Peace Project Water Use Plan

GMSMON#18 WLL Dust Control Monitoring

Implementation Year 9

Reference: GMSMON#18

BC Hydro Williston Reservoir Air Monitoring 2016 Annual Report

Study Period: 2016/01/01 – 2016/12/31

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GMSMON#18 WLL Dust Control Monitoring

BC Hydro Williston Reservoir Air Monitoring 2016

Annual Report

Prepared For: BC Hydro and the Joint Planning Committee

Prepared By: Chu Cho Environmental

Study Period: 2016/01/01 – 2016/12/31

Tsay Keh Dene, BC, V0J 3N0

GMSMON#18 WLL DUST CONTROL MONITORING

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Executive Summary:

Chu Cho Environmental began operating and maintaining the GMSMON#18 Williston Reservoir regional air quality monitoring network in March of 2014 (year 7 of the project) and continued work through years 2015 and 2016 (years 8 and 9 of the project). GMSMON#18 is a 10-year air quality monitoring program that is designed to assess the impact of dust mitigation treatments on Aeolian dust emissions from the Finlay Reach of the Williston Reservoir. The program was expanded in year 4 to include Federal Reference monitoring for the development of baseline ambient air quality data in the villages of Tsay Keh Dene and Kwadacha. The Federal Reference data will be used to contextualize the northern Finlay Valley region within the air quality standards developed by the BC Ministry of Environment (BC MoE) and the Canadian Council of Ministers of the Environment (CCME). Year-4 also included a significant change in instrumentation and the development of additional monitoring sites.

Following the rationale of the monitoring program Terms of Reference - Addendum 3, Chu Cho Environmental revised the network design in 2014 to increase the spatial and temporal resolution of the data. This allowed for a better evaluation of the impact of dust mitigation treatments on fugitive emissions from the reservoir beaches.

Chu Cho Environmental views GMSMON#18 as having two distinct network components, each of which addresses a different question posed in the GMSMON#18 Addendum 3 document:

1. The **Regional Monitoring Network** comprises between 16 and 18 E-Samplers and 8 Meteorology Monitoring sites. This network is designed to assess the impact of dust mitigation treatments on Aeolian dust emissions from the Finlay Reach of the Williston Reservoir.
2. The **Reference Monitoring Network** comprises 2 TEOM Monitoring stations and 2 Meteorology Monitoring stations. This network is used to evaluate the regional ambient air quality within the context of the guidelines and standards developed by the BC MoE and the CCME. The guidelines are summarized in Table 14 in Section 3.

The analysis for each of these network components has been separated into two sections for this report. The intended use and Data Quality Objectives (DQOs) for each network component are stated at the beginning of each section.

The GMSMON#18 air quality monitoring project exists 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. These sediments are primarily a loosely packed glacial till consisting of gravel, sand, silt and clay with minimal organic content. At full-pool, or 672m above sea level, these sediments are covered by 5 – 15 meters of water and are not exposed to wind erosion. In November each year, the reservoir freezes and the water inputs are less than the output at the dam, resulting in continued drawdown until the reservoir water level reaches 655m above

sea level (this varies from year to year depending on power demand and precipitation but cannot currently go below 655m asl). Following spring thaw and the melting of the ice, the expanses of sediment are exposed for several months before the reservoir is recharged. During these months the prevailing winds and seasonally changing weather patterns result in periods of wind erosion. The wind erosion results in dust storms that develop locally and if winds are sustained, the dust storms will migrate, eventually filling the valley with airborne sediment. It is during the spring months that dust mitigation techniques are applied to the reservoir sediment expanses in order to slow or stop the erosion. The mitigation program is called the Williston Dust Mitigation Program (WDMP) and is administered by Chu Cho Industries LLP. The primary goal of GMSMON#18 is to evaluate the impact of these mitigation techniques at both a local and regional scale through the monitoring of suspended sediment in the air.

Utilizing the Regional Monitoring Network, Chu Cho Environmental has developed and will continue to refine analysis techniques that provide new insight into the development, evolution and migration of dust storms in the Finlay Valley. We have incorporated spatial techniques such as heatmap analysis and linked this with time-lapse imagery and video editing software to create strong visual tools. This allows us to observe dust storms and the associated particulate matter data values. Chu Cho Environmental will continue to refine our analysis and data capture techniques to better address the key management question in year 10 of the program.

This report demonstrates the direction and approach that Chu Cho Environmental has implemented for the investigation of the data captured by the monitoring equipment. More data collection is required before strong conclusions can be reached. For year-3 of Chu Cho Environmental operation, our project team focused streamlining the analysis techniques and building the required models to address the management question, while simultaneously increasing the security and reliability of the data sources. These advances will be detailed in this report.

In general, the spatial and temporal variability between sites is large. A dust event is identified as exceeding the threshold of 0.1 mg/m^3 Total Suspended Particulate (TSP) for more than 30 minutes. 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 significant 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. E-Samplers are intended for inter-comparison studies because they are internally consistent; these types of studies are often called "Fence Line Studies". Some sampling stations recorded more than 64 dust events over the 2016 dust season, whereas other sites recorded as few as 2. The average was 19 dust events. Some events are short lived and highly localized to an individual beach or group of beaches, while others fill large sections the valley. Overall, 2016 was a moderately dusty year that gave rose to approximately 10-15 small short-lived (<12 hours) but intense dust events and approximately 3 major events lasting more than 24 hours. The Regional Monitoring Network allows our team to observe dust events beginning in one location and then migrating in response to sustained wind events. The distributed network of sample stations has allowed our team to evaluate the relative contribution of local area sources to the overall quantity of airborne sediment in the valley.

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. There are significant data limitations preventing conclusive analysis of this point, however, in general there was limited evidence to suggest that applying tillage to a given beach will result in a reduction in airborne dust over time. So far, the test cases have presented statistically significant but confounding results, in some cases tillage appears to reduce dust emissions after its application and in others it appears to increase emissions after its application. ***Many of these results are linked to multiple confounding variables such as precipitation and wind speed and it has been the bulk of our effort to unpack and evaluate the results by controlling for these environmental variables.***

Chu Cho Environmental has continued to manage the Reference Monitoring Network to the standards of the CCME and will provide a basic analysis of these data following the CCME guidelines. The 2016 dust season was similar to what might be referred to as an average dust season in the Finlay Valley. There were a number of short-lived but intense events along with several long duration large events. At the Tsay Keh Dene Station, there were 4 exceedences of the provincial PM_{10} air quality objective between April and June along with 2 exceedences of the federal $PM_{2.5}$ air quality standard. It should be noted that the data collected by the Reference Monitoring Network are not used to directly address the key management question posed in the Terms of Reference for GMSMON#18, but are used to characterize the long term regional ambient air quality in Tsay Keh Dene and Kwadacha. These data are also not meant to be input into the Canadian Ambient Air Quality Standards (CAAQS) objective determination calculation. The data from this network have provided and will continue to provide valuable insight into the long-term air quality trends within the region.

In addition to managing the air quality monitoring networks there were three other additional program components identified in the Addendum 3 document, these include:

1. Dustfall Monitoring,
2. Mentorship and Capacity Building Objectives, and
3. Community Engagement.

Year-1 of Chu Cho Environmental's control over GMSMON#18 included many successes and learning opportunities. Year-2 included early deployment (April 7th, 2015), procedural refinement and the development of numerous processing algorithms to help improve the project. Our project team found many efficiencies and opportunities to improve the program.

Chu Cho Environmental will continue to advance the GMSMON#18 program through improved data collection procedures, analysis techniques and the application of advanced statistical analysis techniques.

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1.1 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 (Canning et al., 1999).

The region has experienced many glaciations over the previous 200 million years, the last of which left the area 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 655m 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 large amounts 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 cross winds 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 and Kwadacha.

The airborne dust arriving in Tsay Keh Dene and Kwadacha is at minimum a nuisance and if concentrations exceed Canadian Ambient Air Quality Standards (CAAQS) pose an increased concern.

1.2 Management Summary: GMSMON#18 Management Questions and Program Components

The dust control management plan (DCMP) under Section 5.1 of the Peace River Water Use Plan (WUP) was implemented with the expressed 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 a 10-year commitment (2008 to 2018) by BC Hydro to measure fugitive dust emissions that result from the annual operations of Gordon M. Schrum Hydro Power Facility and the Williston Reservoir. The purpose of the AQ monitoring program is to quantify the levels of Particulate Matter (PM) in the air shed surrounding the reservoir. The results of the AQ monitoring program are integral in formalized 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 adaptive management of dust mitigation plans for the Williston Reservoir and will inform water use decisions as they pertain to dust control as identified in the ToR Addendum 3 Section A3.2.5. Ultimately, some of the analysis avenues investigated in this annual report may be changed as required in favor of more concise analyses that become available once we have amassed sufficient data. Other avenues included in this analysis may be foundational and will be the building blocks of what is to come in future iterations of this report. Note that 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. We apply technical definition to these terms in Section 2.

The following table provides a summary of the various program components that pertain to year-9 of GMSMON#18 and the status of those components:

Table 1: Management Summary - Status of GMSMON#18 Program Components

Program Component	Management Question	Management Hypothesis (Null)	Status
Regional Monitoring Network	Do the 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.	16 E-Samplers and 8 Meteorology sites were deployed in 2016 to address this question. The samplers are collecting data at 5-minute intervals from April to October. Statistical analysis of data

			from 2014 and 2015 indicated that mitigation activities have minimal effect on reducing local/regional fugitive emissions. 2015 was a year of little wind and limited dust activity (like no other year in our 8-year dataset) that did not result in highly descriptive or statistically significant data. Currently it is not possible to delineate mitigation treatment effects from the numerous confounding variables such as rainfall, relatively humidity and reservoir rise. 2016 was a typical dust season giving rise to several large events and numerous small events.
Reference Monitoring Network	Are the long-term ambient air quality values for PM_{10} and $PM_{2.5}$ in Tsay Keh Dene and Kwadacha 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 and Kwadacha do not meet the provincial AQOs nor the CAAQS.	In 2016, there were four exceedences of the provincial AQO for PM_{10} and 2 exceedences of the Federal standard for $PM_{2.5}$. The weather in 2016 followed typical patterns giving rise to several large wind events.
Dustfall Monitoring Network	Are the baseline dustfall values within the bounds of the provincial Air Quality Objectives?	Dustfall values recorded in Tsay Keh Dene are not above the provincial AQOs for monthly dustfall.	Dustfall monitoring was conducted at a single site located in the town centre of Tsay Keh Dene. The dustfall sample container was changed monthly from April to October.
Mentorship and Community Engagement	n/a	n/a	Chu Cho Environmental employees who reside in Tsay Keh Dene or Kwadacha are steadily taking on more responsibilities for AQ monitoring. Our Tsay Keh Dene crew members are responsible for monthly instrument maintenance and data management for the regional monitoring network. These employees are also trained on management of the TEOM Reference Monitoring System. Chu

			Cho Environmental has participated in various community events and open houses to promote the AQ monitoring program.
Enhanced Data Security, Transparency and Access	n/a	n/a	New computer systems have been installed to improve network security and reliability. We have enlisted third party applications for hosting data online and have implemented a remote login system to allow remote access to the instrumentation. Currently anyone who wishes could be added to an email list serve and could receive a .csv file summarizing the previous 12 hours of data. Data are synced via Dropbox and are analyzed shortly after using Matlab.

1.2.1 Updates to Monitoring Network

Chu Cho Environmental did not implement any major changes to either of the monitoring networks for the 2016 dust season and proposes no major changes for 2017.

Only 4 minor changes were made to the Regional Monitoring Network in order to improve the overall coverage of the meteorology and dust sampling equipment, these include:

1. Meteorology Station Moved from Lafferty to Moody:
    a. There is no corresponding E-Sampler deployed at Lafferty and the nearby meteorology equipment at Collins Beach approximately account for the wind conditions in this location. For these reasons the meteorology equipment was moved to the Moody E-Sampler site for 2016 and will be deployed here again in 2017.
2. E-Sampler at 25Km (aka Chunamon) was not deployed:
    a. Forestry operations over the winter of 2016 decommissioned the bridge that was required to access this site. As a result the equipment was stranded on the inaccessible side of the road and our team was unable to deploy it.
3. E-Sampler at 35Km not deployed and corresponding meteorology equipment moved the 57km:

a. The water levels were too high in 2016 to safely deploy the meteorology equipment on the beach at 35km. The meteorology that was used at this site was deployed further north at the 57km site and the E-Sampler equipment was reserved as backup. The equipment will be redeployed here in 2017 if the water levels will allow.

1.3 DATA SUMMARY

The following tables provide a detailed summary of all of the components involved in this program and the rate at which each component is collecting data:

Table 2: Summary of Air Quality Response Measures Monitored

	Response Measures								
	Spatial Data	Dustfall		Total Suspended Particle Concentration		Particulate Matter Concentration		Particulate Matter Concentration	
	Shapefile Data	Volatile	Fixed	All levels	All Levels	PM2.5	PM10	PM2.5	PM10
Variable ID		DF-TK-1-3	DF-TK-1-3	001 - 030	Photo_ID	pm25	pm10	BGI_pm 25	BGI_pm 10
Sampling Year(s)	2016	2014-2016	2014-2016	2014-2016	2014-2016	2011-2016	2011-2016	2011-2013	2011-2013
Sampling Frequency	once	monthly (May-Oct)	monthly (May-Oct)	5 min (May-Jun)	10 min	10 min (May-August)	10 min (May-August)	1 in 6 day (May-Sept)	1 in 6 day (May-Sept)
Measurement Units	UTM	mg/dm²/day	mg/dm²/day	mg/m³	per photo	µg/m³	µg/m³	µg/m³	µg/m³
N	lot	3	3	(16 – 19)	8	2	2	8	8
Data type	shapefile	measured	measured	measured	estimated	measured	measured	measured	measured
Equipment	Trimble Juno	Dustfall canisters	Dustfall canisters	E-sampler	Moultrie D-555i Game Camera	TEOM 1405-D	TEOM 1405-D	BGI PQ200	BGI PQ200

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

	Meteorology Monitoring										
	Wind Speed		Wind Direction		Relative Humidity		Rainfall		Air Temperature		Air Pressure
Variable ID	ws	ws	wd	wd	rh	rh	prcp	prcp	temp	temp	press
Sampling Year(s)	2014 - 2016	2011-2016	2014 - 2016	2011-2016	2014 - 2016	2011-2016	2014 - 2016	2011-2016	2014 - 2016	2011-2016	2011-2016
Sampling Frequency	5 min (May-Sept)	10 min (Jan-Dec)	5 min (May-Sept)	10 min (Jan-Dec)	5 min (May-Sept)	10 min (Jan-Dec)	5 min (May-Sept)	10 min (Jan-Dec)	5 min (May-Sept)	10 min (Jan-Dec)	10 min (Jan-Dec)
Measurement Units	m/s	m/s	degrees	degrees	%	%	mm	mm	degrees celcius	degree celcius	kPa
N	8	2	8	2	8	2	8	2	8	2	2
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	TEOM 1405-D

NETWORK COMPONENT I: REGIONAL MONITORING NETWORK

2.0 Regional Monitoring Network

2.1 Network Characterization

The Regional Monitoring Network is designed to assess the impact of dust mitigation treatments on Aeolian emissions from the Finlay Reach of the Williston Reservoir. This network was not altered significantly for 2016; minor changes were identified above in Section 1.2.1. The Regional Monitoring Network consists of 16 MetOne E-Samplers and 8 meteorology monitoring stations. The 16 E-Samplers are dispersed across the many cutbanks, points, beaches and gravel bars in the reservoir's Finlay Arm.

Some locations such as Chowika, Ingenika, and Rat Lake are situated on large gravel bars or rock out crops that do not produce dust. The dust recorded at these locations is coming from elsewhere further upwind within the reservoir basin. Other sites such as Middle Creek North, Shovel and 35km (Discontinued in 2016 – See Section 1.2.1) 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. The number of samplers deployed was limited to site accessibility and the number of available instruments.

E-Samplers are designed to measure continuous air quality data at 1Hz and can record that data at various averaging intervals. We are currently 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), PM_{10}, or $PM_{2.5}$ but they cannot measure all three at the same time. 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 16 E-Sampler sites there are 8 meteorology monitoring stations. These stations were mostly placed in the same location as 2015 with the exception the newly established site at Moody and the discontinued sites at 35km and 25km. Each meteorology station is outfitted with a rain gauge, temperature probe, relative humidity sensor, wind vane, and anemometer. The data are logged using a CR1000 datalogger.

Ultimately, the location of the 16 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 with increased spatial distribution and sampling frequency Chu Cho Environmental has created more opportunities to 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 16 dust monitoring and 8 meteorology monitoring stations within the Finlay Arm of the Williston Reservoir.

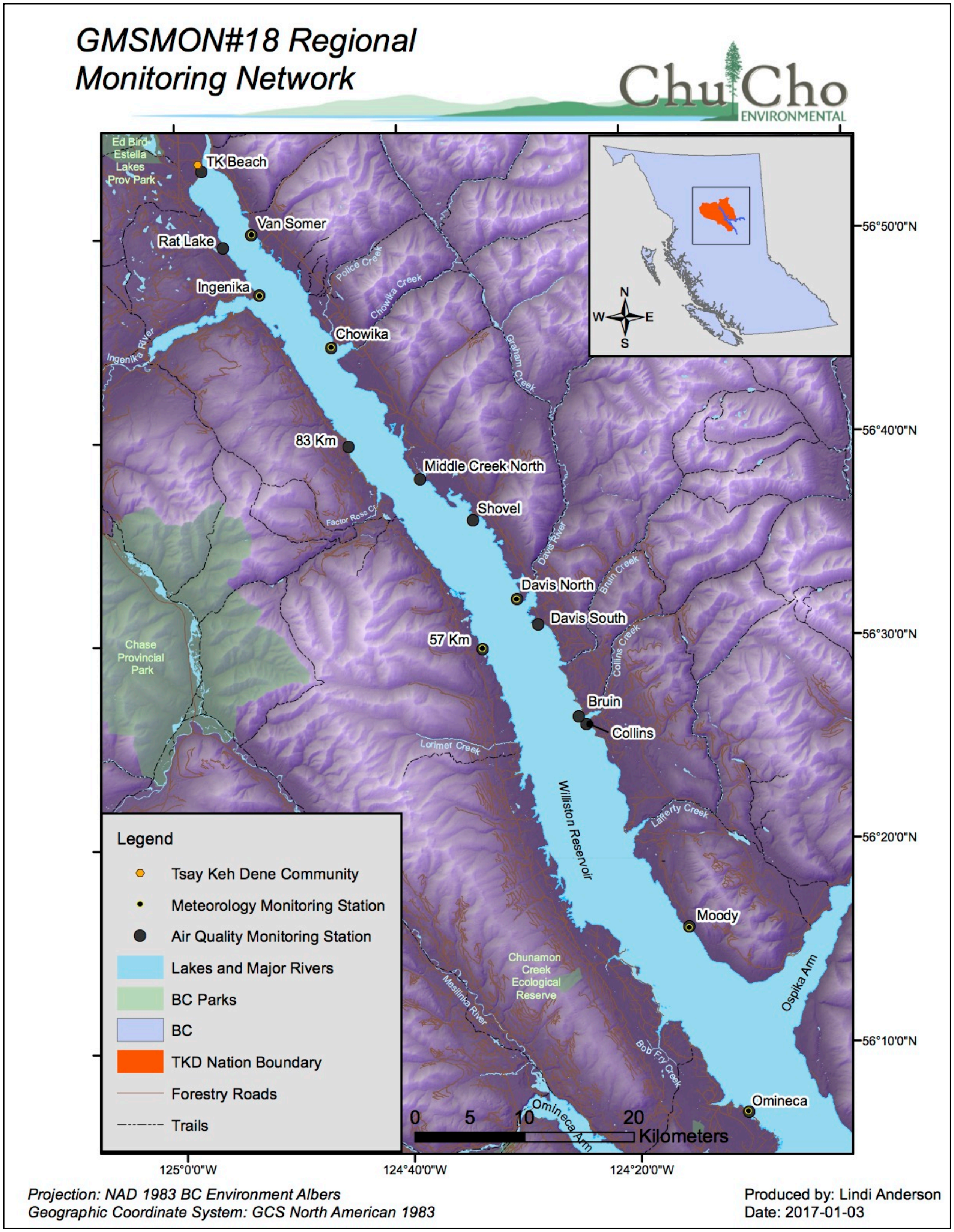


Figure 1: Map of Regional Monitoring Network Sampling Locations

2.1.1 Detailed Site Descriptions

Table 2 provides a detailed overview of the monitoring station site locations, the instrumentation included and the type of airshed representation that the site provides:

Table 4: Regional Monitoring Network Site Descriptions and Locations

Site Name	Lat	Lon	Met Station	Site Description	Airshed Representation	Instrumentation
Tsay Keh Village	56.892	-124.964	Tsay Keh Village	The E-Sampler is Tsay Keh Dene is located on top of the TEOM Monitoring Station and is meant to collect data that is to be compared to the TEOM 1405-D. For 2015, we have added an additional E-Sampler in TKD that is located adjacent to the Tsay Keh Beach, which is a known high emitter.	Regional	E-Sampler, Met Station
Van Somer	56.837	-124.886	Van Somer	Van Somer point is primarily comprised of Sandy Loam type sediment and is a known high emitter beach. This beach tends to hold tillage quite well because the increased clay content tends to hold moisture. The sample site is located on a gravel bar above the beach that is well exposed to southerly and northerly winds. The sampling equipment is well positioned to capture some local dust but also much of the regional dust passing by the area.	Regional /Local Dust	E-Sampler, Met Station
Tsay Keh Beach	56.888	-124.96	Tsay Keh Village	Tsay Keh Beach is located at the northern tip of the Finlay Arm where the Finlay River meets the Williston Reservoir. Tsay Keh Beach is comprised of highly mobile sediments and is considered a beach with high emission potential (Nickling et al. 2012). An E-Sampler was placed in the foreshore zone of this beach in 2015 in order to capture the emissions from Tsay Keh Beach	Local	E-Sampler

				prior to entering the village.		
Chowika	56.743	-124.769	Chowika	The Chowika monitoring station rests on a large gravel bar that extends far into the reservoir. This is very exposed to northerly and southerly winds and captures much of the fugitive dust from southern beaches that migrates towards TK village. This site produces no local dust emissions.	Regional Dust	E-Sampler, Met Station
Middle Creek North (MCN)	56.634	-124.640	Chowika	MCN Beach is an exposed sand sheet and a high elevation beach. This beach is usually 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 southerly winds and moderate exposure to northerly winds. This beach was not tilled in 2015.	Local Dust	E-Sampler
Shovel	56.599	-124.563	Davis South	Shovel beach is a mixed sand/silt/clay type beach that is regarded as a high emitter with many local hot spots. The mixed sediments on this beach tend to create clusters of sparse vegetation. There are numerous anecdotal accounts indicating that this beach regularly emits high amounts of fugitive dust. This site has excellent exposure to southerly winds and moderate exposure to northerly winds.	Local Dust	E-Sampler
Davis North	56.535	-124.497	Davis South	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 northerly and southerly winds.	Local Dust	E-Sampler, Met Station
Davis South	56.514	-124.469	Davis South	Davis South Beach is a mixed sediment type beach that is known	Regional /Local	E-Sampler

