Peace Project Water Use Plan

WILLISTON DUST CONTROL MONITORING

Implementation Year 11

Reference: GMSMON-18

Study Period: January 01, 2018 to December 31, 2018

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GMSMON#18 WLL Dust Control Monitoring

BC Hydro Williston Reservoir Air Monitoring

2018 Annual Report

CHU CHO ENVIRONMENTAL

Prepared For: BC Hydro and the Joint Planning Committee
Prepared By: Chu Cho Environmental LLP
Study Period: 2018/01/01 – 2018/12/31

Tsay Keh Dene, BC, V0J 3N0

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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 that results in the exposure of large expanses of loose sediment with little vegetative cover or other protection from wind erosion. The project consisted of a Reference Monitoring Network to collect baseline particulate matter (PM) data and a Regional Monitoring Network to identify regional source and sink zones of PM around the Finlay airshed. Chu Cho Environmental took over MON18 in March of 2014 (year 7 of the project) and revised the network design in 2014 to increase the spatial and temporal resolution of the regional data. This allowed for a better evaluation of the impact of dust mitigation treatments on fugitive emissions from the reservoir beaches. In 2018 Chu Cho Environmental proposed to continue for an additional two monitoring seasons in order to collect an adequate number of years to constrain the dataset across the full spectrum of dust and weather events. The implementation of this continued work utilizes the following objectives as the guiding focus for a more streamlined program:

- Provide long-term data on air borne 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 and suggest new mitigation techniques when appropriate.
- Identify long-term regional trends, and
- Monitor with a localized focus on new WDMP mitigation techniques.

Chu Cho Environmental's objective is to implement a cost-effective, streamlined program that addresses only the most critical elements necessary to evaluate air quality issues in Tsay Keh Dene and the effectiveness of the WDMP. A summary of the changes made to the program included:

1. A reduction in the number of monitoring locations from 18 to 13 based on the information by removing stations that had been collecting low quality or red redundant data relative to the other locations. Redeploy to locations where the WDMP is applying mitigation trials.
2. Operating the regional monitoring program from April to July during the typical dust season rather than from "snow-to-snow" as was the previous implementation plan. This better aligns the program with the objectives of the ToR and dramatically reduces costs.
3. Removing the reference monitoring station located in Kwadacha. The rationale for this decision was primarily related to the fact that it is located over 80km away from the reservoir and after 5 years of monitoring it was clear that reservoir dust is not an issue in this location.

Data Summary:

In general, the spatial and temporal variability between sites is large. We have defined a dust event as exceeding the threshold of 0.1 mg/m^3 total suspended particulate (TSP) over a 5-minute period. The rationale behind this definition is expanded upon in Section 2. It should be noted that this is not a

regulatory threshold; this is merely an internally consistent threshold that is representative of visually noticeable airborne dust in the Finlay Valley. E-samplers are not a regulatory instrument and the data collected by the Regional Monitoring Network should not be interpreted as such.

From the Regional Monitoring Network, one sampling station recorded 163 dust events over the 2018 dust season, whereas another site recorded 7 events. The regional average was 54 dust events. Some events are short-lived and highly localized to an individual beach or group of beaches, while others fill large sections of the valley. Overall, 2018 was a high dust year whereas the average from the previous four dust seasons (2014-2017) was 32.25 dust events.

In 2014 and 2015, our team attempted to evaluate the before and after effects of applying tillage to beaches on the reservoir as a mitigation technique. This was attempted again along with irrigation for the 2018 report. There are still significant limitations that preventing conclusive analysis of this point. The beaches analyzed for this report, have presented statistically significant but confounding results for both tillage and irrigation, due the date of tillage and commencement of irrigation and the arrival of significant rainfall within the study period.

Chu Cho Environmental has attempted to manage the Reference Monitoring Station to the standards of the Canadian Council of Ministers of the Environment (CCME) and will provide a basic analysis of these data following the CCME guidelines. However, the model of instrument (TEOM) used in Tsay Keh Dene is not designated as a US EPA Federal Equivalence Method (FEM) for $PM_{2.5}$ (PM <2.5 μm in diameter) and PM_{10} (PM <10 μm in diameter) monitoring, which are used for CCME and BC MoE guidelines for Canadian Ambient Air Quality Standards (CAAQS) and Air Quality Objectives (AQO), respectively. Therefore no regulatory claims can be made about the air quality data recorded by the TEOM. Despite this, we still operated the TEOM under the same guidelines and strict standards of the CCME. For 2018, the TEOM in Tsay Keh Dene recorded excellent data and there have been no issues with its operation in 2018.

The 2018 dust season was more active than previous years and might be referred to as an atypical dust season in the Finlay Valley. There were many events of varying duration with intensities not previously recorded in the region. At the reference monitoring station in Tsay Keh Dene, from early May to early July, there were 8 times when there was a 24-hour exceedance of the provincial PM_{10} AQO and 13 instances of a 24-hour exceedance of the federal $PM_{2.5}$ CAAQS. To put in context, there was the same number of PM_{10} AQO exceedances during the 2018 dust season as there were in the combined dust seasons of 2014-2017. For the $PM_{2.5}$ CAAQS, there were only 3 24-hour exceedances in the four previous dust seasons (2014-2017. The data from this station have provided valuable insight into the long-term air quality trends within the region.

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1.0 GLOSSARY

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 the E-Sampler

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

Major dust event: a period where averaged TSP concentrations are equal to or exceed the threshold of 0.1 mg/m^3 over a 24-hour period or longer

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

PM10 (also PM_{10}): particulate matter with a diameter <10 μm, a component of dust

PM2.5 (also $PM_{2.5}$): particulate matter with a diameter <2.5 μm, a component of dust

PMCoarse (also PM_{Coarse}): particulate matter with a diameter between 10 – 2.5 μm

TEOM 1405-D: air particulate sampling unit, measurements in $\mu g/m^3$

TSP: total suspended particulate matter (i.e., dust)

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

2.0 Finlay Valley Airshed and Williston Dust Monitoring

2.1 Finlay Valley Airshed

The Finlay Valley extends from the Peace Arm of the Williston Reservoir north towards Tsay Keh Dene and Kwadacha villages.

The Finlay Valley is part of the northern Rocky Mountain Trench, residing between the Rocky Mountains to the east and the Omineca Mountains to the west. The Rocky Mountain Trench formed shortly after the end of the Laramide Orogeny and the formation of the Rocky Mountains when the land was rebounding after the tectonic pressure was relieved and before the development of the Omineca Mountains (Cannings et al., 1999).

The region has experienced many glaciations over the previous 200 million years, the last of which ended approximately 9000 years ago. Successive glaciations deposited large volumes of sediment through various lacustrine and fluvial processes leaving the Finlay Valley and Rocky Mountain Trench with an extensive layer of glacial overburden that comprises massive sand and gravel benches interlaced by fine lacustrine unconformities (Rutter, 1977). The Williston Reservoir now sits in the northern Rocky Mountain Trench having flooded over 1,775 km^2 of valley bottom. Annual operation of the W.A.C. Bennett dam can change the reservoir surface elevation from roughly 655 m to 672m above sea level, leaving beaches, cutbanks and gravel outcrops exposed for several months during the spring freshet period.

Successive glaciations and river incision have created a valley that is broad and U-shaped but is also deeply incised by the Finlay and Parsnip rivers. Given the shape of the valley, the annual fluctuation in reservoir level has the potential to expose large expanses (~20,000 Ha) of loose erodible sediment during the spring months before the reservoir is recharged following spring freshet. While the water is low, the exposed beaches, which are composed of mixed sand, silt, clay, and gravel beds tend to erode during spring wind events resulting in the emission of fugitive dust.

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.

2.2 Management Summary: GMSMON#18 Management Question & Program Components

The dust control management plan (DCMP) under Section 5.1 of the Peace River Water Use Plan (WUP) was implemented with the goal of reducing the duration and magnitude of the dust storms that affect the quality of life for people living adjacent to the reservoir (BC Hydro, 2007). The DCMP consists of three major components: dust source surveys, erosion control trials and Air Quality (AQ) monitoring.

The AQ monitoring component of the DCMP is the result of an ongoing 12-year commitment (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 and will inform water use decisions as they pertain to dust control. Some of the analysis avenues investigated in this annual report may be changed as required in favour of more concise analyses that become available.

Throughout this report we will refer to the scale of the dust events, in some cases events are small and localized and in other cases, they are broad and widespread; technical definitions to these terms will appear in Section 2.

The following table provides a summary of the various program components that pertain to year-11 (2018) of MON18 and the status of those components.

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 in 2018 to address this question. The samplers collected data at 5-minute intervals from May to July. The start of the season began with above-average temperatures and dry conditions. Williston Reservoir was also operating at it's lowest level in 5-years. Statistical analysis of data indicated that mitigation may have an effect on reducing local/regional fugitive emissions; however, it is currently not possible to delineate mitigation treatment effects from the numerous confounding variables

Program Component	Management Question	Management Hypothesis (Null)	Status
			such as rainfall and reservoir rise.
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 2018 dust season, there was a total of eight instances where the provincial AQO for PM_{10} was exceeded in a 24-hour period and 13 times where the federal CAAQS for PM2.5 was exceeded in a 24-hour period. Most of these exceedances were reported in the early part of the dust season, which was dry and the reservoir levels were low.
Mentorship and Community Engagement	n/a	n/a	Chu Cho Environmental employees who reside in Tsay Keh Dene are steadily taking on more responsibilities across the company. In 2018, Tsay Keh Dene crewmembers participated in or were responsible: -Setup of the regional monitoring network, -Data downloads and weekly 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 enlisted third party applications for hosting data online. A remote login system that allowed remote access to the instrumentation. An email listserve from the Tsay Keh Dene Reference station was available to anyone who wanted to receive a .csv file summarizing the previous 12 hours of data. Regional data were synced after field downloads via Dropbox and reviewed shortly after for completeness.

2.3 Updates to Monitoring Networks

Chu Cho Environmental instituted changes to both monitoring networks from 2017 to 2018. Following the 10th year of the initial GMSMON#18 program, Chu Cho Environmental proposed that the program be continued for two more monitoring seasons in order to collect additional data to assist in answering the management question. It was felt that the data collected during the first six years were not able to sufficiently address the key management question. This is broadly related to a misunderstanding of the scale of the problem and a program that was designed with too few instruments collecting data at too slow a time interval (ex. one sample from one beach would be collected once every three days) (Marini & Tilson, 2019). Chu Cho Environmental remedied these issues in 2014 by deploying a dense monitoring network of 18 E-Samplers collecting data a 5-minute interval (ex. 864 samples from one beach every three days). This meant that there are only four years of data available from the updated (2014) monitoring network and of those four years only one year was a typically "dusty" year. The other three years were not dusty due to high reservoir levels and high precipitation levels so the dataset is not well constrained.

Changes were made to both the Regional Monitoring Network and Reference Monitoring Stations. The changes to the network included:

1) E-Sampler at Shovel was removed due to ongoing wildlife (bear) incidents.

2) E-Sampler at Rat Lake was removed due to low-quality data and proximately to Ingenika Point, which had better exposure to the reservoir.

3) E-Samplers at Moody Beach, Bob Frey South and Omineca were removed due to excessive travel times and low-quality data.

4) The instruments added on the beach at Middle Creek North included two additional E-Samplers and a meteorological station. These instruments were added to better help understand the local conditions.

5) The Reference Monitoring station in Kwadacha, which is approximately 80 km north of the Williston Reservoir, was removed from the Network for 2018 following the end of the original 10-year program. After five years of data collection, there was no discernible impact of reservoir dust at this location and dissociated from the key management question. Also, the cost to maintain the station was significant and completely dissociated from the key management question and project objectives.

2.4 Data Summary

The following tables provide a summary of the components in this program for 2018 and the rate at which the data are collected:

Table 2: Summary of Air Quality Response Measures Monitored.

	Response Measures		
	Total Suspended Particulate Concentration	Particulate Matter Concentration	
	TSP (up to 100 µm)	$PM_{2.5}$	PM_{10}
Variable ID	001-014	pm25	pm10
Sampling Year(s)	2014-2018	2011-2018	2011-2017
Sampling Frequency	5 min	10 min	10 min
Measurement Units	mg/m^3	$\mu g/m^3$	$\mu g/m^3$
N	13	1	1
Data type	measured	measured	measured
Equipment	E-Sampler	TEOM 1405-D	TEOM 1405-D

Table 3: Summary of Meteorological Equipment Used in GMSMON#18.

	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	2018	2018	2018	2018	2018	2018	2018	2018	2018	2018	2018
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	ºC	ºC	kPa
N	7	1	7	1	7	1	7	1	7	1	1
Data type	measured	measured	measured	measured	measured	measured	measured	measured	measured	measured	measured
Equip.	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 NETWORK

3.0 Regional Monitoring Network

3.1 Network Characterizations

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 altered for 2018; these changes were identified above in Section 1.2. The Regional Monitoring Network initially consisted of 14 Met One E-Samplers and 7 meteorology-monitoring (met) stations. The planned network would have seen both an E-Sampler and met station at 35 km on the Chunamon forest service road, but there was no safe access to the beach. The 14 E-Samplers were dispersed across the many points, beaches, and gravel bars as well as a cutbank in the reservoir's Finlay Arm. The data from the Davis South E-Sampler had to be removed from any regional analysis following the seasonal analysis of that site. Later testing would confirm that the E-Sampler at that location was not properly detecting total suspended particulate matter.

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 are designed to measure continuous air quality data at 1 Hz and can record that data at various averaging intervals. Since 2014, we have been using the 5-minute averaged data option, which allows the units to function autonomously for up to 15 days before the on-board memory is full and requires downloading. E-Samplers are designed to 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.

Alongside the 13 E-Sampler sites there were 7 meteorological monitoring stations. These stations were placed in the same remaining locations as 2017, with the addition of a station at Middle Creek North. Each meteorology station was outfitted with a rain gauge, temperature probe, relative humidity sensor, wind vane, and anemometer. The data were logged using a CR1000 datalogger.

Ultimately, the location of the 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 important 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.

Figure 1 shows the location of the 14 dust monitoring and 8 meteorology monitoring stations within the Finlay Arm of the Williston Reservoir.

