Peace Project Water Use Plan

WILLISTON DUST CONTROL MONITORING

Implementation Year 12

Reference: GMSMON-18

BC Hydro Williston Reservoir Air Monitoring 2019 Annual Report

Study Period: January 01, 2019 to March 31, 2020

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July 14, 2020

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GMSMON#18 WLL Dust Control Monitoring

BC Hydro Williston Reservoir Air Monitoring 2019 Annual Report

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GMSMON#18 WLL Dust Control Monitoring:
BC Hydro Williston Reservoir Air Monitoring 2019 Annual Report

Prepared For

BC Hydro and the Joint Planning Committee

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Chu Cho Environmental has prepared this report using sound technical and professional judgment based on our extensive expertise and experience in developing and conducting works of this nature. We have identified and developed this report in order to provide clear and concise information regarding the…

Michael Tilson – General Manager, Chu Cho Environmental

Executive Summary

The GMSMON#18 (MON18) Air Quality Monitoring Program is focused on assessing the regional air quality trends in the Finlay airshed of the Williston Reservoir and the general efficacy of the Williston Dust Mitigation Program (WDMP) operations on an annual basis. This project was implemented as a response measure designed to analyze the fugitive dust emissions created by annual reservoir operations. The project consisted of a Regional Monitoring Network to identify the source and sink zones of PM around the Finlay airshed and a Reference Monitoring Station in Tsay Keh Dene to collected baseline particulate matter (PM) data. The implementation of this continued work utilizes the following objectives as the guiding focus for a more streamlined program:

- Provide long-term data on airborne particulate concentrations in the upper Finlay Reach of the Williston Reservoir airshed.
- Evaluate the effectiveness of dust mitigation treatments applied by the WDMP in the Finlay Reach drawdown zone.
- Identify long-term regional trends.

Based on our threshold of a dust event, 0.1 mg/m^3 of total suspended particulate (TSP), 2019 was a moderate to low dust year throughout the Finlay Reach of the reservoir, in terms of overall number of dust events (moderate) and intensity (low) of dust events (i.e. TSP concentration and duration), compared to past years.

Mitigation efforts of the WDMP appeared to yield positive results when sites had a sizeable number of events. Tillage worked well on Davis North beach but did not seem to have an impact on beaches with a lower number of dust events. Irrigation had positive results on Middle Creek North beach, but too few dust events during the sampling period prevented a proper analysis of efforts on Tsay Keh beach.

At the reference monitoring station in Tsay Keh Dene, the air quality measured according to guidelines set out by Canadian Ambient Air Quality Standards (CAAQS) and provincial Air Quality Objectives (AQO). The station measures PM <2.5 µm in diameter ($PM_{2.5}$) and PM <10 µm in diameter (PM_{10}). CAAQS and AQO are measured to 24-hour averages. During the dust season, there was no exceedance of the CAAQS for $PM_{2.5}$ and two exceedances of the provincial AQO for PM_{10}. Outside of this period there were no other exceedances of either CAAQS or AQO. These results are typical of other moderate/low years but do not always account for short duration high-intensity events.

Acknowledgements

Support for this project from Tsay Keh Dene Nation and BC Hydro has been essential to the continued success. Chu Cho Industries also provides essential support while they implement the Williston Dust Mitigation Program. Coordination between this monitoring program and the dust mitigation project has improved outcomes of both over the years. We would also like to acknowledge the Chu Cho Environmental team who meticulously manage the instrumentation and the volume of incoming data that are generated by this monitoring project. It is no small task and so thank you.

Glossary

Air quality event: Any instance where the TEOM station in Tsay Keh reports an exceedance of Canadian Ambient Air Quality Standards for $PM_{2.5}$ (28 μg/m^3) or British Columbia Air Quality Objectives for PM_{10} (50 μg/m^3) for a 24-hour period.

AQ: air quality

AQO: British Columbia Air Quality Objectives

asl: above sea level

CAAQS: Canadian Ambient Air Quality Standards

CCME: Canadian Council of Ministers of the Environment

DCMP: dust control management plan

Dust event: a period where the level of total suspended particulate matter (TSP) is equal to or exceeds the threshold of 0.1 mg/m^3, sustained over a 5-minute period, as measured by an E-Sampler. This is not a regulatory threshold, but one defined by the current and previous authors of these annual reports to illustrate periods during which dust is present in the air

E-Sampler: air particulate sampling unit, measurements in mg/m^3

PM: particulate matter (primarily in reference to dust emissions)

PM_{10}: particulate matter with a diameter <10 μm, a component of dust

$PM_{2.5}$: particulate matter with a diameter <2.5 μm, a component of dust

PM_{Coarse}: particulate matter with a diameter between 10 – 2.5 μm

TEOM 1405-D: air particulate sampling unit, measurements in μg/m^3

TSP: total suspended particulate matter (i.e., dust) that has a diameter <100 μm

WDMP: Williston Dust Mitigation Program; the program wherein various dust mitigation techniques are applied to exposed reservoir sediment to reduce dust emissions

1 Introduction

1.1 Williston Reservoir and the Finlay Valley Airshed

The Finlay Valley extends from the Peace Arm of the Williston Reservoir northwest toward the communities of Tsay Keh Dene and Kwadacha. The valley is part of the Rocky Mountain Trench residing between the Rocky Mountains on the east side and the Omineca Mountains on the west.

The Williston Reservoir was created following the construction of the W. A. C. Bennett dam on the Peace River approximately 20 km east of Hudson's Hope. The reservoir has a surface area of 1775 km^2, which fluctuates relative to the surface waters' elevation. The GMSMON#18 (MON18) Air Quality Monitoring Program is focused on assessing the regional air quality trends in the Finlay airshed of the Williston Reservoir and the general efficacy of the Williston Dust Mitigation Program (WDMP) operations on an annual basis. This project was implemented as a response measure designed to analyze the fugitive dust emissions created by annual reservoir operations that results in the exposure of vast expanses of loose sediment with little vegetative cover or other protection from wind erosion.

Winds in the northern Rocky Mountain trench tend to follow the orientation of the valley, flowing either Northwest or Southeast. There are many arms along the reservoir, which generate valley crosswinds at different times of the year. Generally, the ground-level winds in this area are steered by the orientation of the valley. This means that southerly winds drive the airborne fugitive dust from the reservoir beaches directly along the Rocky Mountain Trench northward, where they pass through Tsay Keh Dene.

1.2 Management Summary: Management Question & Program Components

The Dust Control Management Plan (DCMP) under Section 5.1 of the Peace River Water Use Plan (WUP) was one of the non-operating alternatives for the water use plan. The DCMP was implemented with the goal of reducing the magnitude of dust storms and their effect on the quality of life for people living adjacent to the reservoir (BC Hydro, 2007).

To fulfill the AQ monitoring component of the DCMP, a 12-year commitment (from 2008-2020 - an initial 10 years plus an additional 2 years) from 2008 to 2020 by BC Hydro to measure the fugitive dust emissions that result from exposed beaches on the Williston Reservoir. Data collected by the AQ monitoring program are integral in formalizing dust control audit procedures for testing the overall effectiveness of the erosion control methods employed by the WDMP. Theoretically, a successful erosion control program will result in diminished PM emissions observed by the AQ monitoring network.

The key management question for this program as defined in the GMSMON#18 ToR document is:

> What is the impact of dust mitigation treatments on Aeolian dust emissions from the Finlay Reach of the Williston Reservoir?

The results of this AQ monitoring program will provide input into the adaptive management of dust mitigation plans for the Williston Reservoir.

The report is split up into two components, regional and reference monitoring. The following table summarizes the components of the program and pertains to year-12 (2019) of MON18 and their status.

Table 1: Management summary - status of MON18 program components.

Program Component	Management Question	Management Hypothesis (Null)	Status
Regional Monitoring Network	Do dust mitigation activities result in decreased regional or local dust emissions?	Dust mitigation activities do not result in a reduction of dust emissions when evaluated at either a regional or local scale.	14 E-Samplers and 7 Meteorology sites were deployed for the 2019 sampling season to address this question. The samplers collected data at 5-minute intervals from late April to early July. The start of the season began with average temperatures and precipitation. At the beginning of the dust season, Williston Reservoir was operating at a lower operating level compared to 2018 (which was also low water level year).
Reference Monitoring Station	Are the long-term ambient air quality values for PM_{10} and $PM_{2.5}$ in Tsay Keh Dene within the provincial Air Quality Objectives (AQOs) and Federal Standards (CAAQS)?	The ambient air quality values for PM_{10} and $PM_{2.5}$ in Tsay Keh Dene do not meet the provincial AQOs or Federal CAAQSs.	During the 2019 dust season, there was one instance where the provincial AQO for PM_{10} was exceeded in a 24-hour period. There were no instances where the federal CAAQS for $PM_{2.5}$ was exceeded in a 24-hour period.
Mentorship and Community Engagement	n/a	n/a	Chu Cho Environmental employs Tsay Keh Dene Nation (TKDN) members who reside both in and outside of Tsay Keh Dene. Over the years, these individuals have steadily been taking on more responsibilities across the company on projects within and outside of Tsay Keh Dene territory. In 2019, for MON18, TKDN crewmembers participated in or were responsible for: -Setup of the regional monitoring network, -Data downloads and weekly

Program Component	Management Question	Management Hypothesis (Null)	Status
			instrument checks and calibration, during the dust season, -Tear down and storage of the regional monitoring network. -Instrument checks and the monthly maintenance of the TEOM reference monitoring station.
Enhanced Data Security, Transparency and Access	n/a	n/a	Chu Cho Environmental enlists third-party applications for hosting data online. All downloaded data collected from both the Regional Network and Reference Station was synced via Dropbox. That allows regional data to be synced after field downloads and reviewed shortly after for completeness. In 2019, internet access to the Reference Station was down for much of the year. Access was restored at the end of 2019 after rounds of troubleshooting identified an equipment malfunction. That issue resulted in the loss of the remote login system to the instrumentation. An email listserve was also unavailable during this time. The listserve usually sends anyone who wants to receive a .csv file summarizing the previous 12 hours of data.

1.3 Updates to the Monitoring Network

Chu Cho Environmental made two minor changes to the monitoring network for the 2019 season in an attempt to better and more efficiently capture dust mitigation activities on both Middle Creek North and Tsay Keh beaches.

1. E-Sampler at Middle Creek North – Middle was removed, as it was redundant due to its proximity to the other stations at Middle Creek North. The goal of having multiple stations on Middle Creek North was to sample particulate matter before and after the irrigation treatment on the beach.

2. An E-Sampler was added to Tsay Keh Beach to sample the air moving from the reservoir before interacting with the sediments on the beach. This decision was made in response to Chu Cho Industries' intent to more intensely concentrate their irrigation equipment to Middle Creek North and Tsay Keh Beach for 2019.

1.4 Data Summary

A summary of the program components for 2019 and the rate at which data were collected can be viewed in the following tables.

Table 2: Summary of air quality response measures monitored.

	Response Measures		
	Total Suspended Particulate Concentration	Particulate Matter Concentration	
	TSP	$PM_{2.5}$	PM_{10}
Variable ID	001-014	PM2.5	PM10
Sampling Year(s)	2014-2019	2011-2019	2011-2019
Sampling Frequency	5 min (April – July)	10 min (Annual)	10 min (Annual)
Measurement Units	mg/m^3	$\mu g/m^3$	$\mu g/m^3$
N	14	1	1
Equipment	E-Sampler	TEOM 1405-D	TEOM 1405-D

Table 3: Summary of meteorological equipment used in MON18.

	Meteorological Monitoring										
	Wind Speed		Wind Direction		Relative Humidity		Rainfall		Air Temperature		Air Pressure
Variable ID	ws	ws	wd	wd	rh	rh	precip	precip	temp	temp	pres
Sampling Year	2019	2019	2019	2019	2019	2019	2019	2019	2019	2019	2019
Sampling Frequency	5 min (May-Jul)	10 min (Jan-Dec)	5 min (May-Jul)	10 min (Jan-Dec)	5 min (May-Jul)	10 min (Jan-Dec)	5 min (May-Jul)	10 min (Jan-Dec)	5 min (May-Jul)	10 min (Jan-Dec)	10 min (Jan-Dec)
Units	m/s	m/s	degrees	degrees	%	%	mm	mm	°C	°C	kPa
N	7	1	7	1	7	1	7	1	7	1	1
Equipment	Met Station	TEOM 1405-D	Met Station	TEOM 1405-D	Met Station	TEOM 1405-D	Met Station	TEOM 1405-D	Met Station	TEOM 1405-D	Met Station

Network Component I: Regional Monitoring Networ

2 Regional Monitoring Network

2.1 Network Characterization

The Regional Monitoring Network was designed to assess the impact of dust mitigation treatments on aeolian emissions from the Finlay Reach of the Williston Reservoir. This network was minimally altered for 2019; these changes were identified above in Section 1.2. The Regional Monitoring Network consisted of 14 Met One Instruments E-Samplers and seven meteorological monitoring (met) stations. The 14 E-Samplers were deployed across the reservoir's Finlay Arm on many beaches and gravel bars, a rocky outcrop and a cut bank.

Not all locations along the reservoir drawdown zone are capable of emitting dust. Some locations such as Chowika and Ingenika are situated on large gravel bars or rock outcrops that do not produce dust. The dust recorded at these locations came from elsewhere further upwind within the reservoir basin. Other sites such as Middle Creek North and Collins are situated directly on or very near to beaches that are known high dust emitters. Samplers located on or near beaches are generally good indicators of the local dust conditions.

E-Samplers measure continuous air quality data every second and record those data at various averaging intervals. Since 2014, CCE has programmed the E-Samplers to save data at 5-minute intervals; this allows the units to function autonomously for up to 15 days before the on-board memory is full and begins to overwrite the oldest saved data. E-Samplers can measure either Total Suspended Particulate (TSP), PM10 (also shown as PM_{10}), or PM2.5 ($PM_{2.5}$), but they cannot measure all three simultaneously. Through joint planning and consultation, it was determined that measuring TSP was the priority for the Regional Monitoring Network. TSP includes all size fractions of fugitive particulate that may be ejected into the air from reservoir beaches by wind erosion.

In addition to the 14 E-Sampler sites, there were seven meteorological monitoring stations. The locations of these stations were unchanged from 2018. Each meteorology station was outfitted with a rain gauge, a combination temperature and relative humidity sensor as well as a combination wind vane and anemometer. The data were logged, averaged and saved in 5-minute intervals using a CR1000 datalogger.

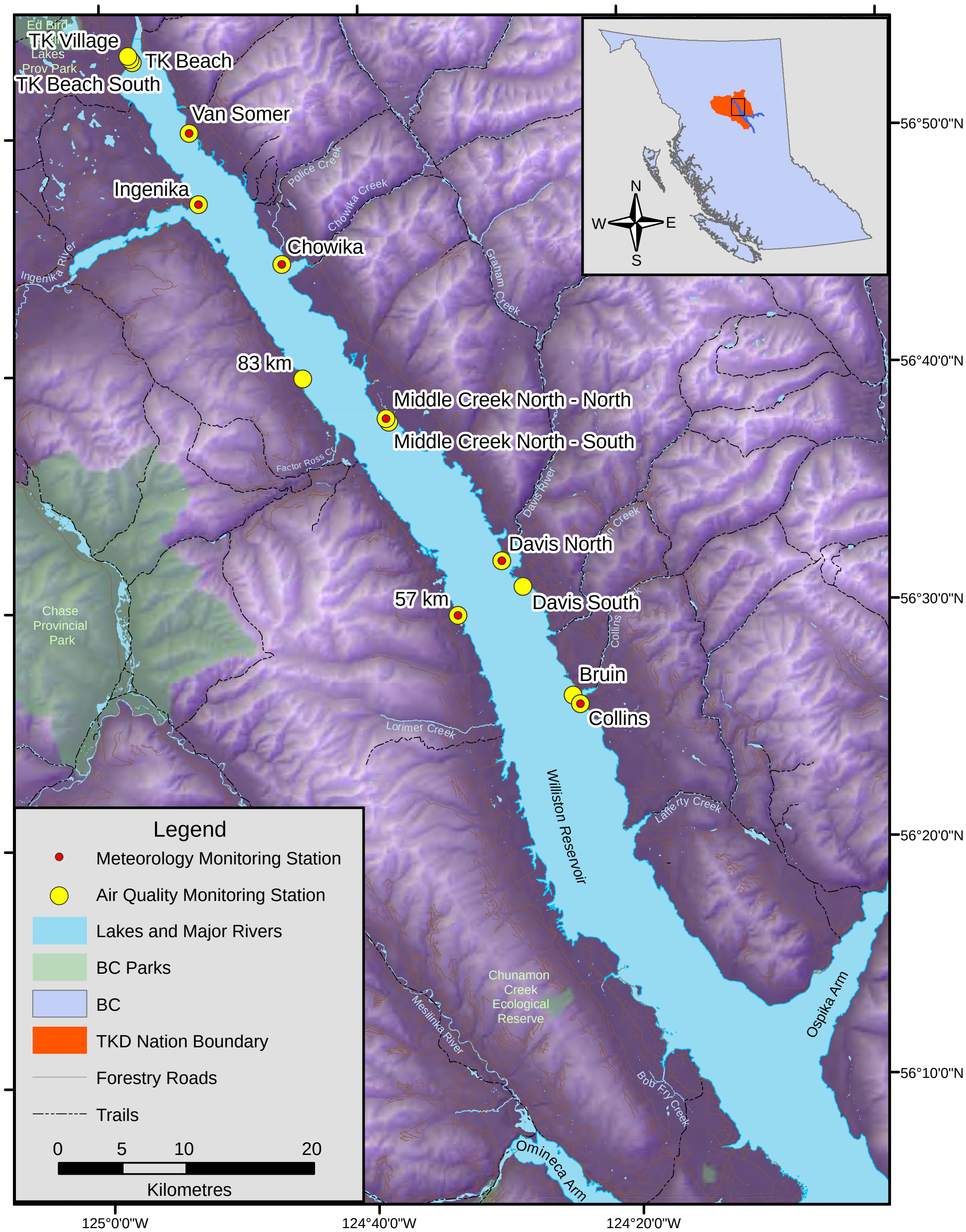
The location of sample sites was determined by accessibility and the characteristics of the site that adequately represent the airshed in that local zone. The Regional Monitoring Network is designed so that when examined as a group of E-Samplers working together, each site provides an essential component for understanding the regional air quality and the overall effect of the WDMP activities. By developing a monitoring network that is optimized for spatial distribution and sampling frequency Chu Cho Environmental is able to efficiently probe and use the data to address the key management question and to provide insight into the effectiveness of WDMP operations.