				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.	Dust	
Bruin Beach	56.437	-124.411	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 and Northerly winds. This site is well positioned to provide a regional evaluation in this area.	Regional	E-Sampler
Collins Beach	56.427	-124.393	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 500m south of the beach access point from Camp Collins. The equipment is well exposed to southerly winds and is moderately exposed to northerly winds.	Local	E-Sampler, Met Station
Lafferty (Discontinued in 2016)	56.344	-124.354	Lafferty	The sampling equipment at Lafferty sits on a large gravel bar that divides the very low elevation sections of the beach from the higher embayments. Some of the higher beach zones will generate vegetative growth while the lower sections are quickly covered up by reservoir water. The northern part of this beach is generally called Collins South and is known to be wet and full of root wads, stumps and deadheads. This site is exceptionally well exposed to	Regional Dust	Met Station

				northerly and southerly winds.		
Moody	56.263	-124.255	Lafferty	The E-Sampler at Moody sits on a high gravel bar above the beach. The beach itself is comprised of mixed sands and silt. This site is exceptionally well exposed to southerly winds and captures early season dust storms from the low elevation Ospika Island Beach that is covered by the reservoir early in the season.	Regional Dust	E-Sampler, Met Station
Rat Lake	56.827	-124.928	Ingenika Point	The E-Sampler is located on a high reservoir cutbank approximately 20 meters above reservoir full-pool level. This site is exceptionally well exposed to southerly winds and moderately exposed to northerly winds. No dust is generated locally and this site provides adequate regional representation.	Regional Dust	E-Sampler
Ingenika Point	56.700	-124.800	Ingenika Point	The sampling equipment is located on a rock outcrop on the northwestern corner where the Ingenika Arm and Finlay Arms intersect. This site is exceptionally well exposed to southerly, northerly and westerly 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
83km	56.662	-124.746	Ingenika Point	The E-Sampler is located on a high reservoir cut bank approximately 20 meters above the reservoir full-pool level. The equipment is located on an old reservoir adjacent road. In 2009 the road was pushed back into the woods away from the reservoir and this site is located on what remains of the old road. This site is well exposed to Southerly winds and provides regional representation. No dust is generated locally and this site provides adequate regional	Regional Dust	E-Sampler

				representation.		
Stromquist	56.567	-124.628	Stromquist	Sampling at this site was discontinued for 2015.	Regional	E-Sampler, Met Station
57km	56.494	-124.552	57km	This site is named after the road kilometer where the access point is located. This site is located approximately 3km 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 southerly winds and captures much of the sediment laden air plumes that drift north from the coreless complex.	Regional /Local Dust	E-Sampler
35km (Lorimer) (Discontinued due to higher than normal reservoir levels)	56.321	-124.457	35km	This site is located adjacent to Lorimer Creek and near Pete Toy Creek and is situated on the beach known as Coreless F. The beach is comprised of very fine mostly silt based sediments and is a very high emitter. The sampling equipment is well exposed to both southerly and northerly winds. No vegetation was found on this beach. Based on the 2014 results this beach was not tilled in 2015. Unfortunately the water level was higher than usual in 2015 and so this site was only deployed for a total of 3 weeks at the end of May.	Local Dust	E-Sampler, Met Station
25km (Chunamon) (Discontinued due access road decommissioning)	56.244	-124.353	Omineca	This site is located on the north shore of the Chunamon Creek embayment. In the area local to the E-Sampler there are mobile sediments but this site is generally marked with large vegetative islands. This site is well exposed to both northerly and southerly winds.	Local/Regional Dust	E-Sampler

Omineca	56.105	-124.160	Omineca	This sample site is located near the center of Omineca Beach and is exceptionally well exposed to both northerly and southerly winds. Omineca beach is a mixed sand/silt/clay beach and is known a high emitter of fugitive dust. Mixed sparse vegetation tends to grow in the vicinity of the sampling equipment.	Local Dust	E-Sampler, Met Station

The following group of images shows each sample location from two perspectives:

Figure 2: Middle Creek North Regional Monitoring Network

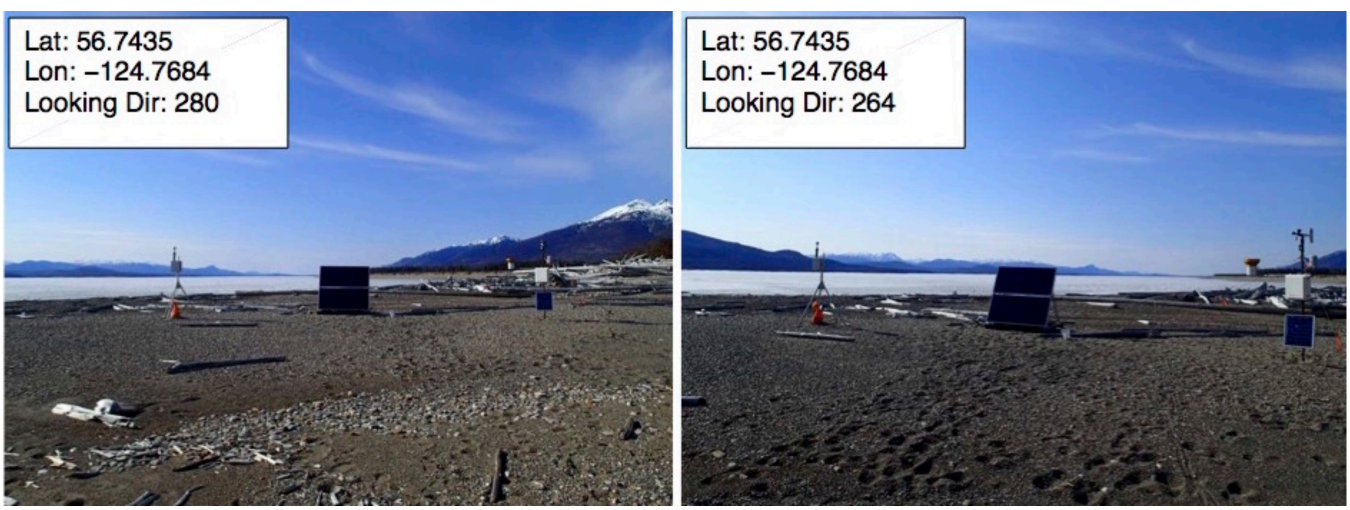
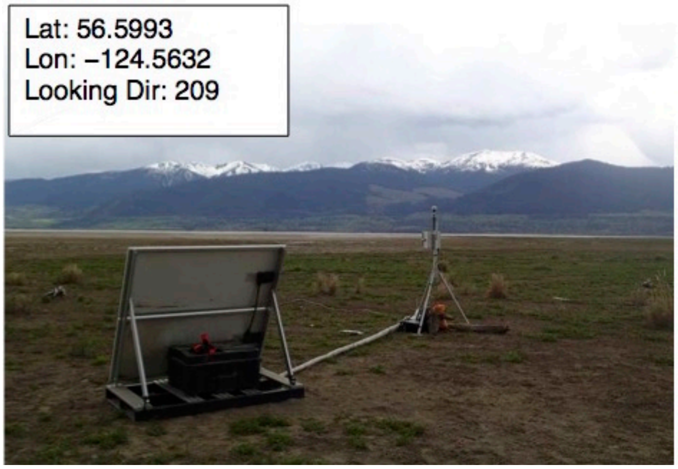


Figure 3: Chowika Regional Monitoring Network



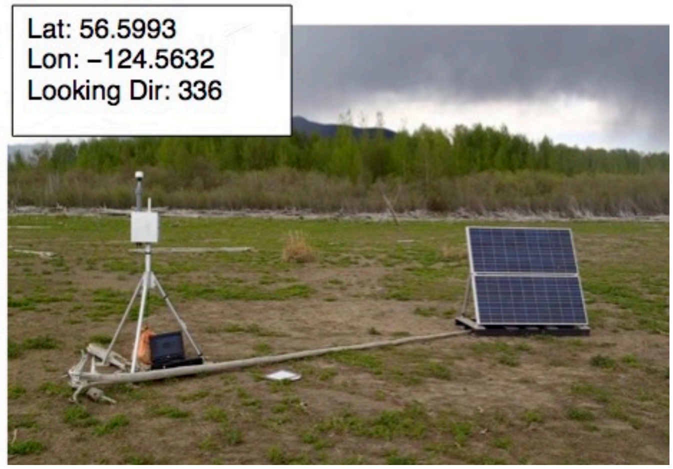


Figure 4: Shovel Regional Monitoring Network

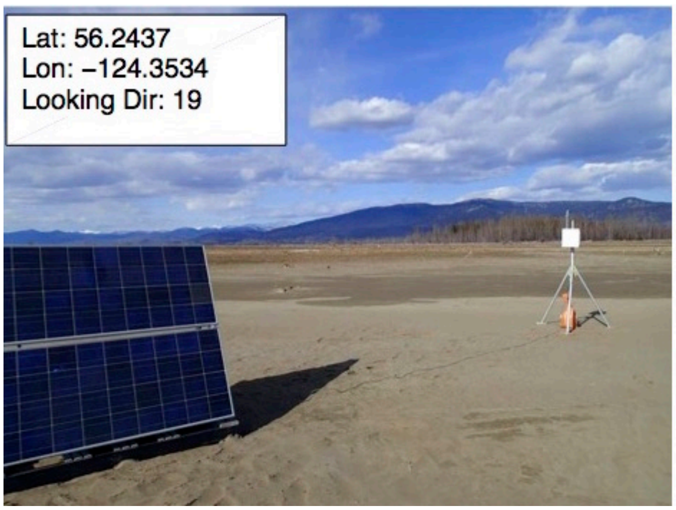


Figure 5: 25Km Regional Monitoring Network – Discontinued in 2016, will be deployed in 2017 if possible.

Figure 6: Bruin Regional Monitoring Network

Figure 7: Moody Regional Monitoring Network

Figure 8: 83Km Regional Monitoring Network

Figure 9: Davis North Regional Monitoring Network

Figure 10: Rat Lake Regional Monitoring Network

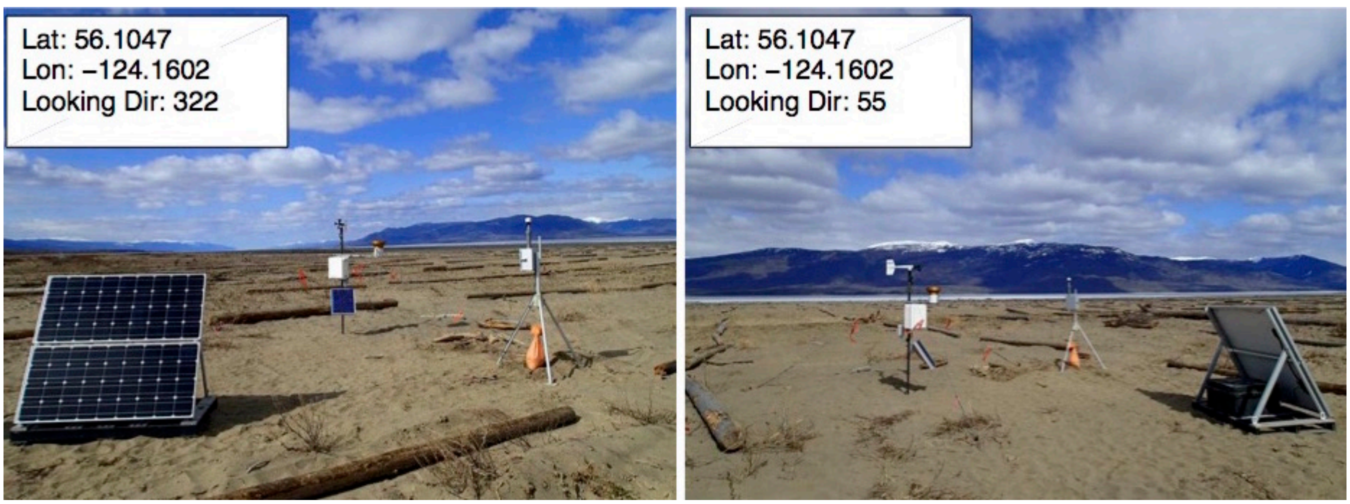


Figure 11: Omineca Regional Monitoring Network

Figure 12: Davis South Regional Monitoring Network

Figure 13: Tsay Keh Dene Regional Monitoring Network and Reference Station – E-Sampler is on top of enclosure.

Figure 14: 57Km Regional Monitoring Network – now includes meteorology equipment.

Figure 15: Collins Beach Regional Monitoring Network

Figure 16: Ingenika Point Regional Monitoring Network

Figure 17: 35Km Regional Monitoring Network – Discontinued in 2016, will redeploy in 2017 if possible.

The remainder of Section 2.0 provides detailed information on the instrumentation, the analyses and the results obtained from the regional monitoring network.

2.1.2 INSTRUMENTATION

MetOne E-Samplers function according to a unique operating principle that employs laser backscatter to estimate the concentration of particulate in air drawn through that instrument at any given moment. Air is drawn into the E-Sampler at a constant velocity where it travels through a defined flow path and measurement chamber. A 690nm laser is shone across the flow chamber, through the particulate laden air where it is received by a light sensor on the opposite side of the chamber. When there are zero particles in the air stream, there is zero scatter of the laser beam and the light sensor responds accordingly. When there are a number of particles in the air stream, there will be some scatter of the laser beam and the light sensor will record a correspondingly reduced signal. The sensor therefore responds to the amount of light, which passes through the flow and the response is inversely proportional to the amount of particulate in the air stream.

The laser scatter method does not hold 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 machine and cannot be used to evaluate CAAQS exceedences or non-compliance. However, they are very useful for dispersion modeling and for observing source/sink locations around the reservoir.

There is no standard protocol or 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. This includes monthly flow calibration, leak check, filter cleaning and data validation.

2.2 Regional Monitoring Network Data Overview

E-Sampler data are read at 1Hz and are recorded at 5-minute average intervals. Data are collected from 16 instruments for the entire snow-free period (approximately May to October) in the Finlay Valley. During the 2016 sampling season the reservoir reached near full-pool levels in late June and peaked by August, this meant that many of the sampling sites that were left accessible in 2014 were not in 2016 similar to the 2015 season. As a result our project team had to remove each sampler sequentially over the month of July to avoid water inundation. There are 8 complete meteorology stations that are located at a subset of the 16 E-Sampler sites (Refer to Table 1 for the E-Sampler/Meteorology Combination list). These stations read the instrumentation at 1Hz and record 5-minute average data for relative humidity, rainfall rate, air temperature, wind speed and wind direction. The regional monitoring network amasses an enormous volume of data very quickly and requires an aggregation of complex computer programming to handle and process. Data are 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 through avenues, which have not yet been investigated and also allows our team to create visuals that provide un-paralleled insight into the development, evolution and termination of dust events.

The analyses discussed in this report represent Chu Cho Environmental's initial 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 generally to 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.

2.2.1 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 are 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 measureable attributes of the monitoring data that will 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 will adopt the following DQO attributes:

- Accuracy:
    - E-Samplers must be calibrated and maintained to sustain an accuracy of greater than +/- 20%. The project samplers are sent to MetOne Instruments for calibration every 18 months.
- 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 and any errors that are detected are recorded and delivered to the user. This calibration process is completed monthly in the field.
- 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.
- Comparability:
    - We maintain a small subset of filter based monitoring instruments that are used to collect samples at random times for comparison to E-Sampler data. These data are used to provide assurance that the E-Samplers are maintaining function through time.
- Averaging Period:
    - E-Sampler data are collected at 1Hz and are recorded as 5-minute averages to the on-board memory. These data are downloaded and verified once or twice per month.
- Measurement Cycle:

  - E-Sampler data is collected from April until October of each year. Data analysis is focused on the Period from April to June or what is typically called the dust season; this may be extended during particularly dry or low-water years.

- 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 more than 2 meters above the earth's surface.
    - Sampler is located a sufficient distance away from roadways and other sources of external contamination such as incinerators or factories.
    - Sampler intake is located a sufficient distance 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 meters away from trees.

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

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

2.2.2 Time Series Analysis

Data collected by the Regional Monitoring Network shows a variety of dust event types throughout the typical April – June dust season ranging in magnitude from small scale isolated occurrences that last less than 30 minutes to large scale valley wide events that may last more than 24 hours. As technical definition for each dust event scale is provided in Table 5 below. In 2014 the Regional Monitoring Network recorded a number of long-duration valley-wide events, but there were no similar events recorded in 2015. In general 2015 was a very low-wind, low-dust year when compared to the previous 7 years. In 2016 there were numerous short lived but intense events and several widespread high intensity events as well. 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 for 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 concentration above 0.1 mg/m^3
Moderate	Between 6 and 18 hours with a concentration above 0.1 mg/m^3
Large	Longer than 18 hours with a concentration above 0.1 mg/m^3
Extreme	Longer than 36 hours with a concentration above 0.1 mg/m^3

Figure 18 contains a time series depiction of the E-Sampler data collected at four locations in the Regional Monitoring Network. The remaining 12 E-Sampler time series graphs are located in Appendix A. Each of the plots in Figure 18 features the time series TSP data read by each instrument. ***The data shown on these charts are unprocessed raw data that represent the 5-minute average being 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 18 demonstrates that there are several relatively high magnitude but short duration TSP peaks throughout the typical dust season. It is also apparent that the E-Samplers are regularly recording a considerable amount of low-level background ambient particulate matter in the airshed.

A large amount of processing is performed on the raw data presented in Figure 18; anomalous values are removed and the data are subjected to intensive statistical analysis probing for maximums, averages, variances and other relationships between samplers and locations.

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 are 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 – We will define numerically what constitutes a dust event in the following paragraphs.

There are microbursts and convective air movements, which sometimes cause the E-Sampler to register particulate matter. These are not the event types we typically wish to analyze because they do not represent the broader dust issue in Tsay Keh Dene and are not the focus of mitigation activities conducted by the WDMP. In order to qualify as a dust event, the E-Sampler must register an average value that is above the threshold value for at least 30 minutes.

Since E-Samplers are not FRM/FEM certified instruments there is no numerical standard by which to define a dust event. For this project we developed a subjective means for defining a dust event using images captured by the network of time-lapse cameras that was deployed in 2014 and 2015. No time-lapse cameras were deployed in 2016. The threshold value is determined by comparing images captured during periods of no dust to those captured during periods of increasing dust. The relative ocular obscurity is proportional to the volume of dust in the air. By repeating this exercise for numerous dust events across numerous sites we are able to arrive at a value that our project team feels is a reasonable approximation for a threshold dust value. We used a number of replicate sites for this exercise (Middle Creek North, Shovel Creek, Van Somer, 35km, Ingenika and Davis North) and arrived at a value of 0.1 mg/m^3 TSP as the E-Sampler threshold for dust events. Obviously there is a great deal of subjectivity in this reading but our project tem feels that it is important that very small non-representative readings are not included in the analysis. Since there are microbursts that result in a reading of 0.1 mg/m^3 we have established 30 minutes or 6 consecutive 5-minute average readings as the time duration over which the threshold concentration must persist in order to be classified as a dust event.

Therefore, in order to be considered a dust event the average reading must exceed 0.1 mg/m^3 TSP for 30 minutes or more. A drop in the average reading below the threshold for 20 minutes or more signals the end of a dust event. This means that there could be numerous dust events registered in a single day that meet the criteria and in our analysis these are considered discrete events. ***Since E-Sampler data are not compared against Federal CCME guidelines or Provincial AQOs we have not reduced these data to 24hr averages.*** Note that this inferred threshold value is a conservative value so that we avoid flagging false positives. In the following section, each reference to a dust event or a number of dust events indicates that the data have met the above criteria.

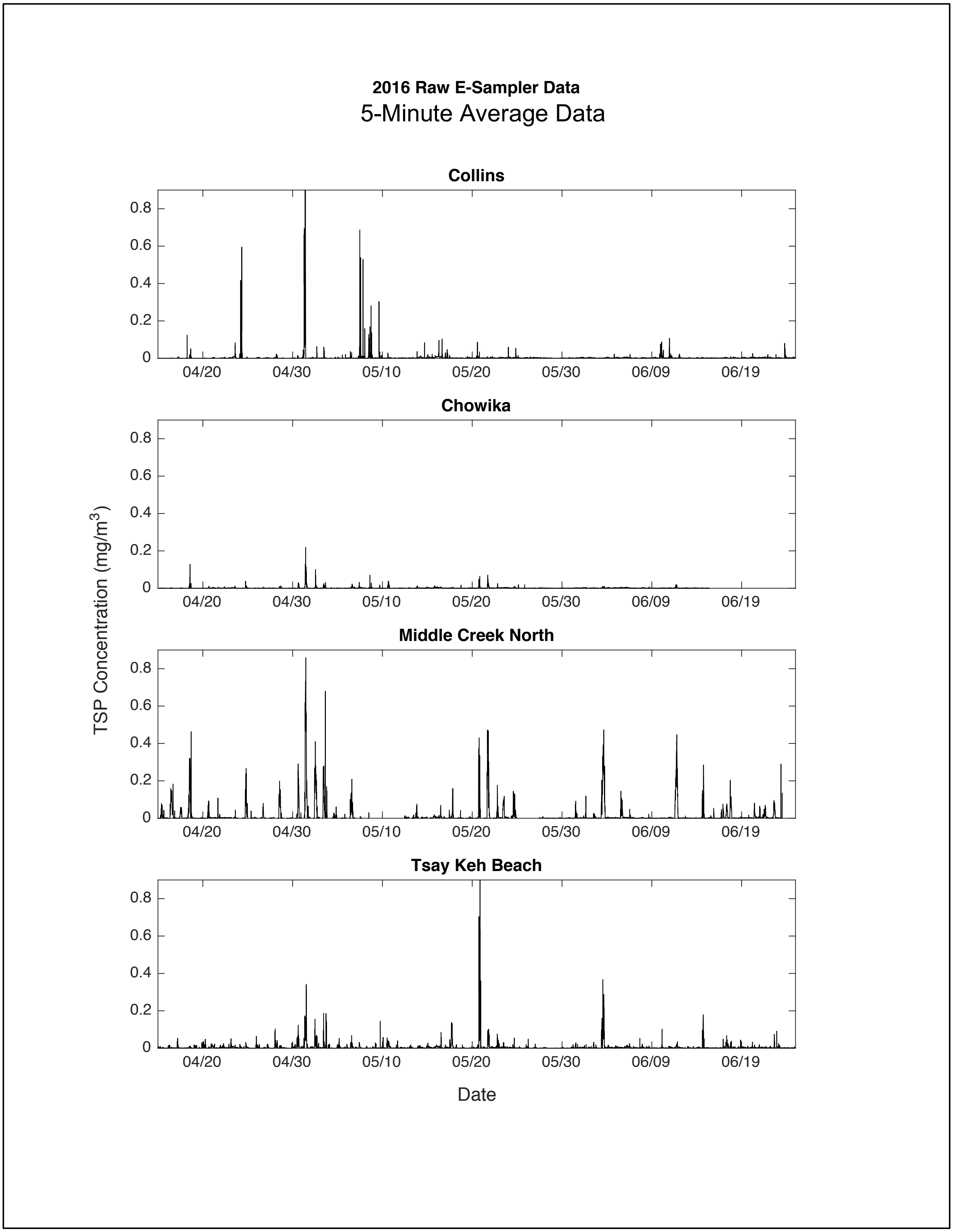


Figure 18: Sample of Regional E-Sampler Data from 4 Locations – Showing 5-minute average data.