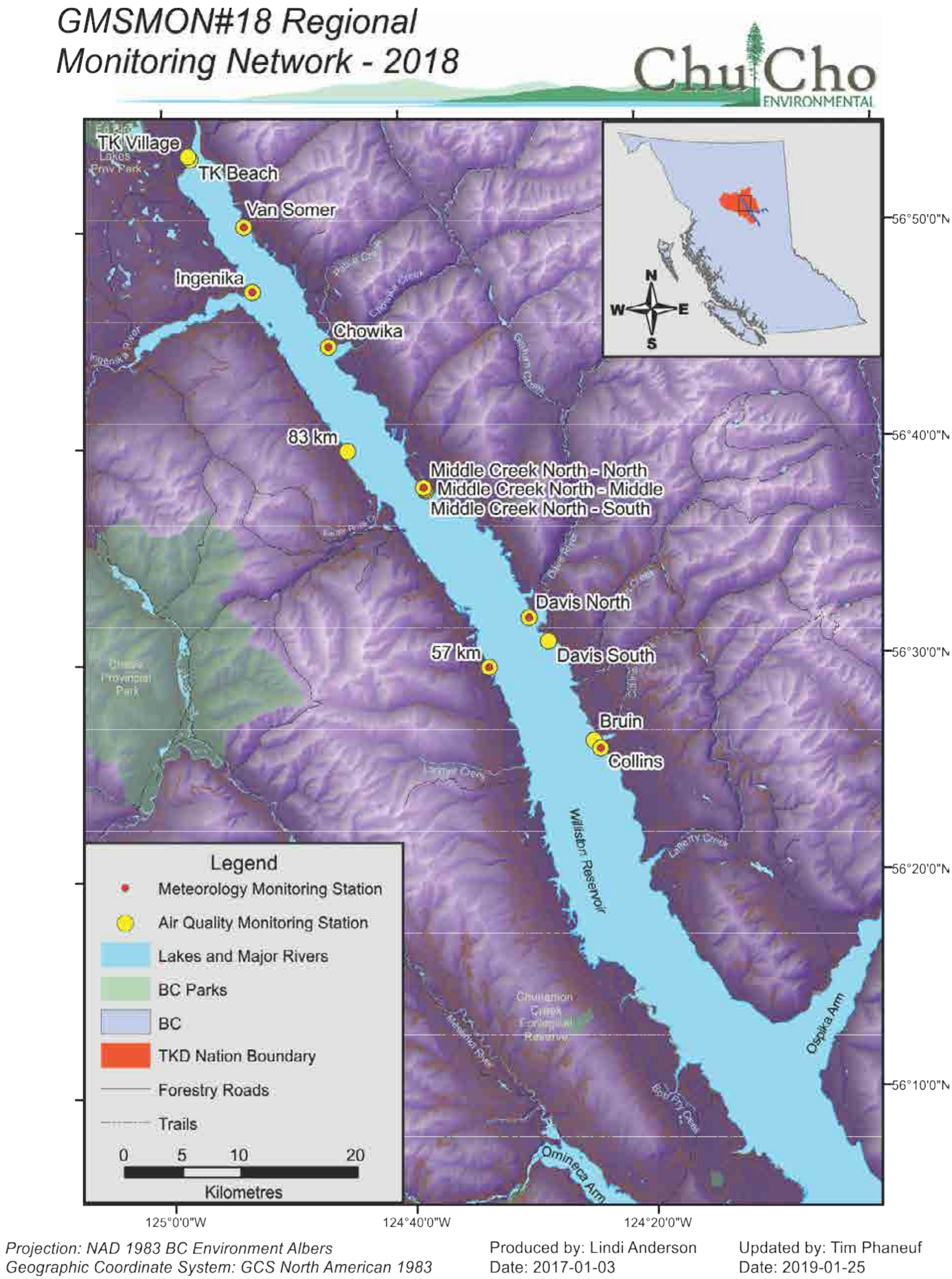

Figure 1: Map of Regional Monitoring Network Sampling Locations

3.1.1 SITE DETAILS

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

Table 4: Regional Monitoring Network Site Descriptions and Locations.

Site Name	Lat	Long	Met Station	Site Description	Airshed Representation	Instrumentation
Tsay Keh Village	56.8369	-124.8861	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.	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 in order to capture the emissions from the beach prior to entering the village.	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 hold 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 Representation	Instrumentation
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 migrate towards Tsay Keh. This site produces no local dust emissions.	Regional Dust	E-Sampler & Met Station
Middle Creek North (MCN) – North	56.6339	-124.6406	Middle Creek North – North	The first site at Middle Creek North Beach, Middle Creek North – North (MCN-N), is located very close to the site in 2017 and is the most northerly site of the three MCN sites. 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. In 2017 and 2018 this beach was only irrigated. 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 – Middle	56.6317	-124.6364	Middle Creek North – North	The site named Middle Creek North – Middle (MCN-M), is located 400 m southeast of MCN-N. The beach material at this site is identical to the beach material at MCN-N.	Local Dust	E-Sampler

Site Name	Lat	Long	Met Station	Site Description	Airshed Representation	Instrumentation
MCN – South	56.6291	-124.6316	Middle Creek North – North	The site named Middle Creek North – South (MCN-S), is located 400 m southeast of MCN-M (and therefore 800 m southeast of MCN-N). The beach material at this site is identical to the beach materials found at MCN-N and MCN-M.	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
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 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

Site Name	Lat	Long	Met Station	Site Description	Airshed Representation	Instrumentation
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 Arm and Finlay Arms intersect. This site is exceptionally well exposed to southeasterly and northwesterly 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 full-pool 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.	Regional Dust	E-Sampler

Site Name	Lat	Long	Met Station	Site Description	Airshed Repre-senta-tion	Instru-menta-tion
57 km	56.4940	-124.5522	57 km	Like 83 km this site is named after it's location on the Chunamon road. This site is located approximately 3 km north of the 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

Figure 2 to Figure 15 show a pair of images at each site from two perspectives. All images were taken from early to mid-May 2018 unless specified differently:

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

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

Figure 4: 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 5: 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 6: 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 7: These images were the view from the middle site setup at Middle Creek North (MCN-M). The image on the left was looking towards the east and the Rocky Mountains, while the image on the right is facing west across the reservoir and the Omineca Mountains.

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 (MCN-M had not yet been set up when the photo was taken). The image on the right shows the view to the north with the E-Sampler & solar assembly and the Rocky Mountains.

Figure 9: Looking to the 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 situated 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.

3.1.2 Instrumentation

The Met One E-Sampler is a nephelometer that functions according to a unique operating principle that employs forward laser light scattering to estimate the concentration of airborne particulate. Air is drawn into the unit through the 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. The particulates in the air stream scatter the laser light, via reflection and refraction, in proportion to the amount of particulate in the air. The laser light not scattered continues forward into a laser trap and the scattered light is collected and focused by lenses onto a special light sensor. This sensor measures the intensity of the 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 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 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 2018 dust season, this included flow calibration, leak check, and filter cleaning with every site visit, which was usually weekly, but never more than 15 days. As well, data was reviewed for verification and errors about a day or two after it was downloaded.

3.2 Regional Monitoring Network Data Overview

E-Sampler light detecting sensor 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. Data were collected from 14 instruments beginning May 7th with the deployment of the first instruments until the end of July. One of the reasons why collection began in early May was due to a deeper snowpack impacting access to sites. A cut-off date of July 13th was chosen so that the length of the data collection was similar to previous seasons. Also, on that date reservoir had an elevation (at Lost Cabin Creek) of 667.08 m asl, an elevation that was well within the dust season of the preceding four years (2017, June 10; 2016, May 26; 2015, May 29; and 2014, June 25).

There were 7 complete meteorology 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 Hz and recorded 5-minute averaged data for relative humidity, rainfall, air temperature, wind speed and wind direction. 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.

This distributed network of continuously monitoring E-Samplers and weather stations has allowed us to probe dust events (some through avenues that have not been investigated) and also allowed our team to create visuals that provide unparalleled insight into the development, evolution and termination of dust events.

The analyses discussed in this report represent Chu Cho Environmental's perspective and current understanding of the air quality issues within the Finlay Valley. Following the presentation of our results, a preliminary data review will be performed to uncover potential limitations of using the data, to reveal outliers and explore the basic structure of the data. 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 and regression.

3.2.1 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 (CCME, 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.

3.2.2 Threshold and Event Scale

Over the years much of the discussion surrounding dust events in the Finlay Valley has focused 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

Since E-Samplers are not FRM/FEM certified instruments there is no numerical standard by which to define a dust event. Previously for this project, we 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. We used a number of replicate sites for the exercise (Middle Creek North, Shovel Creek, Van Somer, 35km, Ingenika and Davis North) and arrived at a concentration value of 0.1 mg/m3 TSP (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 felt that it was important that very small non-representative readings were not included in the analysis. Dust events are categorized by the number of instances where two or more consecutive 5-minute records are >0.1 mg/m3.

3.2.3 Time Series Analysis

Data collected by the Regional Monitoring Network may show a variety of dust event types throughout the typical dust season ranging in magnitude from small scale isolated occurrences that last less than 30 minutes to extreme valley-wide events that may last more than 36 hours. The technical definition for each dust event scale is provided in Table 5 below. In 2018, the Regional Monitoring Network recorded numerous events throughout the season, with many occurring in the latter half of May. The following sections will probe the data captured by the regional monitoring network in order to evaluate and quantify the frequency and magnitude of each dust event. Table 5 provides a description of the internally developed dust event scale classification level. These event scale classifications are used to describe dust events throughout the following sections.

Table 5: Dust Event Definitions.

Dust Event Scale	Technical Definition
Small	Less than 6 hours in duration with a TSP concentration above 0.1 mg/m^3
Moderate	Between 6 and 18 hours with a TSP concentration above 0.1 mg/m^3
Large	Longer than 18 hours but less than 36 hours with a TSP concentration above 0.1 mg/m^3
Extreme	Longer than 36 hours with a TSP concentration above 0.1 mg/m3

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***. 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.

Figure 16 to Figure 19 demonstrate that several locations had some small-scale events at the start of the dust season. The last 11 days in May saw an increased number of dust events ranging from small to large. Excluding the Middle Creek North sites, the region recorded a couple of small events in the second and third week of June; the exception was Collins and Bruin, which reported several small events, especially in the third week. Figure 17 shows the Middle Creek North sites. These sites reported a few events in the first week of the season but then recorded many events over the final two weeks of May; several of these events were medium to large-scale events. Most of the events recorded at the MCN sites had very high magnitude (TSP > 0.5 mg/m^3) small to medium scale events throughout the dust season. Outside of Tsay Keh Beach, all beach sites recorded very high magnitude, short duration dust events.

A large amount of processing is performed on the raw data presented in Figure 16 through Figure 19; anomalous values were removed and the data subjected to intensive statistical analysis probing for maximums, averages, variances and other relationships between samplers and locations.

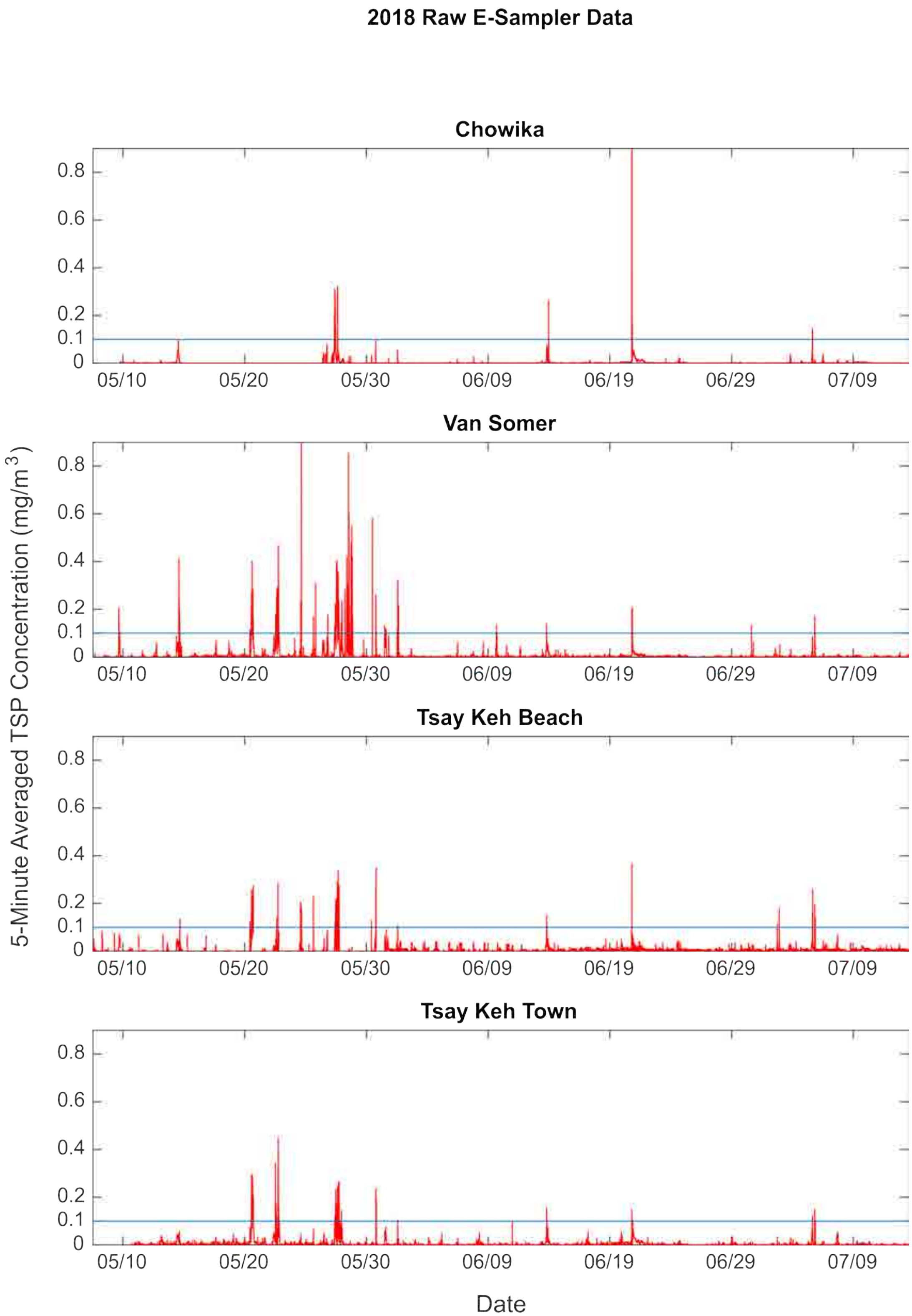

Figure 16: Regional E-Sampler data from Chowika, Van Somer, Tsay Keh Beach and Tsay Keh Town, showing 5-minute average TSP concentration data. The horizontal blue line represents the 0.1 mg/m3 TSP concentration threshold across the chart.

