Millennium Bulk Terminals–Longview SEPA Environmental Impact Statement

SEPA Coal Technical Report

Coal Dust Emissions, Coal Spills Analysis, and Sulfur Dioxide and Mercury emissions Analysis

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Contents

List of Tables iv
List of Figures v
List of Acronyms and Abbreviations vi

PROJECT DESCRIPTION

Project Description 1
Project Description 1
Proposed Action 1
No-Action Alternative 4

COAL DUST EMISSIONS

Chapter 1 Introduction 5
1.1 Regulatory Setting 5
1.1.1 BNSF Coal Dust Requirements 6
1.2 Study Area 7
Chapter 2 Existing Conditions 8
2.1 Methods 8
2.1.1 Data Sources 8
2.1.2 Impact Analysis 9
2.2 Existing Conditions 15
2.2.1 Applicant's Leased Area 15
2.2.2 Cowlitz County 16
2.2.3 Washington State 16
2.2.4 Coal Dust Monitoring 17
Chapter 3 Impacts 23
3.1 Proposed Action 23
3.1.1 Construction: Direct and Indirect Impacts 23
3.1.2 Operations: Direct Impacts 23
3.1.3 Operations: Indirect Impacts 26
3.2 No-Action Alternative 32
Chapter 4 References 33
4.1 Written References 33
4.2 Personal Communications 34

COAL SPILLS ANALYSIS

Chapter 1 Introduction ... 37
1.1 Regulatory Setting ... 37
1.2 Study Area ... 37
Chapter 2 Existing Conditions ... 38
2.1 Cowlitz County ... 38
2.1.1 Aquatic Environments ... 38
2.1.2 Terrestrial Environments ... 39
2.1.3 Built Environment ... 40
2.2 Washington State ... 40
2.2.1 Aquatic Environment ... 40
2.2.2 Terrestrial Environment ... 40
2.2.3 Built Environment ... 41
Chapter 3 Impacts ... 42
3.1 Aquatic Environments ... 43
3.1.1 Physical Effects ... 43
3.1.2 Chemical Effects (Toxicity) ... 44
3.2 Terrestrial Environments ... 45
3.3 Built Environment ... 46
Chapter 4 References ... 48

SULFUR DIOXIDE AND MERCURY EMISSIONS ANALYSIS

Chapter 1 Introduction ... 51
1.1 Assessment Approach ... 51
1.2 Overview of Methods for Mercury and SO2 Assessment ... 52
1.2.1 Literature Review ... 52
1.2.2 Emission Inventory, GCTM, and Concentration Estimate ... 52
1.2.3 Application to the Five Coal Market Assessment Scenarios ... 53
1.2.4 Uncertainty ... 53
Chapter 2 Mercury Assessment ... 54
2.1 Introduction ... 54
2.2 Studies and Findings ... 57
2.3 Application of the GCTM to the Coal Market Assessment Scenarios ... 62
2.3.1 Results from Scenario Comparison ... 62
2.3.2 Uncertainty ... 63

Chapter 3 Sulfur Dioxide Assessment 66
3.1 Introduction 66
3.2 Studies and Findings 66
3.3 Application of the GCTM Model to the IPM Scenarios 68
3.4 Uncertainty 69
Chapter 4 References 71

Appendix A Particulate Matter Measurements in Support of Assessing Coal Emissions from Haul Trains Measurements Report

Tables

Table 1. Regulations, Statutes, and Guidelines Applicable to Coal Dust 5
Table 2. Coal Dust Total Suspended Solids Emissions Rates at Maximum Throughput 9
Table 3. Particle Size Distribution for Coal Dust Deposition Analysis 10
Table 4. Coal Trains for Coal Deposition, Concentration, and Particle Size Analysis 19
Table 5. Estimated Maximum Annual and Monthly Coal Dust Deposition 23
Table 6. Estimated Maximum PM10 and PM2.5 Concentrations 100 Feet from Rail Line—Reynolds Lead and BNSF Spur 26
Table 7. Estimated Maximum and Average Monthly Coal Dust Deposition—Reynolds Lead and BNSF Spur 27
Table 8. Estimated Maximum PM10 and PM2.5 Concentrations 50 and 100 Feet from Rail Line—BNSF Main Line, Cowlitz County 27
Table 9. Estimated Maximum and Average Monthly Coal Dust Total Suspended Particulate Deposition—BNSF Main Line, Cowlitz County 28
Table 10. Maximum Concentrations of Trace Elements Compared with Acceptable Source Impact Levels—BNSF Main Line, Cowlitz County 28
Table 11. Estimated Maximum PM10 and PM2.5 Concentrations 50 and 100 Feet from Rail Line—BNSF Main Line, Columbia Gorge 30
Table 12. Estimated Maximum and Average Monthly Coal Dust Total Suspended Particulate Deposition—BNSF Main Line, Columbia River Gorge 30
Table 13. Estimated Maximum PM10 and PM2.5 Concentrations 100 Feet from Rail Line for Loaded Coal Train —BNSF Main Line, Washington State (Outside Cowlitz County and the Columbia River Gorge) 31
Table 14. Estimated Maximum PM10 and PM2.5 Concentrations 100 Feet from Rail Line for Unloaded Coal Train —BNSF Main Line, Washington State (Outside Cowlitz County and the Columbia River Gorge) 31
Table 15. Estimated Maximum and Average Monthly Coal Dust Deposition from Loaded Coal Rail Cars —BNSF Main Line, Washington State (Outside Cowlitz County and the Columbia River Gorge) 32
Table 16. Estimated Maximum and Average Monthly Coal Dust Deposition from Unloaded Coal Rail Cars—BNSF Main Line, Washington State (Outside Cowlitz County and the Columbia River Gorge) 32
Table 17. Annual and Episodic Net Mercury (Hg) Concentration in Washington State as Elemental (Hg^0), Oxidized Mercury (Hg^{II}), and Total Mercury (pg/m^3) by Scenario 65
Table 18. Annual Hg^{II} Net Deposition Amounts in Washington State (mg/km2/yr) by Scenario 65
Table 19. Annual Sulfate Concentration in Washington State from Coal Exported to Asia from the Proposed Action-related Coal (ng/m^3) Scenario 69

Figures

Figure 1. Project Vicinity 2
Figure 2. Proposed Action 3
Figure 3. Coal Dust Monitoring Site Location 13
Figure 4. Coal Dust Emissions Adjustment Curve Based on Observed to Modeled Coal Dust Concentrations 20
Figure 5. Train 20: Whatcom County Field Study, Bow, WA, September 9, 2015 21
Figure 6. Estimated Maximum Monthly Coal Deposition (g/m^2/month) Near the Project Area 24
Figure 7. Estimated Maximum Annual Coal Deposition (g/m^2/year) Near the Millennium Bulk Terminal 25
Figure 8. Anthropogenic Mercury Emissions Source Contribution 55
Figure 9. Global Mercury Cycle (metric tons/year) 56
Figure 10. HYSPLIT Back-Trajectory for the Mount Bachelor Observatory Episode (April 25, 2004) 58
Figure 11. Distribution of Annual Asian Mercury Emissions (milligrams per year) from (a) Anthropogenic, (b) Natural, (c) Land Re-emission + Ocean Emission, and (d) Biomass Burning Used in the GEOS-Chem Model 60
Figure 12. Maps of March–May 2004 Concentrations and Relative Percentage of Asian Hg^0 61
Figure 13. Maps of March–May 2004 Concentrations and Relative Percentage of Asian HgII 61
Figure 14. Maps of March–May 2004 Concentrations and Relative Percentage of Asian Total Hg Deposition 62
Figure 15. Asian Anthropogenic Enhancements of Sulfate Concentrations in Surface Air during Spring 2001 as Simulated by the GEOS-Chem Model 67
Figure 16. Time Series of Sulfate Concentration in Surface Air at White Pass, Washington. 68

Acronyms and Abbreviations

$\mu g/m^2$	micrograms per square meter
$\mu g/m^3$	microns per cubic meter
AERMOD	AMS/EPA Regulatory Model
Applicant	Millennium Bulk Terminals—Longview, LLC
ASIL	acceptable source impact level
BNSF	BNSF Railway Company
CO	carbon monoxide
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
g	gram
g/m^2	grams per square meter
GCTM	global chemical transport modeling
Hg	mercury
Hg^0	mercury in elemental form
Hg^{II}	gas-phased oxidized mercury
IPM	Integrated Planning Model
km	kilometer
LVSW	Longview Switching Company
mg/km^2-year	milligrams per square kilometer per year
mph	miles per hour
MT/year	metric tons per year
NAAQS	National Ambient Air Quality Standards
ng/m^3	nanograms per cubic meter
NO_2	nitrogen oxides
O_3	ozone
O-M	observed-to-modeled comparison
OH	hydroxyl radical
PAHs	polycyclic aromatic hydrocarbons
pg/m^3	picograms per cubic meter
PHS	Priority Habitats and Species
PM10	particles with a mean diameter of less than 10 microns
PM2.5	particles with a mean diameter of less than 2.5 microns
RCW	Revised Code of Washington
Reynolds facility	Reynolds Metal Company facility
SO_2	sulfur dioxide
SWCAA	Southwest Clean Air Agency
TSP	total suspended particulates
UP	Union Pacific Railroad
WAC	Washington Administrative Code

Project Description

This technical report assesses the potential coal impacts (coal dust, coal spills, and sulfur dioxide and mercury emissions) of the proposed Millennium Bulk Terminals—Longview project (Proposed Action) and No-Action Alternative.

Project Description

Millennium Bulk Terminals—Longview, LLC (Applicant) is proposing to construct and operate a coal export terminal (Proposed Action) in Cowlitz County, Washington along the Columbia River (Figure 1). The coal export terminal would receive coal from the Powder River Basin in Montana and Wyoming, and the Uinta Basin in Utah and Colorado via rail shipment. The coal export terminal would receive, stockpile, and load coal onto vessels and transport the coal via the Columbia River and Pacific Ocean to overseas markets in Asia.

Proposed Action

Under the Proposed Action, the Applicant would develop the coal export terminal on 190 acres (project area) primarily within an existing 540-acre site that is currently leased by the Applicant (Applicant's leased area). The project area is adjacent to the Columbia River in unincorporated Cowlitz County, Washington near Longview, Washington (Figure 2). The Applicant currently operates and would continue to operate a bulk product terminal within the Applicant's leased area.

BNSF Railway Company (BNSF) or Union Pacific Railroad (UP) trains would transport coal on BNSF main line routes in Washington State, and the BNSF Spur and Reynolds Lead in Cowlitz County to the project area. Coal would be unloaded from rail cars, stockpiled, and loaded by conveyor onto ocean-going vessels for export at two new docks (Docks 2 and 3) located in the Columbia River.

Once construction is complete, the Proposed Action could have a maximum annual throughput capacity of up to 44 million metric tons of coal per year. The coal export terminal would consist of one operating rail track, eight rail tracks for storing up to eight unit trains, rail car unloading facilities, a stockpile area for coal storage, conveyor and reclaiming facilities, two new docks in the Columbia River (Docks 2 and 3), and shiploading facilities on the two docks. Dredging of the Columbia River would be required to provide access to and from the Columbia River navigation channel and for berthing at the two new docks.

Vehicles would access the project area from Industrial Way (State Route 432), and vessels would access the project area via the Columbia River. The Reynolds Lead and BNSF Spur track—both jointly owned by BNSF and UP, and operated by Longview Switching Company (LVSW)—provide rail access to the project area from a point on the BNSF main line (Longview Junction) located to the east in Kelso, Washington. Coal export terminal operations would occur 24 hours per day, 7 days per week. The coal export terminal would be designed for a minimum 30-year period of operation.

At full terminal operations, approximately 8 loaded unit trains each day would carry coal to the export terminal, 8 empty unit trains each day would leave the export terminal, and an average of 70 vessels per month or 840 vessels per year would be loaded, which would equate to 1,680 vessel transits in the Columbia River annually.

Figure 1. Project Vicinity

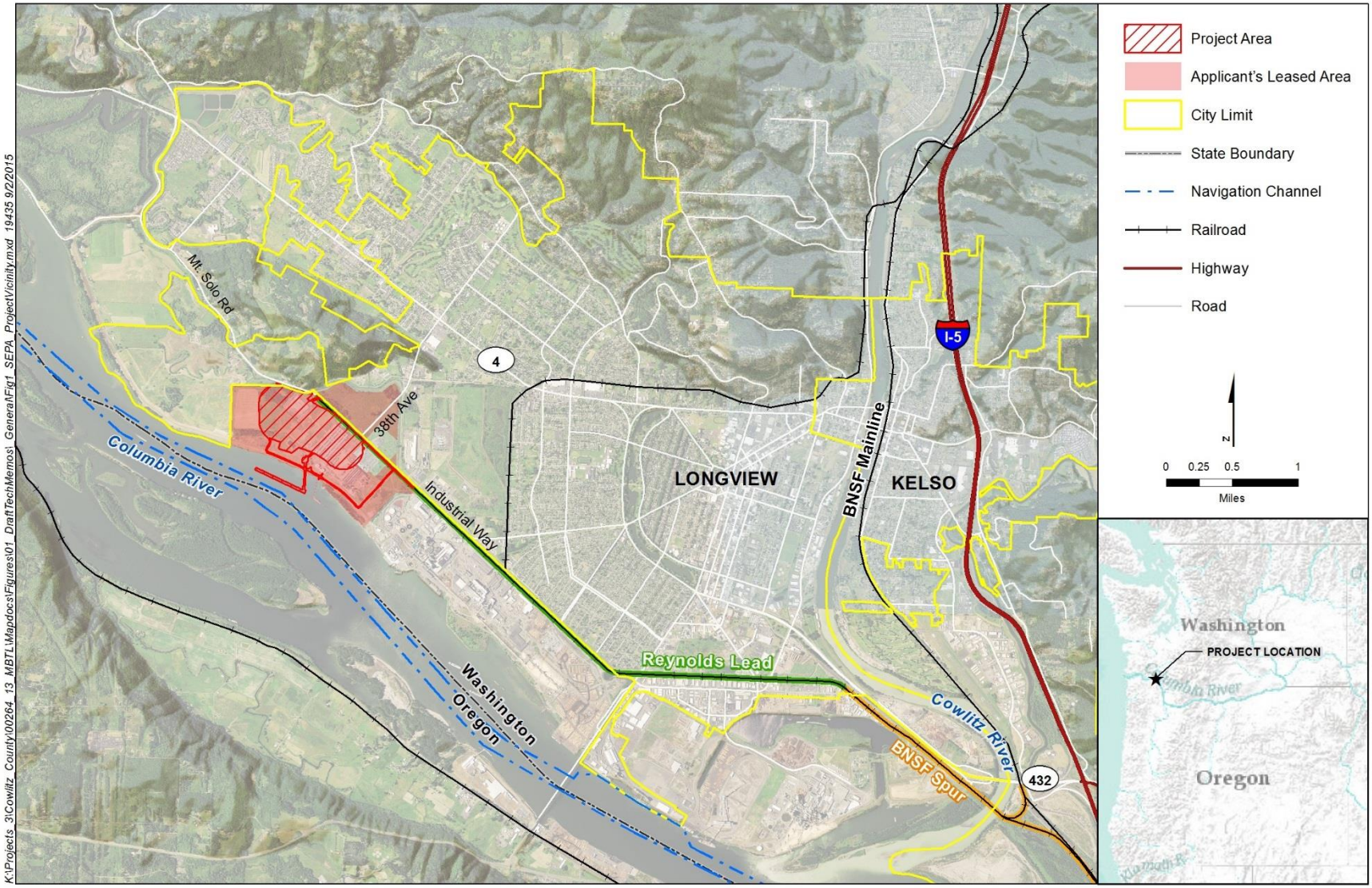
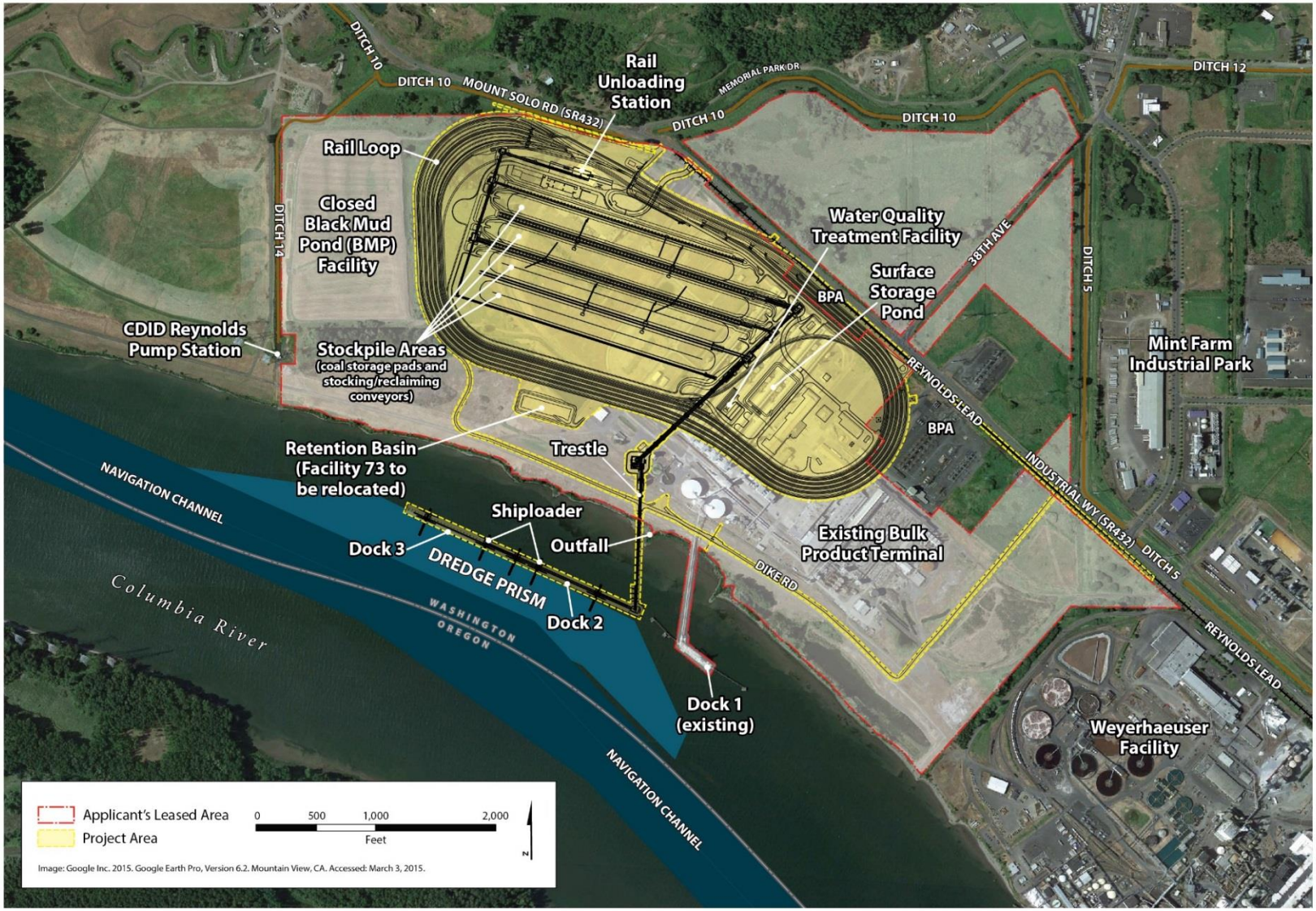


Figure 2. Proposed Action



No-Action Alternative

The Applicant plans to continue operating its existing bulk product terminal located adjacent to the project area. Ongoing operations would include storing and transporting alumina and small quantities of coal, and continued use of Dock 1. Maintenance of the existing bulk product terminal would continue, including maintenance dredging at the existing dock every 2 to 3 years. The Applicant plans to expand operations at the existing bulk product terminal, which could include increased storage and upland transfer of bulk products utilizing new and existing buildings. The Applicant would likely need to undertake demolition, construction, and other related activities to develop expanded bulk product terminal facilities.

If the coal export terminal is not constructed, the Applicant would likely propose expansion of the bulk product terminal onto areas that would have been subject to construction and operation of the proposed coal export terminal. Additional bulk product transfer activities could involve products such as a calcined pet coke, coal tar pitch, cement, fly ash, and sand or gravel. Any new operations would be evaluated under applicable regulations. Upland areas of the project area are zoned Heavy Industrial and it is assumed future proposed industrial uses in these upland areas could be permitted. Any new construction would be limited to uses allowed under existing Cowlitz County development regulations.

Coal Dust Emissions

Chapter 1
Introduction

This chapter assesses potential coal dust exposure resulting from the proposed Millennium Bulk Terminals—Longview project Proposed Action and No-Action Alternative. This chapter describes the regulatory setting, establishes the method for assessing potential coal dust impacts, presents the historical and current conditions in the study area, and assesses potential impacts.

1.1 Regulatory Setting

Regulations, statutes, and guidelines that apply to consideration of potential coal dust in the environment are summarized in Table 1.

Table 1. Regulations, Statutes, and Guidelines Applicable to Coal Dust

Regulation, Statute, Guideline	Description
Federal	
National Environmental Policy Act (42 USC 4321 et seq.)	Requires the consideration of potential environmental effects. NEPA implementation procedures are set forth in the President's Council on Environmental Quality's Regulations for Implementing NEPA (49 CFR 1105).
Clean Air Act and Amendments	As amended in 1970, 1977, and 1990, requires EPA to develop and enforce regulations to protect the public from air pollutants and their health impacts.
National Ambient Air Quality Standards	Specifies the maximum acceptable ambient concentrations for seven criteria air pollutants: CO, O_3, NO_2, SO_2, lead, PM10 and PM2.5, and. Primary NAAQS set limits to protect public health, and secondary NAAQS set limits to protect public welfare. Geographic areas where concentrations of a given criteria pollutant exceed a NAAQS are classified as nonattainment areas for that pollutant.
State	
Washington State Environmental Policy Act (WAC 197-11, RCW 43.21C)	Requires state and local agencies in Washington to identify potential environmental impacts that could result from governmental decisions.
Washington State General Regulations For Air Pollution Sources (WAC 173-400) and Washington State Clean Air Act (RCW 70.94)	Establishes the rules and procedures to control or prevent the emissions of air pollutants. Provide the regulatory authority to control emissions from stationary sources, reporting requirements, emissions standards, permitting programs, and the control of air toxic emissions.
Local	
Southwest Clean Air Agency (SWCAA 400)	Regulates stationary sources of air pollution in Clark, Cowlitz, Lewis, Skamania, and Wahkiakum Counties.
Cowlitz County SEPA Regulations (Cowlitz County Code 19.11)	Provide for the implementation of SEPA in Cowlitz County.

Regulation, Statute, Guideline	Description
Notes: EPA = U.S. Environmental Protection Agency; CO = carbon monoxide; O_3 = ozone; NO_2 = nitrogen oxides; SO_2 = sulfur dioxide; PM2.5 = particulate matter up to 2.5 micrometers in size; PM10 = particulate matter up to 10 micrometers in size; NAAQS = National Ambient Air Quality Standards; WAC = Washington Administrative Code; RCW = Revised Code of Washington; SWCAA = Southwest Clean Air Agency	

In occupational settings (such as coal mines), exposure to airborne coal dust is regulated by agencies such as the Occupational Safety and Health Administration and the Mine Safety and Health Administration. In nonoccupational settings (such as outdoor exposures) exposure to coal dust in combination with all other types of particulate matter and dust in the ambient air is regulated by the U.S. Environmental Protection Agency (EPA). The federal regulation that applies to particulate matter is a part of the National Ambient Air Quality Standards (NAAQS). These standards apply to particle sizes with diameter of less than or equal to 10 micrometers (PM10) and particles with a mean diameter of less than or equal to 2.5 micrometers (PM2.5) (40 Code of Federal Regulations 50). The NAAQS were established under the authority of the Clean Air Act to protect human health, including sensitive populations such as children and the elderly, with a margin of safety.

No federal or state guidelines or standards identify acceptable levels of ambient dust deposition. Washington Administrative Code (WAC) 173-400-040(3) relates to fallout but does not provide a reference level: "No person shall cause or allow the emission of particulate matter from any source to be deposited beyond the property under direct control of the owner or operator of the source in sufficient quantity to interfere unreasonably with the use and enjoyment of the property upon which the material is deposited." The New Zealand Ministry of Environment *Good Practice Guide for Assessing and Managing the Environmental Effects of Dust Emissions* (New Zealand Ministry of Environment 2001) cites acceptable levels of dust deposition and identifies two benchmarks for dust nuisance impacts[1] above current background levels.

- 4.0 grams per square meter per month (g/m^2/month) for industrial or sparsely populated locations. This equates to an approximate visible layer of dust on outdoor furniture or windowsills.
- 2.0 g/m^2/month for sensitive residential locations. This is the benchmark for the analysis.

A highly visible dust, such as black coal dust, will cause visible soiling at lower levels than other types of dust. British Columbia, Canada, has a less stringent maximum desirable level for average dustfall in a residential area of 5.1 g/m^2/month and for nonresidential areas of 8.7 g/m^2/month (British Columbia Ministry of Environment 2014).

1.1.1 BNSF Coal Dust Requirements

Per the BNSF Coal Loading Rule,[2] BNSF has imposed a tariff (a schedule of shipping rates and requirements) that requires coal shippers in Wyoming and Montana to control coal dust emissions from rail cars. One method allowed by the tariff is to use one of topper agents (surfactants) that, along with shaping the load profile, have been shown to reduce average coal dust emissions by at least 85%. This is most commonly done by loading coal cars with a modified loading chute that

[1] *Nuisance level* refers to the level of dust deposition that affects the aesthetics, look, or cleanliness of surfaces but not the health of humans and the environment.

[2] For more information, see http://www.bnsf.com/customers/what-can-i-ship/coal/coal-dust.html

produces a rounded profile of the top of the coal load. This shaped profile limits the loss of coal dust from wind while the train is moving.

In addition to the shaped profile, topper agents (i.e., surfactants) are applied to the surface of the coal mound to limit coal dust loss. The topper agent must be applied before leaving the coal mine area. In addition, in 2014, BNSF constructed and began operating a surfactant spray facility along its main line in Pasco, Washington, where coal trains traveling west along the main line route through the Columbia River Gorge are sprayed with a topper agent to lessen potential coal dust release from rail cars. The Safe Harbor provision in BNSF's Coal Loading Rule identifies five acceptable topper agents and application rates that BNSF states have been shown to reduce coal dust losses by at least 85% when used in conjunction with coal load profiling. A shipper can use any of the five approved topping agents.[3]

1.2 Study Area

The study area for direct impacts is the area in and near the project area that could be affected by construction and operation activities in the project area.

The study area for indirect impacts differs for each co-lead agency.

- **Cowlitz County and Washington State Department of Ecology (Ecology).** The areas within 1,000 feet of the Reynolds Lead and BNSF Spur.
- **Ecology only.** The areas within 1,000 feet of the rail routes for Proposed Action-related trains on BNSF main line routes in Washington State.

[3] For more information, see http://www.bnsf.com/customers/what-can-i-ship/coal/include/dust-toppers.xls

Chapter 2
Existing Conditions

This chapter describes the methods for assessing the existing conditions and determining impacts, and the existing conditions in the study area as they pertain to coal dust emissions.

2.1 Methods

This section describes the methods used to characterize existing conditions and assess the potential impacts of the Proposed Action and No-Action Alternative on coal dust emissions.

2.1.1 Data Sources

The following sources of information were used to identify the potential impacts of the Proposed Action and No-Action Alternative on coal dust in the study area.

- *Millennium Coal Export Terminal, Longview, Washington, Air Quality Environmental Report.* (URS Corporation 2015).
- *Final Report Environmental Evaluation of Fugitive Coal Dust Emissions from Coal Trains Goonyella, Blackwater and Moura Coal Rail Systems Queensland Rail Limited* (Connell Hatch 2008).
- *Duralie Extension Project, Air Quality Assessment* (Heggies 2009).
- *Analysis of Carry-Back at the RG Tanna Coal Terminal (Draft), Exploration & Mining* (Commonwealth Scientific and Industrial Research Organisation 2007).
- *Diesel particulate matter and coal dust from trains in the Columbia River Gorge, Washington State* (Jaffe et al. 2015).
- *Inorganic composition of fine particles in mixed mineral dust– pollution plumes observed from airborne measurements during ACE-Asia* (Maxwell-Meier et al. 2004).
- Information from the Applicant about anticipated coal handling and transfer activities in the project area.
- Information from the SEPA Rail Transportation Technical Report (ICF and Hellerworx 2017) on the rail routes of Proposed Action-related trains through Washington State.
- *Coal Train PMCA Study, Appendix A, Gateway Pacific Terminal at Cherry Point: Train Emission and Coal Dust Assessment in Washington* (NewFields 2016).

Operations of the Proposed Action would result in coal dust emissions from the handling and transfer of coal related to rail unloading, ship loading, conveyor transfer and coal-pile storage. Coal transfers would occur in enclosed areas (e.g., rotary coal car dump facility and approximately one-third of conveyors) and unenclosed areas (e.g., coal storage piles).

Over the last 10 years, air quality monitoring studies have collected information on the deposition and ambient concentration levels of coal dust associated with coal train operations. These studies have been conducted in various locations, including Australia, Canada, and the United States (with

two recent studies in Washington State). However, the available documentation from these studies often does not provide information on all factors that affect coal dust emissions from trains. Also, there are many differences between the Australian coal trains, which have been studied the most extensively, and U.S. coal trains. Some of these limitations of the Australian studies are as follows.

- Size of the coal rail car (Australia cars have about a 30% smaller surface area).
- Distance over which the coal is transported (coal through Washington is coming from greater distances).
- Shaping of the coal (often not described in Australian studies).
- Application and type of topping agent (surfactant) to minimize coal dust emissions (often not described in Australian studies).
- Lower humidity than in western Washington.

2.1.2 Impact Analysis

The following sections describe the impact analysis methods for the coal export terminal and for Proposed Action-related coal trains. For operations of the proposed coal export terminal, air quality modeling was performed for the sources of coal dust (transfer handling of the coal from rail to storage piles, fugitive emissions from coal storage piles, transfer and handling of coal from piles to ship).

2.1.2.1 Coal Export Terminal

Coal dust emissions sources were assessed for their potential air quality impacts using the AMS/EPA Regulatory Model (AERMOD) Version 15181.

The potential for coal dust emissions from the coal export terminal and impacts on the area surrounding the coal export terminal were estimated using AERMOD Version 15181. AERMOD was used because impacts would be localized, and the model is designed to estimate emissions for multiple point, area, and volume sources in simple and complex terrain, and uses hourly local meteorological data. In addition, AERMOD estimates the deposition of particulates (such as coal dust) using information on the particulates' emissions rate and particle sizes.

The modeling estimated the near-field coal dust deposition impacts from coal dust emissions at planned full operational capacity of the coal export terminal. Table 2 summarizes the sources of coal dust emissions and their estimated annual average emissions rates that were used in the analysis.

Table 2. Coal Dust Total Suspended Solids Emissions Rates at Maximum Throughput

Operation	Annual Average TSP Emissions Rate (tons per year)
Coal pile wind erosion	3.05
Coal pile development and removal	2.62
Vessel transfer and conveyors	5.25
Train unloading	3.68
Total	**14.60**

Notes:
TSP = total suspended particulates

Coal dust emissions were characterized as two source types: volume and area. Coal transfer operations were characterized as volume sources, which included eight transfer towers, a rotary rail dump, surge bins work points, and two conveyors to load coal onto the ships with emissions rates estimated based on EPA AP-42, Section 13.2.4. Area sources are used to model low-level ground releases. The four coal piles were modeled as area sources with the emissions estimated following the EPA AP-42, Section 13.2.5 approach. The coal dust emissions from tandem rotary unloaders that would unload the coal were modeled as a volume source with emissions estimated following the EPA AP-42, Section 13.2.5 approach. Weyerhaeuser's Mint Farm meteorological station was used in the analysis for the years 2001 to 2003. This station is located approximately 0.5 mile southeast of the project area.

In general the modeling approach built on the approach in the *Millennium Coal Export Terminal, Longview, Washington, Air Quality Environmental Report* (URS Corporation 2015) which provides further details on the air quality modeling. The changes applied included modeling for the deposition of the coal particles and a more conservative assumption about the effectiveness of full enclosures and spray/fogging for conveyors. A 95% reduction effectiveness was assumed for the enclosed conveyor and spray/fogging systems, which is consistent with a similar facility's permit from the Oregon Department of Environmental Quality (2013).

No information was available on the particle size distribution for Powder River Basin or Uinta Basin coal for particle sizes smaller than 65 microns that would be received at the coal export terminal; however data were available from 11 coal mines in Australia (Katestone 2009). The coal type with the highest near-field deposition, from the Moranbah North mine, was used in the Applicant's deposition analysis, as shown in Table 3.

Table 3. Particle Size Distribution for Coal Dust Deposition Analysis

	Mean Mass Diameter Size Range (microns)					
	65–42.5	**42.5–30**	**30–20**	**20–10**	**10–3.75**	**3.75–0.5**
Mass Fraction	0.143	0.147	0.196	0.245	0.218	0.051

2.1.2.2 Coal Trains

For the rail transport of the coal to the coal export terminal, air quality modeling was conducted based on the coal dust emissions estimated from a moving train with some adjustments in the emission rates based on the air quality monitoring study as described in Section 2.2.4, *Coal Dust Monitoring*.[4]

Two recent coal train studies included an assessment of coal dust from passing coal trains operating in Washington State. Analyses of data from these studies were used to better characterize coal dust emissions and air quality impacts.

[4] In the Columbia River Gorge, additional adjustments included an effective wind speed to determine the strength of the coal dust emissions. The effective wind speed is the speed of the train plus the component of the ambient wind in the direction of the train If the wind component is opposite the direction of the train then the component is subtracted.

Cowlitz County Field Program

As part of the analysis for the environmental impact statement, a field study to collect data on coal dust emanating from passing coal trains in Cowlitz County was undertaken. Appendix A, Particulate *Matter Measurements in Support of Assessing Coal Emissions from Haul Trains Measurements Report*, contains a detailed report on the study including the sampling program, laboratory analysis, quality assurance, and results. The objective of the sampling program was to collect coal dust data at a location in Cowlitz County under conditions that were conducive to coal dust emissions from passing coal trains. Data collected during the first 2 weeks in October 2014, were suitable to allow a small sample to be collected to improve knowledge regarding coal dust emissions and improve the reliability of the assessment of potential impacts. This analysis used the data collected during the field study to evaluate coal train emissions estimates based on studies done in Australia, to verify their applicability to similar projects in the United States, and to evaluate the potential future impacts from the increased transport of coal to the coal export terminal via rail. Because only a limited number of coal trains travel to the Applicant's leased area per week and travel at low speeds, a sampling network was deployed in southern Cowlitz County along the BNSF main line just north of the Lewis River where several loaded coal trains passby (Figure 3).

Data collected at the site included the following elements.

- Continuous airborne particulate matter using a size-segregating laser-based optical scattering technique with data recorded at a 10-second time resolution. Measurements were made at the anticipated downwind (east) side of the tracks.
- Short-term particulate matter deposition using deposition plates on both sides of the tracks that sampled during triggered events with a train passage.
- Short-term airborne particulate matter on both sides of the tracks using impaction sampling techniques triggered during selected train passages.
- Integrated 24-hour airborne particulate matter using filter-based techniques with measurements primarily focused on the anticipated downwind (east) side of the tracks.
- Meteorological measurements of wind speed, wind direction, temperature, humidity and solar radiation at a 30-second time resolution to document the conditions during the sampling events.
- Train speed and video recording (documenting the number of coal cars, etc.)

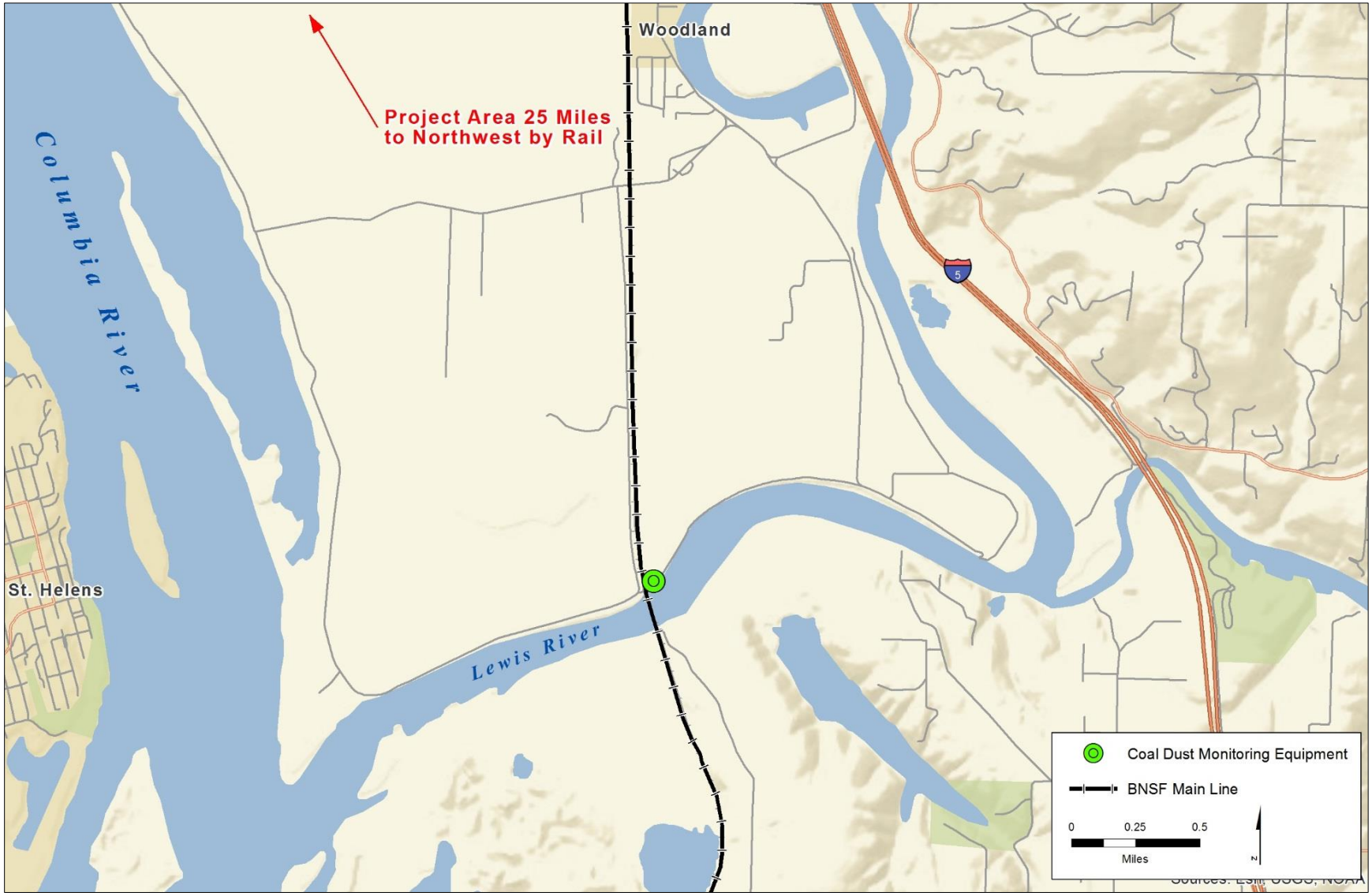
To determine the coal particle concentrations from the collected samples, analytical methods were developed to evaluate the coal particle concentrations in the three different types of measurements and collection devices: fallout of particles (deposition plates for approximately 20 microns and larger); airborne concentrations in the optical microscopy size range (Air-O-Cell slit impaction cassettes 3 to 100 microns); and particles in the "respirable" size range (less than 3 microns). All data collected during the measurement program were processed and validated prior to using in the coal dust analysis.

A total of 23 coal trains were observed during the study period (October 2014) and samples were obtained for 22 of the trains.[5] Of the 22 coal train sample sets collected, 11 were submitted to the laboratory for full analyses, along with two noncoal freight trains for comparison. Prior to the start of the study period, it was verified with the receivers of the coal trains (TransAlta Power Plant near

[5] The other data were not analyzed because the train came to a complete stop on the section of track being studied.

Centralia and Westshore Terminals in British Columbia, Canada) originated in the Powder River Basin and surfactant was applied at the mine. At the time of this study the BNSF Pasco spray station was not yet operational and no additional surfactant material was being applied to the coal.

Figure 3. Coal Dust Monitoring Site Location



To improve the reliability of the impact assessment, results from the coal dust monitoring study were used to compare with the air dispersion and emissions modeling using the information observed at the air quality monitoring site (e.g., meteorology, train speed, number of coal cars). Findings from the comparison of modeled data to monitored data were then used to adjust the emissions estimates to produce the best fit with the observed data. The revised emissions estimates were then adjusted to reflect the projected activity levels along the rail line during full operation and the impact assessed.

Air quality modeling was performed using AERMOD for the periods when wind direction was clearly across the tracks and when a complete set of deposition plates and impaction samplers were recorded at the site. This resulted in four periods (sample sets 6, 21, 22, and 25) in which suitable measurements were made to use with the model.

A key input to the modeling is the emissions factor used to characterize the amount of coal dust from moving, fully loaded coal rail cars. The approach used the equation reported in the Connell-Hatch study (Connell-Hatch 2008). This equation has since been used in a number of environmental impact assessments in Australia (GHD 2012; Heggies 2009).

The emissions factor for the rate of coal dust emitted (total suspended particulate [TSP]-sized) is expressed in metric units of grams (g) of TSP per kilometer (km) of rail per metric ton of coal moved as follows.

$$\text{Emissions Factor (loaded coal train)} = 0.0000378(V)^2 - 0.000126(V) + 0.000063$$

where V is the speed of the train (km/h)

This equation was developed from the analysis of coal dust loss (without mitigation) and a minimum air velocity needed for particle lift-off from a wind tunnel study over a variety of wind speeds. The approach assumed no significant rainfall and so likely represents an overestimate for western Washington State. This emission factor was further adjusted by 1.34 to account for the larger-sized rail cars used to transport coal in the United States (44.12 square meters) versus those used in Australia (30.37 square meters) (Connell-Hatch 2008). Each loaded rail car was estimated to hold 122 tons of coal and an 85% emission reduction effectiveness[6] was applied based on best practice of shaping the coal for transport by rail to minimize fugitive emissions and the application of a topping agent at the mine. Emission rates were also estimated for the unloaded train based on a study (Commonwealth Scientific and Industrial Research Organisation 2007) of the amount of coal carry-back found in returning rail cars. Over a 6-month survey period at the Port of Gladstone Australia, the average amount of coal carry-back was 0.36 ton per car and the worst-case was 0.93 ton per car, which was observed in June following 2 months of heavy rainfall that increased the stickiness of the coal. This worst-case coal carry-back value was used in this assessment for the empty rail cars, and no emissions reductions were applied for coal shaping or application of topping agent. Emissions rates for each operations setting were calculated and used in the AERMOD dispersion model using representative meteorological data.

