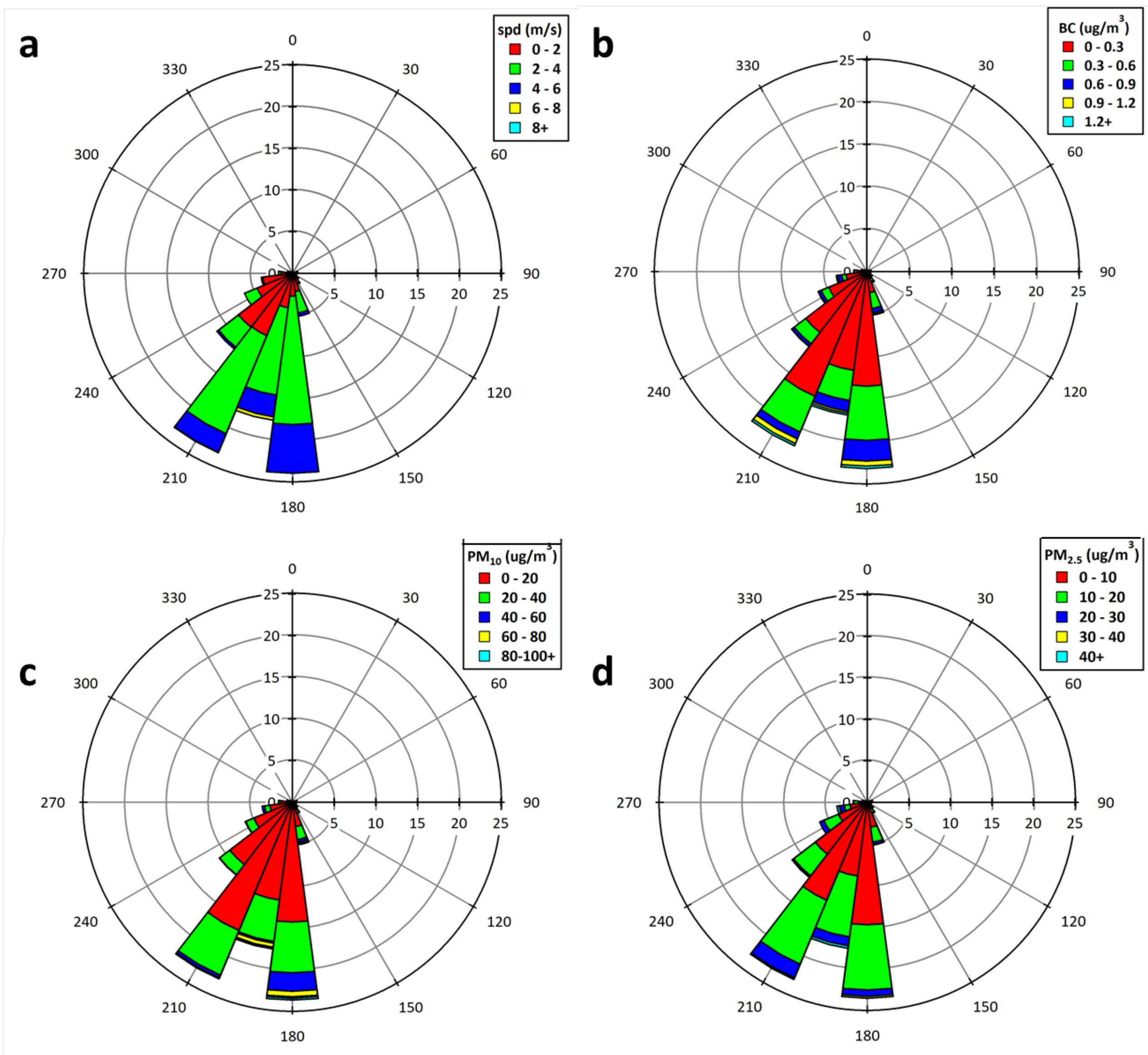


Figure 2. Wind rose (a) showing typical wind speeds and directions (S & SW) measured at the Marin Municipal Water District Tank between July 24 and October 3, 2018. Pollution roses illustrate that the highest concentrations in BC (b), $PM_{10}$ (c), and $PM_{2.5}$ (d) were all observed during these southerly and southwesterly wind conditions.