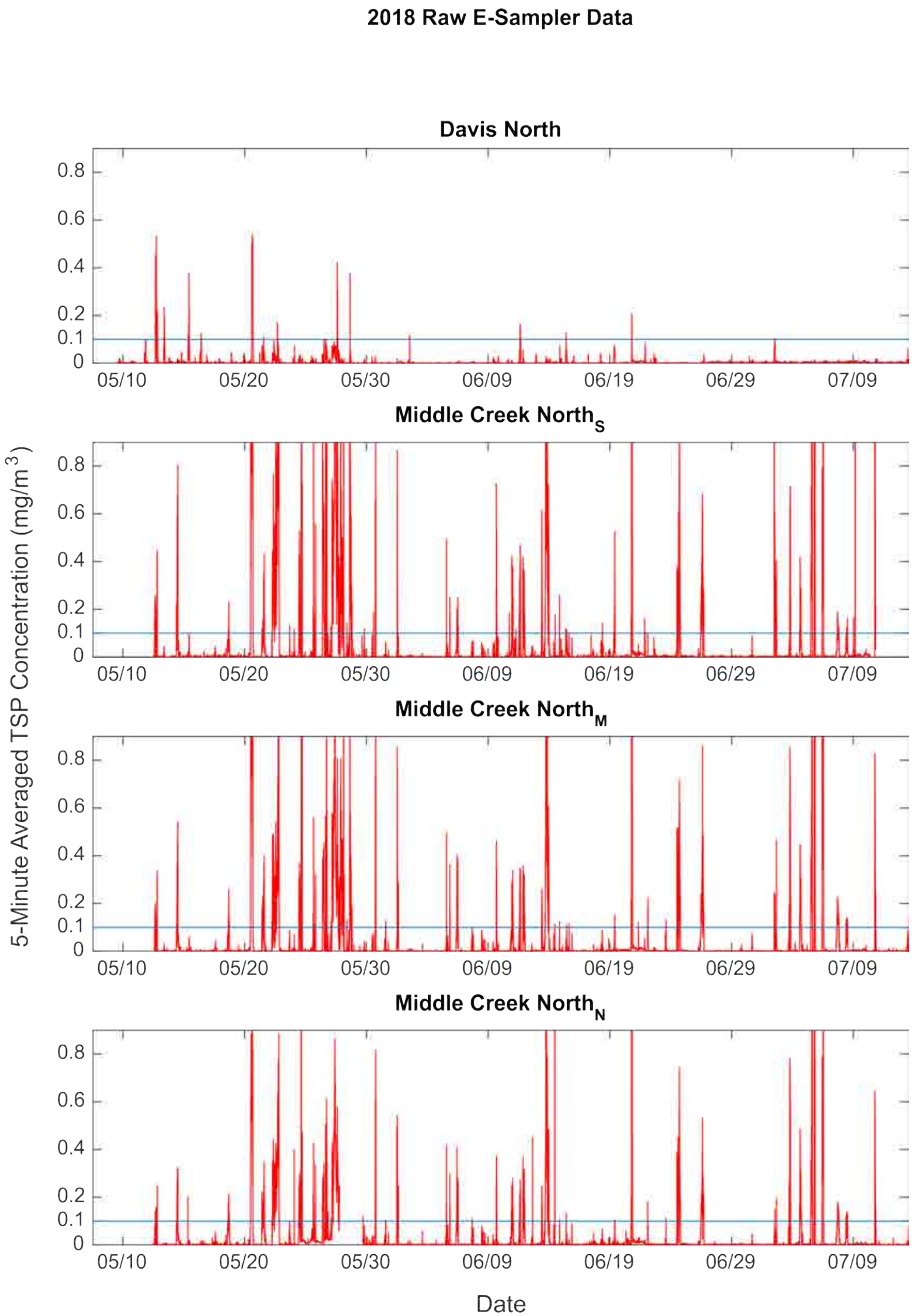

Figure 17: Regional E-Sampler data from Davis North, and the three sites at Middle Creek North: South, Middle and North, showing 5-minute average TSP concentration data. The horizontal blue line represents the 0.1 mg/m³ TSP concentration threshold across the chart.

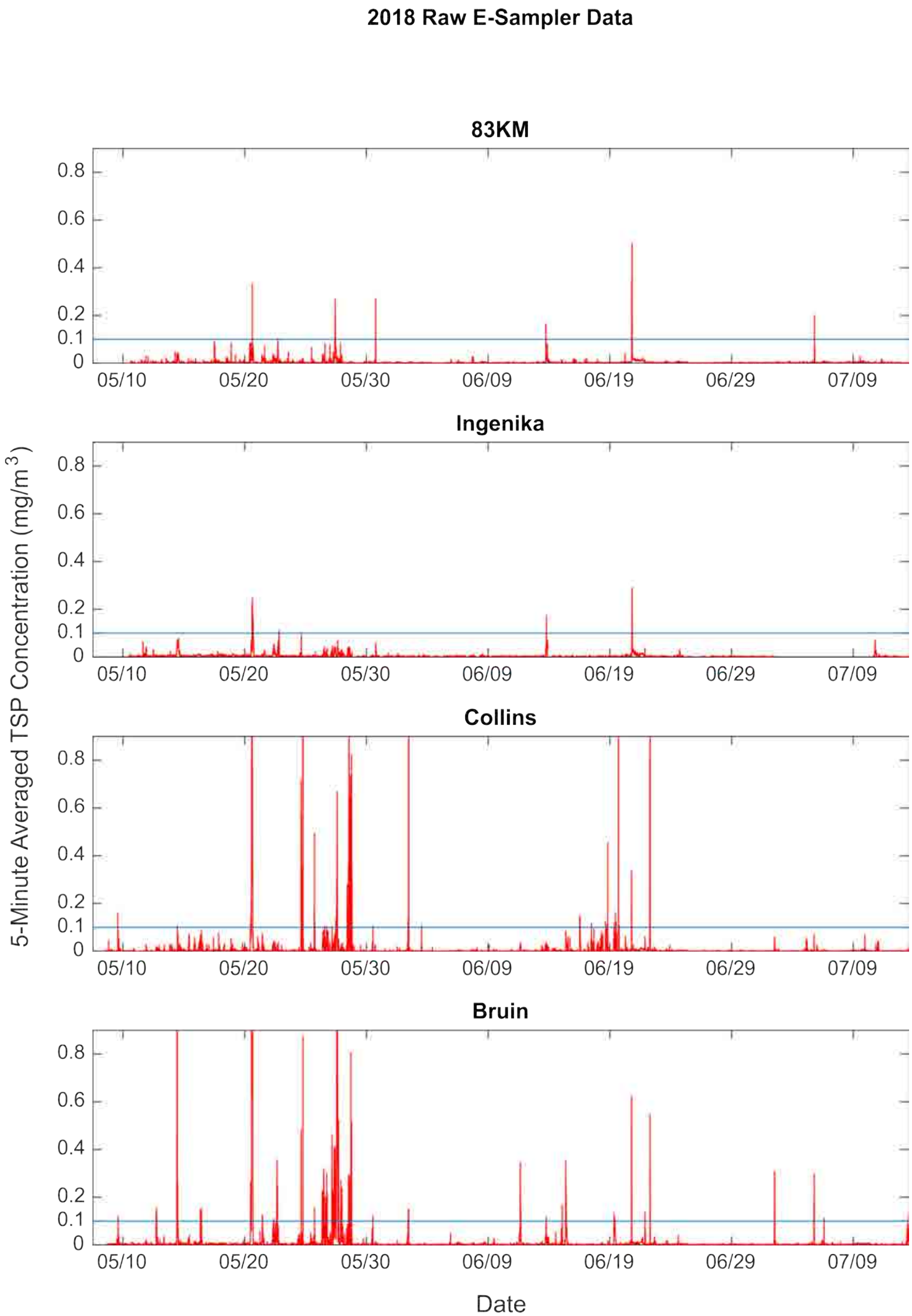

Figure 18: Regional E-Sampler Data from 83 km, Ingenika Point, Collins and Bruin, showing 5-minute average TSP concentration data. The horizontal blue line represents the 0.1 mg/m³ TSP concentration threshold across the chart.

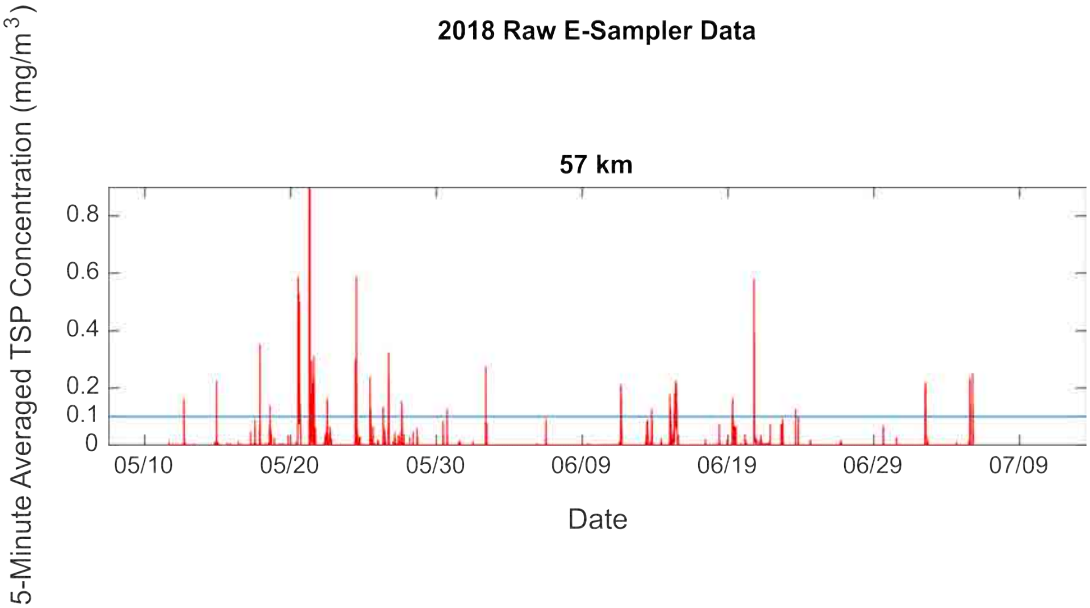

Figure 19: Regional E-Sampler Data from 57 km showing 5-minute average TSP concentration data. The horizontal blue line represents the 0.1 mg/m³ TSP concentration threshold across the chart.

3.3 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 6 on page 30. As previously detailed, the 2018 dust season was from May 7th until July 13th, 2018, a total of 67 days.

3.3.1 Dust Events and Total Suspended Particulate

There was an average of 54 dust events recorded across all locations during the 2018 dust season. The three sites located at Middle Creek North Beach were averaged into one value in determining the regional statistics so as to make comparisons to previous years more similar. The average number of dust events for 2018, is roughly double the averages from 2014 (29 events), 2016 (19 events) and 2017 (25 events) (Table 7). Only 2015 averaged more dust events on the Finlay Reach of the reservoir, with 56 dust events; which was due to an even greater disproportionate number of total dust events at MCN (266 events) and Tsay Keh Beach (201 events) in 2015. The percentage of time during the dust season that the region exceeded the threshold for a dust event (again sites at MCN averaged into one value) was 1.46%, nearly one day or approximately 23 hours. This value is higher than the previous four years, with the next closest year, 2014, when 1.05% of the dust season in the region exceeded threshold standards for a dust event. The average TSP concentration during dust events for the region was 0.257 mg/m³, similar to both 2014 (0.25 mg/m³) and 2016 (0.26 mg/m³), but less than 2015 (0.30 mg/m³) and 2017 (0.29 mg/m³).

Table 6: 2018 dust season dust event summary statistics, calculated from 5-minute averaged data.

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	32	0.17	0.7	11:25	3	6.2	0.4	3.1	1.1	138
Tsay Keh Beach	44	0.17	0.56	9:00	3.1	6.7	0.4	3.1	1.2	146
Van Somer	83	0.2	1.7	27:20	4.4	10.5	0.3	4.9	2.2	186
Chowika	11	0.23	0.24	3:50	11.5	15.8	5.9	10.9	1.7	146
MCN-N*	152	0.39	6.79	109:10	8.1	16.3	0.8	7	1.2	204
MCN-M*	163	0.45	7.53	121:05	8.1	16.3	0.8	6.9	1.2	210
MCN-S*	151	0.55	7.6	122:10	7.9	16.3	0.1	6.6	1.5	221
Davis North	38	0.22	0.71	11:25	7.8	13	4.4	7	1.4	255
Bruin	88	0.39	2.11	33:55	6.8	11.2	0.5	6.2	1.6	221
Collins	54	0.42	0.96	15:25	7.1	11.2	0	5.8	2.4	224
Ingenika	7	0.17	0.2	3:15	8.7	12.1	1.2	8	3.3	193
83 km	9	0.19	0.17	2:45	7.8	11.9	0.1	7.7	3.9	174
57 km	74	0.2	1.18	19:00	6.1	8.4	0.1	6	1.6	208
Average*	54	0.26	1.44	23:10	6.8	11.2	1.3	6.3	2.0	191

*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 7: Dust season averages for all sites in the Regional Network since 2014 based on dust event summary statistics, calculated from 5-minute averaged data.