The study measured the fugitive emissions of coal from the passing trains with a set of air samplers on each side of the tracks to measure the upwind "background" concentrations and deposition and

[6] BNSF tariffs require shippers to control coal dust emissions through use of load profiling and application of an approved topping agent or other measures to reduce emissions by at least 85 percent (BNSF Price List 6041-B and Appendices A and B, issued September 19, 2011). This surfactant efficiency factor was refined for this analysis using the monitoring study as described in Section 2.2.4, *Coal Dust Monitoring.*

the downwind concentrations and deposition—the difference being the contributions of the passing trains. A variety of sampling techniques captured the specific emissions from the coal train hauling activities. Short-term measurements using deposition plates, impaction samplers, and continuous particulate matter measurements were used to resolve individual train events, while longer averaging intervals of particulate matter (24 hours) were collected using filter-based collection media to help relate the more standard methods of measurement to the shorter-term type sampling (train event). During the study period, high time-resolution meteorological measurements were made to capture wind flow and document the upwind and downwind environment during each train passing. The meteorological measurements also provided needed data on temperature, humidity, transport, and atmospheric stability that were used in the coal train modeling.

Whatcom County Field Program

To support the environmental impact statement for the proposed Gateway Pacific Coal Export Terminal in Whatcom County, Washington, data were collected on coal dust and train emissions from passing loaded and unload coal trains in Whatcom County (NewFields 2016). The report contains a detailed description of the field monitoring program, laboratory methods, analysis, and quality control. The objective of the sampling program was primarily focused on assessing coal train emissions for particles matter and their health related composition for particles less than 10 microns (largest particles for which health based standards are set). Particulate matter monitoring data (Dust Trak PM10, PM2.5 and PM1) collected at the Bow, Washington site during August and September 2015, was available for analysis to potentially to improve knowledge regarding coal dust emissions and improve the reliability of the assessment of potential impacts. A total of 30 coal trains passed by the site during the study period but at relatively slow average speeds (18 miles per hour [mph]). Because coal dust emissions are roughly proportional to the square of the train speed, a subset of the highest loaded coal trains was analyzed. In addition, a small number of empty coal trains and freight trains were analyzed for comparison with the coal trains.

2.2 Existing Conditions

The existing environmental conditions related to coal dust exposure in the study area are described below.

2.2.1 Applicant's Leased Area

The existing bulk product terminal in the Applicant's leased area currently receives 1 to 2 coal trains per week, consisting of 25 to 30 coal rail cars. Coal is stored in silos in the Applicant's leased area, adjacent to the project area, and transferred via truck to the Weyerhaeuser facility, 1 mile to the southeast. Because the coal is stored in silos and only 1 to 2 trains are received each week, coal dust emissions are estimated to be small and confined almost entirely within the Applicant's leased area. Operations at the existing bulk product terminal comply with the air permit issued by the Southwest Clean Air Agency.

2.2.2 Cowlitz County

Approximately two loaded coal trains per day, consisting of approximately 125 cars, typically operate along the BNSF main line northbound in Cowlitz County (Western Organization of Resource Councils 2014).

Cowlitz County is classified as an attainment area or unclassified for both PM10 and PM2.5. Of these two pollutants only PM2.5 is currently being monitored. The PM2.5 monitoring station located at Olympic Middle School is a neighborhood-scale site, affected primarily by smoke from home heating. It is considered representative of the Longview-Kelso area and is used for curtailment calls[7] during the home heating season. The estimated 24-hour design value in 2014 was 18 micrograms per cubic meter (μg/m^3) (Washington State Department of Ecology 2015). While not a reference instrument, it is considered a strong indicator of the relative PM2.5 concentration of the Longview-Kelso area. Air quality in other locations of Cowlitz County is generally as good as or better than in the Longview-Kelso area.

2.2.3 Washington State

In 2014, 2 to 4 coal trains per day operated within Washington State, typically consisting of approximately 125 rail cars, mainly along the BNSF main line (Western Organization of Resource Councils 2014, The Herald of Everett Washington 2013). Coal dust emissions associated with the operations of these trains occurs mostly along the BNSF main line routes because of the high operating speeds of the trains. Most of the coal dust deposition, as well as the highest concentration of coal dust in the air, occurs within the railroad right-of-way.

The following paragraphs describe the existing air quality conditions for the route that would be used for the proposed project (for westbound-loaded trains and eastbound-unloaded trains).

Air quality along the rail route in eastern Washington State from Spokane to Pasco is generally good. Spokane is a maintenance area for carbon monoxide, but has not had an exceedance of the carbon monoxide standard in over 10 years. From spring through fall in this region of the Columbia Plateau, high winds can combine with dry weather conditions to create dust storms that can lead to extremely high levels of PM10. The state monitors for PM2.5 along this route but in general, the monitoring is below the state's goal of keeping concentrations below 20 μg/m^3, well below the PM2.5 NAAQS of 35 μg/m^3.

Air quality through the Columbia River Gorge is also generally good, the primary concern being visibility impairment and regional haze issues, with these issues occurring at much lower concentration levels than for health effects. Air quality from Vancouver north to Longview is generally good with PM2.5 being the pollutant of most concern. Readings are generally well below the state's goal of keeping concentrations below 20 μg/m^3.

The rail route between Tacoma and Auburn over the Cascades via Stampede Pass passes through the only PM2.5 maintenance area in the state, the Tacoma-Pierce County PM2.5 maintenance area. The primary cause of poor air quality in the nonattainment area is residential wood burning during periods with colder-than-average temperatures and low wind speeds. The area east of Auburn does experience some of the highest ozone levels in Western Washington but are below the NAAQS.

[7] When meteorological conditions indicate the probability that PM 2.5 levels are likely to exceed EPA standards, the Department of Ecology and Local Air Authorities are authorized to issue a burn ban or other restriction.

Air quality from Stampede Pass through Ellensburg to Yakima and back to Pasco is generally good but recent monitoring data has shown a high fraction of the PM2.5 concentration to be nitrates in the Yakima region. In Yakima, much of the PM2.5 comes from wood burning with highest levels in the wintertime due to increased wood burning and stagnate conditions. Up to one-fourth of PM2.5 may be in the form of nitrate during the wintertime (Washington State Department of Ecology 2014). In addition, air quality in the Ellensburg area has, in recent years, shown that residents breathe unhealthy levels of PM2.5 2 to 3 weeks each year (Washington State Department of Ecology 2013).

2.2.4 Coal Dust Monitoring

This section describes the findings from the Cowlitz County field program and Whatcom County field program.

Cowlitz County Field Program

The Cowlitz County field program was described in Section 2.1.2, *Impact Analysis*. Appendix A, *Particulate Matter Measurements in Support of Assessing Coal Emissions from Haul Trains Measurements Report,* provides details of the program. A total of 23 coal trains were observed during the study period and samples were obtained for 22 of the trains. Of the 22 sample sets collected, 11 were submitted to the laboratory for full analyses, along with two noncoal freight trains for comparison (Table 4). The other sample sets were not analyzed for several reasons; the most common being that the train came to a complete stop on the section of track being studied.

Coal-like particle deposition amounts were 350 micrograms per square meter (μg/m^2) upwind and 1,140 μg/m^2 downwind on average per coal train, based on the upwind/downwind deposition plates located 15 meters from the track. Based on the collected data, this increase in mass appears to be fugitive coal dust emissions from the coal cars passing, as coal-like concentrations for deposition plates collected during noncoal train passage were notably very low (averaging 25 μg/m^2).

The maximum increase in the 24-hour PM-2.5 concentration from coal dust associated with the passing of two (2) unit coal trains traveling at an average speed of 41.5 mph in Cowlitz County at 40meters downwind was 1.33 μg/m^3. In a recent study by Jaffe et al (2015), where $PM_{2.5}$ monitoring data was collected in the Columbia River Gorge, the authors reported the maximum increase observed during the study in the 2-minute average $PM_{2.5}$ concentration of 232 μg/m^3 from the passage of a single coal train traveling at 44.5 mph located 20 meters from the rail line. These results are generally consistent with the results found in the coal dust monitoring study in Appendix A, *Particulate Matter Measurements in Support of Assessing Coal Emissions from Haul Trains Measurements Report,* when the 2-minute average $PM_{2.5}$ concentration is expressed in terms of the regulatory averaging period as the average increase in $PM_{2.5}$ concentration over 24 –hours for two coal trains per day would be:

$$\left(2\frac{trains}{day}\right) x \left(2\frac{min}{train}\right) * \frac{232\ \mu g/m^3}{60\frac{min}{hr} * \frac{24hr}{day}} = 0.65\ \mu g/m^3$$

Overall, air concentrations of coal-like particles, measured from the impaction samplers downwind from the track for periods with “winds across the tracks” averaged 16.5 μg/m^3 during the

approximate 2-minute coal train passage, compared to 0.6 μg/m^3 from similarly placed upwind samplers.[8]

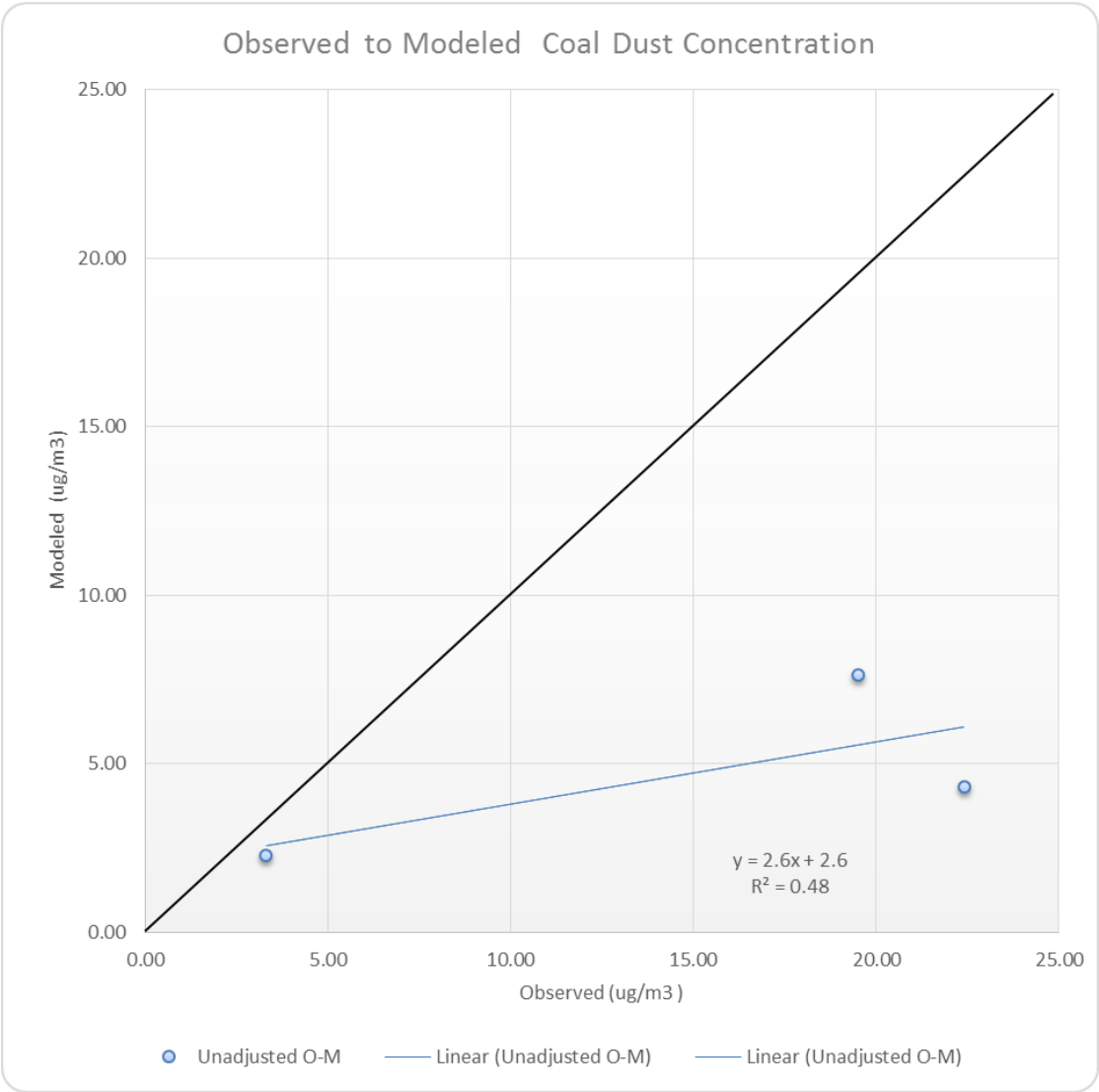
Air quality modeling results for coal train dust emissions in comparison with observations are shown in Figure 4 for the observed-to-modeled (O-M) concentration comparison and the ideal 1:1 ratio between observed and modeled concentration. Only three periods were modeled for comparison because sample sets 12, 13, and 18 had only one of the upwind and downwind measurement pairs. Sample set 15 had the winds nearly parallel to the track, and sample sets 24 and 25 had a new sampling configuration. Using a best-fit linear regression to these O-M data points suggests that the coal dust emissions reduction effectiveness at this location is 61% effective, rather than 85% reported at the time when the surfactant is first applied. Subsequent air quality modeling of the coal trains used this lower estimate of 61% for the surfactant efficiency.

[8] Iron-oxide concentrations measured during this same time period averaged 11.3 μg/m^3 on the downwind side and 1.5 μg/m^3 on the upwind side. The origin of the iron oxide is mostly likely from train wheels grinding against steel rails. This may contribute additional particulate matter to the near field air concentration, as well as deposition.

Table 4. Coal Trains for Coal Deposition, Concentration, and Particle Size Analysis

Sample Set	Date	Arrival Time Depart Time	Passage Time	Speed (mph)	Cars		Total	Est. Train Length (miles)	Comments
					Coal	Other			
1	10/1/2014	18:30:17 18:32:16	0:01:59	40	126		130	1.3	
3	10/2/2014	17:53:33 17:55:07	0:01:34	53	119		123	1.4	Stopped sampling 1 minute after train passage because of road traffic
6	10/3/2014	10:22:34 10:24:48	0:02:14	38	125		129	1.4	Sampled for 107 cars
12	10/5/2014	16:04:36 16:06:49	0:02:13	37	124		128	1.4	
13	10/6/2014	4:25:01 4:26:54	0:01:53	44	122		126	1.4	
15	10/6/2014	17:57:20 17:59:05	0:01:45	41	126		130	1.2	
18	10/8/2014	5:00:14 5:01:54	0:01:40	43	125		129	1.2	
21	10/10/2014	5:22:42 5:24:21	0:01:39	43	124		129	1.2	
22	10/10/2014	7:30:22 7:32:07	0:01:45	40	125		129	1.2	
24	10/12/2014	12:58:01 12:59:34	0:01:33	48	122		126	1.2	New sample configuration
25	10/13/2014	9:47:54 9:49:48	0:01:54	43	125		129	1.4	New sample configuration
7	10/3/2014	16:29:18 16:31:05	0:01:47	46		112	115	1.4	Freight train
14	10/6/2014	16:13:18 16:15:03	0:01:45	38		111	114	1.1	Freight train

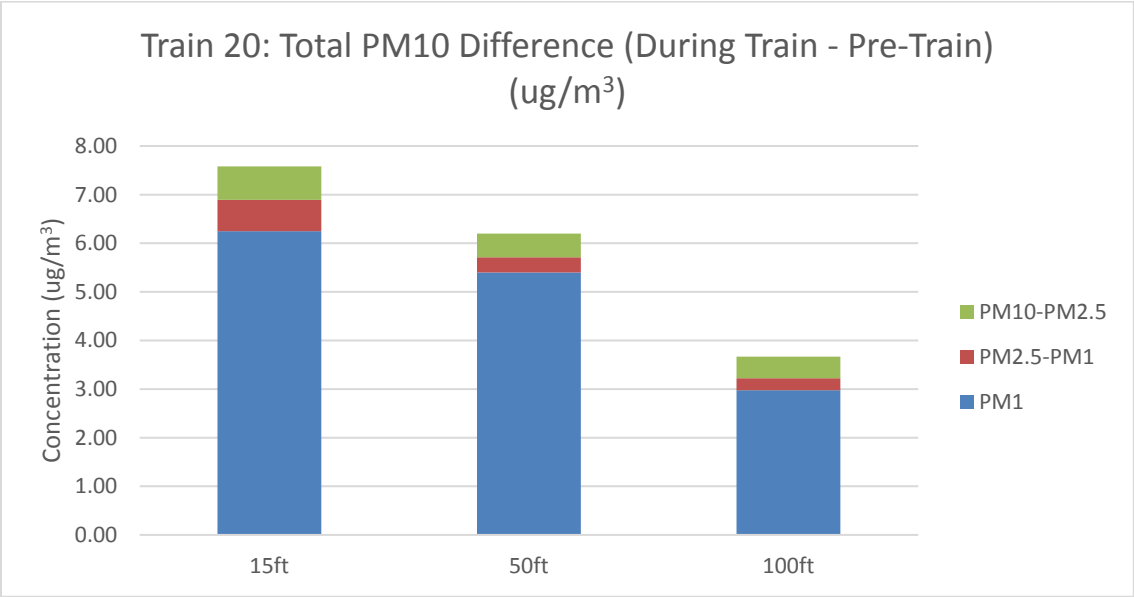
Figure 4. Coal Dust Emissions Adjustment Curve Based on Observed to Modeled Coal Dust Concentrations



Whatcom County Field Program

Nine coal trains were identified as suitable for further analysis because they had relatively high train speeds (average train speed 28 mph) during pass-by and had complete DusTrak measurements at sampling distances perpendicular to the railroad track at 15, 50, and 100 feet. These second-by-second particulate matter data were analyzed for periods before, during, and after train passage with concentrations plotted by particle size bins for the difference between before and during train passage. Figure 5 shows an example for Train 20, with a train speed 33 mph, 3 locomotives in front and 1 in back, and 126 loaded coal cars.

Figure 5. Train 20: Whatcom County Field Study, Bow, WA, September 9, 2015



Key findings from this analysis of the nine trains were as follows.

- PM10, PM2.5, and PM1 data show that nearly all of the mass is less than 1 micron in size, indicating that primarily diesel exhaust emissions were measured.
- Second-by-second analysis shows no variation between PM1 and PM10.
- Microscopy analysis of the particulate matter showed that no more than 0.21% was coal particles for any size category.

A number of factors likely contributed to limited observations of coal dust.

- The Bow site is a location near Puget Sound with prevailing westerly winds, frequent high humidity, and/or rainfall conditions.
- Slow train speeds.
- Reapplication of surfactant at the Pasco, Washington BNSF surfactant facility.
- Study was limited to measurement of particle sizes no larger than 10 microns, while the majority coal dust mass is expected to be found in larger-sized particles.

Despite these limitations a model to monitor comparison was performed for particles of less than 10 microns. For the 9 trains, only 5 had ambient wind speeds for which a model to monitor comparison is possible but 1 of the 5 was eliminated from comparison because rainfall occurred near the time of the monitoring, which suppresses coal dust emissions. Key findings from the comparison are as follows.

- Cowlitz County estimated that 61% surfactant efficiency leads to overestimated modeled particulate matter concentrations.
- Accounting for the Pasco surfactant facility that began operation in early 2015, the best fit of monitor to modeled concentration suggests a 99.7% surfactant efficiency. This is in agreement with the microscopy analysis that found little of the particulate matter data was coal dust.

Overall, the findings from the Whatcom County field program support the Cowlitz County field program, but the slow train speeds and particulate matter size limitation limit this support. The Whatcom County data also suggest that coal dust emissions are reduced with the use of surfactant, this conclusion is limited by the location and slow train speeds.

Analysis of a few empty coal trains and freight trains revealed similar patterns to the coal trains, with the vast majority of mass found in the PM1 bin. The freight trains showed PM10 and PM2.5 fractional amounts similar to those found for coal trains, suggesting that a sizeable fraction of the coarse particles at this location are due to abrasive processes from wheels and track interactions as well as brakes.

Chapter 3
Impacts

This chapter describes the impacts of coal dust that would result from the Proposed Action and No-Action Alternative.

3.1 Proposed Action

This section describes the impacts of coal dust that would result from the Proposed Action.

3.1.1 Construction: Direct and Indirect Impacts

Construction of the Proposed Action would not include any coal-handling activities. No direct or indirect impacts from coal dust would occur during construction of the Proposed Action.

3.1.2 Operations: Direct Impacts

As stated previously, the assessment for the Proposed Action was modeled using the AERMOD dispersion model. This included coal dust handling from the rail unloading, loading onto vessels, and wind erosion emissions from the coal piles.

3.1.2.1 Site-Specific Operations Impacts—Deposition

To assess the coal dust deposition impacts from the on-site operations was conducted based on full terminal operations. Table 5 presents these deposition amounts and shows both the estimated maximum annual coal dust deposited, based on a 3-year modeling period, and the estimated maximum monthly deposition, along with a comparison to the benchmark for the analysis.

Table 5. Estimated Maximum Annual and Monthly Coal Dust Deposition

Location	Maximum Annual Deposition ($g/m^2/year$)	Maximum Monthly Deposition ($g/m^2/month$)	Benchmark for Analysis ($g/m^2/month$)
Fence line	1.99	0.40	2.0

Notes:
$g/m^2/year$ = grams per square meter per year; $g/m^2/month$ = grams per square meter per month

The estimated maximum coal dust deposition from coal export terminal operations would be below the benchmark for the analysis. The highest estimated monthly deposition amounts would be near Mount Solo Road, as shown in Figure 6.

The spatial extent of the estimated maximum annual coal dust deposition near the coal export terminal is shown in Figure 7, which shows the maximum annual deposition near the coal export terminal. This shows that within a few thousand feet of the coal export terminal, the annual cumulative deposition of coal dust is estimated to be less than 0.1 g/m^2.

Figure 6. Estimated Maximum Monthly Coal Deposition (g/m^2/month) Near the Project Area

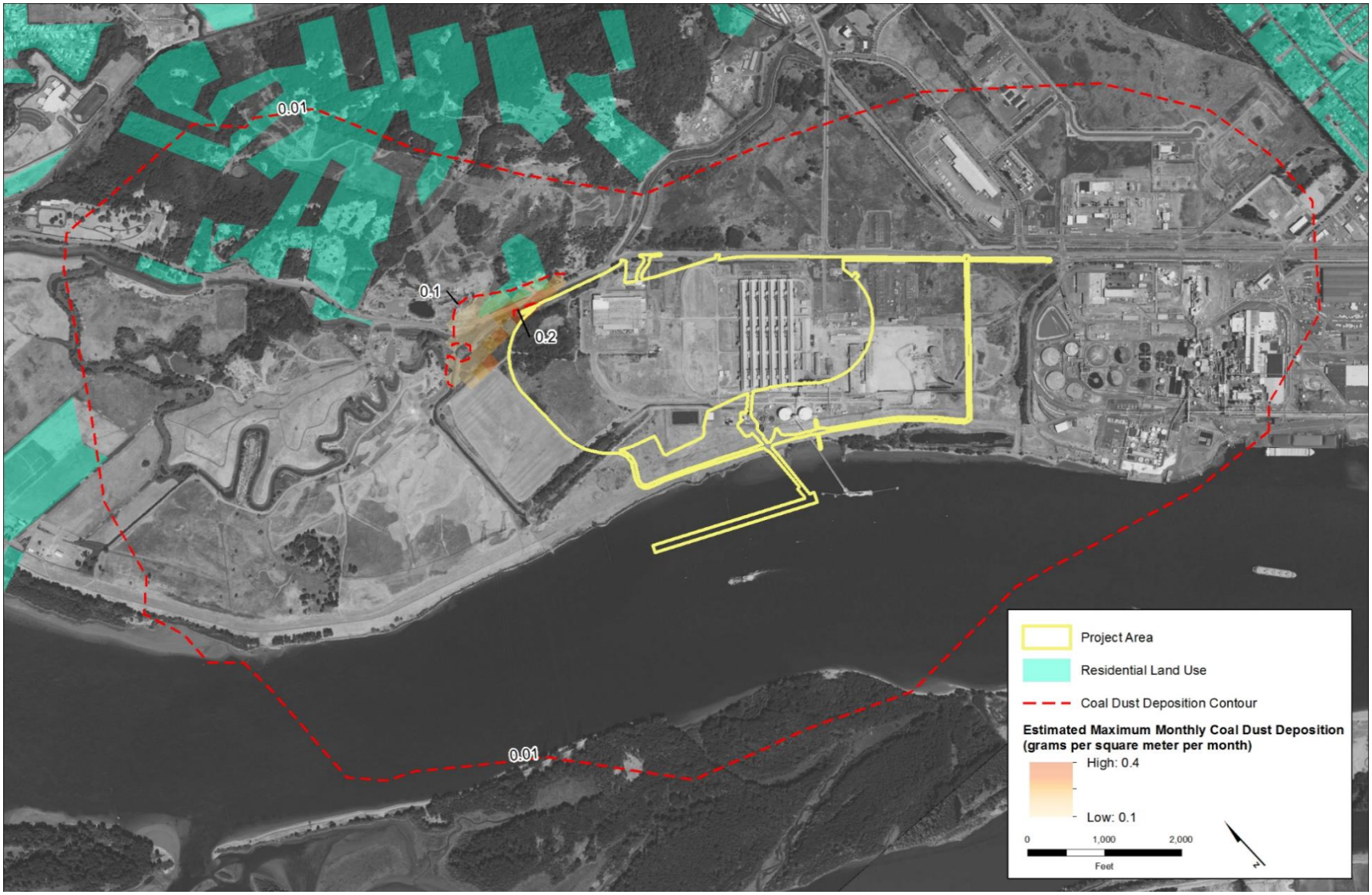
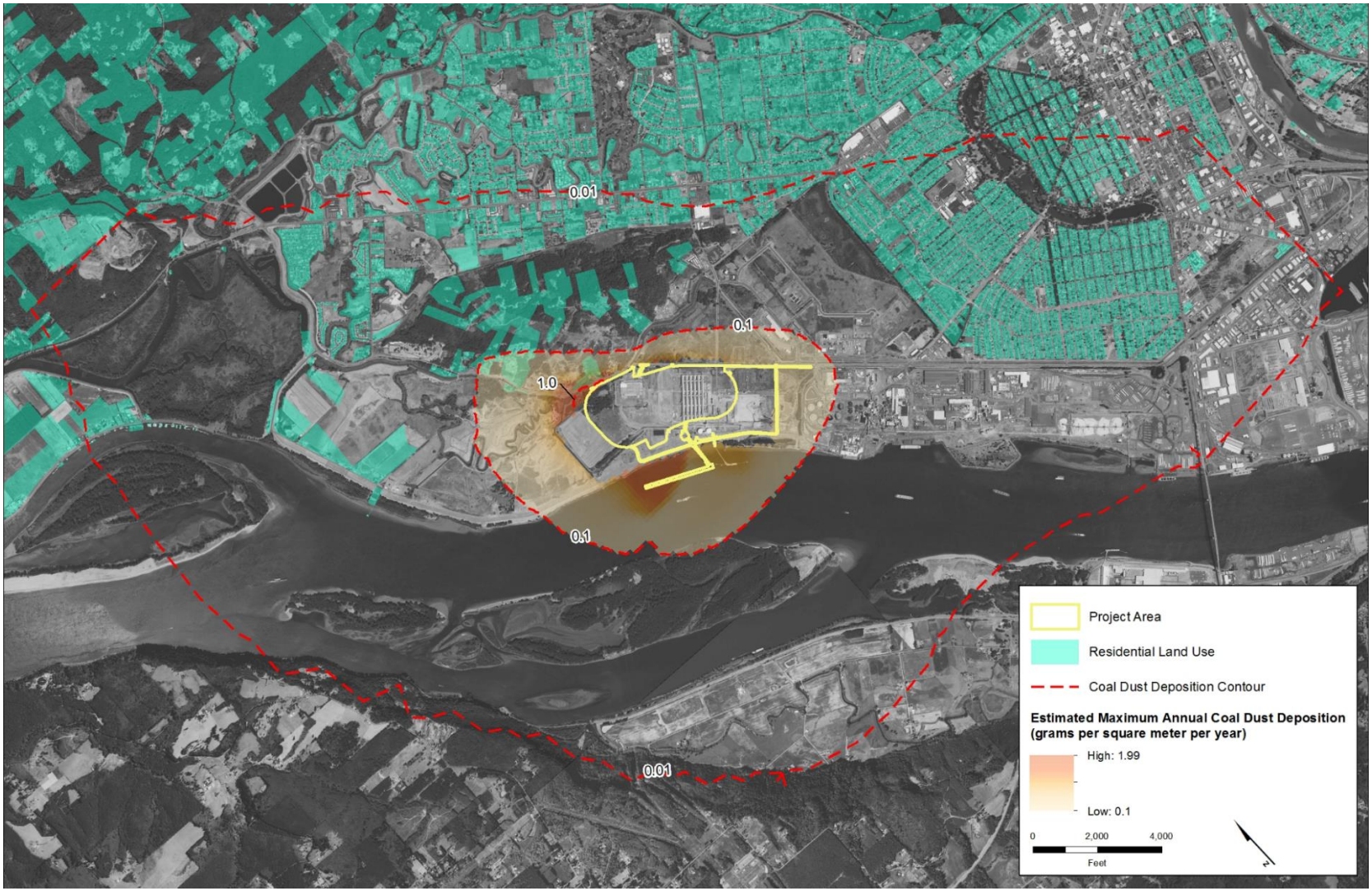


Figure 7. Estimated Maximum Annual Coal Deposition (g/m^2/year) Near the Millennium Bulk Terminal



3.1.3 Operations: Indirect Impacts

3.1.3.1 Cowlitz County

Reynolds Lead and BNSF Spur

To assess the coal dust air quality and deposition impacts from Proposed Action-related train operations, an air quality dispersion modeling using AERMOD was conducted based on an average speed of 10 mph for trains along the Reynolds Lead and BNSF Spur and the planned activity level of an average of eight loaded and eight unloaded Proposed Action-related trains per day. Results are presented in Table 6 showing the estimated maximum coal dust concentration (including background) relative to the PM10 and PM2.5 standard at 100 feet from the rail line. The closest maximum model residential receptor is located 180 feet on the north side of the rail line. These estimated concentrations are below the NAAQS standards. Further distances would experience even lower concentrations as concentrations decrease by about 50% another 160 feet from the rail line.

Table 6. Estimated Maximum PM10 and PM2.5 Concentrations 100 Feet from Rail Line—Reynolds Lead and BNSF Spur

Pollutant	Averaging Period	Maximum Modeled Impact (µg/m³)	Background[a] (µg/m³)	Total Concentration (µg/m³)	NAAQS (µg/m³)
PM10	24 hour[b]	0.28	28.0	28.3	150
PM2.5	24 hour[c]	0.05	16.0	16.05	35
	Annual[d]	0.01	5.3	5.31	12

Notes:
[a] Background concentrations are monitoring design values from Northwest International Air Quality Environmental Science and Technology Consortium (2015).
[b] The PM10 24-hour modeled impact is 3-year average of the high 2nd high concentration.
[c] The PM2.5 24-hour modeled impact is the 3-year average of the 98th percentile of the daily maximum concentrations.
[d] Modeled impact is the high 2nd high over the 3 modeled years.
NAAQS = National Ambient Air Quality Standards; µg/m³ = micrograms per cubic meter

The same modeling approach was used to determine the coal dust TSP deposition. Table 7 reports the results for the estimated maximum increase in deposition from Proposed Action-related train operations for the closest maximum modeled residential receptor (a distance of 180 feet from the rail line). Modeling indicates that the maximum monthly deposition would occur during July. The highest-estimated monthly deposition would be below the benchmark for the analysis.

Table 7. Estimated Maximum and Average Monthly Coal Dust Deposition—Reynolds Lead and BNSF Spur

Material	Distance (feet)	Average Maximum Monthly Deposition ($g/m^2/month$)	Maximum Monthly Deposition ($g/m^2/month$)	Benchmark for Analysis ($g/m^2/month$)
Coal Dust	180	0.013	0.017	2.0
Coal Dust	340	0.006	0.008	2.0

Notes:
$g/m^2/month$ = grams per square meter per month

BNSF Main Line in Cowlitz County

To assess potential coal dust air quality and deposition impacts from Proposed Action-related trains traveling to the coal export terminal on the BNSF main line, air quality modeling was conducted based on an average 50 mph speed on the BNSF main line near Woodland and Kalama, Washington. Table 8 presents the results that show the maximum coal dust concentration (including background) at 50 and 100 feet in comparison with the PM10 and PM2.5 standards. Estimated concentrations are higher than concentrations estimated for the Reynolds Lead and BNSF Spur because of the higher train speeds on the BNSF main line that enhance the entrainment (dust lift-off) of coal particles from the open rail cars. However, in all cases, these concentrations remain below the NAAQS.

Table 8. Estimated Maximum PM10 and PM2.5 Concentrations 50 and 100 Feet from Rail Line—BNSF Main Line, Cowlitz County

Pollutant	Averaging Period	Distance from Rail Line (feet)	Modeled Impact ($\mu g/m^3$)	Background[a] ($\mu g/m^3$)	Total Concentration ($\mu g/m^3$)	NAAQS ($\mu g/m^3$)
PM10	24 hours[b]	50	30.0	28.0	58.0	150
		100	23.0	28.0	51.0	150
PM2.5	24 hours[c]	50	4.5	21.0	25.5	35
		100	3.8	21.0	24.8	35
	Annual[d]	50	2.1	5.9	8.0	12
		100	1.7	5.9	7.6	12

Notes:
[a] Background concentrations are monitoring design values for Woodland, Washington (Northwest International Air Quality Environmental Science and Technology Consortium 2015).
[b] The PM10 24-hour modeled impact is 3-year average of the high 2nd high concentration.
[c] The PM2.5 24-hour modeled impact is the 3-year average of the 98th percentile of the daily maximum concentrations.
[d] Modeled impact is the annual average over the 3 modeled years.
$\mu g/m^3$ = micrograms per cubic meter

The same modeling approach was used to estimate coal dust TSP deposition along the BNSF main line in Cowlitz County. The results show the estimated increase in deposition at distances of 50, 100, and 150 feet from the rail line (Table 9). The deposition amounts are higher than the Reynolds Lead because of the higher train speeds. Estimated maximum monthly deposition would occur during

January. The estimated maximum monthly deposition is above the benchmark for the analysis up to 100 feet.[9]

Table 9. Estimated Maximum and Average Monthly Coal Dust Total Suspended Particulate Deposition—BNSF Main Line, Cowlitz County

Material	Distance (feet)	Average Monthly Deposition ($g/m^2/month$)	Maximum Monthly Deposition ($g/m^2/month$)	Benchmark for Analysis ($g/m^2/month$)
Coal Dust	50	2.2	3.1	2.0
Coal Dust	100	1.4	2.3	2.0
Coal Dust	150	1.0	1.8	2.0

Notes:
$g/m^2/month$ = grams per square meter per month

Table 10 compares the maximum trace element concentrations found in coal dust for the Proposed Action-related trains operating along the BNSF main line location with their respective acceptable source impact levels (ASILs). ASILs are screening concentrations for toxic air pollutant in the ambient air, and are based on the levels established in WAC 173-460-150 for stationary sources but are shown here for comparison purposes. The fraction of trace elements found in coal is based on the maximum fraction of these elements found in two Powder River Basin coal beds (Stricker et al. 2007) in combination with the coal dust air quality modeling. All of the predicted maximum concentrations of these trace elements in coal dust are less than their respective ASILs. Chromium (VI) is likely substantially lower than as shown in the table as the percent of chromium as chromium (VI) was conservatively assumed the same as coal fly ash, which is a post-combustion coal residual. This process is known to increase substantially the percentage of chromium as chromium (VI) (Stam et al. 2011).

Table 10. Maximum Concentrations of Trace Elements Compared with Acceptable Source Impact Levels—BNSF Main Line, Cowlitz County

Substance[a]	Maximum Concentration ($\mu g/m^3$)	ASIL ($\mu g/m^3$)	Averaging Time	Percentage of ASIL (%)
Arsenic and inorganic arsenic compounds	0.000062	0.000303	Annual	20.4
Beryllium and compounds	0.000007	0.000417	Annual	1.8
Cadmium and compounds	0.000002	0.000238	Annual	0.7
Chromium (VI)[b]	0.0000047	0.00000667	Annual	70.4
Cobalt as metal dust and fume	0.00013	0.1	24 hour	0.1
Copper, dusts and mists	0.0015	100	1 hour	0.002
Lead compounds	0.000038	0.0833	1 year	0.046
Manganese dust and compounds	0.00093	0.04	24 hour	2.3
Mercury, aryl and inorganic	0.000005	0.09	24 hour	0.005

[9] These modeled results are comparable to those found during recent monitoring conducted by Corporation of Delta (2014) that reported coal dust deposition amounts ranging from 2 to 10 $g/m^2/month$ (July 2013, April 2014, and October 2014) for an average of six 125-car loaded coal trains passing each day at an average speed of 35 mph (Brotherston pers. comm). The dust fall monitor was located 66 feet from the BNSF main line.

Substance[a]	Maximum Concentration (µg/m³)	ASIL (µg/m³)	Averaging Time	Percentage of ASIL (%)
Nickel and compounds	0.000031	0.0042	Annual	0.74
Selenium compounds	0.000065	20	24 hour	0.0003
Vanadium compounds	0.000732	0.2	24 hour	0.37
Crystal silica (PM4 -respirable) daily average	0.94[c]	3.0	8 hour	31

Notes:

[a] The fraction of trace elements found in coal is based on the maximum fraction of these elements found in two Powder River Basin coal beds (Stricker et al. 2007) in combination with the coal dust air quality modeling

[b] Chromium (VI) is likely substantially lower than as shown in the table because the percent of chromium as chromium (VI) was conservatively assumed the same as coal fly ash, which is a post-combustion coal residual. Combustion is known to increase substantially the percentage of chromium as chromium (VI) (Stam et al. 2011).

[c] Based on analysis of coal dust sample from field program. Total crystal silica fraction in coal dust is the sum of the crystal silica quartz and silicate fractions.

ASIL = acceptable source impact level; µg/m³ = micrograms per cubic meter

BNSF Main Line in the Columbia River Gorge

To assess potential coal dust air quality and deposition impacts from Proposed Action-related trains traveling to the coal export terminal on the BNSF main line through the Columbia River Gorge, air quality modeling was conducted based on an average 50-mph train speed on the BNSF main line near Dallesport, Washington using 2014 The Dalles Municipal Airport meteorological data. Table 11 presents the results that show the maximum coal dust concentration (including background) at 50 and 100 feet in comparison with the PM10 and PM2.5 standards. Estimated concentrations are somewhat lower than those estimated for the BNSF main line in Cowlitz County because of the higher average wind speeds in the Columbia River Gorge, which increases dispersion, although the full effect is offset by the enhanced entrainment (coal dust lift-off) when the ambient wind is blowing toward the train. In all cases, these concentrations remain below the NAAQS.

Table 11. Estimated Maximum PM10 and PM2.5 Concentrations 50 and 100 Feet from Rail Line—BNSF Main Line, Columbia Gorge

Pollutant	Averaging Period	Distance from Rail Line (feet)	Modeled Impact (μg/m³)	Background[a] (μg/m³)	Total Concentration (μg/m³)	NAAQS (μg/m³)
PM10	24 hours[b]	50	18.8	56.0	74.8	150
		100	14.1	56.0	70.1	150
PM2.5	24 hours[c]	50	2.9	19.0	21.9	35
		100	2.2	19.0	21.2	35
	Annual[d]	50	0.94	6.1	7.0	12
		100	0.75	6.1	6.9	12

Notes:
[a] Background concentrations are monitoring design values for Columbia Hills Historical State Park, Washington (Northwest International Air Quality Environmental Science and Technology Consortium 2015).
[b] The PM10 24-hour modeled impact is the high 2nd high concentration.
[c] The PM2.5 24-hour modeled impact is the 98th percentile of the daily maximum concentrations.
[d] Modeled impact is the annual average.
μg/m³ = micrograms per cubic meter

The same modeling approach was used to estimate coal dust TSP deposition along the BNSF main line in the Columbia River Gorge. The results show the estimated increase in deposition from the Proposed Action-related trains at distances of 50, 100, and 150 feet from the rail line (Table 12). The deposition amounts are similar to those along the BNSF main line in Cowlitz County. The estimated maximum monthly deposition would occur during June. The estimated maximum monthly deposition is above the benchmark for the analysis at 50 feet.

Table 12. Estimated Maximum and Average Monthly Coal Dust Total Suspended Particulate Deposition—BNSF Main Line, Columbia River Gorge

Material	Distance (feet)	Average Maximum Monthly Deposition (g/m²/month)	Maximum Monthly Deposition (g/m²/month)	Benchmark Used for Analysis (g/m²/month)
Coal Dust	50	2.2	2.6	2.0
Coal Dust	100	1.5	1.9	2.0
Coal Dust	150	1.0	1.4	2.0

Notes:
g/m²/month = grams per square meter per month

3.1.3.2 Washington State

To assess the coal dust air quality and deposition impacts in other locations in the state, air quality modeling was performed for 8 loaded and 8 unloaded[10] Proposed Action-related trains moving at an average speed of 50 mph along the BNSF main line running in a southwest-northeast orientation in eastern Washington[11] using Moses Lake meteorological data. Results are presented in Table 13 for loaded trains showing the maximum coal dust concentration (including background) relative to

[10] Because emissions from unloaded coal trains are highest after drying following unloading, the impacts were only evaluated in eastern Washington following return via Stampede Pass.
[11] This is the general orientation of the main line running from the Tri-Cities to Spokane.

the PM10 and PM2.5 standard. The maximum concentrations occur at a distance of 100 feet. These concentrations fall off by 50% another 100 feet away from the rail line. These concentrations plus background are all below the NAAQS standards. Table 14 shows the results for unloaded trains. These concentrations are well below the NAAQS standards and the combined exposures from loaded and unloaded coal cars remains below the NAAQS.

Table 13. Estimated Maximum PM10 and PM2.5 Concentrations 100 Feet from Rail Line for Loaded Coal Train —BNSF Main Line, Washington State (Outside Cowlitz County and the Columbia River Gorge)

Pollutant	Averaging Period	Modeled Impact (μg/m³)	Background[a] (μg/m³)	Total Concentration (μg/m³)	NAAQS (μg/m³)
PM10	24 hour[b]	24.2	101	125	150
PM2.5	24 hour[c]	2.8	24.2	27.0	35
	Annual[d]	0.92	8.9	9.83	12

Notes:
[a] Background for PM10 is the maximum high second high 24-hour average over the 3-year period (2012–2014) from Kennewick or Spokane. The background PM2.5 from the Spokane monitor from the 2012–2014 period.
[b] The PM10 24-hour modeled impact is 3-year average of the high 2nd high concentration.
[c] The PM2.5 24-hour modeled impact is the 3-year average of the 98th percentile of the daily maximum concentrations.
[d] Modeled impact is the annual average over the 3 modeled years based on Moses Lake meteorological data (2010–2012).
μg/m³ = micrograms per cubic meter

Table 14. Estimated Maximum PM10 and PM2.5 Concentrations 100 Feet from Rail Line for Unloaded Coal Train —BNSF Main Line, Washington State (Outside Cowlitz County and the Columbia River Gorge)

Pollutant	Averaging Period	Modeled Impact (μg/m³)	Background[a] (μg/m³)	Total Concentration (μg/m³)	NAAQS (μg/m³)
PM10	24 hour[b]	0.24	101	101.2	150
PM2.5	24 hour[c]	0.03	24.2	24.23	35
	Annual[d]	0.01	8.9	8.91	12

Notes:
[a] Background for PM10 is the maximum high second high 24-hour average over the 3-year period (2012–2014) from Kennewick or Spokane. The background PM2.5 from the Spokane monitor from the 2012–2014 period.
[b] The PM10 24-hour modeled impact is 3-year average of the high 2nd high concentration.
[c] The PM2.5 24-hour modeled impact is the 3-year average of the 98th percentile of the daily maximum concentrations.
[d] Modeled impact is the annual average over the 3 modeled years based on Moses Lake meteorological data (2010–2012).
μg/m³ = micrograms per cubic meter

The same modeling approach was used to determine the coal dust TSP deposition in eastern Washington (Table 15) for loaded and unloaded Proposed Action-related trains (Table 16). The results show the increase in deposition from Proposed Action-related rail operations located about 100 feet from the rail line. Maximum monthly deposition occurs during December. The monthly deposition is well below the benchmark for the analysis for both loaded and unloaded trains. The

maximum concentration of trace metals would be less than that found in Cowlitz County, which did not show concentrations above the ASIL.