On the following page, Figure 1 shows the location of the 14 dust monitoring and eight meteorological monitoring stations within the Finlay Arm of the Williston Reservoir.

2.1.1 Site Details

Table 4 provides a detailed overview of the site locations, the instrumentation and the type of airshed representation the site provides.

GMSMON#18 Regional Monitoring Network - 2019



Projection: NAD 1983 BC Environment Albers
Geographic Coordinate System: GCS North American 1983

Produced by: Lindi Anderson
Date: 2017-01-03

Updated by: Tim Phaneuf
Date: 2019-11-21

Figure 1: Map of Regional Monitoring Network sampling locations.

Table 4: Regional Monitoring Network site descriptions and locations.

Site Name	Lat	Long	Met Station	Site Description	Airshed	Instru-ment
Tsay Keh Village	56.8915	-124.9638	Van Somer	The E-Sampler in Tsay Keh Dene was located on top of the TEOM Monitoring Station and its data can be compared to the TEOM 1405-D. In this report, Tsay Keh Village and Tsay Keh Town refer to this location.	Regional	E-Sampler
Tsay Keh Beach	56.8889	-124.9594	Van Somer	Tsay Keh Beach is located at the northern tip of the Finlay Arm where the Finlay River meets the Williston Reservoir and has excellent exposure to southeasterly winds. The beach is composed of highly mobile sediments and is considered a beach with high emission potential (Nickling et al., 2013). An E-Sampler has been placed in the foreshore zone of this beach since 2015 to capture the emissions from the beach before entering the village.	Local Dust	E-Sampler
Tsay Keh Beach South	56.8832	-124.9562	Van Somer	Tsay Keh Beach South is about 670 m southeast of the other beach site. It is located on a gravel bar adjacent to the old Finlay River channel and slightly above the fine beach sediments to the northwest. This site is well exposed to all southeasterly winds and capable of capturing regional fugitive dust that travels towards Tsay Keh. This site is also capable of recording local emissions from the foreshore area with local westerly winds.	Regional & Local Dust	E-Sampler
Van Somer	56.8367	-124.8861	Van Somer	Van Somer point is primarily comprised of sandy loam type sediment and is a known high emitter beach. This beach holds tillage quite well because the increased clay content tends to retain moisture. The sampling site was on a gravel bar above the beach that was well exposed to southerly and northwesterly winds. The sampling equipment was well-positioned to capture some local dust but also much of the regional dust passing through the area.	Regional & Local Dust	E-Sampler & Met Station

Site Name	Lat	Long	Met Station	Site Description	Airshed	Instru-ment
Chowika	56.7432	-124.7694	Chowika	The E-Sampler and met station were located on a large gravel bar that extends far into the reservoir. This site was very well exposed to northwesterly and southerly winds and the equipment there can sample much of the fugitive dust from beaches to the south that migrates towards Tsay Keh. This site produces no local dust emissions.	Regional Dust	E-Sampler & Met Station
Middle Creek North (MCN) – North	56.6319	-124.6454	Middle Creek North – North	The first site at Middle Creek North Beach, Middle Creek North – North (MCN-N), was located about 375 m further out on the beach (towards the reservoir) than the site in 2018, to better capture mitigation efforts. As a whole, MCN Beach is located on an exposed sand sheet and a high elevation beach with excellent wind exposure from the southeast and northwest. This beach is usually the first to be exposed in the spring and the last one to be covered up by the reservoir. Large depositional and erosional sand features form on this highly mobile beach. This beach is considered a high emissions beach. This site has excellent exposure to southeasterly winds and moderate exposure to northwesterly winds. Since 2017, this beach has only been irrigated, and irrigation efforts were intensified for the 2019 season. Access to the beach is limited by a temporary bridge, which in 2018, became overtopped with a reservoir elevation of 667.6 m (± 0.2 m).	Local Dust	E-Sampler & Met Station
MCN – South	56.6269	-124.6362	Middle Creek North – North	The site named Middle Creek North – South (MCN-S), is located about 785 m southeast of MCN-N. The beach material at this site is identical to the beach materials found at MCN-N.	Local Dust	E-Sampler
Davis North	56.5346	-124.4995	Davis North	Davis North Beach is a massive mixed sediment type beach that is considered a high fugitive dust emitter. The sampling equipment is well exposed to both northwesterly and southerly winds.	Local Dust	E-Sampler & Met Station

Site Name	Lat	Long	Met Station	Site Description	Airshed	Instru-ment
Davis South	56.5138	-124.4691	Davis North	Davis South Beach is a mixed sediment type beach that is known to emit large volumes of fugitive dust. Very large wet areas make fording and tilling the beach difficult. The sampling equipment is located in a clearing above a gravel bar that is above the reservoir's full-pool level. This site is well exposed to southerly winds and is not exposed to northerly winds.	Regional & Local Dust	E-Sampler
Bruin Beach	56.4377	-124.4113	Collins	Bruin Beach is primarily composed of mixed sand and gravel and is considered a moderate emitter. The E-Sampler is located on a gravel point that is exceptionally well exposed to southerly, southeasterly and northwesterly winds. This site is well-positioned to provide a regional representation of this area.	Regional Dust	E-Sampler
Collins Beach	56.4309	-124.4003	Collins	Collins Beach is a mixed gravel/sand/silt beach that extends from Collins Bay to Lafferty. This beach has limited vegetation at higher elevations and is a known high emitter. The sampling equipment is located on a gravel bar approximately 500 m south of the beach access point from Camp Collins. The equipment is well exposed to southeasterly winds and is moderately exposed to northerly winds.	Local Dust	E-Sampler & Met Station
Ingenika Point	56.7867	-124.8755	Ingenika Point	The sampling equipment was located on a rock outcrop on the northwestern corner where the Ingenika and Finlay Arms intersect. This site is exceptionally well exposed to southeasterly winds and provides a regional representation of dust events that arrive at the old village location. No dust is produced locally here.	Regional Dust	E-Sampler & Met Station
83 km	56.6620	-124.7458	Ingenika Point	This site is named after the approximate location on the old Chunamon road. The E-Sampler was located on a high reservoir cut bank approximately 20 metres above the reservoir's full-pool	Regional Dust	E-Sampler

Site Name	Lat	Long	Met Station	Site Description	Airshed	Instru-ment
				level. The equipment is located on an old road adjacent to the reservoir. In 2009, the road was relocated to the west away from the reservoir and this site is located on what remains of the old road. This site is well exposed to Southeasterly winds and provides adequate regional representation. No dust is generated locally at this site.		
57 km	56.4940	-124.5522	57 km	Like 83 km, this site was named after its location on the Chunamon road. This site is located approximately 3 km north of Ole Creek Beach and is not included as part of the mitigation program due to its small size. The beach is comprised of highly mobile sand/silt sediments and is a moderate emitter of fugitive dust. The site is well exposed to northerly and southeasterly winds and captures much of the sediment-laden air plumes that drift north from the Coreless complex.	Regional & Local Dust	E-Sampler & Met Station

The following pairs of photos show each site from two perspectives. All images were taken from early to mid-May 2018 unless specified otherwise.

Figure 2: Regional Monitoring Network site and Reference Station within Tsay Keh Dene. E-Sampler atop the TEOM enclosure on the left (next to a ladder) and TEOM inlet on the right. The right image is facing towards the southeast and the reservoir.

Figure 3: Tsay Keh Beach sampling site. Looking southeast down the reservoir in the left image, north in the right image with the solar panel assembly and E-Sampler.

Figure 4: A new site for 2019 was Tsay Keh Beach South. This site is further towards the reservoir than the other Tsay Keh beach site. The photo on the left shows the view from the Tsay Keh Beach South site looking northwest towards Tsay Keh and the other beach site. The photo on the right is looking toward the southeast and the reservoir. Both photos show the site is located on gravel.

Figure 5: Van Somer. The image on the left is looking towards the south with the met station. The right image is looking towards the northwest.

Figure 6: Sightlines from Chowika. Looking towards the south in the left image and the northwest in the right image. In the right image, the gravel beach drops down towards the reservoir.

Figure 7: The northern site at Middle Creek North (MCN-N). The left image shows the view down the length of the reservoir to the southeast, while the image on the right shows the view to the northwest. The two other sites at Middle Creek North were to the southeast and spaced 400 m apart.

Figure 8: The view from the southern site at Middle Creek North (MCN-S). The image on the left is looking towards the northwest and the site at MCN-N. The image on the right shows the view to the north with the E-Sampler & solar assembly and the Rocky Mountains.

Figure 9: Looking south from Davis North in the image on the left and to the northwest in the right image.

Figure 10: The left image shows the view to the southeast from Davis South, while the image on the right shows the site during the setup in 2017.

Figure 11: The left image from Bruin shows the view to the southeast with Collins Beach in the background separated from Bruin Beach by the entrance into Collins Bay. The image on the right shows the view towards the northwest.

Figure 12: Images from Collins show the view to the south in the left image and the view towards Bruin and the northwest in the right image.


Figure 13: The image on the left shows the view from Ingenika Point towards the southeast. The image on the right shows the view down to the reservoir towards the east.


Figure 14: The site at 83 km is on an old forest service road (FSR) above the reservoir. The site name originates from its location on the Chunamon FSR. The image on the left is towards the southeast and the image on the right is towards the northeast.

Figure 15: The view from the site at 57 km (in reference to the location on the Chunamon FSR). The image on the left is facing the east-southeast and the image on the right is towards the north.

The reservoir had a low water year with the pool ranging in elevation from (approximately) 655.9 m above sea level (asl) on April 6th to 669.6 m asl on October 9th. Data collection began April 26th and ended July 7th, 2019, with reservoir elevation ranging between 656.4 m and 665.1 m, respectively.

The remainder of this section will provide information on the instrumentation, the analysis and the results obtained from the Regional Monitoring Network.

2.1.2 Instrumentation

The primary piece of equipment used for the Regional Monitoring Network is the E-Sampler by Met One Instruments. The E-Sampler is a nephelometer and uses forward laser light scattering to estimate the concentration of airborne particulate. To do this, the air is first drawn into the unit through a screened TSP inlet at a constant flow rate of 2.0 L/min. The air enters a chamber, referred to as the laser optical module, where a laser diode emits a visible light (670 nm) laser beam directed through the sample air stream. When the particulates in the air pass through the laser beam, the laser light is scattered via reflection and refraction. The laser light not scattered continues forward into a laser trap, and the scattered light is collected and focused by lenses onto a specialized light sensor. The more particulates, or the larger the particulates in the air stream, the greater the amount of laser light scatters. The light sensor measures the intensity of this focused laser light, which results in a proportioned particulate matter count within the air. No laser light detected by the sensor indicates that there is no light scatter, and therefore, no detectable particulates in the air.

The laser-scatter method does not hold a U.S. Federal Reference Method (FRM) or Federal Equivalent Method (FEM) designation but has been approved for fence-line type inter-comparison studies by the U.S. Forest Service. This means that E-Sampler data are not directly comparable to that collected by an FRM or FEM device and cannot be used to evaluate CAAQS or AQO exceedances or non-compliance. However, they are very useful for dispersion modelling and for observing source/sink locations around the reservoir.

There is no standard protocol or US National Institute of Standards and Technology (NIST) traceable method for calibrating and maintaining the E-Sampler since it does not carry FRM nor FEM designation. However, Chu Cho Environmental does employ a U.S. EPA quality program for monitoring and maintaining the function of the E-Sampler. For the 2019 dust season, this included flow calibration, leak check, and filter cleaning with every site visit, which was usually weekly, but not more than 15 days.

2.2 Regional Monitoring Network Data Overview

The light sensor within the E-Sampler operates at 40 Hz; these measurements are internally averaged, and temperature compensated into 1-second samples and are then averaged and recorded at 5-minute intervals. There were 7 complete meteorology (met) stations located at a subset of the 14 E-Sampler sites (Refer to Table 1 for the E-Sampler/Meteorology Combination list). These stations read the instrumentation at 1-second intervals, and recorded 5-minute averaged data for relative humidity, air temperature, wind speed and wind direction. Rainfall was measured upon occurrence through the use of a tipping bucket mechanism.

Data were collected from the 14 E-Samplers and 7 met stations beginning April 26th, 2019, with the deployment of the first instruments and went until July 7th, a total of 72 days. This was about five days longer than in 2018. The regional monitoring network amassed an enormous volume of data very quickly and required an aggregation of complex computer programming to handle and process. Data were managed primarily through Dropbox syncing and Matlab scripting.

Two locations were not set up during the scheduled set up period. Davis South was not accessible as the outfitter with a camp at that location had blockaded the access road that is used to get to the site. In early May, access to the site was reopened and the monitoring equipment was setup on May 9th. Access to the location at 57 km was also blocked during the scheduled set up due to deep snow on the access road. Usually, this is not an issue with the tracked UTV vehicle that is rented to complete the setup; however, due to a mechanical failure, the rental company made a last-minute substitution to a non-tracked UTV. The substituted UTV was not able to navigate through the deep snow. Access to 57 km, is made using a north-facing access road that travels down to the shoreline, so the snow can take a while to melt before the site becomes accessible. The snow prevented the setup on May 10th when a second attempt was made to access the site. On May 15th, the site was set up on the third attempt to access the site. Unfortunately, at that time, the E-Sampler was not put into an operation mode after it was set up; thus, data from this site did not begin until it was revisited a week later on May 22nd.

This distributed network of continuously monitoring E-Samplers and weather stations has allowed us to probe dust events in the Finlay Reach. The analyses discussed in this report represent Chu Cho Environmental's perspective and current understanding of the air quality issues within the Finlay Valley.

This review will begin with an exploration of the quality of the data through a basic statistical examination followed by an advanced statistical assessment using analysis of variance (ANOVA).

2.2.1 Excluded Data

Every effort is made to ensure that collected E-Sampler data is a representation of TSP data related to dust from reservoir beaches. This did not occur at all sites, but E-Sampler measurements do not distinguish between the types of particulate matter in the air they draw from (e.g. dust or smoke).

In 2019, random write errors in only the TSP data were present from the download files of E-Samplers at seven sites. These errors presented themselves exclusively within the concentration (TSP) data column. These write errors had not been seen in previous years but did coincide with a required new version of the software used to download data from the E-Samplers. Raw data from all downloads were scrutinized to identify this issue. Of the seven sites that had these write errors, no more than 20 rows were affected of the approximately 20000 rows of data for each site. While it was not expected that these rows would have affected the quantitative analysis, some had affected the time series plots of some sites prior to their removal. This issue will be scrutinized during the next field season.

E-Sampler data collected within the community (Tsay Keh Village) had to be excluded from analyses. Following two abrupt spikes in readings on May 30th, beginning at 22:05 (0.38 mg/m^3 and 0.201 mg/m^3), persistent anomalous data began on May 30 at 22:15. No alarms were displayed on the E-Sampler following these events.

2.2.1.1 Wildfire Smoke

In most years, the most active period for dust events are recorded from the end of April to about the middle of June, a time that does not usually coincide with intense wildfire activity. In 2019, smoke from two massive wildfires in northwestern Alberta impacted the airshed of the region. The Chuckegg Creek and Jackpot Creek wildfires were large fires (>1000 km^2) that emitted enough smoke that covered a massive area of western Canada (Figure 16). Figure 17 shows two photos showing the difference between Davis North without and with the presence of the wildfire smoke. The smoke impacted the region and E-Sampler data at all locations were impacted; therefore, all TSP data from 03:00 on May 22nd to 12:00 on May 29th and from 12:00 on May 30th to 21:00 on May 31st were excluded from quantitative analysis to avoid inflated particulate level readings. These exclusion periods were determined by examining the data from all sites to determining when smoke was impacting the airshed. This was done by identifying TSP values of zero prior to the arrival of the smoke and identifying consistent, gradual raises or elevated steady-state values of TSP that then gradually return to zero. Characteristics of dust events are much more abrupt, and changes between 5-minute observations are sharp or sudden and TSP values that can have high variability between observations.