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.
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

The largest numbers of dust events over the 2018 dust season were recorded at the Middle Creek North Beaches, MCN-N, MCN-M and MCN-S with 152, 163 and 151 events, respectively. The next closest number of dust events recorded was Bruin Beach with 88 dust events, followed by Van Somer with 83 events. Davis North had the least number of dust events at a beach site with 38 dust events. Non-beach sites on the reservoir, Chowika, Ingenika Point and 83 km averaged 9 dust events each. Tsay Keh Village, regarded as a non-beach site but downwind of Tsay Keh Beach, experienced 32 dust events, as recorded by the E-Sampler atop the TEOM enclosure.

A high number of dust events didn't always equate into intense dust events. In the case of the Middle Creek North sites, which had the highest number of dust events they also had the highest average TSP concentrations. MCN-N, MCN-M and MCN-S, had average dust event TSP concentrations of 0.39 mg/m^3, 0.45 mg/m^3 and 0.55 mg/m^3, respectively. Bruin had the fourth most dust events over the season with 88 and had an average TSP concentration of 0.39 mg/m^3. Comparatively, Tsay Keh Beach, Van Somer, Davis North and 57 km had 56 dust events averaged between them and a TSP concentration of 0.20 mg/m^3. That value was very similar to the four non-beach sites (Tsay Keh Town, Chowika, Ingenika Point and 83 km, with an average TSP concentration of 0.19 mg/m^3 during dust events.

While the intensity of a dust event can be impressive and an important indicator of the impact of these events, the duration of an event is also important to consider. It can be seen that the Middle Creek North sites in Figure 17 spent a lot of time during the dust season above the dust event threshold. Table 6 shows that the sites at MCN spent more than three times as much time under dust conditions compared to the next closest site, Bruin. All three MCN sites spent more time above threshold conditions than any site in the previous four years of the monitoring program. That is equivalent to approximately 109 consecutive hours for MCN-N and 121 and 122 hours for MCN-M and MCN-S, respectively. Bruin and Van Somer also had high averaged concentrations of TSP during the dust events: Bruin with 2.11% (34 hours) and Van Somer 1.7% (27 hours). While Tsay Keh Town spent roughly half the time experiencing a dust event compared to the regional average (Table 6), it was still more time than the previous four years (Table 7).

3.3.2 Wind Speed and Wind Threshold

Middle Creek North along with Chowika recorded the highest wind speeds on the reservoir in 2018 (Table 6). Unlike 2018, wind speed measurements and therefore threshold wind speed were not recorded at MCN but modelled based on the surrounding met sites.

The average wind speed during dust events across the region was calculated at 6.8 m/s in 2018, which is up from 3.9 m/s in 2017, and higher than in 2015 (3.1 m/s) and 2014 (6.4 m/s); it is very similar to the 2016 season (6.9 m/s) (Table 7). The Middle Creek North sites along with Chowika recorded the highest wind speeds during a dust event. The average wind speeds during a storm were pretty much even for Beach and Non-Beach sites alike. Van Somer, Tsay Keh Beach and Tsay Keh Village reported the lowest average wind speeds during dust events.

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 and averaging the previous 30 minutes of data. The average wind speed threshold for the region was calculated at 6.3 m/s for the 2018 dust season. That regional wind speed threshold is greater than last year (4.0 m/s), 2015 (3.1 m/s) and 2014 (5.9 m/s) and slightly less than 2016 (6.6 m/s).

Threshold wind speeds were greatest at three non-beach sites (Chowika, Ingenika Point and 83 km) (Table 6). This should not be surprising, as the dust detected at these sites would have been transported from an upwind beach. The Tsay Keh TEOM site is a non-beach site and reported a lower threshold wind speed, but it also averaged a much lower average wind speed during dust events. This could be a result of its location as that site is set back a few hundred metres from the reservoir, as opposed to all other sites in the regional network.

3.3.3 Wind Direction

There was some degree of 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 191° (Table 6). 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). Tsay Keh Beach and Tsay Keh Town sites along with Chowika had threshold wind directions from the southeast. These sites also had wind direction standard deviations that were quite low relative to the rest of the sites; this indicates that dust events were originating and travelling with a southeasterly wind. For Chowika, this means that dust was travelling up from the southeast from dust likely originating from the Middle Creek beaches. All of the other emitter (beach) sites had some southerly or westerly component to their predominately southwesterly winds. These sites also had a higher standard deviation, indicating that there were sometimes when the wind was blowing from the northwest.

3.3.4 Mitigation Treatment Analysis

Dust concentration recorded at E-Samplers from locations where tillage and irrigation occurred for highly erodible beaches was examined. Data recorded before and after the implementation of the tillage were processed and a Student T-test was prepared as a comparison of means between these datasets. Conversely, for irrigation, a Student T-test was calculated for the period before and while irrigation was applied.

3.3.4.1 Tillage

Technicians working for the WDMP recorded the day on which tillage was applied to the reservoir beach. For this analysis, we will look at dust data for the 14 days preceding tillage and compare them to the 14 days following tillage. The day on which tillage is being applied to the beach is not included in the analysis. The primary driver for this analysis is to determine if it is possible to tease out a result that might indicate 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 our 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 the tillage was applied to the specified beaches. For 2018, a subset of data from four highly emissive beaches was selected for this analysis.

Table 8: 2018 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/m³)	T Test P-value	Stat. Significant
Van Somer	June 14 – June 16	69	Before	1.7	36.4	0.0041	1.62×10^{4}	Yes
			After	1.7	50	0.0030		
Davis North	May 19 – May 28	692	Before	2.4	1.6	0.0089	2.89×10^{-36}	Yes
			After	2.6	38.1	0.0015		
Bruin	May 29 – June 1	305	Before	2.9	1.8	0.0410	6.77×10^{-28}	Yes
			After	2.1	30.9	0.0049		
Collins	June 2 – June 4	294	Before	3.0	5.2	0.0211	7.64×10^{-25}	Yes
			After	2.1	8.7	0.0026		

In all cases the p-value was less than the alpha test values, therefore we can reject the null hypotheses and accept that there is a significant difference in the data from before and after the application of tillage on the given beaches. However, the inclusion of the total precipitation preceding and following the tillage dates also tells a large reason for the T-test result and why it is difficult to constrain the results. At Van Somer, the average TSP concentration values before and after were small, and there was quite a bit of precipitation that preceded the tillage and even more in the 14 days following. With Davis North, some of the most active periods of dust events occurred while tilling was taking place and could not be analyzed. At Davis North and Bruin, there was a very large difference between the amount of precipitation before and after tilling, which alone would have helped reduced fugitive dust emissions. At first glance of the results from Collins, it does seem as though the mitigation efforts worked, as there was a decrease in the average TSP concentrations for 14 days following tilling. However, tillage of the beach at Collins took place over three days (June 2 – June 4), from the weather station data we know on one of those days 20 mm of rain was recorded. This fact, not shown in the data, could have been an important contributing factor to the reduction in TSP concentration.

Looking back to 2014 (Tilson, 2016), half of the examined beaches saw increases in TSP concentration following the tillage; it was also noted that some sites tended to "dry out" immediately following the application. This leads to a resumption of fugitive dust emissions at the same threshold speed as previously reported at the site (Tilson, 2016).

For a better analysis, a less dramatic difference in precipitation between the periods before and after the beaches are tilled is needed.

3.3.4.2 Irrigation

Irrigation was applied to the beaches at Middle Creek North and Tsay Keh. Irrigation start and end dates were recorded and dust data for the 14 days preceding irrigation was compared to dust data from 14 days following the commencement of irrigation. The analysis was completed for Tsay Keh Beach only, as the roll-out of the irrigation program began at roughly the same time as the weather station and E-Samplers were setup at Middle Creek North. As with tillage, the main driver for this analysis is to determine if irrigation is an effective mitigation solution for the treated 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 14 days before the start of the application of irrigation on a given beach to those collected for 14 days following the commencement of irrigation.

The data presented in Table 9 analyzes the frequency and magnitude of a dust event both before and while irrigation was applied to Tsay Keh Beach.

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

Beach	Start of Irriga-tion	Area Irrigated (ha)	Before/ During	Avg Wind Speed (m/s)	Total Precip. (mm)	Avg TSP Concentration (mg/m^3)	T Test P-value	Stat. Signi-ficant
TK Beach	May 29	262	Before	2.9	1.8	0.0117	4.99×10^{-25}	Yes
			During	2.1	33.2	0.0046		

The p-value for the data from Tsay Keh Beach was less than the alpha test value; therefore we can reject the null hypotheses and accept that there is a significant difference in the data collected before and during irrigation. As seen with the results from the tillage analysis, the results are confounded, as there was a difference in the amount of precipitation between the two groups of data (before and during). Ideally, a clearer result would have been had if there were similar levels of participation between the periods prior to and following the start of irrigation.

3.3.5 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 13 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 nine E-Samplers from moderate to highly erodible sites.

Most sites had a mean value of similar magnitude (0.20 – 0.23 mg/m^3) with some notable outliers. The most notable outliers ranged from 0.39 to 0.55 mg/m^3 and included highly erosive beach sites: Collins, Bruin and the sites at Middle Creek North. Sites with an average TSP below 0.20 mg/m^3 include the non-erosive sites at TK Town, Ingenika Point and 83 km, but also included the moderately erodible TK Beach.

Sites located near or on moderate to highly erodible locations had an overall average TSP concentration during the dust season, 0.427 mg/m^3, more than twice the concentration of non-erosive sites, 0.188 mg/m^3.

Non-erosive beach sites had TSP values below 0.2 mg/m^3 (Table 11) with the exception of Chowika that had a value (0.227 mg/m^3) similar to other erodible sites.

The highest recorded TSP values in 2018 were all at Middle Creek North. These maximum values were the highest values since 2014 when the E-Samplers were first deployed around the reservoir. The maximum TSP values were 8.46, 8.85, and 7.78 mg/m^3, at MCN-N, MCN-M, and MCN-S, respectively. Averaging these into one value for Middle Creek North results in a TSP value of 8.36 mg/m^3. While the sites at Middle Creek North may have had additional readings slightly below the values above in 2018, only a comparison of seasonal maximum values for all sites is being examined. These Middle Creek North values eclipse the next highest maximum TSP value recorded at a site on the reservoir. In 2014, a former beach site (no longer accessible) at 35 km (on the Chunamon forest service road) reported a TSP value of 5.98 mg/m^3 (Tilson, 2015). The next highest maximum TSP value for 2018 was at Bruin with 4.00 mg/m^3. That value is also the third-highest seasonal maximum TSP value for a site since the dust season of 2014 (Tilson, 2015-2017; Phaneuf & Tilson 2018).

Table 10: Basic descriptive statistics for TSP concentrations (mg/m³) from all 13 regional E-Sampler monitoring sites (calculated from 5-minute averaged data during dust events).

	TK Town	TK Beach	Van Somer	Chowika	MCN-N	MCN-M	MCN-S	Davis North	Bruin	Collins	Ingenika Point	83 km	57 km
Mean	0.1655	0.1713	0.2046	0.2272	0.3896	0.4451	0.546	0.2206	0.394	0.4183	0.1671	0.1925	0.2027
Min.	0.1	0.1	0.1	0.101	0.1	0.1	0.1	0.1	0.1	0.101	0.1	0.101	0.1
Max.	0.45	0.368	1.043	0.995	8.46	8.85	7.779	0.542	3.997	2.421	0.291	0.502	1.206
Std. Dev.	0.0624	0.0584	0.1217	0.1731	0.6391	0.6719	0.6657	0.1171	0.565	0.4222	0.0495	0.0984	0.1376
Var.	0.0039	0.0034	0.0148	0.03	0.4084	0.4515	0.4432	0.0137	0.3192	0.1783	0.0025	0.0097	0.0189

Table 11: Basic descriptive statistics for TSP concentrations (mg/m³) from four non-erosive regional E-Sampler monitoring sites (calculated from 5-minute averaged data during dust events).

	Tsay Keh Town	Chowika	Ingenika Point	83 km
Mean	0.1655	0.2272	0.1671	0.1925
Minimum	0.1	0.101	0.1	0.101
Maximum	0.45	0.995	0.291	0.502
Standard Deviation	0.0624	0.1731	0.0495	0.0984
Variance	0.0039	0.03	0.0025	0.0097

Table 12: Basic descriptive statistics for TSP concentrations (mg/m³) from nine moderate- to highly-erodible regional E-Sampler monitoring sites (calculated from 5-minute averaged data during dust events).

	TK Beach	Van Somer	MCN-N	MCN-M	MCN-S	Davis North	Bruin	Collins	57 km
Mean	0.1713	0.2046	0.3896	0.4451	0.546	0.2206	0.394	0.4183	0.2027
Minimum	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.101	0.1
Maximum	0.368	1.043	8.46	8.85	7.779	0.542	3.997	2.421	1.206
Std. Dev.	0.0584	0.1217	0.6391	0.6719	0.6657	0.1171	0.565	0.4222	0.1376
Variance	0.0034	0.0148	0.4084	0.4515	0.4432	0.0137	0.3192	0.1783	0.0189

3.3.6 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). For our analysis of variance, we have selected a confidence interval of 99%, which means that our alpha value against which to test our p-value is 0.01.

3.3.6.1 ANOVA Between All E-Samplers

The following analysis is based on a one-way ANOVA used to examine the 13 E-Sampler datasets for significant differences in dust concentration data between site locations. This approach will allow 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:

> **H_0**: There is no significant difference in the mean dust concentration between all 13 E-Sampler instrument locations.

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

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F	p-value
Groups	77.74	12	6.4787	18.8425	8.9206×10^{-41}
Error	2.0166×10^{3}	5865	0.3438		
Total	2.0943×10^{3}	5877			

As p = 8.9206×10^{-41} and is than 0.01, we may reject the null hypothesis at a 99% confidence interval. Therefore the mean dust concentration between the E-Sampler monitoring sites is significantly different. This means that there are sites within the dataset that contain mean dust concentrations that are significantly different than the rest. In order to evaluate which samplers are driving this significance, we create a box and whisker plot of the ANOVA data, shown in Figure 20. It is clear that the significant difference is driven by the presence of very strong outliers at the Middle Creek North sites (MCN-N, MCN-M and MCN-S) and strong outliers at Bruin and Collins sites. These sites are all beach sites that are located in erodible, emissive zones. This means in 2018 these beaches had many instances where the dust concentrations were significantly higher than the other regional sites. This indicates that dust concentrations are significantly higher in the areas that are close to erosive zones than those sites that are not located near to erosive zones. However, some sites such as Van Somer and 57 km are not driving the significance but they do contain outlier values that are slightly greater than 1.0 mg/m^3. As is expected sites such as Chowika, Ingenika and 83 km report values that are significantly smaller than the remainder of the dataset as well as fewer outliers. It should be noted that erodible beach sites like Tsay Keh Beach has very little outliers and Davis North doesn't seem to have any.