Table 15. Estimated Maximum and Average Monthly Coal Dust Deposition from Loaded Coal Rail Cars —BNSF Main Line, Washington State (Outside Cowlitz County and the Columbia River Gorge)

Material	Distance (feet)	Average Maximum Monthly Deposition ($g/m^2/month$)	Maximum Monthly Deposition ($g/m^2/month$)	Benchmark for Analysis ($g/m^2/month$)
Coal Dust	100	0.73	0.88	2.0
Coal Dust	200	0.27	0.52	2.0

Notes:
$g/m^2/month$ = grams per square meter per month

Table 16. Estimated Maximum and Average Monthly Coal Dust Deposition from Unloaded Coal Rail Cars—BNSF Main Line, Washington State (Outside Cowlitz County and the Columbia River Gorge)

Material	Distance (feet)	Average Maximum Monthly Deposition ($g/m^2/month$)	Maximum Monthly Deposition ($g/m^2/month$)	Benchmark for Analysis ($g/m^2/month$)
Coal Dust	100	0.018	0.022	2.0
Coal Dust	200	0.011	0.021	2.0

Notes:
$g/m^2/month$ = grams per square meter per month

3.2 No-Action Alternative

Under the No-Action Alternative, the Applicant would not construct the Proposed Action and impacts related to coal dust from construction and operation of the Proposed Action would not occur. The Applicant would continue with current and future operations in the project area. The project area could be developed for other industrial uses, including an expanded bulk product terminal or other industrial uses. The Applicant has indicated that, over the long term, it would expand the existing bulk product terminal and develop new facilities to handle more products such as calcine petroleum coke, coal tar pitch, and cement. Petroleum coke transfer would have minimal coal dust emissions because the material is stored in a building and the transfer from vessel occurs through vacuum unloader.

Chapter 4
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Coal Spills Analysis

Chapter 1
Introduction

1.1 Regulatory Setting

There are no known statutes, regulations, or guidelines at the federal, state, or local level that are specific to spills of elemental unprocessed coal. However, there could be federal, state, or local requirements (e.g., permits) that may be required for clean-up activities related to a coal spill after-the-fact, depending on the location and extent of the coal spill, and nature of the response and clean-up actions. Any spill into a jurisdictional waterbody would likely be treated as an unauthorized discharge under the federal Clean Water Act and the state Water Pollution Control Act and clean-up activities would be permitted after-the-fact. Federal, state, or local requirements (e.g., permits) could be required for clean-up activities related to a coal spill, depending on the location and extent of the spill, and nature of the response and clean-up actions. Any coal spill into a jurisdictional waterbody would likely be treated as an unauthorized discharge under the federal Clean Water Act and the state Water Pollution Control Act.

1.2 Study Area

The coal spill study area includes the project area where coal handling would occur, including the dock areas where coal would be loaded onto vessels in the Columbia River. The coal spill study area also includes areas along the rail line corridor(s) in Cowlitz County and Washington State where trains would operate, transporting coal to the coal export terminal; coal transport to the coal export terminal would likely follow the BNSF and UP routes described for loaded coal trains in the SEPA Rail Transportation Technical Report (ICF and Hellerworx 2017). The size and extent of a coal spill cannot be predicted and would depend on various factors such as location of the incident (dock or railway), train speed, surrounding topography, adjacent structures, and characteristics of the adjacent natural and aquatic environment (e.g., terrestrial vegetation and habitat types, lentic (still) or lotic (flowing) surface waters.

This is a qualitative evaluation of coal spills and the study area focuses on the aquatic (e.g., surface waters and wetlands), terrestrial (e.g., vegetation/habitat), and built environments because these could be affected most directly by spilled coal.

Chapter 2
Existing Conditions

Descriptions of existing conditions relative to terrestrial and aquatic habitats and species, and the built environment for the Proposed Action can be found in the SEPA Vegetation Technical Report (ICF 2017a), SEPA Surface Water and Floodplains Technical Report (ICF 2017b), SEPA Fish Technical Report (ICF 2017c), SEPA Wildlife Technical Report (ICF 2017d), SEPA Land and Shoreline Use Technical Report (ICF and BergerAbam 2017), and SEPA Water Quality Technical Report (ICF 2017e).

The existing conditions in the rail line study area are described for two areas: Cowlitz County and those portions of Washington State beyond Cowlitz County.

2.1 Cowlitz County

The environment in Cowlitz County can be described in three broad categories:

- Aquatic habitats (i.e., rivers, streams, surface waters, and wetlands).
- Terrestrial habitats (i.e., deciduous and coniferous forests, and disturbed areas).
- The various built environments associated with rural, residential, agricultural, commercial, and industrial areas.

2.1.1 Aquatic Environments

Aquatic environments in Cowlitz County include surface waters (e.g. streams, rivers, wetlands) that are intersected by or adjacent to the rail line. These surface waters are important components of the natural environment, providing habitat for fish, wildlife, and vegetation. Major rivers in the study area include the Columbia River, Cowlitz River, Kalama River, North Fork Lewis River, and Toutle River, and there are many smaller streams, such as Ostrander Creek, Salmon Creek, and Mill Creek, most of which are tributaries to the Columbia River. These rivers and streams are known to, or have the potential to, support various species of fish, including salmonids, such as Chinook salmon, chum salmon, coho salmon, sockeye salmon, pink salmon, steelhead, and bull trout. Steelhead and coho salmon spawning habitat has been identified at the Kalama River rail crossing (Washington Department of Fish and Wildlife 2015a). Five of these salmonid species are federally protected under the Endangered Species Act: Chinook salmon, chum salmon, coho salmon, steelhead, and bull trout. Eulachon, a small anadromous fish, and green sturgeon are also federally protected under the Endangered Species Act and are found in rivers and streams in the study area. Critical habitat is designated in several study area streams for Chinook salmon, chum salmon, steelhead, bull trout, and eulachon. Other fish, amphibian, and reptile species may also utilize surface waters in the study area, such as the Pacific pond turtle, Dunn's salamander, western toad, leopard dace, and Pacific lamprey.

Wetlands are also an aquatic environment of concern in the study area. The National Wetland Inventory (U.S. Fish and Wildlife Service 2015) maps wetlands along much of the rail study area within Cowlitz County, with higher concentrations where the rail is closer to the Columbia River and

outside of developed areas (e.g., outside the cities of Kalama and Longview, and agricultural areas). Noted higher wetland concentrations occur south of the confluence of the Cowlitz River with the Columbia River and around the confluence of the Kalama River with the Columbia River. Wetlands mapped along the rail line include Palustrine[12] Emergent, Palustrine Scrub Shrub, and Palustrine Forested wetlands, with various hydrologic regimes. Wetlands provide habitat that can support a variety of wildlife species, including birds, mammals, amphibians, and reptiles. A review of Washington Priority Habitats and Species (PHS) data (Washington Department of Fish and Wildlife 2015b) indicates several large areas of waterfowl concentrations and cavity nesting ducks associated with various wetland habitats. Species identified with these habitat areas include downy woodpeckers, green backed herons, great horned owl, short-eared owl, goldeneyes, and wood ducks. Waterfowl concentrations in the southern part of Cowlitz County in the rail study area (just north of the North Fork Lewis River) include dusky and cackling Canada geese, tundra swans, and sandhill cranes; this area provides seasonal migration habitat for these species.

2.1.2 Terrestrial Environments

The terrestrial environment along the rail line includes a mix of natural habitats (forest, shrub, herbaceous upland), disturbed and developed areas (i.e., rural and urban areas), and agricultural areas. South of Longview and the confluence of the Cowlitz and Columbia Rivers, terrestrial vegetation and wildlife habitat conditions improve compared to the more industrial and urban character of the cities of Longview and Kelso, with some forested areas, wetlands, and ash mounds (associated with the eruption of Mount St. Helens in 1980 and subsequent dredging of the Cowlitz River to remove the mud and ash from the river). South of the Kalama River near the town of Kalama, terrestrial conditions again revert to more industrial and urban land uses. From the town of Kalama south to Martin Island, habitat conditions revert to areas of forests and wetland areas interspersed with rural development. From Martin Island south to the Cowlitz-Clark County line, the BNSF rail corridor intersects primarily agricultural land and rural development, with the exception of the city of Woodland, which has some commercial, urban, and residential development.

Representative wildlife in the study area may include black-tailed deer, red fox, coyote, raccoon, striped skunk, beaver, Oregon and grey-tailed vole, red-tailed hawk, Cooper's hawk, Canada geese, mallard and northern pintail ducks, great blue heron, white-breasted nuthatch, chipping sparrow, and a variety of amphibians and reptiles (Commission for Environmental Cooperation 2011). A review of PHS data (Washington Department of Fish and Wildlife 2015b) for terrestrial habitats indicates small areas of oak woodlands in a few places along the rail line; species associated with this habitat include various woodpeckers, migrant birds, reptiles, invertebrates, and the western gray squirrel (Washington Department of Fish and Wildlife 1998). In addition, two osprey point locations are mapped within 300 feet of the rail line; no further information is provided (Washington Department of Fish and Wildlife 2015b). No designated critical habitat for federally protected species under the jurisdiction of the U.S. Fish and Wildlife Service is mapped in the terrestrial environment near the rail line corridor(s) potentially used to transport coal.

[12] Palustrine wetlands are inland wetlands which generally lack flowing water, contain ocean-derived salts in concentrations of less than 0.5 parts per thousand (ppt), and are non-tidal.

2.1.3 Built Environment

The built environment in the rail line study area in Cowlitz County consists of structures and infrastructure associated with urban, rural, and commercial/industrial land uses. More developed areas around Longview, Kalama, and Woodland are dominated by industrial facilities and residential neighborhoods. Less-developed rural areas are found in-between these more urbanized areas. Structures include housing, commercial and industrial buildings, and associated infrastructure such as roads, bridges, and transmission and utility lines.

2.2 Washington State

Washington State beyond Cowlitz County has various and substantially different types of natural and built environmental conditions. Beyond Cowlitz County, the BNSF rail corridor (rail study area) primarily travels through three ecoregions, including the Cascades, Eastern Cascades Slopes and Foothills, and Columbia Plateau (Commission for Environmental Cooperation 2006), which is the largest ecoregion the rail study area passes through. In general, similar categories for the natural and built environment are applicable at the statewide scale (i.e., natural [aquatic and terrestrial] environments and built environments).

2.2.1 Aquatic Environment

The aquatic environment in Washington State beyond Cowlitz County includes many rivers and streams that are intersected or adjacent to the rail corridor. Many rivers and streams in the rail study area in Clark and Skamania Counties support or have the potential to support the same fish species described for Cowlitz County, as well as similar amphibian and reptile species. However, east of Skamania County (e.g., Klickitat and Benton Counties) the ecological conditions transition to the drier climate of the Columbia Plateau in Eastern Washington (i.e., east of the Cascade Mountains). As a result, smaller tributary streams originating in this ecoregion are generally ephemeral; most summer precipitation is evaporated or transpired, leaving little water for streamflow (Commission for Environmental Cooperation 2011). These conditions may be one factor limiting potential fish distribution. For example streams that support salmonids are much less prevalent in the drier region of eastern Washington compared to western Washington (Washington Department of Fish and Wildlife 2015a). Wetlands occur in the Columbia Plateau, but many have been drained and altered (Commission for Environmental Cooperation 2011).

2.2.2 Terrestrial Environment

The vast majority of the rail study area beyond Cowlitz County is within the Columbia Plateau ecoregion (Commission for Environmental Cooperation 2011). This ecoregion has dry desert and steppe climates, marked by hot, dry summers and cold winters, and consists of shrub-steppe vegetation communities. Vegetation is typically dominated by sagebrush, bitterbrush, bluebunch, needle- and thread-, Idaho fescue, and Sandberg's bluegrass. Numerous annual and perennial flowers often grow in the spaces between the shrubs and bunchgrass. Shrub-steppe historically dominated the landscape of the ecoregion, but much of it has been degraded, fragmented, and isolated from other similar habitats due to conversion to croplands (Washington Department of Fish and Wildlife 2015c).

Representative wildlife of the Columbia Plateau include mule deer, pronghorn antelope (last reintroduced in 2011 at the Yakama Indian Reservation), coyote, black-tailed jackrabbit, ground squirrels, American kestrel, golden eagle, red-tailed hawk, western meadowlark, savanna sparrow, western diamondback rattlesnake, greater sage-grouse, sage sparrows, sage thrashers, and pygmy rabbits, in addition to many other birds, mammals, reptiles, and insects (Commission for Environmental Cooperation 2011 and Washington Department of Fish and Wildlife 2015c). Shrub-steppe communities can also support federally protected species, including the pygmy rabbit and Spalding's catchfly, and the Washington Department of Fish and Wildlife considers shrub-steppe a priority habitat under the PHS program.

The Cascades and Eastern Cascade Slopes and Foothills ecoregions make up a smaller area intersected by the rail study area and mostly coincide with Clark, Skamania, and Klickitat Counties. Typical vegetation in the Cascades ecoregion at lower elevations include Douglas fir, western hemlock, western red cedar, big leaf maple, and red alder; representative wildlife includes black-tailed deer, black bear, coyote, beaver, river otter, pileated woodpecker, and northern goshawk. Typical vegetation in the Eastern Cascades Slopes and Foothills ecoregion includes open forests of ponderosa pine and some lodgepole pine, with sagebrush and steppe vegetation at lower elevations. Representative wildlife species in this ecoregion include black bear, black-tailed deer, mule deer, cougar, wolverine, coyote, yellow-bellied marmot, bald and golden eagles, Cooper's hawk, and osprey (Commission for Environmental Cooperation 2011). PHS data (Washington Department of Fish and Wildlife 2015b) indicate various priority habitats and species along the rail line study area, including talus slope and cliffs/bluffs habitats, bald eagle concentrations and breeding areas, and western pond turtle regular occurrence areas.

2.2.3 Built Environment

The built environment in the rail study area in Washington (beyond Cowlitz County) consists of structures and infrastructure associated with urban, rural, agricultural, and industrial land uses. More developed areas occur along the southern BNSF corridor around Ridgefield, Vancouver, Stevenson, Camas, Washougal, Kennewick, Walla Walla, Richland, Pasco, and Spokane, while to the north more developed areas include Tacoma, Seattle, Everett, Wenatchee, and Yakima. These areas are dominated by a mix of commercial, industrial, and residential land uses. Less-developed rural areas are found in-between these urban areas. Structures include housing, industrial buildings, commercial buildings, and associated infrastructure such as roads, bridges, and transmission and utility lines.

Large-scale coal spills from operation of the coal export terminal and trains transporting coal to the terminal could potentially affect the aquatic, terrestrial, and built environments. Such an event could occur as a result of a train incident (collision and/or derailment) or to a lesser extent during coal handling at the coal export terminal that occurs outside the rail loop (i.e., trestle and docks). Potential effects on the natural environment from a coal spill would likely be more pronounced during a train incident compared to a spill occurring in the confines of the coal export terminal for two reasons: (1) the absence of terrestrial and aquatic environments within the already developed project area compared to the presence of various terrestrial and aquatic resources along the rail line throughout the state, and (2) the amount of coal that could be spilled during operations at the coal export terminal would likely be relatively low when compared to a spill resulting from a train incident or derailment. Additionally, coal would be contained within the rail loop during operations. The magnitude of the potential impact from a coal spill on the aquatic, terrestrial, and built environments would depend on the location of the spill, the volume of the spill, and success of efforts to contain and clean-up the spill.

A coal spill during operations of the coal export terminal could occur. Direct impacts resulting from a spill during coal handling at the coal export terminal would likely be relatively minor because the amount of coal that could be spilled during operations would be relatively small and because of the absence of terrestrial and aquatic environments that exist within the areas to be developed and the contained nature of the coal export terminal and features of the terminal (e.g., fully enclosed belt conveyors over water, transfer towers, and shiploaders).

Further, it is unlikely that coal handling within the upland portions of the project area would result in a spill of coal that would affect the Columbia River as the rail loop and stockpile areas would be contained, and other areas adjacent to the coal export terminal are separated from the Columbia River by an existing levee, which would prevent coal from being conveyed from upland areas adjacent to the rail loop to the Columbia River. Coal could be spilled during vessel loading operations; however, such a spill would be caused by human error or equipment malfunction and would be expected to result in a limited release of coal into the environment due to safeguards to prevent such operational errors resulting in a spill. These include start-up alarms, dock containment measures to contain spillage/rainfall/runoff, and enclosed shiploaders.

The potential impact of a coal spill from train operations is directly related to the probability of a train incident occurring. A train incident (collision/derailment) risk analysis was developed by ICF (2017f) to estimate the number of train incidents that could potentially occur during coal transport (i.e., loaded coal trains) within Cowlitz County and Washington State. In Cowlitz County, the predicted number of loaded coal train incidents is approximately one every 2 years. The predicted number of loaded coal train incidents within Washington State is approximately five per year (ICF 2017f).

Not every incident of a loaded coal train would necessarily result in a rail car derailment and/or a spill of coal. A train incident could involve just one or two rail cars or multiple rail cars, and could include derailment in certain circumstances. Not all of the coal cars that may derail in any train incident would necessarily result in some or all of their contents spilling, depending on the nature of

the incident (i.e., size of train, speed of the train, terrain where incident occurs). A broad range of spill sizes, from a partial rail car to multiple rail cars, could potentially occur from loaded unit coal trains as the result of a train incident (ICF 2017f).

In addition, containment and clean-up efforts for coal spills associated with both operations and rail transport factor significantly into the ultimate fate of a coal release and its potential impact on the environment. It is assumed that coal spills in the terrestrial and built environments would be easier to contain and clean up than if such spills were to occur in the aquatic environment because coal would be on the ground surface and visible, response time would be more swift, and clean-up equipment would likely have easier access to the spill site. The impacts from unintended or coal releases on the aquatic, terrestrial, and built environments are described in the context of the train incident risk analysis and the containment and clean-up measures to remove the spilled coal.

3.1 Aquatic Environments

Coal is transported over land and water throughout the world. However, there is little existing literature and research regarding the effects of unburnt coal on the aquatic environment.

The most comprehensive literature review on the potential impacts of unburnt coal in the aquatic environment was conducted by Ahrens and Morrisey (2005). Their review summarized the potential physical and chemical (toxicity) effects of unburnt coal released into the aquatic environment; the following summarizes these effects and draws heavily from their review.

3.1.1 Physical Effects

In sufficient quantities, coal can have measurable physical effects on aquatic organisms and habitats similar to suspended and deposited sediments (which are well documented). The potential physical effects of increased coal in the aquatic environment are likely to dominate over potential toxic chemical effects (see below) of coal (Ahrens and Morrisey 2005). The physical effects of coal on aquatic organisms and the aquatic environment can include abrasion, smothering, diminished photosynthesis, alteration of sediment texture and stability, reduced availability of light, temporary loss of habitat, and diminished respiration and feeding for aquatic organisms. The magnitude of these potential impacts would depend on the amount and size of coal particles suspended in the water and settling on the bed/organisms (which will, in turn, depend on rate of flow and patterns of water movement), duration of coal exposure, and existing water clarity (Ahrens and Morrisey 2005). Therefore, depending on the circumstances of a coal spill and the existing conditions of a particular aquatic environment (e.g. lake, stream, wetland), the physical effects on aquatic organisms and habitat from introduced coal could vary significantly and range from no perceptible impact (i.e., relatively small spill followed by rapid and complete clean-up) to more severe impacts that could include reduced growth, reproduction, and abundance; elevated mortality; and altered population and community structure (i.e., large spill that impacts significant habitat and/or species with prolonged and more invasive clean-up effort).

Similarly, clean up of coal released into the aquatic environment could result in temporary impacts to habitat, such as smothering, alteration of sediment composition, temporary loss of habitat, and diminished respiration and feeding for aquatic organisms. The time required for recovery of the aquatic environment and resources would depend upon the extent and duration of clean-up efforts and the environment in which the incident occurred. For benthic organisms, such as

macroinvertebrates, recolonization rates of temporarily disturbed benthic habitats range from 30 to 45 days (National Marine Fisheries Service 2003). Aquatic vegetation would likely require more time to recolonize benthic habitats temporarily disturbed by clean-up efforts, with the duration dependent upon site-specific conditions (i.e., water depth, water clarity, water velocity, substrate type).

3.1.2 Chemical Effects (Toxicity)

Some research suggests that the bioavailability of contaminants in coal is limited, and that at levels of coal contamination at which estimates of bioavailable concentrations of contaminants might give cause for concern, the acute physical effects are likely to be more harmful than the chemical effects (Ahrens and Morrisey 2005). However, the variable chemical properties of coal and the aquatic environment in which it might occur, may give rise to circumstances in which contaminant mobility and bioavailability is enhanced. Coal can be a source of acidity, salinity, trace metals, polycyclic aromatic hydrocarbons (PAHs), and chemical oxygen demand (a measure of organic pollutants found in water), and interactions between coal and water could result in the alteration of pH and salinity, release of trace metals and PAHs, and an increase in chemical oxygen demand. However, if and how much these alterations occur in the aquatic environment and whether the alterations are significant enough to be potentially toxic to aquatic organisms depends on many factors, notably the type of coal, the relative amount of time the coal is exposed to water and broken down, dilution, buffering, and bioavailability.

Because of these unknown factors it is difficult to evaluate specifically what would happen in the event of a coal spill in the aquatic environment. For example, the acidity-generating potential of coal is largely a function of sulfur content, with sulfur-rich coals generally producing low pH levels in water and sulfur-poor coal generally producing more pH-neutral water (Ahrens and Morrisey 2005). The low pH of sulfur-rich coal further favors dissolution and release of metal ions such as iron, copper, manganese, chromium, and zinc compared to sulfur-poor coal (Anderson and Youngstrom 1976 in Ahrens and Morrisey 2005).[13]

Coal from the Powder River basin and Uinta Basin are low-sulfur coal. However, to provide a sense of the worst-case, more sulfur-rich coal is considered in the context of impacts to water quality. In general, how sulfur-rich coal could affect the aquatic environment largely depends on the context in which the coal is present. In the context of a coal stockpile at an export terminal that is exposed to rain water, the leachate generated from sulfur-rich coal could result in stormwater runoff with low pH levels and metal ion concentrations that could potentially be released into the environment if not contained and treated prior to discharge (operation of the coal export terminal would require a federal and state permit for any discharge of stormwater from the facility; effluent would be required to meet state and federal water quality criteria). In the context of coal released into a large flowing river like the Columbia River (e.g., from train derailment or during vessel loading), acidity could be immediately buffered by the river's naturally occurring bicarbonate concentrations, which would limit the release of metals, potentially resulting in imperceptible changes in the aquatic environment. Further, if any metals were released, their concentrations would likely be diluted by the river's velocity and discharge volumes. In this scenario, any negative impacts on aquatic

[13] It should be noted that the coal export terminal would primarily handle western U.S. coal from the Powder River Basin, and to a lesser extent the Uinta Basin; the sulfur content of coal from these basins is poor—the lowest sulfur content from U.S. domestic sources (Grette Associates, LLC 2014). This suggests that there would be a much lower acidity-generating potential (i.e., low pH levels) and lower potential metal release in the aquatic environment.

organisms, assuming chemicals were bioavailable, would likely be localized and kept in the immediate vicinity of the coal. In smaller streams and lakes, the impact could be more pronounced, but the extent of any impact would depend on site-specific conditions as well as the amount of coal released into the system.

Despite the variable factors and uncertainty of potential effects of coal spilled into the aquatic environment, some research suggests that under certain conditions chemicals released from coal could interfere with metabolizing enzymes and metal detoxification proteins, destabilize and increase permeability of membranes, and bioaccumulate in the tissue of aquatic organisms (Ahrens and Morrisey 2005). Whether there would be any measurable impact would depend on a variety of factors, but could potentially result in reduced growth, reproduction, and abundance; elevated mortality; and altered population and community structure (Ahrens and Morrisey 2005).

Depending on the circumstances of a coal spill and the existing conditions of a particular aquatic environment (e.g., stream, lake, wetland), the chemical effects on aquatic organisms and habitats could vary significantly and range from no perceptible impact to more severe impacts. A recent coal train derailment and coal spill in Burnaby, British Columbia, in 2014, and subsequent clean-up and monitoring efforts provide some insight into the potential impact of coal spilled on the aquatic environment (i.e., Silver Creek and Burnaby Lake). Phase one of the effort involved removing as much coal as possible from the terrestrial and aquatic environment; a total of approximately 143 tonnes of mixed coal, organic and mineral fines were removed using a vacuum-truck system and hand tools (Borealis Environmental Consulting 2015). Some coal was left in place in the stream and lake because it was considered impractical to remove additional coal without concomitant removal of significant volumes of native substrate and potential disturbance of riparian habitats. Post clean-up water quality and biota studies were then conducted to determine the potential short- and long-term impacts from the residual coal that remained in the aquatic environment. The study included four major elements: water quality, sediment quality, sediment leachate toxicity, and bioaccumulation potential. The study's summary results state that water quality was generally consistent with provincial and/or federal guidelines protective of aquatic life. Sediment concentrations of three metals and PAHs exceeded sediment guidelines, which indicated a potential for adverse effects on aquatic biota, requiring additional laboratory toxicity tests regarding the bioavailability of these metals and PAHs. The toxicity test results determined all samples to be nontoxic to all species tested (fish, invertebrate, and algae), except at one sample site, which yielded marginal effects on the survival of benthic macroinvertebrates. The bioaccumulation potential results indicated no potential at any sample site, except for one sample site where PAHs present have the slight potential to accumulate in benthic invertebrates in that sample area. The overall conclusion of the weight-of-evidence evaluation was that there are potentially minor impacts in the coal spill study area, and that these impacts are restricted to a small, localized area of the stream and lake. Further, no additional mitigation was recommended (as any removal of residual coal mixed with sediments was determined to pose a greater risk to environmental receptors); it was not anticipated that higher trophic levels would experience any adverse effects; and impacts beyond the spatial extent of the area assessed would be unlikely (Borealis Environmental Consulting 2015).

3.2 Terrestrial Environments

Coal released as the result of a spill into the terrestrial environment could physically damage and smother vegetation and terrestrial habitat. The potential for this impact within the confines of the

coal export terminal would be low because of the developed nature of the coal export terminal, which has little to no existing vegetation or suitable terrestrial habitat, and containment measures which would already be in place during operations. Vegetation and terrestrial habitat immediately adjacent to the rail line would be susceptible to impacts from a coal spill, but the area adjacent to the rail line is generally disturbed from rail right-of-way maintenance (i.e., routine mowing and trimming of vegetation), and provides little high quality habitat and vegetation diversity, as well as higher incidences of nonnative plant species. There would be a greater risk of affecting more natural and undisturbed vegetation and habitats if a coal spill were to occur beyond these maintained areas or the rail right-of-way. Herbaceous vegetation would be more susceptible to damage and smothering from a coal spill compared to more rigid, woody vegetation like shrubs and trees, which would be able to better withstand the weight and force of a coal spill, depending upon the magnitude of the spill. The magnitude of potential impacts would depend on the size (volume) and extent (area) of the coal spill.

The physical impact of coal spilled on vegetation would range from minor plant damage to complete loss of vegetation until assumed restoration measures would be implemented. Some plant species may be more sensitive to these impacts than others may, and a coal spill could create an opportunity for nonnative plants to thrive and outcompete damaged native plants, although nonnative plants would likely sustain similar damage. Coal dust associated with a coal spill could also cover vegetation, resulting in reduced light penetration and photosynthesis, which could lead to reduced vegetation density and plant diversity. More tolerant plant species could benefit from decreased competition, particularly nonnative species that could outcompete native species. The magnitude of potential coal dust impact would depend on duration of exposure, tolerance of vegetation, and aggressiveness of nonnative species.

Ground disturbance related to clean-up of coal spilled during operations may further affect vegetation by either removing or further damaging it. Any pieces of residual coal that might remain on the ground after a clean-up effort could leach chemicals from exposure to rain, which could damage or kill vegetation. However, if this were to occur, the impact area would generally be highly localized and limited to the extent of the spill, and unlikely to disrupt the overall plant ecosystem.

Coal spilled into the terrestrial environment could also affect wildlife that may be in the area during a coal spill. It is unlikely that wildlife would be present within the confines of the coal export terminal due to the lack of vegetation and suitable habitat in the developed facility, presence of surrounding facility fences that would limit wildlife movement and presence of humans and machinery during operations. Wildlife present along the rail line during a train incident or derailment, and that are unable to escape the area, could be harmed by direct physical contact if rail cars derail. Depending on the size of the coal spill, wildlife could sustain injuries from blunt force trauma as the rail car derails and coal is spilled, and if the spill is severe enough, could smother and die. Smaller and less mobile species would be at a higher risk than larger and more mobile species. However, it is anticipated that most wildlife would have already moved out of the immediate area along the track because of the relatively loud sounds and vibrations generated from oncoming and passing trains.

3.3 Built Environment

Coal spills in the built environment could potentially affect structures in the event of a large and concentrated coal spill associated with a train incident and/or derailment; however, more likely

impacts on the built environment would include the potential disruption and delay of traffic, reduced access to business and services, and disruption of utility services. Although clean up of coal in the built environment would likely commence immediately and access to the spill would be relatively uninhibited, there could be some delays and detours for vehicles, bicyclists, and pedestrians. Access to businesses, industries, services, and first responders could also be blocked or restricted. These impacts would likely be short-term and temporary burdens until removal and clean-up efforts were completed. The magnitude of these impacts would depend on the location and extent of a coal spill.

Chapter 4
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Sulfur Dioxide and Mercury Emissions Analysis

Chapter 1
Introduction

This chapter assesses the potential impacts in Washington State resulting from the combustion of Millennium Bulk Terminals–Longview coal exported to Asia and combusted in Asia. The air pollutants that could affect Washington State, given the distant location, are emissions of mercury (Hg) and sulfur dioxide (SO_2). These pollutants are chemically transformed, deposited, and, in some cases, re-emitted[14].

Mercury is mostly (53%) released to the atmosphere in elemental form (Hg^0), with another 37% released as gas-phased oxidized mercury (Hg^{II}), and 10% as particle bound mercury. Hg^0 is oxidized to Hg^{II} by ozone and hydroxyl radical (OH) in the atmosphere; however, this process is relatively slow, and, because Hg^0 is relatively insoluble in water and has a low deposition velocity, it stays in the atmosphere for long periods. Hg^{II} is lost from the atmosphere through wet and dry deposition; however, in cloudy regions Hg^{II} can be reduced back to Hg^0; thus, a portion of the Hg^{II} Particle-bound mercury is rapidly removed from the atmosphere through deposition and is found only close to the source.

The process for SO_2 entering the atmosphere is similar to mercury's process. The atmospheric chemistry responsible for the conversion of SO_2 to particulate sulfate is primarily through the oxidation of SO_2 by the hydroxyl radical in the absence of clouds or fog. The rate of this conversion process increases with both increasing temperature and relative humidity. The conversion of SO_2 to sulfate via aqueous solution chemistry in clouds and fog is more complex and dependent on several variables, including concentrations of the principal oxidants (hydrogen peroxide and ozone), ammonia, droplet size, and composition. The speed of the reaction can vary from less than 1% SO_2 converted per hour to a maximum of about 10% converted per hour at high temperature and relative humidity. Competing with the conversion to sulfate is the removal process that includes loss to cloud droplets, rainout, and washout and loss to sea salt aerosols at the ocean's surface.

Because this chemical transformation and removal process of Hg and SO_2 is complicated, the best approach for assessing the impacts is through chemical transport modeling.

1.1 Assessment Approach

The objective of this assessment is to determine how much of the mercury and sulfate levels that would be found over Washington State could be attributable to the mercury and sulfur emitted from coal combustion in Asia (from coal that passed through the coal export terminal). The assessment was conducted in a four-step process.

1. Conduct a literature review of the current state of the science for the air monitoring and modeling of SO_2 and Hg in the Pacific Northwest.

[14] Chemically transformed meaning the pollutants interact with other chemicals in the atmosphere to form other air pollutants. Deposited meaning the pollutant is deposited to the earth surface. Re-emitted meaning pollutants which are first deposited to the surface of the earth but are later re-emitted to the atmosphere due mostly to changes in meteorological or physical oceanic conditions.

2. Use the best understanding of the source-to-receptor relationship from the global chemical transport modeling (GCTM) that has been done to date and apply those findings to answer the objective of this study.
3. To apply the findings from the GCTM, compare the emission inventory for mercury and SO_2 used in the modeling with the projected air emissions of mercury and SO_2 in Asia (China, Japan, South Korea, Hong Kong, and Taiwan) for each of the five incremental scenarios completed using the Integrated Planning Model (IPM). This model was used to conduct the coal market assessment. Finally, identify the impacts from a long-range transport episode and on an annual basis.
4. The literature review and emission inventory uncertainties provide an upper bound on the mercury and SO_2 attributable to coal that passed through the coal export terminal.

This report discusses each of these four steps and presents the findings from this assessment. Because the two pollutants' (SO_2 and mercury) chemical fate and behavior in the atmosphere is very different, the final part of the report addresses mercury and SO_2 separately.

1.2 Overview of Methods for Mercury and SO_2 Assessment

This section provides an overview of the methods for the mercury and SO_2 assessment.

1.2.1 Literature Review

This step involved identifying, gathering, and reviewing peer-reviewed literature published in the past 15 years on the fate and transport of mercury and SO_2 emissions injected into the atmosphere from Asian countries where coal would be burned and any impact analyses completed to assess the impacts of the emissions in the Pacific Northwest of the United States and British Columbia, Canada. The best understanding of the fate and transport of those emissions would be used in assessing the fraction of the coal consumed and the impact in Washington State using a GCTM used to determine impacts in the Pacific Northwest.

1.2.2 Emission Inventory, GCTM, and Concentration Estimate

To determine the concentration or deposition amounts over Washington State from coal consumed, the emission source strength for each country of interest was collected as used in the fate and transport GCTM. The resulting concentration or deposition from the GCTM modeling was then adjusted for the projected country emissions for when the Applicant would become operational relative to the GCTM baseline modeling year. Finally, the projected concentration or deposition was adjusted for the fractional amount of coal to country emissions. This is expressed mathematically in the equation below and then simplified in the following step.

$$X_{tt} = X_{00} \times \frac{EA_{tt}}{EA_{00}} \times \frac{EA_{MTBL,tt}}{EA_{tt}},$$

Which simplifies to:

$$X_{tt} = X_{00} \times \frac{EA_{MTBL,tt}}{EA_{00}} \qquad \text{(Equation 1)}$$

Where *tt* is the forecast year, 00 is the baseline year of the GCTM modeling, *X* is the concentration or deposition at the representative location, *EA* is East Asia SO_2 or mercury emissions from all sources, and *MBTL* is the SO_2 or mercury emission from Proposed Action-related coal.

1.2.3 Application to the Five Coal Market Assessment Scenarios

Each emission rate (mercury or SO_2) for the five SEPA Coal Market Assessment Technical Report (ICF 2017) scenarios was applied to future years of the five IPM scenarios for three future years (2025, 2030, and 2040) when the coal export terminal would be operational. Estimates of the concentrations and deposition are determined for each scenario on annual and episodic bases. More information about the scenarios can be found in the SEPA Coal Market Assessment Technical Report.

1.2.4 Uncertainty

Based on the literature review on uncertainty an upper-bound estimate was developed on the possible coal combustion impact on mercury and sulfate concentration and deposition impact in Washington State. This is explained in the following sections.

Chapter 2
Mercury Assessment

Over 40 peer-review publications were found during the literature review, which spanned approximately the past 15 years. The studies included mercury emission inventories, emission projections, coal consumption in Asia, air monitoring studies in the Pacific Northwest and British Columbia, Canada, and global transport chemical modeling studies focused on assessing the fate and transport from Asia to North America. Also included in the assessment is the United Nations Environment Programme Global Mercury Assessment (United Nations Environment Programme 2013) report, which contains the most recent estimate of global mercury emissions.

The following discusses the nature of the emissions of mercury, how those pollutants behave and change in the atmosphere, and the form of those pollutants once they reach Washington State. This discussion is followed by a description of the papers most relevant to this study, with emphasis on the key findings from those papers as used in developing the impact assessment for the coal burning.

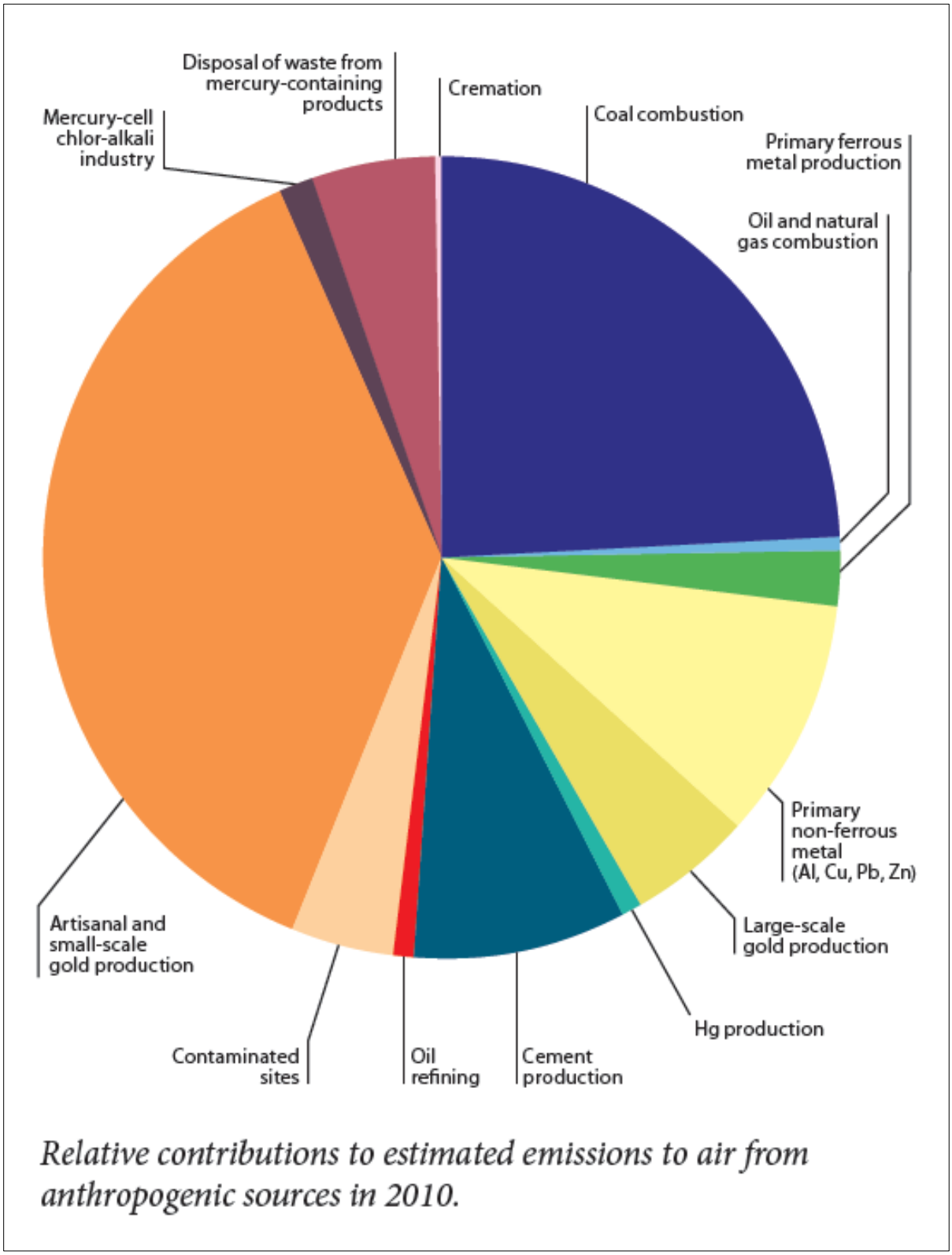
2.1 Introduction

Mercury is a naturally occurring element and is found throughout the world. Many natural sources of mercury emit mercury into the atmosphere, including the weathering of mercury-containing rocks, volcanoes when they erupt, and geothermal activity. Most recent models of the flow of mercury through the environment (United Nations Environment Programme 2013) find that natural sources account for about 10% of the annual mercury emission.

Anthropogenic sources of mercury emissions account for about 30% of the total amount of mercury entering the atmosphere each year. Globally, the largest source of emissions within this category is from artisanal and small-scale gold mining (estimated at 37%), followed by coal combustion (24%). The next largest sources are from the primary production of non-ferrous metals (aluminum, copper, lead, and zinc) and cement production. These sources together account for about 80% of the annual anthropogenic emission of mercury. Figure 8 shows the estimated emissions by anthropogenic source category.

The third category of mercury emissions is re-emissions, which account for about 60% of the mercury emitted to the air annually. Mercury previously deposited from air onto soils, surface waters, and vegetation from past emissions can be emitted back to the air. Re-emission is a result of the conversion of inorganic and organic forms of mercury to elemental mercury, which is volatile and therefore readily returns to the air. Mercury may be deposited and re-emitted many times as it cycles through the environment.