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 summarized in Table 6 on the following page. The 2016 dust season was approximately 71 days long ranging from April 15th to June 25th, 2016.

There were an average of 19 events recorded across all samplers during the 2016 dust season and the percentage of time with dust was measured at 0.63%. This number is up from 0.1% measured in 2015 but is slightly lower than the 2014 season at 1.05%. At Middle Creek North (MCN) there were 64 recorded dust events with an average TSP concentration of 0.22 mg/m^3. The average wind speed during these events was 5.5 m/s while the maximum recorded wind speed was 9.4 m/s. Large dust concentrations were also recorded at Collins Beach (0.39 mg/m^3), Bruin Beach (0.39 mg/m^3), Davis North (0.47 mg/m^3) and 57km (0.55 mg/m^3). By far, Middle Creek North was the beach that recorded the highest percent of time with dust. This beach has consistently been the highest recorded dust emitter since monitoring began here in 2014. It should be noted that this instrument suffered several days of downtime in 2016 as a result of multiple bear attacks and so 64 events is likely an underestimation. It is difficult to determine how many events were missed during the 2016 dust season but the instrument did suffer more than 12 days worth of down time.

Both Chowika and Ingenika are typically the locations where the greatest wind speeds are recorded, and while the average wind speeds in these locations were high, in 2016 additional large wind speeds were recorded on beaches such as Davis North, Omineca and Van Somer. These high wind speeds are correspondingly represented in the high average dust concentrations recorded at these locations. Middle Creek North is again the anomaly in this regard, measuring a relatively low wind speed for the large number of events recorded. This confirms the observation that is often lauded about Middle Creek North, that it is a high emitter for very low wind speeds because of the incredibly loose and dry sediments, which comprise the beach surface.

In nearly all cases where threshold events were recorded in 2016 the wind was arriving from a southerly direction. Exceptions to this observation include Bruin, Collins and Shovel Beach.

It should be noted that there were significant issues with the Moody Beach E-sampler and as a result this machine recorded no useful data during the dust season. Similarly, Shovel Beach, which is typically a very high dust emitter suffered reliability issues, however these issues were related to the frequent bear attacks that resulted in excessive equipment downtime.

To date, bear attacks on equipment have been rare with only one prior encounter in 2009. It is not known why there was a drastic increase in 2016 but our project team will take special care to monitor for wildlife at the sites in 2017 to safely ensure that no equipment is damaged and no bears are harmed.

The data presented below were extracted using the threshold criteria described above and are reported within the context of our definition of dust events. For example, the column marked %

of Time with Dust Above Threshold represents the percentage of the total time that the sampler was reading above the threshold value.

Table 6: 2015 Dust Season Dust Event Summary Statistics – Statistical data calculated using the 5-minute average data.

Site ID	# of Dust Events	TSP Conc. (mg/m³)	% Time With Dust Above Threshold	Avg. Wind Speed (m/s)	Max Wind Speed (m/s)	Min Wind Speed (m/s)	Threshold Wind Speed (m/s)	Threshold Wind Spd. Std. Dev. (m/s)
TK Beach	34	0.2	0.84	5.5	9.4	0.7	5.1	2.5
MCN	64	0.22	3.78	6.5	14.6	1.2	5.9	2.7
Chowika	5	0.13	0.06	8.2	15.8	5.8	8.7	4.1
Collins	18	0.39	0.45	5.8	8.2	0	5	2.5
Moody	-	-	-	-	-	-	-	-
83KM	11	0.28	0.22	6.7	14	1.9	5	3.6
Davis	22	0.47	0.45	9.3	17.8	3.6	9	2.8
Rat Lake	8	0.15	0.24	10.2	12	6.9	10.2	0.9
Davis	2	0.17	0.02	10.2	10.9	9.5	10.2	1
Van Somer	17	0.24	0.53	7.9	12.5	3	7.4	1.5
Omineca	34	0.26	0.89	8.6	13.4	6.7	7.7	1.1
Tsay Keh	7	0.24	0.21	3.7	8.8	0.1	3.4	3.3

57km	40	0.55	1.16	5.5	11.3	0.5	5.8	2.3
Ingenika	5	0.13	0.1	6.5	10.2	1.4	5.5	4
Shovel	5	0.13	0.05	5.3	8.5	3.3	5.3	2.3
Bruin	31	0.39	1.01	4.2	11.3	0	4.2	2.8
Average:	**18.94**	**0.26**	**0.63**	**6.94**	**11.91**	**2.97**	**6.56**	**2.49**

Wind Speed and Wind Threshold:

The average wind speed during dust events was calculated as 6.9 m/s in 2016, which is up from 3.1 m/s in 2015 and 6.4 m/s in 2014. This means that events recorded in 2016 were likely of slightly higher wind intensity overall than the last two years. This generally conforms to observations made by field crews during the 2016 season.

Interestingly, those sites, which registered dust events with a northerly wind direction also recorded the lowest average wind speed and wind speed threshold values, suggesting that there may be an intensity factor that is related to wind direction. This line of analysis will be investigated in a future report.

Sites such as Ingenika, Chowika and Rat Lake are interesting because they represent distal location from dust sources and required very high average wind speeds to register any dust. This suggests that the measurements that are recorded here are related to dust that has travelled a large distance from beaches further to the south.

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 all dust samplers was calculated at 5.9 m/s in 2014, 3.1 m/s in 2015 and 6.6 m/s in 2016.

Wind Direction:

There is a great deal of variability within the average wind direction between many of the sample sites, however the dominant wind direction typically contains a southerly component but might vary from Southwest to Southeast. Many of the sites will generally respond to either Northwest or Southeast winds, which have been identified as the dominant wind directions in this part of the Finlay Valley (Nickling et al. 2013). To some extent the dominant wind direction value is influenced by some of the unavoidable compromises (such as site access) that must be made during our site selection. We do strive to avoid placing sites where the influence of local geography and vegetation will affect the wind readings.

2.2.3 BGI PQ200 Air Quality Samplers

The use of BGI PQ200's was discontinued in 2015 and was not reinstated in 2016. It was determined that the data collected by the PQ200's is not of high enough temporal or spatial resolution to functionally address the key management question and that the labor costs associated with maintaining these instruments is prohibitively high. Chu Cho Environmental decided that it would be prudent to spend project resources on improving the reliability, accuracy and precision of the E-Sampler monitoring network.

Initially it was planned that the data collected by these instruments would provide an independent verification for the co-located E-Sampler. However, the BGI PQ200s are built to collect PM_{10} and $PM_{2.5}$ sized particles while the E-Samplers were setup to collect TSP. These measurement values are fundamentally different and are not directly comparable.

Ultimately, the BGI PQ200s are an excellent instrument but their use in the regional monitoring network is not well founded. The purpose of the regional monitoring network is to address the GMSMON#18 key management question. By sampling on either a random or a 1-in-6-day schedule the BGI PQ200s are bound to miss dust events and therefore are unable to address the key management question. The BGI PQ200s are a reference monitor and if used at regular intervals over a long enough time period, can begin to provide insight into baseline air quality issues. This is the primary use of the instrument.

2.2.4 Dust Event & Occurrence Type Heatmap Analysis

The images presented over the next several pages (Figures 20 - 24) were created using a heatmap interpolation analysis that was applied to the Regional Monitoring Network data. This process uses nearest neighbor triangulation to create a high density array of coloured triangles where the greatest "heat," or in our case dust, is indicated by deep red, and the least dust is indicated by dark blue.

The heatmap interpolation is performed across the entire 16 – 18 E-Sampler/8 Met Station dataset for every 5-minute interval. The result is a time series of spatial data and images that show where the greatest concentration of dust is at any given 5-minute interval within the Finlay Valley. This perspective has truly revolutionized our thinking surrounding dust events in the reservoir. Namely, it was widely accepted that dust events occur at relatively infrequent intervals, usually on a large scale. This analysis has shown us that there are in some cases hundreds of events on a single beach throughout the dust season. These dust events range in size from small to large scale, and that some locations regularly emit much higher levels of dust than others. This conclusion, as reached through analysis of the heatmap data is consistent with the anecdotal observations provided by numerous people who have in some way worked on the dust mitigation project since 2008.

In order to fully appreciate this analysis we have created programming that enables us to observe these spatial heatmap images temporally by linking each image in time lapse. The result is a video, which can be sped-up or slowed down to view the initiation, development, evolution and dispersion of dust events in 5-minute time segments. The time-lapse videos are discussed in Section 2.2.5 Time Lapse Analysis.

Firstly we will examine 4 snapshots from the heatmap analysis for 3 different event types from the 2014 dust season and two event types recorded during the 2016 season. Our intention is to discuss the development of various dust events over time and it is apparent that the data collected in 2014 are well suited to this purpose. Figures 20 through 22 show three distinct types of dust event that were observed on several occasions throughout the 2014 dust season. Note that the arrows on the images point towards the direction winds are coming from and the length of the arrow is proportional to strength of the wind. All data shown below were calculated using the 5-minute average data recorded by the E-Samplers, therefore each image represents a 5-minute average data snapshot of the dust conditions surrounding the reservoir. We have also included 2 example storms from 2016 (Figures 23 and 24) that are representative of the prevailing conditions during that year.

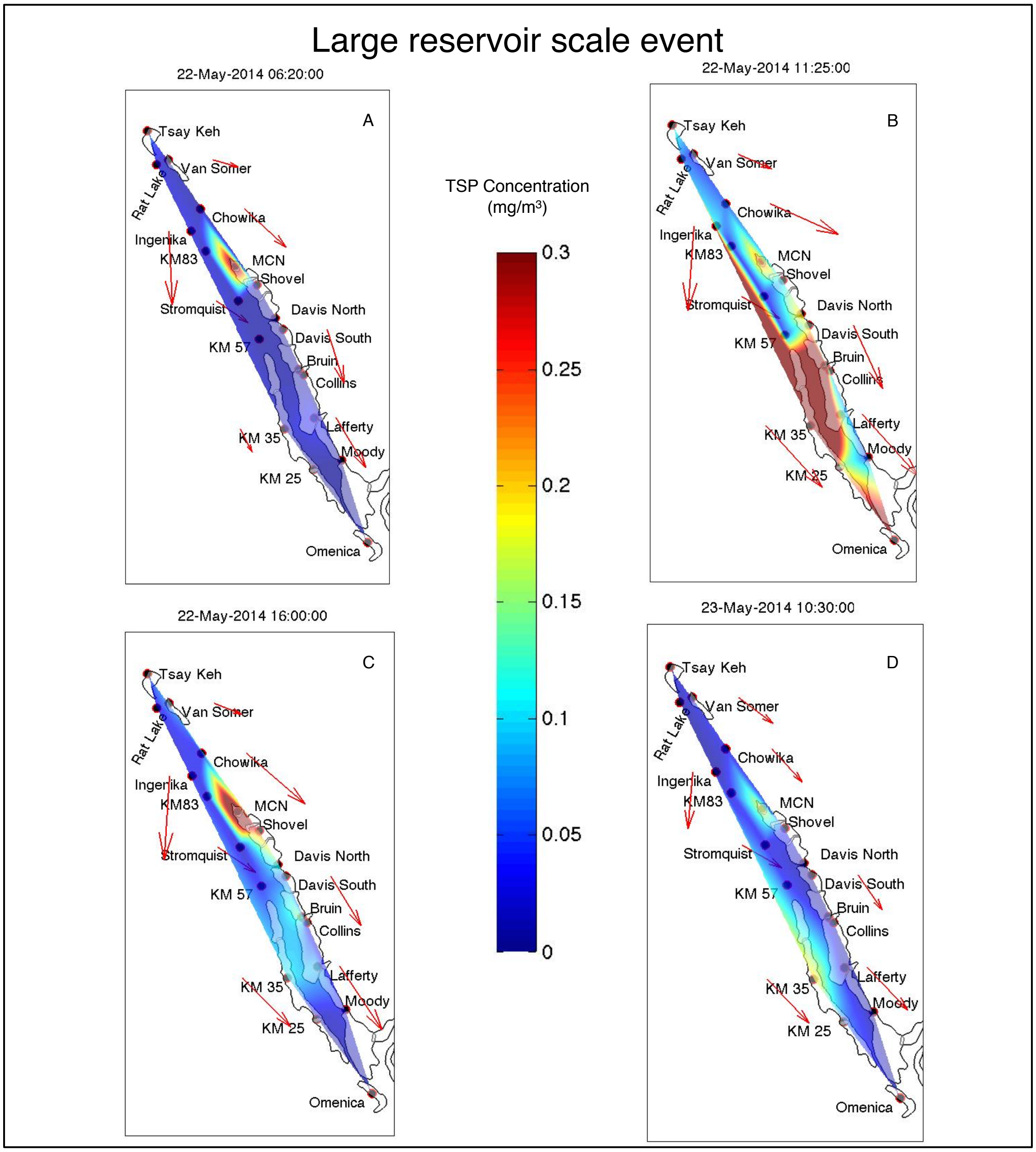


Figure 19: Heatmap Analysis - Large Scale Event – Each plots shows an instantaneous snapshot of the 5-minute average data.

Large Scale Event:

Figure 20 contains four images, which show the development of a valley wide dust event. Figure 20 (A) shows the storm beginning near MCN at 06:20 on May 22nd, 2014 with winds from the south. 5 hours later, Figure 20 (B) shows how the storm has grown to fill the southern section of the Finlay Valley. Figure 20 (C) shows that the storm took a brief hiatus near 16:00 (with the exception of the MCN area) but didn't completely subside until after 10:30 on May 23rd, 2014.

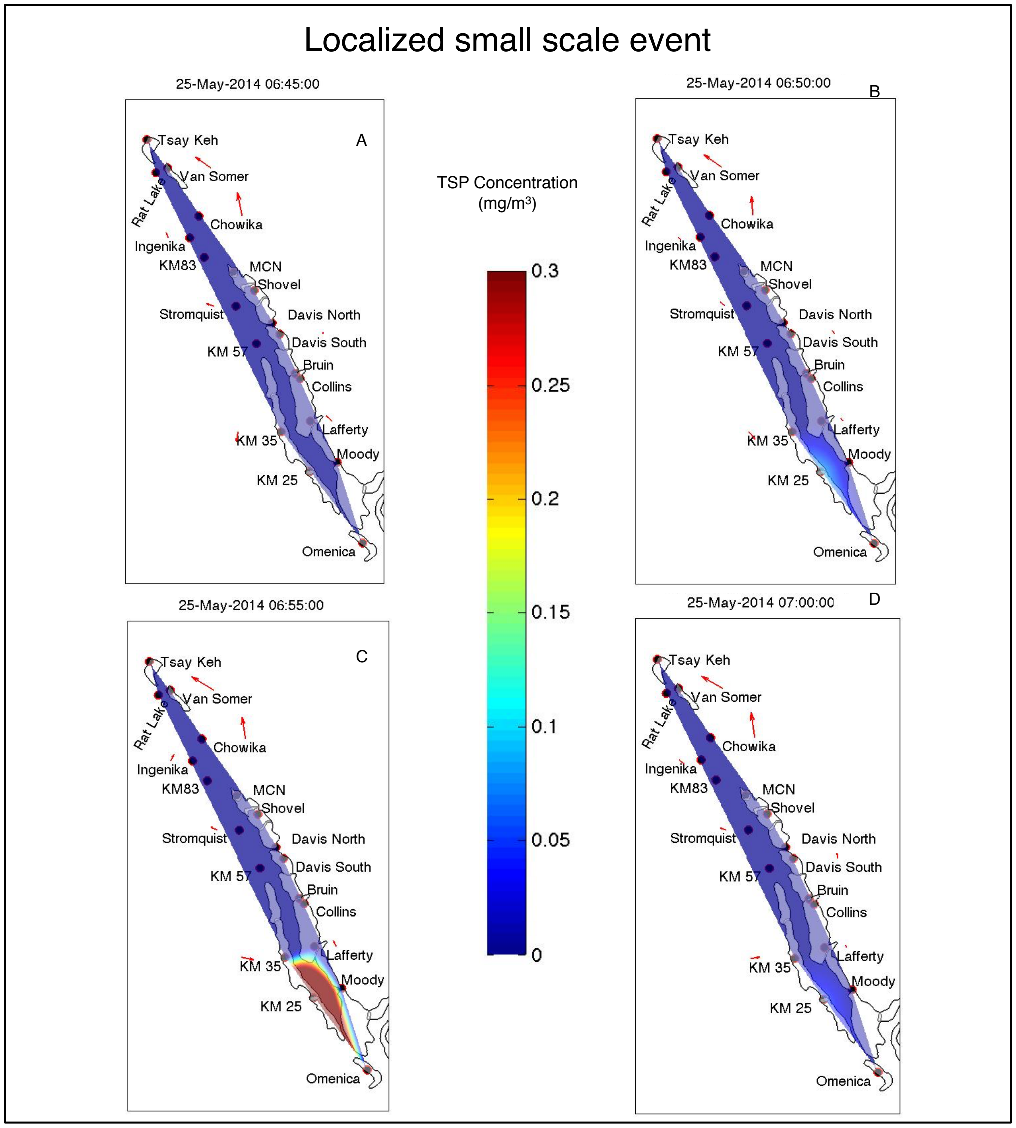


Figure 20: Heatmap Analysis - Localized Occurrence – Each plots shows an instantaneous snapshot of the 5-minute average data.

Small Scale Occurrence:

Figure 21 contains four images, which show the development of a small occurrence localized to a single beach. Figure 21 (A) shows the Finlay Valley under pristine air quality conditions at 06:45 on May 25th, 2014. Figure 21 (B) shows the development of a small microburst at 25Km and 35Km starting at 06:50. At 06:55, the microburst has blown up to a very high concentration localized dust occerence (Figure 21 (C). Then at 07:00, Figure 21 (D) shows that the microburst dust occurrence has stopped and dissipated. This entire micro-occurrence took place over a 20-minute period and although this would not adversely affect the air quality in Tsay Keh Dene it is a prime example of the variability across the reservoir. This occurrence does not pass our threshold limit to be considered a dust event.

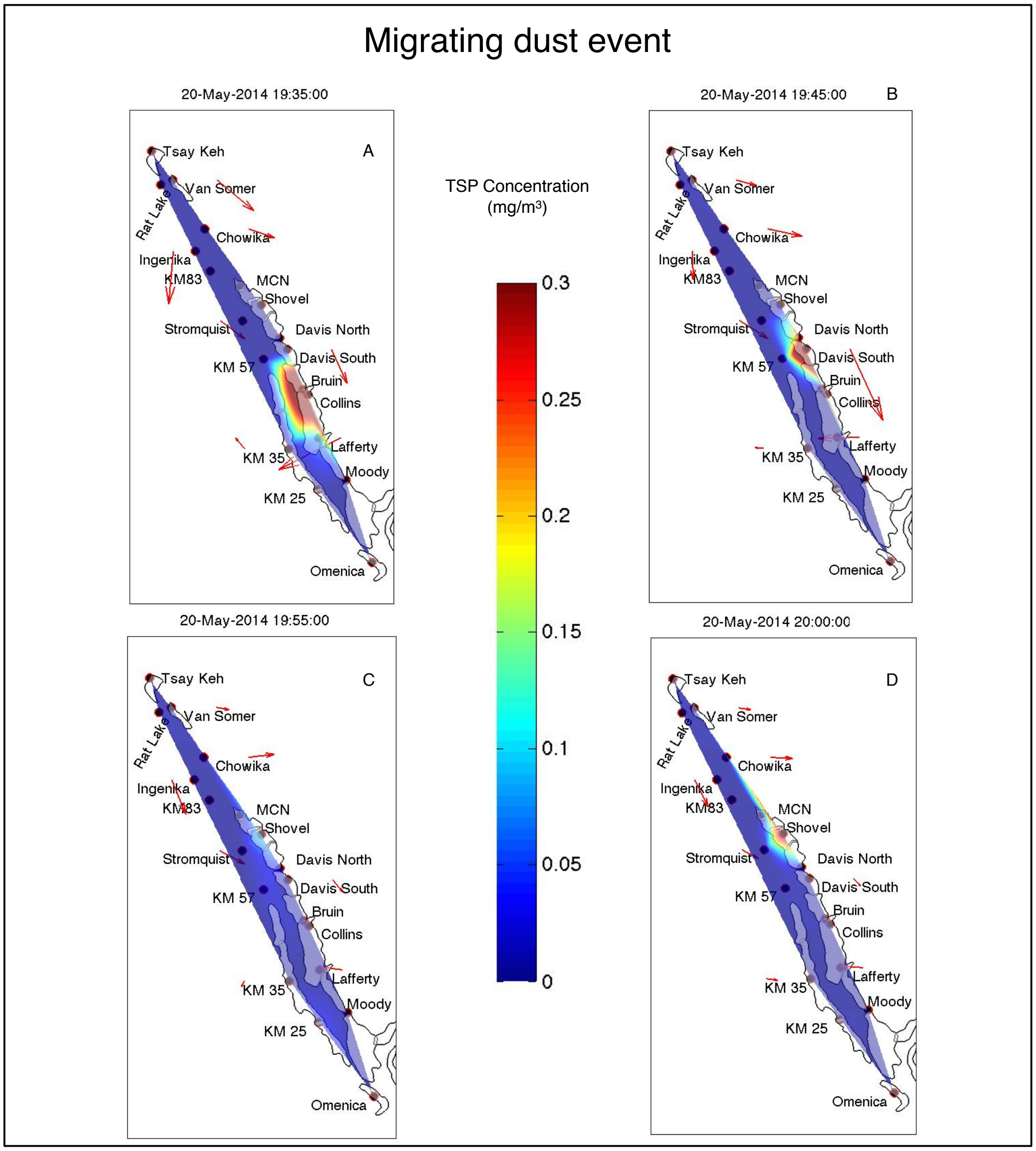


Figure 21: Heatmap Analysis - Migrating Dust Event – Each plots shows an instantaneous snapshot of the 5-minute average data.

Migrating Event:

Figure 22 contains four images, which show the development of a small but migrating dust event. This is perhaps the most interesting new observation that our distributed network of E-Samplers has allowed us to observe. Figure 22 (A) shows the start of a dust event at 19:35 on May 20th, 2014 on Collins Beach and Bruin Beach with winds from the south. Figure 22 (B) show the same event 10 minutes later arriving at Davis South and Davis North beaches. Figure 22 (C) shows this same event beginning to arrive at Shovel Creek at 19:55 and then 5 minutes later, Figure 22 (D) shows the event arriving at MCN. There are numerous short-lived events that begin in the southern regions of the Finlay Valley and migrate north like the example in Figure 22. We should note that on May 20th, 2014 this phenomenon had been happening all day, the example shown in Figure 22 was the 3rd such occurrence of the day.