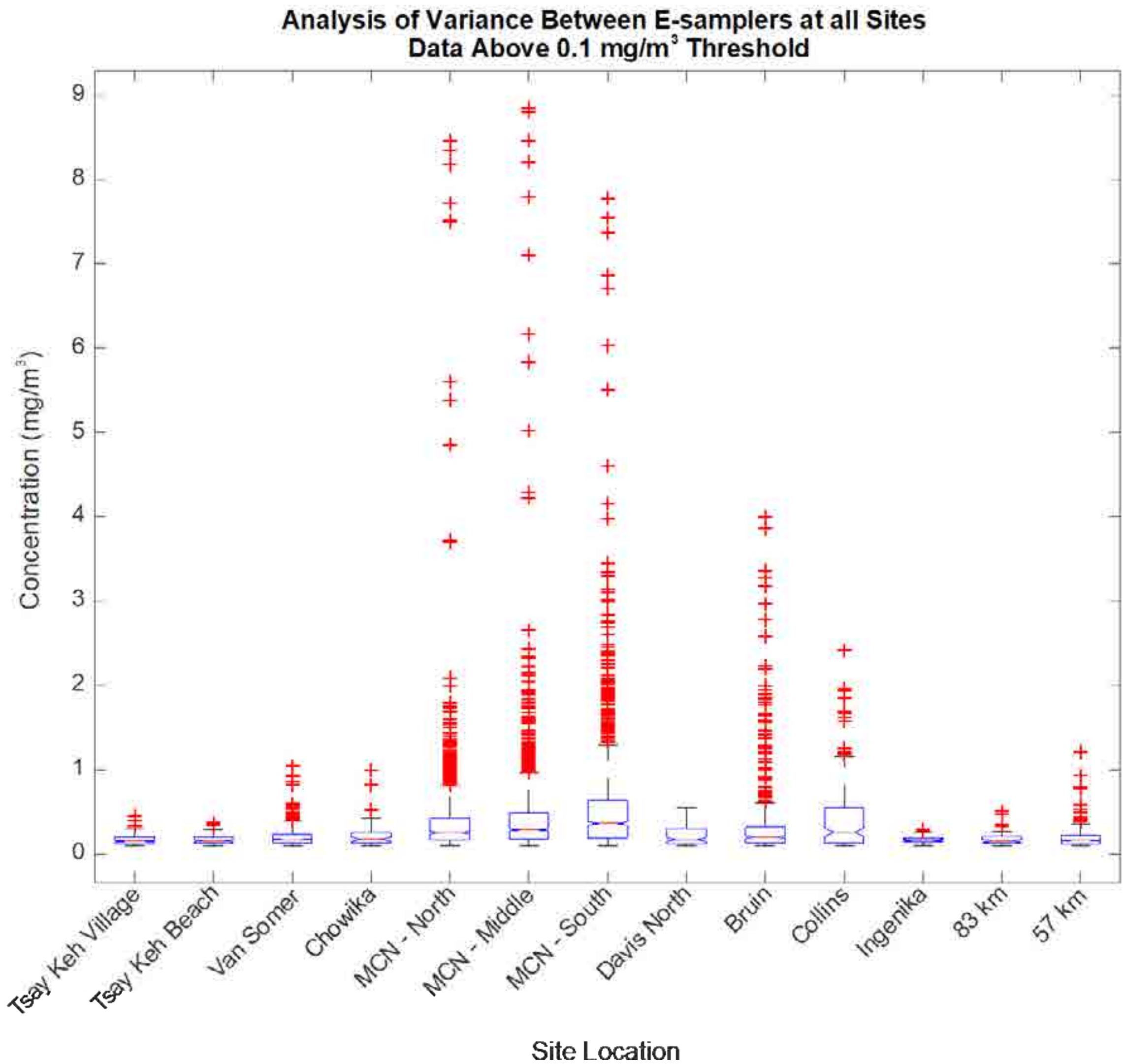

Figure 20: ANOVA box and whisker plot for entire 13 E-Sampler dataset.

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

Since significant differences in mean dust event concentrations were identified above in section 3.3.6.1, it is 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. These data have divided the data into these two groups for the following ANOVA. The first group is the Non-Erosive group and 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	0.1445	3	0.0482	5.2139	0.0017
Error	2.3008	249	0.0092		
Total	2.4453	252			

As p = 0.0017 and is less than 0.01 we may reject the null hypothesis at a 99% confidence interval. Therefore the mean dust concentration values between the E-Samplers located at non-erosive sites are significantly different at the 99% confidence interval. Figure 21 below shows the box and whisker plot for the ANOVA at non-erosive sites. The only big surprise is that Chowika appeared to have some intense outliers for a site in a non-erosive zone.

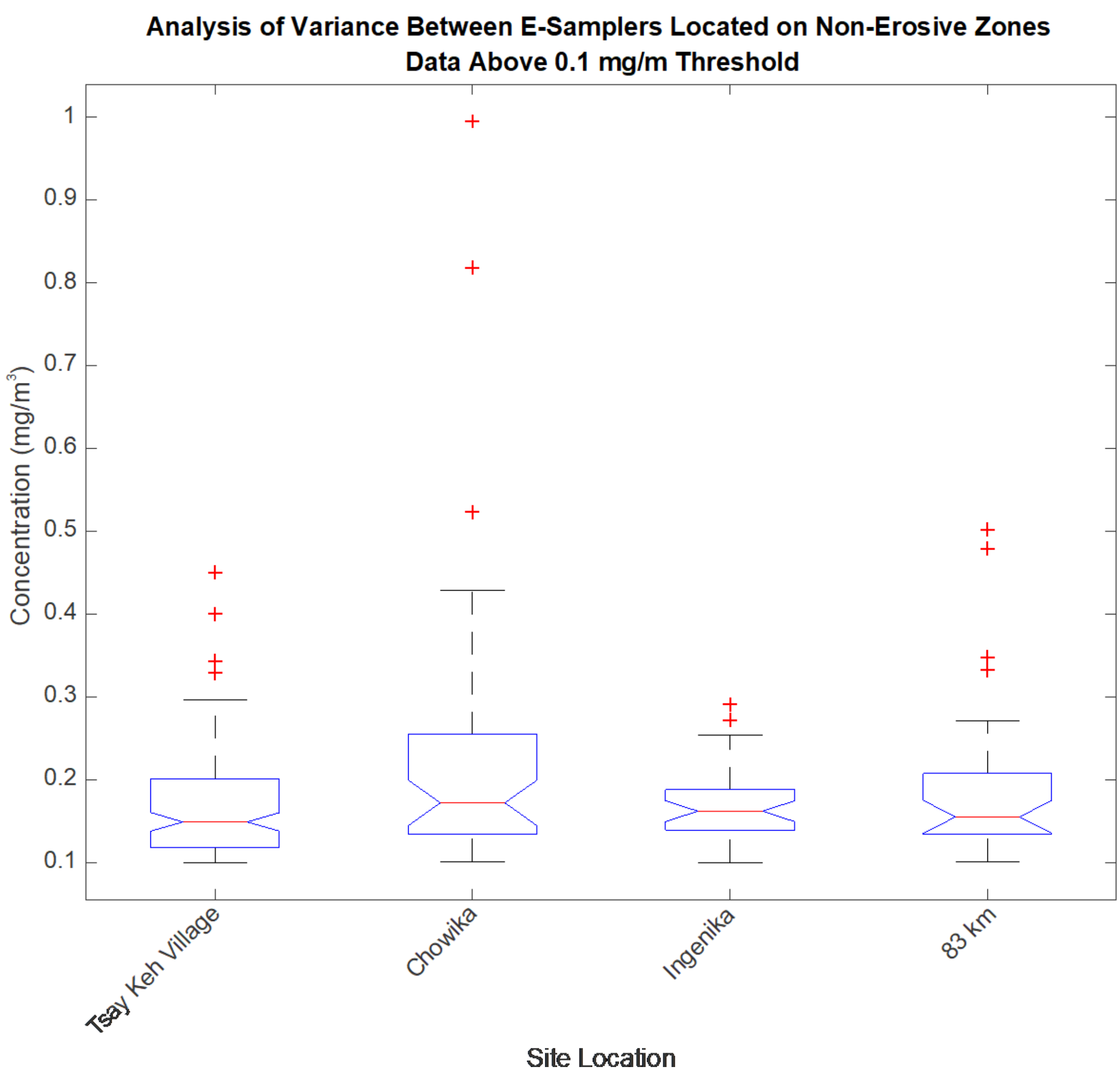

Figure 21: ANOVA box and whisker plot for E-Sampler data from non-erosive sites.

3.3.6.3 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 erodible zones surrounding the reservoir. These include the sites at Middle Creek North, Collins 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	63.81	8	7.9767	22.2397	1.0220×10^{-33}
Error	2.0143×10^{3}	5616	0.3587		
Total	2.0781×10^{3}	5624			

As $p = 1.0220\times10^{-33} < 0.01$ we may reject the null hypothesis at a 99% confidence interval. Therefore there are significant differences in dust concentration values between E-Samplers located in moderate to highly erosive zones. Figure 22 below shows the box and whisker plot for the ANOVA at moderate to highly erodible sites. The highest dust readings were recorded at the Middle Creek North Davis sites in 2018 and these values were significantly higher than many of the other erosive sites with this value being driven by the relatively very high outlier values. Bruin and Collins beaches were the locations that recorded the next highest averages with Bruin having many outliers with high dust concentrations. One site, Davis North, which regularly recorded high values in previous years did not record high dust concentrations in 2018. The only other year since 2014 where Davis North posted similar results was 2015. Van Somer and 57 km, while experiencing many dust events, don't usually have seasons with very intense storms with as many outliers seen at other erodible zones.

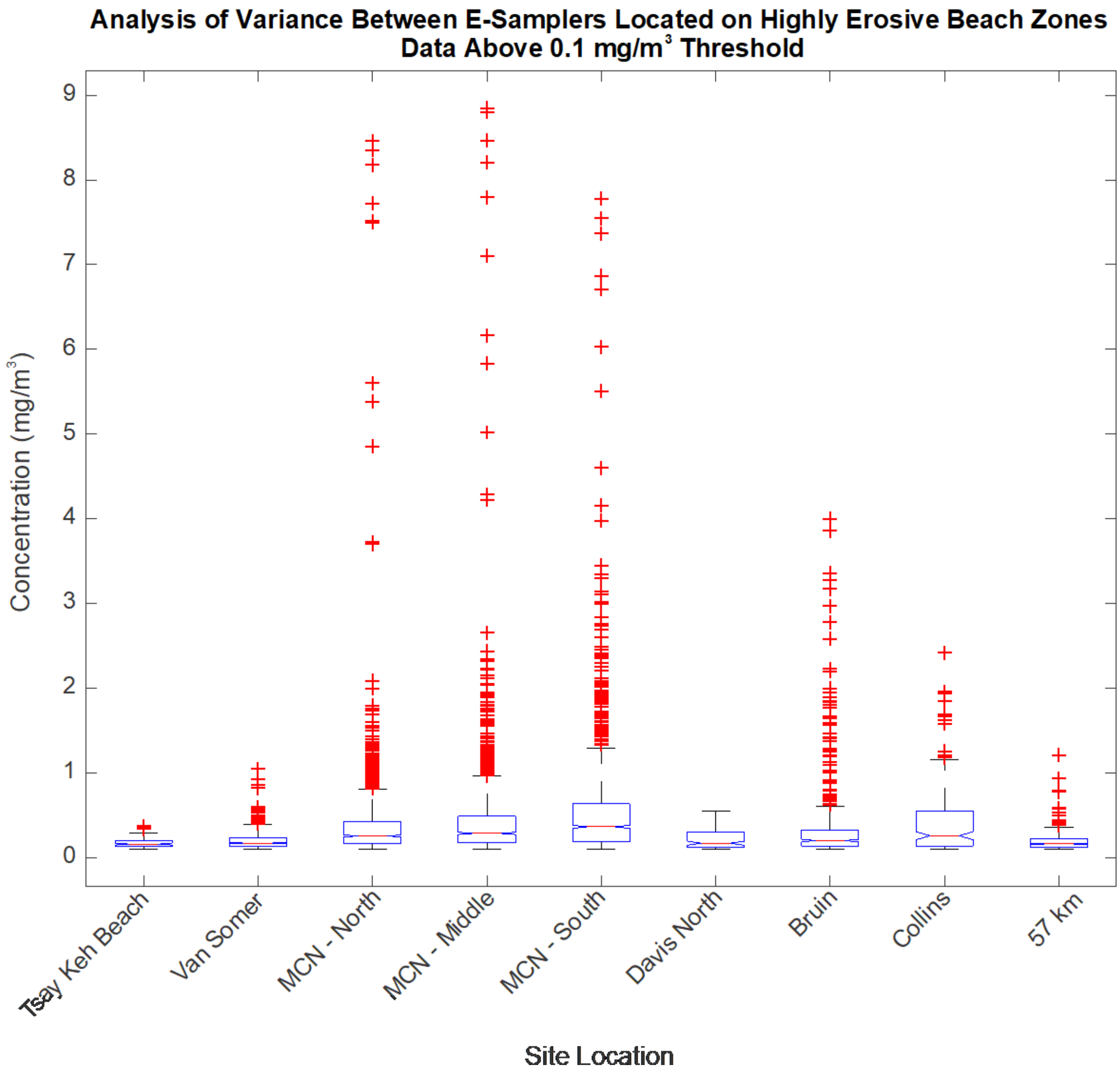

Figure 22: ANOVA box and whisker plot for E-Sampler Data from moderate to highly erodible sites.