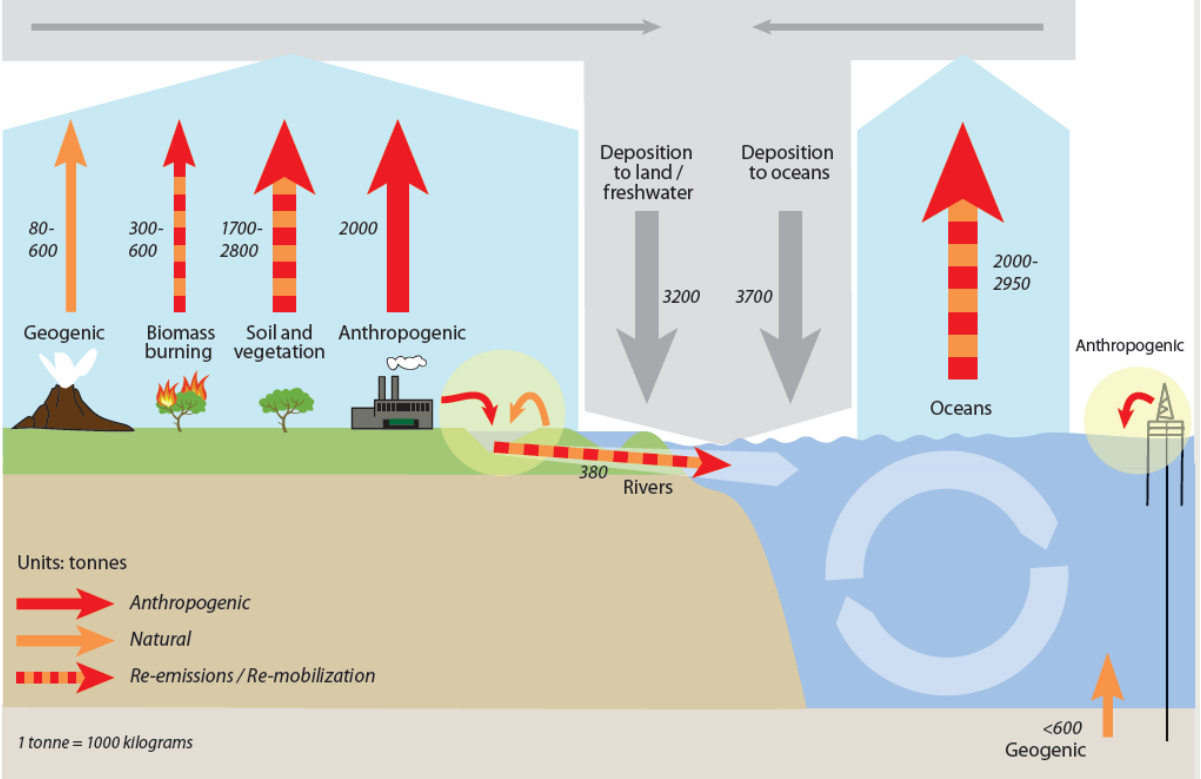
Figure 8. Anthropogenic Mercury Emissions Source Contribution



Source: United Nations Environment Programme 2013.

Re-emitted mercury should not be considered a natural source—it may originally have been either natural or anthropogenic, but by the time it is re-emitted, its specific origin cannot be identified other than from atmospheric modeling. Estimating re-emission rates is done using global modeling approaches based on data of atmospheric levels of mercury and an understanding of chemical transformations and other processes that affect how mercury moves between air, land, and water. The models act to balance the amount of mercury in circulation at any given time consistent with observational data. This analysis conservatively assumes that the re-emitted mercury is all anthropogenic. Figure 9 shows the current global mercury emission cycle.

Figure 9. Global Mercury Cycle (metric tons/year)



Source: United Nations Environment Programme 2013.

Mercury is largely released in its elemental form, which has a lifetime in the atmosphere of between 6 and 24 months, and therefore can be transported globally. The chemical speciation of mercury has been further studied by Pacyna et al. (2006). Across industries, about 53% of mercury in gases is in Hg^0 (elemental form), 37% is Hg^{II} (gas-phased oxidized mercury), and 10% is particle-bound mercury. This is important as the latter two phases of mercury have much shorter lifetimes—days or weeks—which mean they are deposited close to the source.

Mercury deposited in its elemental form is an inorganic compound. Inorganic mercury can be converted to organic methylmercury, which is of concern because of known toxicological effects on highly exposed or sensitive populations. Although mercury is a globally dispersed contaminant, it is normally a problem only where the rate of natural formation of organic methylmercury from inorganic mercury is greater than the reverse reaction (U.S. Geological Survey 2000).

After conversion to this methylated form, mercury can bioaccumulate up the food chain beginning with microorganisms that are consumed by fish, which may be consumed by larger fish. Organic methylmercury is the only form of mercury that accumulates appreciably in fish (U.S. Geological Survey 2000). Such bioaccumulation can result in high levels of mercury in some fish, which is one of the primary sources of human exposure to organic methylmercury. However, because human exposure to organic methylmercury occurs almost exclusively through fish consumption and varies by type and amount of fish consumed, variations in human exposure to organic methylmercury are based on individual fish consumption patterns (National Research Council 2000). Organic methylmercury can also be released back to the atmosphere by volatilization (U.S. Geological Survey 2000).

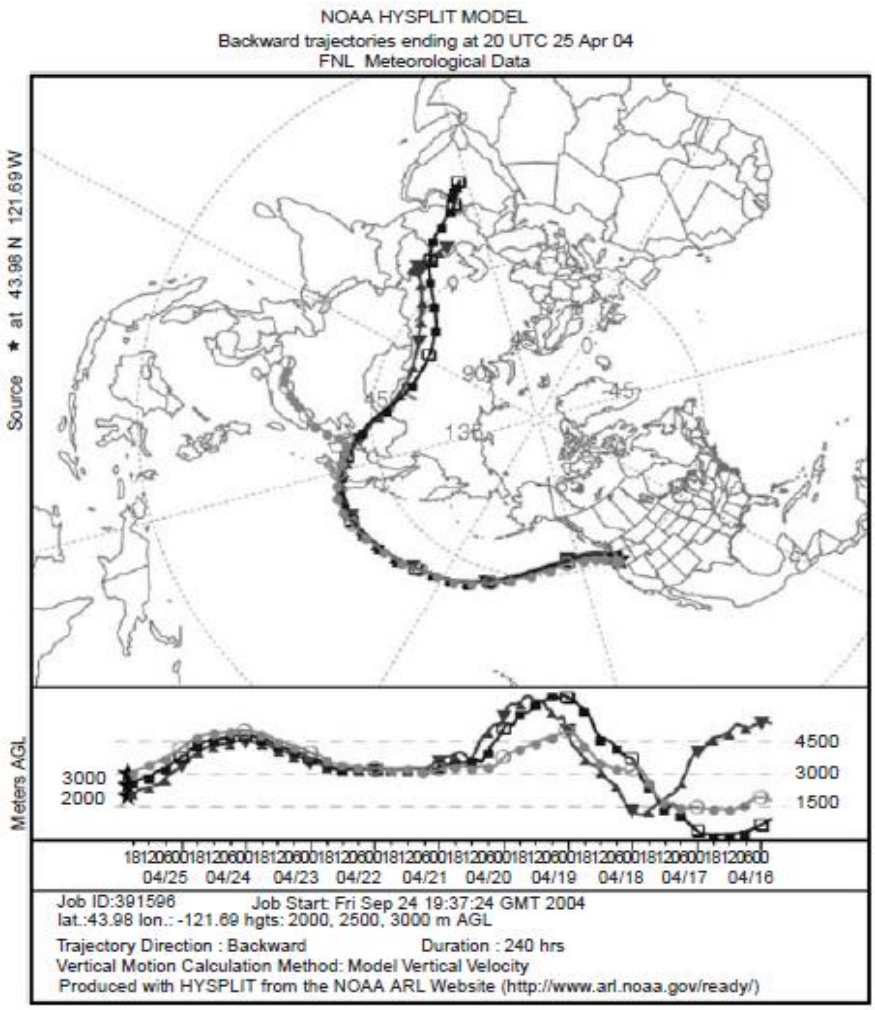
Environments that are known to favor the production of organic methylmercury include certain types of wetlands, dilute low-pH lakes in northeast and north central United States, parts of the Florida Everglades, newly flooded reservoirs, and coastal wetlands, particularly along the Gulf of Mexico, Atlantic Ocean, and San Francisco Bay (U.S. Geological Survey 2000).

2.2 Studies and Findings

A number of observational studies have examined the long-range transport of Asian mercury emissions to North America (Jaffe et al. 2003, 2005; Weiss-Penzias et al. 2006). Weiss-Penzias et al. found that total mercury (elemental + reactive and particle) over the period from March 28 to May 19, 2004, at Mount Bachelor, Oregon (44.0° N, 121.7° W) had periods where the air mass originated from East Asia, with an average increase in total mercury during these periods of 0.16 nanograms per cubic meter (ng/m^3) attributable to emissions from northern China, Korea, and Japan. This was based on the analysis of thousands of back trajectories using the National Oceanic and Atmospheric Administration's HYSPLIT trajectory model and mercury-to-carbon monoxide measurement ratios. Two pollution events within this period were examined in detail, which showed that travel time from East Asia to the Pacific Northwest was about ten days. Back-trajectories for the April 25, 2004, episode at several elevations above and below the Mount Bachelor site elevation, along with back-trajectories for the same date on the corners of a 1° x 1° box around the Mount Bachelor location and at multiple elevations, all showed similar flow from East Asia (Figure 10).

Because of the large amount of coal consumed in East Asia, which is projected to increase, and because studies show long-range transport from East Asia to North America is a frequent occurrence, several global modeling studies have been conducted to explore the impact of mercury emissions from East Asia on North America. The first such assessment was presented by Seigneur et al. (2004), who reported that Asian mercury emissions were estimated to contribute between 5 and 36% of the total mercury concentration in the United States. The most extensive modeling study of East Asian mercury emission impacts on the Pacific Northwest was conducted by Strode et al. (2008). That study included both global modeling of mercury and an observational analysis and comparison of the models' findings using the Mount Bachelor monitored mercury data.

Figure 10. HYSPLIT Back-Trajectory for the Mount Bachelor Observatory Episode (April 25, 2004)

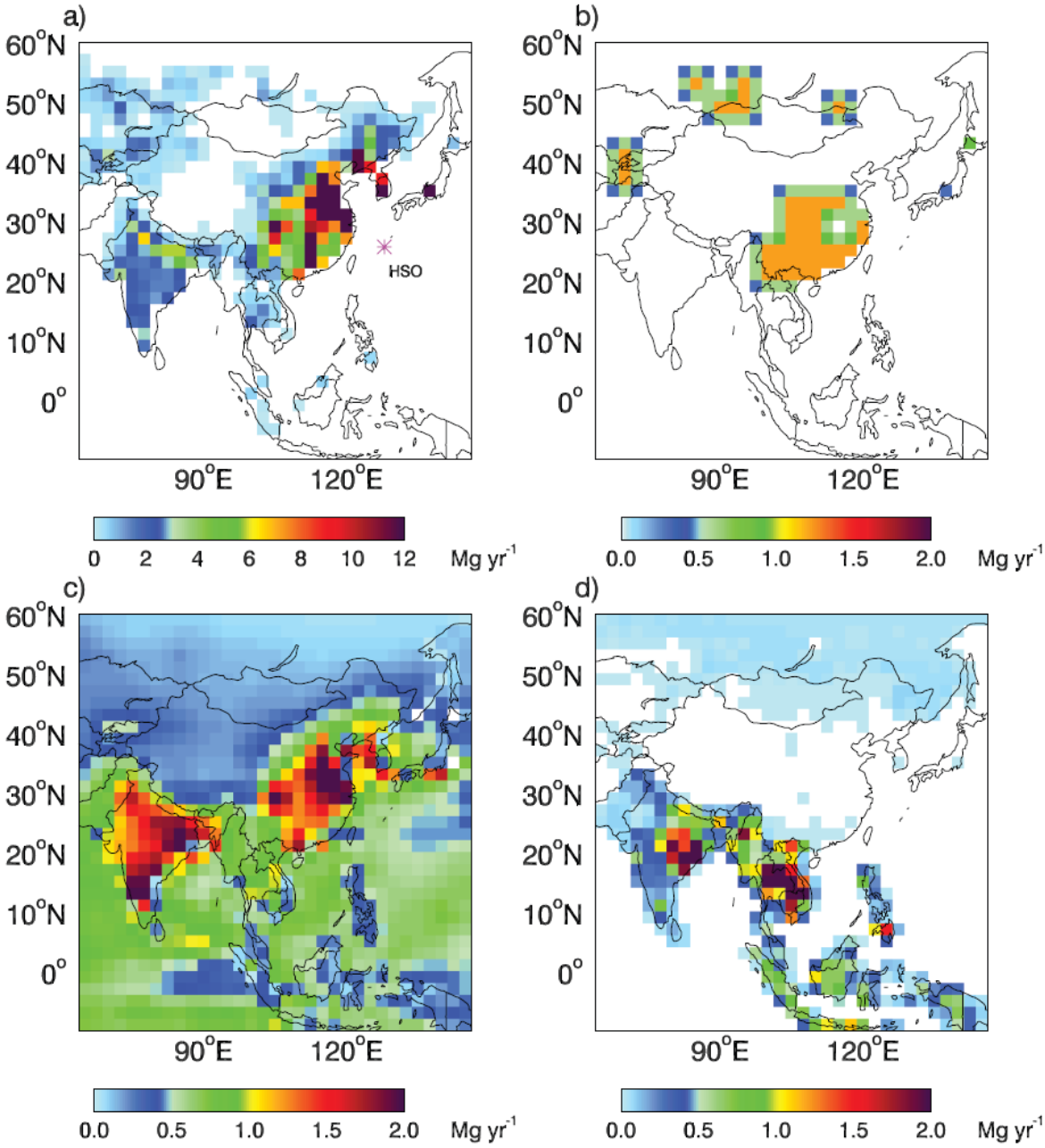


The GCTM used in this study was the GEOS-Chem global tropospheric chemistry model (Atmospheric Chemistry Modeling Group 2015). The model was run for the meteorological year 2004 with a model horizontal resolution of 2° latitude by 2.5° longitude. Hourly output from the model was extracted from the grid boxes corresponding to Mount Bachelor. The model includes emission, transport, deposition, and chemistry and is coupled to an ocean mixed layer. The model includes mercury entering the ocean mixed layer through deposition or ocean mixing whereby it is converted in the ocean to elemental mercury and then emitted to the atmosphere through gas-exchange, or it can be lost to the deep ocean through mixing and sinking of particles.

The model simulation includes global emissions from anthropogenic sources (Pacyna et al. 2006; Wilson et al. 2006), biomass burning, and natural emissions plus re-emissions from land and ocean. Figure 11 shows the distribution of anthropogenic, land, and biomass burning emissions over Asia (defined here as 9°S–60°N, 65°–146°W). For this region, anthropogenic emissions are 610 metric tons per year (MT/year) of Hg^0, 380 MT/year of Hg^{II}, and 100 MT/year of particle Hg. Natural emissions of 100 MT/year Hg are located primarily in southeast China. Land re-emissions of 310 MT/year Hg are distributed throughout the region, with large emissions from southeast China and

India. All sources of Hg emissions are needed for evaluating the modeling results. At the Mount Bachelor Observatory, the mean model total Hg concentration was 1.61 ± 0.09 ng/m^3. This compared to an observed mean of 1.53 ± 0.19 ng/m^3, yielding a mean model bias of just 5% for total mercury. In addition to identifying the source of emissions, the GCTM tagged emissions from biomass burning, land, and ocean emissions as well as anthropogenic emissions by region. For Asia, anthropogenic mercury includes both direct emission from Asia and ocean re-emission for previously deposited Asian anthropogenic mercury.

Figure 11. Distribution of Annual Asian Mercury Emissions (milligrams per year) from (a) Anthropogenic, (b) Natural, (c) Land Re-emission + Ocean Emission, and (d) Biomass Burning Used in the GEOS-Chem Model



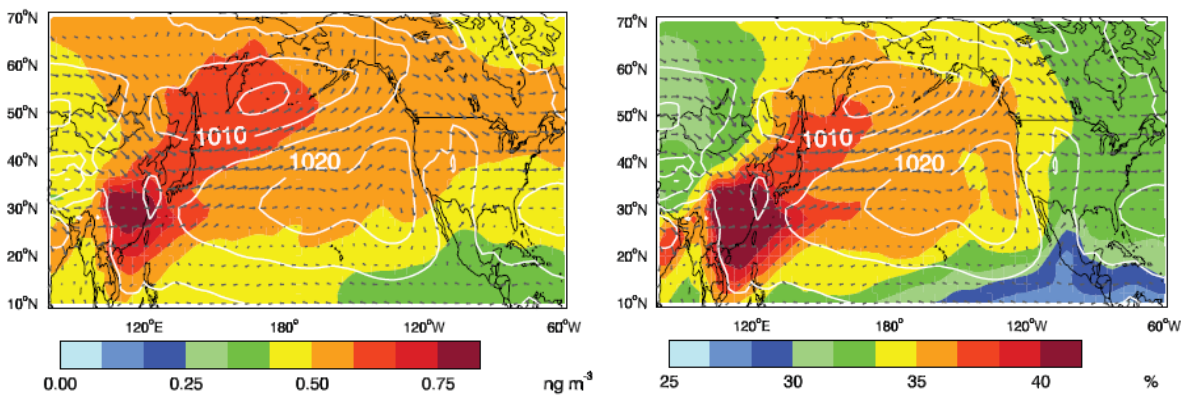
Source: Strode et al. (2008)

The model results showed that the Asian anthropogenic percent contribution to Hg^0 at Mount Bachelor shows little variability between seasons, with an Asian anthropogenic contribution of 18% in spring (0.29 ng/m^3 for Hg^0 and 0.015 ng/m^3 for Hg^{II}) and in the annual average. This source-to-receptor relationship is value applied to determine the contribution of the Proposed Action using Equation 1. The modeling results also show that the largest Asian Hg^0 contribution occurred on April 28, when the Asian sources accounted for 41% of Hg^0 (1.18 ng/m^3). Additionally, the modeling

study showed that the regional contribution of Hg^{II} deposition (wet and dry) at Mount Bachelor was 14% (~ 2,900 milligrams per square kilometer per year (mg/km^2-year) from Asian anthropogenic emissions. Finally, the model shows that mercury reaches the Mount Bachelor location only in the form of Hg^0 and Hg^{II}; therefore, the following focuses only on these two forms of mercury.

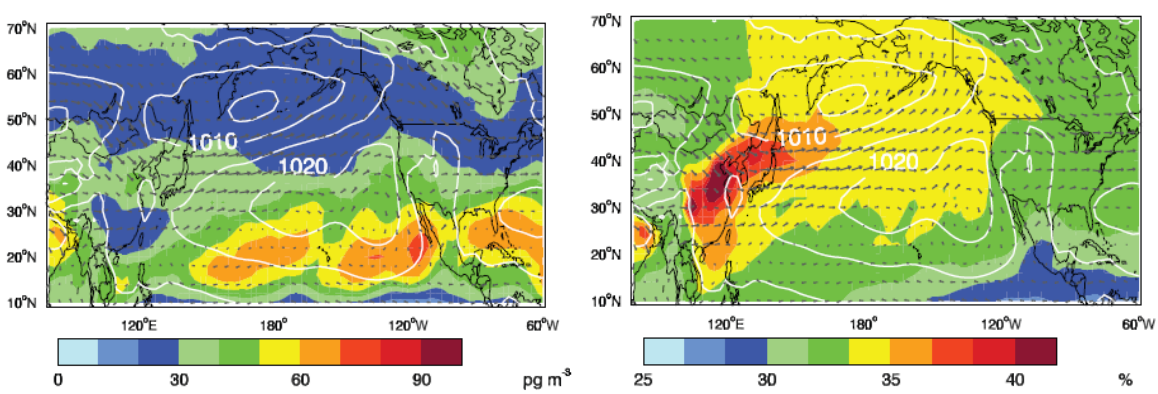
The general trans-Pacific transport of mercury from Asia to North America is shown in Figure 12. The different mechanisms by which Asian Hg^0 reaches North America affect the latitudinal distribution of their contributions. Hg^0 is transported to the northeast from Asia with the prevailing winds. Consequently, the Asian influence is largest over Alaska, western Canada, and the northwestern United States. The relative contribution of Asian emissions to the Hg^0 concentration is no more than 36%.

Figure 12. Maps of March–May 2004 Concentrations and Relative Percentage of Asian Hg^0



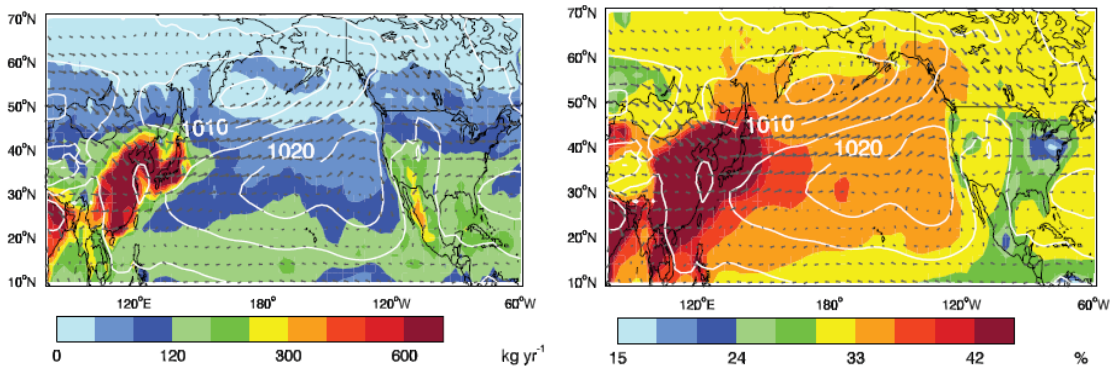
In contrast, Asian emissions influence North American Hg^{II} concentrations from oxidation of the global Asian Hg^0 pool within the atmosphere, rather than by direct transport of Hg^{II} from the emission source. The Asian Hg^{II} contribution is largest at low latitudes where high oxidant concentrations and descending dry air lead to higher concentration levels of Hg^{II} (Figure 13).

Figure 13. Maps of March–May 2004 Concentrations and Relative Percentage of Asian HgII



Asian Hg^{II} deposition follows a similar pattern to Asian Hg^{II} concentration as both wet and dry deposition depend on Hg^{II} concentrations (Figure 14).

Figure 14. Maps of March–May 2004 Concentrations and Relative Percentage of Asian Total Hg Deposition



2.3 Application of the GCTM to the Coal Market Assessment Scenarios

For each of the five SEPA Coal Market Assessment Technical Report (ICF 2017) scenarios (IPM scenarios), emissions of mercury for 2025, 2030, and 2040 were used in Equation 1 as the defining the Proposed Action's emission source strength ($EA_{MBTL,tt}$). The development methodology for the mercury emissions is described in the IPM modeling. The baseline year emission rate for the GCTM modeling was the year 2000. GCTM modeled concentration and deposition results (X_{00}) are available for just anthropogenic Hg^0 and Hg^{II}, so that each contribution to total Hg can be reported. However, X_{00} is based on total Asian Hg emissions, which include additional Asian countries where Proposed Action-related coal would not be consumed. Thus, rather than using the total Asian anthropogenic emissions, which total approximately 610 MT/year for Hg^0 and 380 MT/year for Hg^{II}, this study used a more conservative emission total for just the countries that would potentially consume the Proposed Action-related coal: Japan, Korea, China (includes Hong Kong), and Taiwan. The total Hg emission (as found in Pacyna et al. 2006) for these countries was 408 MT/year for Hg^0 and 285 MT/year for Hg^{II}. This conservatively assumes that only Asian emissions from these countries contribute to the portion of Asian mercury in Washington State. The X_{00} is based on the modeled concentrations as reported for Mount Bachelor, which lies within the same grid box as the Proposed Action.

2.3.1 Results from Scenario Comparison

To estimate the episodic concentration it was conservatively assumed that during an episode all of the impact in Washington State from Asia only occurs in the country with Proposed Action-related coal mercury emissions. This greatly increases the scaling ratio and conservatively estimates the episodic mercury impact.

Table 17 shows annual and episodic concentrations from Proposed Action source coal (Proposed Action minus the No Action) in 2025, 2030, and 2040 for Hg^0, Hg^{II}, and total Hg. Overall, the differences between the three scenarios relative to the No Clean Power Plan scenario are relatively small, with the maximum total Hg emissions ranging from 0.42 to 0.57 picogram per cubic meter (pg/m^3) and the maximum episodic emission ranging from 0.53 to 0.71 for pg/m^3. In general, the

mercury concentration remains about the same as in 2025. In all cases elemental mercury (Hg^0) is the dominate form of Hg. Strode et al. (2008) found the annual average Asian-originated Hg^0 for Mount Bachelor was 0.29 ng/m^3 or 290 pg/m^3 in 2000. Assuming that overall growth in coal burning is balanced with reductions in mercury emissions due to application of control technology implemented under the 2013 Minamata Convention on Mercury,[15] the fraction of Hg^0 exposure in Washington State from the Proposed Action in 2040 would be less than 0.2%. Similarly, the Hg^{II} annual average for Mount Bachelor is 150 pg/m^3 and the maximum Proposed Action-related concentration would be 0.039 pg/m^3 or less than 0.1%. The episodic maximum for Hg^0 shows slightly higher concentrations over the annual average; still, the maximum Hg^0 contribution of 0.82 pg/m^3 in 2025 or 0.65 pg/m^3 in 2040 from the coal exported from the proposed coal export terminal relative to the episodic Hg^0 at Mount Bachelor of 1,180 pg/m^3 is a contribution of less than 0.1%.

Table 18 shows the annual net Hg deposition amounts associated with coal (exported from the proposed coal export terminal) over Washington State for the proposed action minus the No Action by year, starting in 2025. In the first 5 years, the deposition amounts are approximately the same for the Lower and Upper Bound scenarios, while the deposition amounts for the Energy Policy and No Clean Power Plan scenarios are slightly lower. By 2040, the No Clean Power Plan shows the lowest mercury deposition, with a maximum deposition amount of 5.7 milligrams per square kilometer per year (mg/km^2/yr). The maximum mercury deposition is found for the Lower Bound scenario in 2040. This amount represents less than 0.3% of the total Asian-sourced mercury deposition over Washington State as estimated by Strode et al. (2008) at 2,900 mg/km2/yr.

2.3.2 Uncertainty

As with any estimate of impacts a level of uncertainty is inherent in the analysis. The largest source of uncertainties comes from the global estimates of mercury emissions to the air. These stem from various sources, including the availability of information on activity levels, but mainly from the lack of information concerning the mercury content of some raw materials and the validity of the assumptions regarding processes and technologies used to reduce mercury emission releases. However, recent methods used to produce the global inventory for 2010 (United Nations Environment Programme 2013) were compared with a number of national inventories and emissions reported under other systems covering the same period, and in general the level of agreement was found to be good. Other studies have also reported the average uncertainty associated with anthropogenic industrial emission of mercury at ±30% (Pirrone et al. 2010). In the Pacyna et al. (2006) study, the accuracy of the emission inventory was estimated by source categories as fuel combustion ±25%, various industrial process ±30%, and waste disposal a factor of 2–5. Note that the dominant emissions are from fuel combustion and industrial processes.

Historically, Asian emissions have been most uncertain from China given the uncertainties in activity levels due partly to the rapid changes, type, and amount of coal combusted and level of controls. However, the recent work of Zhang et al. (2015) using a probabilistic process-based approach based on information of the mercury content in fuel and raw materials, the production process, and Hg removal efficiencies obtained from field tests yielded more accurate emission

[15] The Minamata Convention on Mercury is a global treaty established to protect human health and the environment from the adverse effects of mercury. Controlling the anthropogenic releases of mercury throughout its lifecycle has been a key factor in shaping the obligations under the convention (United Nations Environment Programme 2013).

estimates and lowered uncertainties. They estimate total mercury emissions from China at 356 MT/year or about 40% lower than the number used in the GTCM modeling. The study also included was better understanding of the spatial allocation of those emissions.

Another source of uncertainty is the chemistry in the atmospheric transport model. The largest uncertainty in the atmospheric mercury models is the chemical mechanism used to determine how mercury changes forms in the air. Improved experimental data will help improve model performance by making sure that the correct reactions are simulated. The processes that lead from deposition to re-emission also need to be better understood. Advances in this area are showing improvement, with model results becoming closer to estimates based on experimental data (United Nations Environment Programme 2013). However these chemical transformation uncertainties are, in general, less than the emission inventory uncertainties.

Given these uncertainties the mercury impacts in Washington State would be within ±50% of the estimates presented earlier and could be further reduced if GCTM modeling were specifically performed to assess the impacts for the countries expected to import the coal from the proposed export terminal, by using the most recent Asian mercury inventories and applying the advances in understanding atmospheric mercury chemistry.

Table 17. Annual and Episodic Net Mercury (Hg) Concentration in Washington State as Elemental (Hg^0), Oxidized Mercury (Hg^{II}), and Total Mercury (pg/m^3) by Scenario

Hg^0	2025	2030	2040	Hg^{II}	2025	2030	2040	Hg^{Tot}	2025	2030	2040
2015 U.S. and International Energy Policy Scenario											
Annual	0.48	0.43	0.47	Annual	0.035	0.032	0.035	Annual	0.51	0.46	0.50
Episodic	0.58	0.53	0.57	Episodic	0.06	0.05	0.05	Episodic	0.64	0.58	0.62
Lower Bound Scenario											
Annual	0.51	0.51	0.53	Annual	0.038	0.038	0.039	Annual	0.55	0.55	0.57
Episodic	0.62	0.62	0.65	Episodic	0.06	0.06	0.06	Episodic	0.68	0.68	0.71
Upper Bound Scenario											
Annual	0.51	0.44	0.48	Annual	0.038	0.033	0.035	Annual	0.55	0.47	0.51
Episodic	0.62	0.54	0.58	Episodic	0.06	0.05	0.06	Episodic	0.68	0.59	0.64
No Clean Power Plan Scenario											
Annual	0.47	0.46	0.40	Annual	0.035	0.034	0.029	Annual	0.50	0.49	0.42
Episodic	0.82	0.80	0.48	Episodic	0.09	0.09	0.05	Episodic	0.91	0.89	0.53

Table 18. Annual Hg^{II} Net Deposition Amounts in Washington State (mg/km2/yr) by Scenario

2025	2030	2040
2015 U.S. and International Energy Policy Scenario		
6.8	6.2	6.7
Lower Bound Scenario		
7.3	7.3	7.6
Upper Bound Scenario		
7.3	6.3	6.8
No Clean Power Plan Scenario		
6.7	6.6	5.7

Notes:
mg/km^2yr = milligrams per square kilometer per year

Chapter 3
Sulfur Dioxide Assessment

Over two dozen peer-review publications were found during the literature review, which spanned approximately the past 15 years. The studies included SO_2 emission inventories, emission projections, coal consumption in Asia, air monitoring studies in the Pacific Northwest and across the United States for impacts associated with the long-range transport of Asian SO_2 emissions, and global transport chemical modeling studies focused on assessing the fate and transport from Asia to North America.

The following discusses the nature of the SO_2 emissions, how SO_2 behaves and changes in the atmosphere, and its form once it reaches Washington State. This discussion is followed by a description of the papers most relevant to this study, with emphasis on the key findings from those papers as used in developing the impact assessment for coal combustion related to the Proposed Action.

3.1 Introduction

Worldwide natural sources of SO_2 make up about one-quarter to one-third of the global budget. The primary sources are volcanoes and the atmospheric oxidation of oceanic dimethyl sulfide, with a small additional fraction from wildfires (Intergovernmental Panel on Climate Change 2001). Anthropogenic SO_2 emissions originate chiefly from fossil fuel combustion, with coal combustion the largest source, representing about 53% of all anthropogenic sources of SO_2 globally. Other important anthropogenic sources of SO_2 include the burning of petroleum products for both transportation and industrial process (26%) and the smelting of metals (9%). In China, the country with the highest SO_2 emission rates, coal combustions is responsible for about 84% of the total SO_2 emissions (Ohara et al. 2007).

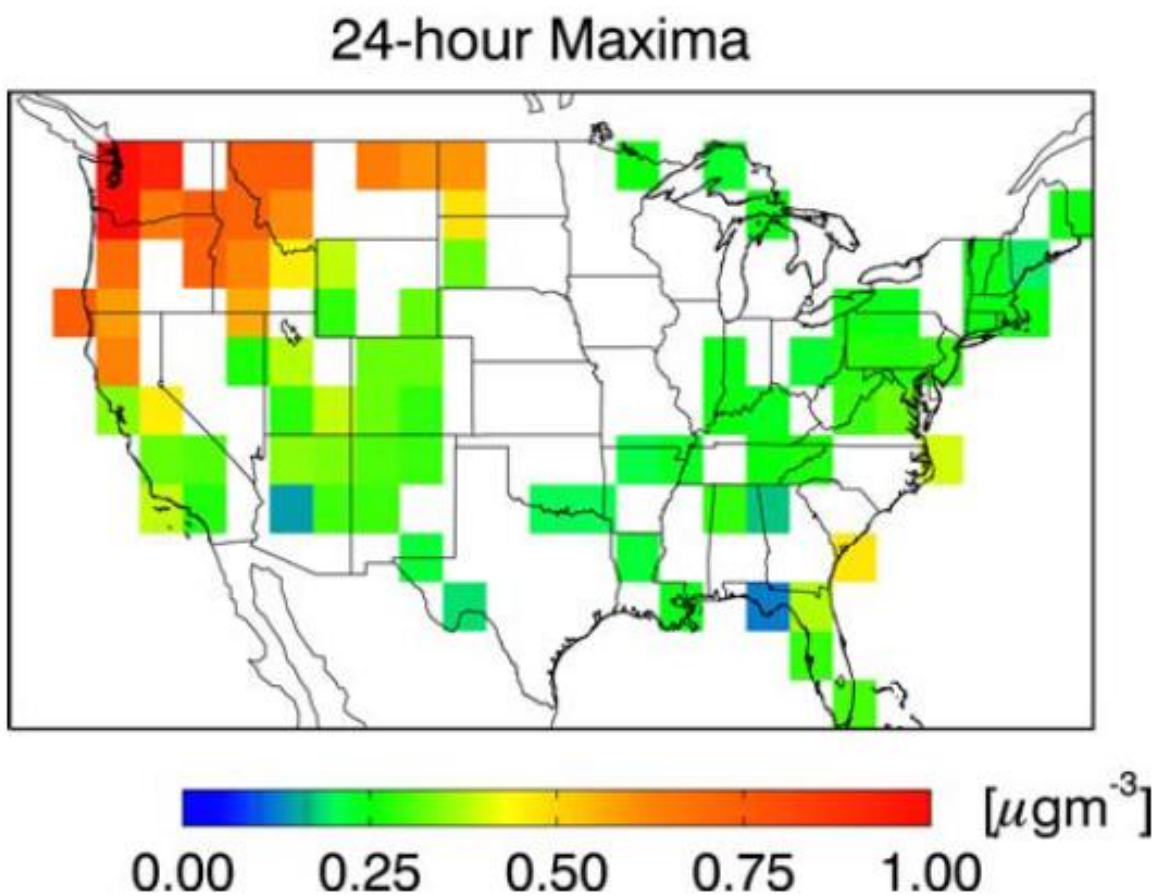
The emissions of SO_2 lead to sulfur deposition primarily in the local to regional scale, with the remainder of SO_2 converted to sulfate aerosol available for long-range transport. This availability occurs when the major SO_2 removal processes from loss to cloud droplets and rainout in the free troposphere is absent and the air is lifted above the boundary layer, preventing the other important removal process by interaction with sea salt aerosols or ocean surface. These conditions occur most frequently during the spring (Maxwell-Meier et al. 2004) and are documented in global chemical transport models. Because nearly all sulfur deposition occurs with the first 1,000 kilometers from the point of origin, sulfur deposition of Asian emissions over Washington State will not be determined.

3.2 Studies and Findings

Long-range transport of Asian anthropogenic sulfate emissions across the Pacific Ocean was first documented in the 1980s from observations at island sites (Prospero et al. 1985; Huebert et al. 2001).

Aircraft observations of transpacific Asian plumes over the northeast Pacific (Andreae et al. 1988; Price et al. 2003) provided subsequent evidence of sulfate aerosol transport in the lower free troposphere. Similarly, ground- and aircraft-based observations in the Pacific Northwest have identified episodes of trans-Pacific transport of sulfate aerosols (Jaffe et al. 2003; McKendry et al. 2008). Heald et al. (2006), using satellite imagery, GEOS-Chem (GCTM) mode, and surface air monitoring data for the western United States, demonstrated the high sulfate aerosol concentration due to trans-Pacific pollutant transport. They found that the springtime Asian sulfate aerosol enhancements were greatest in Washington State (White Pass) and southern British Columbia, with maximum 24-hour enhancements reaching approximately 1.5 μg/m^3 (Figure 15). This source-to-receptor relationship is applied to determine the contribution of the Proposed Action using Equation 1 for estimating maximum episodic impact.

Figure 15. Asian Anthropogenic Enhancements of Sulfate Concentrations in Surface Air during Spring 2001 as Simulated by the GEOS-Chem Model



Source: Heald et al. 2006.
Note: The color scale is saturated at 1 μg/m^3.

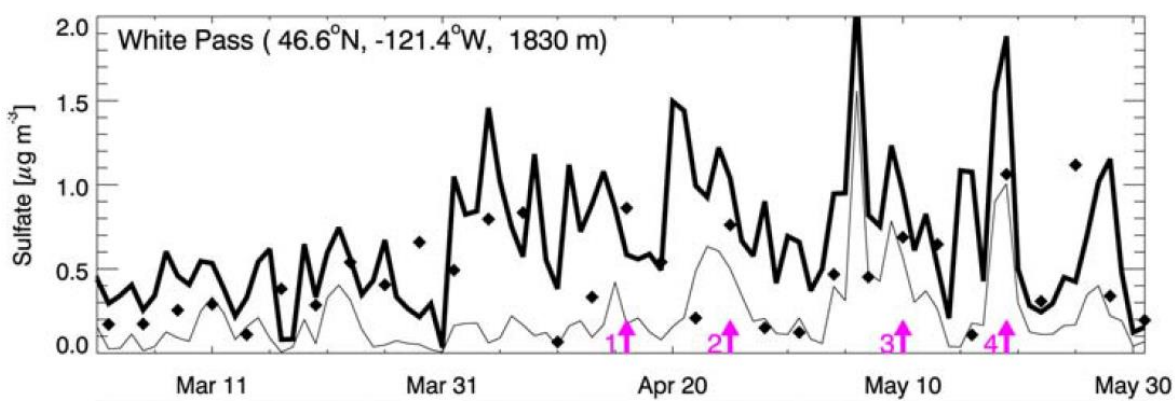
Park et al. (2004) used the GCTM model for two full-year simulations, which showed that 30% of the annual average background sulfate in both the western and eastern United States was due to trans-Pacific Asian transport. In Park et al. (2006), GCTM modeling with improved chemistry showed that the annual average sulfate concentration in the western United States due to trans-Pacific Asian

transport was 0.10 µg/m³. This source-to-receptor relationship is value applied to determine the contribution of the Proposed Action using Equation 1.

3.3 Application of the GCTM Model to the IPM Scenarios

For each of the five IPM scenarios, emissions of SO_2 for 2025, 2030, and 2040 were used in Equation 1 as the defining emission source strength ($EA_{MBTL,tt}$) for the Proposed Action. The development methodology for the SO_2 emissions is described in the IPM modeling (ICF 2017). The baseline year emission rate for the GCTM modeling was based on 1999–2000 global anthropogenic emissions. GCTM modeled concentrations (X_{00}) are available based on total Asian SO_2 emissions, which include additional Asian countries where Proposed Action-related coal will not be consumed. Thus, rather than using the total Asian anthropogenic emissions, which totals some 42,800 MT/year, a more conservative emission total was used for just the countries that will potentially consume the coal exported from the proposed coal export terminal: Japan, Korea, China (includes Hong Kong), and Taiwan. The total SO_2 emissions (as found in Ohara et al. 2007) for these countries were 29,800 MT/year. These were adjusted downward to reflect the SO_2 emission source strength used in the GCTM by Park et al. (2006). This conservatively assumes that only Asian emissions from these countries contribute to the portion of Asian sulfate concentration in Washington State. The X_{00} is based on the modeled concentrations as reported for the western United States, as the annual average SO_2 concentration is more uniformly dispersed. To estimate the episodic concentration, based on Equation 1, the 24-hour maximum modeled sulfate concentration of 1.5 µg/m³ (Heald et al. 2006) was used as modeled at White Pass, Washington (Figure 16).

Figure 16. Time Series of Sulfate Concentration in Surface Air at White Pass, Washington.



Note: The diamonds are observations, the thin blue line is the Asian anthropogenic contribution in the GCTM, and the thick black line the total GCTM values. The pink arrows are the start of transpacific event as observed midway in the Pacific.

Table 19 shows the annual and episodic sulfate concentrations from coal exported to Asia from the proposed coal export terminal for the Proposed Action minus the No Action by year starting in 2025. Overall, the Lower Bound and 2015 U.S. and International Energy Policy scenarios are similar in magnitude for the first 5 years. The Upper Bound and No Clean Power Plan scenarios are similar but more than double the concentrations from the Lower Bound and 2015 U.S. and International Energy Policy scenarios. By 2040, all scenarios have similar concentrations, although the No Clean Power

Plan scenario has the lowest concentrations amongst the four scenarios. Park et al. (2006) found the annual average Asian sulfate concentration for Washington State at 0.10 µg/m^3 or 100 ng/m^3 in 2000. Assuming that overall growth in coal combustion is balanced with reductions in SO_2 emissions due to application of additional control technology, the maximum Proposed Action coal source contribution would represent less than 0.2% of the Asian sulfate concentration in Washington State in 2040.

Episodic maximum shows substantially higher concentrations over the annual average; still, the maximum increase in sulfate concentration of 6.30 ng/m^3 in 2025 from the Proposed Action coal would represent 0.42% of the episodic maximum Asian source sulfate concentration determined at White Pass, Washington, of 1,500 ng/m^3 (Heald et al. 2006).

Table 19. Annual Sulfate Concentration in Washington State from Coal Exported to Asia from the Proposed Action-related Coal (ng/m^3) Scenario

	2025	2030	2040
2015 U.S. and International Energy Policy Scenario			
Annual	0.14	0.16	0.15
Episodic	2.12	2.38	2.21
Lower Bound Scenario			
Annual	0.13	0.13	0.16
Episodic	1.91	1.92	2.35
Upper Bound Scenario			
Annual	0.42	0.14	0.17
Episodic	6.30	2.07	2.52
No Clean Power Plan Scenario			
Annual	0.31	0.29	0.12
Episodic	4.63	4.33	1.81

Notes:
ng/cm^3 = nanogram per cubic meter

3.4 Uncertainty

As with any estimate of impacts, a level of uncertainty is inherent in the analysis. The largest source of uncertainty is associated with the Asian SO_2 emissions. One approach to estimating the level of uncertainty in the inventories is to compare the estimated SO_2 emissions developed by different researchers using different methods for development. Ohara et al. (2007) reports on inventory projects for SO_2 emissions in East Asia, presenting ranges from a low of 22.6 million MT/year to 42.9 million MT/year, with an average of 31.5 million MT/year, suggesting an uncertainty of approximately ±35%. Historically, Asian emissions have been most uncertain from China, in terms of total SO_2 emissions, due to uncertainties in activity levels, rapid changes in the type and amount of coal combusted, and level of controls. Sulfur content of Chinese coals varies from 0.6 to 2.1%. In recent years, refinements in the understanding of the sulfur content in the coal and improved understanding of coal plants control technology efficiencies and their use have led to a better understanding of the SO_2 emission rates.

Another approach to estimating uncertainty is to compare modeled versus observed sulfate for the Pacific Northwest sulfate monitoring sites. This allows an estimation of error bounds on the global chemical transport modeling to better estimate Asian sulfate pollution influence. This approach was used by Heald et al. (2006), who estimated a ±50% uncertainty in the model results for Asian sulfate enhancements over the northwest United States.