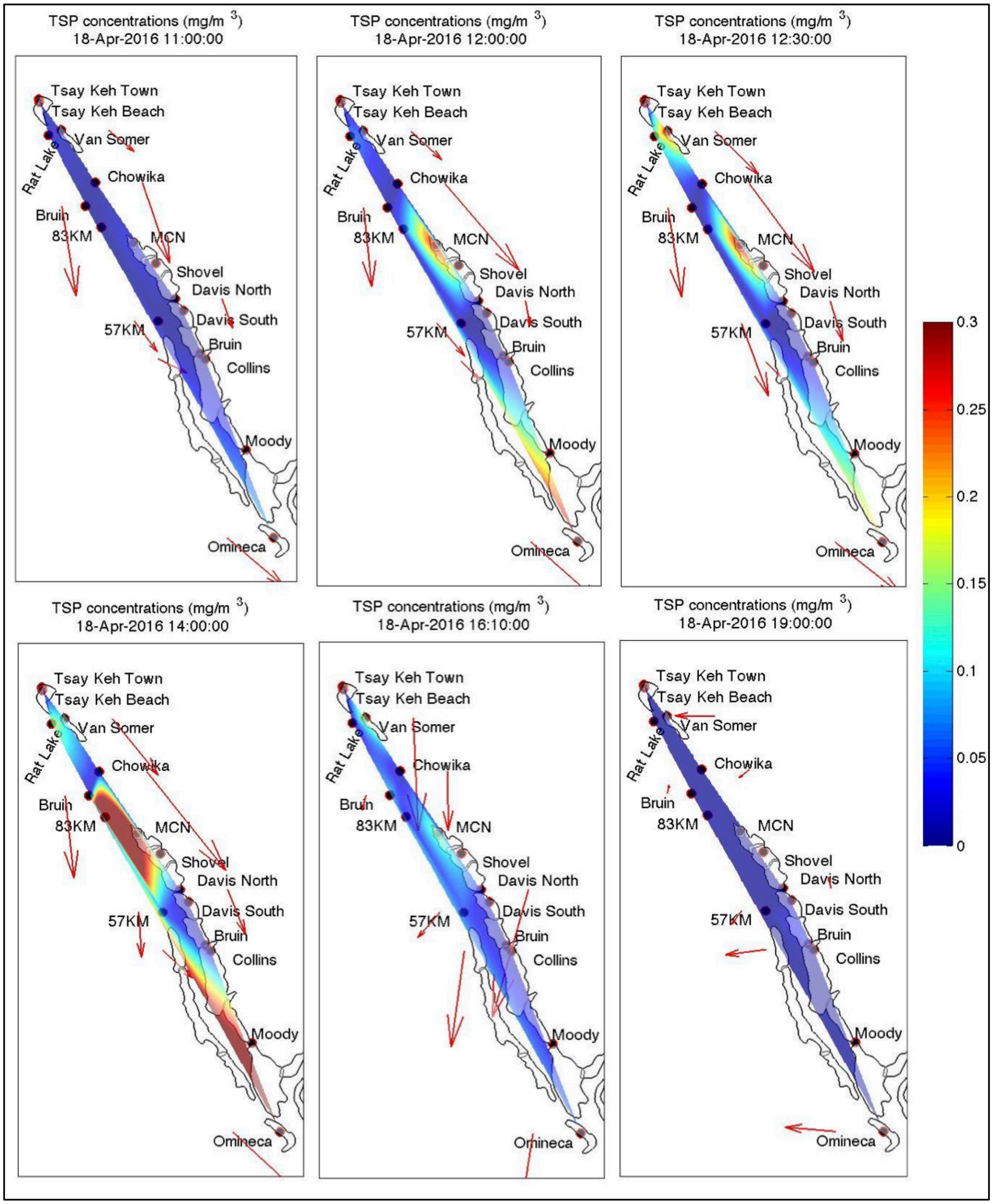


Figure 23: Early season dust event recorded in 2016. Short-duration, high intensity event.

Figure 23 above shows an early season moderate dust event recorded in the spring of 2016. This event started at approximately 11:00 on April 18th, 2016 as the wind gathered coherence and momentum. Within an hour the steady winds had began the process of initiating a dust event. High-speed winds persisted for approximately 2 – 3 hours and the resulting dust storm reached peak intensity around 14:00. By 16:00 the winds had begun to lose coherence and started to focus in different directions rather than along the valley orientation. By 19:00 the winds had dissipated and the storm along with them. This type of early season event was rarely recorded before 2014 and in 2016 there were several because of the limited snowpack from the previous winter and the early spring melt.

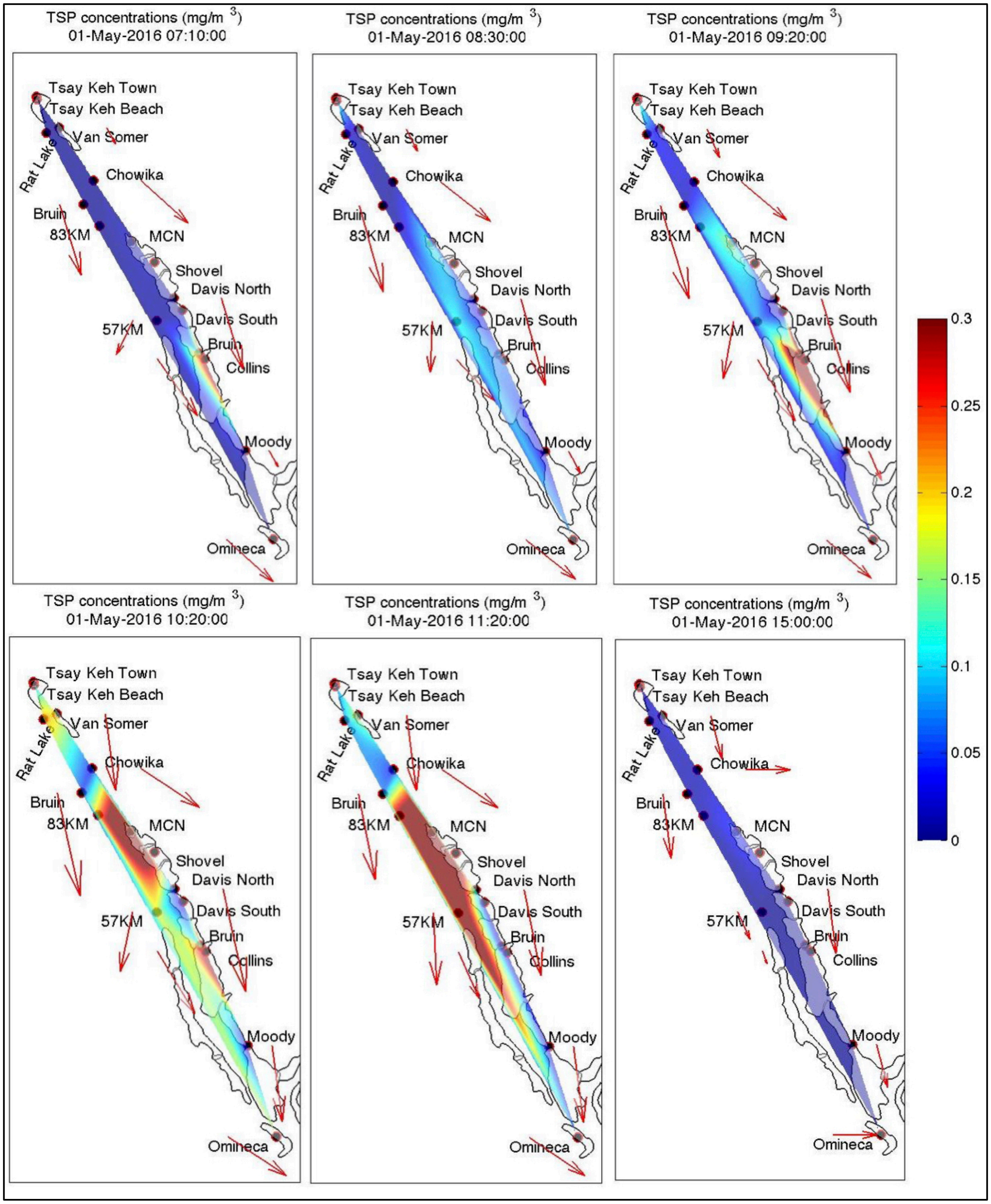


Figure 24: Very high intensity moderate event recorded on May 1st, 2016.

Figure 24 above shows a very high intensity event that last several hours on May 1st, 2016. This event began around 07:00 as the winds gathered momentum. Over the course of approximately 2 hours the steady winds created a valley wide event that persisted from approximately 09:30 until 14:00. The storm reached peak intensity around 12:00 with values at some stations reading over 2.0 mg/m^3. By 14:00 the winds had slowed and the storm dissipated altogether by 15:00.

The storm sequences depicted in Figures 23 and 24 are typical of dust events that occurred during the 2016 dust season. There were a number of very high intensity but short-lived events that persisted for between 6 and 18 hours.

2.2.5 Time-Lapse Analysis

Moultrie D-555i game cameras were deployed at selected regional monitoring sites. These cameras were set to record images at 5-minute intervals synced with the collection schedule of the nearby E-Sampler. Although the manufacturer specifications indicated that the Moultrie game cameras would be well suited to this application, in practice the cameras lacked the ability to auto-focus quickly and performed poorly in low light conditions. The cameras were also very inconsistent in power consumption patterns, some batteries lasting months while others would last only 2 weeks. Moving forward we will acquire cameras that represent the latest in affordable time lapse image capture technology for this project.

The primary use of the game cameras was to capture time-data synced images in order to provide a visual record of dust events along side the numerical value for the same event. In this way, the viewer of the video can associate the visual aspect of the dust events to the numerical data read by the E-Samplers. This exercise was completed for both the 2014 and 2015 dust seasons. We opted not to link the time-lapse images to the heatmap video for 2016 but instead opted to upload a 7-minute video of the entire dust season. Viewing the dust season in this way provides the viewer with an intuitive and rapid method for constructing conclusions about the frequency and magnitude of dust events in 2016.

Videos from the 2014 dust season are posted here:

https://vimeo.com/118043075

https://vimeo.com/117007358

Videos from the 2015 dust season are posted here:

https://vimeo.com/152634706

https://vimeo.com/152631808

The Video from the 2016 dust season is posted here:

https://vimeo.com/202436881

When viewing these videos it may be useful to pause for certain frames in order to step through the frames one by one to observe the progression of the dust events.

We will continue analyzing the data in this way, using strong visuals and time-lapse images to provide greater insight into the dust events. Moving forward we will investigate new and advance analysis techniques that will enable us to extract more detailed information from each video.

2.3 Statistical Analysis and Mitigation Treatment Analysis

For this report Chu Cho Environmental will continue with a basic statistical approach to analyzing the Regional Monitoring Network E-Sampler data. As our project team gains experience working with the E-Samplers and comes to know the full capabilities of the instrument and the network design, we will expand upon this analysis to further address the key management question central to this project.

2.3.1 Descriptive Statistics and Analysis of Variance

All descriptive statistics and ANOVA operations were performed on data that meet the threshold criteria outlined above. It is not relevant to this discussion to analyze the non-threshold data. Therefore each data point used in the following analyses is above 0.1 mg/m^3 TSP and is representative of the station during a dust event.

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.

2.3.1.1 Descriptive Statistics

Table 8 below provides basic descriptive statistics for each of the 16 E-Samplers included in the Regional Monitoring Network. As was mentioned previously, the data collected at Shovel is not representative of a typical dust year in this location due to the frequent bear attacks resulting in instrument downtime. Shovel is typically one of the highest fugitive dust zones around the reservoir.

Generally sites that are located on or near the emission zones of beaches (MCN, Davis North, 57km, etc.) demonstrate higher average values (>0.2 mg/m^3), while those sites that are located some distance away from the erosive zones demonstrated average values closer to 0.15 mg/m^3, the exception of course being Shovel Beach for reasons mentioned above.

The highest value recorded in 2016 was 4.01 mg/m^3 at 57km with the next highest at Davis North (2.25 mg/m^3) followed by Tsay Keh Beach at 1.17 mg/m^3. Values recorded in 2016 were in general higher than those collected in 2015 but were lower than those collected in 2014.

In most cases the standard deviation and variance values recorded at each site were quite large relative to mean, indicating that there is significant variability in the dataset. Moving forward towards the final culminating analytical report that will be compiled for 2018, it will be important to consider meteorological variable such as precipitation, relative humidity, wind speed and direction and the daily reservoir level and that effect that these confounding variable have on the analysis.

Table 7: Basic Descriptive Statistics for the 18 Regional E-Sampler Monitoring Sites (All Units are mg/m³ and were calculated using the 5-minute average data recorded by the E-Sampler)

	MCN	Chowika	Shovel	Ingenika	Bruin	Tsay Keh Beach	Moody
Mean	0.2221	0.1338	0.1266	0.1281	0.3931	0.2011	-
Minimum	0.1	0.101	0.105	0.104	0.101	0.1	-
Maximum	0.859	0.219	0.163	0.198	1.903	1.173	-
Standard Deviation	0.1191	0.043	0.0263	0.0314	0.402	0.158	-
Variance	0.0142	0.0019	0.0007	0.001	0.1616	0.025	-

	83Km	Davis North	Rat Lake	Omineca	Davis South	Van Somer	Collins
Mean	0.2824	0.4742	0.1517	0.2583	0.174	0.2359	0.3859
Minimum	0.103	0.102	0.103	0.103	0.141	0.101	0.103
Maximum	0.901	2.247	0.273	0.751	0.207	0.728	1.19
Standard Deviation	0.2223	0.4698	0.0449	0.1595	0.0467	0.151	0.268
Variance	0.0494	0.2207	0.002	0.0254	0.0022	0.0228	0.0718

	Tsay Keh Town	57Km
Mean	0.2356	0.5472
Minimum	0.105	0.101
Maximum	0.835	4.012
Standard Deviation	0.1839	0.7655
Variance	0.0338	0.586

2.3.1.2 ANOVA Between All E-Samplers

The following analysis is based on a one-way ANOVA used to examine the 16 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 out monitoring network around the reservoir that exhibit significantly higher dust concentrations than others. The null hypothesis for this ANOVA is:

H_0: There is no significant difference in the mean dust concentration between all 16 E-Sampler instrument locations.

Table 8: ANOVA Summary Table for All E-Sampler Data

Source	Sum Squares	Degrees Freedom	Mean Squares	F	p-value
Groups	14.74	14	1.05285	9.51	$4.63567e^{-20}$
Error	111.729	1009	0.11073		
Total	126.469	1023			

Since p = $4.63567e^{-20} < 0.01$ 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 beaches within the dataset that contain mean dust concentrations that are significantly different that the rest.

The following table provides a Site Name/Boxplot Key to reference the groups shown in Figure 26. Note that Moody Beach data were not included in the analysis since they were considered incomplete and with error.

Table 9: Boxplot Site Key

Site Name	Boxplot Key	Site Name	Boxplot Key	Site Name	Boxplot Key	Site Name	Boxplot Key
Tsay Keh Beach	1	83Km	6	Omineca	11	Bruin	16
Middle Creek North	2	Davis North	7	Tsay Keh Town	12		
Chowika	3	Rat Lake	8	57Km	13		
Collins	4	Davis South	9	Ingenika	14		
Moody	5	Van Somer	10	Shovel	15		

Figure 22 below is a box and whisker plot showing the results of the ANOVA. The group key in Table 9 can be used to decode which group corresponds to which monitoring stations. Groups 1, 2, 4, 7, 13 and 16 contains significant outliers as indicated by the red "+" sign in Figure 26, which corresponds to sites Tsay Keh Beach, Middle Creek North, Collins Beach, Davis North, 57km and Bruin Beach. These sites are all beach sites that are located in emissive zones. 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 Omineca, as indicated by Groups 10 and 11 on Figure 26 are not driving the significance but they do contain outlier values that are close to 1.0 mg/m^3. As is expected sites such as Chowika and Ingenika as indicated by Groups 3 and 14 on Figure 26, report values that are significantly smaller than the remainder of the dataset as well as fewer outliers.

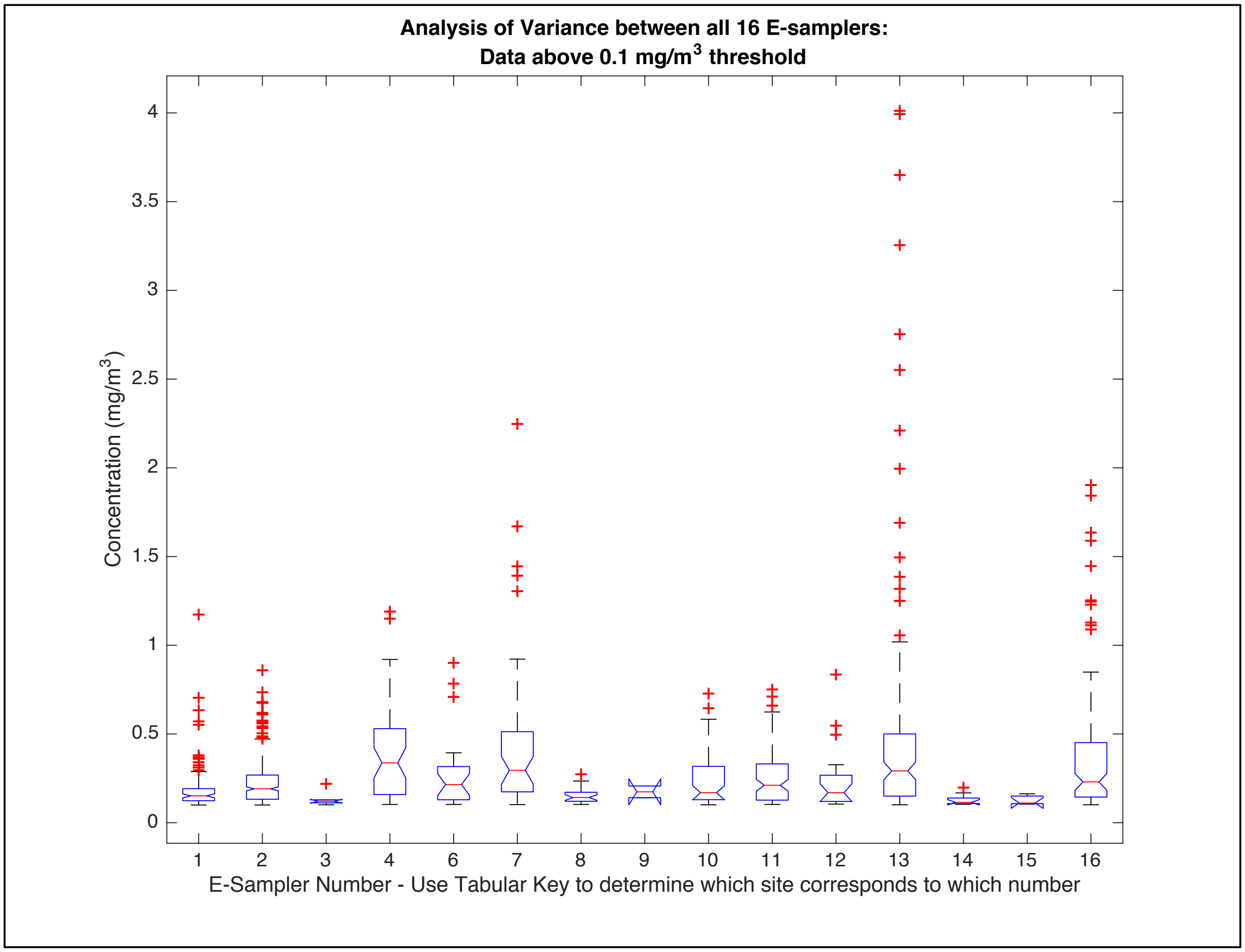


Figure 22: Results of ANOVA for entire 16 E-Sampler Dataset.

2.3.1.3 ANOVA Between E-Samplers Located in Non-Erosive Areas

Since significant differences in mean dust event concentrations were identified above in Section 2.3.1.2, 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. We 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 10: ANOVA Summary Table for E-Sampler Data from Non-Erosive Locations

Source	Sum Squares	Degrees Freedom	Mean Squares	F	Prob > F
Groups	0.31785	4	0.07946	3.47	0.0114

Error	1.8297	80	0.02287
Total	2.14755	84	

Since p = 0.0114 > 0.01 we may not reject the null hypothesis at a 99% confidence interval and therefore the mean dust concentration values between the E-Samplers located at non-erosive sites are not significantly different at the 99% confidence interval. Note that Moody data are not included in this analysis, Moody is located in in the table as a place holder but it is not presented in Figure 27.

Relatively high values above 0.5 mg/m^3 were recorded at both 83km and the Tsay Keh Town site as indicted by the red "+" outliers in Figure 23. However, the relatively small range of values demonstrates that there is no significant difference between sites located in non-erosive zones for 2016.