3.3.7 Wildfires and Air Quality

Wildfire smoke emitted into the atmosphere is made up of particulate matter. This particulate matter like the dust ejected from the reservoir beaches can be recorded by the TEOM in Tsay Keh and E-Samplers positioned around reservoir. The active wildfire seasons experienced in British Columbia in 2017 and 2018 illustrated that the smoke from very large wildfires can be transported hundreds of kilometres downwind and cause air quality concerns. During 2018, there were no "wildfires of note" that occurred within dust season anywhere in BC (BC Wildfire Service, 2019).

NETWORK COMPONENT II: REFERENCE MONITORING

4.0 Reference Monitoring

4.1 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 (CCME 2011). Generally, for CAAQS reporting there should be 1 particulate sampler for every 250,000 people and the sampler should be placed between 6 – 8 km apart or should have a distribution that is dependent on the distance between the CMA and the major 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 MoE, 2018). The suite of criteria that are applicable to this report include the Provincial Ambient Air Quality Objectives (AQOs), the CAAQS and the National Ambient Air Quality Objectives for Air Contaminants (NAAQOs). Those that are relevant to this project can be found in Table 16.

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

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

4.2 GMSMON#18 Air Monitoring Characterization

The reference monitoring station managed by Chu Cho Environmental in Tsay Keh Dene meets or exceeds the above criteria as it consists of a major monitoring station in a village with less than 400 people. 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 is sited away from any structures or other impediments to airflow that might bias the sample. Our reference monitoring station technically does not meet the standards for CAAQS reporting as well as Special Studies (British Columbia Air Protection Section Environmental Quality Branch, 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 dust events are generated by southeasterly winds blowing over the reservoir. The valley is approximately 10 km wide at Tsay

Keh Dene. Figure 2 on page 14 shows the Tsay Keh Dene monitoring station outfitted with an E-Sampler, hygrometer/thermistor (humidity and temperature sensor), barometric pressure sensor, rain gauge, and an anemometer (wind speed and direction monitor).

4.2.1 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. In order 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 1Hz 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.

We will, however, evaluate the data collected by these instruments within the context of the CAAQS and the Provincial AQOs by simply 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.

4.2.2 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:
  - In order 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 with respect to the oscillating microbalance but also for the flow controllers and auxiliary instrumentation.
  - In order 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 and verified 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 from April to June or what is typically 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.
  - As 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.

4.2.3 Methodology

In order 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 MoE, 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 properly, 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 properly 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.

In addition to the standard maintenance routines required to ensure data validity, there are several long-cycle routines associated with the physical TEOM components that suffer wear-and-tear. These items include the air pump (18 – 24 months) and several of the onboard sensors, which monitor airflow or temperature for example.

After each visit to the TEOM station, our team 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 have managed to achieve a very high standard for data quality with only four data outages 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.

4.3 Reference Monitoring Network Data Overview

For this report, we will analyze the 2018 datasets collected at Tsay Keh Dene from January 1, 2018, through to and including December 31, 2018.

4.3.1 Tsay Keh Dene Monitoring Station Meteorology and 24-Hour Average Air Quality Characterization

Figure 23 (a) through (d) shows plots of the 24-hour average air quality and meteorology data recorded at the Tsay Keh Dene monitoring station during 2018.

4.3.1.1 Meteorology

The right mix of weather conditions can either enhance or temper the impacts of fugitive dust emissions from the beaches of the Williston Reservoir. One of these variables is the wind, which can lead to desiccation (drying) of sediments but also saltation and ejection of fine and very fine dust particles from the reservoir beaches. The daily average wind speeds have been comparable to previous years, roughly 1.6 m/s. 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 were about the same as 2014 and 2016, with 2017 being cooler and 2015 warmer than 2018; though, the first half of May did appear to be unseasonable warm during the day. Rainfall helps replenish moisture on the beaches, which helps prevent the ejection of the finer materials. One of the anomalies of the 2018 dust season was the amount of rainfall. From 2014 onwards, 2018 was second only to 2017 in the amount of rain that fell during the dust season; the underlying aspect is the vast majority of it fell in June (Figure 23 d). Only 5 mm of rain fell in May, with more than half (2.7 mm) falling on May 31; compared to June that saw 79.7 mm, roughly two to three times the amount of previous years. Also, seen in Figure 23 d, April 2018 saw very little rainfall as well. The lack of precipitation coupled with the other anomaly, low reservoir levels, set the conditions for a very active dust season in 2018.

4.3.1.2 24-Hour Average Dust Concentrations

The dust season of 2018, was unlike any previous dust season going back to when the TEOM was installed in 2012. In Table 17, if we look from May 7 to July 13, there were 13 times when $PM_{2.5}$ exceeded the 24-hour federal CAAQS for $PM_{2.5}$ and 8 times when PM_{10} exceeded the 24-hour provincial AQO for PM_{10} (Figure 23 a, Table 17). Figure 23 helps at illustrating the duration and intensity of the $PM_{2.5}$ and PM_{10} exceedance (of CAAQS and BC AQO) during the month of May, compared to the dramatic cessation of exceedance for $PM_{2.5}$ and PM_{10} with the arrival of rain to the area.

Both Figure 23 a and Table 17 also show a number of $PM_{2.5}$ and PM_{10} exceedance dates in late August. This was also during a time of some of the worst wildfires British Columbia had ever experienced. The reservoir at this time was still, relative to the time of year (and as previously mentioned at levels well within the dust season of previous years), we cannot be certain as to the origin of the particulates recorded. Rainfall was recorded at the same time $PM_{2.5}$ and PM_{10} fell back below exceedance levels (Figure 23 d) but rain would have both the same positive impact on air quality, regardless of source (fugitive dust or forest fire smoke).

Table 18 compares the CAAQS and AQO exceedances dating back to 2012. For $PM_{2.5}$, the dust season of 2017 had just one exceedance of the 24-hour CAAQS, there were two during the season in 2016, and no exceedances from 2012 to 2015 (Table 18). Looking back at the British Columbia 24-hour AQO for PM_{10}, there was also only one exceedance in 2017, five in 2016, one in 2015, two in 2014, and none in either 2013 or 2012.

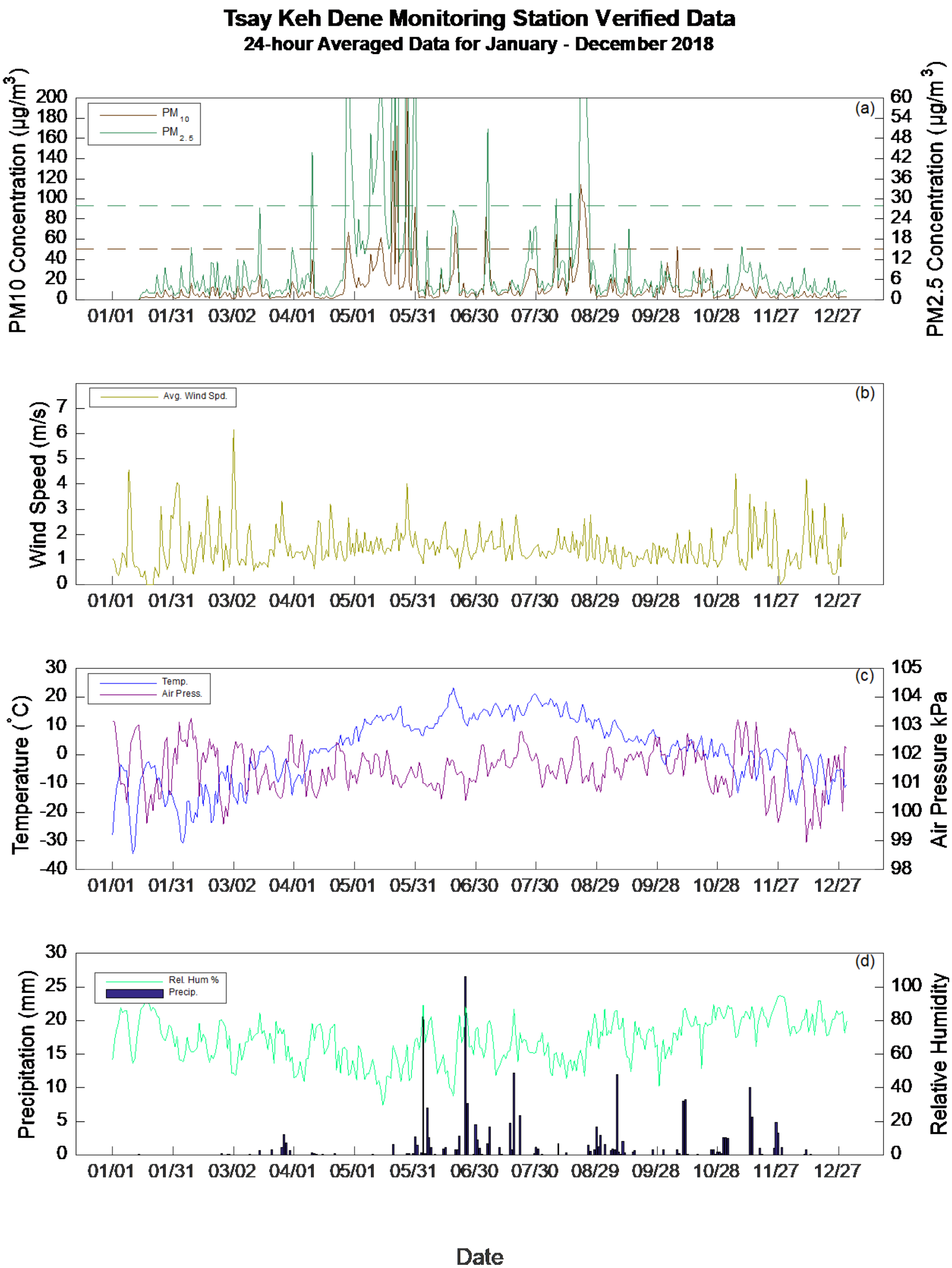

Figure 23: 2018 Tsay Keh Dene air quality monitoring station data - 24-hour averaged data. Exceedance standards in (a) for $PM_{2.5}$, 28 µg/m³ (CAAQS), and PM_{10}, 50 µg/m³ (AQO) are illustrated by the colour coded horizontal dashed lines.

Table 17: 2018 24-hour averaged 2018 $PM_{2.5}$ and PM_{10} values that were above the CAAQS and provincial AQO.

Date	$PM_{2.5}$ Value (µg/m³)	Date	PM_{10} Value (µg/m³)
10-Apr-2018	44.0 (dust)	**27-Apr-2018**	51.3 (dust)
27-Apr-2018	65.0 (dust)	**28-Apr-2018**	66.7 (dust)
28-Apr-2018	73.3 (dust)	**13-May-2018**	51.4 (dust)
29-Apr-2018	48.4 (dust)	**14-May-2018**	61.5 (dust)
30-Apr-2018	35.0 (dust)	**20-May-2018**	157.7 (dust)
09-May-2018	49.6 (dust)	**22-May-2018**	172.8 (dust)
10-May-2018	31.3 (dust)	**27-May-2018**	208.4 (dust)
11-May-2018	35.1 (dust)	**31-May-2018**	92.1 (dust)
12-May-2018	40.7 (dust)	**20-Jun-2018**	72.3 (dust)
13-May-2018	56.6 (dust)	**05-Jul-2018**	81.8 (dust)
14-May-2018	67.8 (dust)	**09-Aug-2018**	65.1
15-May-2018	52.3 (dust)	**21-Aug-2018**	114.6
20-May-2018	173.2 (dust)	**22-Aug-2018**	98.5
22-May-2018	181.5 (dust)	**23-Aug-2018**	96.0
27-May-2018	229.9 (dust)	**24-Aug-2018**	69.7
30-May-2018	48.9 (dust)	**08-Oct-2018**	52.7
31-May-2018	101.8 (dust)		
06-Jul-2018	50.8 (dust)		
09-Aug-2018	30.1		
16-Aug-2018	31.7		
21-Aug-2018	68.9		
22-Aug-2018	101.6		
23-Aug-2018	82.8		
24-Aug-2018	59.4		
25-Aug-2018	43.3		

Table 18: Annual Tsay Keh TEOM 24-hour exceedences for PM2.5 and PM10 from 2014-2018.

Year	$PM_{2.5}$ ($\mu g/m^3$)			PM_{10} ($\mu g/m^3$)		
	# of Exceedances	Average Value	Maximum Value	# of Exceedances	Average	Maximum
2018	13	86.12	229.86	8	112.26	208.38
2017	1	40.38	40.38	1	59.04	59.04
2016	2	37.88	44.27	5	149.51	401.49
2015	0	-	-	1	62.42	62.42
2014	0	-	-	2	271.35	279.70
2013	0	-	0	0	-	-
2012	0	-	-	0	-	-

4.3.2 Maximum Particulate Concentrations

Although there were many $PM_{2.5}$ and PM_{10} exceedance events during the 2018 dust season (May 7 to July 13), using the 24-hour metric for reporting air quality still does not adequately represent the mode of air quality issues in Tsay Keh Dene because 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 will evaluate the maximum value recorded for $PM_{2.5}$ and PM_{10} concentrations during the 2018 dust season. ***To be explicitly clear, the following analysis is in no way meant to be compared to the Federal and Provincial air quality standards or objectives and the reference values are merely presented on the following figures in order to provide relative context. This analysis also does not make any health or health-risk claims associated with the data presented below.***

Table 19 and Figure 24 show the unfiltered 10-minute average $PM_{2.5}$ and PM_{10} data recorded by the Tsay Keh Dene TEOM 1405-D during the 2018 dust season. Note that 10-minute averaged data from the TEOM 1405-D is the smallest recordable increment that the instrument outputs. The black dashed line in Figure 24 (a) represents an arbitrary reference value for $PM_{2.5}$ of 28 $\mu g/m^3$, while the black dashed line in Figure 24 (b) represents an arbitrary reference value for PM_{10} of 50 $\mu g/m^3$. These values are provided for reference only and are in no way meant to represent the federal or provincial air quality standards/objectives.