Given these level of uncertainties, the SO_2 impacts in Washington State would be within ±50% of the estimate presented earlier and could be further reduced if GCTM modeling were specifically performed to assess the impacts for the countries expected to import the Proposed Action-related coal and by using the most recent Asian SO_2 inventories.

Chapter 4
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Appendix A

Particulate Matter Measurements in Support of Assessing Coal Emissions from Haul Trains Measurements Report

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PARTICULATE MATTER MEASUREMENTS IN SUPPORT OF ASSESSING COAL DUST FROM COAL HAULING TRAINS

MEASUREMENTS REPORT

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Seattle, WA 98104

Prepared by:

David Bush
Robert Baxter

March 31, 2015

TABLE OF CONTENTS

Section **Page**

1. INTRODUCTION
   - 1.1 Overview of the Study 1-1
   - 1.2 Overview of the Field Activities 1-1
   - 1.3 Overview of the Data Processing and Analysis 1-2
2. SAMPLING PROGRAM
   - 2.1 Sampling Strategy 2-1
   - 2.2 Measurements and Equipment 2-2
3. LABORATORY ANALYSIS
   - 3.1 Initial Testing of Coal Samples 3-1
   - 3.2 Deposition Plates 3-9
   - 3.3 Air-O-Cell CSI Air Samples 3-10
   - 3.4 MiniVol Filter Samples 3-10
4. QUALITY ASSURANCE
   - 4.1 Acceptance Tests 4-1
   - 4.2 Field Quality Assurance/Quality Control (QA/QC) 4-1
   - 4.3 Laboratory Analyses and Data Processing 4-2
5. RESULTS
   - 5.1 Train Traffic 5-1
   - 5.2 Optical Characteristics of Samples 5-3
   - 5.3 Coal Concentrations 5-5
   - 5.4 MiniVol Gravimetric Samples and DustTrak DRX Data 5-8
   - 5.5 MiniVol $PM_{2.5}$ Scanning Electron Microscopy Analyses 5-10
   - 5.6 Iron Oxide Analyses 5-14
6. KEY FINDINGS AND RECOMMENDATIONS 6-1

APPENDICES

- A SUMMARY OF ANALYTICAL RESULTS A-1
- B SAMPLE EAA ANALYTICAL REPORT – OPTICAL MICROSCOPY B-1

1. INTRODUCTION

This field study program was designed to collect information on coal dust that may emanate from passing trains hauling coal, with the focus on 1 micron and greater sized particles that may be emitted. The study was not designed to measure mass emission rate from diesel fueled locomotives, as that has been extensively studied and reliable emission rates have been developed by the U.S. Environmental Protection Agency (EPA), and the newest and future operating fleets of locomotives are all certified to the emission standards. This section provides an overview of the study performed, the field activities included in the study, and the processing and analysis of the data collected.

1.1 Overview of the Study

The overall sampling program was designed to collect data at a location in Cowlitz County under conditions that were conducive to periods when fugitive coal dust could be measured from the passing coal trains. A one-month planning window in October 2014 provided two weeks for suitable sample collection in the field. The goal was to complete the sample collection prior to the arrival of the rainy season that typically starts in October/November. Equipment was prepared in late September with the deployment to the field and start of sampling on October 1, 2014. The primary sampling was conducted during the first half of the month, prior to the change from dry to prevailing rainy conditions. Specific train sampling was terminated on October 13 when the weather pattern shifted from a dry to wet pattern and daily rainfall began. A state of readiness was maintained until October 22, when the extended forecast showed that rainy conditions were expected to persist, and the sampling program was decommissioned.

The study was designed to measure the fugitive coal dust from passing trains hauling coal with a set of samplers on each side of the tracks to measure the upwind “background” concentrations and deposition, and the downwind concentrations and deposition, the difference being the contribution of the passing trains. A variety of sampling techniques were employed to capture the specific coal dust from the coal hauling activities. Short-term measurements using deposition plates, impaction samplers, and continuous particulate matter (PM) measurements were used to resolve individual train events, while longer averaging intervals (24-hour) of particulate matter were collected using filter-based collection media to help relate the more standard methods of measurement to the shorter term (train event) type sampling. For the duration of the study period, continuous meteorological measurements were made to aid in the analysis of wind flow and document the upwind and downwind environment during each train passing. The meteorological measurements also provided needed data on temperature, humidity, transport, and atmospheric stability that can be used in the modeling of the coal dust from the trains.

1.2 Overview of the Field Activities

The sampling network was deployed in southern Cowlitz County just north of the Lewis River. Trains hauling coal all originated from the south so that any trains reaching the region crossed the bridge over the river, giving a couple of minutes warning prior to the train arrival and final identification of the train type. Approximately 50 trains (coal, freight, and passenger) passed the sampling network each day. Over the study period, an average of two of these trains per day were hauling coal, with the arrival time of the trains being random. This required a constant

state of readiness of the sampling network for triggering a sampling event with no more than one or two minutes of advance notice.

A temporary shelter was placed at the sampling site and served as the field headquarters for the duration of the sampling program. Sample preparation, documentation, and entry of data into the project database were performed in this field headquarters. Included in the headquarters was a Digital Video Recording (DVR) system to document the train activities as well as provide an additional measure of security for the network. From this base of operations the following measurements and sampling were conducted:

- Continuous airborne particulate matter using a size-segregating laser-based optical scattering technique with data recorded at a 10-second time resolution. Measurements were made at the anticipated downwind (east) side of the tracks.
- Short-term particulate matter deposition using deposition plates on both sides of the tracks that sampled during triggered events with a coal train passage. Note: throughout the study period, only loaded coal trains passed through the study location. Thus, for the remainder of this report, “coal train” refers to a loaded coal train. In addition, all coal trains were northbound.
- Short-term airborne particulate matter on both sides of the tracks using impaction sampling techniques triggered during selected train passages.
- Long-term (24-hour) airborne particulate matter using filter-based techniques with measurements primarily focused on the anticipated downwind (east) side of the tracks.
- Meteorological measurements of wind speed, wind direction, temperature, humidity, and solar radiation at a high time resolution of 30 seconds to document the conditions during the sampling events.
- Video documentation for train identification, counting of train cars/locomotives, and calculating train speeds.
- Train speed measurements by hand-held radar.
- Bulk sample collection of selected coal samples to aid in the “fingerprinting” of coal and assessment of coal in the soil adjacent to the tracks.
- Train types and characteristics to describe the type, number of engines, number of cars, speed, and other descriptors to document the environment.

A rotating shift of three technicians provided 24-hour coverage of the field sampling effort.

1.3 Overview of the Data Processing and Analysis

All data collected during the measurement program were processed and validated prior to performing analyses. For all of the particulate sampling that required a known flow rate, the samplers were calibrated prior to, and following the sampling program using National Institute of Standards and Technology (NIST) traceable flow measurement standards. This included the real-time optical particle sampler, 24-hour filter, and impaction samplers. These calibrated flows were then used to calculate the total flow through the sampling devices and related final concentration values. Meteorological sensors were calibrated prior to the field program and the calibrations checked following the installation. The most accurate time stamp and maintenance of the time was with the digital data logger used to record the meteorological data. The time on this system was set at the program outset and used as the common time for samples collected. Data downloaded from the continuous particulate monitor were adjusted to match the digital data logger time stamp prior to the merging of the data in the final database. The final database

of this continuous data was loaded into the T&B Systems data display system, which is based on the Vista Data Vision software package. All train passage data (train arrival times) were then added to the database, with coal trains also having the time that the last car or locomotive passed. The display system then had all meteorological and DRX data merged with the train passage information, ready for analysis.

Collection of the deposition plate, impaction, and filter sampled media were all labeled with unique sample identifiers and laboratory chain of custody forms used to transfer the samples to the respective laboratories. Chester LabNet conducted the gravimetric analyses of the conventional MiniVol sampler filters. The vast majority of the laboratory analyses were conducted by Environmental Analysis Associates, Inc. (EAA). At EAA, the deposition plate samples were first screened optically to determine if there were visible particles collected. Plates were then rinsed with the material suspended on a slide for more detailed analysis using optical microscopy. The exposure times noted during collection were then used with exposed area in the dish to determine the deposition rate into the plates. Impaction sampled cartridges were opened and the glass cover slip removed that contained the sample and the slide prepared for analysis. Samples collected were analyzed using optical microscopy, and depending on the location of the sample and other criteria, the samples were also analyzed using Scanning Electron Microscopy (SEM), and compared against samples collected of known coal material. For the majority of the samples, the optical techniques provided the appropriate analysis results. The resulting particle counts, sizing, and estimated mass information were then used with the sample collection duration (and related flow rate) to calculate concentrations per unit volume. Longer term filter measurement samples were pre- and post-weighed by the laboratory to determine the mass increase during the sample collection and concentrations calculated based on the total flow through the samples.

Throughout the collection and data processing efforts, appropriate logs, calibration checks, and a variety of calculation cross-checks were employed to provide a quality controlled final data set for analysis. These checks included using multiple methods to calculate train speeds, duplicate counting of key trains for the number of locomotives and cars, and field and laboratory quality control samples for blanks and sample fingerprinting.

2. SAMPLING PROGRAM

The sampling program was focused on collection of airborne and deposition data for coal dust from trains specifically used for hauling coal. This section presents the sampling strategy used in designing and implementing the measurement program and the equipment used for the collection of the data.

2.1 Sampling Strategy

The goal of this study was to collect particulate matter and meteorological data along the BNSF mainline tracks during periods without precipitation and relatively low humidity, with the objective to collect up to 14 days of data during the month of October 2014, prior to the onset of the winter rainy season. Ambient air particulate matter was measured using several techniques. These included dust fall (or deposition plates), impaction samplers, filter-based collection media, and laser-based light scattering methods. The meteorology during the sampling program was documented using an on-site measurement system with sensors for wind, temperature, humidity, and solar radiation. For the entire study, video recording from multiple cameras documented the timing and speed of the trains, cargo type (passenger, freight, coal), as well as the number of engines and cars associated with each train.

A site survey was conducted at the study outset to select an appropriate location for the sampling. Several prospective sites were chosen based on Google Earth images and a field survey performed to refine the candidate sites. Key goals in selection of a sampling location included:

- Locations associated with faster train speeds and minimal braking (some braking adds sand to the braking process, which potentially increases silica levels).
- Locations adjacent to grade crossings and/or public State-owned facilities to simplify permission logistics and placement of samplers.
- Meteorology conducive to upwind/downwind sampling in as predictable a manner as possible.
- Minimal local non-train sources , such as vehicular traffic.
- Power to operate the sampling program equipment.
- Security for equipment during potential “non-attended” time periods.
- Cellular service for appropriate voice and data communications.
- Appropriate exposure for sampling on both the “upwind” and “downwind” sides of the track.
- Permission for access and operations 24-hours per day.

On the basis of the survey performed, a site was selected at the southern edge of Cowlitz County that met the goals listed above. **Figure 2-1** shows the sampling location and surrounding area. A distinct advantage of the selected site was the underpass available to allow movement to either side of the tracks when a train was present. Because of the proximity to the Lewis River, given the low terrain elevation and overall orientation of the tracks, the wind direction was anticipated to cross the tracks in a general west to east flow. Review of past data from meteorological stations in the vicinity also showed that type of flow pattern.

As the schedule for the anticipated time of passage of trains hauling coal was unknown, the sampling network was required to be in a state of attended operational readiness 24 hours per day, allowing initiation of sampling immediately when a coal train was recognized. This required 24-hour staffing of the sampling network and an immediate trigger system for train-specific sampling events based upon visual identification of the appropriate train type, with sampling starting on both sides of the tracks simultaneously.

Figure 2-1. General study area, showing the Lewis River.

The overall goal of the individual sampling events was to capture the coal dust that may be emitted as the trains hauling coal passed. The sampling was designed to monitor dust deposition at various distances away from the tracks, airborne dust concentrations downwind of the train, and a general size distribution of the aerosol on the downwind side of the tracks, both with and without train passages, and with the differing train types (passenger, coal, freight). Samples collected were analyzed for mass, particle count, and composition. For the train-specific samples, the samples were started once the front engines passed, and sampling continued for one to five minutes after the last car or locomotive passed. All of the sampling times were documented in field logs, with the timing of the events verified using the available video from the DVR system.

Summarized below is a description of the individual sampling platforms and samples collected.

2.2 Measurements and Equipment

The measurements made included the following:

- Continuous airborne particulate matter using a laser-based optical scattering technique.

- Particulate matter deposition using deposition plates.
- Short-term airborne particulate matter using impaction techniques.
- Long-term airborne particulate matter using filter-based techniques.
- Meteorology.
- Video documentation.
- Train speed by hand-held radar measurements.
- Bulk soil sample collection.

Each of these methods is described below.

Continuous Airborne Particulate Matter

At the anticipated downwind side of the tracks (east side), a TSI DustTrak DRX was located at the 45 meter "downwind" location, adjacent to the meteorological sensor mast and 24-hour MiniVol samplers. The DRX is a battery operated, data-logging, light-scattering laser photometer used commonly in air quality studies that provides real-time aerosol mass readings, simultaneously measuring both mass and size fraction in the size range cut points of PM_1, $PM_{2.5}$, PM_4, PM_{10} and "Total" size ranges. Data were collected and stored for the duration of the monitoring effort in 10-second averages. Data were downloaded from the system every three days, with a zero check and flow verification performed at each of the download times. **Figure 2-2** shows the tripod mounted case that housed the DRX, adjacent to the MiniVols and meteorological station.

Figure 2-2. Instruments placed at the anticipated downwind side of the tracks. Measurements included the real-time DRX, MiniVols, and weather station.

Particulate Matter Deposition

Particle deposition was measured using a customized sampling mechanism designed specifically for this study. While deposition sampling has been commonly conducted during air

quality studies, the operational parameters for this study were uncommon in that they required that the samplers be manually and simultaneously activated for a relatively short sample duration (typically about 7 minutes), exposing the deposition plates only when coal trains (and an occasional freight train, as a control) were passing by the sampling network. Sterile laboratory-grade 100-millimeter (mm) deposition plates were used for the sampling. The deposition plates were placed inside 150-mm-diameter round canisters, 50 mm below the lip of the canister. The height of the sample plate was 1 meter above ground level. The canister lids were in place during non-sampling periods, protecting the plates from any unwanted deposition until the desired sampling period. Opening of the sample canister to expose the plate was performed by remote control using a radio transmitter operated by the on-site technician when a desired sample period was to start. When triggered, the lid was opened by a servo that would completely remove it and leave it attached to the side of the canister, exposing the inside deposition plate to any particles that fall into the canister. The complete lid removal ensured that there was nothing above the sampler opening to influence the collection sample, such as a lid partially open.

Upon completion of the sampling period, the lids were manually placed back over the canister by the technician until the plates were retrieved. The short distance to all sample canisters allowed this covering within a few-minute time period. Upon retrieval, each of the sample plates was given a unique pre-printed identifier and sticker placed on the plate lid, and the lid placed over the sample. Rubber bands were then used to affix the plate top and bottom, and the entire unit was placed in a small zip type bag. In this manner, if a plate lid did come off during transport, the contents would be retained in the bag. **Figure 2-3** shows the sampler with the lid over the plate. **Figure 2-4** shows the exposed plate inside the sample canister. **Figure 2-5** shows the placement in the field at the location nearest to the tracks.

Figure 2-3. Deposition plate sampler with the lid covering the sampling media.

Figure 2-4. Deposition plate sampler with the lid in the off position exposing the sample plate.

Figure 2-5. Placement of two deposition plate samplers on the east side of the tracks. In this configuration, both samplers were located 5 meters from the track.

Short-Term Airborne Particulate Matter

During train passages, ambient air samples were collected using the Air-O-Cell CSI (Collector for SEM Identification) sample cartridges. The Air-O-Cell CSI sample cartridges have been used in a number of sampling programs including forensic investigation of air quality, indoor air quality studies to trace the origin of allergens and pollutants, and outdoor studies to look at ambient concentrations and counts of a variety of organic and inorganic materials. This collection media allowed an ambient air sample to be collected over a short time duration (e.g., the period of a train passage) that is not possible with conventional ambient air sampling media. The sample was collected using a "slit" type inlet with an adhesive media below the slit to capture and hold the sampled particles. The Air-O-Cell CSI has a D50 cut point of 1 micron, efficiently collecting particles greater than 1 micron on the media. The technology for collection of enough sample over the required short time duration to analyze for particles less than 1 micron, such as that performed using a pre-filter cyclone separator, does not yet exist for ambient level concentrations. **Figure 2-6** shows the sample cartridge. **Figure 2-7** provides a diagram of the air flow path through the cartridge with the impaction of the sample on the collection media.

Air flow through the Air-O-Cell CSI was provided using a 12-volt vacuum pump at a flow of 15 liters per minute (lpm). A radio receiver was mounted in the pump/battery case that provided the received signal to trigger both the Air-O-Cell CSI and the above described deposition plates simultaneously with a train passage. While the deposition canisters remained open after the

sample signal was turned off, the pump system would respond immediately to stop the sampling at the conclusion of the sampling period. **Figure 2-8** shows the pump/battery system in the case that was placed at the base of the tripod. **Figure 2-9** shows the system with the 2-meter vacuum tube leading to the sample cartridge mounted at 1.5 meters above ground level on the tripod.

Figure 2-6. Air-O-Cell CSI sample cartridge.

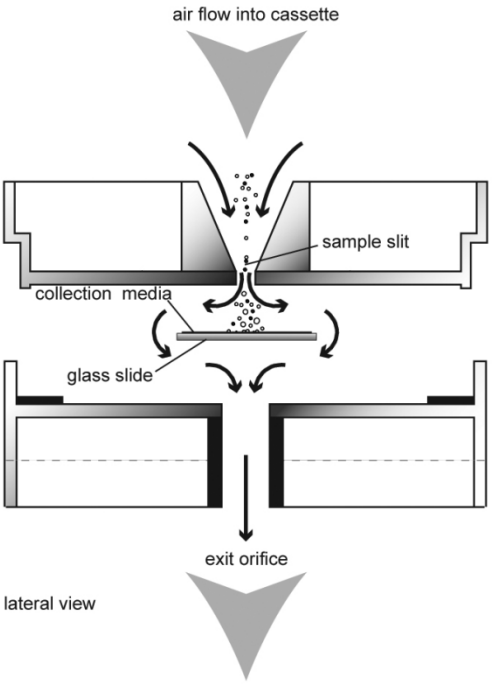


Figure 2-7. Air flow path through the Air-O-Cell CSI cartridge.

Figure 2-8. Battery and pump system with radio receiver for triggering the Air-O-Cell CSI and deposition plate samplers.

Figure 2-9. Air-O-Cell sampling system mounted on a tripod with the pump and battery in the case at the bottom of the tripod.

Long-Term Airborne Particulate Matter

Twenty-four hour average particulate matter concentrations were measured on both sides of the tracks using MiniVol medium volume samplers. These samplers have been used in many large air quality studies, collecting data that correlate well with EPA-approved reference measurement samplers. The samplers are battery powered and integrate the samples over a 24-hour period. The filter collection typically occurred from 1600 to 1600 each day with filters and batteries serviced during the change out period. On the west side (anticipated to be upwind), one $PM_{2.5}$ sampler was operated using polycarbonate filters to collect data for mass and SEM analysis to help understand the fraction of coal in a 24-hour sample relative to other particulate matter. On the east side (anticipated to be downwind), three sets of samples were collected. $PM_{2.5}$ and PM_{10} were collected on Teflon filters and an additional sampler collected $PM_{2.5}$ on polycarbonate filters, similar to the upwind location. The Teflon filters were analyzed for mass, with the option to also analyze for elemental content using XRF (X-ray fluorescence). The polycarbonate filters were analyzed using SEM for the coal fraction. Figure 1 shows the samplers on the east (anticipated downwind) side of the tracks.

Meteorology

The meteorological station consisted of a 3-meter mast for the wind sensor, and temperature, relative humidity (RH), and solar radiation measured at 2 meters. The meteorological equipment all meet EPA specifications required for air quality studies. All data were recorded on a Campbell Scientific CR1000 data logger with averaging intervals of 30 seconds and one hour. Data were downloaded from the station daily. Power for the station was provided from a solar charged battery system. The sensors used are summarized below:

- Wind speed and wind direction – RM Young 05305 AQ Wind Monitor.
- Temperature/relative humidity – RM Young Model 41382 temperature/RH sensor.
- Solar radiation – Licor LI-200.

The mounting and sensors was shown in Figure 2-2.

Video Documentation

Video images of train passages were documented using a Swann DVR9-4200 digital video recorder. The system provided motion–activated, 15 frames per second video with 960H DVD quality resolution. Infrared illumination at night provided a visual range up to 25 meters. Cameras were located in areas to allow documentation of the train types and the ability to replay the videos to count the train cars and calculate the train speeds. This video record became the primary method to perform the speed measurements and car counts for each of the coal train passages. Track distances within the field of view of key cameras were quantified and combined with the known camera frame rate to calculate the speed of the passing trains. These calculated speeds and the number of cars from the video were used for each of the train passages, except when the view was obstructed by fog. Under the foggy conditions, the in-field observations from the field technicians were used. All videos collected were converted from H.264 to AVI format for viewing in Microsoft Windows and other viewer environments.

On October 6 at 0900, camera 2 was moved closer to the tracks to obtain a closer view of the passing trains to improve the IR illumination of the cars at night. The locations of the video cameras were again changed mid-day on October 10 to further improve the train identification during the nighttime hours by having an additional camera located closer to the tracks to

optimize the network. This third camera was mounted on the RV once it too was moved closer to the tracks. During this move, cameras 1 and 2 maintained their same positions with only slight changes in rotation to optimize the pictures. The setup of the system with camera locations is shown in **Figure 2-10**. Camera 3 on the RV looked toward the northwest. Camera 1 looked to the south, while camera 2 looked to the west-southwest.

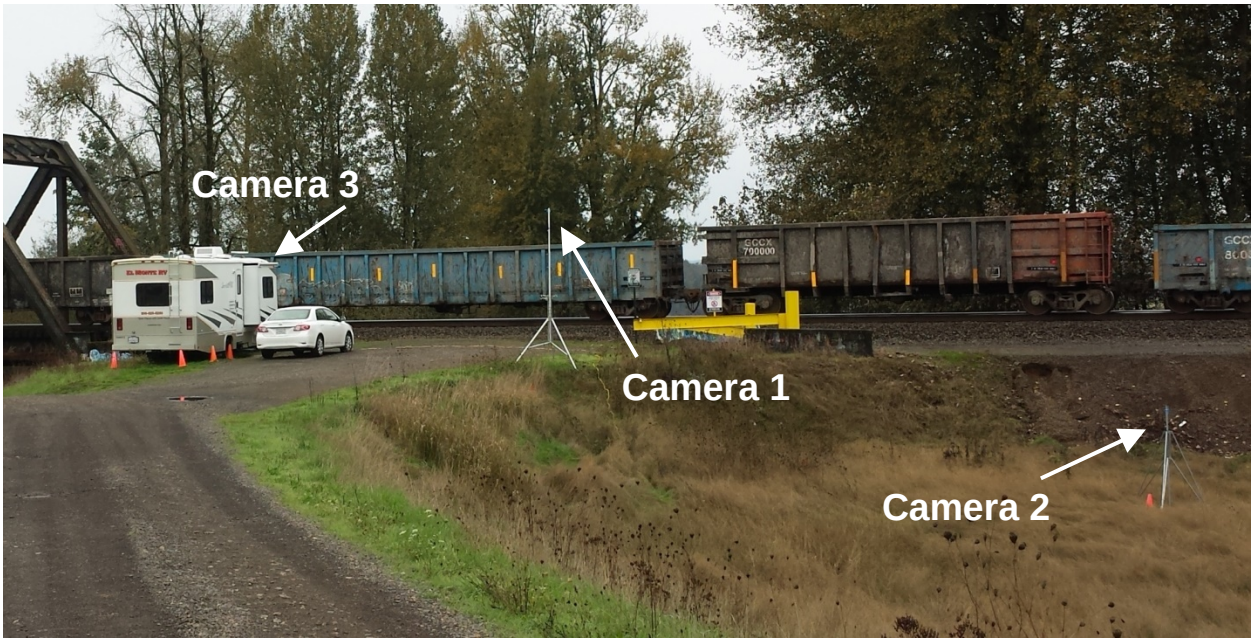


Figure 2-10. Locations of the cameras for documenting the train passages.

Train Speed by Hand-Held Radar Measurements

A Bushnell Speedster III radar speed gun was used to measure the speed of passing trains. The unit measures the relative speed of a target as it approaches (or departs) the unit. If the target is in a direct line then the measurements are accurate. Moving away from the direct line, (i.e., measuring off-axis) decreases the accuracy by biasing the measurements low. For any of the measurements made with the unit, a cosine correction for the off-axis readings was applied to maintain the accuracy of the speeds. Measurements made with the Speedster III were considered backup to the visual measurements made using the DVR post-processing method and were used when the DVR method was not possible due to video obscuration by either fog or a distance too far from the camera.

Bulk Soil Sample Collection

Two types of bulk samples were collected for analysis. The first was from visible coal at a public grade crossing between the study location and the terminus for the coal trains, with the sample placed in a plastic bag and shipped to the laboratory for analysis. This sample provided a “fingerprint” of the material that was anticipated in the both the deposition plate and Air-O-Cell CSI samples, and allowed a more positive identification of coal-like material in the microscopic analysis. The second type of bulk samples were soil samples collected at the study locations, immediately outside of the right-of-way of the rail line (about 5 meters from the rails). These samples were collected to see if there was any deposition of coal-like particles into the soil

adjacent to the tracks where the public has access. These samples are discussed in more detail in Section 3.1.

Sampling Network

The sampling network was designed to place the primary measurements in the prevailing downwind direction of the tracks, with measurements upwind to document the concentrations entering the study domain. On the basis of the original meteorological analyses, **Figure 2-11** shows the initial sampling locations. The MiniVols collected the 24-hour samples, plates and Air-O-Cell CSI units collected short-term samples, and the meteorological station was collocated with the MiniVols at the “downwind” location. Following the first several sample days, selected samples from the deposition plates were shipped to the laboratory for a preliminary screening analysis to determine what was being measured in the network and if the sampling strategy should be modified. The initial screening showed little, if any material being deposited in the plates. As a result, it was recommended that the network be moved closer to the tracks in an attempt to bring the deposition levels up to where they could be more readily detected. On October 10 the network was relocated to collect closer in samples. **Figure 2-12** shows the locations of the samplers following the move. As part of the move, an additional deposition sampler was added to the west side of the network to help capture particle fall. **Table 1-1** describes the locations of all samplers before and after the change in the network. The distances from the tracks represent the distance to the nearest rail.

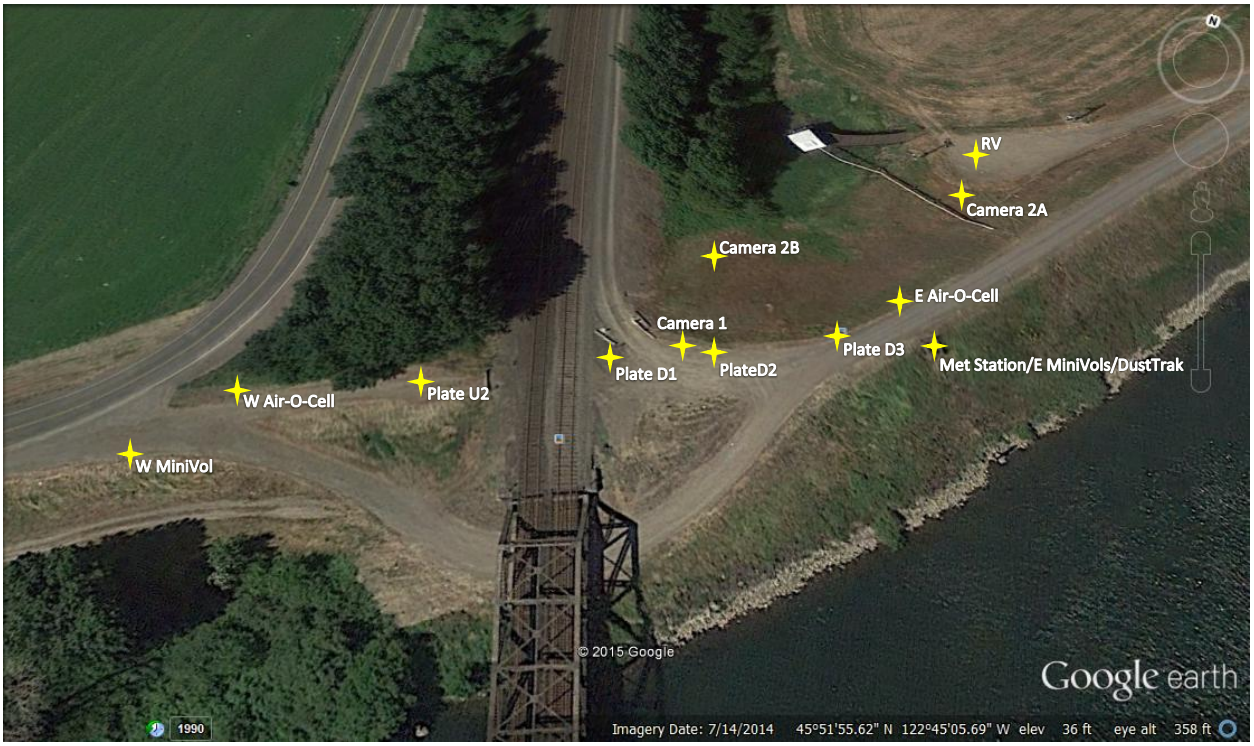


Figure 2.11. Location of the sampling network from the initial sampling on October 1 through mid-day on October 10.

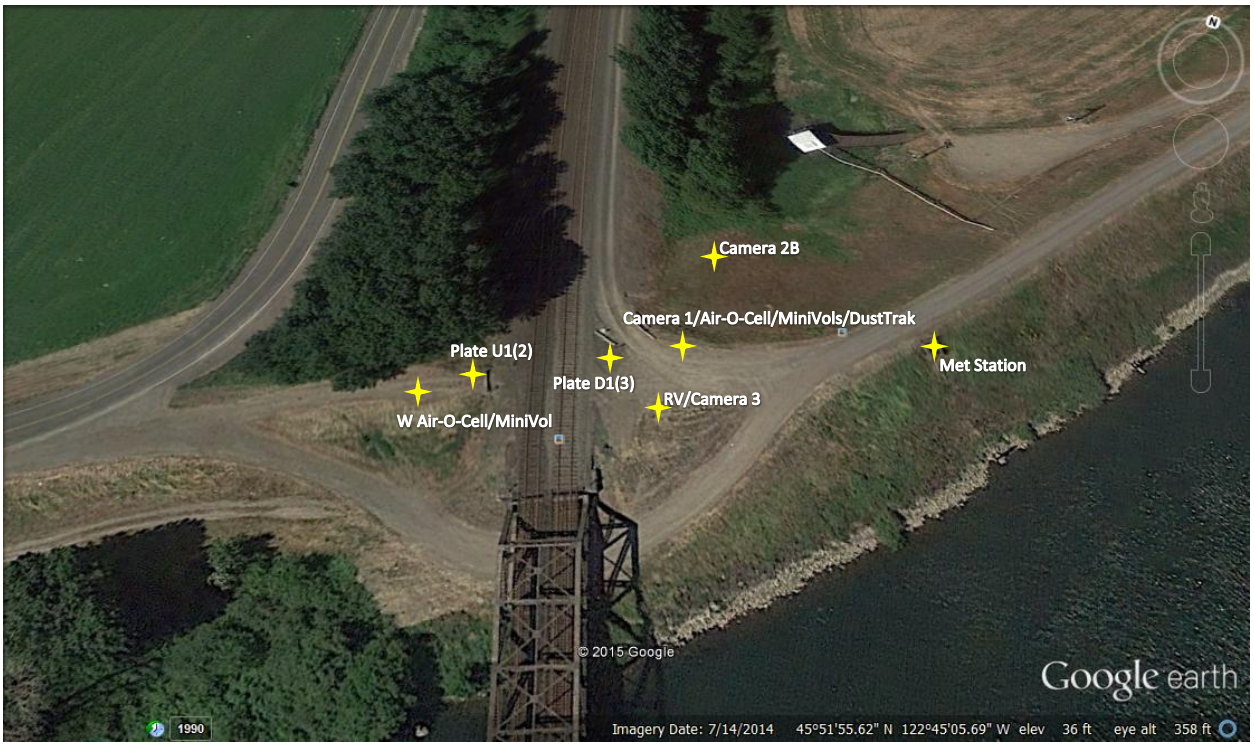


Figure 2-12. Location of the sampling network from mid-day on October 10 through the end of the sampling program.

Table 2-1. Summary of equipment.

Measurement	Measurement Location		Make/Model	Sampling parameters
	Prior to mid-day (10/10)	Starting mid-day (10/10)		
Continuous Airborne Particulate Matter	45 meters (m) east	15 m east	TSI DustTrak DRX	10-second averages
Particulate Matter Deposition	Plate 1 – 5 m east Plate 2 – 15 m east Plate 3 – 30 m east Plate 4 – 5 m west	Plate 1 – 5 m east Plate 2 – 5 m east Plate 3 – 5 m east Plate 4 – 5 m west Plate 5 – 5 m west (samples separated by 2 m)	T&B Deposition Plate Samplers	Sample is taken after the engine of a train passed the sample location and continued for a time after the last car or engine passed
$PM_{2.5}$ SEM $PM_{2.5}$ SEM $PM_{2.5}$, PM_{10} Mass	45 m west 43 m east 43 m east	15 m west 15 m east 15 m east	Airmetrics MiniVol	Integrated 24-hour samples from ~1600 to 1600 local time.
Short-term Particulate Matter	40 m west 40 m east	15 m west 15 m east	Zefon Air-O-Cell CSI with T&B Pump System	Sample is taken after the engine of a coal train passes the sample location. Analysis by optical or scanning electron microscopy.
Wind Speed	45 m east, 3 m high		RM Young 05305 AQ Wind Monitor	1-second scan, 30-second and hourly averages
Temperature	45 m east, 2 m high		RM Young Model 41382	1-second scan, 30-second and hourly averages
Humidity	45 m east, 2 m high		RM Young Model 41382	1-second scan, 30-second and hourly averages
Solar Radiation	45 m east, 2 m high		Licor LI-200 Pyranometer	1-second scan, 30-second and hourly averages

3. LABORATORY ANALYSIS

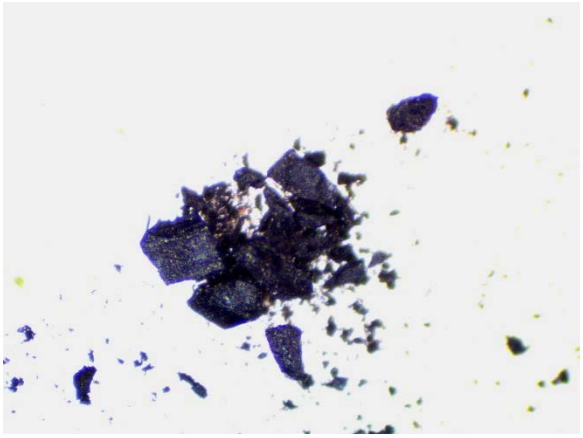
EAA developed specific analytical methods designed to evaluate the potential coal particle concentrations in the three different types of measurements and collection devices: fallout of particles (deposition plates for ~20 micrometers [µm] and larger); airborne concentrations in the optical microscopy size range (Air-O-Cell slit impaction cassettes 3–100 µm); and particles in the "respirable" size range (MiniVol samplers <3 µm). These methods were developed during the initial Optical and Scanning Electron Microscopy analysis of random coal samples, and examination of selected samples collected from the on-site monitoring.

3.1 Initial Testing of Coal Samples

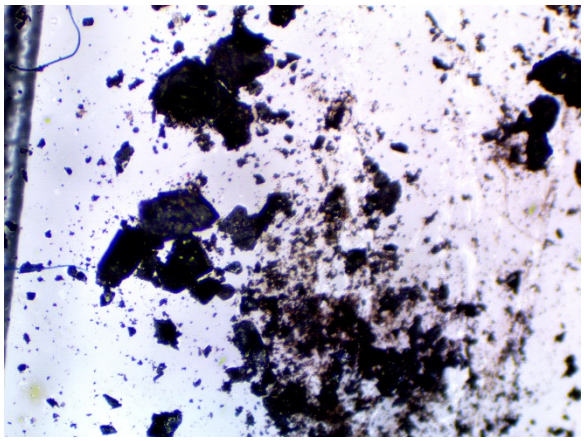
Two randomly collected coal samples were examined by both Optical and Scanning Electron Microscopy to determine the identifying properties of the coal. Based on this examination, the coal samples were found to have very similar "microscopic" and chemical (elemental) properties.

Optical Properties

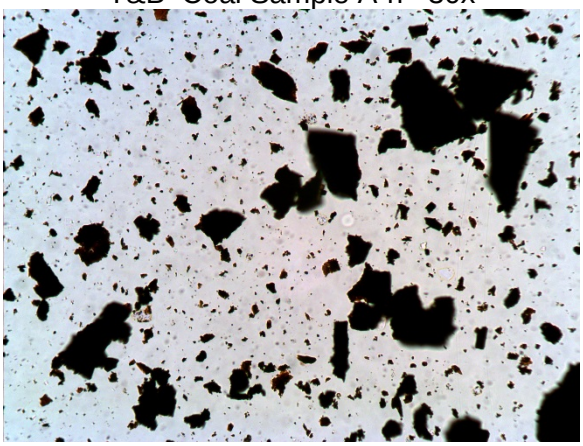
The coal samples appear granular and black/brown with an orange tint present in very thin areas of the particle. This condition was observed in both transmitted light and reflected light. Particles less than approximately 20 µm also have a brown/orange coloring and are a mixture of both angular and rounded particles. The optical properties of the coal, especially the brown-orange-tint coloration in very thin particles, can be used as an indicator to differentiate the coal from other biogenic or organic particles in the sample. Based on examination of the samples collected at the test area, similar potential "look-alike" particles were found, including fire residue, diesel soot, tire rubber, asphalt, and a significant amount of iron oxide. Iron oxide flakes were found to be a significant particle type in all of the air samples collected during the passage of trains, as well as in the bulk soil samples collected in proximity to the railroad tracks. As a result, it was very important to distinguish these particles from "coal-like" particles. Example micrographs of the coal samples and other types of "look-alike" particles are shown in **Figure 3-1**. The abbreviation "rl" refers to reflected light illumination and "bf" refers to bright field transmitted light illumination.



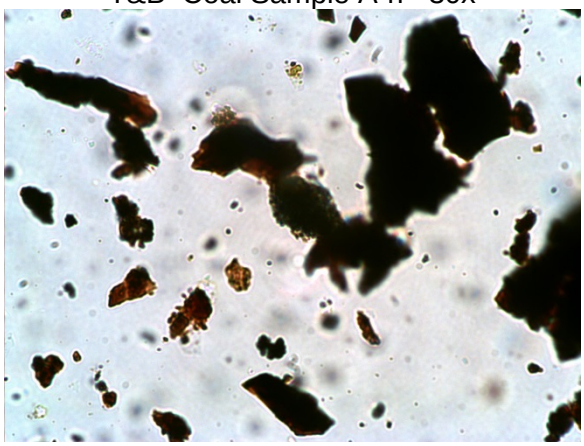
T&B Coal Sample A-rl ~30x



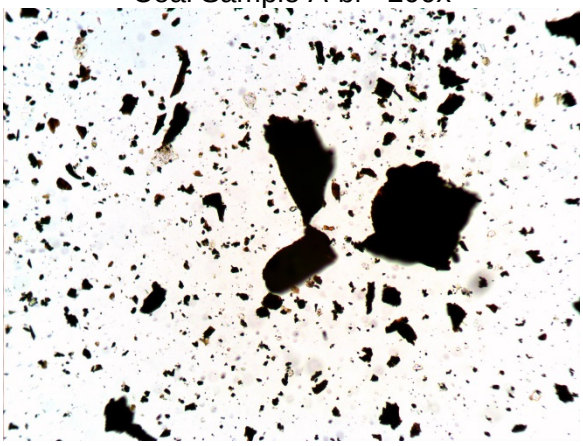
T&B Coal Sample A-rl ~30x



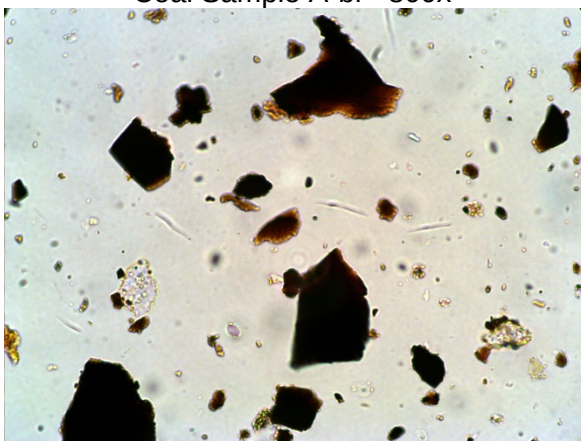
Coal Sample A-bf ~200x



Coal Sample A-bf ~800x



Coal Sample B-bf ~200x



Coal Sample B-bf ~800x

Figure 3-1. Example micrographs of coal samples under differing light and magnification.

Three bulk soil samples were also collected from the vicinity of the railroad tracks to look for the presence of coal particles. All three soil samples were obtained on the east side of the tracks, approximately 5 meters from the tracks. Locations were chosen where track ballast was light and the soil surface exposed. Soil was scraped from the top layer of these exposed areas using a clean utensil and placed in a petri dish (the same type of dish used for the deposition sampling). Review of the sample locations during a rain event revealed that the exposed area

where sample #1 was obtained consisted of a spot that runoff from the area first collected in and then flowed out of. Thus, both concentration and depletion of deposited material are a possibility at this location. The location for sample #2 was at the end of the short road leading up to the tracks, and had the possibility of being impacted by foot traffic. Of the three samples, sample #3's location appeared to be the location with the least possibility of disturbances that could potentially impact deposited concentrations. Coal was found in all three samples as well as significant amounts of iron oxide particles and the expected soil minerals including quartz and other feldspar and clay minerals. The highest relative concentrations of coal were observed in sample #1. Example micrographs of the bulk soil samples are shown in **Figures 3-2**, **3-3,** and **3-4** for each of three bulk samples.

