CORPORATION OF THE CITY OF COURTENAY
COUNCIL MEETING AGENDA

Date: December 6, 2021
Time: 4:00 p.m.
Location: CVRD Civic Room, 770 Harmston Ave, Courtenay

We respectfully acknowledge that the land on which we gather is the Unceded traditional territory of the K'ómoks First Nation

AMENDED AGENDA

K'OMOKS FIRST NATION ACKNOWLEDGEMENT

5. EXTERNAL REPORTS AND CORRESPONDENCE FOR INFORMATION

6. INTERNAL REPORTS AND CORRESPONDENCE FOR INFORMATION

7. REPORTS/UPDATES FROM COUNCIL MEMBERS INCLUDING REPORTS FROM COMMITTEES

7.1. Councillor Cole-Hamilton

7.2. Councillor Frisch

7.3. Councillor Hillian

7.4. Councillor McCollum

7.5. Councillor Morin

7.6. Councillor Theos

7.7. Mayor Wells

8. RESOLUTIONS OF COUNCIL

8.1. In Camera Meeting

That a Special In-Camera meeting closed to the public will be held December 6, 2021 at the conclusion of the Regular Council Meeting pursuant to the following sub-sections of the *Community Charter*:

- 90 (1) (c) labour relations or other employee relations;
- 90 (1) (d) the security of the property of the municipality.

9. UNFINISHED BUSINESS

10. NOTICE OF MOTION

11. NEW BUSINESS

12. BYLAWS

12.1. For First, Second and Third Reading

12.1.1. City of Courtenay Fees and Charges Amendment Bylaw No. 3055, 2021 (2022 Water User Fees) 493

(A bylaw to amend City of Courtenay Fees and Charges Bylaw No. 1673, 1992, to amend the water user fees for 2022)

12.1.2. City of Courtenay Fees and Charges Amendment Bylaw No. 3056, 2021 (2022 Sanitary Sewer User Fees) 499

(A bylaw to amend City of Courtenay Fees and Charges Bylaw No. 1673, 1992, to amend the sanitary sewer user fees for 2022)

12.1.3. City of Courtenay Fees and Charges Amendment Bylaw No. 3057, 2021 (2022 Solid Waste Collection User Fees) 505

(A bylaw to amend City of Courtenay Fees and Charges Bylaw No. 1673, 1992, to amend the solid waste collection user fees for 2022)

12.2. For Third Reading

12.2.1. Zoning Amendment Bylaw No. 3021, 2021 (2099 Hawk Drive) 509

(A bylaw to amend Zoning Bylaw No. 2500, 2007 to rezone 2099 Hawk Drive from Residential One Zone (R-1) to Residential One S Zone (R-1S) to allow for a secondary suite, and that Schedule No. 8 Zoning Map be amended accordingly)

12.2.2. Zoning Amendment Bylaw No. 3043, 2021 (1544 Dingwall Road) 511

(A bylaw to amend Zoning Bylaw No. 2500, 2007, Section 8.6.1 (5) by adding "notwithstanding any provision of this bylaw, a secondary suite is a permitted use on Lot B, Section 17, Comox District, Plan EPP72243 (1544 Dingwall Road)" and renumbering accordingly)

12.3. For Final Adoption

12.3.1. Zoning Amendment Bylaw No. 3021, 2021 (2099 Hawk Drive)

(A bylaw to amend Zoning Bylaw No. 2500, 2007 to rezone 2099 Hawk Drive from Residential One Zone (R-1) to Residential One S Zone (R-1S) to allow for a secondary suite, and that Schedule No. 8 Zoning Map be amended accordingly)

See Page 509

12.3.2. Zoning Amendment Bylaw No. 3043, 2021 (1544 Dingwall Road)

(A bylaw to amend Zoning Bylaw No. 2500, 2007, Section 8.6.1 (5) by adding "notwithstanding any provision of this bylaw, a secondary suite is a permitted use on Lot B, Section 17, Comox District, Plan EPP72243 (1544 Dingwall Road)" and renumbering accordingly)

See Page 511

13. ADJOURNMENT

Minutes of a Regular Council Meeting

Meeting #: **R23/2021**
Date: **November 29, 2021**
Time: **4:04 pm**
Location: **CVRD Civic Room, 770 Harmston Ave, Courtenay and via video/audio conference**

Attending:
Mayor: **B. Wells**
Councillors: **W. Cole-Hamilton**
D. Frisch
D. Hillian
M. McCollum
W. Morin
M. Theos

Staff: **G. Garbutt, CAO**
J. Nelson, Director of Financial Services, via video/audio conference
K. O'Connell, Director of Corporate Support Services
S. Saunders, Director of Recreation, Culture & Community Services via video/audio conference
K. Shaw, Director of Public Works Services
R. Wyka, Manager of Finance, via video/audio conference
A. Berard, Manager of Financial Planning, Payroll & Business Performance, via video/audio conference
N. Borecky, Manager of Information Systems, via video/audio conference
B. Brooks, Engineering Technologist - Utilities
R. Matthews, Deputy Corporate Officer

The Mayor respectfully acknowledged the lands on which the meeting was conducted is the Unceded traditional territory of the K'ómoks First Nation.

1. ADOPTION OF MINUTES

1.1 Adopt November 15th, 2021 Regular Council meeting minutes (0570-03)

Moved By Frisch
Seconded By Cole-Hamilton

THAT the November 15th, 2021 Regular Council meeting minutes be adopted.
Carried

2. INTRODUCTION OF LATE ITEMS

3. DELEGATIONS

4. STAFF REPORTS/PRESENTATIONS

4.1 CAO and Legislative Services

4.1.1 Signing Authority Amendment (1940-01)

Moved By Hillian
Seconded By Frisch

THAT based on the November 29th, 2021 Staff Report "Signing Authority Amendment", Council approves the following individuals to be authorized as signing authorities for the City of Courtenay in regard to the following:

1. **all banking, investment and financial transactions:**

   Robert Wells, Mayor
   William Cole-Hamilton, Councillor
   David Frisch, Councillor
   Douglas Hillian, Councillor
   Melanie McCollum, Councillor
   Wendy Morin, Councillor
   Emmanuel Theos, Councillor

   Geoff Garbutt, Chief Administrative Officer
   Kate O'Connell, Director of Corporate Support Services
   Renata Wyka, Manager of Finance and or Acting Director of Financial Services
   Annie Berard, Manager of Financial Planning, Payroll and Business Performance
   Wendy Sorichta, Corporate Officer
   Rayanne Matthews, Deputy Corporate Officer

1. **land disposition, acquisition, and land title related documents - after statutory and/or Council requirements have been satisfied**:

   Director Responsible for Engineering
   Director Responsible for Development Services
   Manager Responsible for Legislative Services
   Deputy Corporate Officer

1. **grant applications**

Director Responsible for Engineering
Director Responsible for Public Works Services
Director Responsible for Recreation, Culture and Community Services; and,

THAT the Chief Administrative Officer, the Director of Financial Services, and the Director of Corporate Support Services, the Corporate Officer, and the Deputy Corporate Officer be designated as signing authorities for all documentation, including but not limited to financial documentation, land agreements, grant applications, and other agreements in accordance with, and as necessary to conduct City business.
Carried

4.1.2 Appointment - Chief Financial Officer (0155-01)

Moved By Frisch
Seconded By Cole-Hamilton

THAT in accordance with Section 149 of the *Community Charter*, Renata Wyka, Acting Director of Financial Services be appointed as the Acting Chief Financial Officer until such time as the recruitment process for a new Director of Financial Services is completed and the successful candidate has been appointed as Chief Financial Officer.
Carried

4.1.3 Lease Assignment for Lot 4, 100-20th Street - Courtenay Airpark (2380-30)

Moved By Cole-Hamilton
Seconded By McCollum

THAT based on the November 29th, 2021 staff report “Lease Assignment Agreement for Lot 4, 100-20th Street - Courtenay Airpark”, Council adopt OPTION 1 and authorize the attached lease addendum between Sealand Flight Inc. (Inc.590714), Andreas Ruttkiewicz dba: Airspeed High Utlralights, and the City of Courtenay for the property having a legal description of PID: 000-892-149, Lot 1, Section 66, Comox Land District Plan 14942 except any portion of the bed of the Courtenay River and further identified as Lot 4 on Plan VIP64872.
Carried

4.2 Public Works Services

4.2.1 Lake Trail Road Pedestrian Infrastructure Options (5420-02)

Moved By Hillian
Seconded By Frisch

THAT Council direct staff to design an active transportation facility in 2022 that meets B.C. Active Transportation (BCAT) grant funding requirements, and to further submit an application to BCAT funding once the design is complete.
Carried

4.2.2 Solid Waste Service - Cost of Service Review (5360-20)

Moved By Frisch
Seconded By Morin

THAT based on the November 29, 2021 staff report "Solid Waste Cost of Service Review", Council approve Option 1:

THAT Council direct Staff to remove multi-residential apartment and condo (complexes only) and Institutional, Commercial, and Industrial customers from the City of Courtenay solid waste collection service;

THAT Council direct Staff to provide notification of the discontinuation of solid waste collection services as of October 31, 2022 to all multi-residential apartment and condo (complexes only) and Institutional, Commercial, and Industrial customers; and,

THAT Bylaw No. 2244 City of Courtenay Refuse Materials Collection, Removal and Regulation and Bylaw No. 3022 City of Courtenay Fees and Charges - Solid Waste and Recycling be amended to reflect these changes.
Carried

4.2.3 Solid Waste Service - Request for Proposal (5360-02)

Moved By McCollum
Seconded By Frisch

THAT based on the November 29, 2021, 2021 staff report "Solid Waste Service Request for Proposal" Council approve Option 1:

THAT Council direct Staff to issue a Request for Proposal to solicit proposals for a 3 stream curbside collection service, for a five year contract with the provision for a five year extension; and,

THAT Council direct Staff to seek a memorandum of understanding between the City of Courtenay and the Town of Comox and Village of Cumberland to undertake this joint Request for Proposal with legal fees to be apportioned based on service population.
Carried

5. EXTERNAL REPORTS AND CORRESPONDENCE FOR INFORMATION

6. INTERNAL REPORTS AND CORRESPONDENCE FOR INFORMATION

6.1 Parks and Recreation Advisory Commission Meeting Minutes - September 3, 2020 & October 7, 2021

Moved By Hillian
Seconded By Frisch

THAT the Parks and Recreation Advisory Commission meeting minutes for September 3, 2020 & October 7, 2021 be received for information.
Carried

7. REPORTS/UPDATES FROM COUNCIL MEMBERS INCLUDING REPORTS FROM COMMITTEES

7.1 Councillor Cole-Hamilton

Councillor Cole-Hamilton reviewed his attendance at the following event on November 28th:

- *Community Substance Use Strategy Co-Launch with 'Walk with Me' (WWM)* event (WWM is a Comox Valley Art Gallery community action research project focused on addressing the human dimensions of the toxic drug poisoning crisis).This event marked the launch of the Community Substance Use Strategy Committee's Phase One Report.

7.2 Councillor Frisch

Councillor Frisch reviewed his attendance at the following event:

- Comox Valley Kiwanis Village Board meeting re: “The Junction” (988 - 8th Street)

7.3 Councillor Hillian

Councillor Hillian reviewed his attendance at the following event:

- Community to Community Forum hosted in partnership with K’ómoks First Nation and Comox Valley Regional District

7.4 Councillor Morin

Councillor Morin mentioned that the Comox Valley Arts has begun their Community Arts Roundtables; upcoming sessions and schedule can be found on the Comox Valley Arts website.

7.5 Mayor Wells

Mayor Wells reviewed his attendance at the following events:

- 2021 Housing Central Conference hosted by BC Non-Profit Housing Association (BCNPHA)
- Comox Valley Chamber of Commerce Leaders meeting re: housing
- Tree Lighting Ceremony at *Moonlight & Magic* event in Downtown Courtenay
- North Island College meeting re: their new craft brewery and chef program
- Community to Community Forum hosted in partnership with K’ómoks First Nation and Comox Valley Regional District
- Town of Comox Tree Lighting Ceremony
- *Community Substance Use Strategy Co-Launch with ‘Walk with Me’ (WWM)* event (WWM is a Comox Valley Art Gallery community action research project focused on addressing the human dimensions of the toxic drug poisoning crisis)

8. RESOLUTIONS OF COUNCIL

8.1 Councillor Cole-Hamilton - Amenity Contributions & Development Variance Permits

Moved By Cole-Hamilton
Seconded By Frisch

WHEREAS the impact of growth and development imposes a special burden on the demand for amenities, particularly affordable housing; and,

WHEREAS the City's development variance permitting process does not currently identify or include amenity contribution requirements or options; and,

WHEREAS the basic premise of amenity packages is that the increased value conveyed with development variance permits should be shared between the community and the applicant.

THEREFORE BE IT RESOLVED that staff be directed to negotiate amenity contributions as part of the development variance permit application process.
Carried

9. UNFINISHED BUSINESS

10. NOTICE OF MOTION

11. NEW BUSINESS

11.1 Change to December 2021 Council Meeting Schedule

Moved By Frisch
Seconded By Cole-Hamilton

WHEREAS the December 20th, 2021 Council meeting is scheduled during the 2021 holiday season;

THEREFORE BE IT RESOLVED that the December 20th, 2021 Council meeting be cancelled with the next regular Council meeting scheduled in year 2022.
Carried

12. BYLAWS

13. ADJOURNMENT

Moved By McCollum
Seconded By Frisch

THAT the meeting now adjourn at 5:18 p.m.
Carried

CERTIFIED CORRECT

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Deputy Corporate Officer

Adopted this 6th day of December, 2021

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Mayor

Minutes of a Special Council Meeting

Meeting #: **S8/2021**
Date: **December 3, 2021**
Time: **9:25 am (The Council meeting was delayed due to technical complications)**
Location: **City Hall Council Chambers**

Attending:
Mayor: **B. Wells**
Councillors: **W. Cole-Hamilton**
D. Frisch
D. Hillian
M. McCollum
W. Morin
M. Theos

Staff: **G. Garbutt, CAO**
C. Davidson, Director of Engineering Services
J. Nelson, Director of Financial Services
K. O'Connell, Director of Corporate Support Services
K. Shaw, Director of Public Works Services
A. Berard, Manager of Financial Planning, Payroll, and Business Performance
N. Borecky, Manager of Information Systems
R. Matthews, Deputy Corporate Officer
E. Hayden, Executive Assistant

The Mayor respectfully acknowledged the lands on which the meeting was conducted is the Unceded traditional territory of the K'ómoks First Nation.

1. STAFF REPORTS/PRESENTATIONS

1.1 Financial Services

1.1.1 2022-2026 Water Fund Financial Report (1705-20/1715-20)

Moved By Cole-Hamilton
Seconded By Morin

THAT the December 3rd, 2021 staff report, "2022-2026 Water Fund Financial Plan", be received for information.
Carried

Moved By Frisch
Seconded By McCollum

THAT based on the December 3rd, 2021 staff report "2022-2026 Water Fund Financial Plan", Council approve OPTION 1, and proceed with the proposed 2022-2026 Water Fund Financial Plan; and, that water user fees increase by 2.0% for 2022.
Carried

The Council meeting recessed at 10:20 a.m.
The meeting reconvened at 10:26 a.m.

1.1.2 2022-2026 Sewer Fund Financial Report (1705-20/1715-20)

Moved By Cole-Hamilton
Seconded By Morin

THAT based on the December 3rd, 2021 staff report "2022-2026 Sewer Fund Financial Plan", Council approve OPTION 1, and proceed with the proposed 2022-2026 Sewer Fund Financial Plan; and, that sewer user fees be increased by 7.5% for 2022.
Carried

1.1.3 2022-2026 Solid Waste, Recycling and Yard Waste User Fees Report (1705-20/1830-05)

Moved By Frisch
Seconded By Morin

THAT based on the December 3rd, 2021 staff report "2022-2026 Municipal Solid Waste, Recyclables, and Yard Waste Budgets", Council approve OPTION 1 and endorse the proposed increase to the 2022 Solid Waste, Recyclables and Yard Waste user fees for single residential and multi-residential curbside service by 5.0% and Institutional, Commercial and Industrial (ICI) and multi-residential apartment and condo non curbside service by 15%.
Carried

2. ADJOURNMENT

Moved By Hillian
Seconded By Frisch

THAT the meeting now adjourn at 11:17 a.m.
Carried

CERTIFIED CORRECT

____

Deputy Corporate Officer

Adopted this 6th day of December, 2021

____

Mayor

THE CORPORATION OF THE CITY OF COURTENAY

STAFF REPORT

To:	Council	**File No.:**	7900-02 Florence Filberg Centre
From:	Chief Administrative Officer	**Date:**	December 6, 2021

Subject: Earl Naswell Community Christmas Dinner Request to use Florence Filberg Centre

PURPOSE:

The purpose of this report is for Council to consider the request for the City of Courtenay to waive facility rental fees for the 39th annual Earl Naswell Community Christmas Dinner at the Florence Filberg Centre.