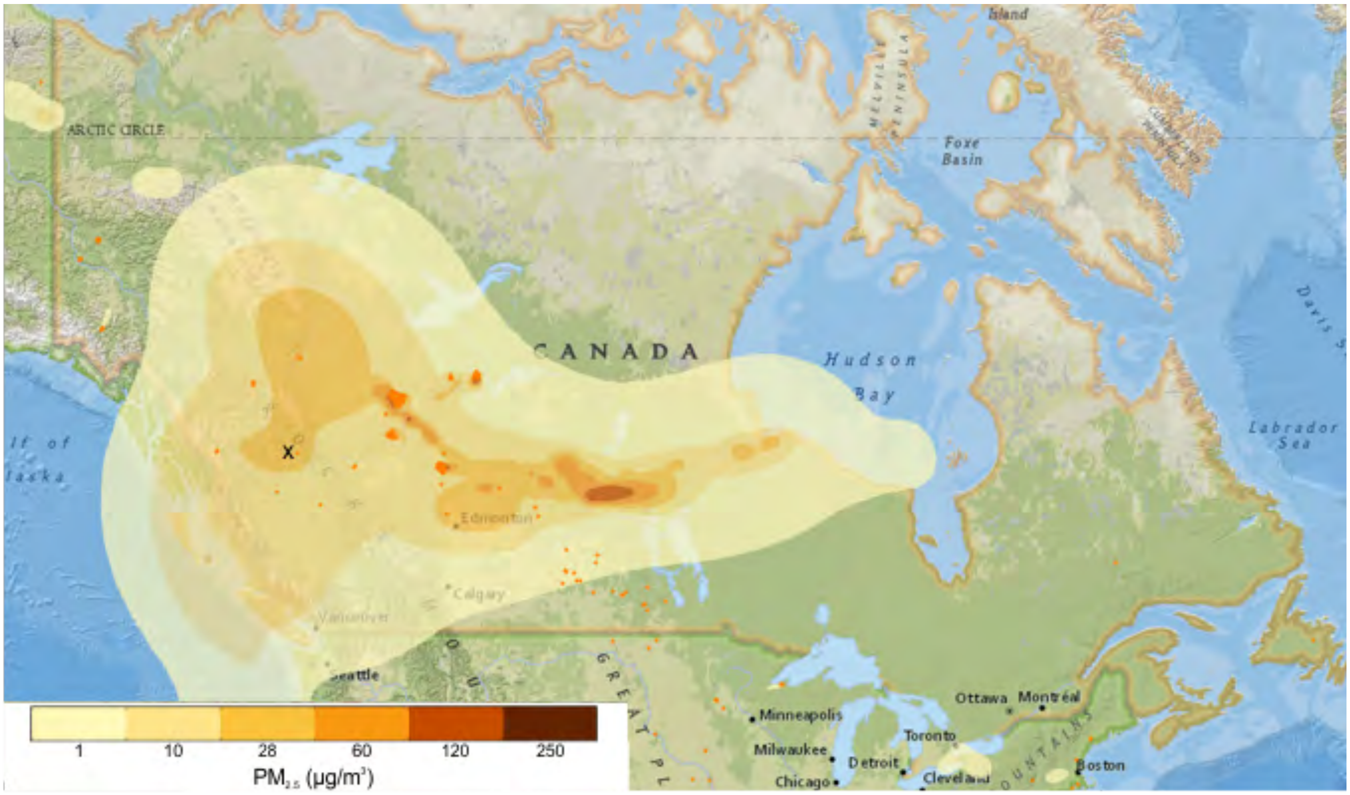


Figure 16: Image from FireSmoke Canada showing the modelled $PM_{2.5}$ values of smoke in the atmosphere on May 27, 2019. The x on the map indicates the approximate location of Tsay Keh Dene (BlueSky Canada, 2019).

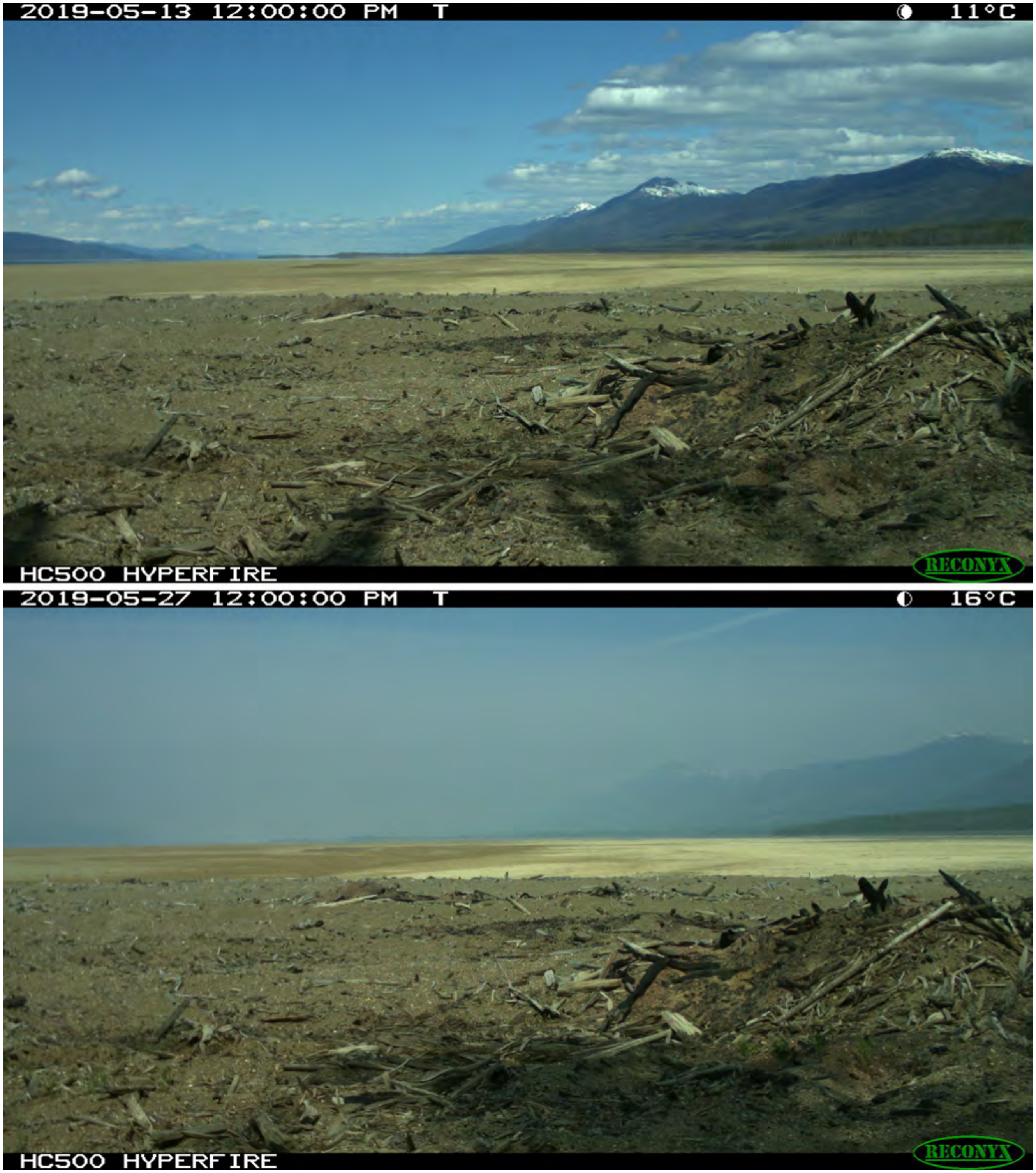


Figure 17: Contrast between conditions where wildfire smoke was not present (top photo) and present (bottom photo) in the atmosphere (top photo). The TSP value at the time of the top photo was 0.005 mg/m^3 and 0.025 mg/m^3 in the bottom photo.

2.2.2 Data Quality Objectives

For air monitoring networks, Data Quality Objectives (DQOs) are statements that document and specify the data quality criteria that must be satisfied in order to have adequate confidence in the conclusions of studies (Canadian Council of Ministers of the Environment, 2011). Ultimately the DQOs are a series of statements that relate the quality of the measurements to the level of uncertainty that we were willing to accept for results derived from this data.

DQOs must have attributes that are both qualitative and quantitative and are generally defined as those measurable attributes of the monitoring data that allow program objectives and measurement objectives to be met.

As is typical for most air quality monitoring networks, even those of a non-regulatory nature, we have adopted the DQO below.

- Accuracy:
    - E-Samplers must be calibrated and maintained to sustain an accuracy of greater than ± 20 %. The project samplers are returned to the manufacturer (Met One Instruments) for service and calibration. Calibration is due 24 months following the date of first use.
- Precision:
    - E-Samplers must be calibrated and maintained to sustain a precision that deviates less than 10% from a zero standard. This is done through an internal automated process within the E-Sampler that occurs at the top of every hour. Any errors detected are recorded and delivered to the user. This process is completed with every field visit, usually once per week and no more than 15 days apart.
- Completeness:
    - In order to be considered a valid data reading, the E-Sampler must record data for greater than 75% of the available minutes within an hour. This means that in order to be considered a valid hour of data, there must be at least 45 minutes of data recorded.
- Averaging Period:
    - E-Sampler data are collected at 1 Hz and are recorded as 5-minute averages to the on-board memory. These data are downloaded and verified weekly and no more than 15 days apart.
- Measurement Cycle:
    - E-Sampler data was collected from the beginning of May until the end of July. Data analysis focused on the period from May to mid-July.

E-Samplers do not have a Federal Reference Method designation and therefore we did not adhere to a national or international traceable standard (e.g. NIST) for auditing procedures. However, we utilized a TSI 4146 flow meter and record-keeping standards that are of NIST quality to ensure that our network data was internally comparable.

2.2.3 Threshold and Event Scale

Over the years of monitoring dust events in the Finlay Reach, there has been consideration on threshold wind speeds for initiating sediment movement. The high temporal resolution of the E-Samplers means that we were able to capture more events of varying magnitude at relatively high frequency, however not all the activity recorded by an E-Sampler should be considered a dust event

E-Samplers are not FRM/FEM certified instruments; therefore,, there are no numerical standards by which to define a dust event. Previously for this project, CCE developed a subjective means for defining a dust event using images captured by a network of time-lapse cameras. The threshold value was determined by comparing images captured during dust-free periods to those captured during periods of increasing dust where the relative ocular obscurity was proportional to the volume of dust in the air. By repeating this exercise for numerous dust events across numerous sites, we were able to arrive at a value that our project team felt was a reasonable approximation for a threshold dust value. A number of replicate sites for that exercise were used (Middle Creek North, Shovel Creek, Van Somer, 35 km, Ingenika and Davis North) and we arrived at a TSP concentration value of 0.1 mg/m^3 (per average 5-minute period) as the E-Sampler threshold for dust events. Obviously, there is a great deal of subjectivity in this reading, but our project team concluded that it was important that very small non-representative readings were not included in the analysis. Therefore, for the regional monitoring network, dust events are categorized by the number of instances where one or more consecutive 5-minute records are ≥0.1 mg/m^3.

It should be noted that the current definition has been defined that way since the 2017 annual report. The annual reports from 2014-2016 do describe a different definition; however, the actual output from the program and the analysis in the 2014-2016 reports were actually based on the above definition.

2.2.4 Time Series Analysis

The figures over the next few pages contain a time series depiction of the E-Sampler data collected at four locations in the Regional Monitoring Network. Each of the plots in these figures features the time series TSP data measured by each instrument. ***The data shown on these charts are unprocessed raw TSP data recorded by the instrument; this includes wildfire smoke***. The smoke was kept in for these figures to show how the presence of wildfire smoke can impact the measurements made by the E-Sampler. Also included were all E-Sampler data from the Tsay Keh Village (TEOM) site. While both the smoke and anomalous data were not part of any quantitative analysis, it still helps to show the spikes in TSP activity during those periods. Viewing the raw data through this lens is highly useful as it demonstrates the variability in the data and the frequency of events, both large and small.

Over the following few pages, Figure 18 to 21 demonstrate that several locations small, short-duration events over the entire dust season. The Tsay Keh beach sites did not record as many events as the other beach sites. Unsurprisingly, the sites at Middle Creek North reported many dust events but not as many as 2018 (Phaneuf, 2019). The absence of many TSP spikes for the non-Beach sites (Chowika, Ingenika and 83 km) shows that there weren't many dust storms that migrated very far from their source beaches. This is especially noticeable with dust recorded on Middle Creek North not being readily observed at Chowika, or dust at 57 km being recorded at 83 km. There were no events above the dust event threshold at 83 km during the season. There were two times when it did eclipse the 0.1 mg/m^3 threshold, but those were during the exclusion period caused by the wildfire smoke. Those two times do look like the threshold was exceeded due to the influence of smoke in the air.

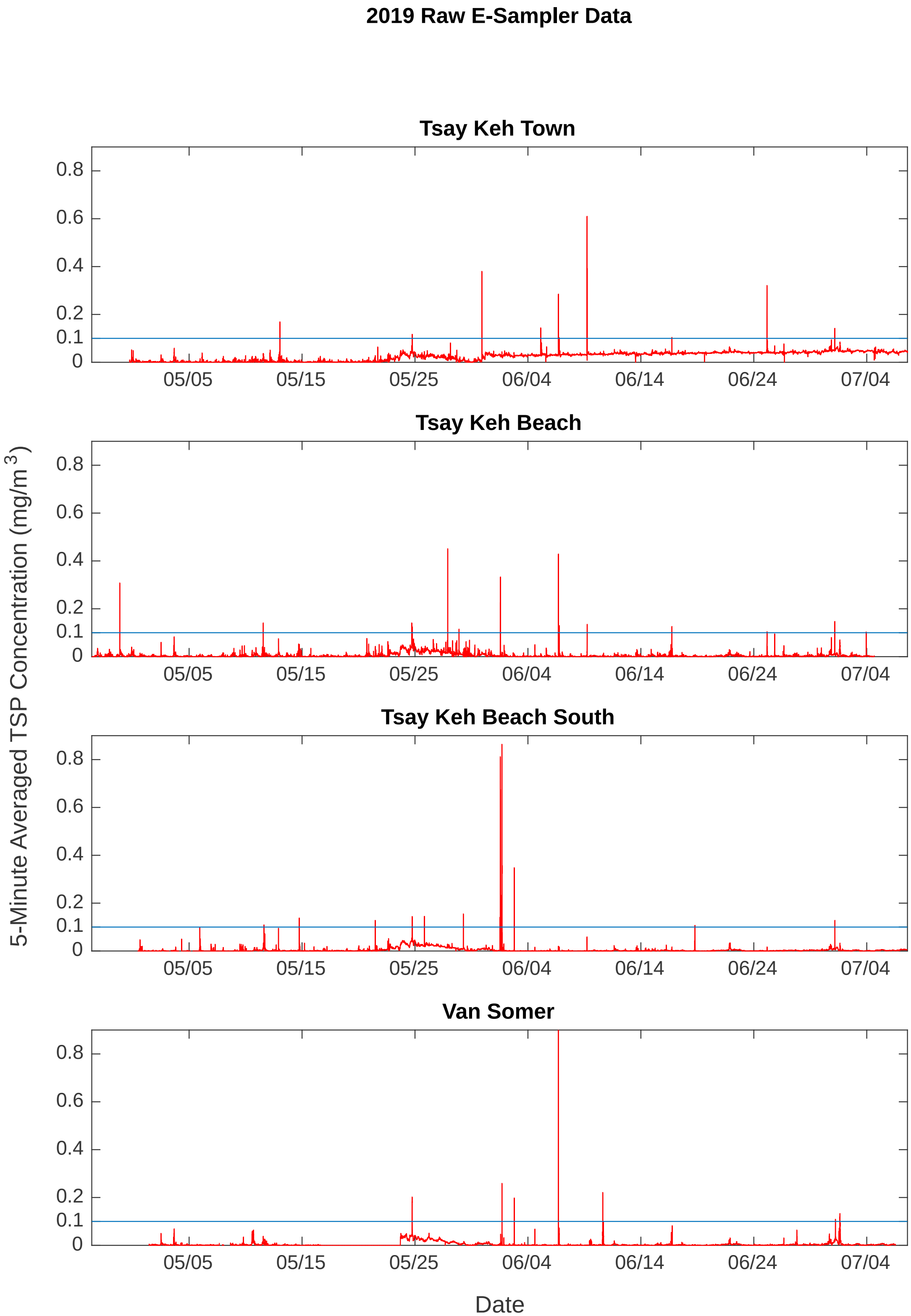


Figure 18: Regional E-Sampler data from Tsay Key Village, Tsay Keh Beach, Tsay Keh Beach South and Van Somer, showing 5-minute average TSP concentration data. The horizontal blue line represents the 0.1 mg/m^3 TSP concentration threshold across the chart. Wildfire smoke influence can be seen centred around May 25th.