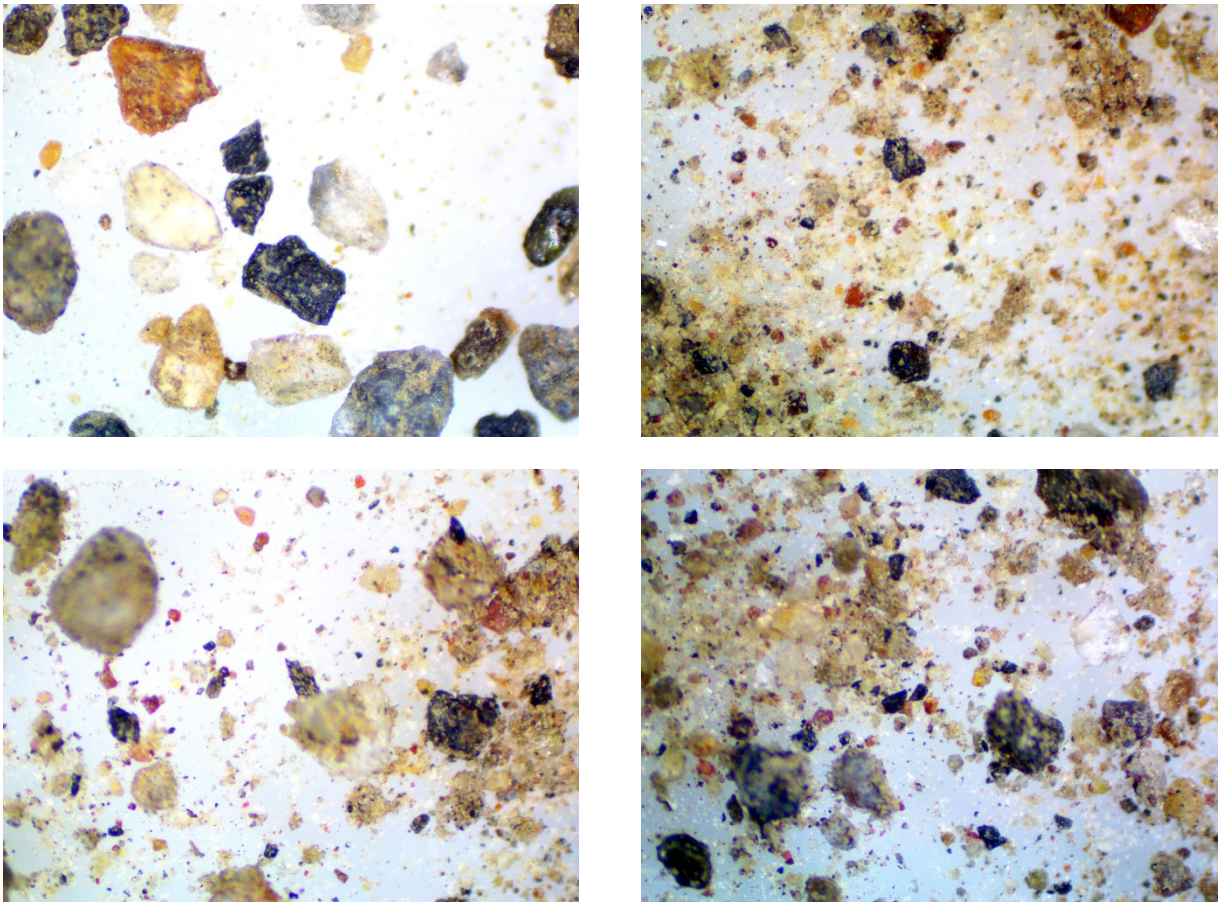


Figure 3-2. Bulk soil sample #1 – rl - 30x, with high amounts of coal and iron-oxide flakes. Horizontal field of view at 30x is 3.7 mm (3,700 µm).

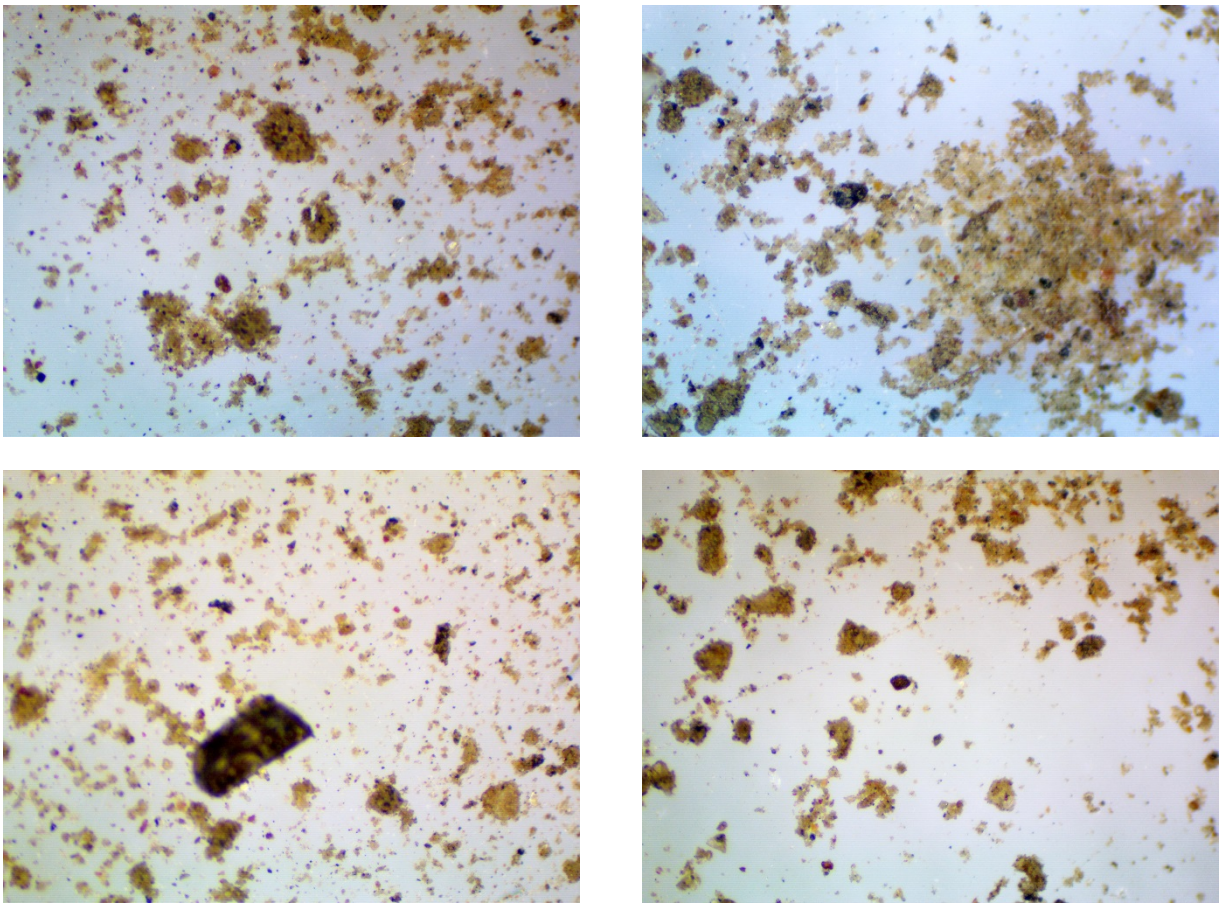


Figure 3-3. Bulk soil sample 2 – rl - 30x, with low to moderate amounts of coal and fine iron-oxide flakes.

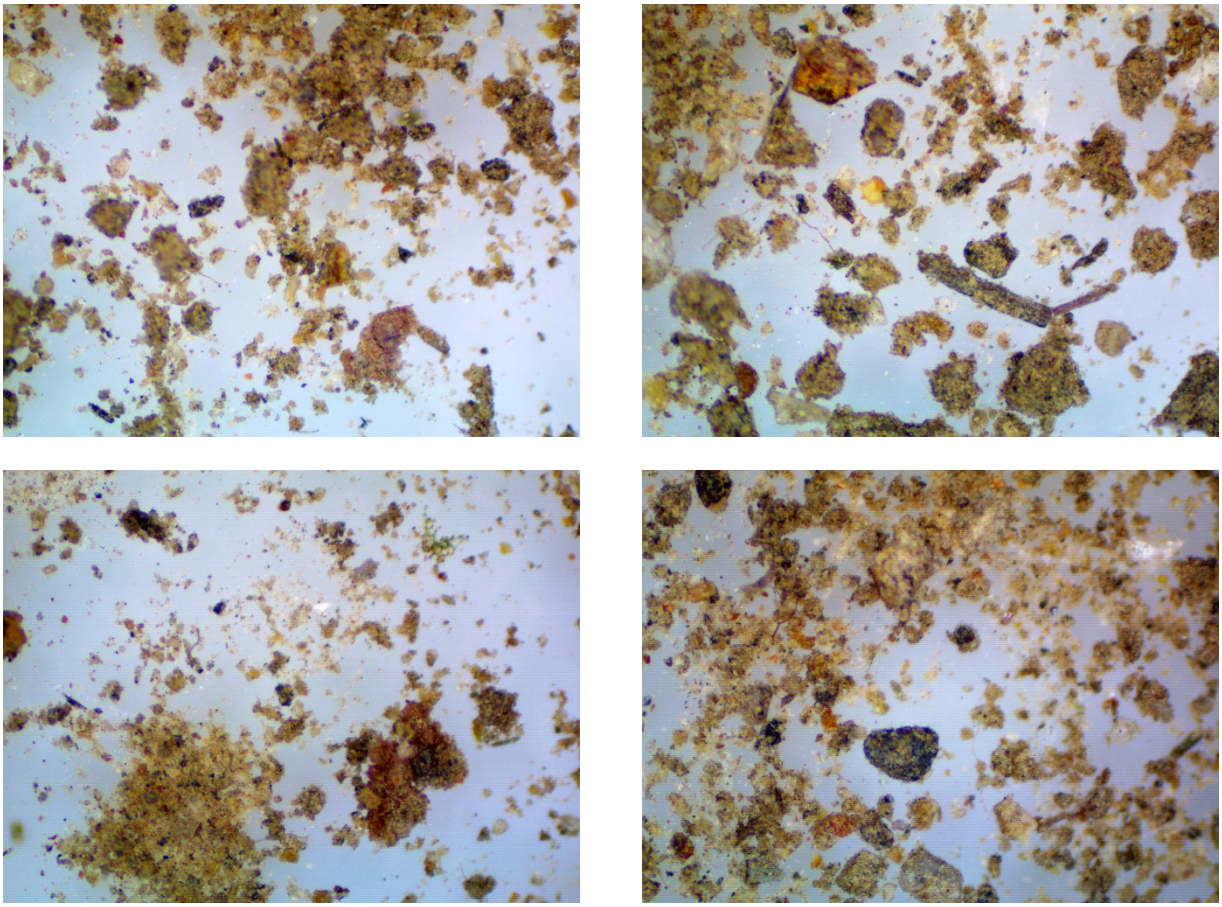
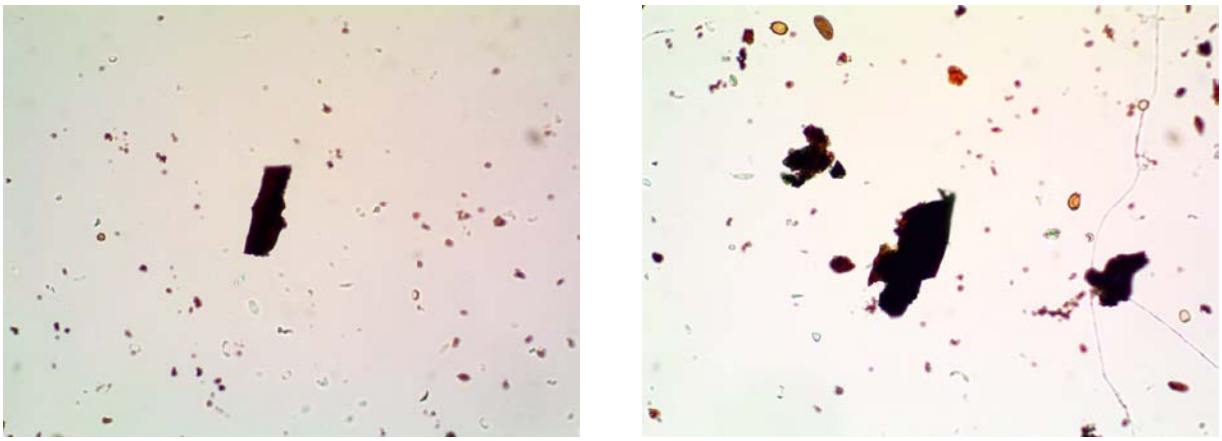


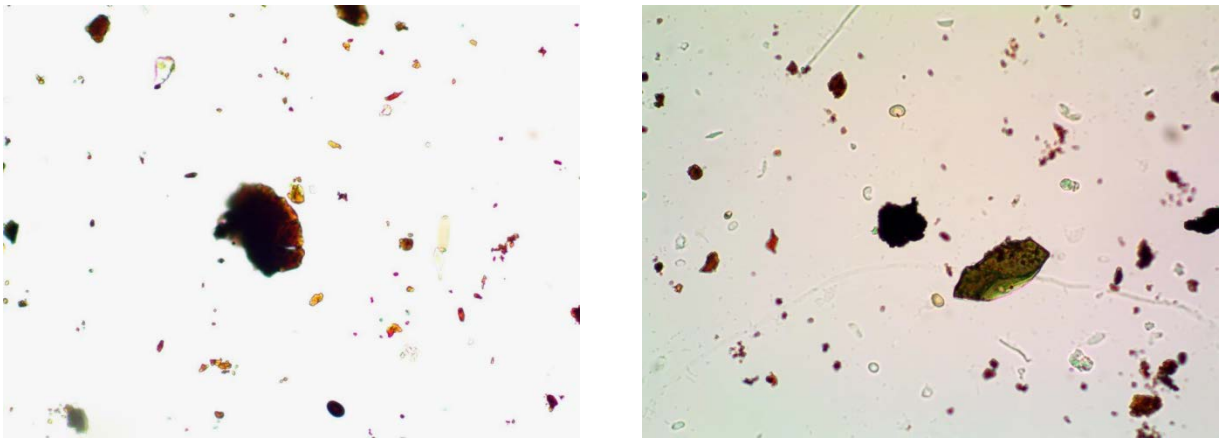
Figure 3-4. Bulk soil sample 3 – rl - 30x, with moderate amounts of coal and iron-oxide flakes.

Particle Classifications Used During Analysis

Examples of the coal-like particles (e.g. soot) encountered during the analysis and their respective classification codes are provided below in **Figure 3-5**. The coal-like particles are differentiated from the "Iron-oxide" classifications based on the uniform coloration edge texture, and internal texture observed in the coal particles and not observed in the iron-oxide particles. The iron-oxide particles have rough edge and internal texture from mechanical and corrosion "pitting."



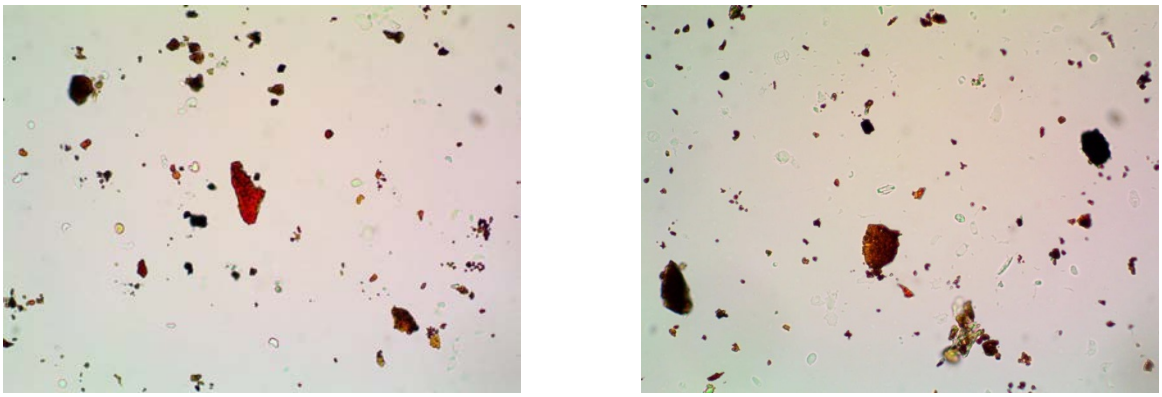
Angular “Coal-like” (AC) U4-016



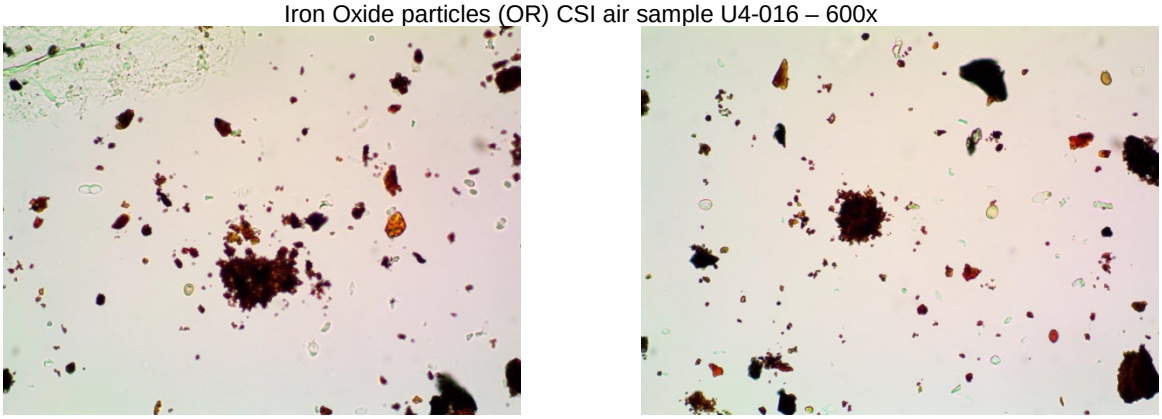
Rounded “Coal-like” (RC) U4-016

Figure 3-5. Angular (AC) and rounded (RC) samples in the same CSI sample at 600x. Horizontal field of view at 600x is 185 µm.

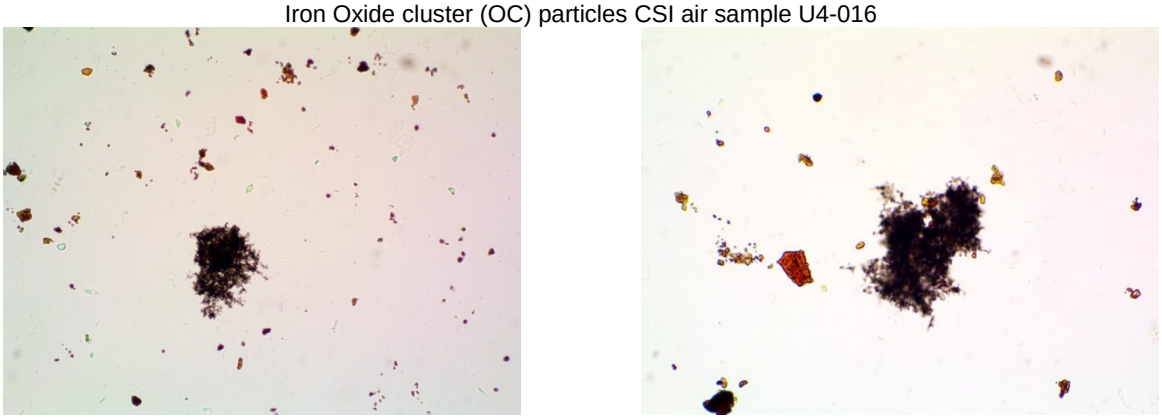
Examples of the common “non-coal” particles encountered during the analysis, and are the basis for the non-coal particle classifications, are shown in **Figure 3-6**.



Iron Oxide particles (OR) CSI air sample U4-016 – 600x



Iron Oxide cluster (OC) particles CSI air sample U4-016



Soot-like (SL) – CSI air sample 600x ~ 900x

Quartz (Q) – CSI air sample

Figure 3-6. Common non-coal particles observed in the samples.

The optical properties of actual coal samples include an orange tinged color when the thin sections or edges of the particles are examined. There is a uniform gradation of coloration from dark brown to orange with the relative thickness of particle. The interior and edge texture of the particles are relatively uniform and without any granular texture that would be indicative of corrosion or pitting. As described below, this morphology is used as an identifying feature separating the coal-like particles from other sources (e.g., diesel soot). This required the use of automated SEM/X-ray techniques to help decide on the morphological parameters required to separate coal-like from non-coal particle types.

Elemental Chemistry Properties (Dispersive X-ray Analysis)

Both of the coal samples (labeled as A & B) exhibit similar morphological and chemical properties. The compositions of both samples are a mixture of highly carbonaceous particles (over 90% carbon and oxygen), carbonaceous silicates, carbonaceous alumino-silicates (clays), and iron-containing carbonaceous silicates. Approximately 30% of the coal particles analyzed in sample B were also found to contain a simultaneous presence of iron and sulfur exceeding weight percentages of 1%. These low concentrations can only reliably be detected in particles larger than approximately 2 µm in thickness. Minor amounts of quartz, and iron oxide particles were also identified. The orange "tint" to the particles is likely due to the presence of iron in both of the coal samples.

Based on the initial X-ray analysis of both coal samples, a particle "classification" library was developed to analyze the collected air samples. The following classifications found in the coal samples were developed into a rule-based particle recognition and classification system for the automated SEM/X-ray analysis of the filter samples. A chi square fit analysis (based on the theoretical elemental weight percent) was used to "classify" particles within the sample. The major coal classifications decided upon for this project are given below:

Carbon-H	Highly carbonaceous particles (carbon/oxygen > 90%)
CMgAlFe silicate	Carbonaceous aluminum silicates (Fe and Mg present)
AlSi silicate	Aluminum silicate particles (low carbon)
MgAlSi carbon	Carbonaceous particles (MgAlSi present)
AlSiFe silicate	Aluminum silicate particles (Fe)
Quartz	Quartz – silicon dioxide
FeC oxide	Iron oxide particles with carbon present

Coal particles found with Sulfur (S) present – additional categories based on analysis of coal sample B:

AlSiS carbon	Carbonaceous coal (Al, Si and sulfur [S] present
CaFeS carbon	Carbonaceous coal (Ca, Fe, and sulfur [S] present

Because numerous "biogenic" particles in the outdoor environment may have similar carbon chemistry (carbon and oxygen ratios) when compared to the "highly carbonaceous" particles (Carbon-H) found in the source coal particles, a high percentage of these particles cannot be differentiated by the carbon/oxygen chemistry ratio alone. As a result, particles collected on air filter samples covering the "respirable" size range (<3 µm) cannot be reliably differentiated using the "Carbon-H" classification portion of the X-ray analysis. Thus, a large percentage of the highly carbonaceous particles (Carbon-H) collected over a 24-hour time period may be naturally occurring, and not from a coal source. The "Carbonaceous Silicate" classifications can be used

to differentiate coal-like from non-coal particles. Upon examination of the actual Air-O-Cell CSI air samples, the large category of potentially interfering particles has been shown to be iron oxide particles. These particles are likely related to the abrasion of the train rails and can be differentiated from the coal-like particles.

3.2 Deposition Plates

Analysis of the deposition plates showed very little "visible" particle deposition. As a result, direct analysis of the plates could not be performed. Therefore, the dust collected within the deposition plate was concentrated by washing with deionized water into a 25-mm filter funnel loaded with a 0.4 µm pore size mixed cellulose ester filter. By transferring to a filter with a smaller deposition area, the particles are concentrated by approximately 35-fold. The diameter of the deposition plate was 100 mm with an area of approximately 7854 mm^2. The deposition diameter of the transfer filter was ~17 mm with an effective area of 227 mm^2.

The filters were then dried and infiltrated with Triacetin to make them transparent for examination by optical microscopy. Potential coal particles on the filter were quantified in two (2) ways;

1) The entire filter was first screened at approximately 10x to locate any large potential coal-like particles, or areas of the filter where the particle density was highest. The field-by-field analysis was started at this location in order to have the analysis represent a worst-case scenario. The actual detection of any "large coal-like particles" using low power microscopy was a rare occurrence. Particle concentrations were quantified as the number of coal-like particle per deposition plate.

2) The size distribution of particles were calculated according to the following classifications.

   Coal-like Carbonaceous particles:

Code	Description
AC	Angular Carbonaceous – Black/brown/orange-tinged – (coal-like)
RC	Rounded Carbonaceous – Black/brown/orange-tinged – (coal-like)

   Note: The interior of the particles must have a smooth/non-corrosion morphology

   Other Potential "look-alike" particles (not associated with coal):

Code	Description
OR	Orange tinged Iron-oxide (corrosion morphology present)
OC	Orange tinged Iron-oxide aciniform cluster (corrosion morphology present)
I	Indeterminate Opaque – (likely biogenic or other brown/black particles)
SL	Soot-like black aciniform (not associated with coal)
Q	Quartz
M	Other unidentified minerals

Both Bright Field and Polarized Light Microscopy were employed during the analysis to classify and measure particles. The particles were classified using optical properties including their shape, texture, and coloration as compared to the actual submitted coal samples. The particles with coal-like morphology were then counted and sized and the results reported as a numerical concentration (particles/deposition plate). The size distribution was also reported for coal-like particles and the estimated mean particles sizes and theoretical mass concentrations of coal-like particles were reported as estimated micro-grams per settling plate (µg/plate).

3.3 Air-O-Cell CSI Air Samples

Initial examination of the Air-O-Cell CSI samples showed moderate surface particle deposition and good discrimination of coal-like particles from other biogenic particle classifications. Initial comparisons between the actual measured upwind and downwind locations showed a differential in the concentration and distribution of the particle classifications. Coal-like particles were observed to be more prevalent in the downwind samples. Both Bright Field and Polarized Light Microscopy were employed during the analysis. The same classifications for Optical Microscopy were used as with the deposition plate samples described above.

The particles with "coal-like" morphology were analyzed by Optical Microscopy using two types of reporting formats:

1). Numerical Concentrations: The numerical concentrations of particles were reported as particles/cubic meter of air (particles/m^3) in each particle classification given above, and based on the sampling times and volumes reported during sampling.

2). Size Distribution & Estimated Mass: The samples were separately analyzed for the size distribution of particles in the carbonaceous classifications (only) that are consistent with coal particles (see reports for Sample U2-025). A known percentage of the sample was analyzed and the size distribution statistics and estimated mass concentrations were calculated. The resulting mean particles sizes and theoretical mass concentrations of coal-like particles are reported as micro-grams per cubic meter of air (µg/m^3).

3.4 MiniVol Filter Samples

MiniVol filter samples were collected in an attempt to examine and chemically analyze the respirable (<3 µm) size fraction of dust emitted from the passing coal trains. The 24-hour duration MiniVol filter samples showed very low surface deposition in both the upwind and downwind locations. Any coal concentrations will also likely be masked by background biogenic particles that continue to be collected during the "non-train passage" sampling period. Because the biological particles contain carbon and oxygen ratios similar to a percentage of carbon/coal particles found in samples of the actual coal, the ability to differentiate coal-like particles from non-coal related particles was diminished. Analysis of the two collected coal samples showed high percentages of particles with primarily carbon and oxygen. These samples also showed highly carbonaceous alumino-silicate and iron silicate particles that can be readily differentiated from non-coal particles using the automated SEM analysis. However, these particles were found in a lower concentration. When these observations were combined with the dilution of "non-train passage air," the value of the MiniVol samples was significantly diminished. Collection of a sufficiently concentrated air sample in the "respirable" size range will require both a sample with more concentrated particle deposition (higher volume/flow rates), and a collection

interval that only samples during the passage of coal trains. Based on these initial observations, it was determined that further analyses of the collected MiniVol filters using SEM would provide no additional information, and no additional samples were analyzed.

It must also be recognized, that the inability to detect significant coal particles in the respirable size fraction over a 24-hour period (as measured during the initial sampling) also indicates that coal-like particles in the respirable range appears to be low.

4. QUALITY ASSURANCE

The quality assurance efforts implemented throughout the program were designed to create a data set of known quality suitable for the study goals.

4.1 Acceptance Tests

All instrumentation used for collection of data in the field underwent evaluation and acceptance testing before the start of the field program. The study included the use of automated deposition samplers that were designed and constructed specifically for this sampling effort. The TSI DustTrak DRX Aerosol Monitor used was obtained from a rental agency (EcoRental Solutions) and upon receipt was checked using the manufacturers procedures for the zero and flow checks. The instrument was then allowed to run overnight to confirm operation.

4.2 Field Quality Assurance/Quality Control (QA/QC)

Calibrations

All equipment were calibrated during installation using known standards and procedures consistent with EPA guidelines and/or manufacture recommendations:

- MiniVol Samplers – The sampler's internal flow meter (a rotameter) was calibrated against an NIST-certified Bios flow meter. Flows were confirmed to be operating within 5% of the sampler's design flow rate of 5 lpm, which is necessary for maintaining the cutpoints of the impactors.
- Air-O-Cell CIS Samplers – The operational flow rate of 15 lpm was confirmed at the beginning and end of the study using an NIST-certified Bios flow meter.
- DustTrak DRX – The operational flow rate of the DRX was verified at the beginning and end of the study using an NIST-certified Bios flow meter. The zero response of the instrument was verified using the manufacturer-supplied HEPA filter used to produce particulate-free air.
- Wind Speed – The RM Young wind speed sensor was calibrated using a certified selectable speed anemometer drive connected to the sensor shaft to simulate wind speeds the operating range of the sensor.
- Wind Direction – The RM Young wind speed sensor was calibrated by aiming the sensor at a landmark of known orientation and through rotation of the sensor to known directions and comparison to the data logger output values.
- Temperature – The RM Young temperature and relative humidity sensor was compared at multipoint points to known standards of temperature and humidity.
- Solar Radiation – The Licor pyranometer was compared to a recently certified unit at multiple times during the day.

Field QC

Study-specific sample forms were designed to collect required sampling information. In addition, the forms provided a checklist for conducting routine quality control during the study. Key elements of the quality control effort include the following:

- Battery voltages for all equipment were checked on a daily basis, and batteries changed as required.
- The zero response of the DustTrak DRX was checked every three days using the HEPA filter supplied by the manufacturer. The zero response did not deviate more than 0.001 $\mu g/m^3$ from zero over the course of the study.
- MiniVol flow rates were recorded at the beginning and end of each sample period.
- Field blanks were collected for each of the sample media used during the study, This included filed blanks for the MiniVol samplers, deposition plates, and Air-O-Cell CSI samplers. All blanks were handled in the same manner as normal samples, and in actuality were samples that for one reason or another did not have the sample pump turned on (in the case of the CSI samples) or were not exposed to ambient air (in the case of the deposition plates). Thus, using the deposition plates as an example, the blanks included the process of removing the lid of the petri dish, inserting the dish into the sampler, closing the top of the sampler, and repeating the reversed process to remove the petri dish. The samples were then analyzed by the laboratories as normal samples using the same procedures used to analyze the collected samples. No coal-like particles were found on the five blank deposition samples. Coal-like concentration for the five CSI blank samples average an equivalent concentration of 0.12 $\mu g/m^3$.

Sample Chain-of-Custody

Sample chain-of-custody was controlled from the field to the laboratory using chain-of-custody forms to document and verify handling of the sampling media.

4.3 Laboratory Analyses and Data Processing

Continuous meteorological and DRX instrumentation data were loaded into the T&B Systems data display system, which is based on the Vista Data Vision software package. All train passage data (train arrival times) were then added to the database, with coal trains also having the time that the last car or locomotive passed. This allowed for quick review of data for reasonableness and to identify any data quality issues. This review did reveal an issue with the solar radiation data where, due to an installation siting oversight, it became clear that the wind sensor shaded the radiation sensor at times, and under specific wind direction conditions. The 30-second data were edited, removing the invalid data, and the hourly averages were recalculated for solar radiation.

Data from EAA were submitted to T&B as five- to six-page reports for each sample analyzed (an example report can be found in Appendix B). Key data from these reports were then compiled into spreadsheets in order to better review the data and to allow for analysis of the data. The compiled data were verified independently by a second reviewer. Appendix A contains these summaries. An important task in this effort, given the large number of samples sent to the EAA, was to verify that reports were received for each of the samples submitted. Review of the compiled data indicated that near-zero readings for the Air-O-Cell CSI sampler located across the tracks on the west occurred during the middle of the study. This was the sampler that could not be manually confirmed to be sampling during the passage of the train, due to the number of tasks occurring during train passage sampling and the far proximity of this sampler from the other sampling efforts. Midway through the study, a disconnected wire associated with the control of this sampler was discovered, apparently due to minor vandalism and/or an inadvertent unplugging of the sampler at night. The near-zero readings correspond to three days prior to

this discovery, supporting the conclusion that sampling issues had occurred. These samples were designated as field blanks and excluded from the upwind/downwind analysis used to support the conclusions in this report.

Review of the laboratory data also revealed an issue with the calculation of mass concentrations for the deposition plate and CSI sampler data. EAA, when calculating the mass concentrations, simplified the calculations by taking a mean of the particle diameters and using this and the total number of particles identified to calculate particle volume and mass. Review showed that this approach had the possibility of significantly underreporting the mass, since mass increases as the cube of the particle radius, and even a few large particles can contribute enormously to the mass content of a sample. The analytical reports contained details on all particles identified during the analyses, including particle diameter. T&B Systems used the data in the reports to calculate the mass of each particle individually, and sum these up to obtain a more representative estimate of mass concentration for each sample.

5. RESULTS

Detailed summaries of the analytical results are presented in Appendix A. An example laboratory analysis report is presented in Appendix B..

The data supplied EAA contains considerable information regarding the deposition plate samples and Air-O-Cell CSI samples, including size distribution and particle characterization. The results presented here focus on the primary goal of the study, to characterize coal dust concentration in air and deposition from the coal hauling trains. Note that when comparing the data in Appendix A with that reported in the analytical reports, the mass concentrations in Appendix A will be higher than those in the reports for the reason discussed in Section 4.3, above.

A number of issues impacted sample collection for this study, including the following:

- While the study enjoyed 10 days of little to no precipitation, rainy weather dominated the area beginning October 14, and the study was terminated on October 20.
- In designing the study, a limited number of viable sampling locations were identified in Cowlitz County. The chosen location was picked for several reasons as described in Section 2, including that it appeared to offer the best possibility of cross-track winds, which review of available local meteorological data showed to consist of westerly winds (flowing west to east) for this time of the season. The samplers and deposition plates were laid out in a grid based on this assumption, with the majority of the measurements located on the east side of the tracks. However, winds with an easterly component were much more common during the study than anticipated based on available data, with only four of the 25 trains monitored occurring during winds with the expected westerly component. This impacted the goals in identifying gradients in deposition rates, and limited the usefulness of the DustTrak and MiniVol PM_{10} and $PM_{2.5}$ data.
- The relative humidity at this site was higher than anticipated, with nighttime fog common during the study period. It is unknown whether this might affect release of coal from trains that passed by the monitoring location.

5.1 Train Traffic

All train traffic was recorded and documented during the 11 days of active sampling. Train traffic data are summarized in **Table 5-1**. The number of freight trains indicated includes those that were hauling coal.

Table 5-1. Train traffic during study.

Date	Type	Northbound				Southbound		
		No. of Trains	Average Speed (mph)	Average No. of Cars/Train	No. of Stopped Trains	No. of Trains	Average Speed (mph)	Average No. of Cars/Train
1-Oct	Freight	9	41	111		7	44	78
(partial day)	Passenger	2	70	11		1	70	10
2-Oct	Freight	22	41	91	2	20	37	89
	Passenger	4	61	11		6	60	10
3-Oct	Freight	26	34	94	3	20	23	90
	Passenger	4	70	11		6	70	11
4-Oct	Freight	27	37	93	1	17	31	88
	Passenger	4	61	11		5	60	12
5-Oct	Freight	21	20	108	5	13	35	89
	Passenger	5	66	13		4	68	11
6-Oct	Freight	33	33	100	4	14	34	103
	Passenger	6	60	13		6	60	11
7-Oct	Freight	29	30	94	6	19	42	79
	Passenger	5	62	12		5	66	11
8-Oct	Freight	28	38	102	3	20	42	91
	Passenger	5	67	12		5	62	12
9-Oct	Freight	28	42	89	2	21	36	98
	Passenger	5	67	12		5	68	11
10-Oct	Freight	16	34	88	2	8	36	52
	Passenger	1	74	13		0	0	0
12-Oct	Freight	23	42	98	3	10	32	86
	Passenger	5	70	11		4	62	11

Due to work north of the site, northbound trains (and only northbound trains) would sometimes stop at the location of the sampling to allow southbound trains to pass. The duration of the stop would vary from 10 to 50 minutes. This affects the average northbound freight speed because the trains that stopped were generally traveling at a lower speed than other rail traffic when they passed the sampling location. There were more northbound trains in a given day than southbound, and generally northbound trains had more cars and apparently more locomotives. About the same number of passenger trains came from the north as from the south, and their speeds were in the 65–70 mph range, with 11–13 cars.

Figure 5-1 shows the distribution of train traffic over a one-week period during the study. The plot shows that the distribution of train traffic is relatively uniform through the day. While some gaps in traffic are noted, they do not appear to be limited to a particular time of the day. Passenger train traffic is predictably limited primarily to the period from 9 a.m. to 9 p.m. Coal trains occur at a consistent rate of about two per day, though there is no apparent pattern concerning when during the day they passed.

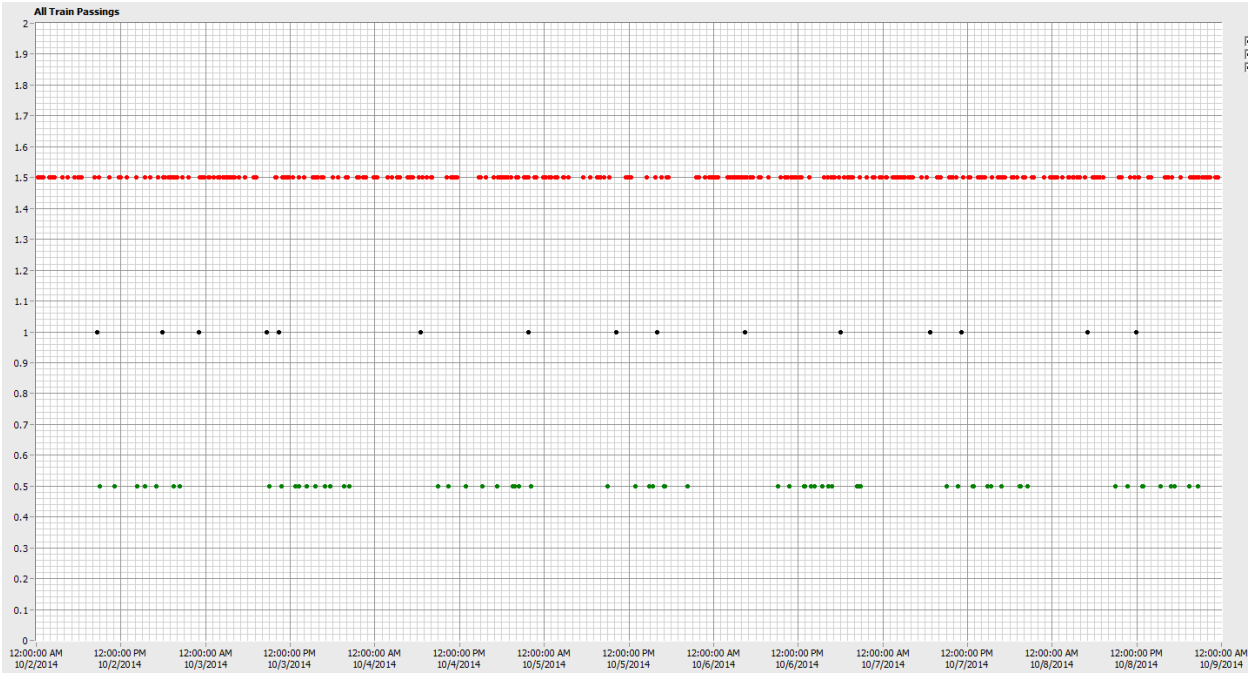


Figure 5-1. Train traffic during one-week period. Red dots = freight train; black dot = coal train; green dots = passenger train.

During the 11 days of active monitoring, 23 coal trains were observed, and samples were obtained during passage of 22 of the trains. All coal trains were northbound, and no empty coal trains were observed. **Table 5-2** presents a descriptive summary of the coal trains observed and the sampling conducted. Note that the last two trains in the summary are actually non-coal freight trains sampled as controls.

Of the 22 coal train sample sets collected, 11 where submitted to the laboratory for full analyses. These are highlighted in green in Table 5-2. The remaining 11 sample sets were not analyzed for several reasons, the most common of which was that the train stopped on the section of track being studied. Between the variable and relatively low speeds of these trains (see Table 5-2) and the confounding issues created by either sampling or not sampling while the train was stopped, it was determined that analytical data from these sample sets would not provide useful data for this study. The other reasons for not analyzing sample sets were due to measurement issues or vehicle traffic in the area adjacent to the samplers that would have confounded results.

5.2 Optical Characteristics of Samples

<u>Deposition Plates</u>

Based on the deposition plate analysis, quantitative information can be obtained; however, the results are likely to be less conclusive than the Air-O-Cell CSI samples because of the lower number of identifiable particles collected, and reliance on passive collection.

Table 5-2. Summary of coal train activity, and sampling and analyses activity (green highlighted sets had laboratory analysis).

						Engines		Cars				
Sample Set	Date	Arrival Time	Depart Time	Passage Time	Speed	Front	Back	Coal	Other	Total	Estimated Train Length (miles)	Comments
1	10/1/2014	18:30:17	18:32:16	0:01:59	40	3	1	126		130	1.3	
2	10/2/2014	8:34:08	8:35:55	0:01:47	44	3	1	122		126	1.3	Sampled only last 70 cars, closest plate malfunctioned
3	10/2/2014	17:53:33	17:55:07	0:01:34	53	2	2	119		123	1.4	Stopped sampling 1 minute after train passage because of road traffic.
4	10/2/2014	23:02:25	23:13:46	0:11:21	19 to 0 to 31	3	1	165		169		Train stopped
5	10/3/2014	8:38:59	8:40:38	0:01:39	43	3	1	114		118	1.2	Sampled for 89 cars. Pickup on road during sampling
6	10/3/2014	10:22:34	10:24:48	0:02:14	38	3	1	125		129	1.4	Sampled for 107 cars
8	10/4/2014	1:59:51	2:01:31	0:01:40	46	2	1	89		92	1.3	Nightime. Tech not absolutely sure cars contained coal
	10/4/2014	6:24:08	6:25:43	0:01:35	52	3	1	121		125	1.4	Not sampled because of very heavy dew
9	10/4/2014	11:43:33	11:44:27	0:00:54	38	2	0	25	24	51	0.6	Half freight, half coal
10	10/4/2014	21:46:53	22:26:31	0:39:38	15 to 0 to 26	4	0	126		130		Train stopped for 35 minutes, passed by 2 trains
11	10/5/2014	10:12:10	10:42:33	0:30:23	22 to 0 to 22	3	1	122		126		Train stopped for 25 minutes, passed by 1 train
12	10/5/2014	16:04:36	16:06:49	0:02:13	37	3	1	124		128	1.4	
13	10/6/2014	4:25:01	4:26:54	0:01:53	44	3	1	122		126	1.4	
15	10/6/2014	17:57:20	17:59:05	0:01:45	41	3	1	126		130	1.2	
16	10/7/2014	6:42:10	6:43:01	0:00:51	47	3	0	72		75	0.7	2 cars on levy road during sampling
17	10/7/2014	11:07:47	11:30:56	0:23:09	9 to 0 to 16	3	1	123		127	NA	Train stopped for 25 minutes
18	10/8/2014	5:00:14	5:01:54	0:01:40	43	3	1	125		129	1.2	
19	10/8/2014	11:55:26	12:05:14	0:09:48	13 to 0 to 16	3	1	124		128	NA	Train stopped for 5 minutes
20	10/10/2014	3:13:17	3:21:32	0:08:15	16 to 0 to 16	3	1	126		130		Train stopped for 1 minute
21	10/10/2014	5:22:42	5:24:21	0:01:39	43	3	2	124		129	1.2	
22	10/10/2014	7:30:22	7:32:07	0:01:45	40	2	2	125		129	1.2	
24	10/12/2014	12:58:01	12:59:34	0:01:33	48	3	1	122		126	1.2	New sample configuration
25	10/13/2014	9:47:54	9:49:48	0:01:54	43	3	1	125		129	1.4	New sample configuration
7	10/3/2014	16:29:18	16:31:05	0:01:47	46	2	1		112	115	1.4	Freight train
14	10/6/2014	16:13:18	16:15:03	0:01:45	38	2	1		111	114	1.1	Freight train

Examination of the initially selected deposition plate samples (both upwind and downwind) show very low but visible surface deposition of particles. The settled coal-like particles range in size from 10–50 microns. The concentration of the collected dust through filtration on to a small sized filter does provide usable particle concentrations in the locations closest to the train tracks.