Table 11: Boxplot Name Key for Non-Erosive Sites

Site Name	Boxplot Key	Site Name	Boxplot Key	Site Name	Boxplot Key
Chowika	1	Rat Lake	4		
Moody	2	Tsay Keh Town	5		
83km	3	Ingenika	6		

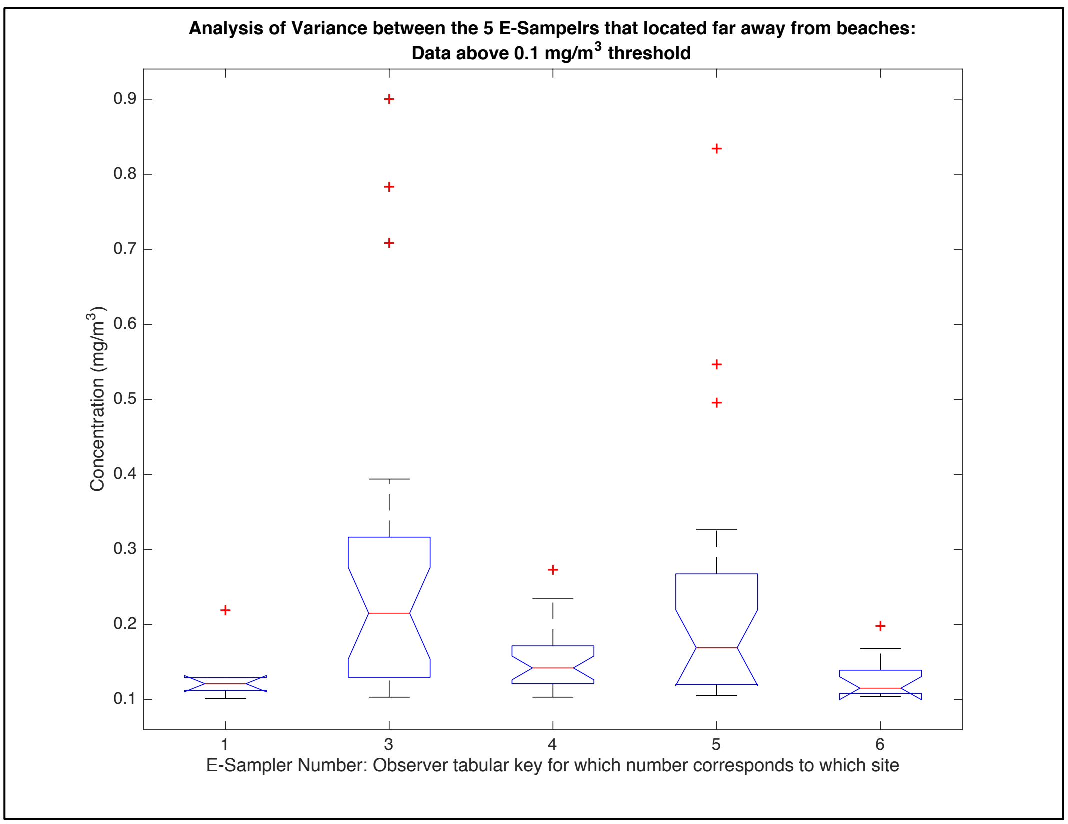


Figure 23: ANOVA Box and Whisker Plot for E-Sampler Data from Non-Erosional Sites

2.3.1.4 ANOVA Between E-Samplers Located in Erosive Areas

The second parsing of data represents the E-Samplers that are located in the moderate to highly erosive zones surrounding the reservoir. These include sites such as Middle Creek North and Davis North 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 12: Summary Values for the ANOVA of E-Sampler Data Collected in Moderate to highly Erodible Zones

Source	Sun Squares	Degrees Freedom	Mean Squares	F	Prob > F
Groups	13.635	9	1.51501	12.81	$2.28783e^{-19}$
Error	109.899	929	0.1183		
Total	123.534	938			

Since p = $2.28784e^{-19} < 0.01$ we may reject the null hypothesis at a 99% confidence interval. Therefore there is significant differences in dust concentration values between E-Samplers located in moderate to highly erosive zones.

Table 14 provides a key that indicates which site corresponds to the group indication on Figure 24. Groups 4, 8 and 10, corresponding to Davis North, 57km and Bruin beach appear to contain the largest and greatest number of outliers as indicated by the red "+" sign in Figure 28. It would appear that these locations are driving the significant differences found in the 2016 dataset. Beaches such as Middle Creek North and Omineca, which are often two of the highest emitters, were not in 2016. Although the greatest number of dust events was recorded at Middle Creek North in 2016, the magnitude of these dust events was much lower than normal. 57km, which in the past has been an average location, recorded very large dust concentrations in 2016, perhaps indicating that wind intensities on this site of the reservoir were higher than average in 2016.

Table 13: Boxplot Reference Key for Figure 25

Site Name	Boxplot Key	Site Name	Boxplot Key
Tsay Keh Beach	1	Van Somer	6
Middle Creek North	2	Omineca	7
Collins	3	57km	8
Davis North	4	Shovel	9
Davis South	5	Bruin	10

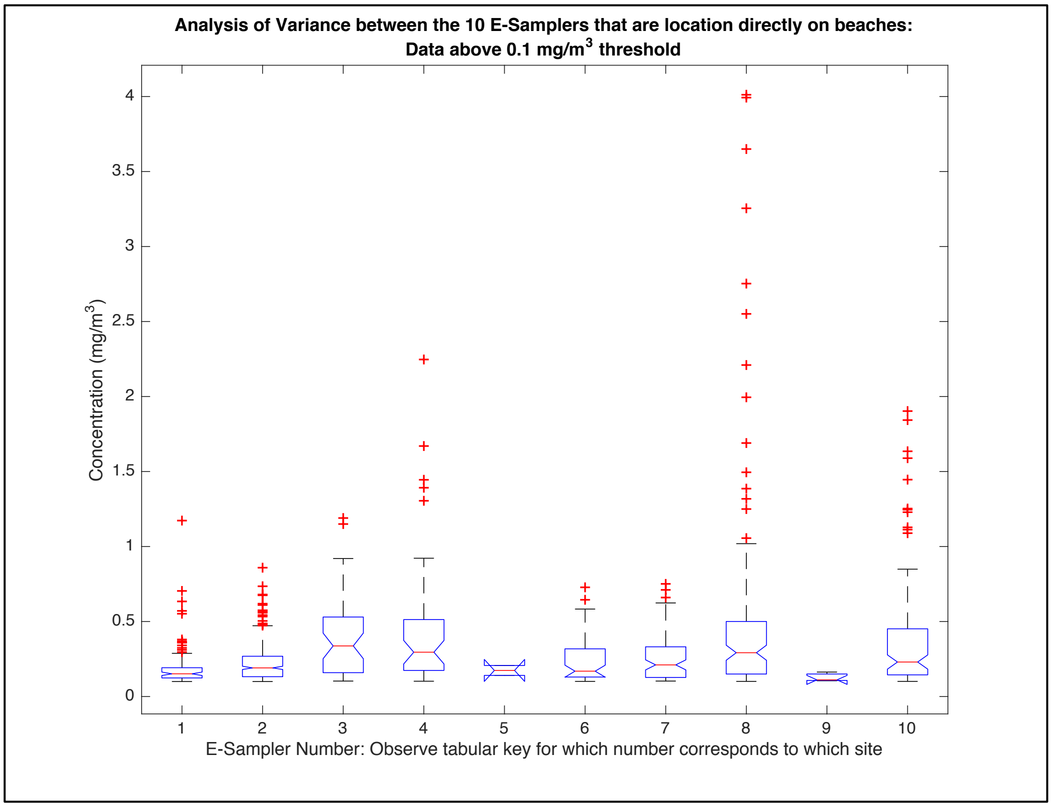


Figure 24: ANOVA Box and Whisker Plot for E-Sampler Data from Moderate to Highly Erosional Beach Sites.

2.4 General Discussion Related to the Regional Monitoring Network

Chu Cho Environmental's updated continuous monitoring network has given us the ability to observe the small-scale and migrating events that would otherwise be missed with periodic non-continuous sampling. Examples such as those shown in Figures 20 through 24 in Section 2.2.4 provide powerful examples of the type of analyses we are able to conduct with the data collected by the new Regional Monitoring Network. This will ultimately allow us to observe, on a much more detailed level, the impact that mitigation treatments are having on reservoir dust concentrations.

The results presented in this report represent a preliminary approach to the analysis of this dataset. Significant improvements in terms of rigor and approach will be made moving towards the final 10-year dataset analysis in 2018.

Network Component II: Reference Monitoring Network

3.0 Reference Monitoring Network

3.1 Network 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, 2013). The suite of criteria that are applicable to this report include the Provincial Ambient Air Quality Objectives (AQOs), the CAAQS and the Pollution Control Objectives (PCOs) of industry. The most recent revisions to the BC Ambient Air Quality Objectives were accepted in June 2013. Those that are relevant to this project include:

Table 14: Air Quality Objectives and Standards Relevant to this Project

Contaminant	Average Period	Objective/Standard	Date Adopted	Source
PM2.5	24 Hour	28 μg/m^3	2013	CAAQS
PM2.5	Annual	10 μg/m^3	2013	CAAQS
PM10	24 Hour	50 μg/m^3	2005	Provincial AQO
Dustfall	1 Month - Lower	1.7 mg/(dm^2*day)	1979	PCOs for Mining, Smelting and Related Industries
Dustfall	1 Month - Upper	2.9 mg/(dm^2*day)	1979	PCOs for Mining, Smelting and Related Industries

3.1.1 GMSMON#18 Air Monitoring Network Characterization

The reference monitoring network managed by Chu Cho Environmental in the Finlay Valley meets or exceeds the above criteria as it consists of two major monitoring stations located approximately 72km apart in villages with less than 400 people each. The monitoring station in Tsay Keh Dene is located approximately 450m away from the edge of the major source which affects the village (the reservoir) and is sited away from any structures or other impediments to air flow that might bias the sample. The monitoring station in Kwadacha is located approximately 75km away from the reservoir along the Rocky Mountain Trench and within the village is sited reasonably far away from structures and other impediments to airflow. The spatial distribution of these samplers fits within the Regional Scale category for monitoring and since the populations of both Tsay Keh Dene and Kwadacha are less than 400 each, our Reference Monitoring Network is considered adequate to meet the standards for CAAQS reporting as well as Special Studies (British Columbia Air Protection Section Environmental Quality Branch, 2006). However, it is not the intention of the project to use this monitoring network for this purpose. 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.

Figure 25 below, shows the location of each monitoring station within the Finlay Valley relative to the reservoir. The Finlay Valley tends to direct the wind flow either northwest or southeast; all recorded dust events are generated by southeasterly winds. The valley is approximately 10km wide at Tsay Keh Dene and narrows to less than 4km at Kwadacha. Figure 26 shows the Tsay Keh Dene monitoring station outfitted with an E-Sampler, 2 BGI PQ200s, relative humidity/temperature sensor, barometric pressure sensor, rain gauge, and a wind speed/direction monitor. Figure 27 shows the Kwadacha monitoring station outfitted with a relative humidity/temperature sensor, barometric pressure sensor, rain gauge, and a wind speed/direction monitor.

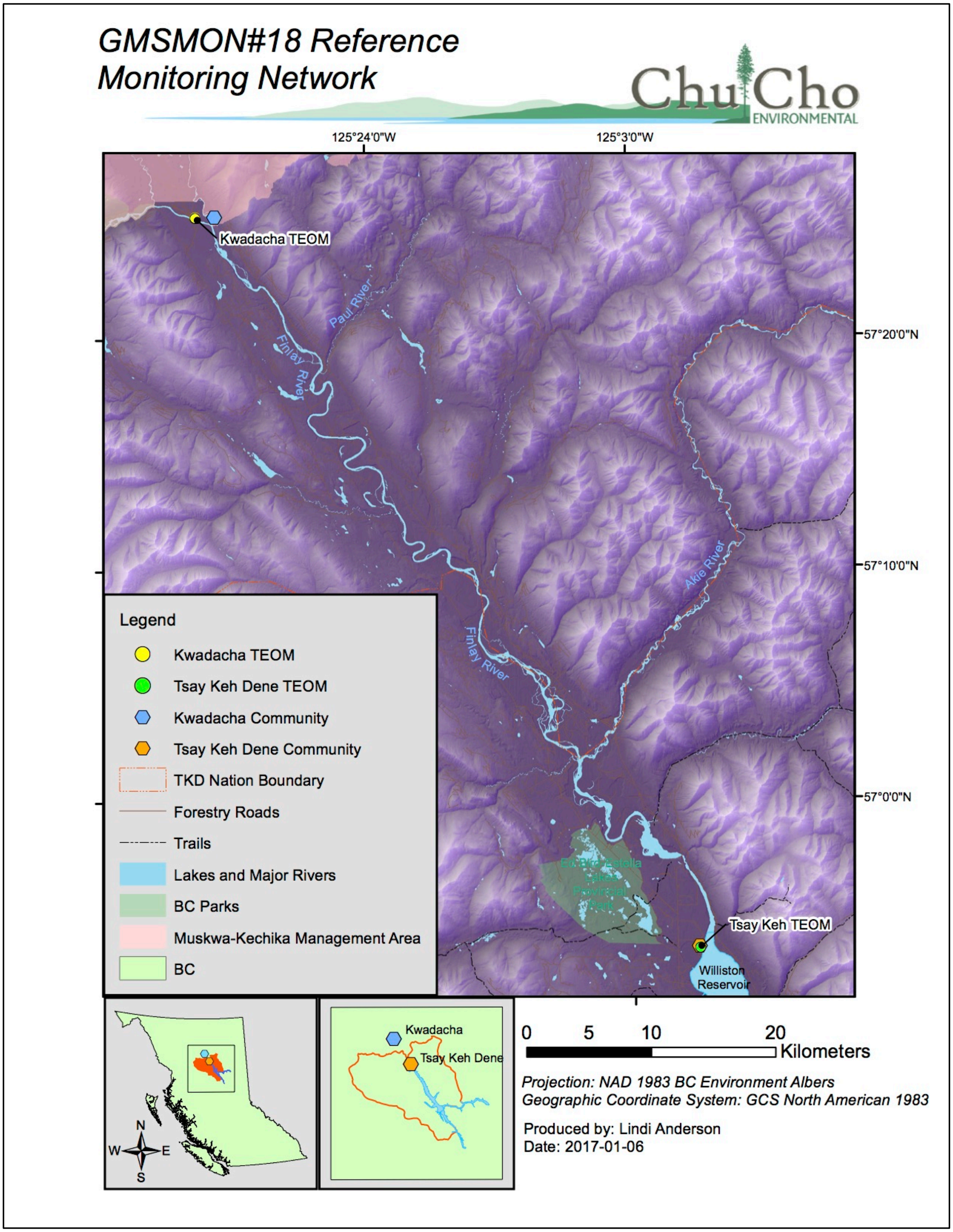


Figure 25: GMSMON#18 Reference Monitoring Network

Figure 26: Tsay Keh Dene Air Monitoring Station

Figure 27: Kwadacha Air Quality Monitoring Station

3.1.2 Instrumentation

The GMSMON#18 air quality monitoring project uses both Federal Reference Monitoring (FRM) and Federal Equivalent Monitoring (FEM) equipment for measuring and verifying air quality.

FEM:

- Thermo-Fischer Scientific TEOM 1405-D Dichotomous Ambient Particulate Monitor.
- U.S. EPA Designation EQPM-0609-182 for $PM_{2.5}$ (U.S. EPA 2012)
- U.S. EPA Designation EQPM-1090-079 for PM_{10} (U.S. EPA 2012)
- FEM instruments estimate mass concentration by using an active sensor to determine the particle concentration within a flow-controlled air stream where the sample is collected. The sensor responds to the presence of particles in the air stream and is designed to measure the mass concentration of particles in the air stream with a known precision and accuracy.
- 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, thus 2014 represented the 3rd complete year of operation for the system. 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. Chu Cho Environmental will use the unprocessed high frequency data that is stored on the TEOMs internal memory to verify as best as possible the data from this record but with no maintenance records the data will not be considered valid for use in CAAQS determination. Furthermore, TEOMs themselves are a notoriously unreliable instrument suffering frequent breakdowns that stop the collection of valid data. In 2015, the TEOM in Kwadacha suffered a circuit board failure. This TEOM was removed on July 7th, 2015, sent to the manufacturer for repair and wasn't returned until April 2016, at which point the drive pump suffered catastrophic failure. The Kwadacha TEOM was repaired and brought back online once again in July 2016. The TEOM functioned well until November 2016 when the pump suffered failure again. The system will be brought back online again in February 2017. TEOMs are known to have a multitude of reliability issues hence the provincial decision to migrate to the Thermo Sharp 5030. The TEOM in Tsay Keh Dene performed well during 2014, 2015, and 2016 seasons, however Chu Cho Environmental did have to replace the flow controller circuit board in this TEOM as well as perform several maintenance procedures that resulted in some limited loss of data. Overall the Tsay Keh TEOM data are of good quality while the Kwadacha data are of poor quality.

Given the lack of legacy maintenance records, unknown data quality from previous years and large portions of missing data, we are unable to perform a proper CAAQS determination for this report. 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 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 and Kwadacha and to work towards addressing the key management question. Once we obtain proper service records and have created the algorithms required to process the high frequency TEOM data, it is our plan to include a CAAQS determination calculation for $PM_{2.5}$.

In 2017, 2 FRM instruments will be co-located in Tsay Keh Dene with the FEM sampler and will be used for data validation and verification.

FRM:

- BGI PQ200 Ambient Particulate sampler.
- U.S. EPA designation RFPS-0498-116 for $PM_{2.5}$ (U.S. EPA 2012)
- U.S. EPA designation RFPS-1298-125 for PM_{10} (U.S. EPA 2012)
- BGI PQ200s are robust and easily configurable for $PM_{2.5}$ or PM_{10} applications.
- BGI PQ200s do not provide continuous PM monitoring and require significant labor costs and analysis costs for collecting air quality data.
- From 2012 – 2013 these were the primary instrument used to address the key management question posed by GMSMON#18 however, Chu Cho Environmental does not believe that these instruments are capable of doing this for two reasons:
    - These instruments can only record 24-hour average data and we know that reservoir dust storms may be short and sporadic in duration.
    - The labor costs in managing the instruments constrain the number of devices that can be deployed around the reservoir.
    - For these reasons the BGI PQ200 units are no longer being used to address the GMSMON#18 key management question.

- The BGI PQ200 units are used as independent verification tools for examining the validity of the TEOM 1405-D data.

- FRM Machines use a standard air filter that becomes loaded with particulate as air is pulled through the instrument. These filters are usually 47mm in diameter and must be placed in a sealed chamber across the flow path. Air is pulled though the instrument at 16.67 lpm for 24 hours. The filters are removed after 24 hours in the machine and are sent to a lab for gravimetric analysis to determine the mass of the particles that were deposited on the filter. Using the mass of particulate on the filter, the flow volume and the time that the filter was in the instrument the particulate concentration is calculated in $\mu g/m^3$.

3.1.3 Reference Monitoring Network Data Quality Objectives

When assessing the data obtained from the Reference Monitoring Network 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.
- Comparability:
    - We maintain a small subset of filter based monitoring instruments that are used to collect samples at random times for comparison to TEOM 1405-D data. These data

are used to provide assurance that the TEOM 1405-D units are maintaining proper function through time. Note, these instruments were not used in 2015 but will be in 2016.

- Averaging Period:
    - TEOM 1405-D data are measured at 1Hz 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. For CAAQS determination the analysis is expanded to focus on the entire annual dataset and moving forward will incorporate the data collected since 2011.
- 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 meters 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 meters 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 and is completed 4 times annually.
    - 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 catalog the processes that lead to successful achievement of the DQOs.

3.1.4 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 utilizes a strict schedule of sites visits, instrument calibrations and audits and data validation.

TEOM 1405-D air samplers require that the primary air filters be changed every 6 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 air tight,
- Inspection of numerical data recorded by the dataloggers 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 and 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 securely inside the TEOM enclosure. Data in this logbook are transcribed into a Word document at regular monthly intervals. 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.

3.2 Reference Monitoring Network Data Overview

For this Year-9 final report we will analyze the 2016 datasets from the period covering January 2016 to December 2016, collected at both Tsay Keh Dene and Kwadacha. Note: The Kwadacha TEOM data only spans the months from July 2016 to October 2016, however the meteorology data spans the entire year and is of consistent and of high quality.

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

Figure 28 (a) through (d) shows plots of the 24-hour average meteorology and air quality data recorded at the Tsay Keh Dene monitoring station during between the period spanning January 2016 to December 2016.

Meteorology:

In general, the 2016 dust season was similar to an average or typical dust season where there were a number of dust events related to frontal systems but it was neither particularly wet nor dry. However, 2016 was dryer than the 2011, 2012, and 2013 (Nickling et al. 2013) seasons, and similar to the 2014 season (Tilson, 2015). The 2016 season was significantly more dusty and windy than the 2015 season (Tilson, 2016). There were several large dust events lasting longer than 12 hours and a number of smaller events lasting less than 12 hours. Although there were rain events between the months of April and June they were not particularly heavy and as noted in the past, large dust events tend to be associated with rain events because of the high winds associated with the drop in pressure (Nickling et al 2013). Even though most large frontal systems move across the valley west to east, winds in Tsay Keh Dene are typically oriented along the Finlay Valley and so either arrive from the Northwest or Southeast. Wind speed and wind direction are shown in

Figure 28 (b). Wind speeds in 2016 were not particularly high, however they were consistent and frequently reached speeds above 3.0 m/s. Contrast this with 2015 when days with wind above 2.0 m/s were rare and there was only a single dust event.

Precipitation and relatively humidity are shown in Figure 28 (d) and air temperature and air pressure are shown in Figure 28 (c). These values all charted a typical course over the dust season and the year in general. It was not a particularly hot and dry dust season with average temperatures ranging from approximately 0^0C in April/May to approximately 10^0C by June.

24-Hour Average Dust Concentrations:

24-hour average PM concentrations are shown in Figure 32 (a). The brown line represents PM_{10} and the green line represents $PM_{2.5}$. The colour coded dashed lines across the plot represent the Air Quality Objectives (AQOs) of 50 μg/m^3 for PM_{10} and 28 μg/m^3 for $PM_{2.5}$ (CCME, 2012).

On Figure 28 (a) there are 2 large spikes in January and then again in September. The January spikes are related to wood smoke from home heating while the September spikes are related to open burning of slash piles and reservoir debris. Exceedence values observed between the months of April and July are related to dust events. Table 16 shows the 24-hour average value for days where the $PM_{2.5}$ value was greater than 28 μg/m^3 and the PM_{10} value was above 50 μg/m^3. It is clear that PM_{10} values in excess of 50 μg/m^3 are not necessarily associated with $PM_{2.5}$ values that are in excess of 28 μg/m^3. For example the wood smoke event on January 28th, 2016 saw only a very modest increase in PM_{10} while the $PM_{2.5}$ was 33.5 μg/m^3. The fall wood smoke events associated with slash burning are significant in magnitude and suggest that better care should be taken to ensure that the proper venting index is in place before burning can occur.

The large spikes in both the green and brown lines between April and June are related to large dust events, there were 6 instances in 2016 when the 24-hour average PM_{10} reading on the Tsay Keh TEOM rose above 50 μg/m^3, with the highest being May 20th at 401.5 μg/m^3, the instantaneous maximum value on this date was 924.0 μg/m^3, which is nearly the limit of the capability of the instrument. The storm on May 20th, 2016 lasted 2 days; the May 21st 24-hour average reading was 93.2 μg/m^3. Over the same storm period, $PM_{2.5}$ was 31.5 μg/m^3 on May 20th and fell to near zero on the 21st. There were 9 instances where the 24-hour average $PM_{2.5}$ valued reached numbers in excess of 28 μg/m^3.

Table 15: 24-hour average 2016 PM_{10} and $PM_{2.5}$ values that were above the provincial AQOs and federal CAAQS.