POLICY ANALYSIS:

City Council adopted the City of Courtenay Fees and Charges Bylaw No. 1673, 1992. The Recreation Facility Rental and User Fees outline the fees to be charged to rental and user groups based on facility and or user group or event type. Deviation from the Recreation Facility Rental and User Fees Bylaw requires Council approval either through amendment of the bylaw or by resolution. Rental fees have not historically been charged for the Earl Naswell Community Christmas Dinner use of the Florence Filberg Centre. A resolution directing staff to waive rental fees for the 2021 event as outlined in the Recreation Facility Rental and User Fees Bylaw in recognition of the significant community benefit of this event and the historical practice of not charging fees would be appropriate and preferred to permanently amending the bylaw.

CAO RECOMMENDATIONS:

That based on the December 6, 2021 staff report, "Earl Naswell Community Christmas Dinner Request to use Florence Filberg Centre," Council approve OPTION 1 and direct staff to not enforce the rental fee rate as outlined in the Recreation Facility Rental and User Fee Bylaw No. 1673, 1992 for the 2021 Earl Naswell Community Christmas Dinner; and,

That staff advise the organizers of the Earl Naswell Community Christmas Dinner to apply for a Grant in Aid for future year events instead of requesting a waiving of the facility rental fees.

Geoff Garbutt, M.PI., MCIP, RPP
Chief Administrative Officer

BACKGROUND:

Since 1982, the Earl Naswell family, friends, volunteers and community sponsors have been working together to provide an annual free Christmas meal on December 25 to community residents, including those experiencing homelessness and those who are alone. 2021 will be the 39th year that this event has taken place in the Comox Valley.

Historically this event has taken place at the Filberg Centre Conference Hall and rental fees have not been charged. Until 2020 it was organized as a sit-down afternoon meal serving hundreds of community citizens. In 2020, during the first year of the Covid-19 pandemic, the format was changed to a service whereby a hot meal was picked up and delivered by volunteers to those in need, with 625 dinners handed out. The goal in 2021 is to prepare and distribute700 dinners, also in the same pick-up and delivery format, which minimizes a communicable disease risk.

DISCUSSION:

The Earl Naswell Christmas Dinner uses the Florence Filberg Conference Hall and kitchen for the collection, preparation, staging, distribution and service of donations of groceries goods and meals. Many community businesses, church groups, agencies and individuals contribute time and donations to the event, in order to ensure it takes place each year. The event occurs on December 25th, 2021 and requires two preparation days (December 23rd and 24th, 2021) immediately prior. While the rental and custodial costs associated with this event amount to $2825.00, the Conference Hall and kitchen facilities are not typically in demand for other functions on these particular dates.

Historically rental fees have simply not been charged for this event, however variation from the Recreation Facility Rental and User Fee Bylaw requires Council authorization either through a bylaw amendment or resolution. Staff recommend that Council direct staff to not enforce the bylaw for 2021 in light of previous years practice of not applying rental or custodial fees to the event. As staff and Council regularly receive requests to waive rental fees for City recreation facilities however, staff recommend that the organizers are encouraged to apply for funding to cover rental and custodial fees through the City's Grant in Aid program for future years. This process would ensure a more fair and transparent application of the Recreation Facility Rental and User Fee Bylaw for all parties.

A dedicated group of family, friends, volunteers and community sponsors has been planning, implementing and serving the annual Earl Naswell Christmas Dinner on Christmas Day for nearly four decades. They have developed finely tuned systems through years of practice in order to make the event safe, cost-effective, and meaningful for all involved. People from diverse backgrounds and needs come together to share a meal and to experience the meaning of community. During the COVID pandemic the organizers have creatively managed ways of ensuring that recipients may still enjoy the benefits of a hot meal and sharing the spirit of Christmas through the implementation of a meal delivery system.

FINANCIAL IMPLICATIONS:

The cost, including rent and custodial staff would be $2825.00, if fees were to be applied. As fees have not been historically applied and the dates in question are typically not in demand by other events, waiving of the fees will not have a negative revenue impact in 2021.

ADMINISTRATIVE IMPLICATIONS:

Administrative and staff support have been provided to the organizers to support the coordination of onsite activities and ensure compliance with health and safety protocols.

ASSET MANAGEMENT IMPLICATIONS:

There are no asset management implications at this time.

STRATEGIC PRIORITIES REFERENCE:

We focus on organizational and governance excellence.

● Responsibly provide services at levels which the people we serve are willing to pay

We continually invest in our key relationships.

●▲ Consider effective ways to engage and partner for the health and safety of the community.

● **AREA OF CONTROL:** The policy, works and programming matters that fall within Council's jurisdictional authority to act

▲ **AREA OF INFLUENCE:** Matters that fall within shared or agreed jurisdiction between Council and another government or party

■ AREA OF CONCERN: Matters of interest that are outside Council's jurisdictional authority to act

OFFICIAL COMMUNITY PLAN REFERENCE:

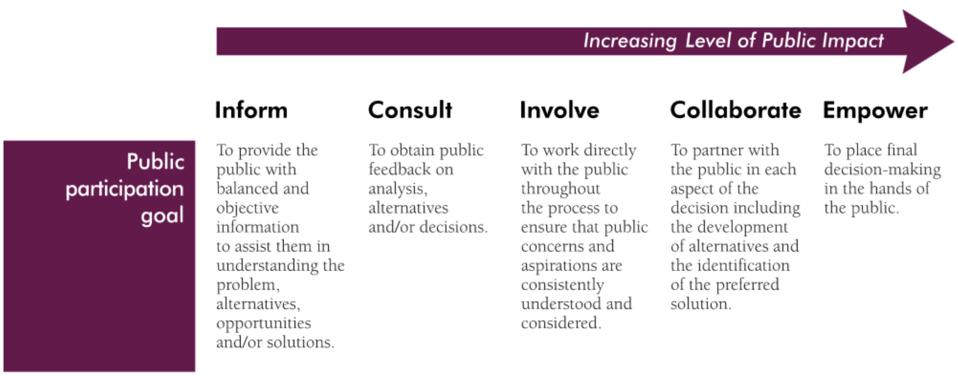
Not referenced.

REGIONAL GROWTH STRATEGY REFERENCE:

No specific reference.

CITIZEN/PUBLIC ENGAGEMENT:

Staff would inform the public based on the IAP2 Spectrum of Public Participation:



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OPTIONS:

OPTION 1: That based on the December 6, 2021 staff report, "Earl Naswell Community Christmas Dinner Request to use Florence Filberg Centre," Council approve OPTION 1 and direct staff to not enforce the rental fee rate as outlined in the Recreation Facility Rental and User Fee Bylaw No. 1673, 1992 for the 2021 Earl Naswell Community Christmas Dinner; and,

That staff advise the organizers of the Earl Naswell Community Christmas Dinner to apply for a Grant in Aid for future year events instead of requesting a waiving of the facility rental fees.

OPTION 2: That Council direct staff to not enforce the rental fee rate as outlined in the Recreation Facility Rental and User Fee Bylaw No. 1673, 1992 for the 2021 Earl Naswell Community Christmas Dinner.

OPTION 3: That Council does not approve the request for free use of the Florence Filberg Centre for the 2021 Earl Naswell Community Christmas Dinner.

Prepared by,

Carol Millar
Manager, Recreation Facilities Operations

Reviewed by:

Susie Saunders
Director, Recreation, Culture, and Community Services

Concurrence by,

Geoff Garbutt, M.PI., MCIP, RPP
Chief Administrative Officer

THE CORPORATION OF THE CITY OF COURTENAY

STAFF REPORT

To:	Council	**File No.:**	0570-01
From:	Chief Administrative Officer	**Date:**	December 6th, 2021
Subject:	**2022 Council Meeting Calendar**		

PURPOSE: To seek Council approval of the 2022 Council Meeting Calendar.

CAO RECOMMENDATIONS:

THAT based on the December 6th, 2021 staff report "2022 Council Meeting Calendar" Council approve Option 1 and set the 2022 Council meeting calendar as outlined in Appendix A of the report; and,

THAT the meetings identified in the 2022 Council Meeting Calendar be held at 4:00 p.m. in the Civic Room at the Comox Valley Regional District administrative building located at 770 Harmston Avenue, Courtenay, BC, unless otherwise posted.

Geoff Garbutt, M.PI., MCIP, RPP
Chief Administrative Officer

BACKGROUND:

Historically the annual meeting schedule has been planned in accordance with the Council Procedure Bylaw with Council meetings occurring on the first, second and third Monday of each month. The Council meeting that occurs on the third Monday is a Committee Of the Whole. In the event the Monday is a holiday, Council meets the day proceeding the holiday (Tuesday). The annual Council meeting schedule must be approved by Council before the end of the year (2021) and identify the dates, times and places of regular meetings with notice to the public provided before January 15th of 2022.

DISCUSSION:

The historical council meeting calendar schedule presents some challenges in regard to workflow, balanced agendas, internal and external engagement opportunities, and over all communication. Additionally the number of meetings combined with other duties fulfilled by members of Council may present barrier to participation for those that require a more flexible work environment. As we prepare for the 2022 local government election, including candidate sessions that will review the roles and responsibilities of local government officials, decreasing barriers to participation is top of mind.

Courtenay City Councillors participate in a myriad of activities, the majority of which are not captured in the annual Council meeting calendar. Historically, in addition to attending thirty-six (36) annually scheduled Council meetings, members of Council also participate on committees, attend Public Hearings (e.g. twelve (12) in 2019) , participate in strategic planning sessions and budget workshops, special Council meetings (e.g.

budget, emergency response etc.), act as liaisons with community stakeholder groups, meet with Provincial Government Ministers, attend conferences and engage in information sharing and professional development opportunities. Some members of Council, as Directors on the Comox Valley Regional District (CVRD) Board also attend regular Board and committee meetings. In addition to these formal roles, members of Council engage with their constituents and attend public events as representatives of their local government, field questions and concerns and act as information conduits relaying information back to the community. Overall the level of time scheduled to attend meetings is substantial and although a reduction of work is not being proposed, a schedule that focuses on efficiency and effectiveness is intended to decrease barriers to participation, and provide further opportunities to address, complete and communicate City business and Council policy directives through an manageable and sustainable meeting schedule.

For staff, the historical Council meeting schedule has the unintended consequence of causing workflow pinch points resulting in disproportionate meeting agendas and challenges in undertaken and implementing Council direction in a timely manner. The current schedule has in each five (5) week cycle three (3) back-to-back Council meetings. This meeting schedule does not include public hearings and mid-day information sessions which exacerbate workflow challenges. The rapid report turnaround time necessitated by the historical schedule is particularly challenging for senior leadership and management teams that are responsible for producing the majority of the reports presented to Council, leading the implementation of Council initiatives, communicating to their respective teams the directions of Council and encouraging collaboration with internal and external stakeholders while simultaneously overseeing daily department operations.

As part of the process to identify options to improve workflows, and decrease scheduled time to reallocate limited resources to communication, collaboration, and implementation, twelve municipalities' annual council meeting calendars were reviewed and are presented in the table below. It is recognized that not all meeting types are captured in the published annual calendars, and each municipality has different council and committee structures that represent differences that are not reconcilable in a simple comparison. However, at a glance and with the exception of Campbell River and North Cowichan, the historical rapid workflow required between meetings is anomalous by comparison.

	Population (2020 Municipal) [1]	**# of Council Meetings**		**# of COW**	**Winter Gap**	**Summer Gap**
Comox	15,182	20		0	4 weeks	3 weeks July 3 week August
Port Alberni	19,060	22		1	4 weeks	4 weeks
Squamish	21,273	22			2 weeks	6 weeks
Cranbrook	21,502	22		6	5 weeks	8 weeks
Langley City	27,774	21		0	5 weeks	8 weeks
COURTENAY	28,862	Current	24	12	2 weeks	No gap
		Proposed	22	0	4 weeks	4 weeks
North Cowichan	32,475	21		12	4 weeks	3 weeks
Port Moody	35,151	19		0	3 weeks	6 weeks
Campbell River	36,167	24		21	4 weeks	no gap
West Kelowna	36,496	22		As needed	4 weeks	no gap
Penticton	36,597	19		Combined	6 weeks	4 weeks
Nanaimo	101,336	22 (includes 2 budget workshops)		0	4 weeks	5 weeks
Burnaby	257,926	22		0	5 weeks	4 weeks

[1] *Municipal and sub-provincial areas population 2011-2022*, Province of British Columbia, accessed online https://www2.gov.bc.ca/gov/content/data/statistics/people-population-community/population/population-estimates, 2021.11.15.

In addition to adjustments to the annual meeting calendar, further workflow efficiencies will be gained in 2022 with the implementation of agenda and report workflow processes using the City's new agenda management system. The combination of a balanced and manageable schedule with automated workflow processes will further enhance staff's ability to support Council and their initiatives as we collectively seek to achieve more with existing resources.

To ensure development processes are not negatively impacted by the proposed schedule, staff recommend that the City eliminate the Committee of the Whole (COW) meeting structure. COW meetings have previously taken place on the last Monday of the month and although many approval authorities have been delegated to the COW, bylaws such as zoning amendments must be considered and approved at a regular council meeting. By having all meetings of Council be regular meetings, the number of meeting at which bylaws can be read will not decrease.

As the City adjusts to the new schedule, should an urgent event arise or an additional meeting be required, Council retains the option to call a special meeting.

FINANCIAL IMPLICATIONS:

There are no financial implications.

ADMINISTRATIVE IMPLICATIONS:

Staff will have greater opportunity to communicate the directions of Council both internally and externally, plan and implement policy directions and enhance City operations.

ASSET MANAGEMENT IMPLICATIONS:

N/A

STRATEGIC PRIORITIES REFERENCE:

We focus on organizational & governance excellence

●Support and encourage initiatives to improve efficiencies.

●Recognize staff capacity is a finite resource and support staff training and development.

●Communicate appropriately with our community in all divisions we make.

●Responsibly provide services at levels which the people we serve are willing to pay.

We continually invest in our key relationships

●■Consider effective ways to engage with and partner for the health and safety of the community.

● **AREA OF CONTROL:** The policy, works and programming matters that fall within Council's jurisdictional authority to act

▲ **AREA OF INFLUENCE:** Matters that fall within shared or agreed jurisdiction between Council and another government or party

■ AREA OF CONCERN: Matters of interest that are outside Council's jurisdictional authority to act

OFFICIAL COMMUNITY PLAN REFERENCE:

N/A

REGIONAL GROWTH STRATEGY REFERENCE:

N/A

CITIZEN/PUBLIC ENGAGEMENT:

Notice will be provided in accordance with Section 127 of the *Community Charter* and the Council Procedure Bylaw:

Community Charter: Notice of Council Meetings (Section 127(1)(b))

127(1)(b) *(b) give notice of the availability of the schedule in accordance with section 94* [public notice] *at least once a year.*

Council Procedure Bylaw: Annual Meeting Schedule (Section 6)

6. (1) Council must prepare annually on or before December 31, a schedule of the dates, times and places of regular Council meetings and must make the schedule available to the public by posting the schedule on the notice board.

(2) Council must give notice annually on or before January 15 of the availability of the annual meeting schedule.

OPTIONS:

OPTION 1: THAT based on the December 6th, 2021 staff report "2022 Council Meeting Calendar" Council approve Option 1 and set the 2022 Council meeting calendar as outlined in Appendix A of the report; and,

THAT the meetings identified in the 2022 Council Meeting Calendar be held at 4:00 p.m. in the Civic Room at the Comox Valley Regional District administrative building located at 770 Harmston Avenue, Courtenay, BC, unless otherwise posted. (Recommended)

OPTION 2: Council direct staff to advertise a 2022 Council Meeting Calendar scheudle as prescribed by the Council Procedure Bylaw.

OPTION 3: Council refer the 2022 Council Meeting Schedule back to staff with direction.

Prepared by,

Kate O'Connell, BA, M.P.P.
Director of Corporate Support Services

Concurrence by,

Geoff Garbutt, M.Pl., MCIP, RPP
Chief Administrative Officer

THE CORPORATION OF THE CITY OF COURTENAY

STAFF REPORT

Appendix A: 2022 Council Meeting Calendar

2022

January

Su	Mo	Tu	We	Th	Fr	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

February

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27	28					

March

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27	28	29	30	31		

April

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17	18	19	20	21	22	23
24	25	26	27	28	29	30

May

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15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

June

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			1	2	3	4
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12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

July

Su	Mo	Tu	We	Th	Fr	Sa
					1	2
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10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

August

Su	Mo	Tu	We	Th	Fr	Sa
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

September

Su	Mo	Tu	We	Th	Fr	Sa
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

October

Su	Mo	Tu	We	Th	Fr	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

November

Su	Mo	Tu	We	Th	Fr	Sa
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30			

December

Su	Mo	Tu	We	Th	Fr	Sa
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

- CONFERENCES
- STATS
- GENERAL ELECTION DAY
- INAUGURAL MEETING
- COUNCIL ORIENTATION
- STRATEGIC PLANNING
- SPRING BREAK

THE CORPORATION OF THE CITY OF COURTENAY

STAFF REPORT

To:	Council	**File No.:** 3010-01
From:	Chief Administrative Officer	**Date:** December 6, 2021
Subject:	**Release of covenant restricting secondary suite – 2948 Cascara Crescent**	

PURPOSE:

To consider the release of a restrictive covenant limiting development to single family dwellings only.