From about May 8 to June 1, 2018, there were daily spikes of varying duration and intensity that represent large volumes of particulate entering the airspace around the TEOM 1405-D. The very high-intensity spikes are visible in Figure 24 (a) and (b) from May 20 to May 31, and represent extraordinary levels of fine (PM_{10}) and very fine ($PM_{2.5}$) dust particulates from the raw un-processed 10-minute average TEOM 1405-D PM_{10} and $PM_{2.5}$ data. These events were also seen a couple of times early in June and a few events in the second half of June with a few more instances in early July (Figure 24).

To demonstrate the high frequency and in some cases high-intensity events that impact Tsay Keh Dene, the daily maximum value has been extracted from the TEOM dataset for each day where one 10-minute average value was above the arbitrary reference values of 50 μg/m^3 for PM_{10} and 28 μg/m^3 for $PM_{2.5}$. These data are shown in Table 19.

Table 19: Maximum 10-minute averaged $PM_{2.5}$ and PM_{10} values recorded during the 2018 dust season in Tsay Keh Dene.

Date	$PM_{2.5}$ Value (μg/m^3)	Date	PM_{10} Value (μg/m^3)
07-May-2018	33.74	**08-May-2018**	78.6
08-May-2018	87.3	**09-May-2018**	97.6
09-May-2018	107.0	**10-May-2018**	55.0
10-May-2018	61.5	**11-May-2018**	57.0
11-May-2018	62.7	**12-May-2018**	62.5
12-May-2018	69.1	**13-May-2018**	125.7
13-May-2018	138.2	**14-May-2018**	134.0
14-May-2018	147.2	**15-May-2018**	99.5
15-May-2018	109.7	**16-May-2018**	80.3
16-May-2018	88.7	**17-May-2018**	76.2
17-May-2018	83.7	**19-May-2018**	55.6
18-May-2018	40.2	**20-May-2018**	910.0
19-May-2018	60.5	**21-May-2018**	105.1
20-May-2018	1002.0	**22-May-2018**	898.0
21-May-2018	115.4	**25-May-2018**	88.3
22-May-2018	991.0	**26-May-2018**	112.1
23-May-2018	32.1	**27-May-2018**	597.9

Date	$PM_{2.5}$ Value (µg/m^3)	Date	PM_{10} Value (µg/m^3)
24-May-2018	49.4	**28-May-2018**	270.7
25-May-2018	96.7	**30-May-2018**	332.5
26-May-2018	123	**31-May-2018**	684.8
27-May-2018	659.9	**01-Jun-2018**	88.5
28-May-2018	298.7	**06-Jun-2018**	307.7
29-May-2018	43.39	**13-Jun-2018**	182.4
30-May-2018	365.3	**14-Jun-2018**	65.91
31-May-2018	761.0	**17-Jun-2018**	67.06
01-Jun-2018	97.6	**18-Jun-2018**	234.3
06-Jun-2018	341.8	**19-Jun-2018**	245.9
13-Jun-2018	30.5	**20-Jun-2018**	286.6
18-Jun-2018	248.8	**21-Jun-2018**	347.6
19-Jun-2018	248.7	**24-Jun-2018**	74.91
20-Jun-2018	237.9	**02-Jul-2018**	58.8
21-Jun-2018	272.5	**03-Jul-2018**	77.7
05-Jul-2018	45.72	**05-Jul-2018**	438.2
06-Jul-2018	677.3	**06-Jul-2018**	613.0
		07-Jul-2018	250.0

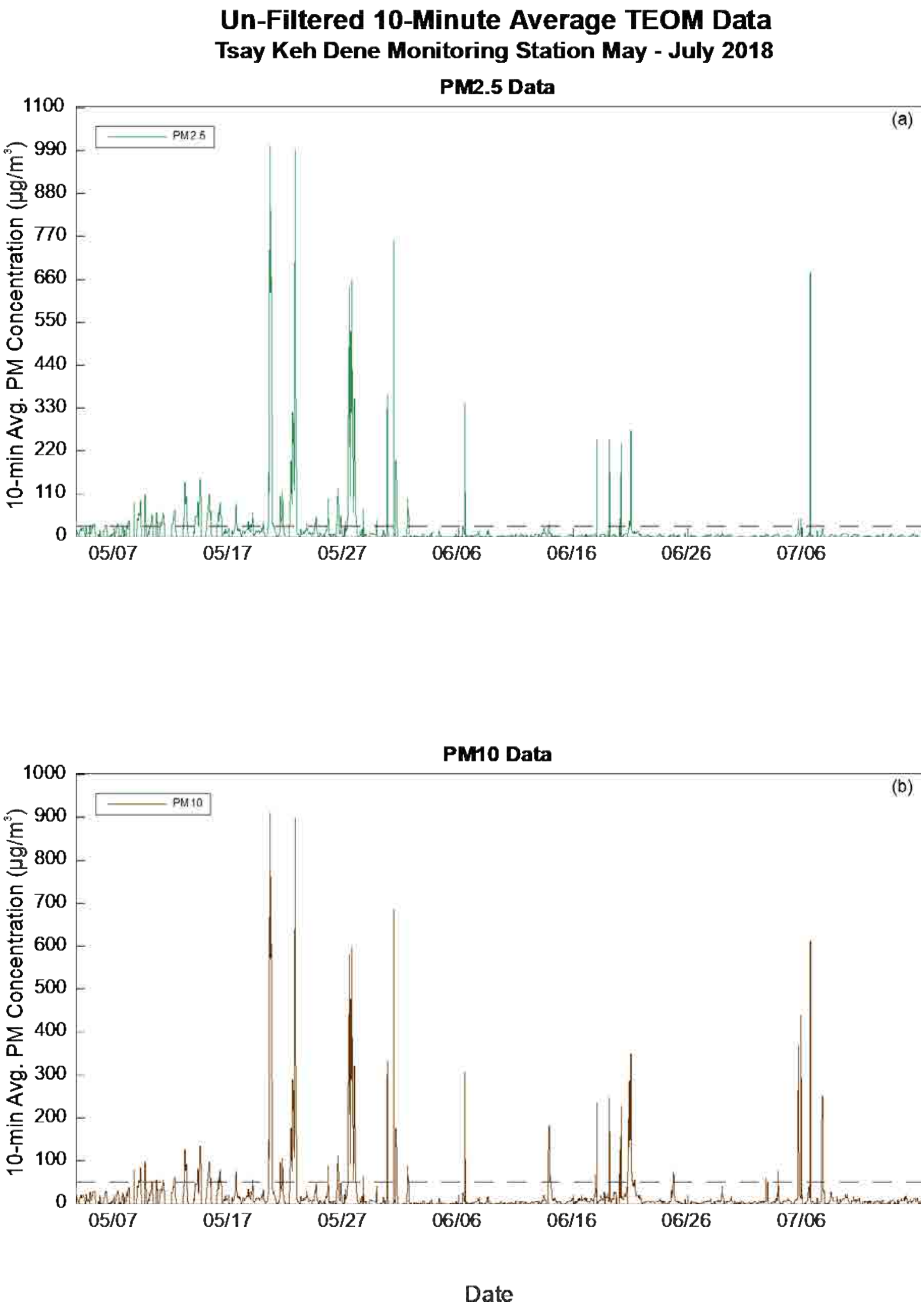

Figure 24: Raw 10-minute averaged TEOM data for the 2018 dust season. Horizontal dashed lines represent an arbitrary reference value.

5.0 Ancillary Objectives

In addition to providing the management services required to operate the air quality monitoring systems, Chu Cho Environmental built a program centred on capacity building, knowledge transfer and community engagement. This program is focused on mentorship and skills development within Tsay Keh Dene band members and is also meant to provide a link between community members and the science of the Williston Dust Mitigation Program.

5.1 Mentorship Program

In our mentorship program, we utilize a process of employee self-evaluation and management evaluation of employees to monitor metrics in the form of Key Performance Indicators (KPIs) such that each employee can track their success and growth as an environmental monitor and in particular an air quality technician. The metrics that we use as guidelines include but are not limited to the following:

- Worker is able to fully download the data and recalibrate the instrument on their own.
- Worker is able to diagnose problems and develop, record and communicate a working solution in the field.
- Worker is able to make, record and communicate management decisions in the field.
- Worker is careful, thoughtful and thorough with regards to scientific issues.
- Worker is always safe.
- Worker always makes unbiased decisions with regards to the scientific process.
- Worker makes good field notes with clear observations and records that are both relevant and important.
- Worker is competent with a field computer for data capture and storage.
- Worker is developing a sense of confidence with regards to the program tasks and knowledge about air quality.
- Worker is sensitive to QA/QC issues and takes great pride and care in ensuring that the instrumentation is always functioning properly and with proper calibration requirements.

We at Chu Cho Environmental recognize that it is our responsibility and commitment to provide an open and communicative work environment in order to cultivate success and growth within our employees. We also utilize a number of non-specific personality metrics in order to evaluate the overall confidence and aptitude growth of our employees. To date we achieved exceptional growth in knowledge and confidence in our employees and we expect continued growth through the final year of this project.

Chu Cho Environmental now has employees in Tsay Keh Dene who are able to autonomously manage the basic maintenance and operation of the Air Quality Monitoring Stations. These employees possess a rudimentary understanding of how the instrument functions and what normal operation should entail. When a major issue is encountered, the employees alert the Chu Cho Environmental project manager immediately and the problem is rectified as soon as possible. Due to the remoteness of the TEOM monitoring station and the difficulty in maintaining a reliable internet connection to the machine, it is imperative to have well trained local employees who can frequently visit the instrumentation to ensure proper operation. This is a valuable part of our program and has contributed to our overall success in reducing instrument downtime.

5.2 Environmental Stewardship

In 2018, Chu Cho Environmental thoroughly tested the deep-cycle batteries used by the GMSMON#18 program over the past 11 years and transported 30 dead or unreliable lead-acid batteries back to Prince George for proper disposal (recycling).

6.0 DISCUSSION

6.1 BRIEF SUMMARY FOR 2018

Overall, we consider 2018 a successful year for the GMSMON#18 project. The team has continued to collect an enormous amount of data. The dust season for 2018, was atypical compared to the previous four years, as only one of these years was "dusty". There were some disappointments in 2018. The freshly calibrated E-Sampler at Davis South did not collect any useful data and existing methods used to report errors (on a weekly timescale) did not catch the error. The E-Samplers at some sites like Ingenika Point and Tsay Keh Beach required multiple swap-outs of batteries, especially at the end of the season, as some batteries would often not provide power through the entire night during prolonged periods of cloudy daytime conditions. E-Sampler power issues should be rectified for 2019 with a better system of identifying and monitoring battery health throughout the year and with the purchase of three pairs of new batteries for 2019.

The primary finding presented somewhat repeatedly throughout this report note that 2018 was a very active year for dust events in the Finlay Reach of the Williston Reservoir. These dust events, defined by both, years of observation on the reservoir (0.100 mg/m^3 TSP) or based on regulatory measures (CAAQS and BC AQO), were more intense and of longer duration than in the four previous years, especially for Middle Creek North beach (regional network) and Tsay Keh Dene (reference station). This very active dust season was a combination of very low reservoir levels and very little rain leading up to for the first few weeks of the season. A sudden drop-off of dust events and exceedance levels was seen at many sites with the arrival of a rain event at the beginning of June and again over the last 10 days in June. This made evaluating the effectiveness of dust mitigation activities very difficult.

There are several areas throughout the reservoir that show regular and repeated incidences of fugitive dust emissions. These locations are the so-called "hot spots" and are likely suitable candidates for erosion control measures and trials of new and alternative mitigation techniques.

6.2 DIRECTION FOR 2019

So far in 2019, the Williston Reservoir elevation has been lower than the elevation from the same date in 2018. For example on January 31, 2019, at 06:25 the reservoir elevation was 660.443 m vs. 662.347 m in 2018. This is may be an indication that 2019 could be another dusty year along the Finlay Reach.

We will continue to strive for more complete data sets. This will be done by identifying and minimizing downtime by attempting to download E-Sampler data on a weekly basis. The recent purchase of new battery pairs should all but eliminate past power issues related to overnight power losses on the select E-Samplers that were unfortunately paired with unreliable batteries.

Chu Cho Environmental LLP and Chu Cho Industries LP are in the same family of companies and are working to developing a closer integration for the 2019 season. In 2018 Chu Cho Industries obtained new dust mitigation equipment for use on reservoir beaches. Chu Chu Environmental will continue to deploy additional resources and research different methods of statistical analysis in an attempt to evaluate the effectiveness of the new equipment.