2019 Raw E-Sampler Data

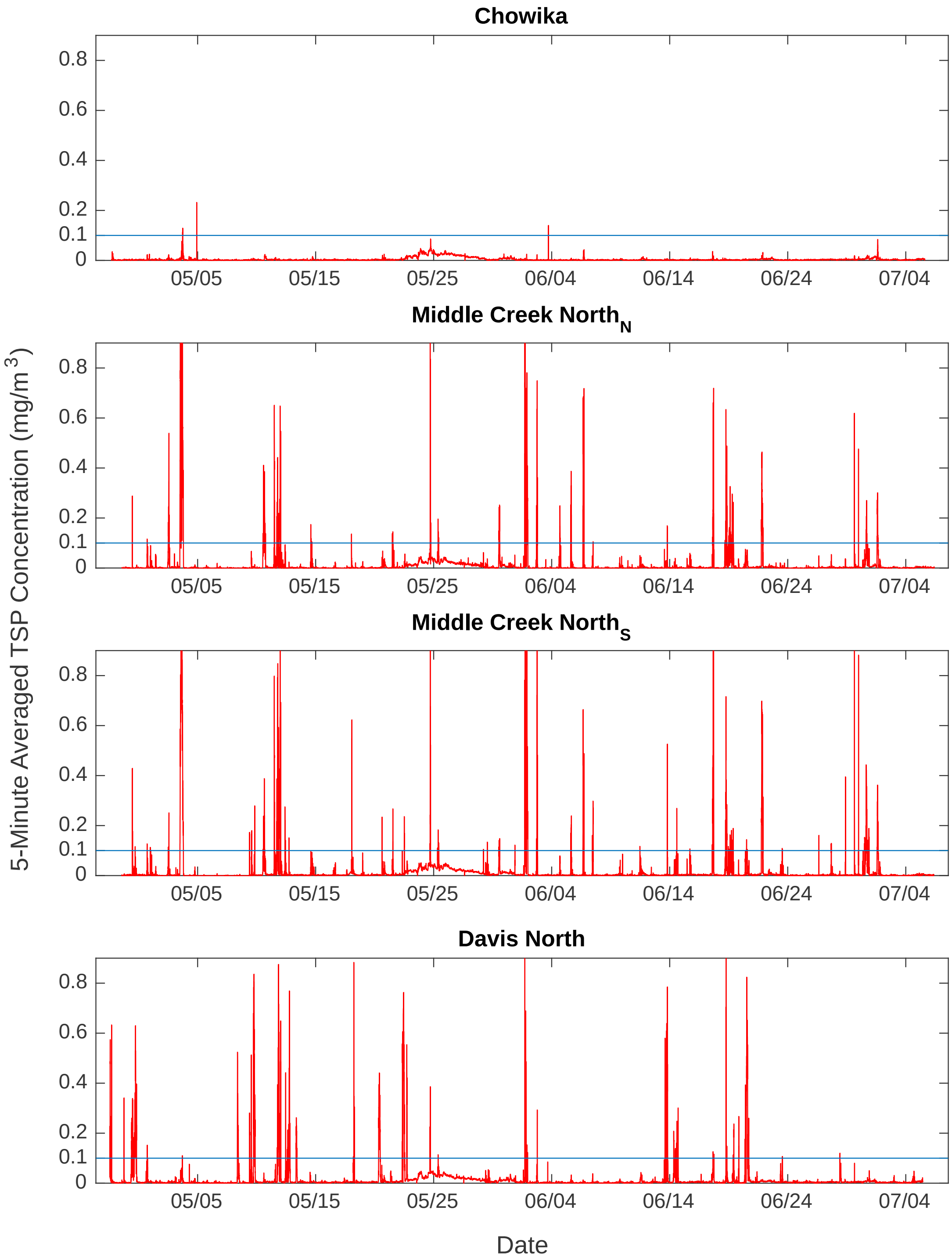


Figure 19: Regional E-Sampler data from Chowika, the two sites at Middle Creek North (North and South) and Davis North, showing 5-minute average TSP concentration data. The horizontal blue line represents the 0.1 mg/m^3 TSP concentration threshold across the chart. Wildfire smoke evidence is present.

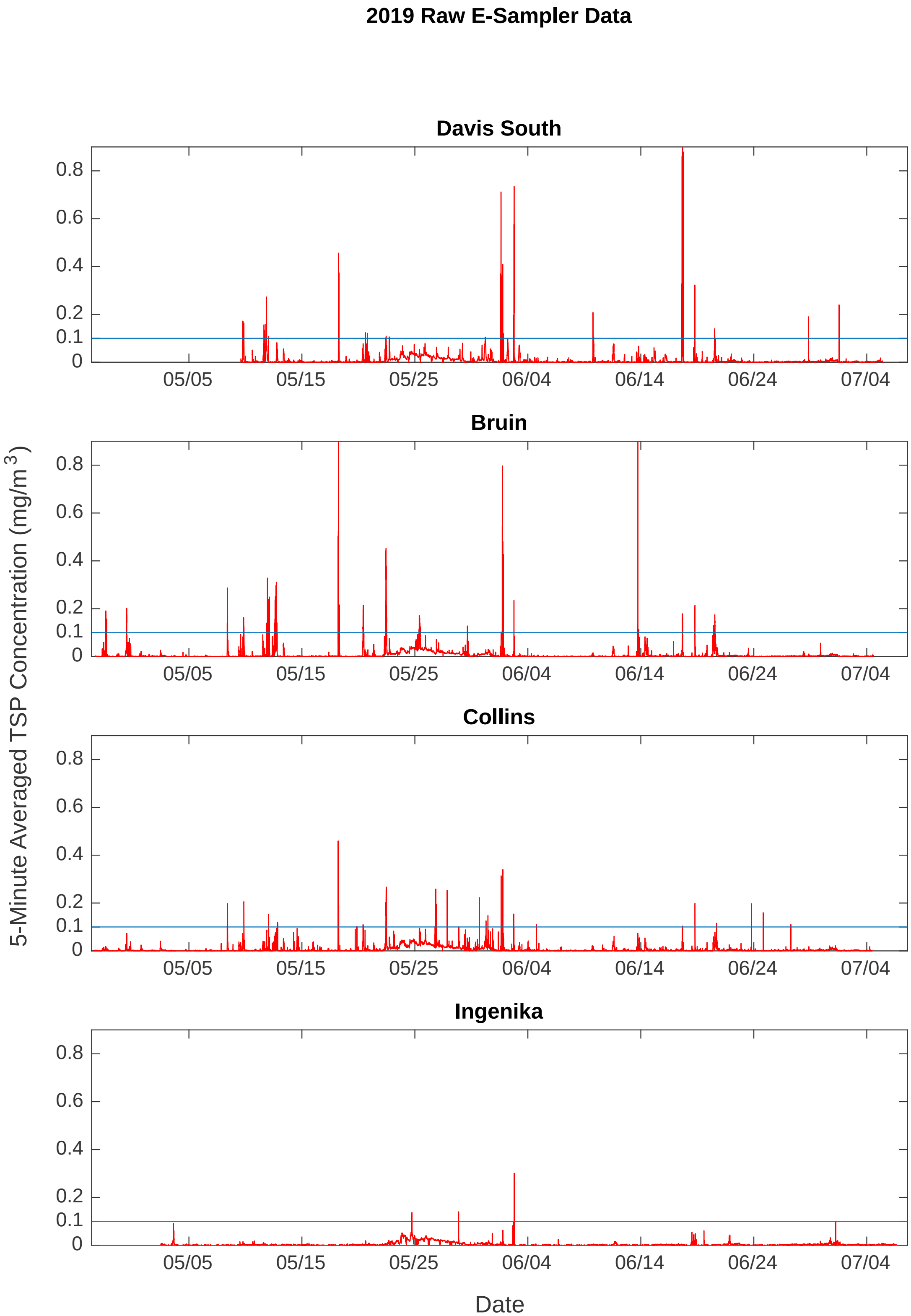


Figure 20: Regional E-Sampler Data from Davis South, Bruin, Collins and Ingenika, showing 5-minute average TSP concentration data. The horizontal blue line represents the 0.1 mg/m^3 TSP concentration threshold across the chart. Wildfire smoke evidence is present.

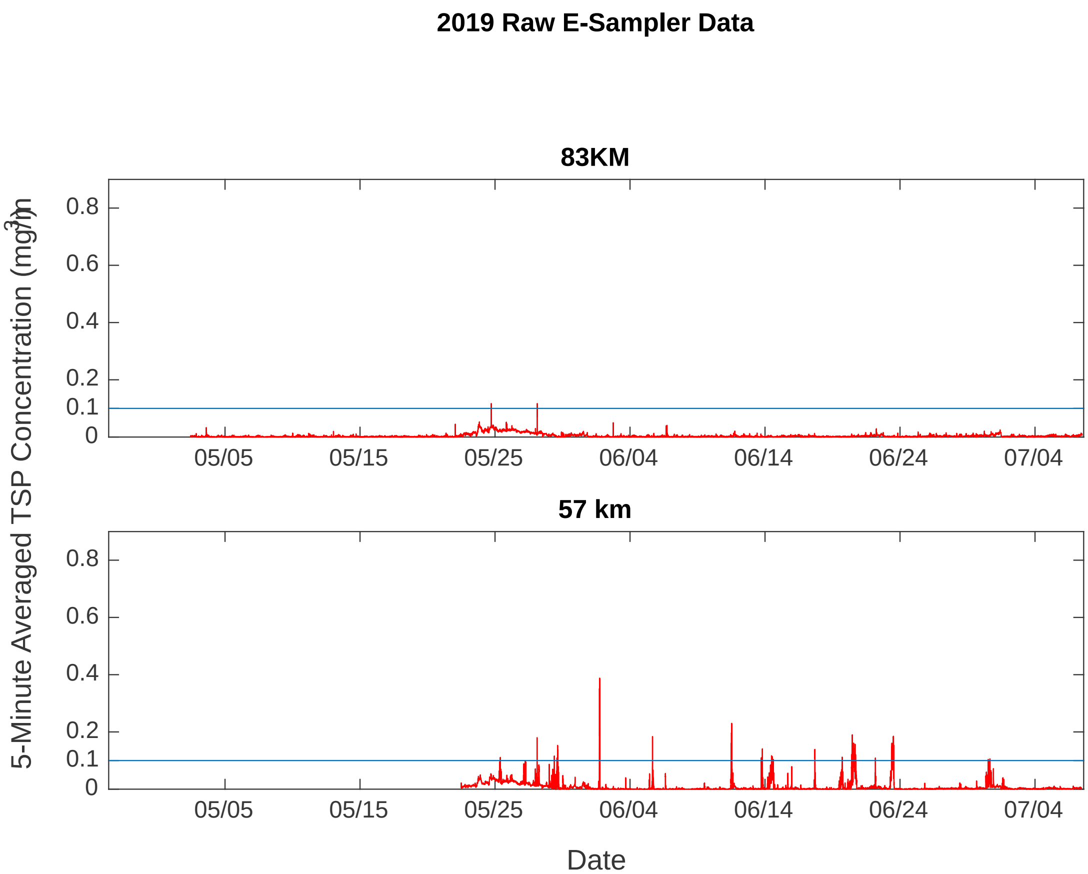


Figure 21: Regional E-Sampler Data from 83 km and 57 km, showing 5-minute average TSP concentration data. The horizontal blue line represents the 0.1 mg/m³ TSP concentration threshold across the chart. Wildfire smoke evidence is present.

2.3 Statistical Analysis

Basic descriptive parameters were extracted from the time series data collected at each location over the duration of the dust season. These data are described in the next three sections and summarized in Table 5 on page 34. As previously noted, the 2019 dust season was 72 days in length.

2.3.1 Dust Events and Total Suspended Particulates

The 2019 dust season recorded an average of 29 dust events across all locations. The two sites at Middle Creek North were averaged together for the purpose of determining the average across both sites, especially considering that both sites are on the same beach with the same surroundings (unlike the Tsay Keh Beach sites that are located along the edges of the beach and have different surroundings and different sediment material). The average number of events is similar to other years, including 2014, 2016 and 2017 (Table 6), but much lower than in 2015 and 2018. It is interesting to note that the average number of dust events during the 2019 season was 25 fewer than in 2018, despite the reservoir elevation being about one to two metres lower during that time period. The percentage of time sites were experiencing dust events over the season was calculated at 0.582% (about 10 hours), which is down from 1.44% in 2018, but similar to 2016 and 2017 (Table 6). Based on the summation of all sites and their individual time elapsed during a dust event, the average TSP concentration during dust events for the region was the lowest in the six years of the CCE monitoring program at 0.230 mg/m^3, though this is not too different when compared to previous years: 0.25 mg/m^3 in 2014, 0.26 mg/m^3 in 2016 and 2018.

The largest numbers of dust events during the 2019 dust season were recorded at the sites on Middle Creek North beach, MCN-S and MCN-N with 108 and 96 events, respectively. Davis North also had many dust events with 93, followed by Bruin (51) and Davis South (43). The site at 57 km may have had a similar number of events as either Bruin or Davis South, had the set up and sampling not been delayed, but still reported 33 dust events. Some beach sites such as Van Somer, Collins and Tsay Keh Beach reported fewer dust events (Table 5).

Many of the sites with the highest number of dust events also had the largest average TSP at or above the threshold value of 0.1 mg/m^3 for a dust event. MCN-S and MCN-N had average TSP values of 0.36 mg/m^3 and 0.33 mg/m^3, respectively. Davis North and Davis South reported values under those of Middle Creek North. Tsay Keh Beach South also reported a high average TSP, though by examining (Figure 18), it is apparent that this influenced heavily by one moderate dust event.

Table 5: 2019 dust season dust event summary statistics, calculated from 5-minute averaged data (TSP reported in mg/m^3, wind speed in m/s and wind direction in degrees).

Site	# of Dust Events	Avg TSP Conc. During Events	% Time with dust Above Threshold	Hours with dust Above Threshold	Avg Wind Speed	Max Wind Speed	Min Wind Speed	Threshold Wind Speed	Threshold Wind Speed Std. Dev.	Threshold Wind Direction
Tsay Keh Village	1	0.17	<0.01	0	0.7	0.7	0.7	0.7	0	70
Tsay Keh Beach	11	0.21	0.07	1:13	2.8	6.5	0.3	2.8	2	183
Tsay Keh Beach S	13	0.29	0.14	2:26	5.8	10.5	0.5	4.7	2.3	228
Van Somer	7	0.25	0.08	1:23	4.9	10.5	2.6	6.2	2.6	211
Chowika	3	0.13	0.04	0:41	6.8	9.1	1.4	4	4	188
MCN-N*	96	0.33	2.37	41:05	7.8	10.9	2.1	7.4	0.9	210
MCN-S*	108	0.36	2.62	45:25	7.5	10.9	1.6	6.9	1.1	222
Davis North	93	0.29	2.49	43:10	7.3	11.3	0.2	7	1.9	291
Davis South	43	0.26	0.64	11:05	6.5	11.2	0	6.6	2.6	222
Bruin	51	0.2	0.77	13:21	4	8.2	0	4	1.8	300
Collins	23	0.17	0.19	3:17	2.7	8.2	0	2.6	2.5	181
Ingenika	1	0.3	<0.01	0	0.8	0.8	0.8	0.8	0	10
83 km	0	-	0	0	-	-	-	-	-	-
57 km	33	0.15	0.65	11:16	7.7	11.1	1	7.2	1.2	295
Average*	29	0.23	0.58	10:05	4.8	8.2	0.8	4.5	1.8	200

*For the overall average values for each column, the Middle Creek North sites have first been averaged into one value in order not to over-represent the number of dust events on the reservoir.

Table 6: Dust season averages for all sites in the Regional Network since 2014 based on dust event summary statistics, calculated from 5-minute averaged data (TSP reported in mg/m^3, wind speed in m/s and wind direction in degrees).

Year	Avg# of Dust Events	Avg TSP Conc. During Events	% Time with dust Above Threshold	Avg Wind Speed	Max Wind Speed	Min Wind Speed	Threshold Wind Speed	Threshold Wind Speed Std. Dev.	Threshold Wind Direction	Threshold Wind Direction Std. Dev.
2019	29	0.23	0.58	4.8	8.2	0.8	4.5	1.8	200	88
2018	54	0.26	1.44	6.8	11.2	1.3	6.3	2.0	191	55
2017	25	0.29	0.45	3.9	8.8	0.7	4.0	2.2	-	-
2016	19	0.26	0.63	6.94	11.91	2.97	6.56	2.49	-	-
2015	56	0.3	0.1	3.1	6.7	0.8	3.1	1.6	179	88
2014	29	0.25	1.05	6.4	10.2	2.0	5.9	2.3	186	84

2.3.1.1 Wind Speed and Wind Threshold

During dust events, Middle Creek North, along with 57 km, recorded the highest wind speeds on the reservoir in 2019 (Table 5). The average wind speed during dust events across the region was calculated at 4.8 m/s in 2019, which is down from 6.8 m/s in 2018 and up from 3.9 m/s in 2017 (Table 5). The average wind speeds during a storm were pretty much even for Beach and Non-Beach sites alike. Collins, Tsay Keh Beach and Tsay Keh Village reported the lowest average wind speeds during dust events (Table 5).

The average threshold wind speed for dust events was calculated by extracting the wind speed data leading up to the point in time when the event threshold of 0.1 mg/m^3 TSP was surpassed. The average wind speed threshold from the different sites was calculated at 4.5 m/s, which is down from 6.3 m/s from the 2018 dust season. The 2019 regional wind speed threshold is greater than 2017 (4.0 m/s) and 2015 (3.1 m/s) but lower than 2014 (5.9 m/s) and 2016 (6.6 m/s) (Table 6).