Air-O-Cell CSI Air Samplers

Very low particle deposition (both upwind and downwind) was observed on the CSI impaction samples analyzed by Optical Microscopy. Although particles were visible down to approximately 1 µm, only particles greater than approximately 3 µm in diameter can be classified. Particle sizes ranged from 1 µm to approximately 100 µm. A higher ratio of particles less than 3 µm to those greater than 3 µm was observed by SEM.

24-Hour Filter Samples

Examination of the initially selected filter samples (both upwind and downwind) showed very low surface deposition of particles when examined by SEM, with the particle sizes ranging from 0.5 µm to 10 µm. The majority of the deposited particles (numerical concentration) were less than 1 µm in diameter. X-ray analysis results showed predominantly iron oxide containing particles (>80% of all particles analyzed). Lower concentrations of carbonaceous particles (biogenic mold spores, plant fragments, and insect dropping fragments) were detected. Concentrations of particles with a morphology consistent with coal particles were rarely detected.

5.3 Coal Concentrations

Table 5-3 summarizes the concentrations of coal-like material identified on the deposition plates and CSI air samples analyzed for this study. Note that in this table, “upwind” and “downwind” refer to actual meteorological conditions during sampling, based on the wind direction relative to the direction of the tracks at the sampling location (160º/340º). For example, remembering that there were three deposition plates east of the tracks and one plate west of the tracks, for Sample Set 3 when winds are coming more from the west, the three plates ended up being on the downwind side of the tracks, but end up being upwind for Sample Set 22, with winds from the east.

While the range of concentrations measured across the number of samples collected makes definitive conclusions difficult, a review of the data does point to a number of likely conclusions, as listed below:

Deposition Plates

- In reviewing the data from the plates, it is worth emphasizing that particles were rarely identifiable visually on the plates, as discussed in some detail in Section 3. In addition, it is important to note that no coal-like particles were identified in any of the field blank samples, as discussed in Section 4. Note also that all the deposition plates were all analyzed for a single coal train event.
- Looking first at data from the revised sampling configuration, concentrating on Sample Set 25, the potential for large variability in concentrations collected by different plates is readily evident. Looking at samples collected on the downwind side (as defined by the

measured wind direction) and only the material identified as coal-like, two plates located at the same distance from the track collected notably different concentrations of 2,591 µg/m^2 and 59 µg/m^2. Eighty percent of the 2,591 µg/m^2 sample is due to one 84.1 µm diameter particle (about the diameter of a human hair) that was collected on this plate. In general, deposition plates showing higher deposition concentrations are due to a large particle deposited on the sample. For example, the 2,234 µg/m^2 concentration shown for Sample Set 18 is due entirely to a single 96.7 µm diameter particle.

- Concentrating on the largest, primary data set with winds across the tracks, the data show that coal particles fall on both the upwind and downwind sides of the tracks. This is likely due to the wake created by the train itself, which was observed by the technicians conducting the sampling but not quantified during this study. The data do, however, show higher deposition on the downwind side of the train. This is most representatively observed by looking at the averages of the samplers located 15 meters from the tracks, which were obtained both upwind and downwind for all sample sets regardless of the wind direction. The average for the downwind coal-like samples is 890 µg/m^2 versus 334 µg/m^2 for the upwind samples.
- Based on the data obtained from sampling two non-coal freight trains (Sample Sets 7 and 14), concentrations of coal-like material for non-coal freight trains are lower than those for coal trains, averaging just 28 µg/m^2 for the non-coal trains, compared to either the upwind or downwind averages (334 and 890 µg/m^2, respectively) stated above.
- The data collected show apparent variability from train to train. This is demonstrated by the data from Sample Set 18, which show notably higher deposition amounts than those for the other sample sets. Conversely, results for Sample Set 1 are consistently low—at essentially the same deposition as those reported for the non-coal freight trains described above.
- The variability shown in the sampling results prevents estimation of a change in deposition as a function of distance from the track.

<u>Air-O-Cell CSI Air Samplers</u>

- Review of the data revealed that there was a period during which the CSI sampler west of the tracks was not operating correctly, which limits the number of sample sets that have both an upwind and downwind CSI sample. Un-run samples, however, were used instead as field blanks. Results from these field blanks showed consistently low coal-like concentrations (0.0, 0.0, 0.0, 0.0, and 0.6 µg/m^3, for an average of 0.1 µg/m^3 for the five samples).
- Despite the above issue, there were six upwind/downwind sample pairs for six individual coal train pass-bys, five of which show a significant upwind/downwind difference in concentrations. Concentrating on the primary data set obtained during across-track winds, the averaged downwind concentration is 9.4 µg/m^3 for the coal-like particles compared to 1.5 µg/m^3 for the upwind samples of coal-like particles. Sample Set 1 is the lone outlier in this data set, with upwind concentrations higher than downwind concentrations. However, it is worth noting that the crosswind component of the wind was particularly low for this sample set, with the wind speed recorded during this 2-minute period as only 0.3 meter per second, and the wind direction just 20º off of the track direction of 160º. It is possible that the train's wake played a bigger role than the winds in this case. If Sample Set 1 is removed from the calculations, the average concentrations are 11.3 and 0.6 µg/m^3 for the downwind and upwind samplers, respectively. The upwind concentrations are consistent with the concentrations measured during the non-coal freight train passages.

Table 5-3. Summary of coal-like concentrations off of coal trains.

								CSI Sampler (ug/m3)		Deposition Plates (ug/m2)					
	Sample			Speed	WS	WD	RH	Upwind	Downwind	Upwind			Downwind		
Winds across tracks	Set	Date	Time	(mph)	(m/s)	(deg)	(%)	40 m	40 m	30 m	15 m	5 m	5 m	15 m	30 m
	1	10/1/2014	1830	40	0.3	140	75	5.1	0.2	18.3	31.1	39.7		28.4	
	3	10/2/2014	1755	53	1	310	56	0.3	8.6		204.3		2.9	17.5	92.6
	6	10/3/2014	1022	38	2	20	70	1.9	5.2	45.2	121.5	1347.3		101.5	
	12	10/5/2014	1602	37	2	310	49		0.5				426.5	950.7	145.6
	13	10/6/2014	424	44	1	70	89	0.6		148.2	134.3	741.0		120.3	
	18	10/8/2014	500	43	0.9	30	87	2.5		0.0	2233.5	1399.9		6934.4	
	21	10/10/2014	521	43	0.9	60	97	0.1	19.6	11.7	17.0	40.8		1484.8	
	22	10/10/2014	730	40	1.3	80	97	0.1	22.5	76.7	55.7	31.6		379.1	

								CSI Sampler (ug/m3)		Deposition Plates (ug/m2)					
	Sample			Speed	WS	WD	RH	Upwind	Downwind	Upwind			Downwind		
New sampling configuration	Set	Date	Time	(mph)	(m/s)	(deg)	(%)	15 m	15 m	5 m	5 m	5 m	5 m	5 m	5 m
Winds across tracks	25	10/13/2014	947	41	2.5	85	87	0.41	26.5	22.7	9.6	90.6	2590.9	59.4	

								CSI Sampler (ug/m3)		Deposition Plates (ug/m2)					
	Sample			Speed	WS	WD	RH	East	West	East of Tracks			West of Tracks		
Winds parallel to tracks	Set	Date	Time	(mph)	(m/s)	(deg)	(%)	40 m	40 m	30 m	15 m	5 m	5 m	15 m	30 m
	15	10/6/2014	1800	45	1.5	340	54	15.1		38.3	56.8	155.9		33.3	

								CSI Sampler (ug/m3)		Deposition Plates (ug/m2)					
	Sample			Speed	WS	WD	RH	East	West	East of Tracks			West of Tracks		
New sampling configuration	Set	Date	Time	(mph)	(m/s)	(deg)	(%)	15 m	15 m	5 m	5 m	5 m	5 m	5 m	5 m
Winds parallel to tracks	24	10/12/2014	1258	50	1.2	160	83	6.76		46.9	64.1	44.9	5.5	0.0	

								CSI Sampler (ug/m3)		Deposition Plates (ug/m2)					
	Sample			Speed	WS	WD	RH	Upwind	Downwind	Upwind			Downwind		
Freight Train	Set	Date	Time	(mph)	(m/s)	(deg)	(%)	40 m	40 m	30 m	15 m	5 m	5 m	15 m	30 m
Winds across tracks	7	10/3/2014	1627	46	0.8	230	29		0.4	15.5	42.1	11.1		17.8	

								CSI Sampler (ug/m3)		Deposition Plates (ug/m2)					
	Sample			Speed	WS	WD	RH	East	West	East of Tracks			West of Tracks		
Freight Train	Set	Date	Time	(mph)	(m/s)	(deg)	(%)	40 m	40 m	30 m	15 m	5 m	5 m	15 m	30 m
Winds parallel to tracks	14	10/6/2014	1613	38	2	340	49	1.1		60.7	16.5	36.3		25.3	

- Similar to the deposition plates, there is evidence of train-to-train variability in emitted coal-like concentrations. Looking at Sample Set 21, the measured downwind concentration is significantly higher than for other trains. This is supported by the downwind deposition plate for this sample set, which has one of the highest concentrations of the study. Sample Set 22 also shows both a high downwind CSI concentration and moderately high deposition plate concentrations.
- Higher concentrations were monitored by the CSI sampler when it was moved closer to the tracks (from a distance of 40 meters to a distance of 15 meters), as evidenced by the Sample Set 25 data.
- One of the goals of the study was to investigate the effect of train speed on the source strength of coal dust from the train. The small number of samples and the relatively consistent speed of the passing coal trains (averaging about 43 mph) make conclusions regarding the effect of train speed difficult. However, it can be observed that for the fast train observed (Sample Set 3 – 53 mph) the downwind concentration is amongst the highest of the study, whereas for the slowest train (Sample Set 12 – 37 mph), the downwind concentration is amongst the lowest. However, the highest concentration measured with the original configuration (22.5 $\mu g/m^3$ – Sample Set 22) occurred for a train traveling at 40 mph, indicating that speed may not be the only factor affecting coal dust source strength..
- Similarly, the data were reviewed to see if relative humidity was correlated with measured coal dust. With the highest concentrations noted during a period when relative humidity was 97% (Sample Sets 21 and 22), this does not appear to be an obvious factor based on the data collected. If average humidity during coal transport does affect coal dust source strength, measurements at a single location would not be representative of the entire haul route in any case.

5.4 MiniVol Gravimetric Samples and DustTrak DRX Data

The data collected from the DRX were anticipated to be used to help understand the differing size distribution of coal dust and particulate matter from the different train types. However, the usefulness of the data is questionable under the observed study conditions due to the high humidity during much of the study period and the resulting drift in the instrument baseline. Laser-based photometers have known issues under high humidity, and this is apparent with the collected data. Many of the nighttime and early morning hours also had extensive fog, as documented with the video taken at the site and measured relative humidity. **Figure 5-2** shows the diurnal pattern of $PM_{2.5}$ during the period of October 3 through October 6 when the largest diurnal swings in relative humidity occurred. The values are averaged RH and $PM_{2.5}$ within each of the hourly periods that reflect the close correlation of high RH values with the higher $PM_{2.5}$ values. Additionally, as the RH increases past about 90%, the noise in the values increases significantly. As a result, not much can be done to remove the influence of humidity on the data when the RH reaches 80 to 90%. This makes correlating the DRX to the collected filter samples to establish a “K” correction factor for calibration inappropriate because during the study period there were always times within each 24 hour period that had high humidity. The best use of the DRX data is therefore to look at any potential relative values during periods when the humidity was lower and wind directions were appropriate to carry coal dust from the train to the location of the DRX. Use of the DRX in future studies should be restricted to applications and time periods with lower humidity, or different instrumentation should be used to measure the size-segregated data under the varying humidity conditions in the study region.

Despite the limitations of the DRX data collected in this study, a comparison of the DRX data with the filter-based MiniVol data was conducted by calculating 24-hour average concentrations obtained from the DRX corresponding to the MiniVol sample times and comparing them with the MiniVol 24-hour averages. These results are presented in **Table 5-4**.

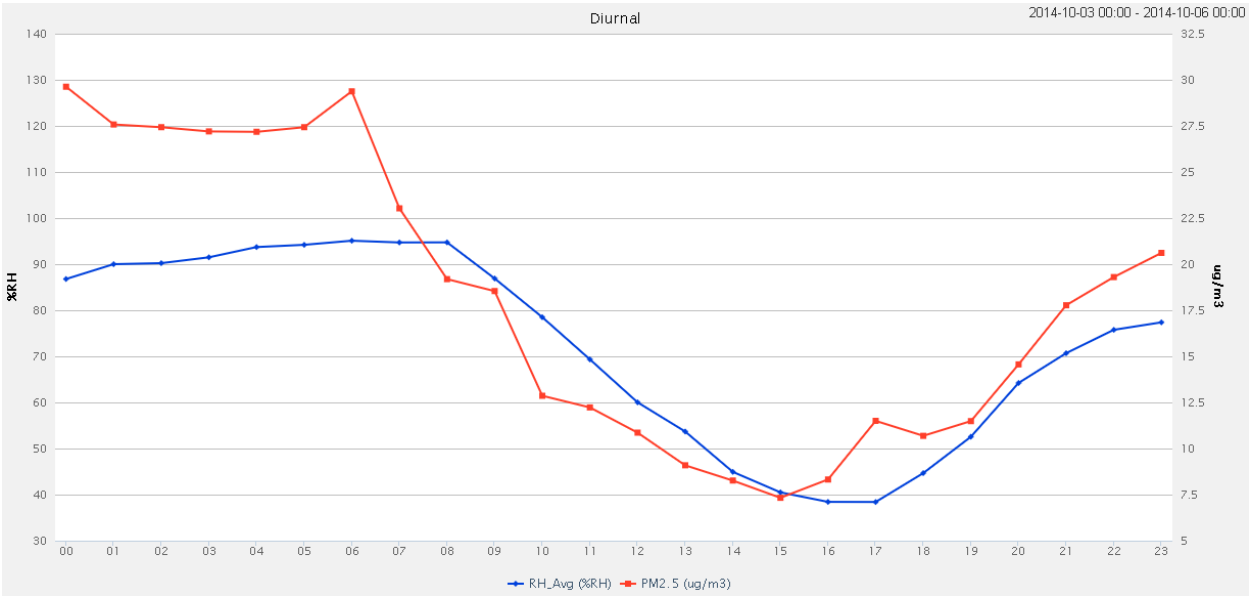


Figure 5-2. Diurnal variation of relative humidity and $PM_{2.5}$ during a three-day period showing the correlation of concentration to humidity.

Table 5-4. MiniVol/DustTrak DRX data and comparison.

		Filter (ug/m^3)		DRX (ug/m3)				Filter/DRX Ratio	
Date	RH	PM 2.5	PM 10	PM1	PM 2.5	PM 4	PM 10	PM 2.5	PM 10
10/1/2014	79.5	9.2	17.4	19.7	21.3	24.1	26.9	0.432	0.647
10/2/2014	69.2	8.6	15.2	17.7	18.7	20.7	21.2	0.460	0.717
10/3/2014	74.5	8.9	16.6	18.2	19.4	22.5	23.9	0.459	0.695
10/4/2014	72.2	11.5	20.2	16.7	17.4	18.4	19.7	0.661	1.025
10/5/2014	70	9.6	19.9	15.2	15.7	16.4	18.1	0.611	1.099
10/6/2014	74.1	7.6	17.2	13.1	14	15.7	17.9	0.543	0.961
10/7/2014	75.8	7	17.5	11.9	12.4	13.2	15.2	0.565	1.151
10/8/2014	82.4	10	14	20.7	21.7	23.2	24.4	0.461	0.574
10/9/2014	83.9	8.1	20.6	24.4	25.4	26.9	28.3	0.319	0.728
10/12/2014	84.6	19.1	16.7	18.4	19.6	20.6	21	0.974	0.795
Study Average	76.6	8.9	17.5	17.6	18.6	20.2	21.7	0.501	0.839

It should be noted that MiniVol samples were changed around 4 p.m. each day. The final sample on October 12 was actually conducted over a 32-hour period in order to include sampling through the end of the study, which was defined by an approaching rain storm.

In reviewing the data, the $PM_{2.5}$ sample dated October 12 (highlighted in yellow on Table 5-4) stands out for a number of reasons. The concentration is notably higher than that for any of the other days. In addition, it is higher than the reported PM_{10} concentration for that day, while the PM_{10} concentration appears to be very similar to those for the other days. Finally, the Filter/DRX ratio is notably different—almost twice the average. For this reason, the $PM_{2.5}$ results for October 12 are considered highly questionable, and have been removed from the calculation of the study averages.

Comparisons with the average relative humidity for the sample period revealed no definitive relationships, though there is a weak correlation between relative humidity and the Filter/DRX ratio ($r = -0.50$ and -0.68 for $PM_{2.5}$ and PM_{10}, respectively), with lower factors associated with higher relative humidity. This is consistent with observations that higher humidity causes an over-reporting of the concentration, and thus requires a lower "K" factor to correct it.

Based on the above comparison, possible "K" correction factors for the DRX data would be 0.50 for the $PM_{2.5}$ data and 0.84 for the PM_{10} data, with some possibility of adjusting these factors for humidity. However, while these factors may be fairly representative for 24-hour averages, their use for shorter time periods (e.g., 1-hour) has not been confirmed with this study.

5.5 MiniVol $PM_{2.5}$ Scanning Electron Microscopy Analyses

As discussed in Section 3.4, the usefulness of the SEM analysis of the 24-hour $PM_{2.5}$ filters collected for this study was found to be limited. This is due to the relatively small amounts of coal being emitted (two train events). Nevertheless, five samples were analyzed to explore further the potential use of this analysis as a tool to extract more information about the ambient concentrations of coal. These samples were as follows:

- Coal sample A – A portion of Coal Sample A was pulverized and fractionated by settling through a water column until the average particle diameter was less than approximately 10 µm. This sample was then analyzed by automated SEM with size discrimination to only analyze particles from 0.5 µm to 5.0 µm in diameter. This preparation procedure was performed in order to simulate coal-like particles that may be found in the "respirable" size range on the ambient air $PM_{2.5}$ samples.
- Samples U4-008 and D4-008 – A 24-hour sample pair was collected during a period when no coal trains passed.
- Samples U4-009 and D4-009 – A 24-hour sample pair was collected during a period when two coal trains passed, immediately following the sample pair above (U4-008 and D4-008). Specifically, these were the trains identified in Table 5-3, above, as Sample Sets 21 and 22, both of which showed strong upwind/downwind gradients for coal-like particles. Both trains passed under similar meteorological (upwind/downwind) conditions. Furthermore, the percentage of across-track upwind/downwind periods for this sample pair were virtually identical to the "no coal train" sample pair, above (80% toward the downwind sampler versus 20% toward the upwind sampler – a 4:1 ratio).

Analysis reports for these and other samples discussed in this section are included in Appendix C.

Figure 5-3 summarizes the results of the analysis of the coal sample. As can be seen, the composition of the coal can be divided into essentially four categories: AlSi carbon (carbonaceous aluminum silicates), Carbon H (highly carbonaceous, >80% carbon), CMgAlFe silicate (carbonaceous silicates, low concentrations of magnesium, aluminum, and iron), and quartz. However, for both CMgAlFe silicate and quartz, the concentrations are extrapolated from a single larger particle, and therefore should not be considered conclusive. Notably missing from this sample is iron oxide (FeC oxide), supporting the assumption that any iron oxide is likely coming from the steel rails.

Figure 5-4 presents a similar summary for the downwind "coal train" ambient air sample. Several differences between this sample and the coal sample are apparent. Most obvious is the increase in the percentage of Carbon H, and the notable difference in the Carbon H to AlSi carbon ratio. Almost half of the mass analyzed by SEM in the "respirable" size range was classified as Carbon H. Optical Microscopy examination of the Air-O-Cell CSI samples (as discussed in previous sections) showed that a significant percentage of carbonaceous particles are likely biologically derived (mold spores, pollen, carbonaceous fragments). The <3 µm size range of particles cannot be accurately classified by Optical Microscopy because of their small sizes. Thus, an important discriminatory was to estimate the portion of Carbon H particles that are potentially coal-like in nature versus those that are organic.

Another very noticeable difference between the two figures is the presence of iron oxide (Fe oxide) in the ambient sample, which again was not detected in the coal sample. This, again, is consistent with the assumption that the primary source of iron oxide concentrations in the air samples are from the train rails.

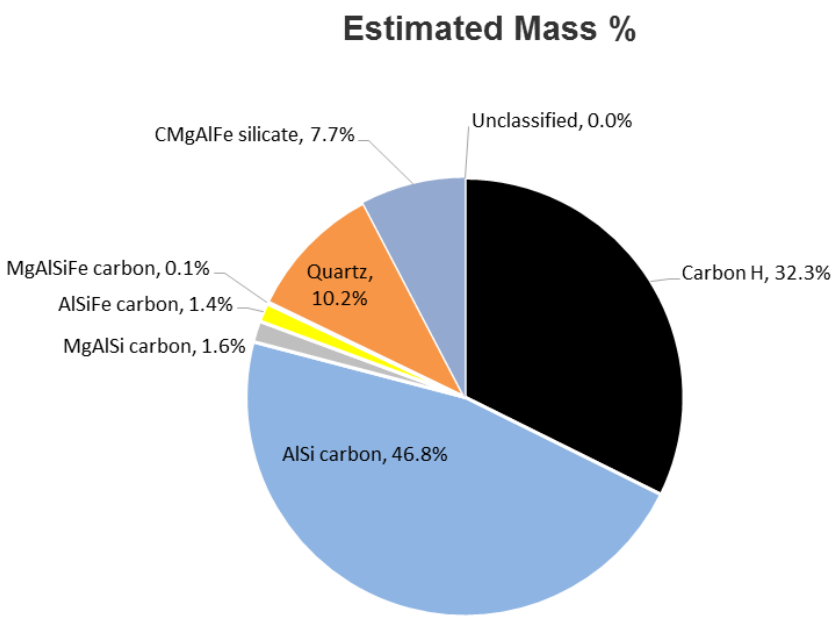


Figure 5-3. Relative mass concentration for coal sample #1 in the respirable range.

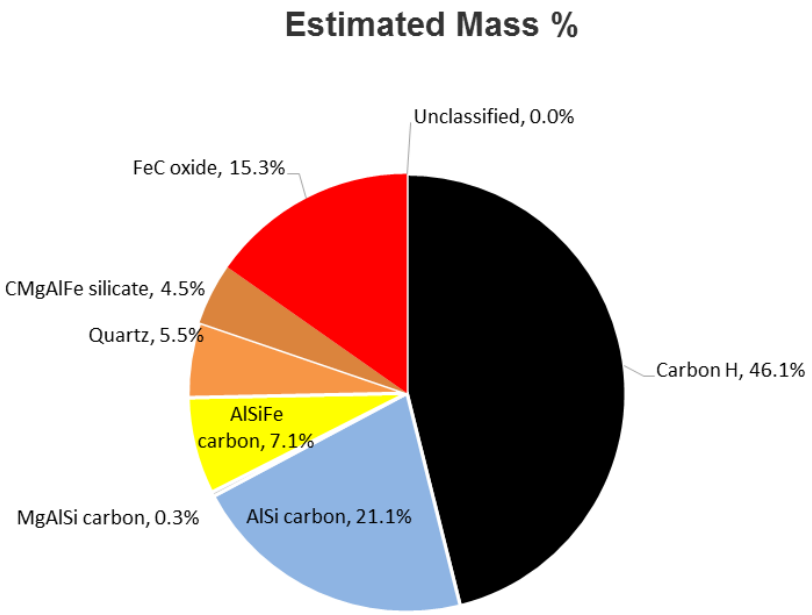


Figure 5-4. Relative mass concentration for downwind "coal train" sample.

Table 5-5 summarizes the concentration data for the five samples. The sample pair collected when no coal trains passed are very similar. The only classifications that show any significant difference between upwind and downwind concentrations are the iron classifications (FeC oxide and AlSiFe carbon), which are not unexpectedly higher downwind than upwind due to the abrasive mass loss from wheels with the steel rail. Furthermore, concentrations for this pair for the two most prevalent coal-related compounds (Carbon H, and AlSi carbon) are almost identical to the upwind sample "coal trains" sample (D4-009), supporting the conclusion that all three of these concentrations could be representative of "background" concentrations. The possible contribution due to the coal-related classifications can therefore be calculated simply as the difference between the downwind and upwind concentrations for the two coal-related classifications (Carbon H, and AlSi carbon). This produces an estimated upper bound for coal-like contribution of 1.33 $\mu g/m^3$ for two trains.

This conclusion, however, should be evaluated taking into account the limitations associated with this methodology. Based on the experience of EAA, the variability in microscopic particle counting will range from a relative standard deviation (RSD) of 0.15 to 0.30. This normal variability is essentially a 50 to 100% difference between two compared "numerical" values (i.e., the difference between detecting 5 particle counts and 10 particle counts). When this variability between numerical counts is further extrapolated to the calculation of mass concentrations, this variability will be even higher. As a result, the upwind and downwind mass concentrations given in Table 5-5 are not statistically different and are within the statistical variability of the method. In other words, the data may indicate a "trend" for the coal-like mass concentrations in a downwind sample (i.e., U4-009) to be higher than in upwind samples (D4-009). However, these two samples are not statistically different. Recognizing these limitations, and for purposes of a upper-bound analysis, it is assumed in Table 5.5 that the "trend" between upwind and downwind samples is indicative of a coal-like contribution.

Table 5-5. SEM analysis of 24-hour $PM_{2.5}$ samples (all values in µg/m^3)

Sample ID	Description	Carbon H	AlSi carbon	MgAlSi carbon	AlSiFe carbon	MgAlSiFe carbon	Quartz	CMgAlFe silicate	FeC oxide	FeMgAlSi carbon	Unclassified	Total
Coal A	Coal sample	1.130	1.630	0.050	0.050	0.000	0.360	0.270	0.000	0.000	0.000	3.490
D4-008-SEM	Upwind, no coal trains	1.205	0.451	0	0.017	0.067	0	0.045	0.010	0	0	1.795
U4-008-SEM	Downwind, no coal trains	1.014	0.541	0	0.274	0.040	0.013	0	0.109	0	0	1.991
D4-009-SEM	Upwind, 2 coal trains	0.991	0.456	0	0.336	0	0.003	0.330	0.173	0.097	0.058	2.444
U4-009-SEM	Downwind, 2 coal trains	1.907	0.874	0.014	0.296	0	0.229	0.187	0.632	0	0	4.139
	Net difference (downwind - upwind) for sample pair 009	0.916	0.418									1.334

Because the use of the Carbon H category appears to be non-specific for coal particles in the ambient environment, an effort was made to look for other chemical indicators for coal particles, particularly for vanadium and manganese, two elements that typically can be found at trace levels in coal. This investigation was performed by conducting additional SEM analyses of both coal samples A and B (labeled as coal samples #1 and #2, respectively, in the lab reports) at longer X-ray acquire times and using a particle definition library refined for identifying trace particles. While manganese and vanadium were only detected at levels greater than 1% in a single isolated particle in each sample, the analyses did reveal a potential simultaneous relationship between elevated sulfur (S >1%) and iron (Fe >4%) in many coal particles, with the ratio of sulfur to iron consistently in the 1:4 to 1:5 range. This simultaneous presence of elevated sulfur and iron was only noticeable when the analysis was performed on particles larger than approximately 2 µm, and when longer X-ray acquire times were utilized. This is directly due to the increased electron beam penetration into the background collection media when the particles are very small. As a result, the X-ray spectra reflects the carbon and oxygen chemistry of the sample media as well as the sample. This effect reduces the detection efficiency of trace elements such as sulfur. Thus, the possibility of identifying sulfur during a reanalysis of $PM_{2.5}$ sample U4-009, even using the longer X-ray acquire times and the modified definition library, was marginal at best. No sulfur containing particles (let alone the detection of both sulfur and iron) were identified in sample U4-009.

Furthermore, of the two coal samples, only coal sample B revealed the consistent presence of sulfur and iron at the ratios described above for particles greater than 2 µm. A total of 46 out of 188 particles analyzed contained S>1%, 26 of which also contained iron in the 1:4 to 1:5 ratio. In contrast, for coal sample A, while 27 of the 188 particles had S>1%, only one particle had iron at the 1:5 (sulfur to iron) ratio. The ratio of sulfur to iron is important if sulfur is to be used a potential tracer. In ambient samples, there are other particle sources that will contain sulfur or iron, and this ratio would appear to be a possible way to differentiate coal from these other sources. Thus, there is a potential in future studies to use this methodology to estimate coal contributions, provided total particulate concentrations rather than $PM_{2.5}$ are collected. The reason for the differences between the two coal samples needs to be resolved (possibly due to different coal sources) before this potential “tracer” can be used to differentiate biogenic carbon sources from coal particles.

5.6 Iron Oxide Analyses

In addition to investigating coal-like concentrations observed during the sampling effort, iron oxide concentrations were reviewed due to the likely presence of iron from the interaction between the rails and train wheels and their potential contribution to $PM_{2.5}$ and PM_{10} concentrations. **Table 5-6** summarizes the iron concentration from the deposition plate and CSI Air-O-Cell sampling. For the purposes of this table, iron oxide and iron oxide cluster concentrations have been summed into a single concentration.

- There is considerable variability in the deposition plate results, again demonstrated by the downwind results for Sample Set 25, where two similarly positioned samples collected significantly different concentrations. Furthermore, some of the highest concentrations are reported by the deposition sampler located farthest from the tracks (Sample Sets 15 and 22), with no consistent concentration gradients as a function of distance from the tracks. A likely source of this variability is due to unusually high variability in iron oxide concentrations for the sample blanks. Iron oxide concentrations for the five blank samples were as follows, with one particularly high concentration:

121.5, 0.0, 49.8, 7,596.3, and 14.2 µg/m^2. This is in stark contrast to the blank concentrations reported for coal-like particles for same plates, which averaged only 0.1 µg/m^2 for the five blank samples. Again, it should be noted that blanks were obtained using all sampling procedures short of actually exposing the sample during a train passage (see discussion in Section 4.2). It is possible that the sampling equipment's continual exposure to iron oxide, which would occur from all trains, makes it difficult to load and unload the sampler without occasionally knocking an accumulated particle off of the sampler and into the deposition plate.

- The Air-O-Cell CSI samples also show more variability and less upwind/downwind correlation in the iron oxide results than in the coal-like results. However, unlike the deposition plates, the blank samples for the CSI samples showed no elevated concentrations, averaging only 0.1 µg/m^3 for five blank samples.
- Despite the complicating issues of the deposition plate blanks, the variability noted in the iron oxide results compared against the coal-like results may be due to the source mechanism. Assuming that iron oxide concentrations are being emitted at the rail level, then dispersion of the particles is dependent on the more random winds generated by the wake of the train. In contrast, coal dust emanates predominantly from the very top of the coal cars, where local crosswinds may have a more significant influence.
- There is no apparent difference in the iron oxide concentrations between the coal trains and the non-coal (freight) trains. This is most apparent when looking at the deposition plate concentrations, with concentrations for the freight trains falling along the same range as those for the coal trains, with the same degree of variability. The CSI concentrations for the non-coal trains are on the low end, but still easily fall within the variability noted for the for coal trains.
- The relationship between the $PM_{2.5}$ and PM_{10} ratio of iron oxide could be of interest for this study. While the study took samples for these two fractions, comparison of the PM_{10} results for the CSI samples with the $PM_{2.5}$ SEM results is problematic for a number of reasons:
  - The analytical methods are inherently different. The optical method used for the CSI samples manually identifies the particles, whereas the SEM analysis automatically infers iron oxide based on the mineral analytical spectrum.
  - The sample periods are very different, with the CSI samples collected for a few minutes and only while a train is present, whereas the SEM samples are integrated over a 24-hour period, which included only about 90 minutes of the 24-hour period when trains were present.
  - Similarly, the CSI samples are obtained over a short period when winds are essentially from a given direction, whereas the 24-hour SEM samples include a mix of both upwind and downwind conditions.

  With this in mind, the SEM $PM_{2.5}$ samples U4-009 (the predominantly downwind sample) and D4-009 (the predominantly upwind sample) showed 24-hour iron oxide concentrations of 0.173 and 0.632 µg/m^3 respectively, as described in Section 5.5. Note that this is consistent with the 4:1 downwind versus upwind ratio noted for these samples. During the same period, two trains were monitored (Sample Sets 21 and 22, discussed above), with reported iron oxide concentrations of 1.8 and 13.8 µg/m^3. These concentrations represent particles predominantly in the 2.5 to 10 µm range.

Table 5-6. Iron Concentrations

								CSI Sampler (ug/m3)		Deposition Plates (ug/m2)					
	Sample			Speed	WS	WD	RH	Upwind	Downwind	Upwind			Downwind		
Winds across tracks	Set	Date	Time	(mph)	(m/s)	(deg)	(%)	40 m	40 m	30 m	15 m	5 m	5 m	15 m	30 m
	1	10/1/2014	1830	40	0.3	140	75	23.7	1.7	80.9	16.6	231.4		113.8	
	3	10/2/2014	1755	53	1	310	56	0.6	17.0		22.5		16.9	90.2	28.9
	6	10/3/2014	1022	38	2	20	70	6.3	1.7	179.1	371.1	44.6		36.3	
	12	10/5/2014	1602	37	2	310	49		98.8		806.5		4312.9	146.8	72.0
	13	10/6/2014	424	44	1	70	89	1.8		572.6	168.3	58.5		96.6	
	18	10/8/2014	500	43	0.9	30	87	6.2		70.8	28.8	18414.5		960.9	
	21	10/10/2014	521	43	0.9	60	97	0.0	13.8	2.2	3496.9	4200.0		10.2	
	22	10/10/2014	730	40	1.3	80	97	0.0	1.8	3979.4	952.6	170.5		66.2	

								CSI Sampler (ug/m3)		Deposition Plates (ug/m2)					
	Sample			Speed	WS	WD	RH	Upwind	Downwind	Upwind			Downwind		
New sampling configuration	Set	Date	Time	(mph)	(m/s)	(deg)	(%)	15 m	15 m	5 m	5 m	5 m	5 m	5 m	5 m
Winds across tracks	25	10/13/2014	947	41	2.5	85	87	0.8	22.0	11.7	423.7	42.5	5514.2	252.9	

								CSI Sampler (ug/m3)		Deposition Plates (ug/m2)					
	Sample			Speed	WS	WD	RH	East	West	East of Tracks			West of Tracks		
Winds parallel to tracks	Set	Date	Time	(mph)	(m/s)	(deg)	(%)	40 m	40 m	30 m	15 m	5 m	5 m	15 m	30 m
	15	10/6/2014	1800	45	1.5	340	54	35			1167.6		63.4	78.7	2859.4

								CSI Sampler (ug/m3)		Deposition Plates (ug/m2)					
	Sample			Speed	WS	WD	RH	East	West	East of Tracks			West of Tracks		
New sampling configuration	Set	Date	Time	(mph)	(m/s)	(deg)	(%)	15 m	15 m	5 m	5 m	5 m	5 m	5 m	5 m
Winds parallel to tracks	24	10/12/2014	1258	50	1.2	160	83	54.9		547.7	155.0	158.2	142.2	71.7	

								CSI Sampler (ug/m3)		Deposition Plates (ug/m2)					
	Sample			Speed	WS	WD	RH	Upwind	Downwind	Upwind			Downwind		
Freight Train	Set	Date	Time	(mph)	(m/s)	(deg)	(%)	40 m	40 m	30 m	15 m	5 m	5 m	15 m	30 m
Winds across tracks	7	10/3/2014	1627	46	0.8	230	29		0.3		108.9		3206.2	896.9	24.9

								CSI Sampler (ug/m3)		Deposition Plates (ug/m2)					
	Sample			Speed	WS	WD	RH	East	West	East of Tracks			West of Tracks		
Freight Train	Set	Date	Time	(mph)	(m/s)	(deg)	(%)	40 m	40 m	30 m	15 m	5 m	5 m	15 m	30 m
Winds parallel to tracks	14	10/6/2014	1613	38	2	340	49	5.2			4.3		177.5	282.5	51.4

6. KEY FINDINGS

The overall sampling program was conducted during the fall of 2014. Throughout the preparatory process, a key objective was to have a monitoring system in place before the weather patterns changed from the dry summer to wet weather patterns in order to measure fugitive coal dust when they would not be mitigated by precipitation and/or high humidity. While the first half of October had favorable (dry) conditions for the study, the weather patterns shifted mid-month with a change to a rainy pattern for the latter half of the month.

The principal challenge of the study design was to attempt to measure coal dust from passing coal trains from fixed ground-based samplers located along the tracks. This operational parameter necessitated using a sampling and analysis methodology that relied on identifying individual particles collected during the train passage.

Key findings of the study can be summarized as follows:

- No coal dust was visible to the technicians in the study area, including any form of deposition on the sampling support equipment. The largest particle collected by any of the deposition plates had a diameter of 97 µm (about the diameter of a human hair), and only nine coal-like particles with diameters greater than 50 µm were identified during analysis. The largest coal-like particle identified by the CSI air sampler was 58 µm.
- Coal-like particle deposition concentrations, based on the upwind/downwind deposition plates located 15 meters from the track, averaged 400 $\mu g/m^2$ upwind and 890 $\mu g/m^2$ downwind on average per coal train. Based on the collected data, the bulk of these concentrations appear to be fugitive coal dust from the coal cars, as coal-like concentrations for deposition plates collected during non-coal train passage were notably lower (averaging 28 $\mu g/m^2$). While detectable concentrations were obtained, the measured deposition values are consistent with the lack of visual evidence of coal residual in the area.
- Air concentrations of coal-like particles greater than 3 µm, measured from samplers located 40 meters downwind from the track, averaged 11.3 $\mu g/m^3$ per coal train, compared to 0.6 $\mu g/m^3$ from similarly placed upwind samplers.
- The collected data indicate that there is train-to-train variability in the amount of coal emitted, with some coal trains showing concentrations similar to those measured for non-coal trains.

In addition to the above, the following observations were made:

- As discussed in Section 5, the usefulness of the DRX data was compromised to a significant degree by the high humidity conditions associated with season in which the study occurred and possibly inherent to the site itself. Use of the DRX in future studies should be restricted to applications that are at lower humidity, or different (and more costly) instrumentation should be used to measure the size-segregated data across varying humidity conditions.
- The use of the deposition plates successfully achieved the study goal of identifying coal dust specifically during the passage of a coal train; however, little material was collected from the approximately two loaded coal trains per day that passed by the monitoring site. While the data collected indicate that some coal particle deposition occurred, quantifying the results at the concentrations observed is somewhat problematic because a few relatively large particles collected during some sampling events can significantly affect

the interpreted results. Even if samples were combined, the total particle count is still small due to low deposition rates, which limits the quantitative conclusions that can be drawn from the data.

- The Air-O-Cell CSI method of sampling provided the best means of identifying coal-like particles given the limited amount of fugitive coal dust from the rail coal hauling operations. Given the high particle resolution for the short duration of sampling, use of this method could be further refined to help establish the gradient of airborne coal as the distance increases from the tracks, providing more definitive information than the deposition plates.