CAO RECOMMENDATIONS:

That based on the December 6, 2021 staff report "Release of covenant restricting secondary suite – 2948 Cascara Crescent", Council approve Option 1 and direct staff to release covenant CA2451158 from Lot 7, District Lot 236, Comox District, Plan EPP17584 (2948 Cascara Crescent).

Geoff Garbutt M.Pl., MCIP, RPP
Chief Administrative Officer

BACKGROUND:

The subject property is located at 2948 Cascara Crescent. In 2010 an application was made by the original developer to rezone the land from R-1B to R-1S to facilitate an 18 lot single family subdivision with the option of secondary suites. Under the R-1B zone there was potential for subdivision of approximately 16 single family lots. The council of the day approved the rezoning.

Subsequent to the rezoning approval the developer was issued a Preliminary Approval Letter from the City's Approving Officer that detailed the requirements to obtain subdivision approval, including payment of Development Cost Charges (DCCs). At that time the City's practice was to require payment of DCCs at the single family rate for all lots and an additional DCC was charged at the multi-family rate for all lots that were zoned for secondary suites. To avoid the collection of the additional DCC related to secondary suites, applicants were given the option of registering a covenant on title that would limit the development to single family dwellings only. The developer of the Cascara subdivision chose to register the covenant.

DISCUSSION:

The first phase of the Cascara Crescent subdivision contains 18 lots, 17 of which are zoned R-1B and one that is zoned R-1. Both the R-1B and R-1 zone restrict the use to single family dwellings without secondary suites. The subject property is within the second phase of the subdivision. As noted above it contains 18 lots all of which are zoned R-1S which permits single family homes with secondary suites, however all but one of the lots are encumbered by the covenant preventing secondary suites. In December 2020, a request for release of the covenant in question was granted by Council for 2977 Cascara Crescent.

At the November 15, 2021 Council meeting, Council directed staff to send notice to the neighbouring property owners subject to the same covenant requesting their input prior to final consideration. To date staff have received 7 responses from 6 households.

FINANCIAL IMPLICATIONS:

The City does not currently have a fee for the consideration of removal or amendment to covenants registered as part of a subdivision. There is a fee of $300 for the release of covenants related to building permits.

ADMINISTRATIVE IMPLICATIONS:

Staff spent approximately 1.5 hours researching and preparing the November 15th, 2021 report. An additional 1.5 hours has been spent processing the mail out, responding to emails and preparing this report.

ASSET MANAGEMENT IMPLICATIONS:

There are no asset management implications with this request.

2019 – 2022 STRATEGIC PRIORITIES REFERENCE:

- Communicate appropriately with our community in all decisions we make
- Encourage and suport housing diveristy

OFFICIAL COMMUNITY PLAN REFERENCE:

The request to release the covenant is consistent with the current zoning and with the Urban Residential land use designation of the Official Community Plan. It represents infill residential development near existing amenities and services, providing a range of housing choice, while fulfilling OCP Section 4.4.3 4 a) – limited infill will be considered only in keeping with the character and scale of an existing neighbourhood and 4.4.3.4 d) – secondary suites will be considered as part of a principle single family residential building subject to zoning approval.

REGIONAL GROWTH STRATEGY REFERENCE:

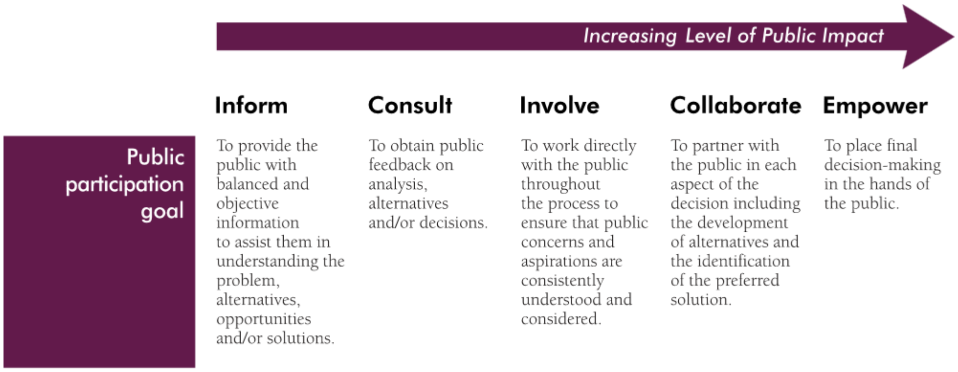
The proposal is consistent with the RGS Housing Goal to “ensure a diversity of affordable housing options to meet evolving regional demographics and needs” including:

Objective 1-A: Locate housing close to existing services; and

Objective 1-C: Develop and maintain a diverse, flexible housing stock.

CITIZEN/PUBLIC ENGAGEMENT:

Staff have consulted with the public by mail out based on the IAP2 Spectrum of Public Participation:



A notice that Council was considering release of the covenant was mailed to the 18 lots encumbered by the same covenant on November 17th, 2021. To date the City has received 7 responses from 6 households. 3 comments were in support, 4 were opposed. Those opposed cited the following reasons:

- They wish to retain the single-family nature of the neighbourhood
- Covenants should be upheld
- Parking and traffic concerns

Any additional feedback will be forwarded to Council prior to the meeting.

OPTIONS:

OPTION 1: Direct staff to relaese the covenant from 2948 Cascara Cres.

OPTION 2: Request further information from staff prior to release of the covenant.

OPTION 3: Direct staff to advise the applicant the City does not support the release of the covenant.

Prepared by:

Cassandra Marsh,
Planner I

Reviewed by:

Matthew Fitzgerald, RPP, MCIP
Manager of Development Planning

Concurrence by:

Geoff Garbutt M.Pl., MCIP, RPP
Chief Administrative Officer

Attachment No 1: Letter Requesting Release
Attachment No 2: Input from neighbours

Attachment No. 1 – Letter Requesting Release

text

Attention:

Cassandra Marsh

Development Services
City of Courtenay
830 Cliffe Ave.
Courtenay BC
V9N 2J7

Re : 2948 Cascara Crescent (secondary Suite Zoning)

To whom it may concern,

This letter is requesting a covenant release for my property at 2948 Cascara Crescent.

I am in the process of building a new residential home and have planned for a secondary suite within the home.
The property is on a quiet residential culdasac where I am aware of one other home with a secondary suite. The slope of the property allows for a level entry walk out basement style which lends itself well to a small suite on the lower basement level. The suite will be one bedroom and is accessed down a flight of outside stairs along the side of the home. There is designated parking for the suite and the suite will otherwise comply with the zoning requirements for suites, should the covenant is released.

I am fully aware of the potential concerns and inconvenience to neighbours whenever there is a new build in the neighbourhood. Construction vehicles, excavation, building noise etc but I can assure you, I too am interested in a quiet family neighbourhood to live with my son. As I indicated the property lent itself to an inconspicuous small 1 bedroom suite and I hope to rent to a single professional person who too will respect the neighbourhood.
I am hoping you will consider this request, as you have for a similar home recently built on the street.

Respectfully submitted

Daryl Hopwood

Page 1

Attachment No 2 - Input from neighbours

Wed 11/24/2021 10:57 AM
[redacted]
Single family homes
To PlanningAlias
Cc [redacted]
You forwarded this message on 11/24/2021 11:00 AM.

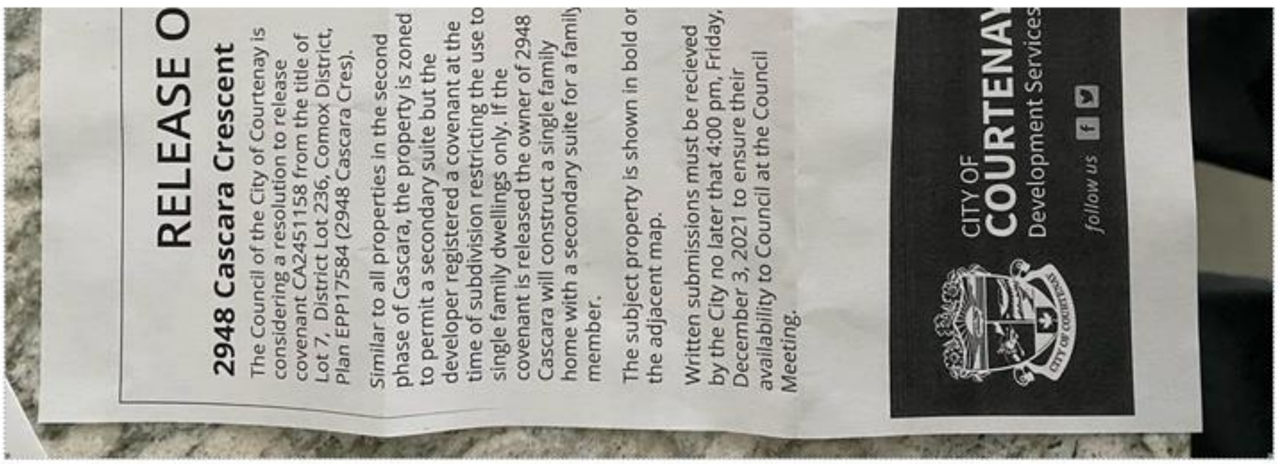
To whom it may concern,

We are the owners of 2939 Cascara Crescent, we are opposed to secondary rental suites. As much as the city of Courtenay does need more rental available, we bought in this subdivision last year because there was a covenant that prevented rental in the second phase of cascara crescent. The subdivision we moved from in Chilliwack allowed secondary suites and it was always a headache for all the owners. It's caused parking chaos on the streets in front of the houses, It brought in too many ppl and caused congestion at every level.

Again we are very opposed to this.

Please do not allow 2948 Cascara Crescent to proceed with a secondary suite. This should not be allowed. If they say it's for a family member then they don't need a secondary kitchen. They can use the main kitchen in the house.

This subdivision has a covenant on it and it should stay that way.



Sincerely,

[redacted]
2939 Cascara Crescent
Courtenay B.C.
[redacted]

Wed 11/24/2021 11:56 AM

[redacted]

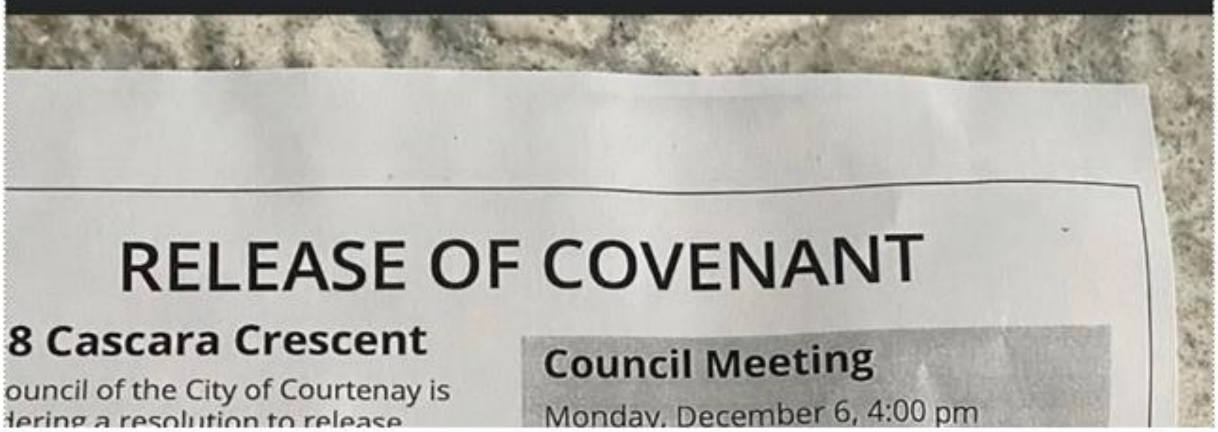
Fwd: Release of Covenant as attached

To PlanningAlias

You forwarded this message on 11/24/2021 12:17 PM.

>
>Hello,
>In regards to release of Covenant we would like to say no to this. We were told when we purchased there would be no having rentals on our properties which is one of the reasons we purchased here. This street already struggles with people parking on the roads and traffic. It is unfair to the rest of us who purchased property here to have something go through that we were told would not happen. There has also been recently approved property development for rentals not far from us. Enough is enough! The single dwelling homes should remain without rental suites.
>
>Regards
>[redacted]
>2906 Cascara Cresent
>Courtenay BC, V9N 4B8
>

[redacted]



Wed 11/24/2021 12:39 PM

[redacted]

Release of Covenant CA2451158 from 2848 Cascara Cres

To PlanningAlias

You forwarded this message on 11/24/2021 12:52 PM.

Good Day, I would like to express my strong APPROVAL for the release of covenant CA2451158 from the title of lot 7, District Lot 236, Comox District Plan EPP17584 (2948 Cascara Cres).

I would like to see a possible approval for the covenant to be removed from entire second phase for all home owners and for the city to consider all houses zoned R1 in the first phase to be changed on Cascara Crescent from R1 to R1S to allow for secondary suites in the subdivision/neighborhood.

Thank you for your considerations.

[redacted]
Home Owner
2836 Cascara Cres
Courtenay BC.

Sent from Mail for Windows

Wed 11/24/2021 11:53 AM

[redacted]

Covenants for cascara

To PlanningAlias

Cc [redacted]

To whom it may concern

If they are going to start breaking covenants then that means your open to changing other covenants like those terrible city trees that look sick and are causing root issues in our front lawns. These trees are always breaking off and causing damage plus the root systems are starting to grow towards the foundation of our home. Apparently there is covenant on one tree in particular that is actually a city tree but is actually inside my property line. We also found out that there is covenant on this particular tree. New builds don't even require city trees. I'd like this tree gone before it damages my front lawn any further or starts to grow into my house drainage system. I'd be putting a red maple back in with a less invasive root system. I wouldn't even ask the city to pay to remove it. We would take on that expense ourself. We just want to prevent future property damage.

If the city goes through with this breach of the covenant then we will be asking for this tree to be removed. It's the only right thing to do.

Sincerely

[redacted]
2939 Cascara Crescent
Courtenay B.C.
[redacted]

Tue 11/23/2021 5:37 PM

[redacted]

2948 Cascara Crescent

To PlanningAlias

You forwarded this message on 11/24/2021 8:48 AM.

Hello Planning Department,

I am a resident at 2969 Cascara Crescent and received a letter this afternoon regarding a potential release of covenant for 2948 Cascara Crescent to permit construction of a secondary suite.

I fully support this, as a number of other homes on the street already have suites and the impact to the neighbourhood is not noticeable.

Regards,

[redacted]

Thu 11/25/2021 11:11 AM

[redacted]

2948 Cascara Cres - Covenant

To PlanningAlias

Cc [redacted]

You forwarded this message on 11/25/2021 11:33 AM.

Dear City of Courtenay Mayor & Council,

We are in support of the release of the covenant on the property at 2948 Cascara Cres. for the purpose of allowing a suite.

Thank you,
Regards,

[redacted]

2876 Cascara Cres
Courtenay, BC V9N 4B8

Tue 11/23/2021 6:25 PM
[redacted]
Release of Covenant - 2948 Cascara Cres
To PlanningAlias

Ref: Release of Covenant CA2451158; 2948 Cascara Cres (Lot 7, District Lot 236, Plan EPP17548)

To whom it may concern,

The occupants of 2920 Cascara Cres will oblige the owners of the Release of Covenant with the following provisions:

- That the Secondary Suite be used exclusively for a (one) Family Member (link for family member guidelines);
- That the Secondary Suite not be used as an Airbnb;
- That the Secondary Suite not be used as any other from of rental for the purpose of generating an income unless used by a "Family Member";

Thank you for this consideration.

Regards,

[redacted]
2920 Cascara Cres

THE CORPORATION OF THE CITY OF COURTENAY

STAFF REPORT

To:	Council	**File No.:**	3060-20-2107
From:	Chief Administrative Officer	**Date:**	December 6, 2021
Subject:	**Updated Proposal Development Permit with Variances No. 2107 – 1600 Riverside Lane**		

PURPOSE:

The purpose of this report is to provide additional information requested by Council while considering a Development Permit with Variances and an exemption to Floodplain Management Bylaw No. 1743 (1994) to allow the construction of a 50-unit multi-residential building at 1600 Riverside Lane.

CAO RECOMMENDATIONS:

1. That based on the December 6th, 2021 staff report "Development Permit with Variances No. 2107 – 1600 Riverside Lane" Council approve OPTION 1 and proceed with issuing Development Permit with Variances No. 2107; and,
2. That Council approve an exemption for the minimum floodplain setback specified in the City of Courtenay Floodplain Management Bylaw No 1743, 1994 subject to the registration of a covenant under section 219 of The Land Title Act to ensure the property is constructed with the recommendations outlined in the report "Report of Geotechnical Assessment, Proposed Apartment Building, 1600 Riverside Lane, Courtenay, BC" dated November 20, 2020 and that the applicant saves harmless the City from any claims for flood damage or injury.

Respectfully submitted,

Geoff Garbutt, M.Pl., MCIP, RPP
Chief Administrative Officer

BACKGROUND:

This proposal was originally considered by Council at the November 15th meeting (see November 15th, 2021 Staff Report for a detail description and assessment of the proposal). Council deferred making a decision on the proposal and requested the following additional information:

1. details on pedestrian connections throughout the site and to the river walkway;
2. details on building massing (as experienced from the river walkway);
3. the potential to increase the amount of usable open space; and,
4. the integration of affordable units into the proposal.