Table 1 contains a summary of the statistical information for BC and PM measurements recorded during the reclamation period, as well as the background period, for comparison. Average hourly concentrations during the reclamation period were 0.29 μg/m$^3$ for BC, 10.1 μg/m$^3$ for $PM_{2.5}$, and 17.5 μg/m$^3$ for $PM_{10}$. These values represent a 70% increase in BC, a 36% increase in $PM_{2.5}$, and an 8% increase in $PM_{10}$ during reclamation compared to the background monitoring period.

Similarly to the springtime background monitoring period, BC and PM concentrations were higher on weekdays than on weekend days. During weekday reclamation work, concentrations averaged 0.32 μg/m$^3$, 10.8 μg/m$^3$, and 19.4 μg/m$^3$, for BC, $PM_{2.5}$, and $PM_{10}$, respectively. These averages correspond to percent differences of 78% for BC, 30% for $PM_{2.5}$, and 53% for $PM_{10}$ when comparing weekday to weekend values. The weekday-weekend differences can be observed visually in Figure 1. For example, between July 31 and August 20 there are sharp increases in $PM_{10}$ for 5 days, then concentrations return to baseline for 2 days, before increasing again for another 5 straight days. The pattern is again observed between September 10 and September 29. During both of these timeframes, $PM_{2.5}$ and BC generally follow the same pattern, though the difference between baseline and spikes is less pronounced. Increased weekday particulate concentrations over weekend values were not observed between August 27 and September 5. The cause for this deviation in trend is unclear, as no meteorological or regional events were identified (e.g., there was not an increase in relative humidity).

**Table 1.** Statistical summary of all BC and PM concentrations observed during the 10-week quarry reclamation period (July 24–October 2). Average values (1σ) are reported along with the standard deviation (1σ), and average values for weekdays and weekends are also included.

| | BC (μg/m$^3$) | $PM_{2.5}$ (μg/m$^3$) | $PM_{10}$ (μg/m$^3$) | BC (μg/m$^3$) | $PM_{2.5}$ (μg/m$^3$) | $PM_{10}$ (μg/m$^3$) |
|---|---|---|---|---|---|---|
| | *Background Period* | | | *Reclamation* | | |
| Average (1σ) | 0.14 (0.14) | 7.0 (4.9) | 16.2 (13.2) | 0.29 (0.19) | 10.1 (6.6) | 17.5 (14.7) |
| 1st quartile | 0.05 | 3.1 | 7.1 | 0.13 | 6.0 | 8.0 |
| Median | 0.1 | 6.1 | 13.1 | 0.21 | 8.9 | 14.0 |
| 3rd quartile | 0.17 | 10.0 | 21.3 | 0.35 | 13.0 | 22.1 |
| Maximum | 1.3 | 39.1 | 115 | 2.3 | 57.0 | 148 |
| | *Weekdays Only* | | | *Weekdays Only* | | |
| Average (1σ) | 0.14 (0.14) | 7.1 (5.4) | 17.2 (14.3) | 0.32 (0.28) | 10.8 (7.0) | 19.4 (16.4) |
| | *Weekends Only* | | | *Weekends Only* | | |
| Average (1σ) | 0.11 (0.11) | 6.8 (4.2) | 14.1 (9.9) | 0.18 (0.13) | 8.3 (4.9) | 12.7 (7.3) |

If we define spikes in BC and PM data as the highest 10% of measurements, the highest concentrations were observed in the early afternoon, during southerly winds with speeds of approximately 2.4 m/s (Table 2). This trend is similar to the trend observed during the background period, but with higher average concentrations.

**Table 2.** Typical time of day, wind conditions, and hourly average particulate concentrations when the highest 10% of concentrations were observed during background monitoring and reclamation.

| Spikes | Time of Day (PST) | Wind Dir. (°) | Wind Speed (m/s) | BC (µg/m³) | $PM_{2.5}$ (µg/m³) | $PM_{10}$ (µg/m³) |
|---|---|---|---|---|---|---|
| Top 10% - reclamation | 12:35 | 193 | 2.4 | 0.86 | 24.2 | 50.8 |
| Top 10% - background | 12:50 | 187 | 3.3 | 0.46 | 16.7 | 45.3 |

## *Influence of Regional Fires*

While the weekday trend in $PM_{10}$ data suggests that rock quarry activities during reclamation are impacting the local air quality, it is not the only influence on BC and PM concentrations. The Mendocino Complex Fire, consisting of the Ranch and River Fires, burned from July 27, 2018, until it was fully contained on September 18, 2018. The complex was the largest fire in California history, burning more than 459,000 acres. While the fire was 130 km north of San Rafael, smoke from the fire was transported to the region, as is visible from satellite imagery shown in Figure 3.