Due to the overall low number of dust events at non-beach sites such as Chowika, Ingenika and 83 km, it is hard to analyze the results of the threshold wind speed. In past years, these sites usually recorded higher wind threshold speeds than beach locations due to the distance the dust needed to be transported to arrive at the non-beach sites. In 2019, there was either none or very few reported dust events at the non-beach sites. On the occasion where dust events occur, the threshold wind speed at these sites has been very low relative to previous years and even when compared to current beach sites.

2.3.1.2 Threshold Wind Direction

There was variability with the average threshold wind direction between many of the sample sites. The dominant threshold wind direction for the region had a southerly component that varied slightly to the west with a direction of 200º (Table 5). Given the orientation of the Finlay Valley (Rocky Mountain Trench), it would be expected the dominant wind directions in this part of the Finlay Valley would be either southeast or northwest winds, which have been identified by Nickling et al. (2013) and more recently by Tilson & Marini (2020). The threshold wind direction represents the average of the two dominant wind directions during dust events for a site, and thus these values will range between those two directions. While most sites had a more southerly component to their averaged threshold wind direction, Bruin and (to a lesser extent), Davis North had values that were more northwesterly (Table 5).

2.3.2 Mitigation Treatment Analysis

Dust concentrations recorded at E-Samplers from locations where tillage and irrigation occurred for highly erodible beaches were examined. Data recorded before and after the implementation of the tillage were processed and a Student's T-test was prepared as a comparison of means between these datasets. Conversely, for irrigation, a Student's T-test was calculated for the period before and while irrigation was applied. As with all quantitative analysis this year, dates impacted by wildfire smoke were removed from the analysis. Table 7 provides a summary overview of the sites that received mitigation treatments in 2019.

Table 7: Summary of the effectiveness of mitigation techniques on emissive beaches in 2019.

Location	Mitigation Technique	Significant Positive Impact
Davis North	Tillage	Yes (see 2.3.2.1)
Bruin	Tillage	No (see 2.3.2.1)
Collins	Tillage	No (see 2.3.2.1)
Tsay Keh Beach	Irrigation	Inconclusive (see 2.3.2.2)
Tsay Keh Beach South	Irrigation	Inconclusive (see 2.3.2.2)
Middle Creek North – North	Irrigation	Yes (see 2.3.2.2)
Middle Creek North – South	Irrigation	Yes (see 2.3.2.2)

2.3.2.1 Tillage

Technicians with Chu Cho Industries working on the WDMP recorded the day on which beaches around the Finlay Reach were tilled. For this analysis, dust data for the 14 days preceding tillage were compared to the 14 days following. The day on which tillage was applied to the beach was not included in the analysis. The primary driver for this analysis is to determine if it is possible to evaluate statistically whether or not tillage is effective as a mitigation solution for a given beach.

The T-test was designed to test the following null hypothesis at a 99% confidence level, which means the alpha value is 0.01:

> **H_0**: There is no significant difference in the mean dust concentration values from data collected 14 days before the application of tillage on a given beach to those collected the 14 days following the application of tillage.

The data presented in Table 8 analyzes the frequency and magnitude of a dust event both before and after tillage was applied to the specified beaches. For 2019, based on the beaches tilled for the WDMP and the beaches that were sampled, a subset of data from three emissive beaches were selected for analysis.

Table 8: 2019 summary of beach tilling dates and the before/after data collected by the E-Sampler and meteorology equipment.

Beach	Tillage Dates	Area Tilled (ha)	Before/ After	Avg Wind Speed (m/s)	Total Precip. (mm)	Avg TSP Concentration (mg/m^3)	T Test P-value	Stat. Significant
Davis North	May 21 – May 24	373	Before	2.8	2.4	0.024	6. 69×10^{-26}	Yes
			After	2.8	7.5	0.008		
Bruin	May 19 – May 21	302	Before	1.8	2.2	0.008	0.224	No
			After	1.8	3.9	0.006		
Collins	May 14 – May 19	230	Before	2.0	5.2	0.003	3.10×10^{-7}	Yes*
			After	1.8	2.7	0.006		

*TSP concentrations were significantly higher following the application of tillage.

Weather conditions were good to test the efficacy of tilling on these three beach sites. Rainfall at these sites was negligible before, during and after tilling, and average wind speed for those periods were either identical or very close.

Davis North had a p-value less than the alpha test value. Therefore, the null hypothesis was rejected and there is a significant difference in data from before and after the application of tillage on that beach. This is the case give that over the 14-day period average wind speeds were identical, and the total rain and relative humidity were very close (RH before was 53.8% and 50.8% after) (Table 8). In 2018, this site did see a statistically significant reduction in TSP concentration after tilling, though there was also a much higher amount of rainfall after tilling. For 2019, it does appear that tilling the beach at Davis North may have had a positive impact on suppressing fugitive dust emissions.

For 2019, it did not appear that tillage had the desired effect on Bruin and Collins beaches. There was a reduction in average TSP concentration at Bruin beach before and after tilling, but the reduction was small and not statistically significant. Collins actually saw an increase in TSP concentration after tilling, but only up to a value slightly below Bruin for the same time period. While both these sites did not appear to report a net benefit from tilling in 2019, both sites did see a statistically significant reduction in 2018 though both reported more rainfall during/following tillage.

2.3.2.2 Irrigation

A more focused irrigation program was applied by the WDMP to the beaches at Middle Creek North and Tsay Keh. Irrigation start dates were recorded and TSP data for the days preceding irrigation were compared to dust concentration data following the commencement of irrigation. In order to eliminate any influence from rainfall, the length of pre and post start date was shortened from 14 days to 9 days. As with tillage, the main driver for this analysis was to determine if irrigation is an effective mitigation solution for the treating beaches. We recognize that other variables will need to be addressed in the future in order to strengthen/support this analysis.

The T-test was designed to test the following null hypothesis at a 99% confidence level (alpha value = 0.01):

> **H_0**: There is no significant difference in the mean dust concentration values from data collected 9 days before the start of the application of irrigation on a given beach to those collected for 9 days following the commencement of irrigation.

The data presented in Table 9 analyzes the frequency and magnitude of dust events both before and while irrigation was applied to Middle Creek North and Tsay Keh beaches.

Table 9: Summary of MCN and TK Beach weather and E-Sampler TSP statistics before and during irrigation.

Beach	Irrigation start date	Area Irrigated (ha)*	Before/ During	Avg Wind Speed (m/s)	Total Precip. (mm)	Avg TSP Concentration (mg/m^3)	T Test P-value	Stat. Significant
MCN–North	May 10	2322	Before	3.2	7.9	0.024	4.13×10^{-9}	Yes
			During	3.2	3.3	0.008		
MCN–South	May 10	2322	Before	3.2	7.9	0.022	0.0082	Yes
			During	3.2	3.3	0.015		
TK Beach	May 11	897	Before	1.9	6.3	0.002	0.0755	No
			During	1.6	2	0.002		
TK Beach South	May 11	897	Before	1.9	6.3	0.001	0.0546	No
			During	1.6	2	0.001		

* Area Irrigated was a total area irrigated over the course of the WDMP on the respective beaches.

The p-value for the TSP data from the Middle Creek North beaches was less than the alpha test value; therefore, we can reject the null hypothesis and accept that there was a significant difference in the data collected before and during irrigation. Due to the change in the sampling period from 14 days to 9 days, the difference in total precipitation was kept to a minimum, thus tapering doubts regarding influence from higher rainfall events once irrigation had begun. The average wind speed was identical, which helps control its influence on fugitive dust emissions. During the date range examined, the reservoir rose roughly 2 m to 658.5 m asl from May 1 to May 19, this elevation, roughly 2 m lower than the same dates in 2018 and well below any inundation of the beach at Middle Creek North. It should be noted that the WDMP began seeding grasses a few days after irrigation began, but no sprouts were visible prior to the end of the sampling period (May 19th). With most variables controlled for, it appears that irrigation efforts on Middle Creek North beach resulted in decreased TSP during dust events.

The average TSP values at Tsay Key Beach and Tsay Keh Beach South during the sampling period were very low (with very little in terms of dust events) to be performing this kind of statistical analysis. It is not surprising that the student t-test failed to find any significance between the before and during irrigation TSP data.

2.3.3 Descriptive Statistics

All descriptive statistics were performed on data that met the threshold criteria outlined previously. It is not relevant to this discussion to analyze the non-threshold data. Therefore each data point used in the following analyses had a TSP value equal to or greater than 0.1 mg/m^3 TSP and is representative of the station during a dust event.

Table 10 below provides basic descriptive statistics for each of the 14 E-Samplers across the Regional Monitoring Network. Table 11 provides an easy comparison for each of the four E-Samplers located on non-erosive sites, while Table 12 presents the ten E-Samplers from moderate to highly erosive sites. It should be noted that the site at 83 km did not report a dust event; therefore, that column does not contain any values. Similarly, the Tsay Keh Town site and Ingenika only reported one dust event each so some of their cells do not report values.

Most sites had a mean value of similar magnitude (0.2 – 0.25 mg/m^3) with some notable outliers (Table 10). The most notable outliers were the two sites at Middle Creek North, as they both had sites over 0.3 mg/m^3. Davis North and Tsay Keh Beach South also reported high mean values but just under 0.3 mg/m^3 (0.287 and 0.294 mg/m^3, respectfully). While Ingenika did report a value over 0.301 mg/m^3, it was only from one event and difficult to compare to sites that had dozens of events. Sites with an average TSP below 0.20 mg/m^3 include the non-erosive sites at Tsay Keh Town, Chowika and technically 83 km as it did not register any dust events. In past years (Tilson, 2015-17; Phaneuf and Tilson, 2018), both Collins and 57 km had always reported an average TSP during dust events >0.2 mg/m^3. In 2018, Collins was amongst the top at 0.418 mg/m^3, though 57 km also had a lower year just over 0.2 mg/m^3 at 0.203 mg/m^3. There is no clear understanding of the lower values in 2019.

Non-erosive beach sites had very little dust events in 2019; therefore, the TSP averages for dust events were not necessarily reliable. Part of this was due to the loss of data due to the impact of wildfire smoke in the region, plus anomalous data at the Tsay Keh Town site. With the data available, the TSP values during dust events for all sites in non-erosive zones averaged 0.2 mg/m^3.

Sites located near or on moderate to highly erodible locations had an overall average TSP concentration during the dust season of 0.240 mg/m^3, down 44% from 2018 (0.427 mg/m^3).

Table 10: Basic descriptive statistics for TSP concentrations (mg/m^3) from all 14 regional E-Sampler monitoring sites (calculated from 5-minute averaged data during dust events). Note that 83 km did not have any dust events, so there is no data to report.

	TK Town	TK Beach	TK Beach South	Van Somer	Chowika	MCN-N	MCN-S	Davis North	Davis South	Bruin	Collins	Ingenika Point	83 km	57 km
Mean	0.169	0.205	0.294	0.251	0.131	0.333	0.358	0.287	0.258	0.200	0.173	0.301	-	0.145
Min.	0.169	0.103	0.100	0.107	0.103	0.100	0.100	0.100	0.100	0.101	0.101	0.301	-	0.101
Max.	0.169	0.429	0.864	0.998	0.232	1.092	1.210	0.941	0.940	0.912	0.460	0.301	-	0.388
Std. Dev.	0.000	0.109	0.233	0.256	0.043	0.252	0.251	0.173	0.199	0.155	0.081	0.000	-	0.051
Var.	0.000	0.012	0.054	0.065	0.002	0.063	0.063	0.030	0.040	0.024	0.007	0.000	-	0.003

Table 11: Basic descriptive statistics for TSP concentrations (mg/m^3) from four non-erosive regional E-Sampler monitoring sites (calculated from 5-minute averaged data during dust events). Note that Tsay Keh Town and Ingenika Point only had one dust event each.

	Tsay Keh Town	Chowika	Ingenika Point	83 km
Mean	0.169	0.131	0.301	-
Minimum	0.169	0.103	0.301	-
Maximum	0.169	0.232	0.301	-
Standard Deviation	0	0.043	0	-
Variance	0	0.002	0	-

Table 12: Basic descriptive statistics for TSP concentrations (mg/m^3) from nine moderate- to highly-erodible regional E-Sampler monitoring sites (calculated from 5-minute averaged data during dust events).

	TK Beach	TK Beach South	Van Somer	MCN-N	MCN-S	Davis North	Davis South	Bruin	Collins	57 km
Mean	0.205	0.294	0.251	0.333	0.358	0.287	0.258	0.200	0.173	0.145
Minimum	0.103	0.100	0.107	0.100	0.100	0.100	0.100	0.101	0.101	0.101
Maximum	0.429	0.864	0.998	1.092	1.210	0.941	0.940	0.912	0.460	0.388
Std. Dev.	0.109	0.233	0.256	0.252	0.251	0.173	0.199	0.155	0.081	0.051
Variance	0.012	0.054	0.065	0.063	0.063	0.030	0.040	0.024	0.007	0.003

2.3.4 Analysis of Variance

Like the descriptive statistics, the ANOVA operations were performed on data that met the threshold criteria (>0.1 mg/m^3 TSP). Due to 83 km not having any data above the threshold, it was removed from the ANOVA. For our analysis of variance, we have selected a confidence interval of 99%, which means that our alpha value to test against our p-value is 0.01.

2.3.4.1 ANOVA Between All E-Samplers

The following analysis was based on a one-way ANOVA used to examine all E-Sampler datasets for significant differences in TSP concentration data from dust events between site locations. This approach allowed us to examine the dataset to determine if there are sites within our monitoring network around the reservoir that exhibit significantly higher dust concentrations than others (Table 13). The null hypothesis for this ANOVA is:

$\mathbf{H_0}$: There is no significant difference in the mean dust concentration between 13 E-Sampler sites.

Table 13: ANOVA summary table for all E-Sampler data.

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F	p-value
Groups	8.5525	12	0.7127	15.9081	9.9078×10^{-33}
Error	93.3665	2084	0.0448		
Total	101.9190	2096			

As $p = 9.9078 \times 10^{-33}$ and is less than 0.01, we may reject the null hypothesis at a 99% confidence interval. This indicates that there are sites within the dataset that contain mean TSP concentrations that are significantly different than the rest. The box and whisker plot in Figure 22 can be used to evaluate which sites are driving this significance. The red "+" symbol indicates that the data point is an outlier. Some sites contain very high outliers relative to other sites, specifically the sites at Middle Creek North (North and South), as well as Davis North, Davis South and Bruin. These sites are all beach sites that are located in erodible, emissive zones and so the outliers effectively represent large emissive events. Figure 22 also shows that the range of and extent of the outliers Middle Creek North (North and South) and Bruin are much lower than what was reported in 2018 (Phaneuf, 2019) and similar to earlier reports (Phaneuf & Tilson, 2018; Tilson, 2015, 2016, 2017). Both Tsay Keh Town and Ingenika only had one threshold value each and explain why they are illustrated with a flat line

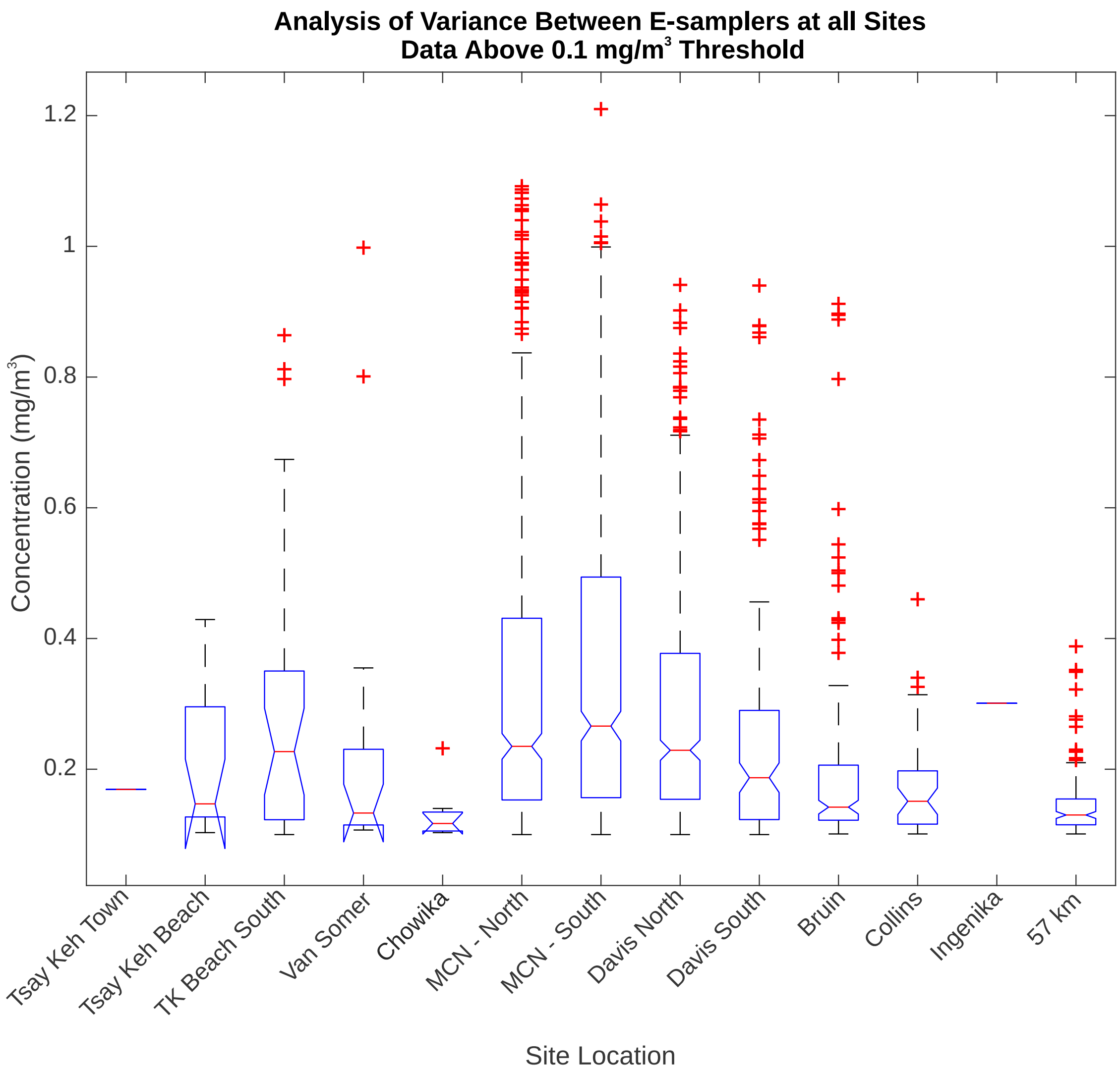


Figure 22: ANOVA box and whisker plot for 13 E-Sampler datasets. Outliers are indicated by +.