DISCUSSION:

Regarding pedestrian connections, the applicant has supplied a diagram showing the proposed building and pedestrian connections throughout the area (See Attachment No. 2). This includes sidewalk connections to the phase 1 building, connections around the proposed building and connections to the river walkway.

A rendering has been created which shows the building as seen from the sidewalk on the 17th Street Bridge. This also includes a schematic showing the outline of the building as experienced from the river walkway (see Attachment No. 3).

Further, the applicant has updated the rooftop patio plan. The original rooftop patio was 186m² (2,000ft²). This has been increased to 253m² (2,720ft²). The space continues to include a communal barbeque area, trellises and seating areas (see Attachment No. 4).

Finally, the applicant has update the proposal to include affordable units (see Attachment No. 5). Two of the units will be in the existing building and three will be provided in the proposed building and assigned rents as detailed below. All five of the units are studio units.

Rental rates will be calculated based on 30% of the gross household income levels published in BC Housing's annual Housing Income Limits (HILs) publication. The HILs rates are intended to reflect the minimum income required to afford appropriate accommodation in the private market. Under this formula rental rates for a 1 bedroom or less apartment would be capped at $987.50 based on the 2021 HILs.

The units in both buildings will be secured through a housing agreement which will last for ten years after which the units will revert to private market rental rates. It will be the responsibility of the property owner under the housing agreement to ensure the units remain at the proposed rents. The agreement will be drafted by the City's solicitor and include the requirement for the owner to provide reports to the City to ensure compliance. Reports will be required on an annual basis or as tenants change in the affordable units. Failure to provide these reports will include a "rent" (penalty) charge under the agreement for non-compliance.

OPTIONS:

OPTION 1: (**Recommended**):

1. Approve Development Permit with Variances No. 2107; and

2. Aprove an exemption for the minimum floodplain setback specified in the City of Courtenay Floodplain Management Bylaw No. 1743, 1994 subject to the registration of a covenant under Section 219 of The Land Title Act to ensure the property is constructed with the recommendations outlined in the Simpson Biotechnical Ltd. letter "Report of Geotechnical Assessment, Proposed Apartment Building, 1600 Riverside Lane, Courtenay, BC" dated November 20, 2020 and that the applicant saves harmless the City from any claims for flood damage or injury.

OPTION 2: Defer consideration of Development Permit with Variances No. 2107 pending receipt of further information.

OPTION 3: Not approve Development Permit with Variances No. 2107.

Prepared by:

Concurrence by:

Matthew Fitzgerald, RPP, MCIP
Manager of Development Planning

Geoff Garbutt, M.Pl., MCIP, RPP
Chief Administrative Officer

Attachments:

1. *Attachment No. 1: Draft Development Permit with Variances No. 2107*
2. *Attachment No. 2: Pedestrian Connections*
3. *Attachment No. 3: Updated Renderings*
4. *Attachment No. 4: Updated Rooftop Patio*
5. *Attachment No. 5: Amenity Contribution Offer*

Attachment No. 1: Draft Development Permit with Variances No. 2107

THE CORPORATION OF THE CITY OF COURTENAY

Permit No. 3060-20-2107

DEVELOPMENT PERMIT WITH VARIANCES

December 6, 2021

To issue a Development Permit with Variances

To:

Name: PACIFIC SWELL DEVELOPMENTS, INC.

Address: 5759 Larson Place
West Vancouver, BC V7W 1S5

Property to which permit refers:

Legal: Lot A, Section 41, Comox District, Plan EPP76829

Civic: 1600 Riverside Lane

Conditions of Permit:

Permit issued to permit construction of a six-storey multi-residential building and a bicycle parking addition to an existing residential building on the above referenced property with variances granted as described below:

Variances to Zoning Bylaw No. 2500, 2007:

Section 6.5.3 – Courtenay River Setback from a minimum of 30 m to 13 m.

Section 7.1.2 (1) – Parking Spaces from a minimum of 1.5 per unit to 0.9 per unit.

Section 7.1.10 (1) – Small Car Spaces from a maximum of 10% to 55%.

Section 8.14.5 (1) – Front Yard Setback from a minimum of 7.5 m to 7.0 m (face); 4.5 m (projections); 1.0 m (trellis).

Section 8.14.5 (2) – Rear Yard Setback from a minimum of 7.5 m to 5.5 m for enclosed bike storage.

Section 8.14.5 (3) – Side Setback Flanking Street from a minimum of 7.5 m to 1.0 m.

Section 8.14.6 – Building Height from a maximum of 10.0 m to 23.0 m to elevator top; 19.0 m to roof peak.

Section 8.14.7 – Usable Open Space from a minimum of 20.0 m^2 per apartment unit to 11.3 m^2 including a minimum 253m^2 rooftop patio.

Section 8.14.10 (1) – Street Landscape Buffer from a minimum of 7.5 m (17th St.), 4.5 m (Riverside Lane) to 1.0 m (17th St.), 1.2 m (Riverside Lane).

Section 8.14.10 (3) – Adjacent Lot Landscape Buffer from a minimum of 2.0 m width and height to

Attachment No. 1
2/15

1.0 m width and height.

Development Permit with Variance No. 2107 is also subject to the following conditions:

1. Development must be in conformance with the site plan, elevations and associated project data dated October 8th, 2021 by MacDonald Hagarty Architects in ***Schedule No. 1***, including the full property SK1 Site Parking Plan as annotated by City staff to match Sheet A1.01 parameters;
2. A Land Title Act Section 219 covenant must be registered prior to issue of building permit to ensure that the property is constructed with the recommendations outlined in the report "Report of Geotechnical Assessment, Proposed Apartment Building, 1600 Riverside Lane, Courtenay, BC" dated November 20, 2020 and that the applicant saves harmless the City from any claims for flood damage or injury;
3. Development must be in substantial conformance with the landscape plan by Biophilia Design Collective and sealed by Elizabeth Balderston March 31st, 2021 in ***Schedule No. 2***;
4. Submission of landscape security in the amount of $60,120.00 ($48,096.00 x 125%) is required prior to issuance of building permit, based on the cost estimate by Biophilia Design Collective and sealed by Elizabeth Balderston March 30th, 2021 in ***Schedule No. 3***;
5. The minimum depth of topsoil or amended organic soil on all landscaped areas is to be as follows: shrubs – 450mm; groundcover and grass – 300 mm; and trees – 300 mm;
6. Tree removal shall require a Tree Cutting Permit;
7. All new street lighting in the proposed development must use Full Cut Off/Flat Lens (FCO/FL) luminaries to light roads, parking, loading and pedestrian areas. Exterior building lighting must have FCO lighting fixtures;
8. A sign permit shall be obtained prior to any signage being installed on the property;
9. Landscaping must be completed within one year of the date of issuance of the occupancy permit by the City;
10. The development shall meet all other applicable requirements, standards and guidelines; and
11. No alterations or amendments shall be made without the City's permission. A formal amendment application is required if the plans change or additional variances are identified after the permit is issued.

Time Schedule of Development and Lapse of Permit

That if the permit holder has not substantially commenced the construction authorized by this permit within (12) months after the date it was issued, the permit lapses.

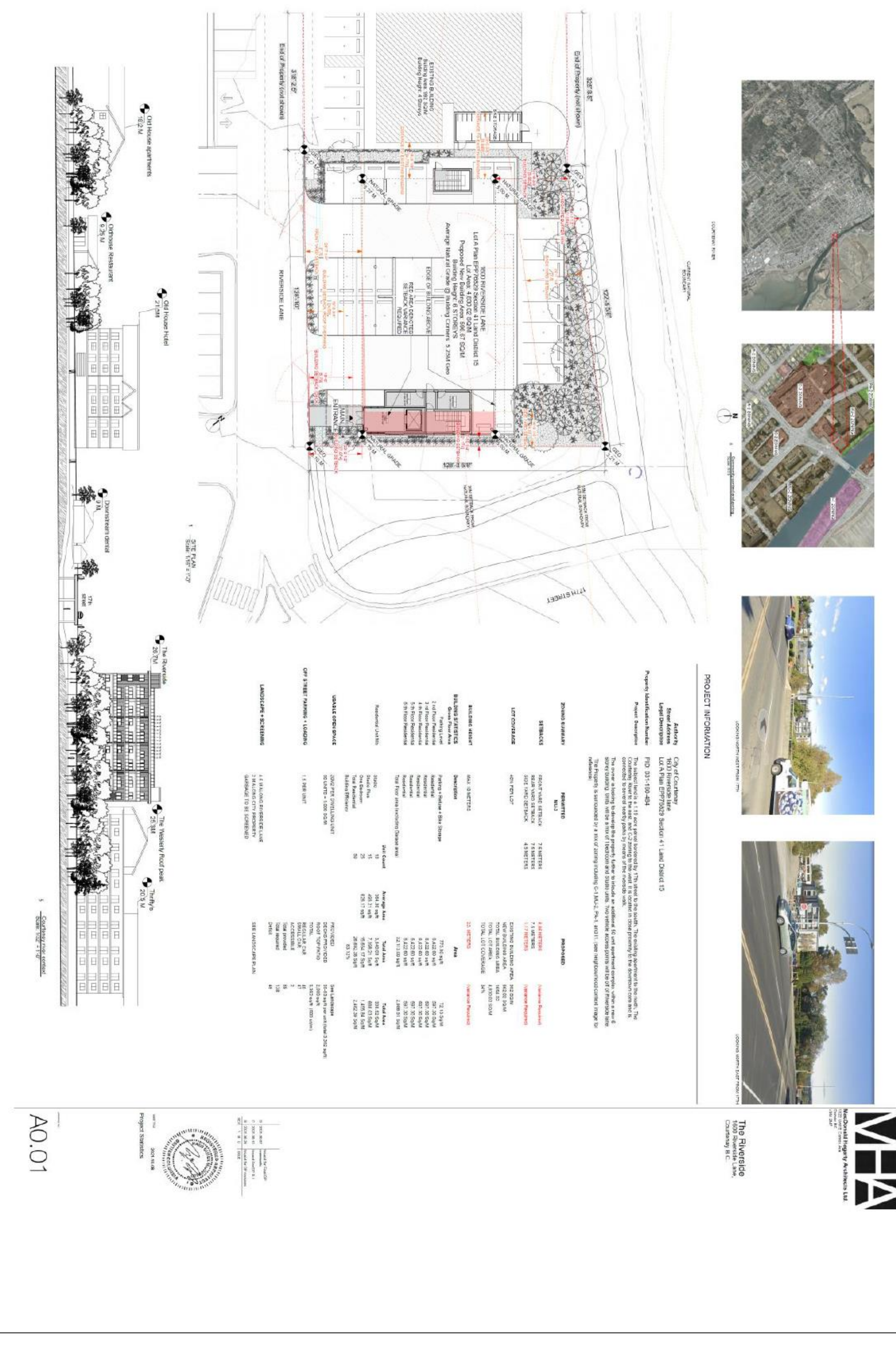
____________________________ ____________________________

Date Corporate Officer

Attachment No. 1
3/15

DPV2107

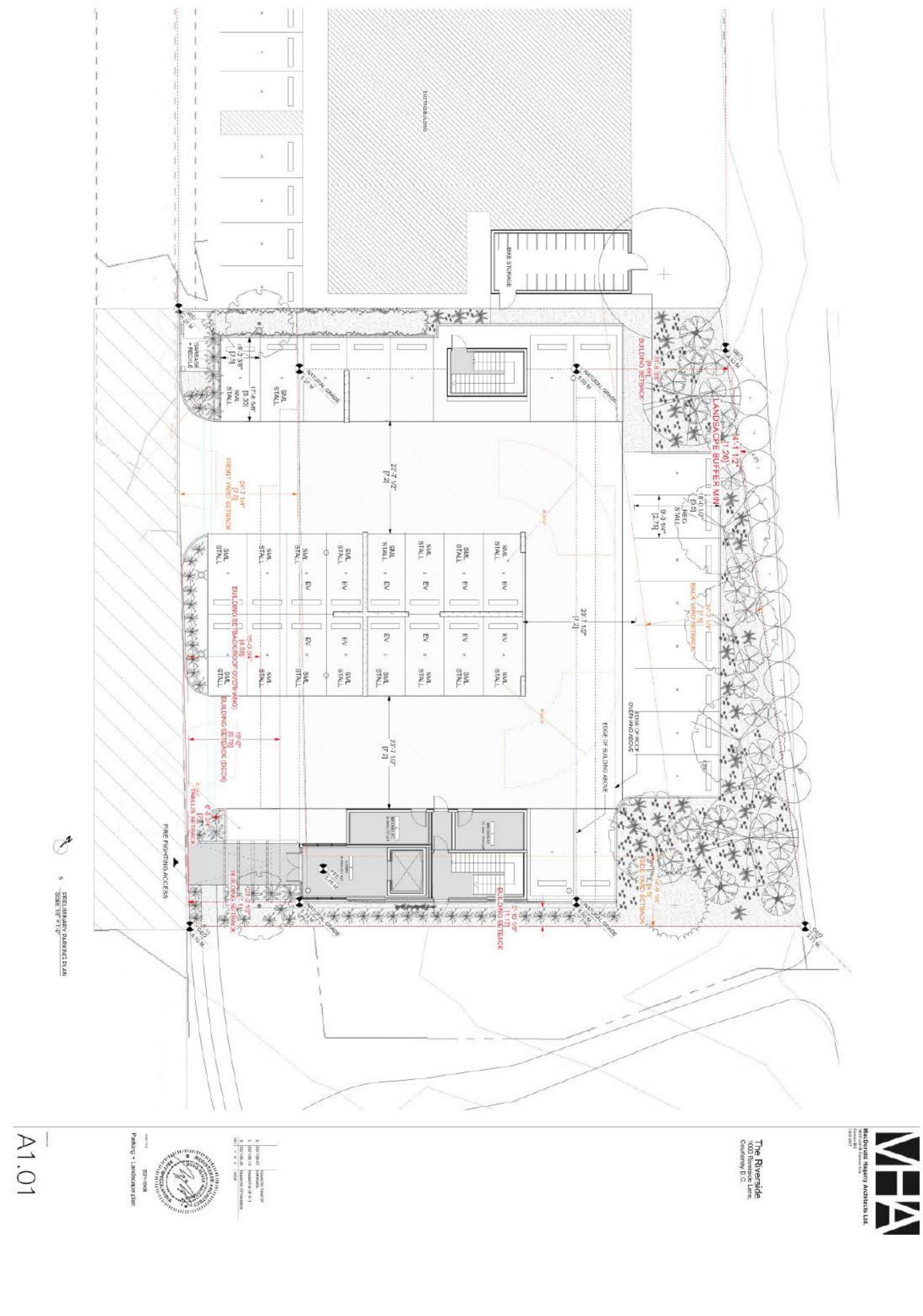
Schedule No.1: Plans & Elevations
Page **1** of **5**



Attachment No. 1
4/15

DPV2107

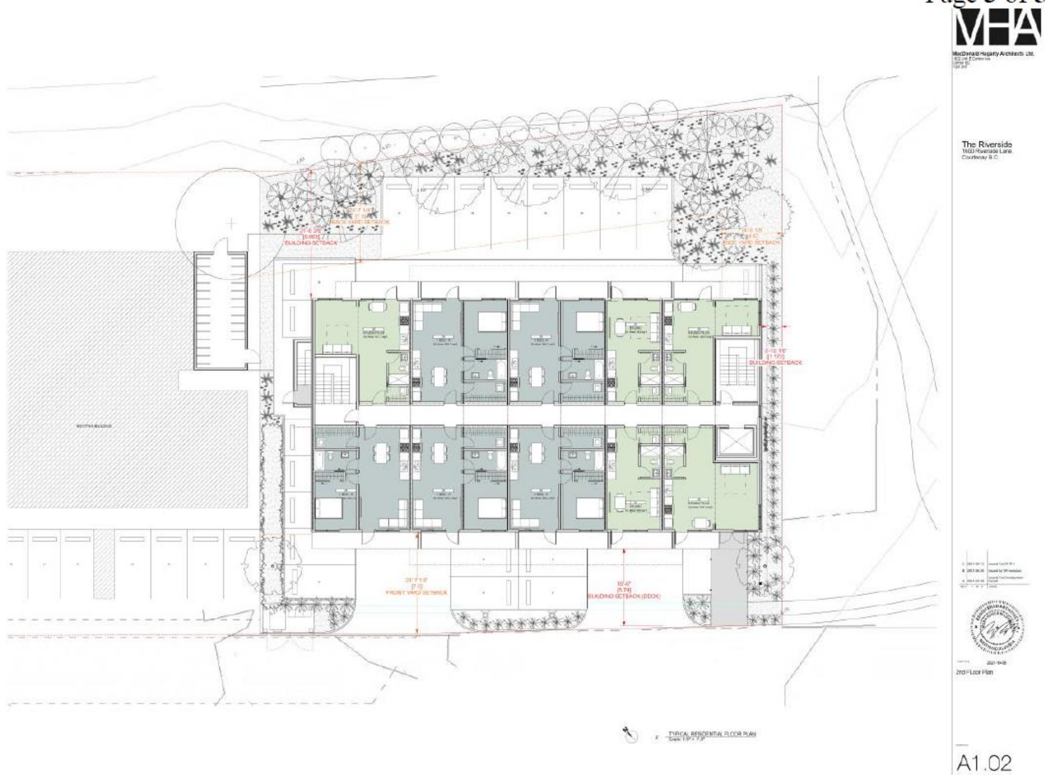
Schedule No.1: Plans & Elevations
Page **2** of **5**