**Figure 3.** Suomi NPP VIIRS satellite imagery showing smoke from the Mendocino Complex Fire impacting the entire San Francisco Bay Area on August 23, 2018. (source: NASA Worldview).

The image was taken on August 23 by the Suomi NPP weather satellite, which contains a Visible Infrared Imaging Radiometer Suite (VIIRS). The satellite is operated by the National Oceanic and Atmospheric Administration (NOAA) and is designed to make passes over a location on the earth at the same time each day. Similar satellite images reveal that the largest smoke impact in the region occurred between August 18 and August 25.

In addition to satellite imagery, the monitoring data collected near the SRRQ indicate increases in BC and PM. To better illustrate the impact of wildfire smoke on BC and PM measurements, a summary of average hourly concentrations for the period between August 18 and August 25 is provided in Table 3. The hourly averages during the overall reclamation period excluding that week are also included in Table 3. BC in the atmosphere is used as a tracer of combustion, and is indicative of wildfires and smoke. Similarly, $PM_{2.5}$ concentrations are increased during wildfires since smoke particles are smaller than the other particles that make up $PM_{10}$ (dust, sea salt, inorganics, etc.). During the week with heavy regional smoke, BC concentrations were 61% greater than during the rest of the reclamation period, and $PM_{2.5}$ was increased by 73%. $PM_{10}$ concentrations were also higher during this week, but only by 22%.

**Table 3.** Statistical summary of black carbon (BC) and particulate (PM) concentrations during reclamation activities without the smoke-impacted week in August (left) and during just the smoke impacted week (right).

| | BC ($\mu g/m^3$) | $PM_{2.5}$ ($\mu g/m^3$) | $PM_{10}$ ($\mu g/m^3$) | BC ($\mu g/m^3$) | $PM_{2.5}$ ($\mu g/m^3$) | $PM_{10}$ ($\mu g/m^3$) |
|---|---|---|---|---|---|---|
| | *All days except Aug 18 –25* | | | *Aug 18–Aug 25* | | |
| Average (1σ) | 0.26 (0.23) | 8.9 (4.8) | 17.0 (14.7) | 0.49 (0.29) | 19.1 (10.6) | 21.2 (14.7) |
| 1st quartile | 0.11 | 5.1 | 8.0 | 0.27 | 11.0 | 11 |
| Median | 0.19 | 8.0 | 13.7 | 0.41 | 17.4 | 18.7 |
| 3rd quartile | 0.31 | 11.9 | 21.8 | 0.62 | 24.1 | 27.0 |
| Maximum | 2.3 | 40.3 | 148 | 1.5 | 57.0 | 114 |

One of the major meteorological factors responsible for regional smoke impacts is reduced wind speed. Without strong winds to transport smoke, stagnation occurs and leads to high surface PM concentrations. This was witnessed on days in late August with the highest concentrations of BC and PM. For example, on August 23, the average wind speed was the lowest of any day that week at 1.6 m/s. The 24-hr average BC that day was 0.98 $\mu g/m^3$, $PM_{2.5}$ was 36.0 $\mu g/m^3$, and $PM_{10}$ was 41.1 $\mu g/m^3$.

## Comparison to 24-Hour Air Quality Standards

During the background monitoring period, 24-hr averages of PM were compared to both California and national (U.S. EPA) ambient air quality standards. Concentrations measured during the 10-week reclamation period were also compared to these standards (Table 4). Average values were 0.29 µg/m$^3$ for BC, 10.1 µg/m$^3$ for $PM_{2.5}$, and 17.5 µg/m$^3$ for $PM_{10}$. These values are higher than the background period by 70%, 36%, and 8% for BC, $PM_{2.5}$, and $PM_{10}$, respectively.