Date	PM_{10} Value (μg/m^3)	Suspected Cause	Date	$PM_{2.5}$ Value (μg/m^3)	Suspected Cause
01-May-16	122.9	**Dust Event**	**28-Jan-16**	33.5	**Wood Smoke**
17-May-16	50.8	**Dust Event**	**05-Feb-16**	38.5	**Wood Smoke**
20-May-16	401.5	**Dust Event**	**18-May-16**	44.3	**Dust Event**
21-May-16	93.2		**20-May-16**	31.5	**Dust Event**
03-Jun-16	79.1	**Dust Event**	**30-Aug-16**	39.2	**Wood Smoke**

02-Sep-16	110.4	**Wood Smoke**	**31-Aug-16**	43.2	**Wood Smoke**
			01-Sep-16	45.6	**Wood Smoke**
			02-Sep-16	116.6	**Wood Smoke**
			09-Sep-16	45.9	**Wood Smoke**

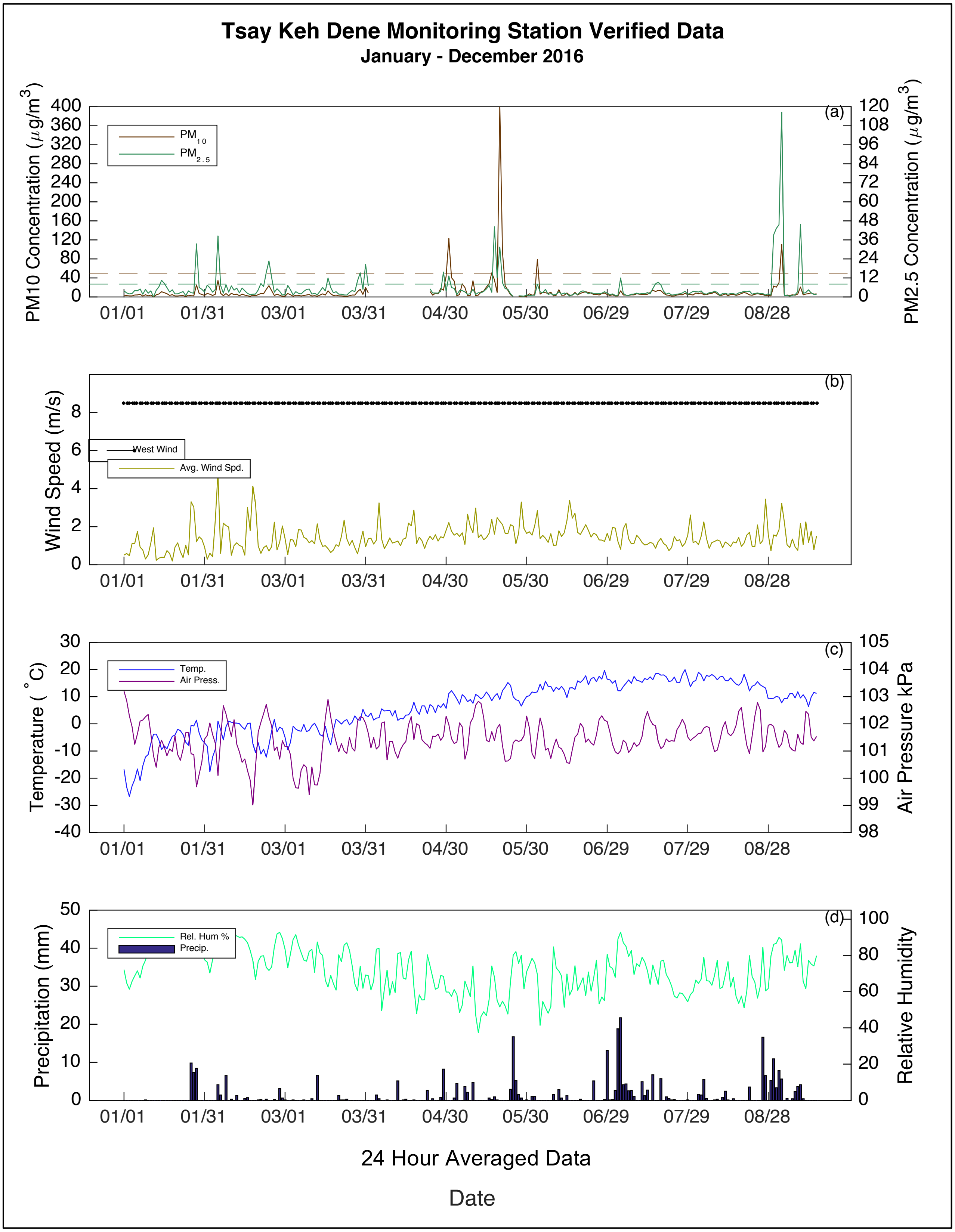


Figure 28: 2016 Tsay Keh Dene Air Quality Monitoring Station Data – 24-Hour Average Data

3.2.2 Maximum Particulate Concentrations

Using the 24 hour metric for reporting air quality 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. 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, calculation of a 24-hour average tends to minimize the actual impact of these acute dust events.

Figure 29 (a) and (b) shows the un-filtered 10-minute averaged TEOM PM_{10} and $PM_{2.5}$ for Tsay Keh Dene recorded between April 15th, 2016 and June 25th, 2016. ***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.***

During the period between April 15th, 2016 and June 25th, 2016, there were a number of spikes that represent large volumes of particulate entering the airspace around the TEOM 1405-D for a short period of time. Although the spikes are large and the volume of dust emitted may be large, when averaged over a 24 hour period the concentration falls below the provincial AQOs and federal standards.

Our project team would like to reiterate that this analysis only meant to draw attention to the high frequency, high intensity, short-duration nature of the dust events in Tsay Keh Dene and is no way meant to be compared to the Federal or Provincial standards discussed above in Section 3.

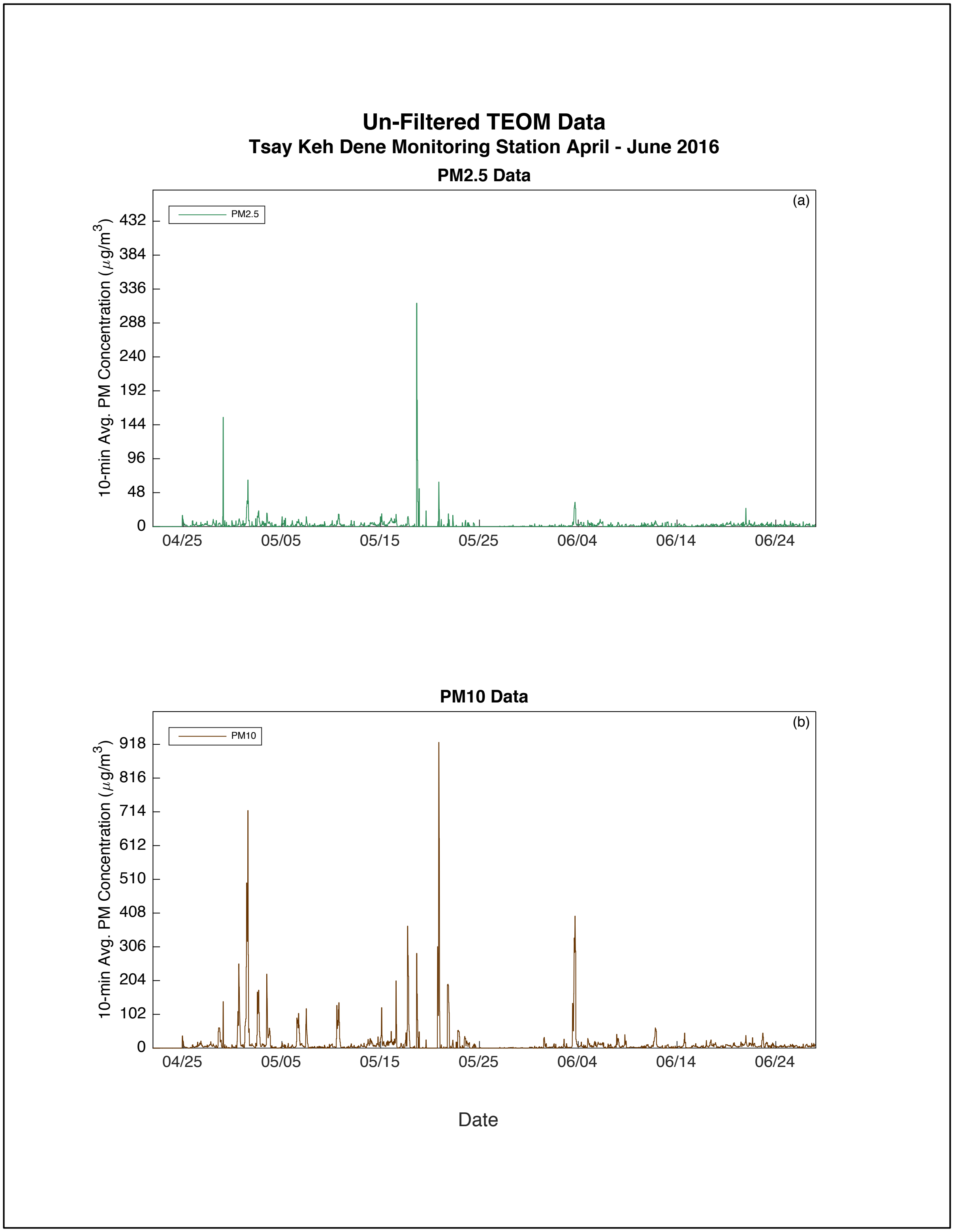


Figure 29: Raw 10-Minute Average TEOM Data for the 2015 Dust Season.

3.2.3 Kwadacha Monitoring Station 24 Hour Average Air Quality and Meteorology Characterization

There were zero exceedences of the Provincial AQO for PM_{10} and zero exceedences of the Federal CAAQS for $PM_{2.5}$ during the 2016 dust season in Kwadacha.

The data collected by the TEOM in Kwadacha are inconsistent and due the poor reliability of the TEOM 1405-D and the remote location of the install, there were a number of long duration periods were no PM data were collected. PM data only exists for the months of July 2016 through October 2016. Meteorology data spans the entire year because of the high reliability of the instruments and the CR1000 datalogger. This TEOM was brought back online again in February 2017.

Average wind speed in Kwadacha is generally lower than that recorded in Tsay Keh Dene and usually does not rise above 2.0 m/s with the exception of larger winter storm events. Precipitation trends in Kwadacha were similar to Tsay Keh Dene with average volumes through the spring and an increase through the summer and fall.

3.3 Data System and Remote Access

Data from the TEOM units and associated meteorological equipment are accessed and displayed in several different ways. Our goal is to provide the highest level of data security and reliability by using multiple redundant systems that record, process, store and distribute the data. We are also looking at methods to continue to improve the ways in which people can view and interact with the data collected by the air quality monitoring network. To date, we have implemented the following system changes to improve connectivity, security and access:

Community Data Display:

Data are currently being streamed from the dataloggers using Campbell Scientific RF401 spread-spectrum 900 MHz radio transmitters and receivers. Campbell Scientific provides hardware and software that can be manipulated to display in real-time the data that are collected by the TEOM 1405-D and meteorological equipment. An omni-directional antenna that broadcasts the 900 MHz signal is mounted on the TEOM enclosure and is powered by the RF401. A second RF401 receiver unit equipped with a whip-antenna is attached to a laptop that is running Campbell Scientific's LoggerNet software. This computer is connected to a 32" TV that is wall-mounted in each band office. This system has proved extremely reliable, requiring only limited intervention to reset following system faults. We will continue to update the data display to keep it relevant and interesting.

Eagle.io:

All data are now available through a remote data access service called eagle.io. eagle.io is a web-based service that can access the data collected by the CR1000 datalogger through the Campbell Scientific NL200 Network Link Interface. eagle.io queries the NL200 for data every 10-minutes, collects that data and then updates the database and the website. These data are available online at the refresh interval and can be viewed in several different ways including a list view, map view, or a dashboard view that contains small widgets to show the data.

Each page is available on eagle.io and can be shared and viewed in a non-editable public profile by anyone who chooses to look. We will be updating our eagle.io profile in the coming months to take full advantage of the functions offered by eagle.io.

If there are readers who are interested in accessing these data, please consult info@chuchoenvironmental.com for more information.

Daily email:

Data from the CR1000 datalogger are downloaded over an RS-232 serial connection to a server computer located inside the TEOM enclosure. These data are processed into 10-minute averages and are then appended into 12-hour data files. After the processing is complete, the 12-hour data file is emailed to the project manager and field managers. Simultaneously the data are backed up to a system USB-key and are also uploaded the Chu Cho Environmental's ftp site. New for 2015 are a fourth and fifth layer of backup redundancy that includes a full system hard drive ghosting every 24 hours and a Dropbox backup of the key system and data files. If there is an issue with the data of if there is an issue with the TEOM of any of the meteorological instrumentation then a special email is sent out alerting the managers of the issue. This email provides a very quick way to check on the monitoring system to ensure that it is functioning properly.

www.logmein.com:

www.logmein.com provides remote desktop access to the server computers inside the TEOM enclosures. This is the most reliable method for creating remote access to these server machines that operate inside the VPN created by the Tsay Keh Dene IT group or Kwadacha IT group. This remote access allows us to reboot any component of the monitoring system and greatly improves our overall system reliability and up-time.

Looking ahead:

We will continue to look for ways to improve the overall reliability of the monitoring system and to create visuals that are more engaging and intuitive for people who are looking at and interpreting the data.

4.0 Dustfall Monitoring

Dustfall monitoring began in Spring 2014 in order to establish a baseline quantity for the volume of settleable particulate levels in the Tsay Keh Dene village area. Dustfall sampling is planned to take place from May to October for each year of this project, however in June of 2015 two of the project's dustfall stands were vandalized beyond repair or were thrown into the Williston Reservoir. Initially in 2016 our project team attempted to deploy 2 dustfall stands and again one was vandalized beyond repair. For this reason our team opted to maintain only a single dustfall stand located in the center of Tsay Keh Dene. This site has not ever been vandalized.

4.1 Equipment and Methodology

Dustfall sampling canisters prepared by ALS Environmental Laboratories were deployed at three locations in the vicinity of Tsay Keh Dene. The sample canister is a large 2-liter Nalgene bottle with a 4" diameter mouth that is open to the atmosphere. The sample canisters are opened, placed in a custom designed and built Dustfall stand and left alone to collect dust fallout for approximately 30 days.

Chu Cho Industries LLP built the Dustfall stands according to design specifications supplied by EDI Environmental Dynamics Inc. Each Dustfall stand has a holder for the Nalgene canister that provides protection from cross winds and has vertical spikes welded on the rim of the wind guard to prevent birds from landing on the stand and contaminating the sample.

After approximately 30 days the sample canisters are removed, resealed and shipped to ALS Laboratories for gravimetric analysis. At this time, another canister is opened and placed in the Dustfall stand. The mouth of the sample canister is located as near as possible to 2 meters above the ground.

ALS Laboratories provides three values following the analysis: Fixed Dustfall, Volatile Dustfall and Total Dustfall. The volatile fraction is those particulates that are carbon based and therefore volatize when the sample is heated. Generally, for this project we are concerned with the Total and Fixed Dustfall amounts since we know that the primary source of dust in TKD village is the reservoir beaches, which are comprised of silica based sands.

4.2 Network Characterization

Figure 31 shows the location of each sample site within Tsay Keh Dene village and relative to the reservoir. Table 18 provides a summary of the sampler ID, location and a site description. Each of the sample sites are shown in Figures 32 through 35.

Note that DF-TK-01 and DF-TK-02 were to be maintained through 2016, however given the vandalism in June; only a single sample was taken from DF-TK-02. DF-TK-01 was maintained through the entire season. Only DF-TK-01 will be maintained in 2017.

Table 16: Summary of Dustfall Monitoring Stations

Sampler ID	Location	Site Description
DF-TK-01	Adjacent to TEOM Monitoring Station	This site is very open and free from the influence of trees, buildings or other impediments to flow. The sampler is located approximately 450m from the reservoir.
DF-TK-02	Southern end of Tsay Keh Airport adjacent to a Finlay River cutbank.	This sampler is adjacent to the reservoir atop a cutbank where the Finlay River meets the Williston Reservoir across from Ruby Red Beach. There are no nearby trees, buildings or other impediments to airflow that would influence the sampler.
DF-TK-03	Adjacent to a household in Tsay Keh village	This sampler is located in a sparsely wooded area adjacent to a household in Tsay Keh village. Airflow in the vicinity of the sampler is moderately influenced by the nearby woody vegetation but the sample canister does not collect pine needles or other falling organics.

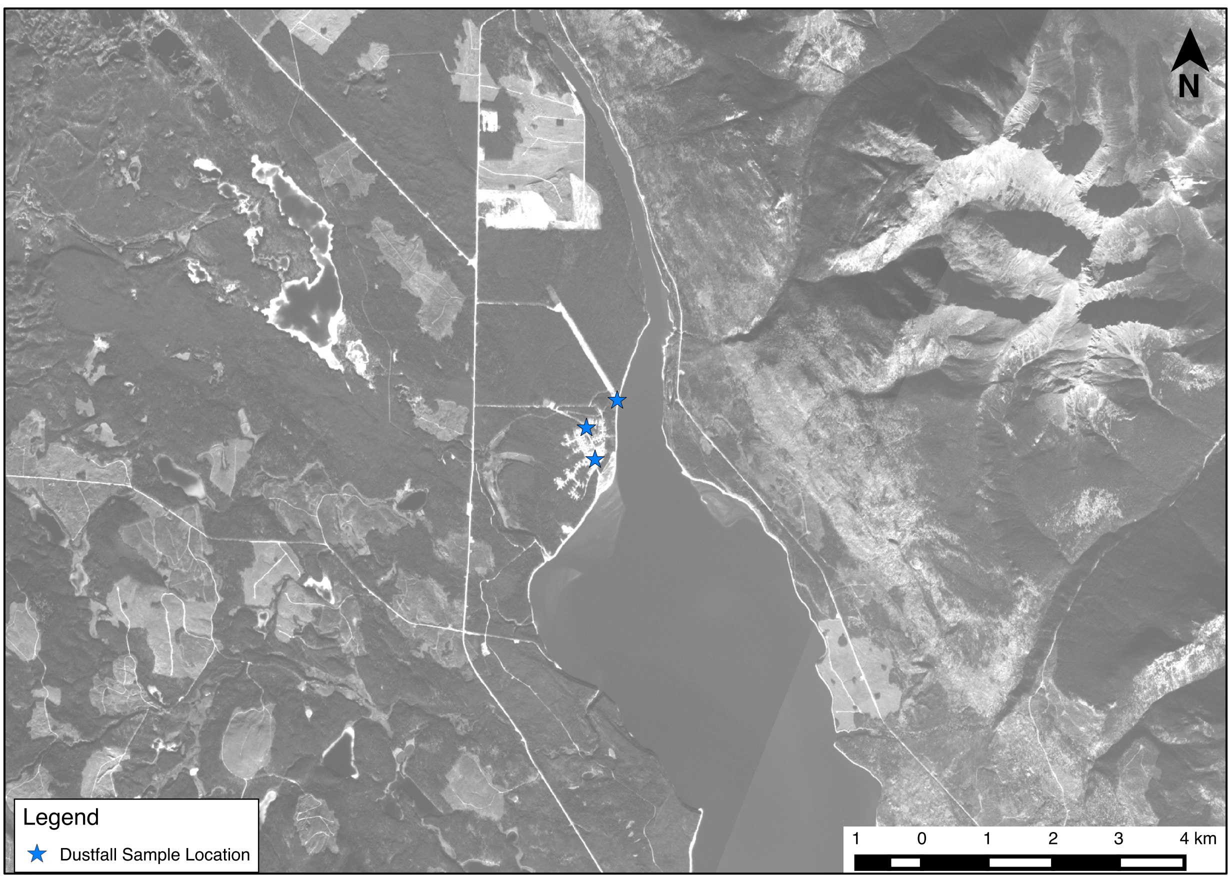


Figure 30: Tsay Keh Dene Dustfall Monitoring Network

Figure 31: DF-TK-01 Dustfall Sampler

Figure 32: DF-TK-02 Dustfall Sampler

Figure 33: DF-TK-03

4.3 Dustfall Analysis and Discussion

In British Columbia the lower dustfall AQO is 1.7 mg/dm^2*day while the upper AQO is 2.9 mg/dm^2*day (BC MoE, 2013). The only exceedence was registered at DF-TK-02, at 14.4 mg/dm^2*day. It is unfortunate that this site was vandalized as this generates suspicion about the validity of the data point. Given the relative largeness of this value and the fact there is no similarly large value recorded at DF-TK-01 there is reason to believe that the value recorded at DF-TK-02 is spurious and should be ignored as inconclusive.

Table 17: Dustfall Monitoring Network Summary Data

Site ID	Sample Date	Month	Fix. DF	Vol. DF	Tot. DF	Units	Det. Lim.
DF-TK-01	2016-04-29	May	1.23	0.34	1.57	mg/dm^2*day	0.1
DF-TK-02	2016-04-29	May	10.5	3.83	14.4	mg/dm^2*day	0.1
DF-TK-01	2016-05-29	June	0.79	0.86	1.65	mg/dm^2*day	0.1
DF-TK-01	2016-06-28	July	0.26	<0.10	0.28	mg/dm^2*day	0.1

DF-TK-01	2016-07-31	Aug	0.13	<0.10	<0.10	mg/dm²*day	0.1
DF-TK-01	2016-08-31	Sept	0.24	<0.10	0.32	mg/dm²*day	0.1

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 centered 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 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 within four of our employees and we expect continued growth through the future of this project.

Chu Cho Environmental now has full-time employees in Kwadacha and Tsay Keh Dene who are able to autonomously manage the basic maintenance and operation of the Air Quality Monitoring Stations. These employees possesses 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 stations 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 has been one of the greatest improvements in our program and has contributed to our overall success in reducing instrument downtime.

5.2 Community Engagement

Chu Cho Environmental is a band owned company and regularly participates in community events such as open houses or village gatherings where the exchange of information is encouraged between community members and organizations. We do not present unverified air quality data at these events but instead provide visuals and information related to the project and what we are doing to monitor and help improve the air quality in Tsay Keh Dene.

Chu Cho Environmental also built community data displays that are presented on TVs that are wall-mounted in the Tsay Keh Dene band office and the Kwadacha school. The data are broadcast in real-time from the TEOM enclosure using an RF401 900 Mhz spread spectrum radio transmitter and are received on an RF 401 that is attached to a computer which runs the TV data display. Figures 35 through 37 show sample screen grabs of the data display, note that there is no live data shown in these images. These displays are meant to be easy to read at a glance and will continue to be updated and refined as Chu Cho Environmental continues to manage the project. The data area broadcast from the monitoring station at the same frequency as they are being recorded by the CR1000 data logging system, this means the weather data are updated every 10 seconds and the air quality data are updated every 10 minutes.

This method of displaying the data is quite reliable but ultimately depends on a PC laptop running Windows 7 and so suffers crashes related to operating system failure. Maintaining and rebooting this system has also been incorporated into the training of the technicians who maintain the TEOM monitoring stations.

The new data display system includes the following major updates:

- More intuitive screen widgets to display the data,
- A "Last Data Update" timestamp that shows when the data were received,
- High quality graphics and visuals that are nice to view, and
- High frequency and increased reliability link to the data source.