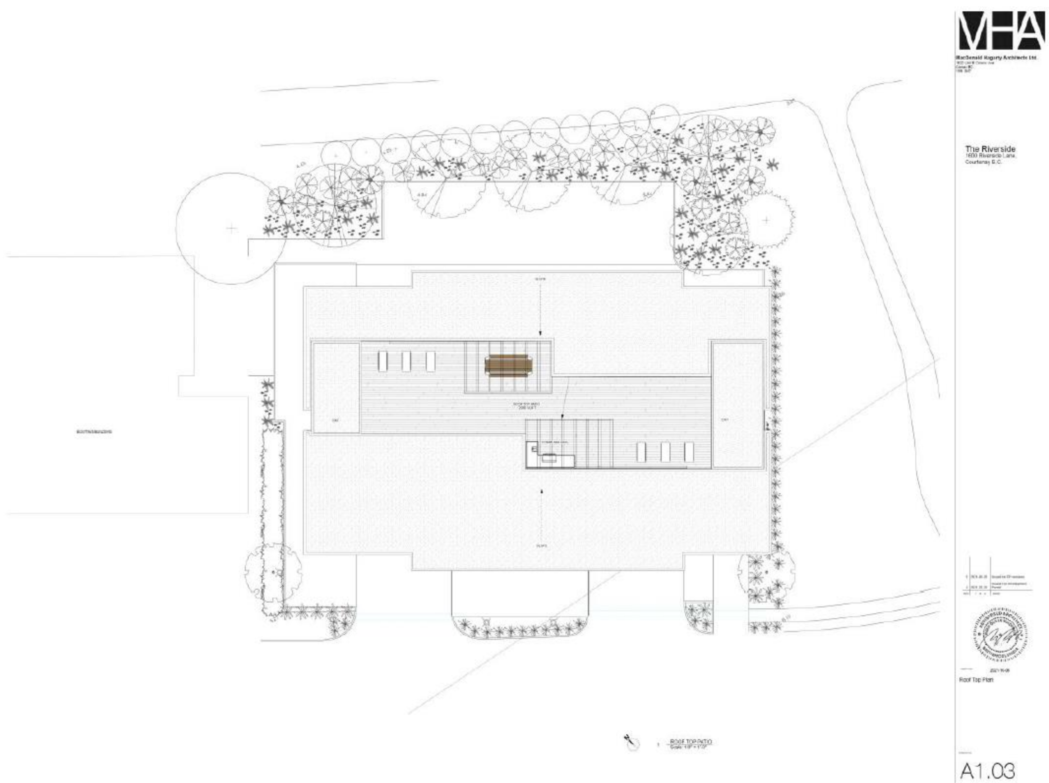


Attachment No. 1
5/15

DPV2107

Schedule No.1: Plans & Elevations
Page **3** of **5**





Attachment No. 1
6/15

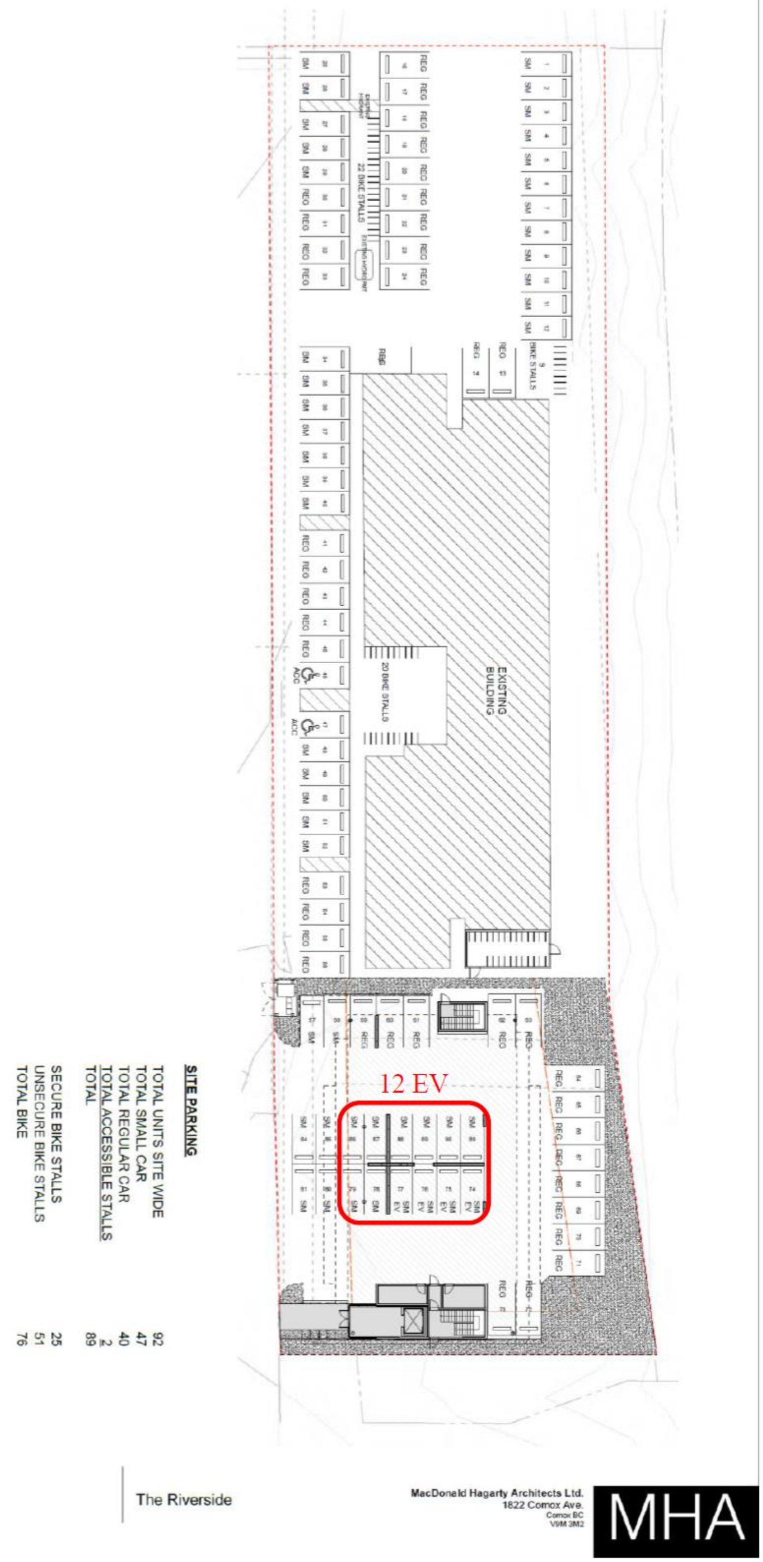
DPV2107

Schedule No.1: Plans & Elevations
Page **4** of **5**

Attachment No. 1
7/15

DPV2107

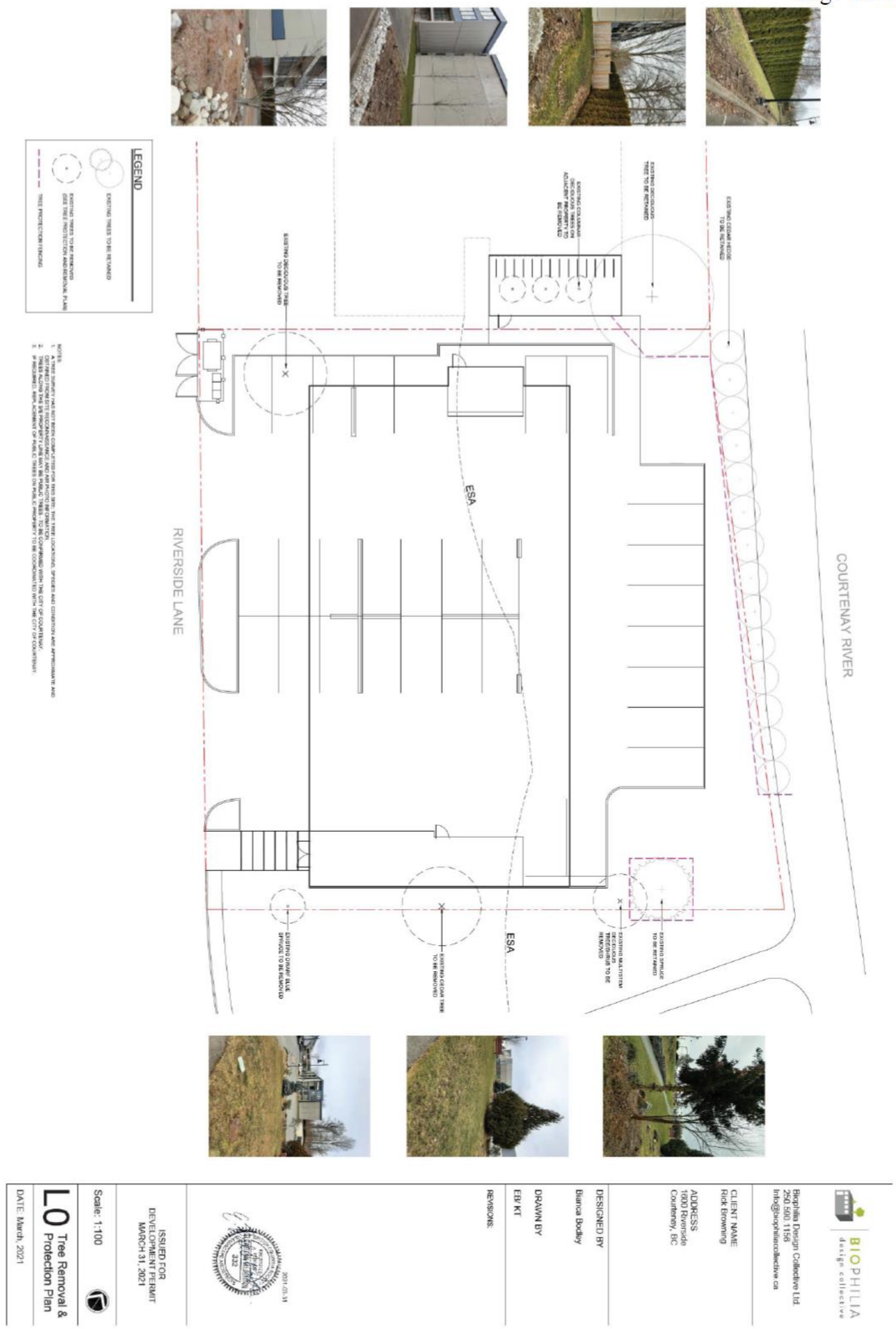
Schedule No.1: Plans & Elevations
Page **5** of **5**



Attachment No. 1
8/15

DPV2107

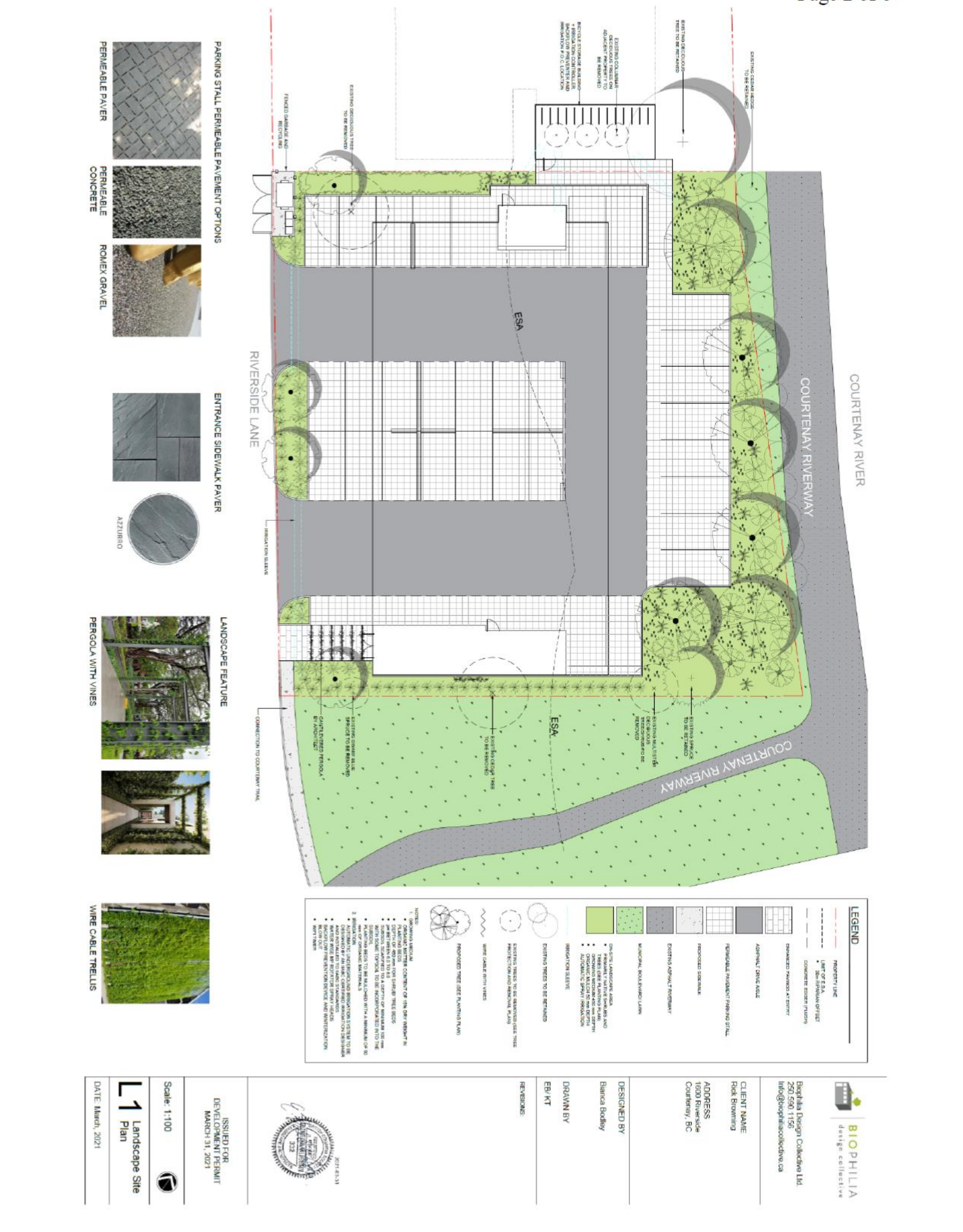
Schedule No.2: Landscape Plan
Page **1** of **6**



Attachment No. 1
9/15

DPV2107

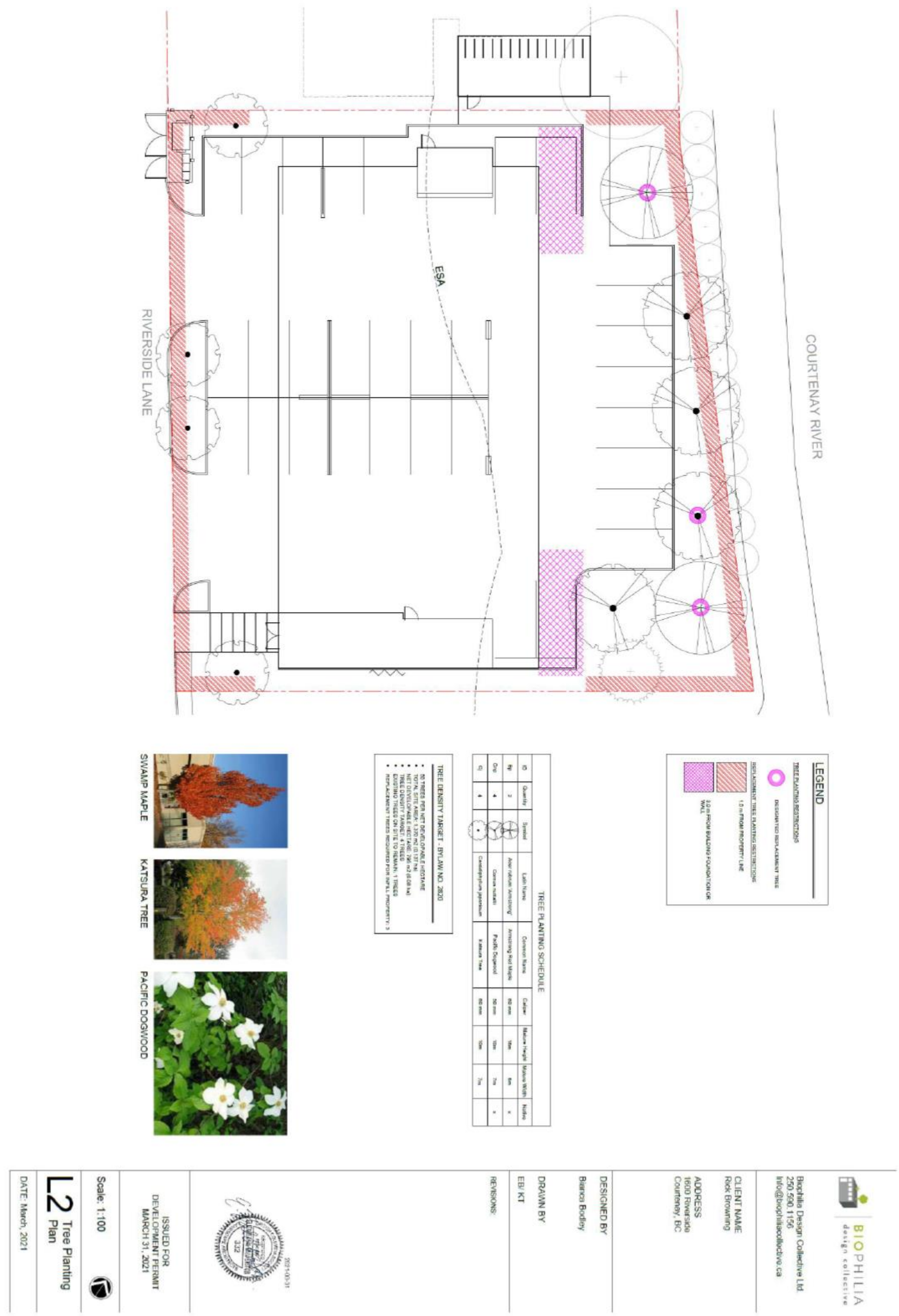
Schedule No.2: Landscape Plan
Page **2** of **6**