If a significant difference in mean dust event concentrations were identified across all sites, it would be relevant to parse the data into two groups, which broadly represent the different geophysical characteristics of the sites. Some sites are located in highly erosive areas, while others are located on non-erosive gravel bars and outcrops. For the following two ANOVA, the sites and data have been divided into these two groups.

2.3.4.2 ANOVA Between E-Samplers Located in Non-Erosive Area

In 2019, there were not many TSP data that met the threshold criteria in Non-Erosive areas, due to data being excluded due to smoke and (at Tsay Keh Town) anomalous data. This analysis has been done for past reports, so it was repeated for this report. For the Non-Erosive areas, the null hypothesis stated for the ANOVA is as follows:

H_0: There is no significant difference in the mean dust concentration between E-Samplers that are located in non-erosive zones surrounding the reservoir.

Table 14: ANOVA summary table for E-Sampler data from non-erosive sites.

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F	p-value
Groups	0.0260	2	0.0130	7.1034	0.0207
Error	0.0128	7	0.0018		
Total	0.0388	9			

As p = 0.0207 and is greater than 0.01, we must accept the null hypothesis at a 99% confidence interval. Therefore, the mean dust concentration values between the E-Samplers located at non-erosive sites are not significantly different at the 99% confidence interval. Given that there were not many samples that met the threshold, this result was not surprising.

2.3.4.3 ANONA Between E-Samplers Located in Erosive Areas

The second parsing of data represents the E-Samplers that are located in the moderate to highly erosive zones surrounding the reservoir. These include the sites at Middle Creek North, Davis North, and Bruin, areas that are located very near to the erosive zones of the beaches. The null hypothesis for ANOVA of the erosive group of E-Samplers is as follows:

H_0: There is no significant difference in the mean dust concentration between E-Samplers that are located in the moderate to highly erosive zones surrounding the reservoir.

Table 15: ANOVA summary table for E-Sampler data from moderate to highly erodible sites.

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F	p-value
Groups	8.3209	9	0.9245	20.5700	1.5786×10^{-33}
Error	93.3537	2077	0.0449		
Total	101.6747	2086			

With p = 1.5786×10^{-33} and therefore less than our alpha at 0.01, we may reject the null hypothesis at a 99% confidence interval. There were significant differences in dust concentration value between E-Sampler data from moderate to highly erosive zones. Figure 23 illustrates these sites showing the range of data collected and the number of outliers at some of the sites. While the sites at Middle Creek North seem to have the greatest range of samples above the threshold value, they are typical for previous years, with the exception of 2018. Comparing data from all erosive sites to previous years (2014-2018), 2019 had the least intense dust seasons, in terms of storm intensity (maximum dust concentration values), ranging from the end of April to early July (Tilson, 2015, 2016, 2017; Phaneuf & Tilson, 2018; Phaneuf, 2019).

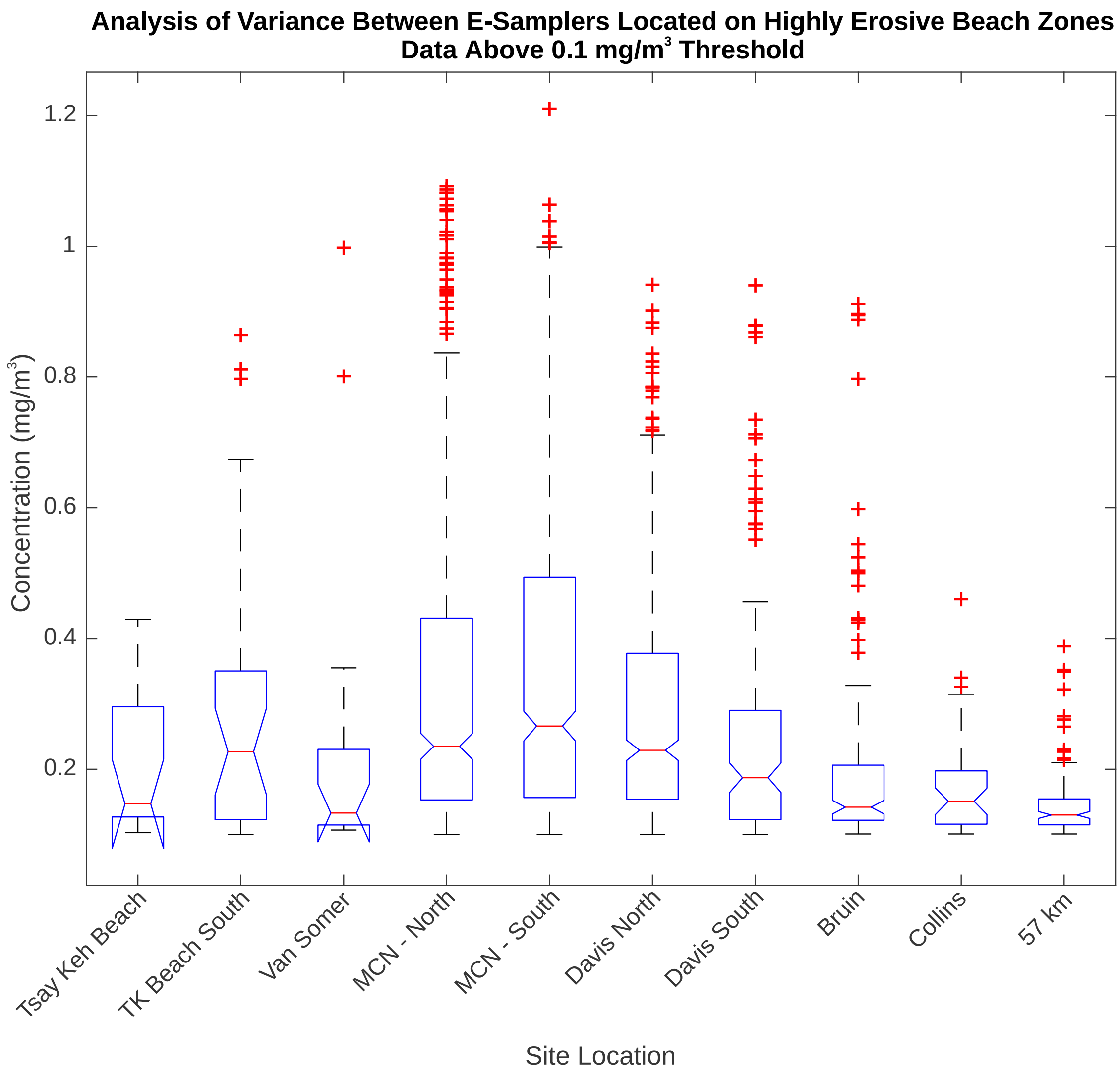


Figure 23: ANOVA box and whisker plot for E-Sampler Data from moderate to highly erosive sites. Outliers are indicated by +.

Network Component II: Reference Monitoring

3 Reference Monitoring

3.1 Characterization

Canadian Ambient Air Quality Standard (CAAQS) achievement determination requires that the Reporting Areas (RA) be based on the Census Metropolitan Areas (CMA) and census agglomerations (CA). Therefore, the distribution of CAAQS reporting stations is based on population numbers and urban density (Canadian Council of Ministers of the Environment [CCME], 2011). Generally, for CAAQS reporting, there should be one particulate sampler for every 250,000 people and the sampler should be placed between six to eight kilometres apart or should have a distribution that is dependent on the distance between the CMA and the primary source that may be affecting it (CCME, 2011).

The province of British Columbia uses a suite of ambient air quality criteria that have been developed provincially and nationally to inform the decisions on the management of air contaminants (BC Ministry of Environment, 2018). The suite of criteria that apply to this report include the BC Ambient Air Quality Objectives (AQOs) and the CAAQS. Those that are relevant to this project can be found in Table 16.

Table 16: Air quality standards and objectives relevant to this project.

Contaminant	Average Period	Objective/Standard	Date Adopted	Source
$PM_{2.5}$	24 Hour	28 µg/m^3	2013	CAAQS
PM_{10}	24 Hour	50 µg/m3	1995	Provincial AQO

3.2 Air Monitoring Characteristics

The monitoring station in Tsay Keh Dene is located approximately 450 m away from the edge of the major source that affects the village (the reservoir) and sited away from any structures or other impediments to airflow that might bias the sample. The reference monitoring station technically does not meet the standards for CAAQS reporting as well as Special Studies (BC Ministry of Environment, 2006) because it is not US EPA FEM designated. It was not the intention of the project to use this monitoring station for a regulatory purpose, but we did aspire to the same standards set by the CCME for the CAAQS and BC MoE for the AQO. This network is intended to monitor the long-term trends in air quality for the region as it relates to reservoir dust and the mitigation activities conducted by the WDMP.

The Finlay Valley tends to direct the wind flow either northwest or southeast; all recorded air quality events are generated by southeasterly winds blowing over the reservoir. At Tsay Keh Dene, the valley is approximately 10 km wide. Figure 2, on page 14, shows the monitoring station in Tsay Keh Dene with TEOM inlet. The TEOM, discussed in the next section, is paired with meteorological equipment consisting of an anemometer (measures wind speed and direction), a temperature and humidity probe, barometer and rain gauge.

3.2.1 Instrumentation

The GMSMON#18 air quality monitoring project uses a Thermo-Fischer Scientific TEOM 1405-D Dichotomous Ambient Particulate Monitor.

- The TEOM (Tapered Element Oscillating Microbalance) measures the volume of particulate in the air by calculating the amount by which the oscillation of the microbalance is attenuated as particles land on the filter, which sits atop the microbalance. To perform this calculation, the TEOM must maintain and record a steady airflow through the instrument.
- Instrument maintenance and calibration techniques are implemented to ensure that the microbalance oscillation and flow volumes through the instrument remain constant and do not drift.
- The TEOM 1405-D reads the oscillation at 1 Hz and records the average particulate concentration over 10-minute, 8-Hour, and 24-Hour periods.

The TEOM units were installed in the fall of 2011 and became fully operational in January of 2012. The CCME guidelines require three years of valid data in order to evaluate and validate the data against the CAAQS. However, the data collected from December 2012 to April 2014 are not of a known quality and Chu Cho Environmental has not been able to obtain records of maintenance or calibration performed during this time period. The TEOM in Tsay Keh Dene has performed well from April 2014 through to 2018; however, Chu Cho Environmental did have to replace the flow controller circuit board in the TEOM back in 2015, but this was performed onsite with less than eight hours of downtime. On February 28, 2018, the data logger was replaced with a newly calibrated unit, during the installation resulted in two data gaps: the first lasting 2 hours 50 minutes and the second lasting 40 minutes. In November 2019, the pump that draws air into the TEOM suddenly failed and resulted in a period of extended downtime before it could be replaced.

We will, however, evaluate the data collected by these instruments within the context of the CAAQS and the Provincial AQOs by comparing the results of our analysis to the standards/guidelines provided by the Federal and Provincial governments. To be clear, the TEOM data presented in the following sections should not be considered valid for comparison to health standards or otherwise. We will use them here to provide insight into the air quality in Tsay Keh Dene.

3.2.2 Reference Monitoring Station Data Quality Objectives

When assessing the data obtained from the reference monitoring station for completeness and validity, Chu Cho Environmental utilizes the following DQOs:

- Accuracy:
  - The TEOM 1405-D units must be calibrated and maintained to sustain an accuracy of greater than +/- 10%.
- Precision:
  - The TEOM 1405-D units must be calibrated and maintained to sustain a precision that deviates less than 10% deviation from a zero standard. This is done through K_0 Verification, Leak Checking and Flow Auditing.
- Completeness:
  - To be considered a valid data reading, the TEOM 1405-D must record data for greater than 75% of the available hours within a day. This means that in order to be considered a valid day of data, there must be at least 18 hours of data recorded.
  - During the hours of data collection, the TEOM 1405-D must be operating within the tolerances described above for accuracy and precision not only concerning the oscillating microbalance but also for the flow controllers and auxiliary instrumentation.
  - To be considered a valid dataset, the TEOM 1405-D must record at least 70% of the available hours within a year.
- Averaging Period:
  - TEOM 1405-D data are measured at 1 Hz and are recorded at 10-minute averages to the on-board memory, the CR1000 datalogger and the backup computer system. These data are downloaded once or twice per month.
- Measurement Cycle:
  - TEOM 1405-D data is collected from January until December of each year. Data analysis is focused on the period typically from April to June or what is called the dust season.
- Spatial Representativeness:
  - The samplers are located in areas where they will not be influenced by external factors that may cause sample bias. This includes the following specifications:
    - Sampler intake height is 5 metres above the Earth's surface.
    - Sampler is located sufficiently far away from roadways and other sources of external contamination such as incinerators or factories.
    - Sampler intake is located sufficiently far away from airflow restrictions through 360 degrees of rotation and must be located at a distance away from an object that is at least 3 times the height of that object.
    - Sampler intake is located greater than 20 metres away from trees.

- Data Verification:
  - Data verification is the process by which the data are assessed to ensure that the minimum criteria are met for completeness and comparability. This process is automated through computer scripting.
  - The data are processed, invalid days or measurements that are suspect are flagged so that the technician performing the verification can then manually inspect the data for the issue. This two-step process is essential in ensuring that the data collected by our network are meeting the requirements of our DQO program.

Chu Cho Environmental ensures that suitable technical procedures are in place to record and catalogue the processes that lead to the successful achievement of the DQOs.

3.2.3 Methodology

To ensure that the data collected by the baseline monitoring stations are of a known quality, we have implemented a Quality Assurance/Quality Control (QA/QC) program that is built on the guiding principles of the provincial monitoring network (BC Ministry of Environment, 2009). For this project, Chu Cho Environmental performs site visits, instrument calibrations and audits and data validation.

TEOM 1405-D air samplers require that the primary air filters be changed every six weeks or sooner as the filter loading approaches 90%. During each filter exchange members of our project team also perform the basic calibration and verification procedures to ensure that the TEOM and its meteorological equipment are functioning correctly, these procedures include:

- K_0 spring constant verification of the oscillating TEOM components,
- Leak check verification to ensure that the TEOM is airtight,
- Inspection of numerical data recorded by the data loggers to ensure that all instruments are functioning correctly and that the readings reflect a reasonable reality,
- A visual inspection of all meteorological and TEOM equipment,
- The TEOM enclosure is swept and all surfaces are cleaned with an ammonia-based cleaning agent,
- The data system is inspected to ensure that all data are being recorded to the appropriate location and are being backed-up at regular intervals.

After every third filter exchange or sooner if necessary, members of our project team will perform the more advanced calibration and verification procedures that are required to ensure proper TEOM function, these include:

- The flow rates are audited and calibrated for each airflow channel: Bypass, $PM_{2.5}$, PM_{Coarse}
- The virtual impactor is dismantled and thoroughly cleaned using an ammonia-based cleaner,
- All rubber gaskets are greased with vacuum seal silicon,
- All voltage points within the TEOM unit are checked to ensure that the numerous sensors are functioning properly,

- The additional TEOM sensors are calibrated, this includes the air pressure and temperature sensors.

After each visit to the monitoring station, our technicians record their activities in a logbook that is kept inside the TEOM enclosure. This logbook is an important component of the QA/QC procedures.

By carefully crafting and implementing our QA/QC strategy we strive to achieve a very high standard for data quality related to failing TEOM system components. Regular data outages are recorded when the technicians perform maintenance routines such as filter exchanges or K_0 verification but these are unavoidable. In order to be considered a valid data day, the TEOM must record data for more than 75% of the available hours in a 24 hour period.

3.3 Reference Monitoring Data Overview

For this report, the 2019 datasets were collected at Tsay Keh Dene from January 1st, 2019, through to and including December 31st, 2019, with the exception of the TEOM data, which were until November 15th, 2019. Similar to the E-Samplers at the regional sites, the TEOM was also impacted by smoke from the Chuckegg Creek and Jackpot Creek wildfires in Alberta. The tables in this section will not present data collected between 03:00 on May 22nd to 12:00 on May 29th, and from 12:00 on May 30th to 21:00 on May 31st. For visual reference, time series plots of the data will include the portion of data within the smoke impacted dates.