The higher 24-hour average $PM_{2.5}$ and $PM_{10}$ concentrations are still lower than the state and national 24-hour air quality standards. While PM may have been higher than the daily air quality standards during certain hours (65 times for $PM_{10}$ and 13 times for $PM_{2.5}$), no 24-hour period average exceeded the California or EPA 24-hr standards. Overall, 24-hr $PM_{2.5}$ and $PM_{10}$ concentrations were higher during reclamation but are still below the allowable annual California standards of 12 µg/m$^3$ for $PM_{2.5}$ and 20 µg/m$^3$ for $PM_{10}$. Measured concentrations will continue to be compared to air quality standards at the end of one full year of monitoring, as well as at the end of the 2-year project timeframe.

**Table 4.** Summary of state (California EPA) and federal (U.S. EPA) 24-hr and annual ambient air quality standards for $PM_{2.5}$ and $PM_{10}$, and 24-hr averages observed in this study. Standard deviations (1σ) are shown in parentheses.

| Pollutant | SRRQ Average (µg/m$^3$) | | CA Standard[a] (µg/m$^3$) | | EPA Standard[a] (µg/m$^3$) | |
|---|---|---|---|---|---|---|
| | *Background* | *Reclamation* | *24-hr* | *Annual* | *24-hr* | *Annual* |
| $PM_{2.5}$ | 7.0 (3.9) | 10.1 (5.3) | - | 12 | 35 | 12 |
| $PM_{10}$ | 16.2 (8.5) | 17.5 (8.0) | 50 | 20 | 150 | - |
| BC | 0.14 (0.1) | 0.29 (0.19) | - | - | - | - |

## Analysis of Daily Filter Samples for Silica and Metals

To better understand the chemical composition and the potential health impacts of the $PM_{10}$ particles measured downwind of the SRRQ, 24-hr filter samples were collected for analysis of silica and metal concentrations. The California Office of Environmental Health Hazard Assessment (OEHHA)[1] sets acute, 8-hour, and chronic Reference Exposure Levels (REL) for nearly 100 different substances; the National Institute for Occupational Safety and Health (NIOSH)[2] sets concentrations above which acute (short-term) exposure is Immediately Dangerous to Life or Health (IDLH); and the

[1] California Office of Environmental Health Hazard Assessment Acute, 8-hour, and Chronic Reference Exposure Level (REL) Summary (https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary).
[2] National Institute for Occupational Safety and Health Table of IDLH Values (https://www.cdc.gov/niosh/idlh/intridl4.html).

U.S. EPA[3] specifies cancer benchmark concentrations for both acute and chronic (long-term) exposure. Filter samples were analyzed for silica and 17 metals for comparison to these benchmarks.

During the springtime background monitoring period, 24-hr filter samples were on a 6-day sampling schedule outlined by the EPA. During the 10-week reclamation phase, filter samples were collected every day. Samples were then sent to the RJ Lee Group, Inc., laboratory for analysis. Of the total 184 filters collected between May and October, 54 were sent for analysis (including some field blanks). This included 28 samples for silica and 26 samples for metals. Filters were selected for analysis based on BC and PM concentrations (large spikes in concentration), and on whether interesting "events" occurred, such as blasting at the SRRQ or regional wildfire smoke.

A summary of the laboratory results is represented in **Figure 4**. The minimum detection limit (MDL) for each compound is represented by the gray bar, and any concentrations above that MDL are denoted in black. Chronic cancer benchmarks (red), acute IDLH levels (green), and chronic RELs (blue) are included for compounds where available. Arsenic, beryllium, mercury, molybdenum, and thallium were excluded from Figure 4 because they were not present above detection limits in any of the 26 filter samples.

Of the 12 metals detected in the filter samples, only zinc, nickel, and copper were ever above IDLH concentrations. For these metals, the high concentrations were observed once, and on the same day—July 31 (shown in purple in Figure 4). This was the day following a blasting event at the SRRQ. It is unclear why the metals were detected at higher amounts on the day after blasting, but 24-hr average BC and PM concentrations are also higher on July 31 than on July 30 (Figure 1).

Nickel and chromium were each detected in two samples at levels above the chronic cancer benchmarks (in one of these samples, nickel was also above the chronic REL). In the context of cancer benchmarks, chronic refers to a long-term period, and a one-day exceedance of the benchmark is not an automatic indicator of a cancer risk. For nickel, the high concentrations were observed on July 24 and July 31, and for chromium on August 4 and October 1. No known quarry activities or other events were noted on those days.