Attachment No. 1
10/15

DPV2107

Schedule No.2: Landscape Plan
Page **3** of **6**



TREE PLANTING SCHEDULE

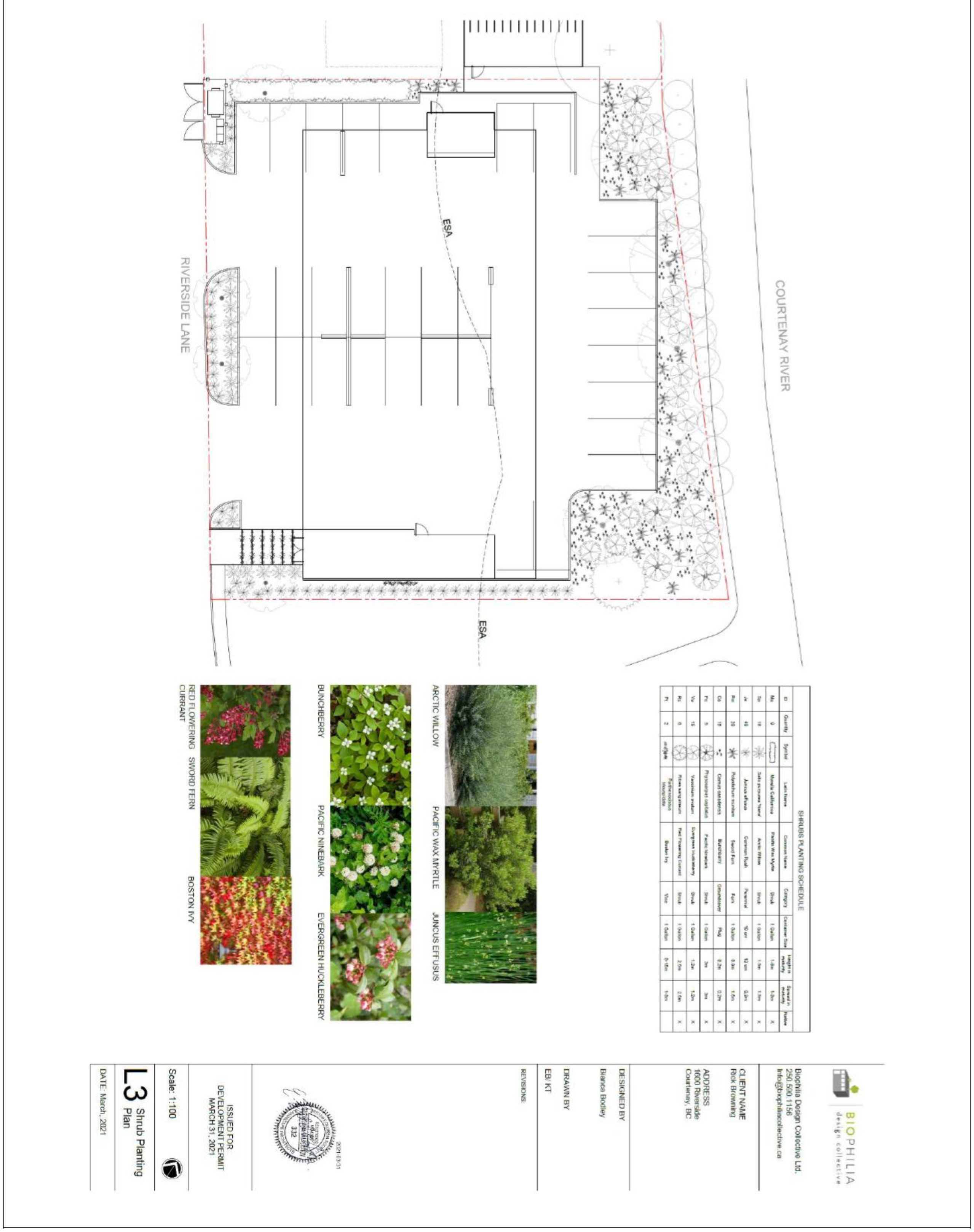
ID	Quantity	Symbol	Latin Name	Common Name	Caliper	Mature Height	Mature Width	Native
Rp	2		Acer rubrum 'Armstrong'	Armstrong Red Maple	60 mm	15m	6m	x
Cnp	4		Cornus nuttalii	Pacific Dogwood	50 mm	10m	7m	x
Cj	4		Cercidiphyllum japonicum	Katsura Tree	60 mm	10m	7m	

TREE DENSITY TARGET - BYLAW NO. 2820

- 50 TREES PER NET DEVELOPABLE HECTARE
- TOTAL SITE AREA: 1,370 m2 (0.137 ha)
- NET DEVELOPABLE HECTARE: 795 m2 (0.08 ha)
- TREE DENSITY TARGET: 4 TREES
- EXISTING TREES ON SITE TO REMAIN: 1 TREES
- REPLACEMENT TREES REQUIRED FOR INFILL PROPERTY: 3

DPV2107

Schedule No.2: Landscape Plan
Page **4** of **6**



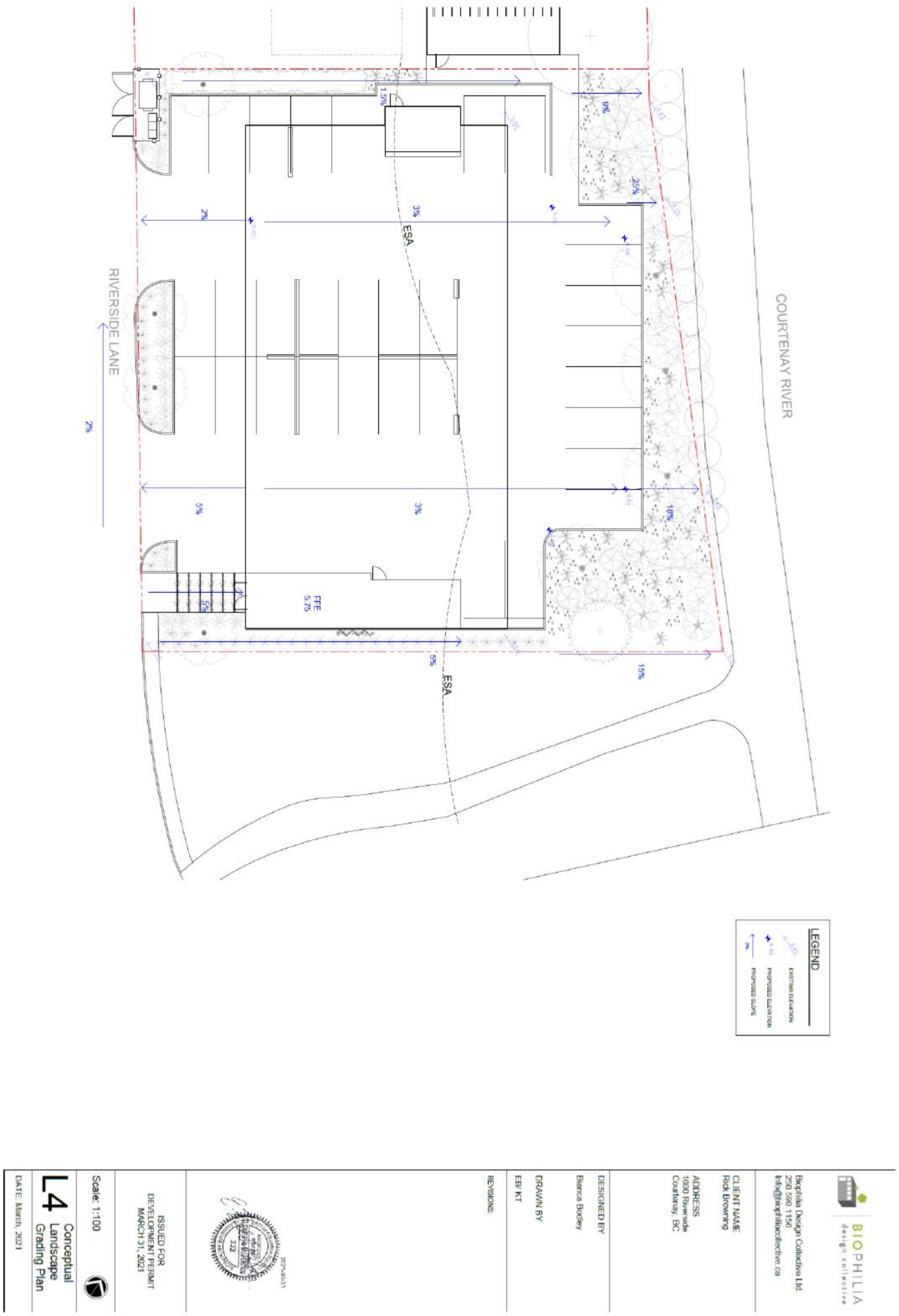
SHRUBS PLANTING SCHEDULE

ID	Quantity	Symbol	Latin Name	Common Name	Category	Container Size	Height in maturity	Spread in maturity	Native
Mc	9		Morella Californica	Pacific Wax Myrtle	Shrub	1 Gallon	1-8m	1-3m	X
Sp	18		Salix purpurea 'Nana'	Arctic Willow	Shrub	1 Gallon	1.5m	1.5m	X
Je	40		Juncus effusus	Common Rush	Perennial	10 cm	10 cm	0.6m	X
Pm	20		Polystichum munitum	Sword Fern	Fern	1 Gallon	0.9m	1.5m	X
Cc	18		Cornus canadensis	Bunchberry	Groundcover	Plug	0.2m	0.2m	X
Pc	9		Physocarpus capitatus	Pacific Ninebark	Shrub	1 Gallon	3m	3m	X
Vo	15		Vaccinium ovatum	Evergreen Huckleberry	Shrub	1 Gallon	1.2m	1.2m	X
Rs	6		Ribes sanguineum	Red Flowering Currant	Shrub	1 Gallon	2.0m	2.5m	X
Pt	2		Parthenocissus tricuspidata	Boston Ivy	Vine	1 Gallon	9-15m	1-3m	

Attachment No. 1
12/15

DPV2107

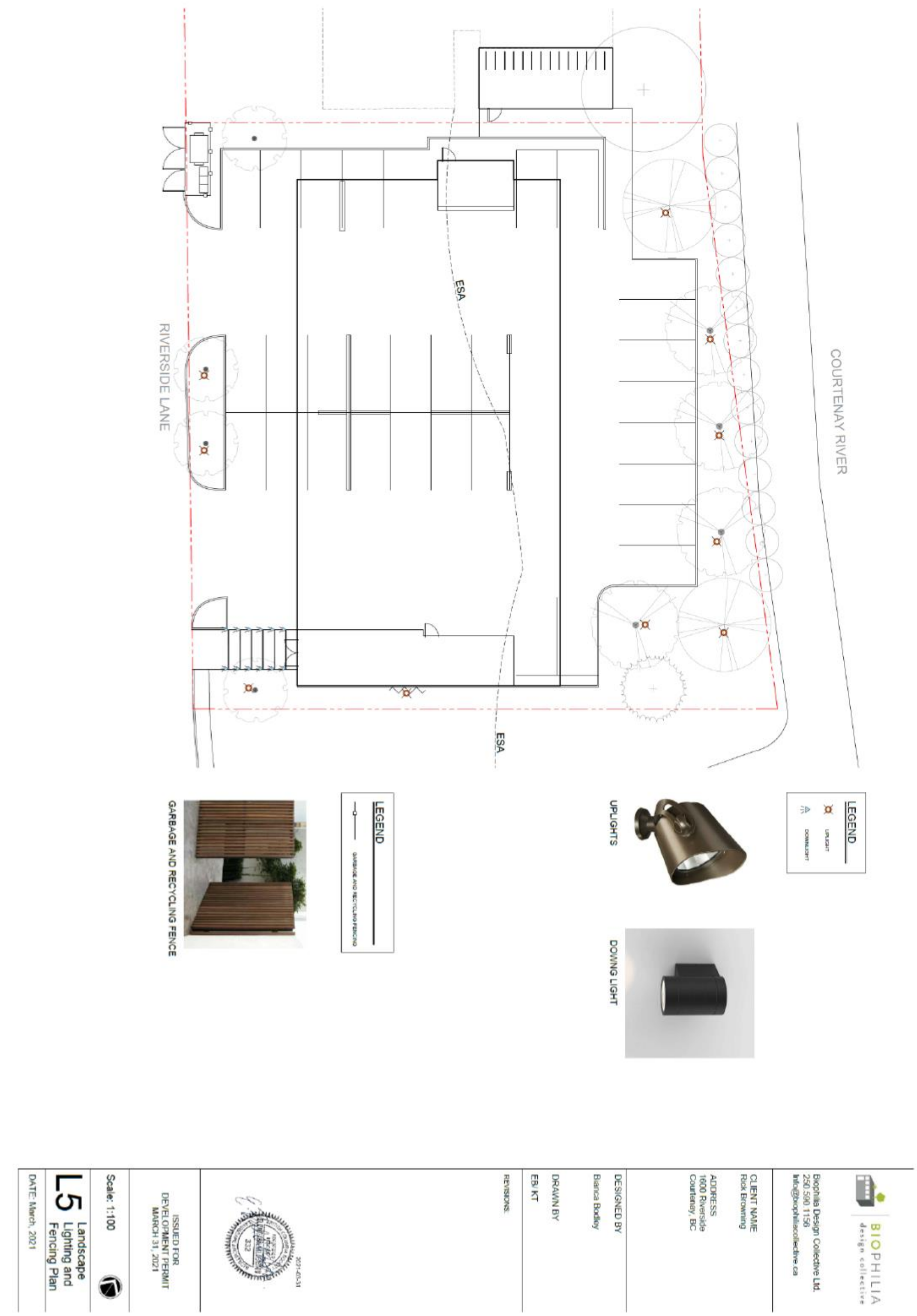
Schedule No.2: Landscape Plan
Page **5** of **6**



Attachment No. 1
13/15

DPV2107

Schedule No.2: Landscape Plan
Page **6** of **6**



BIOPHILIA design collective

Attention:
File Manager
City of Courtenay, Courtenay, BC
March 30, 2021

Re: 1600 Riverside Lane, Courtenay, BC

The following is the landscape budget for drawings submitted for Development Permit dated March 31, 2021.

Landscape Budget Estimate

Tree Protection, Tree Removal and Site Grading	Unit	Price	Qty	Extension
Tree Protection Fencing Installation and Removal	lm	$ 10.00	54	$ 540.00
Tree Removal and Disposal	ea	$ 200.00	7	$ 1,400.00
Clearing and Grubbing, Rough Grading, Shrub Bed Excavation	m2	$ 10.00	350	$ 3,500.00
Sub-Total				$ 5,440.00
Hard Landscape				
Concrete Sidewalk to Trail (including base prep and gravel base)	m2	$ 80.00	17	$ 1,360.00
Concrete Pad for garbage and Recycling (including base prep and gravel base)	m2	$ 80.00	9	$ 720.00
Enhanced Entry Paving (including base prep and gravel base)	m2	$ 200.00	19	$ 3,800.00
Permeable Paving to Bike Parking (including base prep and gravel base)	m2	$ 150.00	32	$ 4,800.00
Sub-Total				$ 10,680.00
Fencing and Trellis				
Cedar Fencing and Gates	lm	$ 185.00	15	$ 2,775.00
Wire Cable Trellis	m2	$ 100.00	20	$ 2,000.00
Sub-Total				$ 4,775.00
Growing Medium and Mulch				
Planting Bed 450 mm Depth - Installed	m2	$ 42.75	350	$ 14,962.50
Mulch 50 mm Depth - Installed	m2	$ 4.75	350	$ 1,662.50
Sub-Total				$ 16,625.00

BIOPHILIA
design collective

Plant Material

Trees (50 mm Cal) - Installed	ea	$ 450.00	10	$ 4,500.00
Shrubs (# 1) - Installed	ea	$ 19.50	86	$ 1,677.00
Groundcovers (10 cm) - Installed	ea	$ 14.00	61	$ 854.00
Vines (# 1) - Installed	ea	$ 22.50	2	$ 45.00
Sub-Total				**$ 7,076.00**

Irrigation

Irrigation	zones	$ 1,000.00	2	$ 2,000.00
point of connection, controller, backflow preventer	ls	$ 1,500.00	1	$ 1,500.00
Sub-Total				**$ 3,500.00**

Total (excluding tax) **$ 48,096.00**

Should you have any questions, please contact our team.