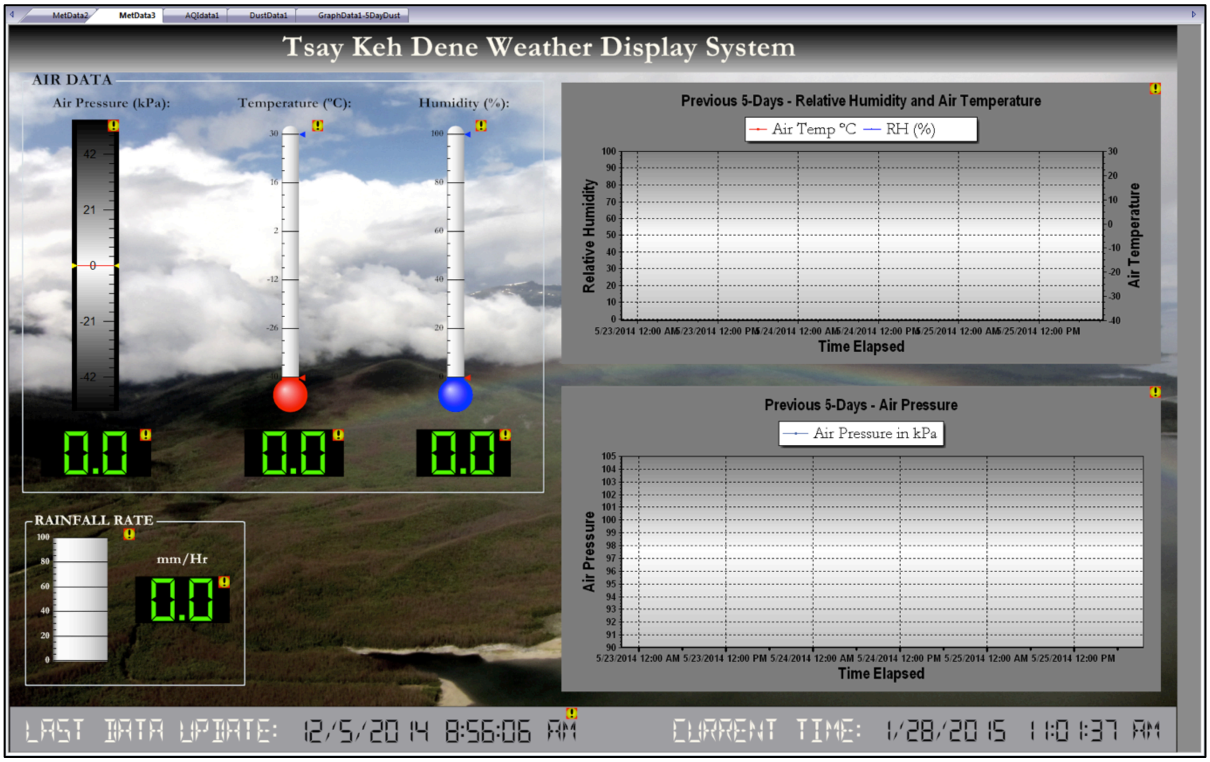


Figure 34: Data Display Air Parameters and 5-Day Charts

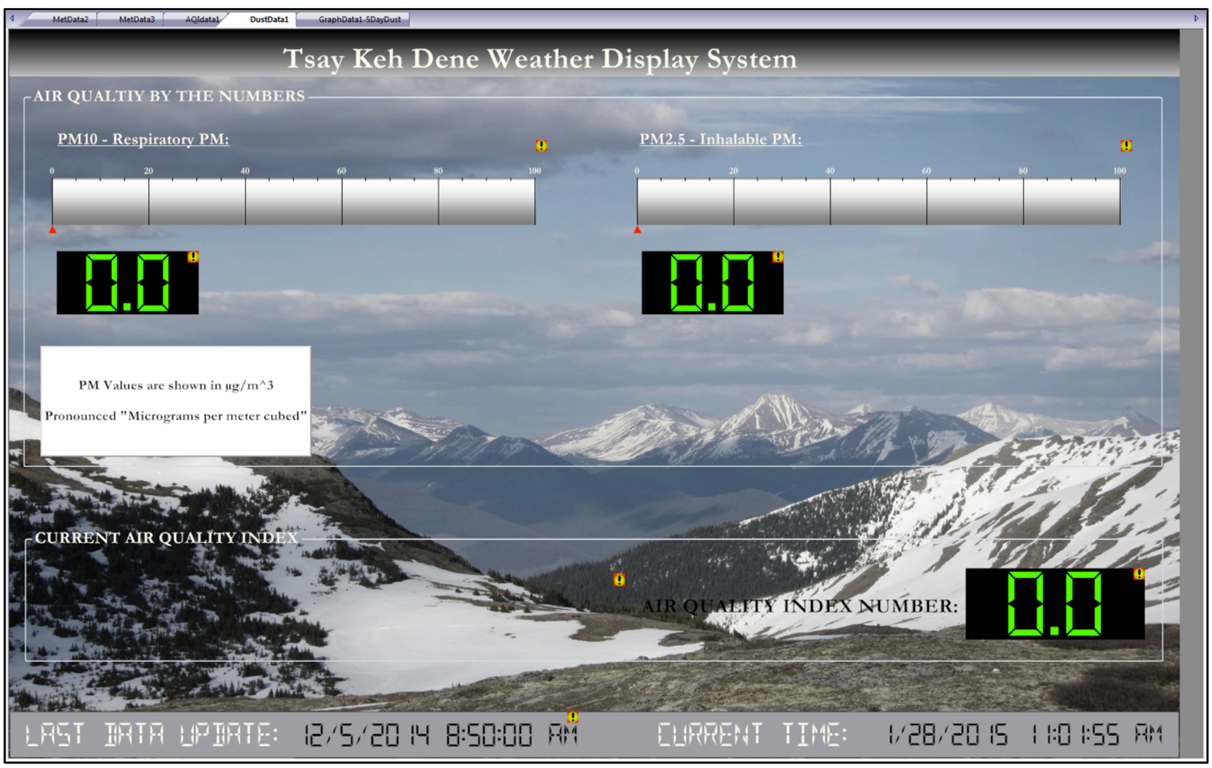


Figure 35: Data Display Air Quality Data and Air Quality Index

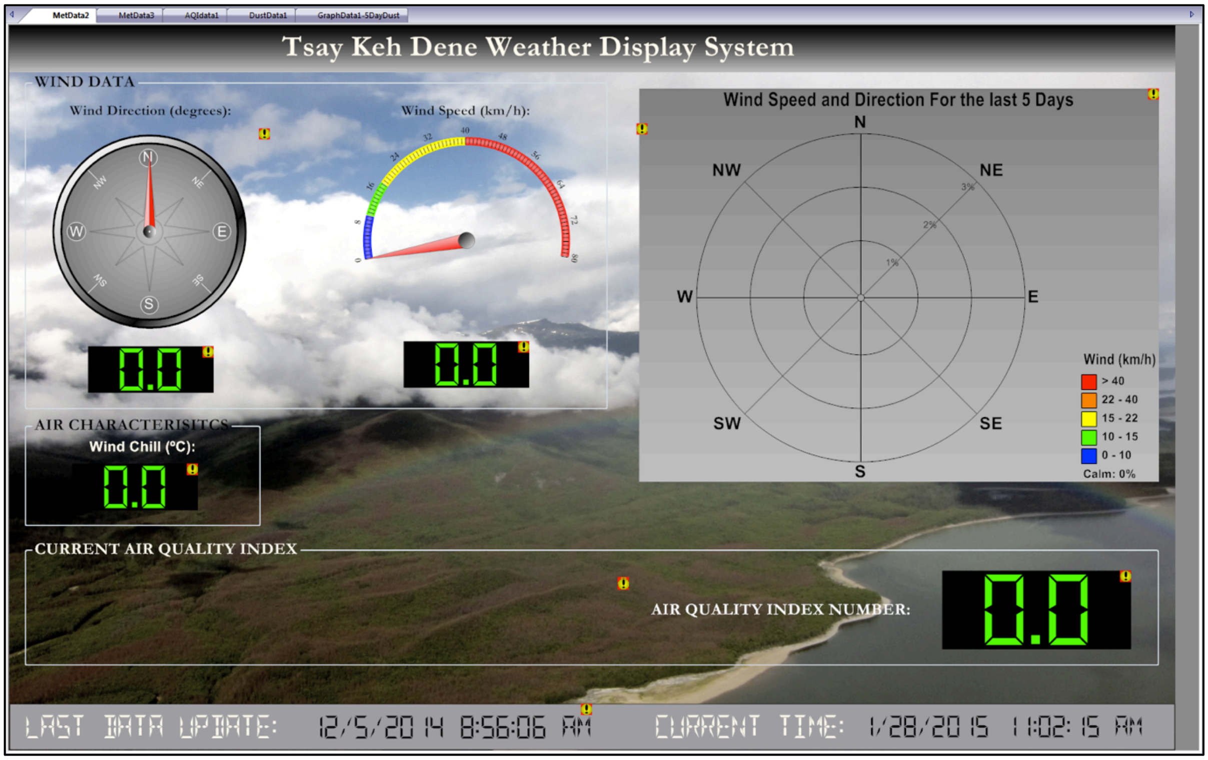


Figure 36: Data Display Wind Parameters and 5-Day Wind Rose

6.0 Discussion and Direction for 2017

6.1 Brief Summary for 2016

Through discussion with BC hydro representatives it was determined that Chu Cho Environmental would submit an annual report in January of each year. This report will be reviewed internally by BC Hydro and the edits will be delivered to Chu Cho Environmental by March/April of each year. Following this, Chu Cho Environmental will update and revise the report and will issue a final version by April/May of each year.

Each of the annual reports prepared by Chu Cho Environmental should ultimately be considered individual annual building blocks that will lead up to a comprehensive 10-year analysis report that will be prepared in 2017/2018.

It is our hope that through the review and revision process that we will gain insight into these data and will discover new perspectives through which to analyze these data, which will ultimately help our project team provide reasonably powerful answers to the key management question of GMSMON#18.

Overall, 2016 was a successful year for Chu Cho Environmental and the GMSMON#18 project with the exception of the repeated catastrophic failure of the Kwadacha Reference Monitoring Station. Our team has continued to collect an enormous volume of data that industry air quality experts (modelers in particular) have deemed unparalleled and unique. 2016 was a year of typical weather conditions for the region that gave rise to several large-scale valley wide dust events and a number of smaller localized dust events.

The primary finding presented somewhat repeatedly throughout this report is that dust storms are not discrete long duration events that always result in the exceedence of Federal and Provincial standards. Instead we must think of dust events as having dynamic impacts and a range of characteristics. Dust events can range in scale from isolated very short duration microburst type occurrences to very large, very long mega events.

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 good candidates for erosion control targeting.

Chu Cho Environmental would like to remind the reader that the analysis and conclusions presented in this report represent a very preliminary approach to examining the enormous amount of data collected by the monitoring networks. In 2014 and 2015, our analysis procedures were streamlined so that we were able to collect data immediately following an event and could have the data analyzed and reduced shortly after. Creating the database and algorithms required to perform these analyses is time consuming but well worth the effort. We continued this effort in 2016 adding iPads to the data capture routine so as to avoid using paper and notebooks for recording critical data. Once iPads are returned to the office each night, the data are synced and archived over Dropbox.

6.2 Direction for 2017

The following summary topics comprise a list of tasks and analysis procedures that we plan to incorporate into GMSMON#18 and future iterations of this report:

Winter 2017 Deployment:

Prior to 2015, air monitoring equipment was typically deployed during the first and second week of May. However, we know that there are early season dust events that occur prior to May when the beaches are exposed in April. The major impediment to setting equipment up earlier has always been snow cover and site access. For the 2016 season, Chu Cho Environmental rented two snowmobiles and a 6-seat Polaris Ranger on tracks, see Figure 38. This allowed us to successfully complete a full system setup by April 4th, 2016. We will continue this initiative in 2017. This early season setup is only made possible by the relatively high operating autonomy of the E-Samplers.

Figure 37: 2015 Winter Setup Crew and Equipment

Future Data Analysis:

Event Magnitude and Response in TKD:

- In 2014 we extended the heatmapping analysis excise to evaluate the processes of dust events that migrate throughout the reservoir and the associated responses of the air monitoring instrumentation throughout the Finlay Valley. For example, it was demonstrated that the May 20th, 2014 storm arrived at the southernmost samplers several hours before arriving in TKD. Moving forward we will work to isolate these events types so that we might fully understand the ways in which the storms develop and how the various confounding variable affect evolution of an event.

- *E-Sampler Flux Analysis:*
    - We will begin to evaluate the flux of sediment that passes the point of sampling for a given wind speed. This will provide the ability to discuss dust concentrations as an approximate volume of dust that enters and exits a particular reservoir zone.

Isolating the impact of reservoir rise from mitigation efforts:

- We have begun examining the rate of reservoir rise and the associated rate of beach inundation and how this relates to dust concentrations recorded by the regional monitoring network. We are currently working on a method to isolate the effect of mitigation treatments from the rate of beach inundation.
- Currently, we know that on any given day the rate of beach inundation has the potential to exceed the rate of tillage application by approximately 4 to 10 times depending on the water elevation. Ultimately this means that the treatable area could disappear very quickly and that we should evaluate our mitigation strategies to ensure that we are meeting the highest possible efficacy over the long term.

Rigorous Statistical Analyses:

- As we continue to collect more data we will be able to begin to focus on the issues from a long-term trend and statistical perspective. Moving forward we will incorporate advanced regression and statistical models into our reporting.

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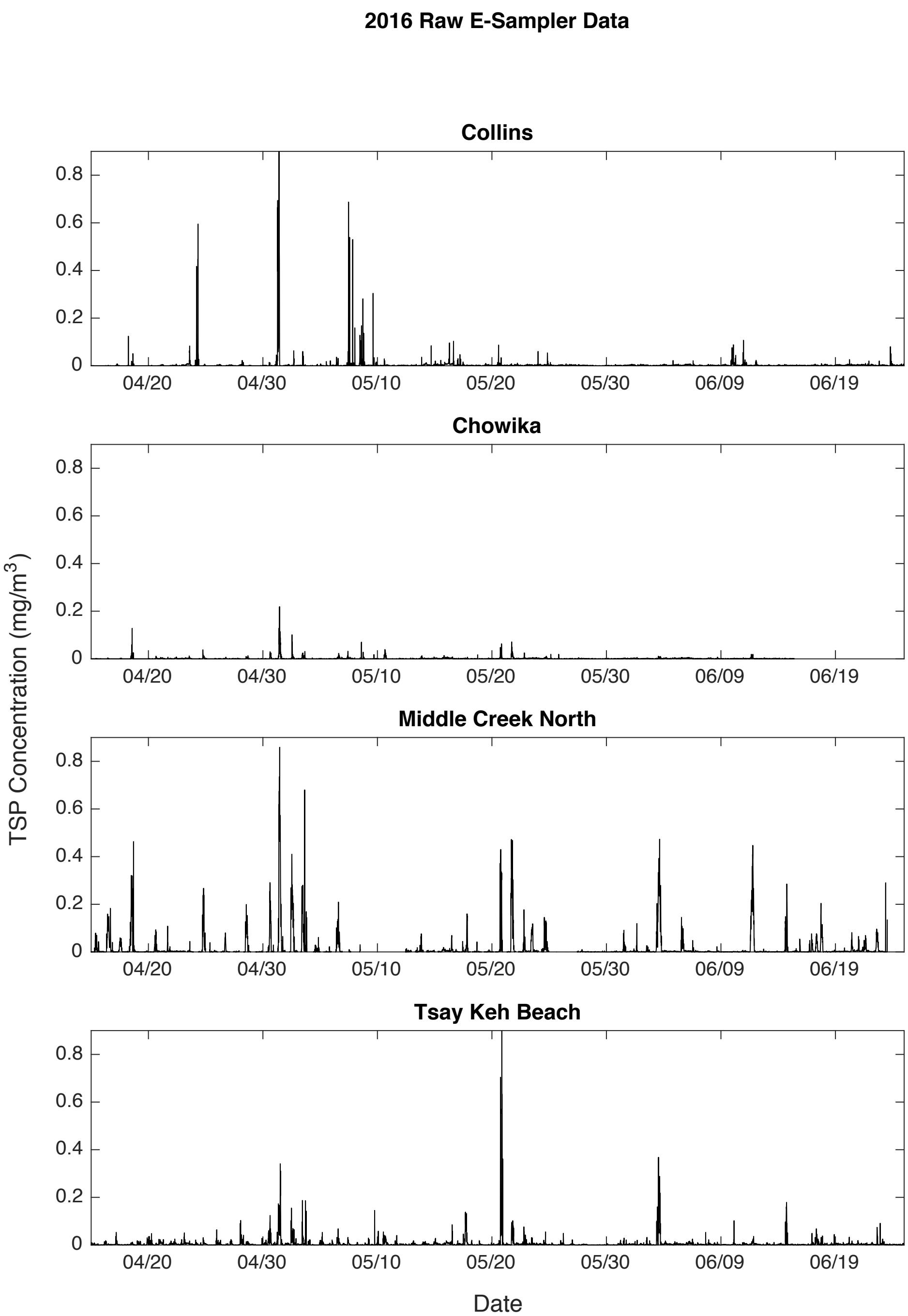
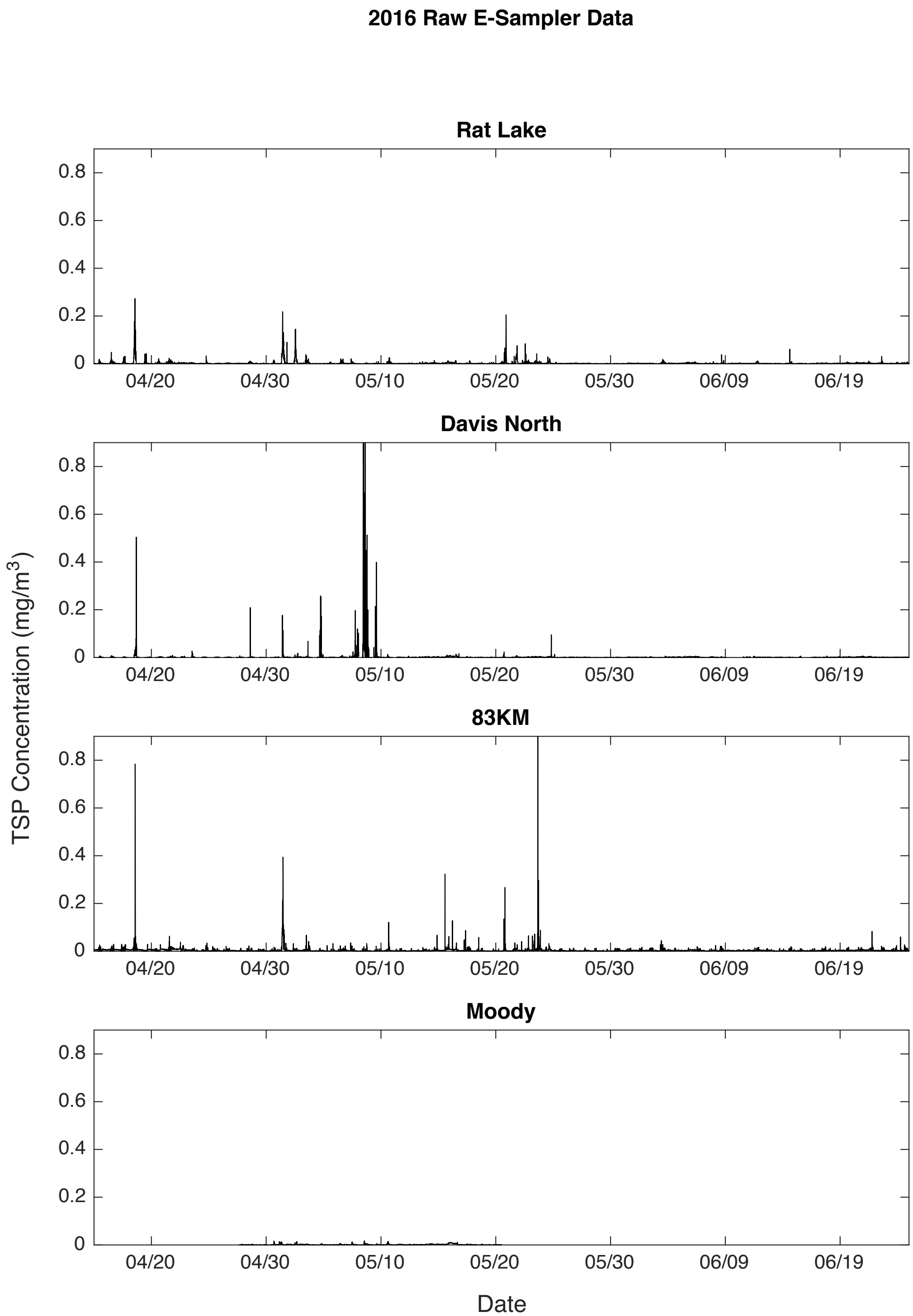
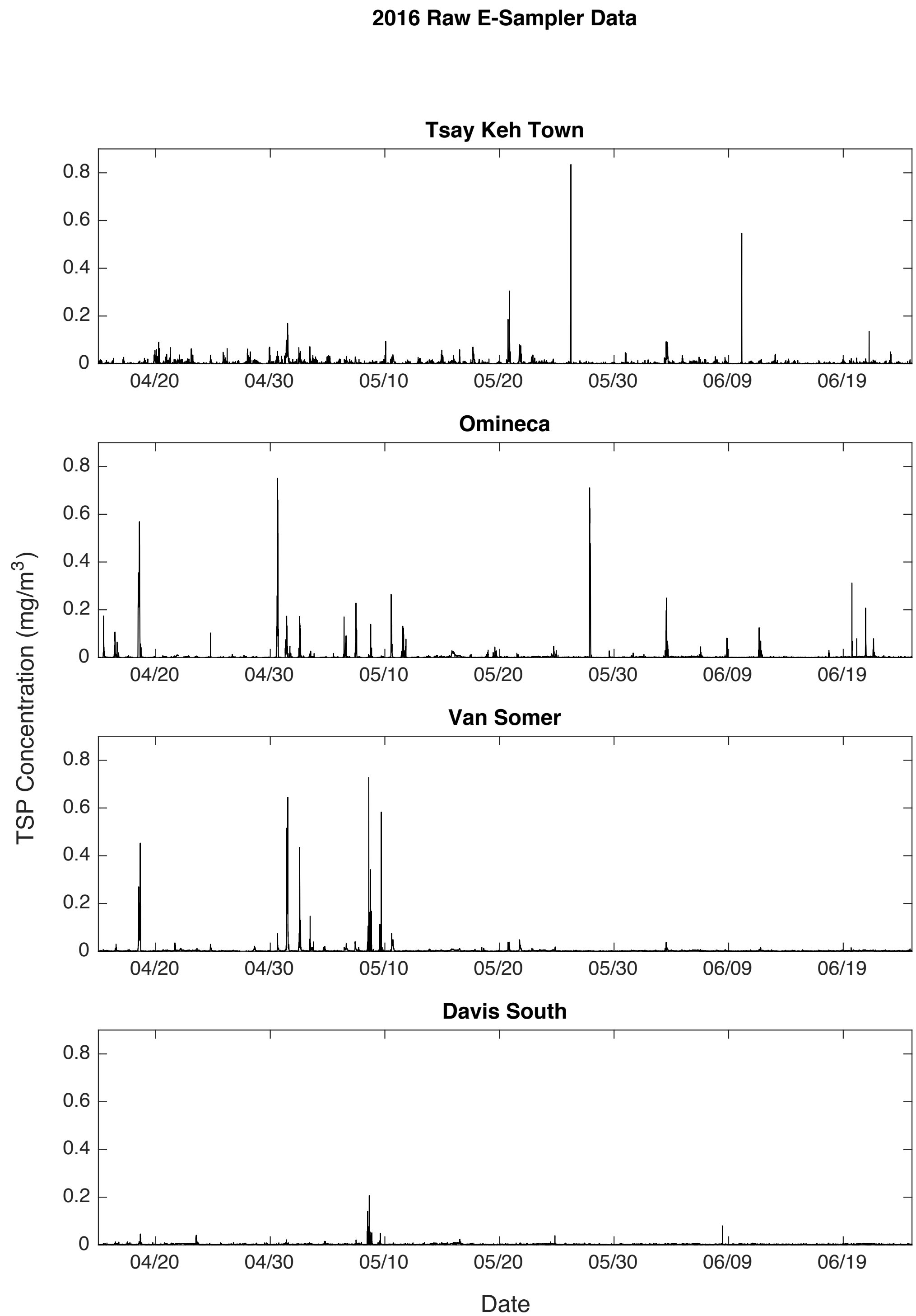
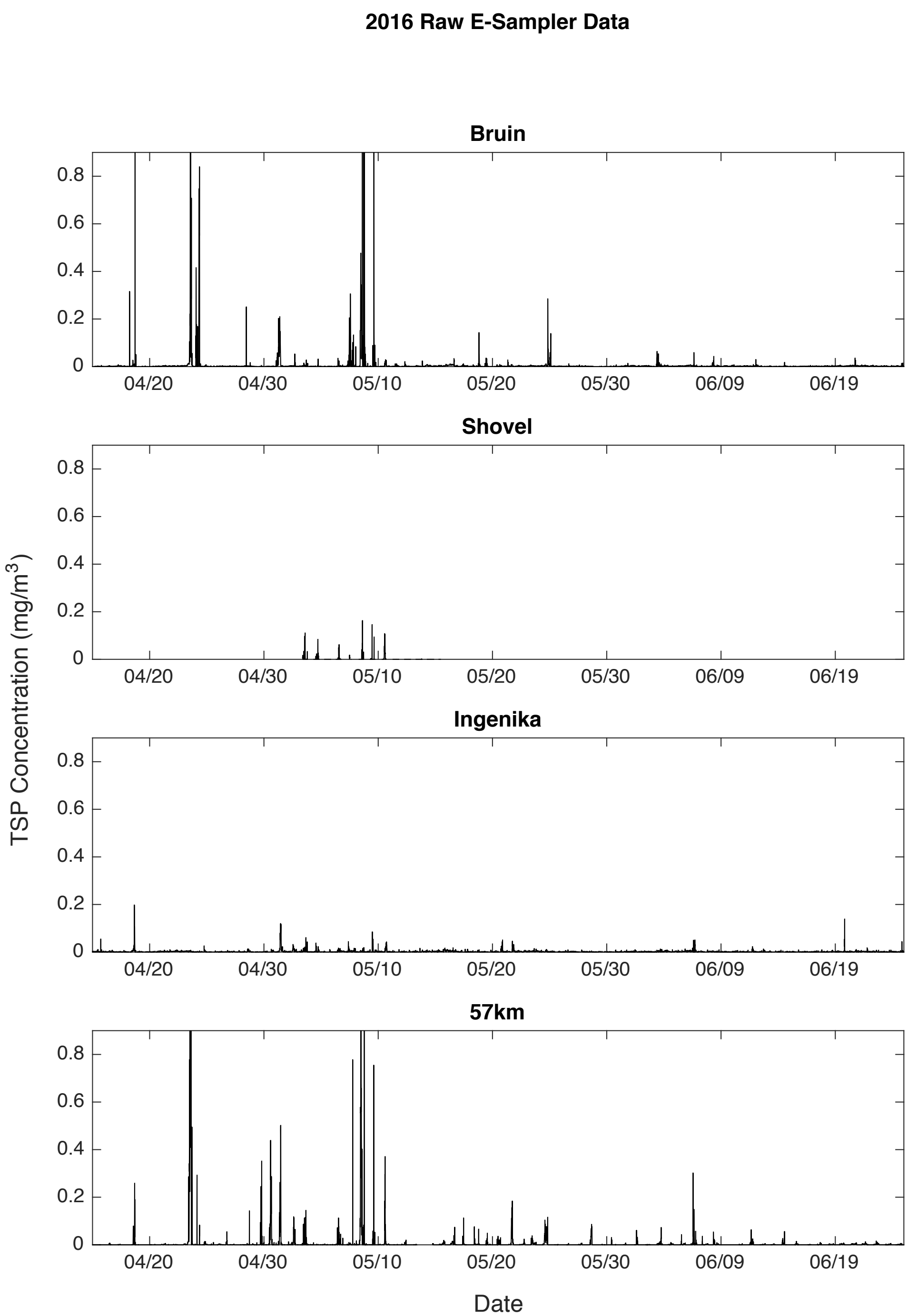
APPENDIX A E-SAMPLER TEMPORAL DATA