[3] United States Environmental Protection Agency Dose-Response Assessment for Assessing Health Risks Associated With Exposure to Hazardous Air Pollutants (https://www.epa.gov/fera/dose-response-assessment-assessing-health-risks-associated-exposure-hazardous-air-pollutants).

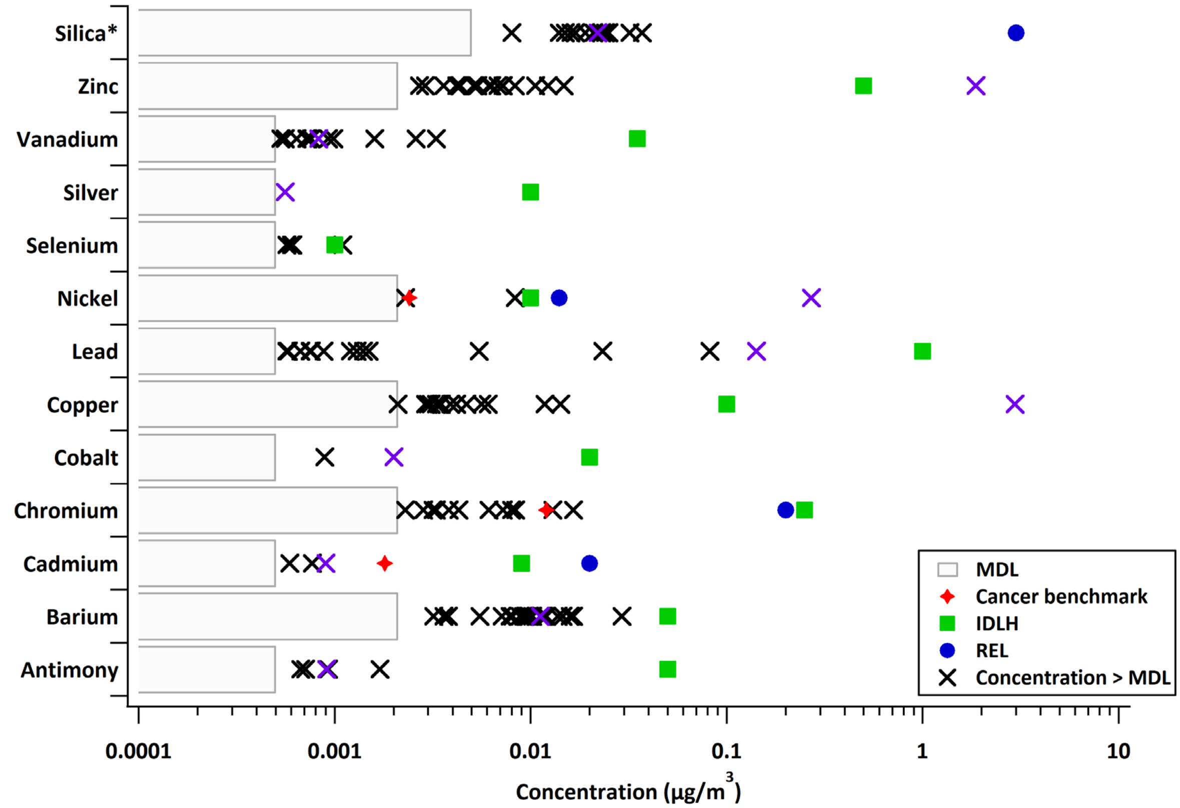


Figure 4. Bar graph summarizing concentrations of silica and metals measured in 24-hr filter samples collected between May 8 and October 2, 2018. This includes MDLs (gray), EPA chronic cancer benchmarks (red), acute IDLH levels (green), chronic RELs (blue), and observed concentrations above the MDL (black). Results from July 31, 2018, are highlighted in purple.

Because silica has several physical forms, it should be noted that only crystalline silica, or respirable dust, is being shown in Figure 4. In all 28 samples analyzed for silica, concentrations never surpassed the REL of 3 µg/m$^3$.

One of the expectations in the filter samples analyzed for silica content was that a higher $PM_{10}$ to $PM_{2.5}$ ratio could correspond to the increased presence of silica. This ratio would be higher in air containing mineral dust, which could be transported downwind when quarry activities are heightened. The weight percent in each silica sample was plotted against the PM ratio and is shown in Figure 5. While the correlation ($r^2$) is only moderate, there is a positive relationship between the two. This trend will be revisited after more filter samples have been analyzed.