Respectfully,

Bianca Bodley

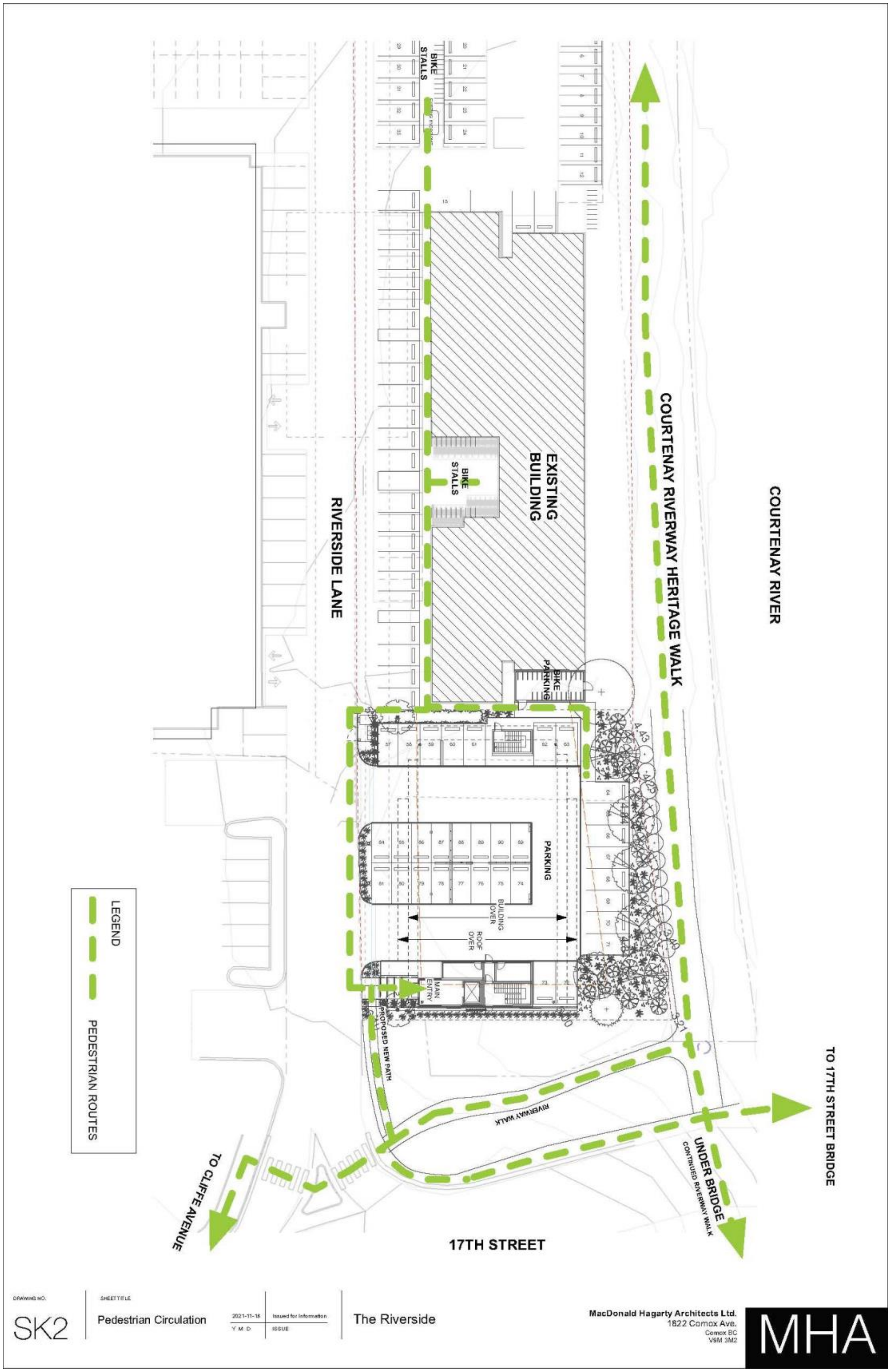
BRITISH COLUMBIA SOCIETY OF LANDSCAPE ARCHITECTS
REGISTERED MEMBER
ELIZABETH M. BALDERSTON
332
2021-03-30

Bianca Bodley
Owner and Principal

Elizabeth Balderston
Project Landscape Architect

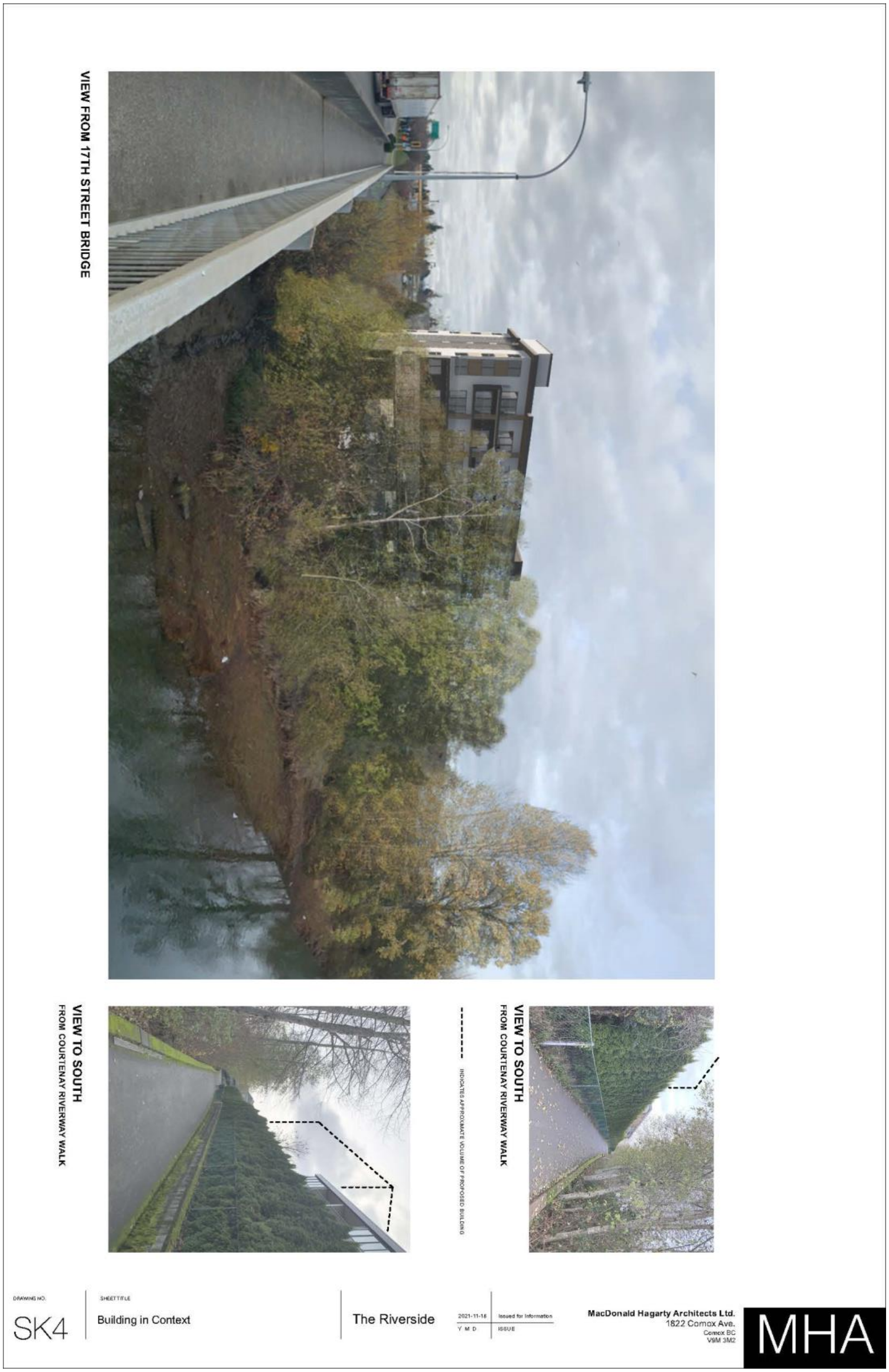
Attachment No. 2

Attachment No. 2: Pedestrian Circulation



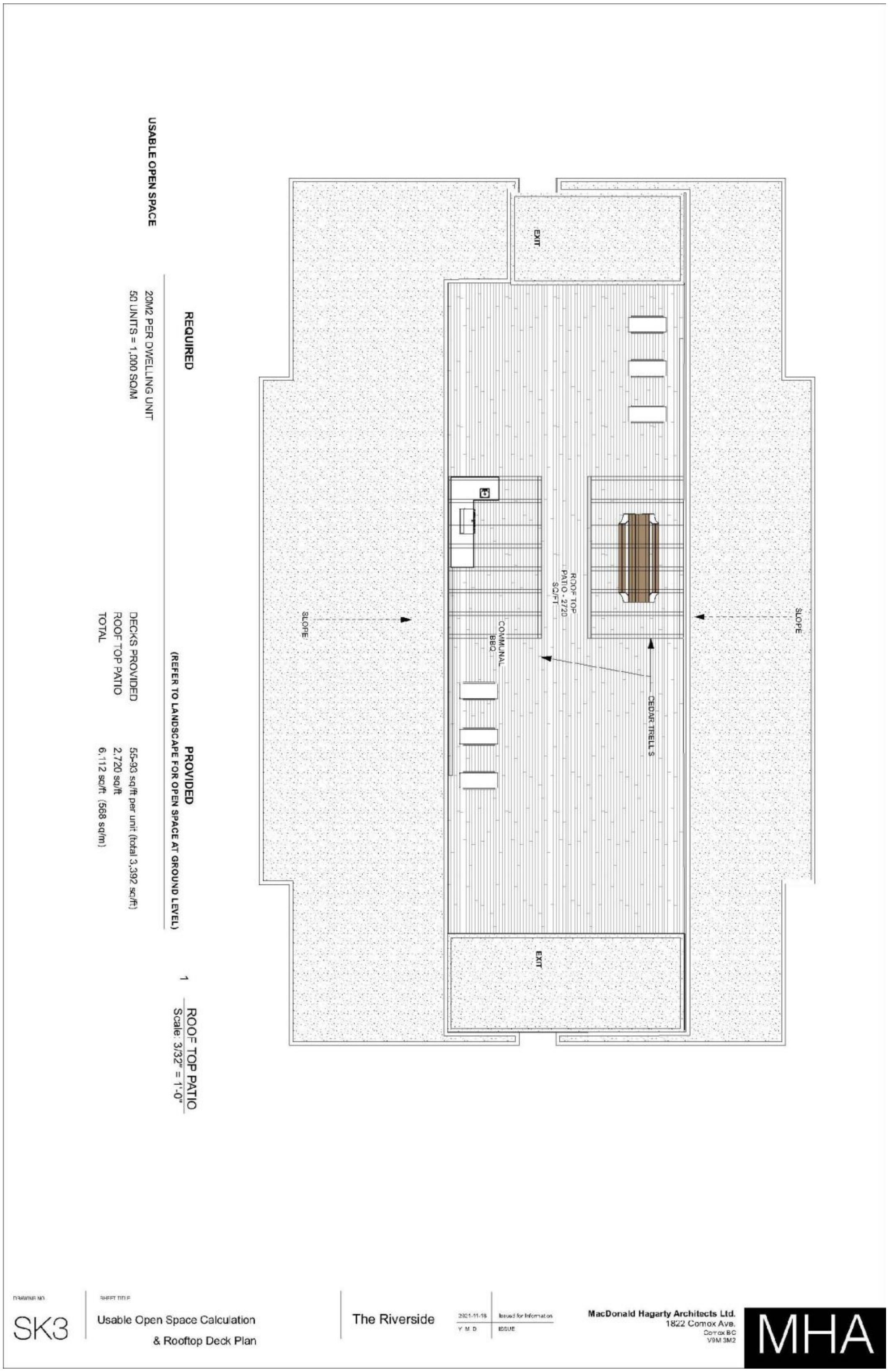
Attachment No. 3

Attachment No. 3: Updated Renderings



Attachment No. 4

Attachment No. 4: Update Rooftop Patio



Attachment No. 5

Attachment No. 5 – Amenity Contribution Offer

PACIFIC SWELL

17 November, 2021

Matthew Fitzgerald
Manager of Development Planning
City of Courtenay
830 Cliffe Avenue,
Courtenay, BC,
V9N 2J7

[Via email: mfitzgerald@courtenay.ca]

Re: PacSwell Developents Courtenay, Inc Affordable Housing Proposal

Dear Mr. Fitzgerald,

As a result of council's request to add affordable housing units to our Development Permit Application, and the discussions which have ensured since; I write you today to formally set forth our proposal to dedicate 10% of the proposed new units, equating to 5 affordable rental units.

As specified by your team, the rental rates will be calculated based on 30% of the gross household income levels published in BC Housing's annual Housing Income Limits (HILs) publication. The HILs rates are intended to reflect the minimum income required to afford appropriate accommodation in the private market. Under this formula rental rates for a "1 bedroom or less" in the Courtenay-Comox planning area would be capped at $987.50.

This is as noted in the BC Housing 2021 Housing Income Limits found at the following link: (https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwju5Ij9u530AhWG_54KHQCADNoQFnoECAgQAQ&url=https://www.bchousing.org/publications/2021-Housing-Income-Limits-HILS-Effective-September-1-2021.pdf&usg=AOvVaw2Xtq-a-wKMj0W400Wn0MUC)

In the hopes of providing immediate affordable rental units, and assisting the City in its efforts, we propose to include 2 studio units (units 108 and 109) in our existing building be placed under this programme immediately, and once construction is complete, an additional 3 studio units in the proposed new building, for a total of 5 units, or 10% of the 50 units planned in the new building.

We acknowledge that the units will be secured through a housing agreement which will last for ten years after which the units will revert to private market rental rates. We understand that it will be our responsibility under the housing agreement to ensure the units remain at the proposed rents of $987.50 per month. The agreement will be drafted by the City's solicitor and include the requirement for us to provide reports to the City to ensure compliance. Reports will be required on an annual basis or as tenants change in the affordable units. Failure to provide these reports will include a "rent" (penalty) charge under the agreement for non-compliance.

I hope this is well received by you and we look forward to doing our part. Please don't hesitate to contact Ryan, Maris or myself.

My very regards,

Rick Browning
General Partner
PacSwell Developments Courtenay, Inc (& Riverside Apartments, LP)

ec: Ryan Cohen via email: ryan@pacswell.ca
Maris MacDonald via email: maris@mharchitects.ca

THE CORPORATION OF THE CITY OF COURTENAY

STAFF REPORT

To:	Council	**File No.:**	5335-20
From:	Chief Administrative Officer	**Date:**	December 6, 2021
Subject:	**Air Quality and Wood Smoke in the Comox Valley**		

PURPOSE:

The purpose of this report is to provide Council with an overview of data related to air quality and wood smoke in the Comox Valley, and to seek support for staff participation in development of a Regional Airshed Protection Strategy.

CAO RECOMMENDATIONS:

THAT based on the December 6, 2021 staff report "Air Quality and Wood Smoke in the Comox Valley" Council approve OPTION 1, and direct staff to:

1. Represent the City of Courtenay at Regional Airshed Committee meetings; and
2. Support the development of a Regional Airshed Protection Strategy.
3. Send correspondence to the regional district encouraging them to adopt regulatory bylaws for the Electoral Areas to limit activities that contribute to poor air quality in the region. This includes: bylaws limiting the installation of new woodstoves, restrictions on backyard burning and non-agricultural or forestry related land clearing burning.

Respectfully submitted,

Geoff Garbutt, MCIP, RPP
Chief Administrative Officer

BACKGROUND:

The City of Courtenay experiences periods of poor air quality during winter months. This is caused by a fine particulate matter ($PM_{2.5}$) emitted from wood burning appliances, and atmospheric temperature inversions.

Air Quality Measurements

The Comox Valley has one provincial air monitoring station located at the Courtenay Elementary School. This air monitoring station continuously records temperature, humidity, wind speed, wind direction, and pollutant concentrations. Concentrations of fine particulate matter, nitrogen dioxide, and ozone are measured at the Courtenay air monitoring station and are compared against the BC Air Quality Objectives (AQO), which define the acceptable limit for pollutants.

Air monitoring occurs continuously; and the data is analyzed by calculating the average concentration over a set time period. This time period is known as the averaging period. The BC AQO specify limits for pollutants over different averaging periods. Table 1 summarizes the BC AQO, and Courtenay air monitoring results recorded in 2020.