3.3.1 Meteorology and 24-Hour Average Air Quality Characterization

Figure 24 (a) through (d) shows plots of the 24-hour average air quality and meteorology data recorded at the Tsay Keh Dene monitoring station during 2019.

3.3.1.1 Meteorology

Different weather variables can either enhance or temper the impacts of fugitive dust emissions from the beaches of the Williston Reservoir. One of these variables, wind, can lead to desiccation of beach sediments but also saltation and ejection of fine and very fine dust particles. The average wind speed at the monitoring station during the 2019 dust season was 1.57 m/s, slightly less than 2018 and 2017 (roughly 1.61 m/s and below 2016 and 2015 (1.77 m/s). In Figure 24 b, it appears that the first half of May was windier than the second half and the second half of June windier than the first half. Higher temperatures can lead to accelerated evaporation of moisture on beaches, as higher temperatures are able to hold a greater amount of moisture. Temperatures over the entire season averaged at 12°C, about the same as 2014, 2015, 2016, and 2018, with 2017 being cooler. May did see a pronounced increase in temperature throughout the month partially tempered by a return to more seasonal temperatures in the second week (Figure 24 c). Much of the rain did not fall until the second half of June and the beginning of July (Figure 24 c). 2019 had less rain over the dust season than 2018 and 2017, about the same as 2016 and almost double 2015.

3.3.1.2 24-Hour Average Dust Concentrations

The 24-hour average PM concentrations for 2019 are shown in (Figure 24 a). The brown line represents PM_{10} and the green line represents $PM_{2.5}$, while the horizontal dashed lines across the plot represent exceedance of the BC AQO of 50 µg/m^3 for PM_{10} (BC MoE, 2016) and 28 µg/m^3 for $PM_{2.5}$ for the CAAQS (CCME, 2012). Table 17 shows the 24-hour averaged value for days where the $PM_{2.5}$ value was greater than 28 µg/m^3 and the PM_{10} value was greater above 50 µg/m^3. Figure 24 (a) also shows a period of both elevated $PM_{2.5}$ and PM_{10} that illustrate the influence wildfire smoke had on the air quality Tsay Keh Dene; neither the BC AQO or CAAQS standards were exceeded during that time.

The two instances of 24-hour exceedance can be seen in Figure 24 (a). There were no exceedances of $PM_{2.5}$ for 2019. The PM_{10} exceedances in April and June can be attributed to dust, given the time of year and the accompanying stronger winds.

Table 18 shows the CAAQS and AQO dust season exceedances dating back to 2014. For $PM_{2.5}$, 2018 was an exceptional year as there were 13 exceedances. That amount is far more than the total number of $PM_{2.5}$ exceedances reported by CCE since in 2014. Looking at the British Columbia 24-hour AQO for PM_{10}, 2019 like 2014, 2015 and 2017 were similar years with only one or two exceedances (Table 18).

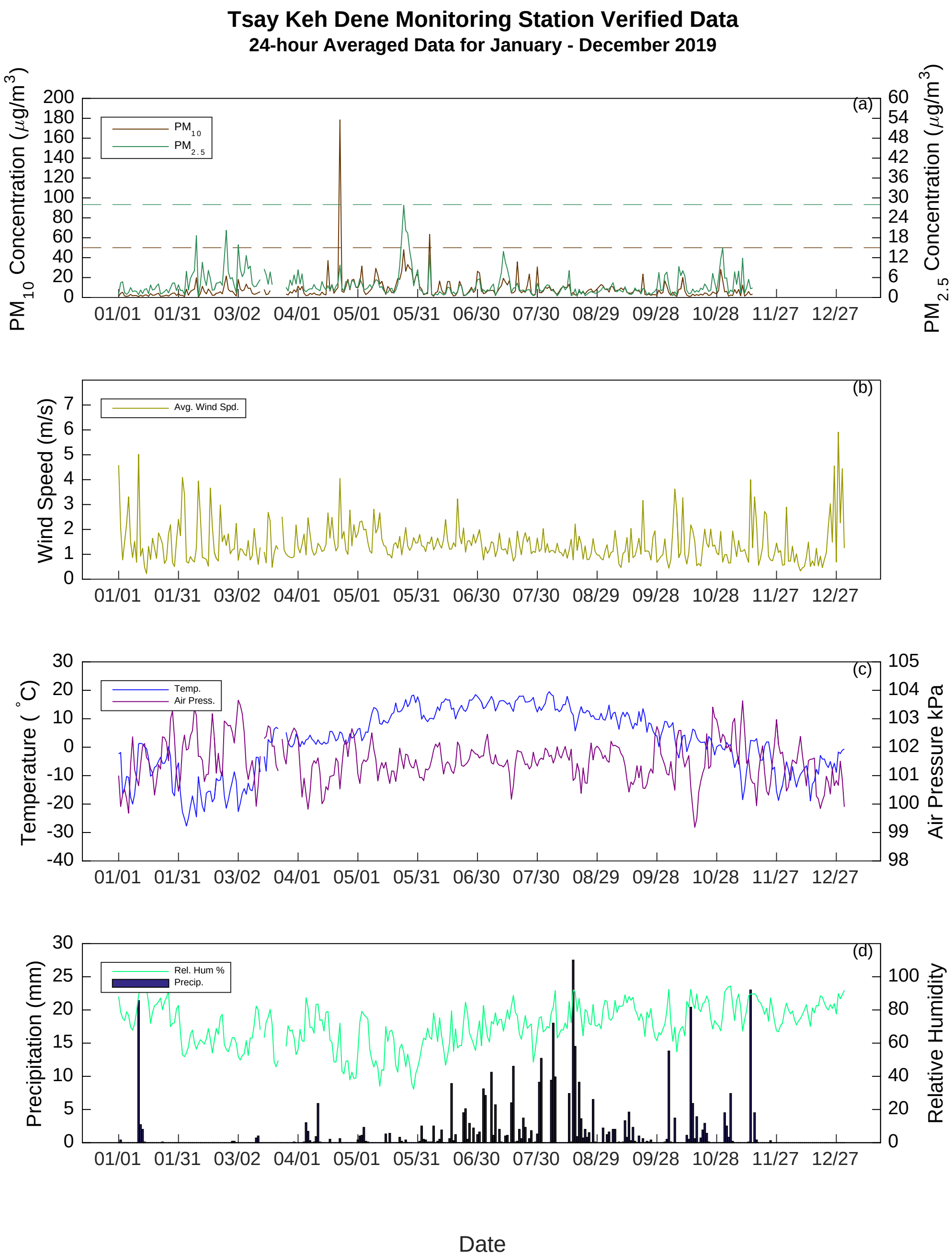


Figure 24: 2019 Tsay Keh Dene monitoring station data - 24-hour averaged data for air quality and meteorology data. Equivalent exceedance standards in (a) for $PM_{2.5}$, 28 µg/m^3 (CAAQS), and PM_{10}, 50 µg/m^3 (AQO) are illustrated by the colour coded horizontal dashed lines.

Table 17: 24-hour averaged 2019 $PM_{2.5}$ and PM_{10} values that were above the CAAQS and provincial AQO.

Date	$PM_{2.5}$ Value (μg/m^3)	Date	PM10 Value (μg/m3)
		22-Apr-2019	178.4 (dust)
		06-Jun-2019	63.4 (dust)

Table 18: Tsay Keh TEOM 24-hour dust season exceedances for $PM_{2.5}$ and PM_{10} for the years 2014 to 2019.

Year	$PM_{2.5}$ (μg/m^3)			PM_{10} (μg/m^3)		
	# of Exceedances	Average Value	Maximum Value	# of Exceedances	Average Value	Maximum Value
2019	0	-	-	2	120.9	63.4
2018	13	86.1	229.9	8	112.3	208.4
2017	1	40.4	40.9	1	59.0	59.0
2016	2	37.9	44.3	5	149.5	401.5
2015	0	-	-	1	62.4	62.4
2014	0	-	-	2	271.4	279.7

3.3.2 Maximum Particulate Concentrations

While there were only two particulate matter air quality events during the 2019 dust season, using the 24-hour AQO metric for reporting air quality but that alone does not adequately represent the mode of air quality issues in Tsay Keh Dene. Averaging tends to “smooth out” the extreme but short duration events that are typical of the air quality issues in Tsay Keh Dene.

All major dust activity in Tsay Keh Dene is derived from wind events that cause erosion on the beaches of the Williston Reservoir. These wind events are sporadic and vary greatly in magnitude, duration and frequency from one event to the next. As a result, these events may be highly localized and might persist for a short duration but the actual volume of dust emitted may be enormous. Under these conditions, the calculation of a 24-hour average tends to minimize the actual impact of these acute dust events.

In this section, we evaluate the maximum value recorded for $PM_{2.5}$ and PM_{10} concentrations during the 2019 dust season. This analysis also does not make any health or health-risk claims associated with the data presented below. The unprocessed, 10-minute, PM_{10} and $PM_{2.5}$ data recorded from the TEOM 1405-D at the Tsay Keh Dene monitoring station for the 2019 dust season can be viewed in Figure 25. Both the $PM_{2.5}$ plot Figure 25 a and PM_{10} plot in Figure 25 b so the same y-axis to help visualize the larger presence of PM_{10} in the air samples.

Both images in Figure 25 show the evidence that the wildfire smoke had on readings of PM_{10} and $PM_{2.5}$ from May 22nd to May 29th; followed by a less intense, second increase from May 30th to 31st. These same two elevated areas were also seen throughout the regional network of E-Samplers.

The graphed unprocessed data in Figure 25 b shows many sharp upticks in PM_{10} concentration. For the most part, these same upticks can be seen in Figure 25 a in the $PM_{2.5}$ plot, but at a reduced intensity. Instances of elevated readings can be viewed in Table 19. The difference in values between PM_{10} and $PM_{2.5}$ seems to indicate that roughly 90% of the particulate from the 2019 dust season is composed of coarse particulates or PM_{Coarse}, which is the particulate matter ranging in size from 2.5 μm to 10 μm.

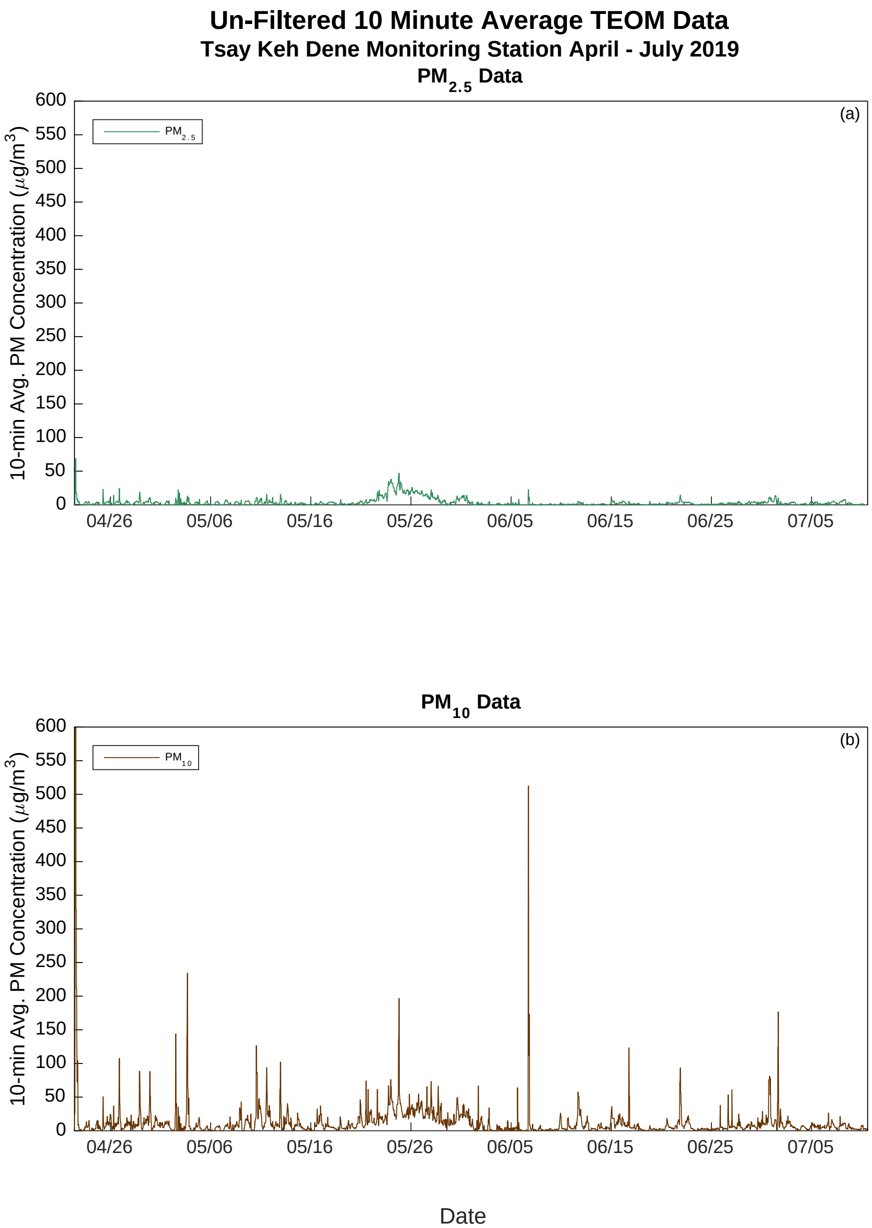


Figure 25: Raw 10-minute averaged TEOM data for the 2019 dust season. Centred on May 26th, both graphs show the impact of wildfire smoke in Tsay Keh.

Table 19: Maximum 10-minute $PM_{2.5}$ and PM_{10} values showing instances of elevated values, recorded during the 2019 dust season in Tsay Keh Dene monitoring station. Due to wildfire smoke, some dates and values have been excluded. There were no real instances of elevated $PM_{2.5}$ values during the dust season.

Date	$PM_{2.5}$ Value (μg/m^3)	Date	PM_{10} Value (μg/m^3)
-	-	26-Apr-2019	107.5
		28-Apr-2019	88.35
		29-Apr-2019	70.96818
		30-Apr-2019	50.41
		02-May-2019	143.9
		03-May-2019	146.1067
		10-May-2019	106.35
		11-May-2019	75.365
		12-May-2019	80.16
		13-May-2019	102
		21-May-2019	67.64
		01-Jun-2019	66.45
		05-Jun-2019	64
		06-Jun-2019	265.7667
		11-Jun-2019	53.01333
		16-Jun-2019	87.41
		21-Jun-2019	74.07667
		26-Jun-2019	53.35
		27-Jun-2019	61.04
		30-Jun-2019	72.694
		01-Jul-2019	150.7

4 Discussion

The MON18 project was successful in 2019, with some caveats. The team has continued to collect an enormous amount of data. There were some delays and gaps in E-Sampler data, the delays being related to site access (Davis South and 57 km) and our oversight (data gaps at Van Somer and 57 km, anomalous data at the Tsay Keh village site). The smoke from the Alberta wildfires was an unfortunate occurrence that interfered with a normally busy time for dust events, as it had an influence on the data collected across all stations.

The primary finding presented somewhat repeatedly throughout this report notes that 2019 was not a very active year for fugitive dust emissions in the Finlay Reach of the Williston Reservoir. The dust season for 2019 was more typical when compared to most of the years since Chu Cho Environmental began managing the MON18 project in 2014. The number of dust events reported around the Finlay Reach of the reservoir was nearly half of what it was in 2018. This was despite the reservoir, during the 2019 dust season, being roughly 2 m lower than the 2018 season drawing attention to the sporadic and relatively unpredictable nature of the dust events that impact Tsay Keh Dene.

At the monitoring station in Tsay Keh, there was no exceedance of the CAAQS ($PM_{2.5}$) and only two exceedances of the provincial AQO (PM_{10}). While this was similar to other low dust years, it was much lower than 2018. Prior to the beginning of the season, it was believed 2019 would also be an active year for dust due to the lower pool level of the reservoir. Reflecting on the data collected, it is surprising that more air quality events did not occur as many conditions were in place to facilitate increased dust activity. Compared to the 2018 dust season, not only was the reservoir lower, precipitation levels were lower and temperature remained similar. It was only wind speed average that was slightly lower in 2019. Despite the low 24-hour exceedance levels at the reference monitoring station in Tsay Keh, there was still evidence of repeated short duration, spikes in particulate matter within the community throughout the season.

While results for tillage did not yield a statistically significant decrease in TSP concentrations from the analysis of Bruin and Collins beaches, there was a statistically significant decrease at Davis North. It should be noted that both Bruin and Collins beaches had fairly low TSP averages both before and after tillage was applied. Also, the average value of TSP concentration after tilling at Davis North was still higher than any average TSP concentration at Collins and Bruin beaches before or after tillage was applied. Due to the presence of rain during and immediately after tilling in 2018 that may have helped reduce dust events (Phaneuf, 2019) and with promising results in 2019, tilling beaches should continue for the 2020 season. Monitoring should also be done to continue to looks for trends to determine which beaches respond best the application of tillage.