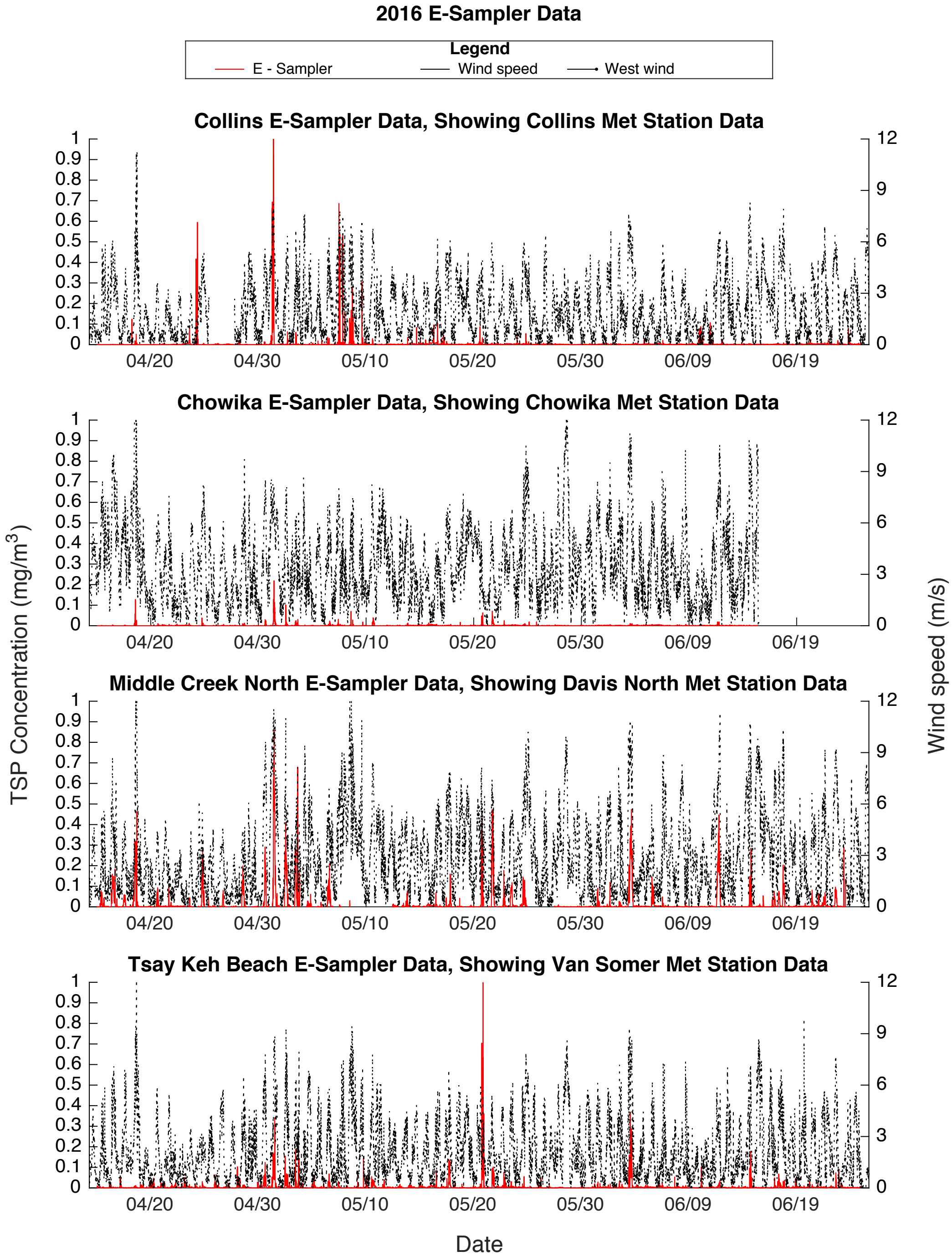

2016 Raw E-Sampler Data
Collins
Chowika
Middle Creek North
Tsay Keh Beach
TSP Concentration (mg/m3)
0
0.2
0.4
0.6
0.8
04/20
04/30
05/10
05/20
05/30
06/09
06/19
Date

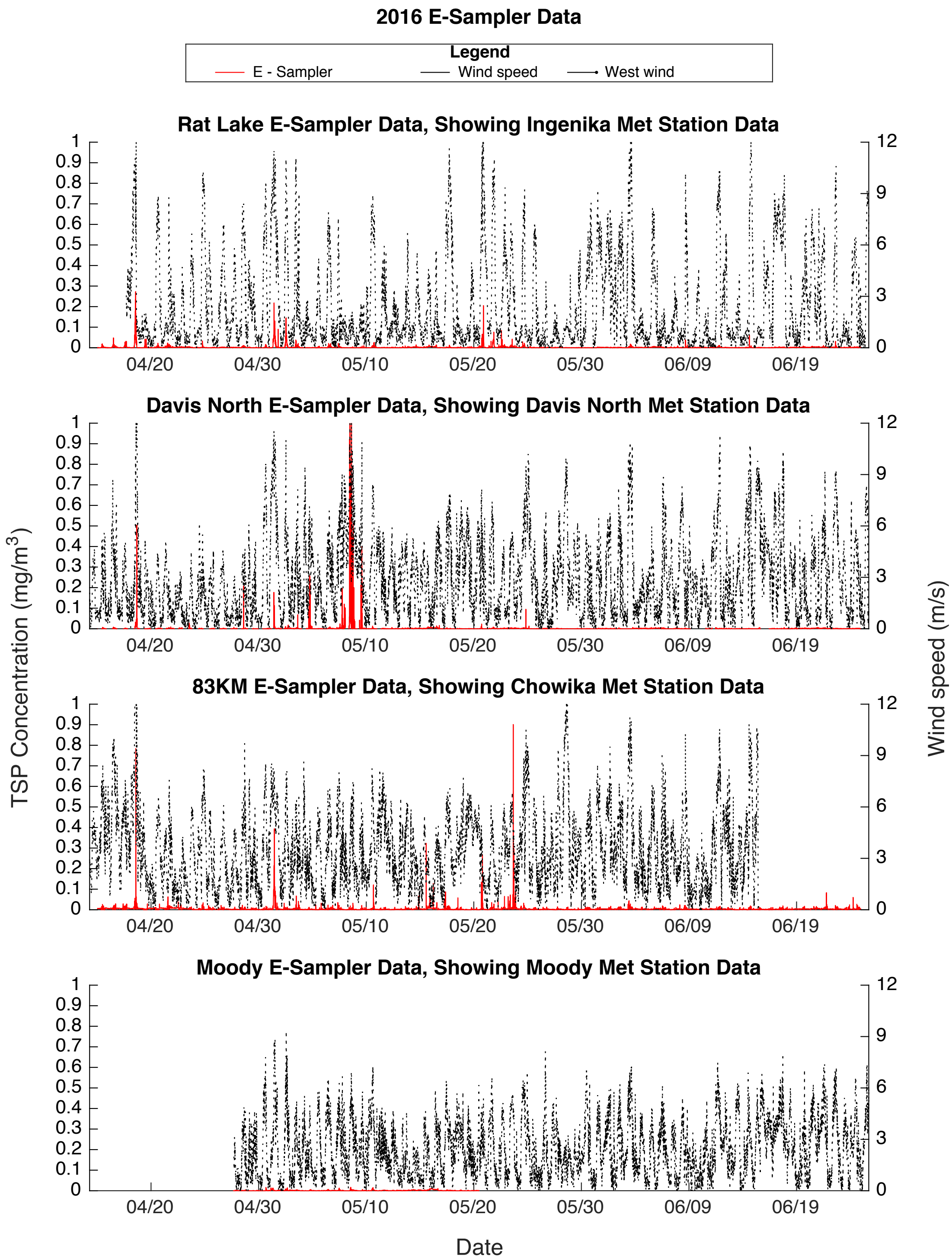

2016 Raw E-Sampler Data
Rat Lake
Davis North
83KM
Moody
TSP Concentration (mg/m3)
Date
0
0.2
0.4
0.6
0.8
04/20
04/30
05/10
05/20
05/30
06/09
06/19

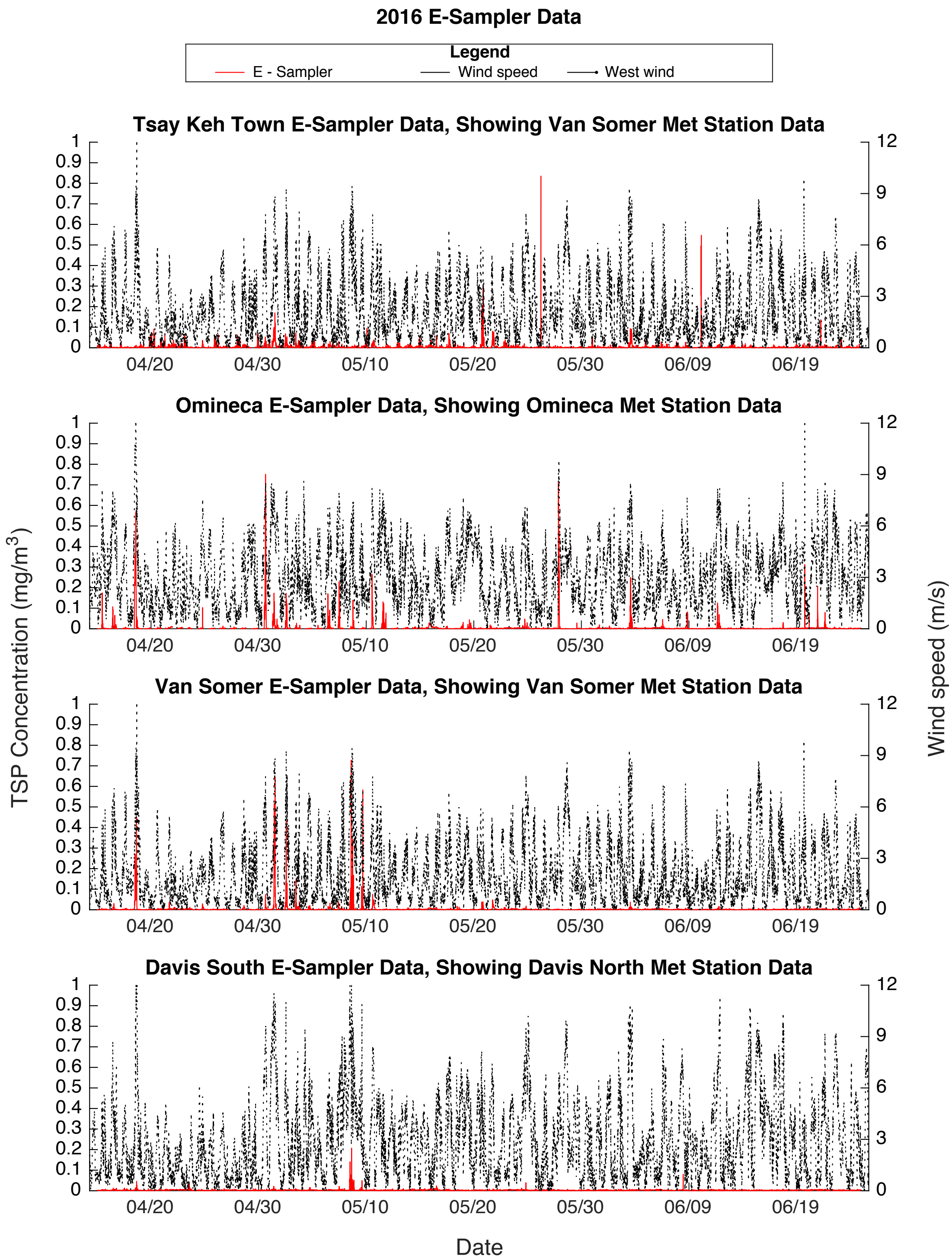

2016 Raw E-Sampler Data
Tsay Keh Town
Omineca
Van Somer
Davis South
TSP Concentration (mg/m3)
0
0.2
0.4
0.6
0.8
04/20
04/30
05/10
05/20
05/30
06/09
06/19
Date

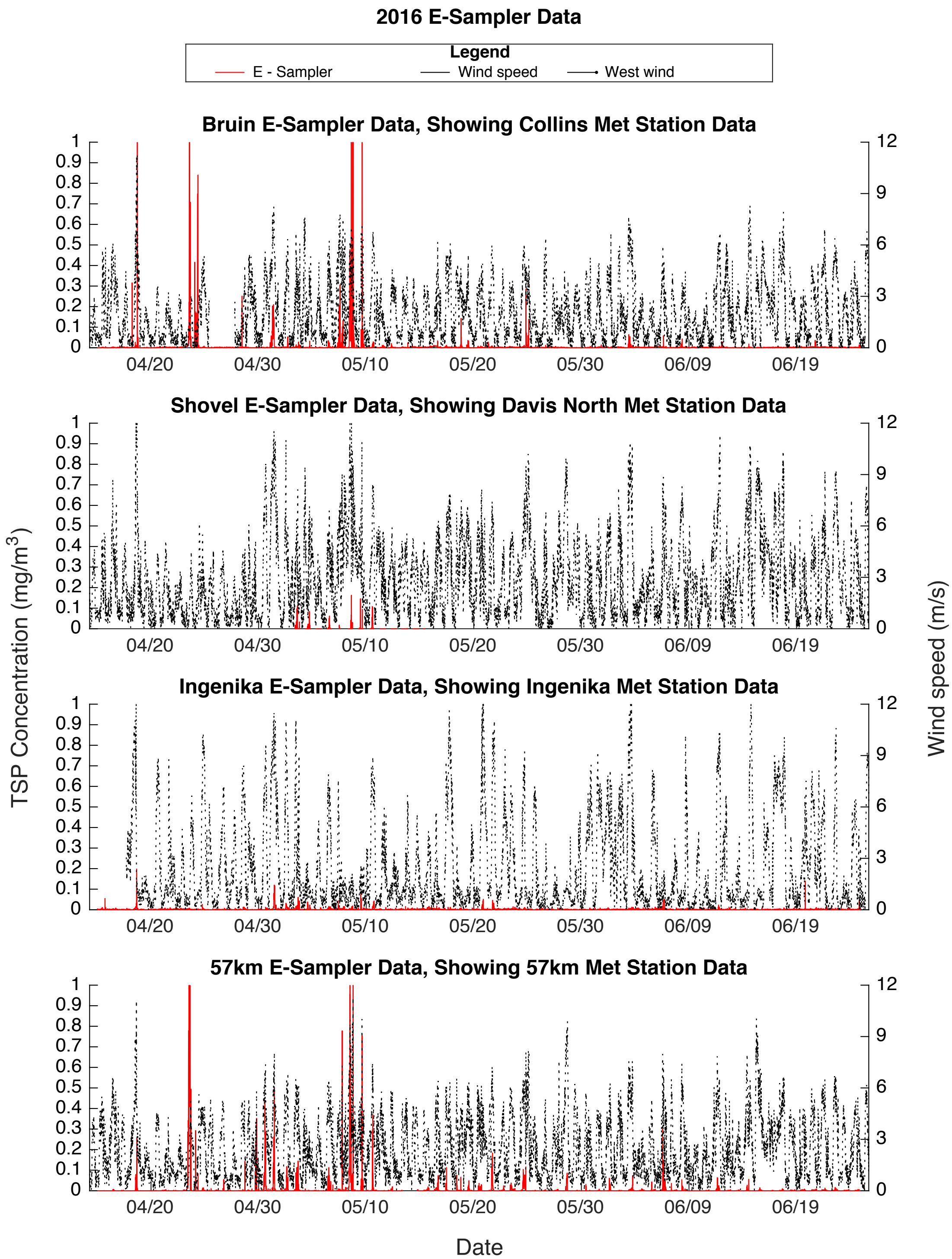

2016 Raw E-Sampler Data
Bruin
Shovel
Ingenika
57km
TSP Concentration (mg/m3)
Date
0
0.2
0.4
0.6
0.8
04/20
04/30
05/10
05/20
05/30
06/09
06/19

APPENDIX B E-SAMPLER DATA OVERLAYED WITH WIND SPEED


2016 E-Sampler Data
Legend
E - Sampler
Wind speed
West wind
Collins E-Sampler Data, Showing Collins Met Station Data
Chowika E-Sampler Data, Showing Chowika Met Station Data
Middle Creek North E-Sampler Data, Showing Davis North Met Station Data
Tsay Keh Beach E-Sampler Data, Showing Van Somer Met Station Data
TSP Concentration (mg/m3)
Wind speed (m/s)
04/20
04/30
05/10
05/20
05/30
06/09
06/19
Date


2016 E-Sampler Data
Legend
E - Sampler
Wind speed
West wind
Rat Lake E-Sampler Data, Showing Ingenika Met Station Data
Davis North E-Sampler Data, Showing Davis North Met Station Data
83KM E-Sampler Data, Showing Chowika Met Station Data
Moody E-Sampler Data, Showing Moody Met Station Data
TSP Concentration (mg/m3)
Wind speed (m/s)
Date
04/20
04/30
05/10
05/20
05/30
06/09
06/19


2016 E-Sampler Data
Legend
E - Sampler
Wind speed
West wind
Tsay Keh Town E-Sampler Data, Showing Van Somer Met Station Data
Omineca E-Sampler Data, Showing Omineca Met Station Data
Van Somer E-Sampler Data, Showing Van Somer Met Station Data
Davis South E-Sampler Data, Showing Davis North Met Station Data
TSP Concentration (mg/m3)
Wind speed (m/s)
Date
04/20
04/30
05/10
05/20
05/30
06/09
06/19


2016 E-Sampler Data
Legend
E - Sampler
Wind speed
West wind
Bruin E-Sampler Data, Showing Collins Met Station Data
Shovel E-Sampler Data, Showing Davis North Met Station Data
Ingenika E-Sampler Data, Showing Ingenika Met Station Data
57km E-Sampler Data, Showing 57km Met Station Data
TSP Concentration (mg/m3)
Wind speed (m/s)
04/20
04/30
05/10
05/20
05/30
06/09
06/19
Date