Appendix A

Summary of Analytical Results

Air-O-Cell CSI Sampler Results in µg/m^3

Position: Down=Downwind, Up=Upwind, Parallel=Wind along tracks

Dist = Distance from tracks

Sample Set	Sample ID	Type	Position	Dist (m)	Units	WS (m/s)	RH (%)	Train Speed (mph)	Angular Coal-like	Rounded Coal-like	Unident-ified Opaque	Iron Oxide	Iron Oxide Cluster	Soot-like-Acinifor m	Quartz	Other Minerals	Total Coal	Total Iron Oxide	Total	Comment
1	D4-001	CSI	Up	40	ug/m3	0.3	75	40	0.3	4.8		22.8	0.9		0.3	430.0	5.1	23.7	459.1	
1	U4-001	CSI	Down	40	ug/m3	0.3	75	40	0.1	0.1		1.2	0.5		0.6	461.0	0.2	1.7	463.5	
3	D4-003	CSI	Down	40	ug/m3	1.0	56	53	5.9	2.7	7.4	15.4	1.6		855.6	10.6	8.6	17.0	899.2	Vehicle on dirt road during sampling
3	U4-003	CSI	Up	40	ug/m3	1.0	56	53	0.2	0.2	0.2	0.6			0.1	1.3	0.4	0.6	2.6	
6	D4-006	CSI	Up	40	ug/m3	2.0	70	53	0.7	1.2		2.8	3.5			1.3	1.9	6.3	9.5	
6	U4-006	CSI	Down	40	ug/m3	2.0	70	38	0.6	4.6	0.2	1.2	0.5	7.5		1.4	5.2	1.7	16.0	
7	D4-007	CSI	Down	40	ug/m3	0.8	29	46	0.3	0.1		0.3			0.2	50.0	0.4	0.3	50.9	
12	U4-012	CSI	Up	40	ug/m3	2.0	49	37								2.3	0	0.0	2.3	Sampler apparently did not run
12	D4-012	CSI	Down	40	ug/m3	2.0	49	37		0.5	0.5	88.9	9.9		0.1	77.1	0.5	98.8	177.0	
13	D4-013	CSI	Up	40	ug/m3	1.0	89	44	0.5	0.1		1.8			6.2	10.8	0.6	1.8	19.4	
14	D4-014	CSI	Parallel	40	ug/m3	2.0	49	38	0.7	0.4	0.4	2.2	3.0	1.2	0.2	1.3	1.1	5.2	9.4	
14	U4-014	CSI	Parallel	40	ug/m3	2.0	49	38	0.6	0.0		0.3			4.8	1.2	0.63	0.3	6.9	Sampler apparently did not run
15	D4-015	CSI	Parallel	40	ug/m3	1.5	54	41	14	1.1		30.8	4.2		0.6	0.4	15.1	35.0	51.1	
15	U4-015	CSI	Parallel	40	ug/m3	1.5	54	41	0.01							4.3	0.01	0.0	4.3	Sampler apparently did not run
18	D4-018	CSI	Up	40	ug/m3	0.9	87	43	0.5	2.0		5.5	0.7	0.4		6.9	2.5	6.2	16.0	
18	U4-018	CSI	Down	40	ug/m3	0.9	87	43								11.3	0	0.0	11.3	Sampler apparently did not run
21	D4-021	CSI	Up	40	ug/m3	0.9	97	43	0.1	0.0						0.6	0.1	0.0	0.7	
21	U4-021	CSI	Down	40	ug/m3	0.9	97	43	1.5	18.1		11.7	2.1	0.2		1.2	19.6	13.8	34.8	Large coal particle captured (44 um)
22	D4-022	CSI	Up	40	ug/m3	1.3	97	40	0.0	0.1				0.1		6.9	0.1	0.0	7.1	
22	U4-022	CSI	Down	40	ug/m3	1.3	97	40	0.2	22.5		1.8			0.6	4.0	22.7	1.8	29.1	Large coal particle captured (58 um)
24	D2-024	CSI	Parallel	15	ug/m3	1.2	83	48	5.67	1.1	1.4	45.5	9.4		0.8	0.4	6.76	54.9	64.3	
24	U2-024	CSI	Blank	15	ug/m3	1.2	83	48	0.001			0.3			1.8	10.6	0.001	0.3	12.7	Sampler did not run
25	D2-025	CSI	Up	15	ug/m3	2.5	87	43	0.26	0.2		0.2	0.6	1.0	0.9	6.1	0.41	0.8	9.2	
25	U2-025	CSI	Down	15	ug/m3	2.5	87	43	26.1	0.4	0.5	10.1	11.9	0.5	0.3	1.8	26.54	22.0	51.7	

Air-O-Cell CSI Sampler Results in particles/m^3

Position: Down=Downwind, Up=Upwind, Parallel=Wind along tracks

Dist = Distance from tracks

Sample Set	Sample ID	Type	Position	Dist (m)	Units	WS (m/s)	RH (%)	Train Speed (mph)	Angular Coal-like	Rounded Coal-like	Unident-ified Opaque	Iron Oxide	Iron Oxide Cluster	Soot-like-Acinifor m	Quartz	Other Minerals	Total Coal	Total Iron Oxide	Total	Comment
1	D4-001	CSI	Up	40	P/m3	0.3	75	40	833.3	1250.0		2083.3	208.3		208.3	5416.7	2083	2291.6	10000	
1	U4-001	CSI	Down	40	P/m3	0.3	75	40	868.1	347.2	173.6	3993.1	173.6		347.2	3125.0	1215	4166.7	9028	
3	D4-003	CSI	Down	40	P/m3	1.0	56	53	2725	817	2180	5450	272		1907	4905	3542	5722.0	18256	
3	U4-003	CSI	Up	40	P/m3	1.0	56	53	163	488	349	349	23	23	558	2721	651	372.0	4674	
6	D4-006	CSI	Up	40	P/m3	2.0	70	38	3324	1995	665	6317	1995			2992	5319	8311.2	17287	
6	U4-006	CSI	Down	40	P/m3	2.0	70	38	3491	6483	2493	4488	997	1496		4987	9973	5485.3	24435	
7	D4-007	CSI	Down	40	P/m3	0.8	29	46	553	221	332	442			111	3648	774	442.0	5307	
12	U4-012	CSI	Up	40	P/m3	2.0	49	37			20					153	0	0.0	173	Sampler apparently did not run
12	D4-012	CSI	Down	40	P/m3	2.0	49	37		1562	7028	23428	2343		781	6247	1562	25771.0	41389	
13	D4-013	CSI	Up	40	P/m3	1.0	89	44	776	621		1242			931	8692	1397	1241.7	12262	
14	D4-014	CSI	Parallel	40	P/m3	2.0	49	38	1674	558	1563	4353	223	335	223	1116	2232	4576.0	10045	
14	U4-014	CSI	Parallel	40	P/m3	2.0	49	38	19	29		10			48	86	48	10.0	192	Sampler apparently did not run
15	D4-015	CSI	Parallel	40	P/m3	1.5	54	41	9601	1130	1130	31627	1130		2259	2259	10731	32757.0	49136	
15	U4-015	CSI	Parallel	40	P/m3	1.5	54	41	12			36			12	349	12	36.0	409	Sampler apparently did not run
18	D4-018	CSI	Up	40	P/m3	0.9	87	43	1042	651	521	1563	130	130		2344	1693	1693.0	6381	
18	U4-018	CSI	Down	40	P/m3	0.9	87	43								56	0	0.0	56	Sampler apparently did not run
21	D4-021	CSI	Up	40	P/m3	0.9	97	43	648	748	598	50		249		150	1396	50	2443	
21	U4-021	CSI	Down	40	P/m3	0.9	97	43	3491	1496	748	6732	499	249		748	4987	7231	13963	
22	D4-022	CSI	Up	40	P/m3	1.3	97	40	332	1108	443	55		388		499	1441	55	2826	
22	U4-022	CSI	Down	40	P/m3	1.3	97	40	1496	1828		3491		166	166	831	3324	3491	7979	
24	D2-024	CSI	Parallel	15	P/m3	1.2	83	48	5682	1420	473	24621	1894		1420	1420	7102	26515	36930	
24	U2-024	CSI	Blank	15	P/m3	1.2	83	48	10			30			30	172	10	30	242	Sampler did not run
25	D2-025	CSI	Up	15	P/m3	2.5	87	43	748	873	499	748	249	374	748	1870	1621	997	6109	
25	U2-025	CSI	Down	15	P/m3	2.5	87	43	5984	1995	499	19947	1496	499	499	1995	7979	21443	32914	

Deposition Plate Results in μg/m^2

Position: Down=Downwind, Up=Upwind, Parallel=Wind along tracks

Dist = Distance from tracks

Sample Set	Sample ID	Type	Position	Dist (m)	Units	WS (m/s)	RH (%)	Train Speed (mph)	Angular Coal-like	Rounded Coal-like	Unidentified Opaque	Iron Oxide	Iron Oxide Cluster	Soot-like-Aciniform	Quartz	Other Minerals	Total Coal	Total Iron Oxide	Total	Comment
1	D3-001	Plate	Up	30	ug/m2	0.3	75	40	13.6	4.7	0.1	80.9				1710.6	18.3	80.9	1809.9	
1	D2-001	Plate	Up	15	ug/m2	0.3	75	40	12.3	18.8	0.8	16.6			369.4	943.8	31.1	16.6	1361.7	
1	U2-001	Plate	Down	15	ug/m2	0.3	75	40	25.2	3.2	2.4	113.8				5484.0	28.4	113.8	5628.6	
1	D1-001	Plate	Up	5	ug/m2	0.3	75	40	36.7	3.0	13.8	231.4			578.8	4186.3	39.7	231.4	5050.0	
3	D3-003	Plate	Down	30	ug/m2	1.0	56	53	25.2	67.4	1.8	28.9			38.0	535.6	92.6	28.9	696.8692	
3	D2-003	Plate	Down	15	ug/m2	1.0	56	53	14.5	3.0	4.3	90.2			534.0	15092.1	17.5	90.2	15738.11	
3	U2-003	Plate	Up	15	ug/m2	1.0	56	53	2.8	201.5	0.2	22.5			178.2	1856.2	204.3	22.5	2261.354	
3	D1-003	Plate	Down	5	ug/m2	1.0	56	53	0.9	2.0		16.9			9924.6	1046.2	2.9	16.9	10990.6	
6	D3-006	Plate	Up	30	ug/m2	2.0	70	38	19.8	25.4	0.2	179.1			5632.8	3894.2	45.2	179.1	9751.5	
6	D2-006	Plate	Up	15	ug/m2	2.0	70	38	22.9	98.6	8.0	371.1			543.4	1174.4	121.5	371.1	2218.4	
6	U2-006	Plate	Down	15	ug/m2	2.0	70	38	4.7	96.8	1.2	36.3			1295.6	864.6	101.5	36.3	2299.2	
6	D1-006	Plate	Up	5	ug/m2	2.0	70	38	101.0	1246.3	3800.3	44.6			125.0	570.8	1347.3	44.6	5888.0	Captured 65 um coal particle
7	D3-007	Plate	Down	30	ug/m2	0.8	29	46	10.9	4.6	5.5	24.9			10.6	423.1	15.5	24.9	479.6	
7	D2-007	Plate	Down	15	ug/m2	0.8	29	46	2.4	39.7	1.6	896.9			8.4	752.5	42.1	896.9	1701.5	
7	U2-007	Plate	Up	15	ug/m2	0.8	29	46	1.6	16.2	3.4	108.9			33.8	620.6	17.8	108.9	784.5	
7	D1-007	Plate	Down	5	ug/m2	0.8	29	46	8.5	2.6	0.1	3206.2			171.4	5171.9	11.1	3206.2	8560.7	
12	D3-012	Plate	Down	30	ug/m2	2.0	49	37	71.8	73.8	3.3	72.0			163.6	1560.2	145.6	72.0	1944.7	
12	D2-012	Plate	Down	15	ug/m2	2.0	49	37	933	17.7	1.3	146.8			730.0	1034.2	950.7	146.8	2863.0	Captured 56 um coal particle
12	D1-012	Plate	Down	5	ug/m2	2.0	49	37	426.5		94.2	43.4	4269.5		430.0	3079.4	426.5	4312.9	8343.0	
13	D3-013	Plate	Up	30	ug/m2	1.0	89	44	41.5	106.7	5.3	572.6			354.2	1259.4	148.2	572.6	2339.7	
13	D2-013	Plate	Up	15	ug/m2	1.0	89	44	13.8	120.5	11.3	168.3			59.4	22327.3	134.3	168.3	22700.6	
13	U2-013	Plate	Down	15	ug/m2	1.0	89	44	44.7	75.6	1.1	96.6				1655.8	120.3	96.6	1873.8	
13	D1-013	Plate	Up	5	ug/m2	1.0	89	44	652.2	88.8	1.5	58.5		24.4	887.2	2330.2	741.0	58.5	4042.8	Captured 58 um coal particle
14	D3-014	Plate	Parallel	30	ug/m2	2.0	49	38	1.7	59.0	0.4	51.4			106.4	715.4	60.7	51.4	934.3	
14	D2-014	Plate	Parallel	15	ug/m2	2.0	49	38	8.4	8.1	4.3	282.5			80.6	706.3	16.5	282.5	1090.2	
14	U2-014	Plate	Parallel	15	ug/m2	2.0	49	38	21.3	4.0	7.1	4.3			1561.2	2471.2	25.3	4.3	4069.1	
14	D1-014	Plate	Parallel	5	ug/m2	2.0	49	38	35.8	0.5	0.8	177.5			1270.4	508.7	36.3	177.5	1993.7	
15	D3-015	Plate	Parallel	30	ug/m2	1.5	54	41	31.5	6.8	0.1	2859.4			90.8	196.9	38.3	2859.4	3185.5	
15	D2-015	Plate	Parallel	15	ug/m2	1.5	54	41	49.1	7.7	122.5	74.8			14.4	864.6	56.8	74.8	1133.1	
15	U2-015	Plate	Parallel	15	ug/m2	1.5	54	41	30.6	2.7	49.1	932.9	234.7		3174.8	5204.0	33.3	1167.6	9628.8	
15	D1-015	Plate	Parallel	5	ug/m2	1.5	54	41		155.9	15.9	63.4			2814.2	433.7	155.9	63.4	3483.1	

Deposition Plate Results in µg/m^2 (continued)

Position: Down=Downwind, Up=Upwind, Parallel=Wind along tracks Dist = Distance from tracks

Sample Set	Sample ID	Type	Position	Dist (m)	Units	WS (m/s)	RH (%)	Train Speed (mph)	Angular Coal-like	Rounded Coal-like	Unidentified Opaque	Iron Oxide	Iron Oxide Cluster	Soot-like-Aciniform	Quartz	Other Minerals	Total Coal	Total Iron Oxide	Total	Comment
18	D3-018	Plate	Up	30	ug/m2	0.9	87	43			18.2	70.8				545.6	0	70.8	634.6	
18	D2-018	Plate	Up	15	ug/m2	0.9	87	43		2233.5	322.3	18.2	10.6			221.7	2233.5	28.8	2806.3	One single large coal particle (89 um)
18	U2-018	Plate	Down	15	ug/m2	0.9	87	43	15.5	6918.9	15.7	960.9			4481.4	108.3	6934.4	960.9	12500.7	Captured 97 um coal particle
18	D1-018	Plate	Up	5	ug/m2	0.9	87	43	1305.2	94.7	6.2	18414.5			4202.6	4664.8	1399.9	18414.5	28688.0	
21	D3-021	Plate	Up	30	ug/m2	0.9	97	43	11.7		7.8	2.2			812.8	7392.1	11.7	2.2	8226.6	
21	D2-021	Plate	Up	15	ug/m2	0.9	97	43	8.7	8.3	9.4	3496.9		0.3		5833.5	17.0	3496.9	9357.1	
21	U2-021	Plate	Down	15	ug/m2	0.9	97	43	1409.3	75.5	1.2	10.2			1042.6	2716.9	1484.8	10.2	5255.7	Captured 72 um coal particle
21	D1-021	Plate	Up	5	ug/m2	0.9	97	43	40.3	0.5	0.3	4200.0				3441.2	40.8	4200.0	7682.3	
22	D3-022	Plate	Up	30	ug/m2	1.3	97	40	15.0	61.7	0.8	3679.4		0.8	1116.8	2297.5	76.7	3679.4	7172.0	
22	D2-022	Plate	Up	15	ug/m2	1.3	97	40	41.1	14.6	296.6	936.0	16.6		1665.6	7458.5	55.7	952.6	10429.0	
22	U2-022	Plate	Down	15	ug/m2	1.3	97	40	0.2	378.9	1.8	66.2			4.6	19533.7	379.1	66.2	19985.4	
22	D1-022	Plate	Up	5	ug/m2	1.3	97	40	22.1	9.5	2.6	170.5			728.0	3695.2	31.6	170.5	4627.9	
24	D1-024	Plate	Parallel	5	ug/m2	1.2	83	48	34.1	12.8		547.7			14.8	1871.5	46.9	547.7	2480.9	
24	D1-024b	Plate	Parallel	5	ug/m2	1.2	83	48	63.1	1.0	0.5	153.2	1.8		105.6	497.1	64.1	155.0	822.3	Captured 58 um coal particle
24	D1-024c	Plate	Parallel	5	ug/m2	1.2	83	48		44.9	5.5	158.2				577.1	44.9	158.2	785.7	
24	U1-024	Plate	Parallel	5	ug/m2	1.2	83	48	4.6	0.9		142.2			96.0	1713.8	5.5	142.2	1957.5	
24	U1-024b	Plate	Parallel	5	ug/m2	1.2	83	48			5.5	71.7			47.6	6478.1	0	71.7	6602.9	
25	D1-025	Plate	Up	5	ug/m2	2.5	87	43	20.4	2.3	145.5	11.7			762.4	1481.9	22.7	11.7	2424.2	
25	D1-025b	Plate	Up	5	ug/m2	2.5	87	43	3.3	6.3	2.0	423.7			168.6	4166.7	9.6	423.7	4770.6	
25	D1-025c	Plate	Up	5	ug/m2	2.5	87	43	60.8	29.8	2.8	42.5			2.0	3572.7	90.6	42.5	3710.6	
25	U1-025	Plate	Down	5	ug/m2	2.5	87	43	2165.1	425.8	0.4	5514.2			405.6	253.3	2590.9	5514.2	8764.4	Captured 84 um coal particle
25	U1-025b	Plate	Down	5	ug/m2	2.5	87	43	3	56.4	0.1	252.9			4.4	458.8	59.4	252.9	775.6	
26	D1-026 A	Plate	Blank	5	ug/m2						3.1	121.5				731.5	0	121.5	856.1	
26	D1-026 B	Plate	Blank	5	ug/m2						3.0					120.4	0	0.0	123.4	
26	D1-026 C	Plate	Blank	5	ug/m2						2.5	49.8				154.0	0	49.8	206.3	
26	U1-026	Plate	Blank	5	ug/m2						1723.8	7596.3			10059.4	9247.7	0	7596.3	28627.2	
26	U1-026 b	Plate	Blank	5	ug/m2						66.3	14.2			1563.4	1228.5	0	14.2	2872.4	
	Water Blank		Water Blank		ug/m2					0.3	3.7	2.5				478.5	0.3	2.5	485.0	

Deposition Plate Results in particles/m^2

Position: Down=Downwind, Up=Upwind, Parallel=Wind along tracks

Dist = Distance from tracks

Sample Set	Sample ID	Type	Position	Dist (m)	Units	WS (m/s)	RH (%)	Train Speed (mph)	Angular Coal-like	Rounded Coal-like	Unidentified Opaque	Iron Oxide	Iron Oxide Cluster	Soot-like-Aciniform	Quartz	Other Minerals	Total Coal	Total Iron Oxide	Total	Comment
1	D3-001	Plate	Up	30	P/m2	0.3	75	40	32625.8	20391.1	4078.2	12234.7				134581.6	53017	12235	203912	
1	D2-001	Plate	Up	15	P/m2	0.3	75	40	45572.6	51269.2	22786.3	11393.2			5696.6	148111.0	96842	11393	284829	
1	U2-001	Plate	Down	15	P/m2	0.3	75	40	52950.1	29416.7	29416.7	17650.0				164733.7	82367	17650	294167	
1	D1-001	Plate	Up	5	P/m2	0.3	75	40	44073.5	18888.6	12592.4	31481.1			18888.6	188886.4	62962	31481	314811	
3	D3-003	Plate	Down	30	P/m2	1.0	56	53	25122	25122	14355	28711			7178	39477	50244	28711	139965	
3	D2-003	Plate	Down	15	P/m2	1.0	56	53	26782	16069	16069	32139			16069	160694	42851	32139	267822	
3	U2-003	Plate	Up	15	P/m2	1.0	56	53	22786	51269	11393	22786			22786	153808	74055	22786	284828	
3	D1-003	Plate	Down	5	P/m2	1.0	56	53	14355	7178		10767			10767	50244	21533	10767	93311	
6	D3-006	Plate	Up	30	P/m2	2.0	70	38	9832	24581	9832	29497			29497	142570	34414	29497	245811	
6	D2-006	Plate	Up	15	P/m2	2.0	70	38	40438	50547	10109	15164			5055	131422	90985	15164	252735	
6	U2-006	Plate	Down	15	P/m2	2.0	70	38	39151	52201	19576	32626			19576	163129	91352	32626	326258	
6	D1-006	Plate	Up	5	P/m2	2.0	70	38	79752	53168	26584	46522			6646	119628	132920	46522	332300	
7	D3-007	Plate	Down	30	P/m2	0.8	29	46	14355	17944	14355	10767			14355	107665	32299	10767	179441	
7	D2-007	Plate	Down	15	P/m2	0.8	29	46	7178	10767	3589	10767			3589	82543	17945	10767	118433	
7	U2-007	Plate	Up	15	P/m2	0.8	29	46	14355	3589	14355	25122			3589	111254	17944	25122	172264	
7	D1-007	Plate	Down	5	P/m2	0.8	29	46	13803	18404	4601	27606			23005	142633	32207	27606	230052	
12	D3-012	Plate	Down	30	P/m2	2.0	49	37	4687	14062	23437	18750			9375	149999	18749	18750	220310	
12	D2-012	Plate	Down	15	P/m2	2.0	49	37	68723	76358	45815	45815			7636	137445	145081	45815	381792	
12	D1-012	Plate	Down	5	P/m2	2.0	49	37	33967		81521	27174	13587		20380	163042	33967	40761	339671	
13	D3-013	Plate	Up	30	P/m2	1.0	89	44	61087	45815	15272	38179			38179	183260	106901.7	38179	381791.8	
13	D2-013	Plate	Up	15	P/m2	1.0	89	44	50547	15164	25274	35383			5055	121313	65711	35383	252735	
13	U2-013	Plate	Down	15	P/m2	1.0	89	44	35888	59814	17944	29907				155517	95702	29907	299070	
13	D1-013	Plate	Up	5	P/m2	1.0	89	44	43648	24249	19399	33949		9700	9700	101846	67897	33949	242489	
14	D3-014	Plate	Parallel	30	P/m2	2.0	49	38	11215	16823	11215	28038			39253	173835	28038	28038	280379	
14	D2-014	Plate	Parallel	15	P/m2	2.0	49	38	41183	11767	11767	23533			29417	176500	52950	23533	294167	
14	U2-014	Plate	Parallel	15	P/m2	2.0	49	38	41410	18404	18404	18404			13803	124229	59814	18404	234654	
14	D1-014	Plate	Parallel	5	P/m2	2.0	49	38	34508	6902	13803	34508			34508	220852	41410	34508	345081	
15	D3-015	Plate	Parallel	30	P/m2	1.5	54	41	4934	4934	4934	49342			9868	172696	9868	49342	246708	
15	D2-015	Plate	Parallel	15	P/m2	1.5	54	41	9375	14062	46875	18750			9375	107812	23437	18750	206249	
15	U2-015	Plate	Parallel	15	P/m2	1.5	54	41	14062	14062	42187	28125	9375		18750	107812	28125	37500	234373	
15	D1-015	Plate	Parallel	5	P/m2	1.5	54	41		18750	23437	18750			14062	121874	18750	18750	196873	

Deposition Plate Results in particles/m^2 (continued)

Position: Down=Downwind, Up=Upwind, Parallel=Wind along tracks Dist = Distance from tracks

Sample Set	Sample ID	Type	Position	Dist (m)	Units	WS (m/s)	RH (%)	Train Speed (mph)	Angular Coal-like	Rounded Coal-like	Unidentified Opaque	Iron Oxide	Iron Oxide Cluster	Soot-like-Aciniform	Quartz	Other Minerals	Total Coal	Total Iron Oxide	Total	Comment
18	D3-018	Plate	Up	30	P/m2	0.9	87	43			51448	40015				194358	0	40015	285821	
18	D2-018	Plate	Up	15	P/m2	0.9	87	43		4687	56250	14062	4687			126562	4687	18749	206248	
18	U2-018	Plate	Down	15	P/m2	0.9	87	43	71777	123046	20508	82031			41015	174315	194823	82031	512692	
18	D1-018	Plate	Up	5	P/m2	0.9	87	43	81565	130503	48939	130503			97878	326258	212068	130503	815646	
21	D3-021	Plate	Up	30	P/m2	0.9	97	43	45492		10109	20219			5055	171860	45492	20219	252735	
21	D2-021	Plate	Up	15	P/m2	0.9	97	43	41183	17650	17650	29417		5883		182384	58833	29417	294167	
21	U2-021	Plate	Down	15	P/m2	0.9	97	43	66256	22085	11043	22085			16564	138032	88341	22085	276065	
21	D1-021	Plate	Up	5	P/m2	0.9	97	43	33128	11043	22085	44170				165639	44170	44170	276065	
22	D3-022	Plate	Up	30	P/m2	1.3	97	40	35185	49259	7037	56296		7037	28148	168887	84443	56296	351847	
22	D2-022	Plate	Up	15	P/m2	1.3	97	40	52012	36409	15604	20805	5201		5201	124829	88421	26006	260061	
22	U2-022	Plate	Down	15	P/m2	1.3	97	40	9444	51944	9444	14167			4722	146387	61388	14167	236108	
22	D1-022	Plate	Up	5	P/m2	1.3	97	40	17650	23533	11767	5883			23533	211801	41183	5883	294167	
24	D1-024	Plate	Parallel	5	P/m2	1.2	83	48	39876	35445		44307			8861	88613	75321	44307	217102	
24	D1-024b	Plate	Parallel	5	P/m2	1.2	83	48	67921	16823	16823	112151	5608		5608	50468	84744	117759	275402	
24	D1-024c	Plate	Parallel	5	P/m2	1.2	83	48		14062	9375	18750				56250	14062	18750	98437	
24	U1-024	Plate	Parallel	5	P/m2	1.2	83	48	28711	10767		3589			7178	71777	39478	3589	122022	
24	U1-024b	Plate	Parallel	5	P/m2	1.2	83	48			4687	14062			9375	107812	0	14062	135936	
	Water Blank		Water Blank		P/m2					3589	10767	3589				32300	3589	3589	50245	
25	D1-025	Plate	Up	5	P/m2	2.5	87	43	78302	45676	78302	19576			26101	78302	123978	19576	326259	
25	D1-025b	Plate	Up	5	P/m2	2.5	87	43	36809	50612	36809	32208			13803	59814	87421	32208	230055	
25	D1-025c	Plate	Up	5	P/m2	2.5	87	43	75918	89721	55213	20705			6902	96623	165639	20705	345082	
25	U1-025	Plate	Down	5	P/m2	2.5	87	43	58995	44246	9832	29497			14749	88492	103241	29497	245811	
25	U1-025b	Plate	Down	5	P/m2	2.5	87	43	35888	17944	4486	94207			13458	58319	53832	94207	224302	
26	D1-026 A	Plate	Blank	5	P/m2						18750	28125				93749	0	28125	140624	
26	D1-026 B	Plate	Blank	5	P/m2						28125					79687	0	0	107812	
26	D1-026 C	Plate	Blank	5	P/m2						18750	28125				117187	0	28125	164062	
26	U1-026	Plate	Blank	5	P/m2						74013	24671			98684	419405	0	24671	616773	
26	U1-026 b	Plate	Blank	5	P/m2						28125	4687			4687	126562	0	4687	164061	

Appendix B

Sample EAA Analytical Report – Optical Microscopy

Optical Microscopy Air Sample - Summary Report

Air-O-Cell CSI Cassette - Size Range - Particles >3.0um

Client Name :	T& B Systems	Analysis Date :	2/2/15
Contact :	Mr. Bob Baxter	EAA Project # :	14-0402
Client Project# :	4300	EAA Sample # :	U4-006
Client Sample # :	U4-006		
Sample Description :	Not specified	Fields Counted / passes :	2
Analysis Method :	Bright Field/Polarized Light Microscopy	Field area cted (mm^2) :	0.640
Analysis Magnifcation :	600	Field area (mm^2) :	15.0
Scale (µm/div.) :	3	% of sample counted :	4%
Total particles counted :	49	Particles / mm^2 :	77
Sample volume (m^3) :	0.047	Particles / sample :	1148
		Estimated Particles / m^3 :	24435

Particle Classification	Part. Cted	Mean (um)	Num. %	* Mass %	* S.G.	Particles / Sample	Particles / m^3	Mass ug/m^3
Angular Coal-like	7	5.7	14.3%	7.3%	1.3	164	3491	0.43
Rounded Coal-like	13	6.9	26.5%	25.0%	1.3	305	6483	1.47
Unidentified opaque	5	4.9	10.2%	3.1%	1.0	117	2493	0.15
Iron oxide	9	4.6	18.4%	18.3%	4.0	211	4488	0.91
Iron oxide cluster	2	7.9	4.1%	7.5%	3.0	47	997	0.76
Soot-like-Aciniform	3	16.0	6.1%	21.2%	1.0	70	1496	3.22
Quartz								
Other Minerals	10	5.3	20.4%	17.7%	2.5	234	4987	0.99
Total counted :	49					Total particle mass (ug/m^3) :		7.9

** The calculated mass/m^3 is based on estimates of the average particle size & specific gravity (S.G.) and should be used as a rough comparative estimates.*

Definitions

Angular Coal-like :	Angular brown/orange particles with uniform interior texture and edges consistent with a coal standard.
Rounded Coal-like :	Rounded brown/orange particles with uniform interior texture consistent with a coal standard
Iron oxide :	Brown to orange tinged individual particles with irregular and pitted morphology consistent with corrosion.
Iron Oxide -" cluster" :	Clusters of brown to orange tinged particles with irregular and pitted morphology consistent with corrosion. Clusters include an assemblage of imacted particles of similar composition. The size is estimated as the diameter of the entire cluster.
Soot-like aciniform :	Black fine particles with "aciniform" morphology consistent with vehicular diesel emissions.
Quartz :	Particles with optical polarized light characteristics of the mineral quartz.
Other minerals :	All other crystalline and non-crystalline translucent particles.

Analysis Method : Bright Field/Polarized Light Microscopy

Analyst : Daniel M. Baxter Date : 2/2/15

NUMERICAL SIZE DISTRIBUTION ANALYSIS

(Optical Microscopy - Total Sample Statistics)

Client Name: T& B Systems
Contact : Mr. Bob Baxter
Client Project# : 4300
Client Sample # : U4-006
Sample Description : Not specified
Analysis Method : Bright Field/Polarized Light Microscopy
Analysis Magnifcation : 600
Scale (µm/div.) : 3.00
Total particles counted : 49 Particles/mm^2 : 77

Analysis Date : 2/2/15
EAA Project # : 14-0402
EAA Sample # : U4-006

SIZE DISTRIBUTION STATISTICS				MORPHOLOGY STATISTICS (all particles)			
Description	**Mean**	Std.Dev.	95%CL	**Description**	**Mean**	Std.Dev.	95%CL
Arith. Mean Aerodynamic Dia.(µm)	6.4	±4.8	±1.3	Aspect Ratio	1.3	±0.44	±0.12
Arith. Mean Projected Dia.(µm)	6.2	±4.5	±1.3	Particle Sphericity	0.9	±0.09	±0.02
Median aerodynamic dia.(µm)	4.8			Particle counts / mm^2		38	
Numerical Mode (size category)	1.6			Field area counted (mm^2)		1.2800	
Skewness	3.0			Estimated particle area (mm^2)		0.00030	
Kurtosis	12.1			Area covered by particles (%)		0.0%	

Numerical Size Distribution (µm >= aerodynamic stated size)

Particle Size (µm)	**>=0.2**	**>=0.4**	**>=0.8**	**>=1.6**	**>=3.1**	**>=6**	**>=13**	**>=25**	**>=50**	**>=100**	**>=200**
Midpoint size (µm)	0.3	0.6	1.2	2	5	9	19	38	75	150	>=200
Cumulative Count	49	49	49	49	31	16	3	1			
Individual Count				18	15	13	2	1			
Individual Numerical %				36.7%	30.6%	26.5%	4.1%	2.0%			
Cumulative Numerical %				36.7%	67.3%	94%	98%	100%			

*** **Estimated Aerodynamic Mass (Volume) Distribution**

Particle Size (µm)	**>=0.2**	**>=0.4**	**>=0.8**	**>=1.6**	**>=3.1**	**>=6**	**>=13**	**>=25**	**>=50**	**>=100**	**>=200**
Individual Volume %				5.7%	15.1%	34.5%	17.1%	27.6%			
Cumulative Volume %				5.7%	20.9%	55%	72%	100%			

* All numerical size distribution statistics are based on the estimated arithmetic mean diameter.
** The largest size category is reported in bimodal distributions.
*** The estimated mass distribution is based on particle volume in each size catagory, and uses an estimate of particle specific gravity.

Statistical Parameter Definitions:

Geometric Aerodynamic Diameter	Geometric mean of feret length, width, and approximate thickness using the sphericity coefficient.
Geometric Projected Diameter	Geometric mean of particle size based on length and width and not accounting for particle thickness.
Median	Number in the middle of a distribution; that is, half the values are greater than the median, and half the values below.
Mode	Most frequently occurring size category/range in a size distribution
Skewness	Degree of symmetry of a population around its mean. Positive skewness indicates a distribution with an asymmetric tail towards more positive values. Negative skewness indicates an asymmetric tail towards more negative values.
Kurtosis	Relative peakedness or flatness of a distribution compared to the normal distribution. Positive kurtosis indicates a relatively peaked distribution. Negative kurtosis indicates a relatively flat distribution.
95% C.L.	95% Confidence Limit (i.e. probability that 95% of time the mean value will fall within the specified size range).
Aspect Ratio	Ratio of the particle longest projected length divided by the particle width
Particle Sphericity	Measure of effective particle size based on the formula (thickness ^2 / (length*width))^0.333
Roundness	Measure of the shape or irregularity of the particle = 0.07948*(perimeter)^2/area. Higher values indicate more angularity
Surface area covered	Theoretical percent area occupied by particles (projected particle area / total area examined)

Analyst : Daniel M. Baxter Date : 2/2/15

COMPOSITION SIZE & MASS DISTRIBUTION ANALYSIS
(Report Detail)

Client Name : T& B Systems
Contact : Mr. Bob Baxter
Client Project# : 4300
Client Sample # : 14-0402
Sample Description : U4-006
Analysis Method : Bright Field/Polarized Light Microscopy
Total particles counted : 49
Analysis Magnifcation : 600

Analysis Date : 02/02/15
EAA Project # : 14-0402
EAA Sample # : U4-006
Scale (µm/div.) : 3.00
Total particles counted : 49

Mineral Category	Numerical Count	Individual Count % >= stated aerodynamic size(µm) >=0.2	>=0.4	>=0.8	>=1.6	>=3.1	>=6	>=13	>=25	>=50	>=100	>=200
Angular Coal-like	7				4.1%	6.1%	4.1%					
Rounded Coal-like	13				14.3%	2.0%	6.1%	4.1%				
Unidentified opaque	5				4.1%	4.1%	2.0%					
Iron oxide	9				8.2%	8.2%	2.0%					
Iron oxide cluster	2						4.1%					
Soot-like-Aciniform	3						4.1%		2.0%			
Quartz												
Other Minerals	10				6.1%	10.2%	4.1%					

Mineral Category	Category Code	Count %	* Estimated Mass %	Mean Size (µm)	Aspect Ratio	Roundness Mean	>3.13	<3.13
Angular Coal-like	ac	14.3%	7.3%	5.7	1.21	3.58	4.14	2.18
Rounded Coal-like	rc	26.5%	25.0%	6.9	1.29	2.42	2.02	2.77
Unidentified opaque	i	10.2%	3.1%	4.9	1.40	2.04	2.21	1.80
Iron oxide	or	18.4%	18.3%	4.6	1.28	1.82	2.21	2.15
Iron oxide cluster	oc	4.1%	7.5%	7.9	1.50	2.06	2.06	
Soot-like-Aciniform	sl	6.1%	21.2%	16.0	1.24	1.38	1.38	
Quartz	q							
Other Minerals	m	20.4%	17.7%	5.3	1.25	2.50	2.72	1.98

INDIVIDUAL SIZE DISTRIBUTION COUNT DATA

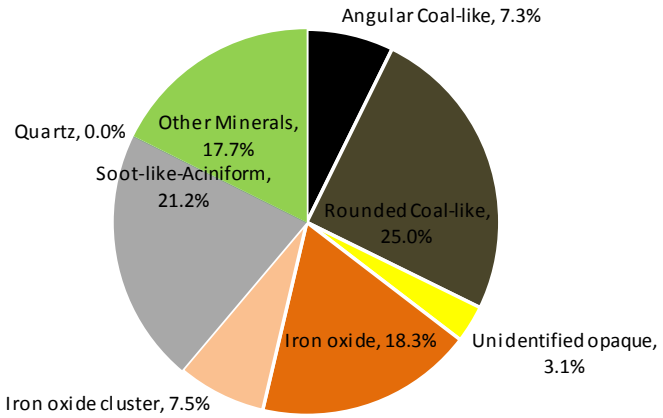
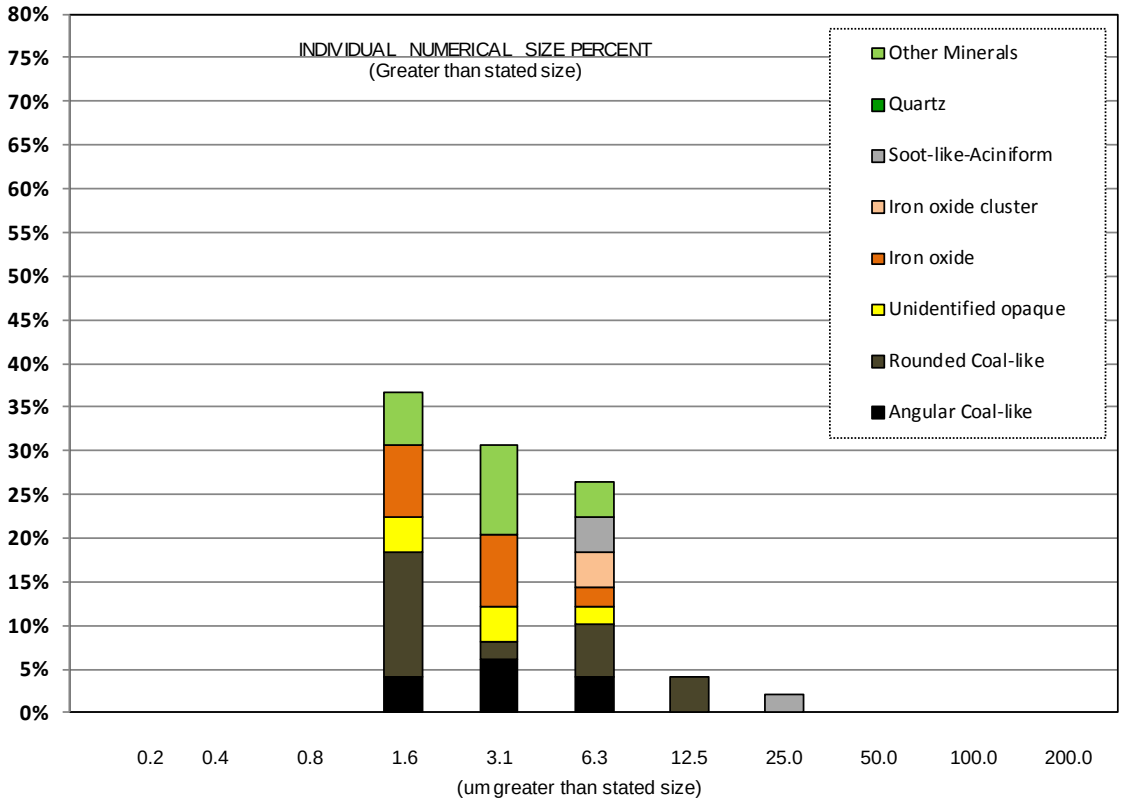
Client Name: T& B Systems
Client Project# : 4300
EAA Project # : 14-0402

Client Sample # : U4-006
EAA Sample # : U4-006

Particle Number	Particle Type	L feret (µm)	I feret (µm)	Proj. L (µm)	Thickness est. (µm)	Projected Dia.(µm)	Mean Dia.(µm)	Aspect Ratio	Round Coeff.	Particle Sphericity
1	m	3.0	3.0	3.0	3.0	3.0	3.0	1.00	1.28	1.0
2	i	3.0	3.0	3.0	3.0	3.0	3.0	1.00	2.52	1.0
3	ac	6.0	6.0	6.0	6.0	6.0	6.0	1.00	6.65	1.0
4	rc	3.0	3.0	3.0	3.0	3.0	3.0	1.00	1.39	1.0
5	rc	9.0	9.0	9.0	9.0	9.0	9.0	1.00	3.73	1.0
6	m	6.0	3.0	6.0	3.0	4.5	4.8	2.00	5.07	0.8
7	m	6.0	6.0	6.0	6.0	6.0	6.0	1.00	1.88	1.0
8	rc	24.0	9.0	24.0	9.0	16.5	17.3	2.67	1.64	0.7
9	or	6.0	6.0	6.0	6.0	6.0	6.0	1.00	1.22	1.0
10	or	3.0	3.0	3.0	3.0	3.0	3.0	1.00	0.99	1.0
11	sl	36.0	21.0	36.0	21.0	28.5	30.1	1.71	1.15	0.8
12	or	6.0	3.0	6.0	3.0	4.5	4.8	2.00	0.97	0.8
13	oc	9.0	6.0	9.0	6.0	7.5	7.9	1.50	2.19	0.9
14	rc	3.0	3.0	3.0	3.0	3.0	3.0	1.00	3.83	1.0
15	rc	3.0	1.5	3.0	1.5	2.3	2.4	2.00	6.18	0.8
16	rc	9.0	9.0	9.0	9.0	9.0	9.0	1.00	1.46	1.0
17	i	9.0	9.0	9.0	9.0	9.0	9.0	1.00	1.28	1.0
18	rc	21.0	12.0	21.0	12.0	16.5	17.4	1.75	2.26	0.8
19	or	3.0	3.0	3.0	3.0	3.0	3.0	1.00	3.36	1.0
20	rc	6.0	6.0	6.0	6.0	6.0	6.0	1.00	1.32	1.0
21	rc	3.0	3.0	3.0	3.0	3.0	3.0	1.00	1.45	1.0
22	ac	6.0	6.0	6.0	6.0	6.0	6.0	1.00	2.88	1.0
23	or	3.0	3.0	3.0	3.0	3.0	3.0	1.00	1.54	1.0
24	or	3.0	3.0	3.0	3.0	3.0	3.0	1.00	2.71	1.0
25	rc	12.0	9.0	12.0	9.0	10.5	10.9	1.33	1.69	0.9
26	i	6.0	3.0	6.0	3.0	4.5	4.8	2.00	3.68	0.8
27	ac	3.0	3.0	3.0	3.0	3.0	3.0	1.00	3.48	1.0
28	ac	3.0	3.0	3.0	3.0	3.0	3.0	1.00	0.87	1.0
29	ac	9.0	9.0	9.0	9.0	9.0	9.0	1.00	5.64	1.0
30	ac	9.0	6.0	9.0	6.0	7.5	7.9	1.50	2.15	0.9
31	sl	9.0	9.0	9.0	9.0	9.0	9.0	1.00	1.63	1.0
32	m	6.0	6.0	6.0	6.0	6.0	6.0	1.00	1.30	1.0
33	m	6.0	3.0	6.0	3.0	4.5	4.8	2.00	2.40	0.8
34	or	9.0	6.0	9.0	6.0	7.5	7.9	1.50	3.30	0.9
35	i	6.0	3.0	6.0	3.0	4.5	4.8	2.00	1.66	0.8
36	or	6.0	6.0	6.0	6.0	6.0	6.0	1.00	1.38	1.0
37	or	6.0	3.0	6.0	3.0	4.5	4.8	2.00	0.95	0.8
38	rc	3.0	3.0	3.0	3.0	3.0	3.0	1.00	0.82	1.0
39	rc	3.0	3.0	3.0	3.0	3.0	3.0	1.00	1.71	1.0
40	m	6.0	6.0	6.0	6.0	6.0	6.0	1.00	5.53	1.0
41	m	9.0	6.0	9.0	6.0	7.5	7.9	1.50	1.81	0.9
42	rc	3.0	3.0	3.0	3.0	3.0	3.0	1.00	4.03	1.0
43	sl	9.0	9.0	9.0	9.0	9.0	9.0	1.00	1.35	1.0
44	m	9.0	9.0	9.0	9.0	9.0	9.0	1.00	1.08	1.0
45	m	3.0	3.0	3.0	3.0	3.0	3.0	1.00	2.70	1.0
46	oc	9.0	6.0	9.0	6.0	7.5	7.9	1.50	1.92	0.9
47	m	3.0	3.0	3.0	3.0	3.0	3.0	1.00	1.96	1.0
48	ac	6.0	3.0	6.0	3.0	4.5	4.8	2.00	3.40	0.8
49	i	3.0	3.0	3.0	3.0	3.0	3.0	1.00	1.08	1.0
50										

Optical Microscopy -Grapical Report - Mass & Size Distribution

Client Name : T& B Systems
Contact : Mr. Bob Baxter
Client Project# : 4300
Client Sample # : U4-006
Sample Description : Not specified
Analysis Method : Bright Field/Polarized Light Microscopy

Analysis Date : 2/2/15
EAA Project # : 14-0402
EAA Sample # : U4-006

Estimated Mass %