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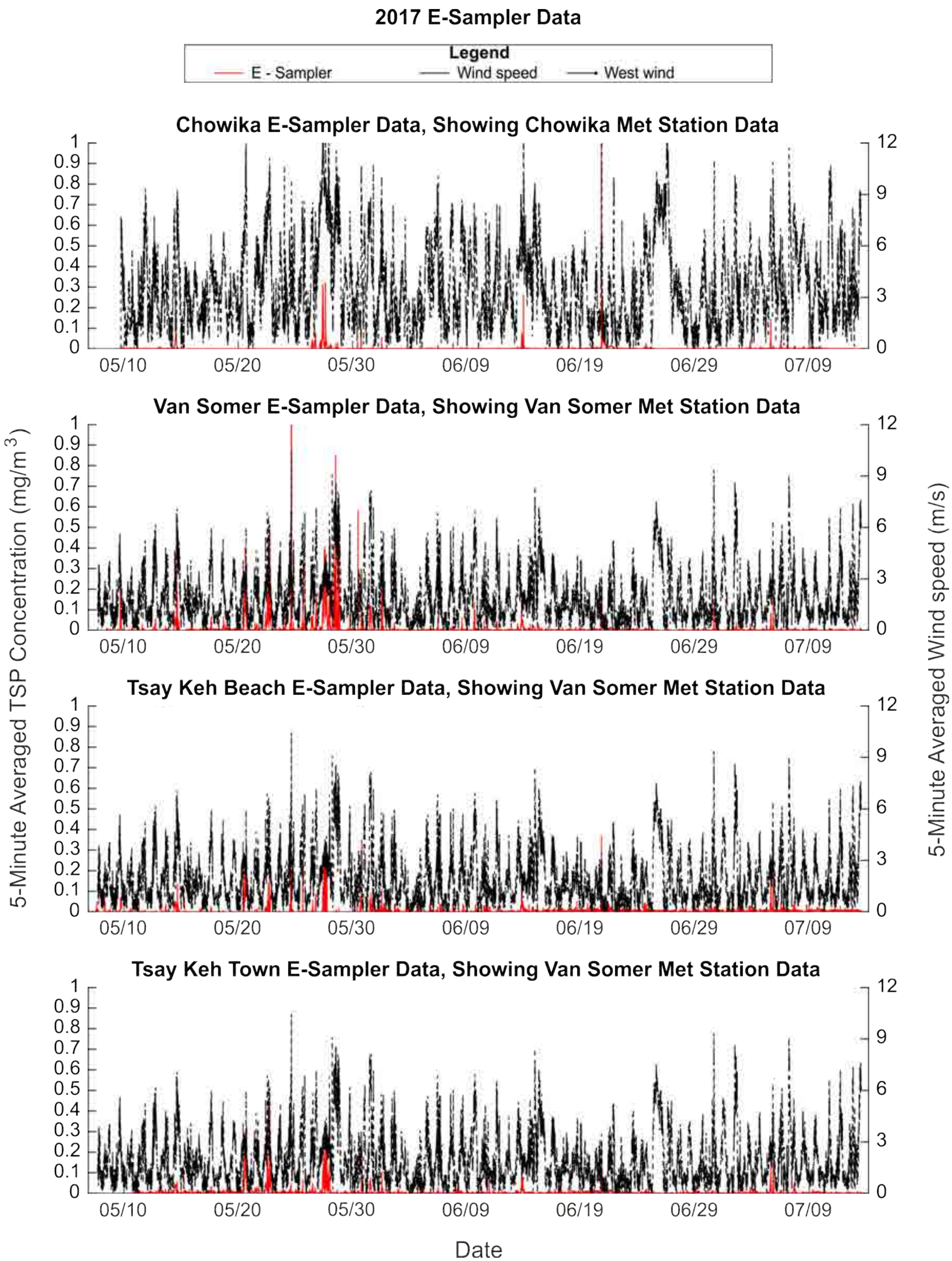
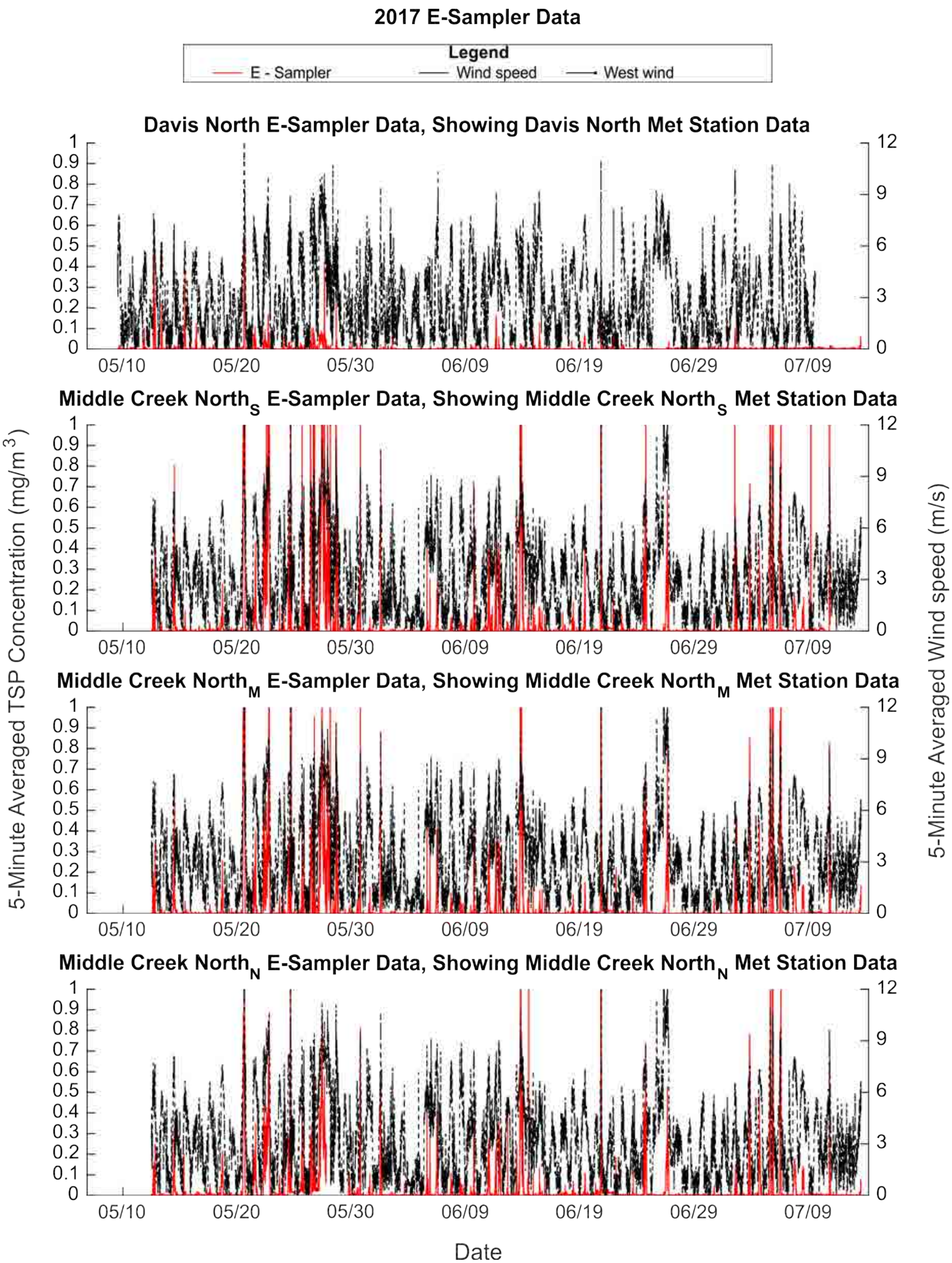
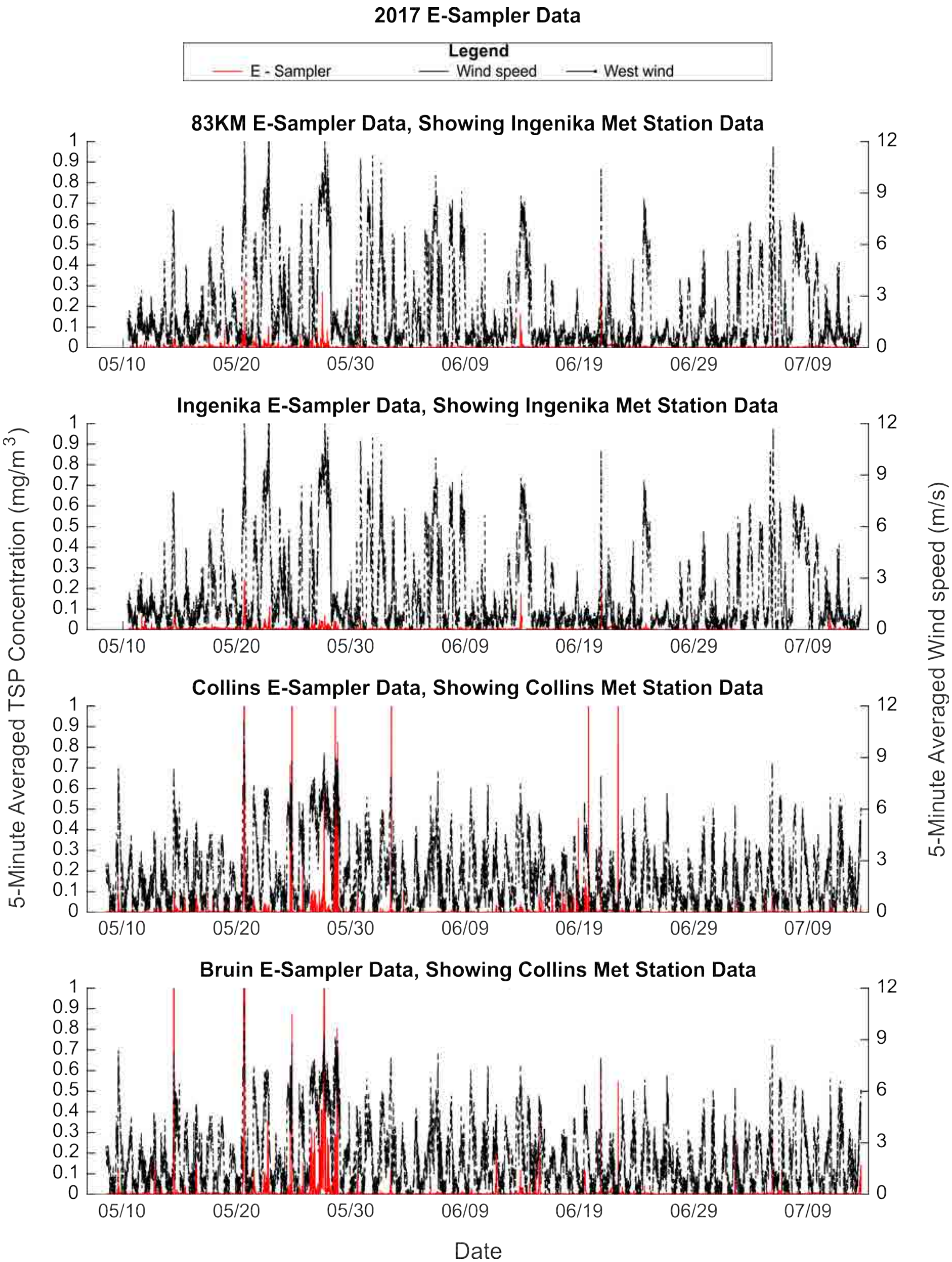
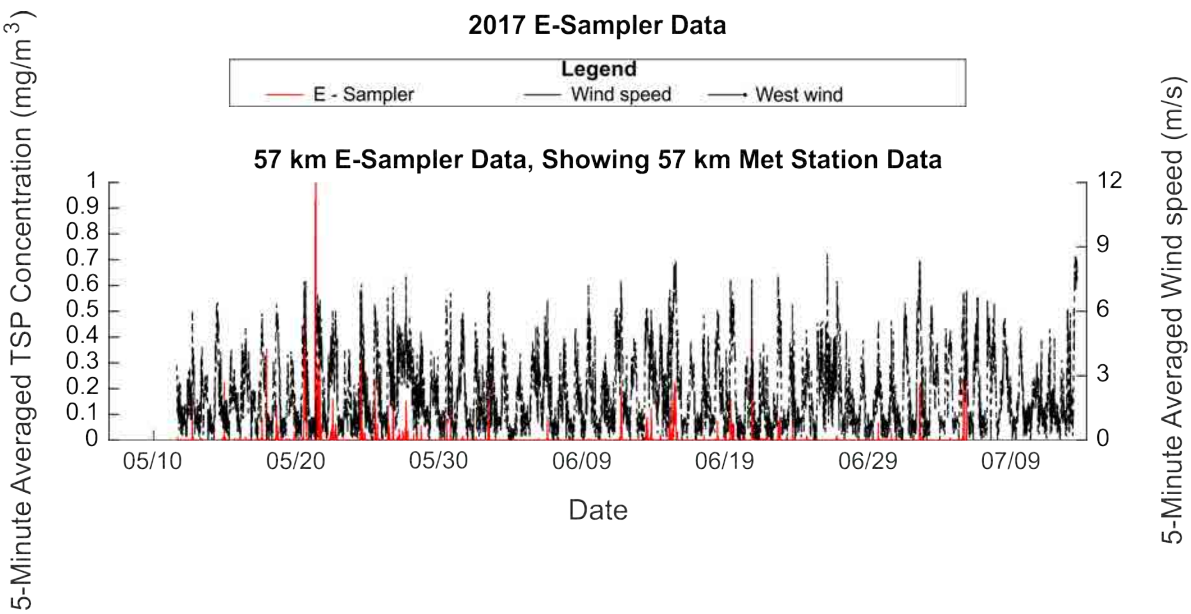
APPENDIX A REGIONAL AIR QUALITY PLOTS: E-SAMPLER DATA OVERLAYED WITH WINDSPEED


2017 E-Sampler Data
Legend
E - Sampler
Wind speed
West wind
Chowika E-Sampler Data, Showing Chowika Met Station Data
Van Somer E-Sampler Data, Showing Van Somer Met Station Data
Tsay Keh Beach E-Sampler Data, Showing Van Somer Met Station Data
Tsay Keh Town E-Sampler Data, Showing Van Somer Met Station Data
5-Minute Averaged TSP Concentration (mg/m3)
5-Minute Averaged Wind speed (m/s)
05/10
05/20
05/30
06/09
06/19
06/29
07/09
Date


2017 E-Sampler Data
Legend
E - Sampler
Wind speed
West wind
Davis North E-Sampler Data, Showing Davis North Met Station Data
Middle Creek North$_S$ E-Sampler Data, Showing Middle Creek North$_S$ Met Station Data
Middle Creek North$_M$ E-Sampler Data, Showing Middle Creek North$_M$ Met Station Data
Middle Creek North$_N$ E-Sampler Data, Showing Middle Creek North$_N$ Met Station Data
5-Minute Averaged TSP Concentration (mg/m^3)
5-Minute Averaged Wind speed (m/s)
05/10
05/20
05/30
06/09
06/19
06/29
07/09
Date


2017 E-Sampler Data
Legend
E - Sampler
Wind speed
West wind
83KM E-Sampler Data, Showing Ingenika Met Station Data
Ingenika E-Sampler Data, Showing Ingenika Met Station Data
Collins E-Sampler Data, Showing Collins Met Station Data
Bruin E-Sampler Data, Showing Collins Met Station Data
5-Minute Averaged TSP Concentration (mg/m3)
5-Minute Averaged Wind speed (m/s)
05/10
05/20
05/30
06/09
06/19
06/29
07/09
Date


2017 E-Sampler Data
Legend
E - Sampler
Wind speed
West wind
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)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
12
9
6
3
0
05/10
05/20
05/30
06/09
06/19
06/29
07/09
Date