The WDMP plan for a more intensive irrigation program focused solely at Tsay Keh and Middle Creek North beaches seemed to have a promising impact on local TSP concentrations. An effort was made to select sample dates outside of precipitation events in order to control the influence that rain could have played on fugitive dust emissions during the sample period. This did not matter at Tsay Keh Beach due to the low values of TSP concentrations before and during the irrigation sampling period. Due to this, the impact of irrigation on Tsay Keh Beach was difficult to evaluate adequately. At the Middle Creek North beaches, a statistically significant reduction in TPS concentration was observed following the commencement of irrigation within the sampling period. These results were promising, considering that wind speed and precipitation were essentially controlled between the sampling period. The WDMP focused plan at Middle Creek North Beach should continue in 2020. The plan for irrigation on Tsay Keh Beach should be considered again in the hope that further monitoring will capture additional data to help determine the efficacy on that beach.

5 References

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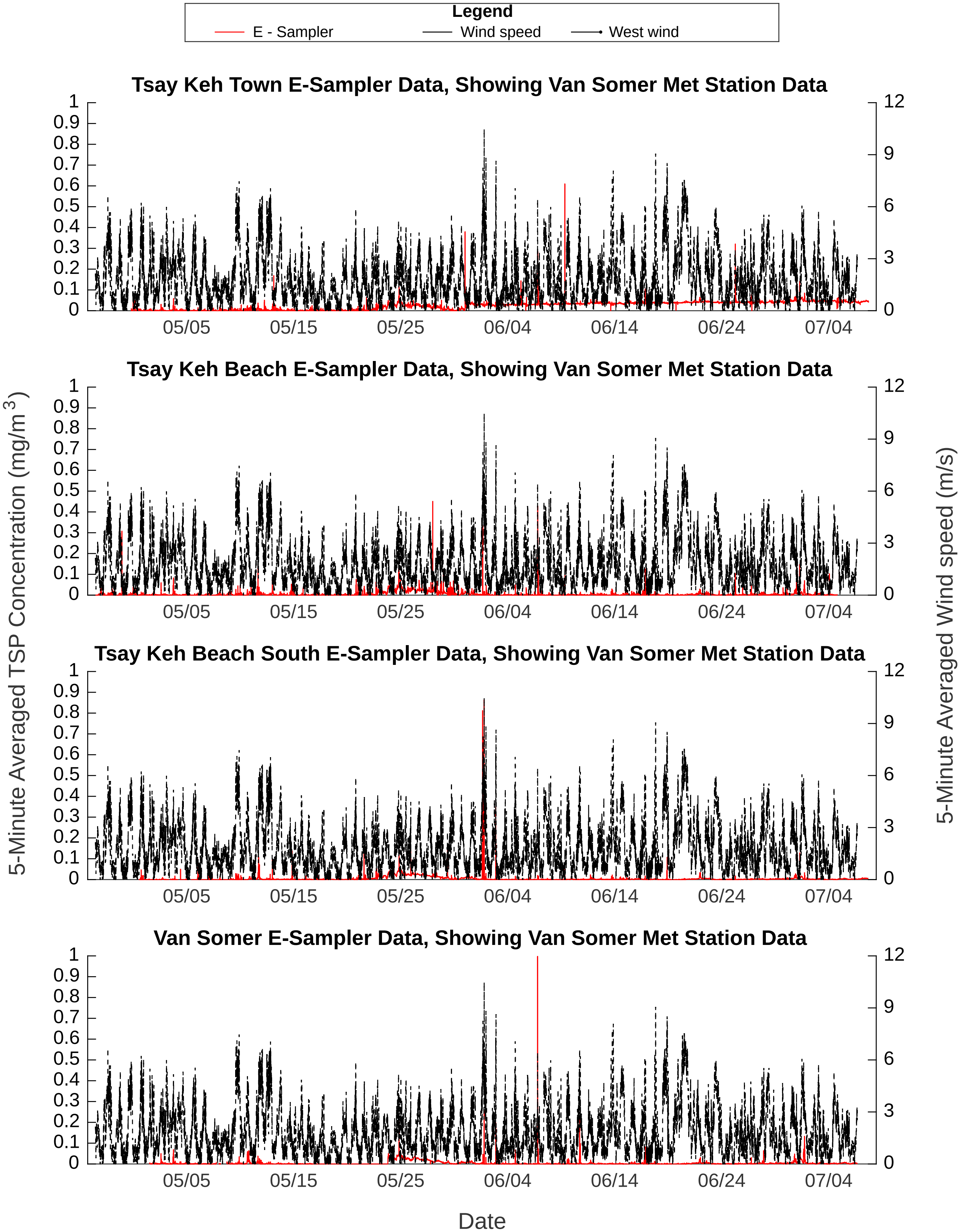
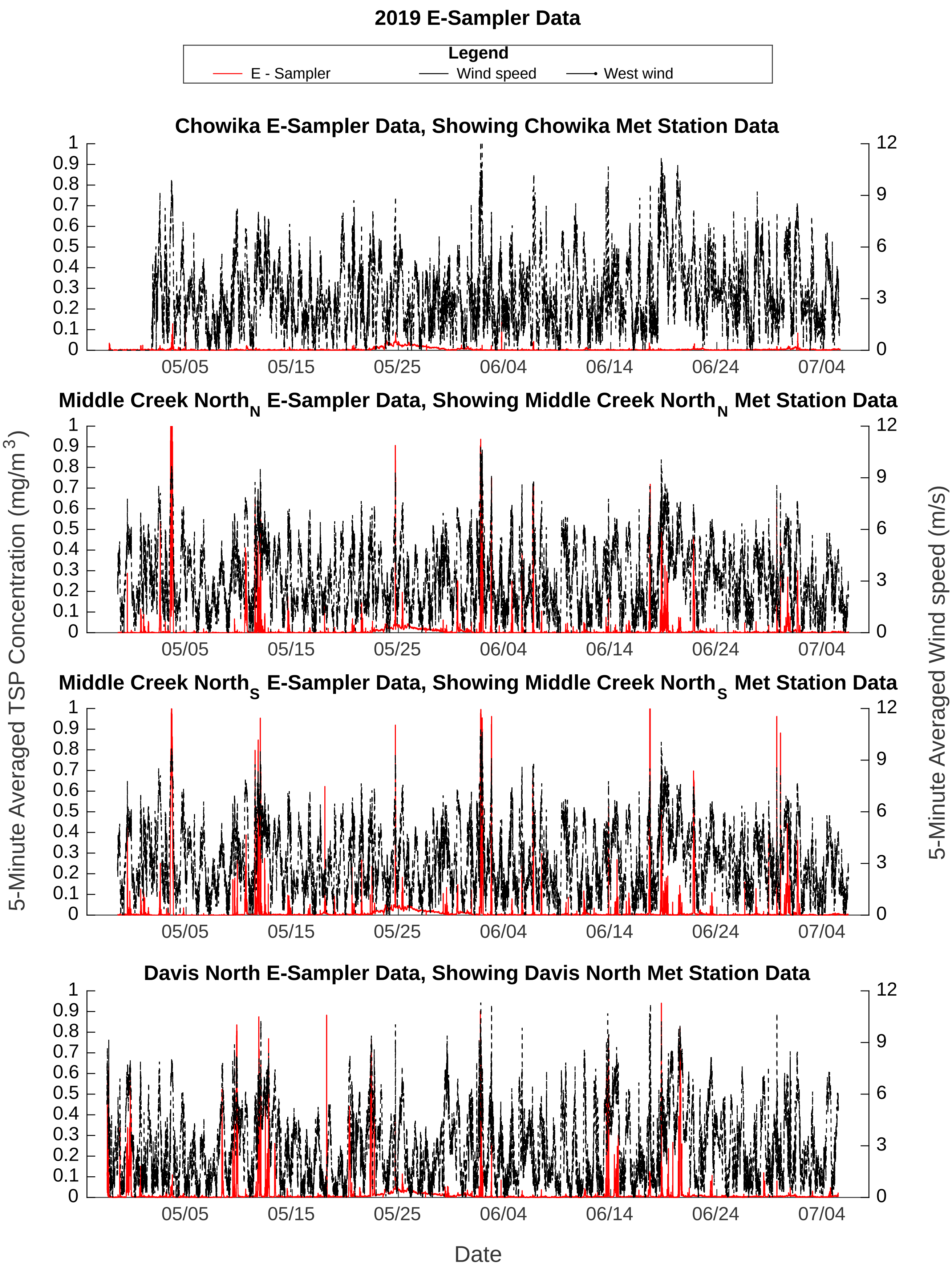
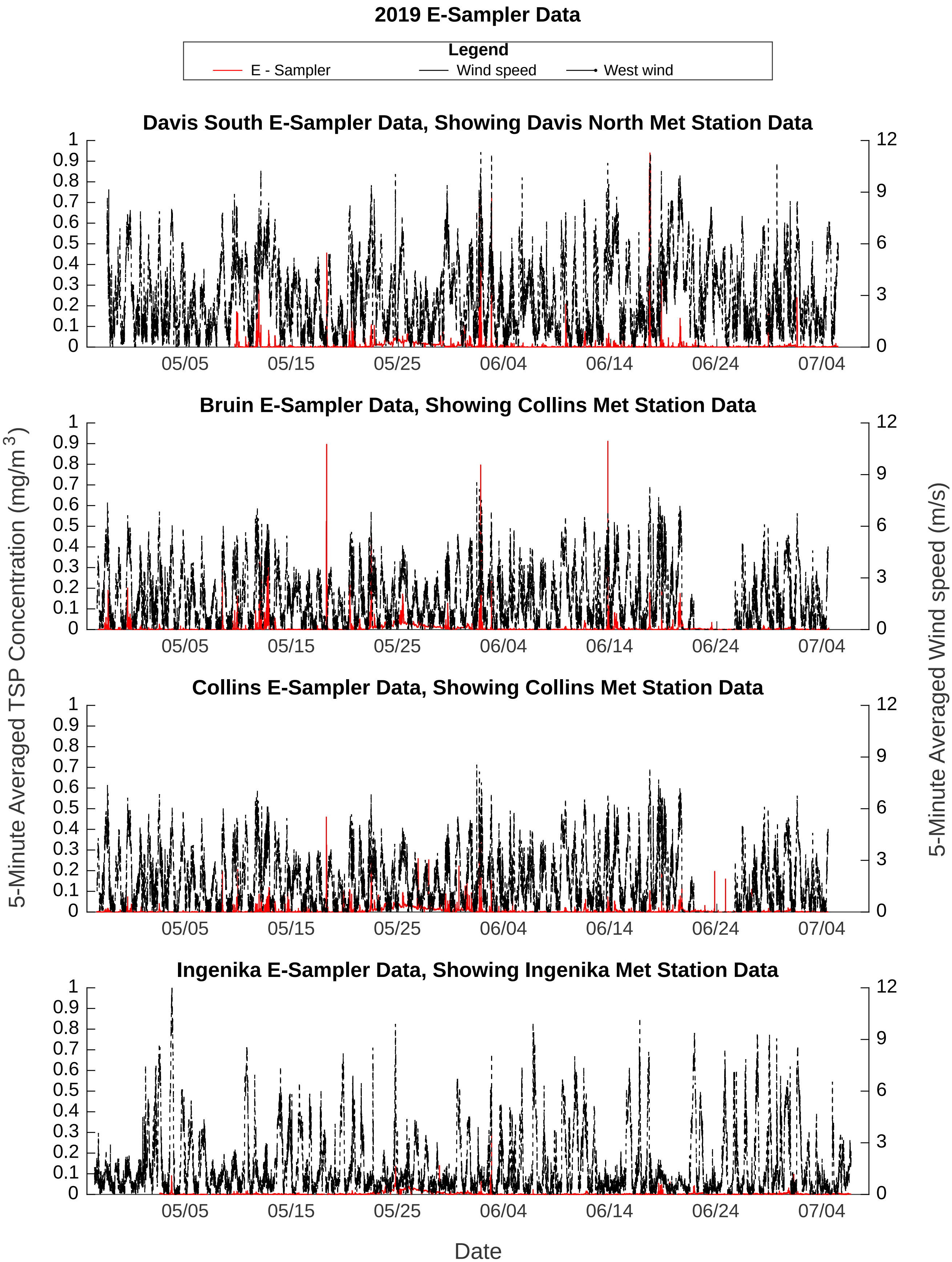
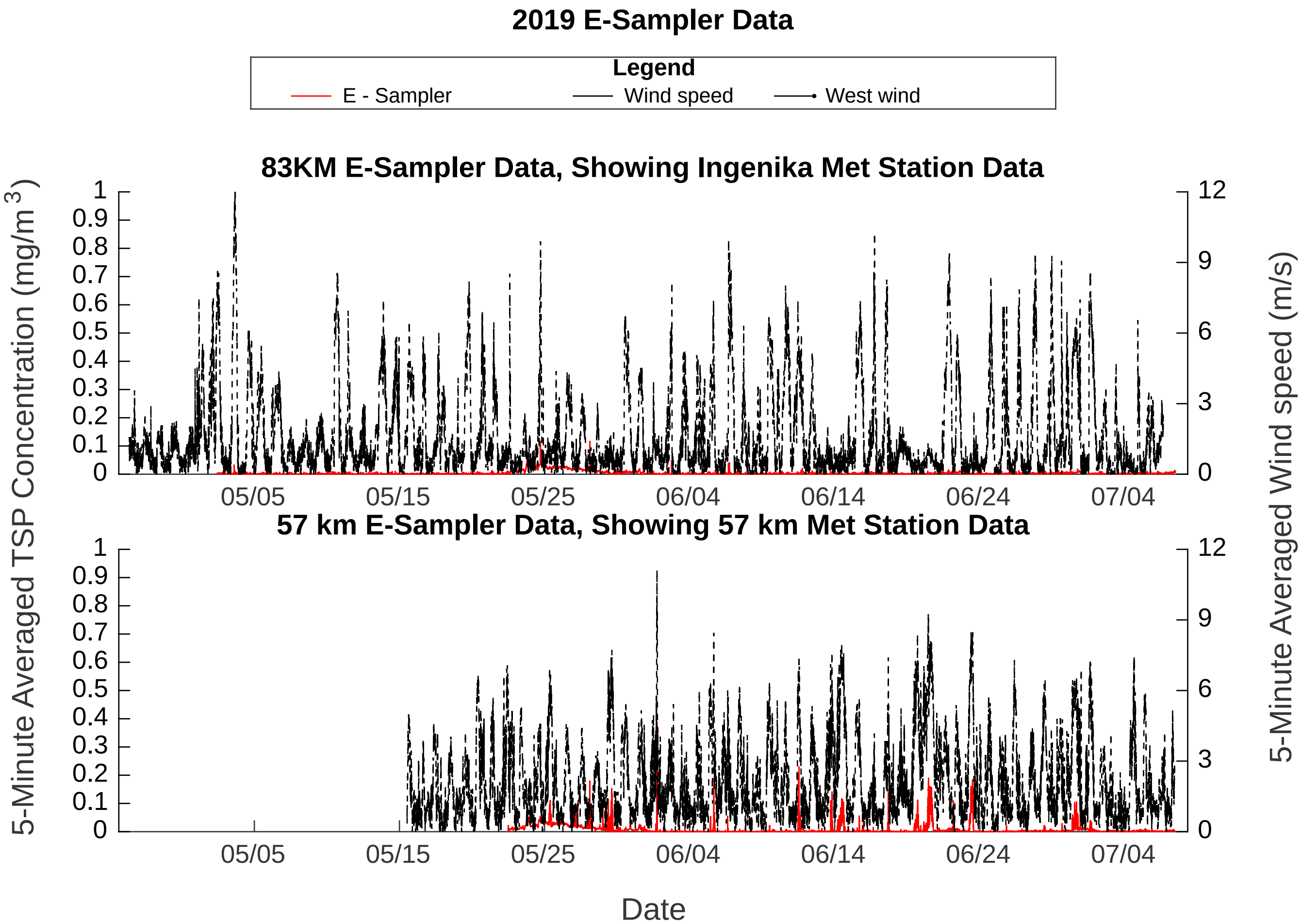
Appendix 1: Regional Air Quality Plots: E-Sampler Data Overlaid with Wind Speed

2019 E-Sampler Data




2019 E-Sampler Data
Legend
E - Sampler
Wind speed
West wind
Chowika E-Sampler Data, Showing Chowika Met Station Data
Middle Creek North$_N$ E-Sampler Data, Showing Middle Creek North$_N$ Met Station Data
Middle Creek North$_S$ E-Sampler Data, Showing Middle Creek North$_S$ Met Station Data
Davis North E-Sampler Data, Showing Davis North Met Station Data
5-Minute Averaged TSP Concentration (mg/m^3)
5-Minute Averaged Wind speed (m/s)
05/05
05/15
05/25
06/04
06/14
06/24
07/04
Date


2019 E-Sampler Data
Legend
E - Sampler
Wind speed
West wind
Davis South E-Sampler Data, Showing Davis North Met Station Data
Bruin E-Sampler Data, Showing Collins Met Station Data
Collins E-Sampler Data, Showing Collins Met Station Data
Ingenika E-Sampler Data, Showing Ingenika Met Station Data
5-Minute Averaged TSP Concentration (mg/m3)
5-Minute Averaged Wind speed (m/s)
05/05
05/15
05/25
06/04
06/14
06/24
07/04
Date


2019 E-Sampler Data
Legend
E - Sampler
Wind speed
West wind
83KM E-Sampler Data, Showing Ingenika Met Station Data
57 km E-Sampler Data, Showing 57 km Met Station Data
5-Minute Averaged TSP Concentration (mg/m3)
5-Minute Averaged Wind speed (m/s)
05/05
05/15
05/25
06/04
06/14
06/24
07/04
Date