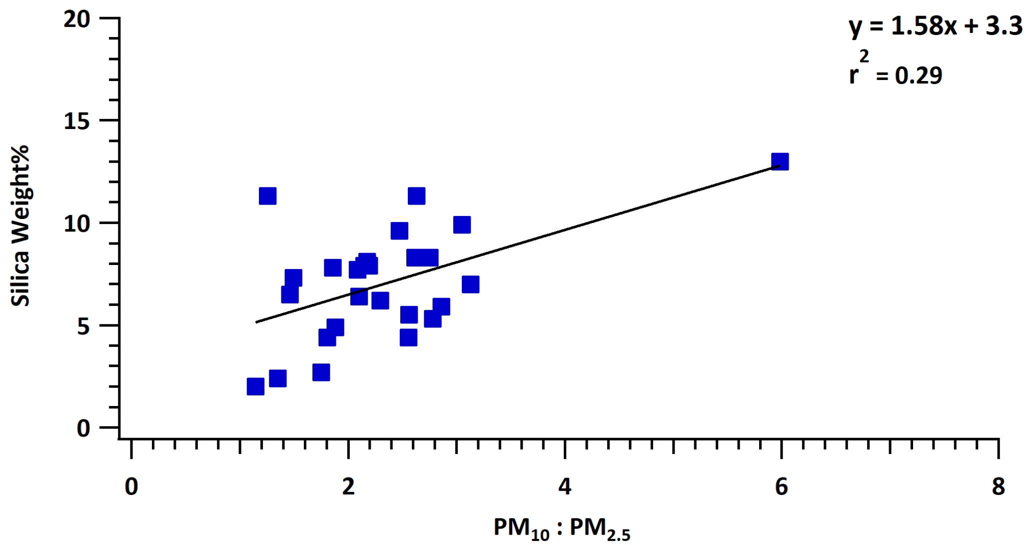


**Figure 5.** Scatter plot showing the relationship between weight percent of silica in each of the filter samples and the $PM_{10}$ to $PM_{2.5}$ ratio.

## Future Plans

Beginning on October 3, 2018, monitoring of the SRRQ returned to a background monitoring phase. Collection of 24-hr filter samples for silica and metals returned to the EPA-recommended 6-day monitoring schedule, and will remain on that schedule until the next 10-week reclamation period is slated to begin in July 2019.

All instrumentation will be serviced prior to the next reclamation period. This includes monthly and quarter leak checks of BC and PM instruments, cleaning of air inlets, and scheduled filter tape changes, as well as internal audits on meteorological sensor performance.

## Summary

The first phase of reclamation of the northeast quadrant of the SRRQ was conducted between July 23 and October 2, 2018. During this time, STI collected 1-minute meteorological data; monitored hourly concentrations of BC, $PM_{2.5}$, and $PM_{10}$; and collected 24-hour discrete filter samples for silica and metal analysis each day. When accounting for instrument maintenance or unexpected disruptions to instrument power, 98% of possible hourly data were successfully collected during this 10-week period.

As was observed during the background monitoring period (May 3–July 23), the prevailing wind direction observed at the monitoring site was from the direction of the SRRQ (southerly). During reclamation, there was a 70% increase in BC, a 36% increase in $PM_{2.5}$, and an 8% increase in $PM_{10}$ compared to the springtime monitoring period. Weekday concentrations of BC and PM are much higher than on the weekends, suggesting a noticeable impact of quarry activities on local air quality. Regional events also impacted the local air quality, as smoke from the Mendocino Complex wildfire was responsible for increased concentrations of BC and PM. However, even with the increased quarry and regional impacts, 24-hour PM concentrations remained within ambient air quality standards established by both the California EPA and the U.S. EPA.

Lastly, analysis of silica and metal in filter samples reveal that concentrations are generally below chronic reference exposure levels and cancer benchmarks. While one individual day (July 31) did have concentrations above acute IDLH levels, residents downwind of the SRRQ are not continually being exposed to dangerous amounts of toxic substances. The daily samples do not indicate long-term trends in exposure to high concentrations of metals.