Table 1: BC Air Quality Objectives and Courtenay Air Monitoring Results

	Averaging Period	BC Air Quality Objective (AQO)	Courtenay Air Monitoring Result (2020)
Fine Particulate Matter ($PM_{2.5}$)	24 hr	25 $\mu g/m^3$	23.2 $\mu g/m^3$
	Annual	8 $\mu g/m^3$	7.2 $\mu g/m^3$
Nitrogen Dioxide (NO_2)	1 hr	100 ppb	12.75 ppb
	Annual	32 ppb	3.02 ppb
Ozone (O_3)	8 hr	63 ppb	41.9 ppb

Concentrations of nitrogen dioxide, and ozone are far below the BC AQO, and do not pose a concern. Concentrations of fine particulate matter met the BC Air Quality Objectives in 2020, for the first time in ten years. This is encouraging, however it is too soon to tell if this is an anomaly, or a part of a larger downward trend of $PM_{2.5}$ concentrations. Graphs presenting the $PM_{2.5}$ monitoring data collected since 2011 are provided in Attachment 1. Key findings of the air monitoring data are summarized below:

- Courtenay experiences multiple days of poor air quality every year caused by elevated $PM_{2.5}$
- The daily average concentration of $PM_{2.5}$ has been decreasing since 2017.
- Good quality air, with low levels of $PM_{2.5}$ is observed from April to September, unless wildfire smoke blows into the region.
- Elevated concentrations of $PM_{2.5}$ only occurs during winter months from October to March.
- During a typical winter day, $PM_{2.5}$ concentrations rise after 6 PM, peak just before midnight, and drop overnight, with a small peak in the morning. Most afternoons are clear with low levels of $PM_{2.5}$.

Sources of Fine Particulate Matter ($PM_{2.5}$) in the Comox Valley

In 2015, the BC Ministry of Environment compiled a particulate matter emissions inventory for the Comox Valley Regional District (Attachment 2). This inventory found that open burning (45%) and space heating (36%) account for most of the $PM_{2.5}$ emissions in the Comox Valley. A detailed breakdown of these sources is presented in Figure 1.

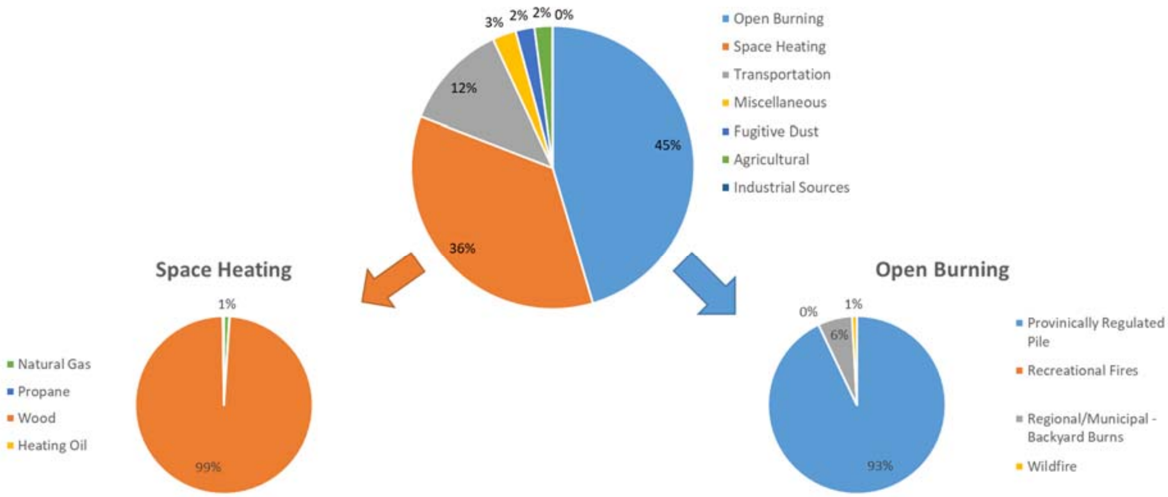


Figure 1: Sources of fine particulate matter in the Comox Valley

This inventory represents an average for the entire Comox Valley Regional District. Most of the $PM_{2.5}$ emissions produced from open burning are provincially regulated by the Open Burning Smoke Control Regulation. Less than 7% of open burning $PM_{2.5}$ emissions are from backyard burns, wildfire, and recreational fires. Within the City limits, land clearing and backyard burning is prohibited by municipal regulation, and therefore space heating is the largest source of $PM_{2.5}$ emissions. Almost all $PM_{2.5}$ emissions related to space heating are produced from wood burning appliances (98.7%), and only a small fraction (1.3%) are produced from a combination of natural gas, propane and heating oil.

In 2018, the Comox Valley Regional District conducted the Home Heating Survey to learn more about local home heating habits. This survey found that 21% of respondents within the Comox Valley used a wood burning appliance as a primary heat source. The Home Heating and Air Quality Survey Report for the Comox Valley is provided in Attachment 3. More information about the emissions produced from each primary heat source, and the proportion of the population that uses them is presented in Figure 2.

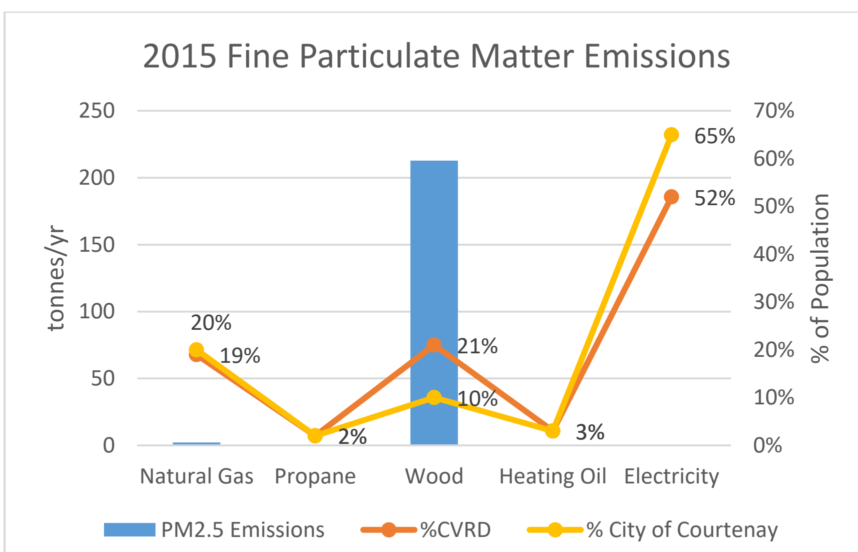


Figure 2: $PM_{2.5}$ Emissions produced from each residential heat source, and use among CVRD and City of Courtenay residents

This graph demonstrates that wood burning appliances emit 70 times more $PM_{2.5}$ than all other home heating options combined. Within the City of Courtenay, only 10% of respondents used a wood burning appliance as a primary heat source. According to the 2016 consensus, the City of Courtenay had approximately 20,000 dwellings. Consequently, an estimated 2000 dwellings use a wood burning appliance as a primary heat source, which are responsible for producing most of the $PM_{2.5}$ within the City of Courtenay.

The Impact of Atmospheric Temperature Inversions

The impact of wood smoke on air quality is magnified by atmospheric temperature inversions experienced by the Comox Valley.

In a normal atmospheric condition, the air near the ground is warmer than the cool air above it, so the warm air rises because it is less dense than cold air above it. As warm air rises, it cools and falls back to the ground. This movement of air creates vertical mixing that carries pollutants away from the surface, and disperses them in the upper atmosphere.

In an inverted atmospheric condition, vertical mixing does not occur because the air near the ground is cooler than the warm air above it. As a result, temperature inversions restrict the upward movement of air, causing pollutants to become trapped and accumulate under the inversion layer. Inversion layers can form near ground level, or thousands of meters in the atmosphere.

A temperature inversion occurs whenever the air temperature at the surface is colder than the air above it. This commonly occurs:

- On clear nights when the ground rapidly loses heat, and the surrounding air retains it.
- In valleys, where cold air from mountain peaks flows down the mountain and fills the valley
- In coastal areas where the upwelling of cold water decreases surface air temperatures.

The geographic position of the City of Courtenay within a valley, and along the coast makes the region especially susceptible to temperature inversions. In the Comox Valley, inversions occur frequently, forming almost daily or multiple times a week. Inversions often form at dusk and break the following day, when the sun warms the surface of the valley. However, inversions may last for multiple days if the weather remains cloudy and the winds are calm. Inversions that last for multiple days, often trigger a provincial air quality advisory because all particulate matter emitted for the duration of the inversion accumulates, creating hazardous conditions.

Atmospheric inversions create poor venting conditions in the evenings when people are most likely to use wood burning appliances. This is problematic because the dispersion of smoke from a wood burning appliance is governed by the atmospheric condition. For example, an appliance may appear to burn well under good atmospheric venting conditions, however the same appliance may appear to burn poorly during an atmospheric temperature inversion when venting conditions are poor.

For this reason, wood burning appliances have a significant and adverse impact on air quality immediately adjacent to them. Those who live in areas where one or more wood burning appliances are operated at the same time, are most impacted. As a result, air quality issues are highly localized and the concentration of $PM_{2.5}$ varies significantly within a neighbourhood, or along a street. This trend was demonstrated in a mobile monitoring study conducted in the Comox Valley in 2017 by Matthew Wagstaff, a master's student from the University of British Columbia. This study is provided in Attachment 4.

Provincial Regulations & Compliance

Open Burning Smoke Control Regulation

In September 2020, the province of BC introduced a new version of the Open Burning Smoke Control Regulation. This regulation applies to open fire combustion of vegetative debris, including: land clearing, forestry operations, agriculture, community wildfire risk reduction, wildlife habitat enhancement, and utility right of ways.

The regulation establishes high, medium, and low smoke sensitivity zones. The Comox Valley and the region along the east coast of Vancouver Island is designated as a high sensitivity zone. Within this zone, restrictions include: the types of items that may be burned, the moisture content, burn time, setbacks and ventilation index. Since this regulation is relatively new, the impact of this regulation on air quality is yet to be determined.

Solid Fuel Burning Domestic Appliance Regulation

The Solid Fuel Burning Domestic Appliance Regulation was first introduced in 1994, to ensure woodstoves and pellet stoves sold in BC meet the US Environmental Protection Agency (EPA) standard. In 2016, the Province of BC amended the regulations to make them more restrictive. The scope of the regulation was expanded to include a wider range of wood burning appliances, and the type of fuel that can be burned was defined. This regulation specifies that a vendor must not sell or offer to sell, a new appliance unless the vendor has records that demonstrate the appliance is certified to meet emission standards set by Canadian Standards Association (CSA) B415.1-10 or the United States Environmental Protection Agency (EPA).

The regulation specifies that only untreated, seasoned wood may be burned. Seasoned wood is defined to be wood with a moisture content of less than 20%. Other fuels that may be burned include: wood pellets, manufactured fire logs, corn kernels and seed hulls. Prohibited items include: garbage, plastics, treated or painted wood demolition debris, rubber or unseasoned wood, with a moisture content above 20%.

Compliance with this regulation can be estimated by the results of the 2018 Home Heating Survey conducted by the CVRD. This survey gathered data on the method of wood storage, and amount of time residents store their firewood before burning, illustrated below in Figure 3 and 4.

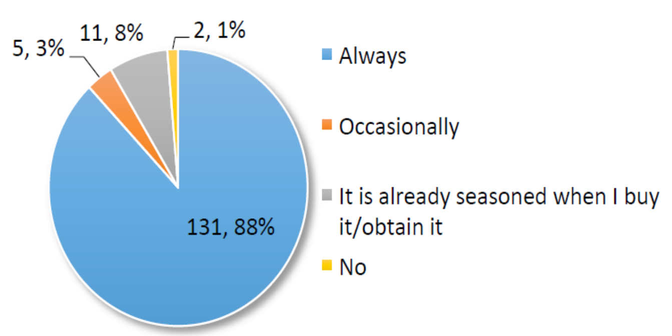


Figure 3: Number of respondents that stack their wood under a sheltered area with sufficient air flow on three sides (n=149)

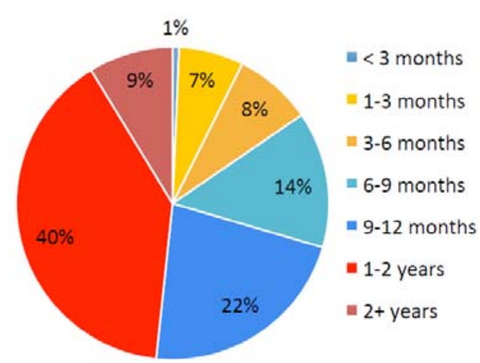


Figure 4: Amount of time respondents store their firewood before burning (n=149)

The CVRD Survey found that 96% of respondents stack their wood in a sheltered area with sufficient airflow, and 84% of respondents season their wood for more than 6 months. This demonstrates that Comox Valley residents already comply with wood burning best practices.

The home heating survey also found that 97% of respondents with wood burning appliances have devices that were installed after 1994. This suggests that almost all stoves currently in use, are certified to comply with US EPA emission limits. The US EPA emission limits have decreased over time. They were first introduced at 7.5 g/hr, dropping to 4.0 g/hr in 2015 and 2.0 g/hr in 2020. Despite these decreases, the real world performance of certified wood stoves has been scrutinized by the Northeast States for Coordinated Air Use Management (NESCUM) who conducted an assessment of the US EPA's Residential Wood Heater Certification Program. This assessment uncovered a systemic failure of the entire certification process.

It was found that emission tests conducted by wood heater manufacturers, and EPA-approved testing laboratories deviated from the approved test method requirements, and from the methods described in the manufacturer's owner manual instructions. These deviations in test methodology artificially lower emissions in the lab to meet certification standards. As such, stated emission standards cannot be achieved in real world circumstances. The findings of the NESCUM report raise serious concerns for public health and local government, because provincial regulations based on a flawed certification system will have limited effectiveness. This report is provided in Attachment 5.

How to Reduce Fine Particulate Matter ($PM_{2.5}$) from Wood Stoves

Three factors determine how much particulate matter is emitted from wood burning appliances:

1. The emission rate from an individual woodstove;
2. The number of hours each woodstove operates; and
3. The number of woodstoves in a community.

As one or more of these factors is reduced, particulate matter emissions are also reduced.

The $PM_{2.5}$ emission rate of an individual woodstove can be reduced by using a certified appliance and only burning dry seasoned wood. However, data indicates that most wood stoves in use in the Comox Valley are already certified, and most residents already season their wood adequately. Even considering these efforts, $PM_{2.5}$ emissions from wood heat are more than 70 times greater than $PM_{2.5}$ emissions from all other sources of residential heat. Consequently, efforts to reduce the emission rate from wood stoves is not effective enough to improve air quality, and should be combined with other actions.

The operating hours of each woodstove can be reduced by using wood burning appliances infrequently - either as a secondary heat source, or an emergency back-up. If each woodstove was operated for fewer hours a year, emissions would drop relative to the reduction in use.

The number of woodstoves within a community can be reduced by switching to a different type of home heating. Other residential heating options emit significantly less $PM_{2.5}$, so this approach will offer the greatest reduction in fine particulate matter.

DISCUSSION:

Improving air quality in the Comox Valley is a local and regional priority. In addition to provincial regulations, air quality is being addressed by: the wood smoke reduction program, local bylaws, regional rebates, and a regional airshed committee.

Wood Smoke Reduction Program

The province of BC has been running the BC Wood Stove Exchange Program since 2008. This program is administered locally by the Comox Valley Regional District, that coordinates the Wood Smoke Reduction Program.

This program offers education about smart burning practices and rebates to residents who replace a wood burning appliance with a gas stove, pellet stove, propane stove; or an electric heat pump. In this program, additional rebates funded by Island Health are offered to residents located in wood smoke hot spot areas such as Cumberland and West Courtenay who install an electric heat pump. Previous versions of the program offered rebates for certified wood stoves, however this option has been removed, since certified wood stoves are no longer considered an effective solution to address air quality concerns.

Local Bylaws

Within the Comox Valley, some municipalities have restrictions on backyard burning and open burning. Bylaws restricting the installation of wood burning appliances have been adopted by the City of Courtenay, the Town of Comox and the Village of Cumberland. An overview of the relevant bylaws is summarized in Attachment 6.

Regional Rebates

The CVRD Wood Smoke Reduction Program offers rebates of $1,000 to residents who replace a wood stove, older than 2016 with an electric heat pump, natural gas furnace or insert, pellet stove, or propane heater. Residents who live in wood smoke hot spot areas such as West Courtenay or Cumberland are eligible for an additional $2,500 if they trade their woodstove for an electric heat pump.

Clean BC offers up to $3,000 to install a heat pump, and BC Hydro offers up to $2000 to install a heat pump. Rebates from each of these three organizations may be combined to offer additional cost savings. A summary of these rebates are presented in Table 3.

Table 2: Summary of rebates offered for residential home heating

Organization	Conditions	Amount
CVRD Wood Smoke Reduction Program	Remove a 5+ year old wood burning appliance	$1,000 toward an electric heat pump, gas furnace or insert, pellet stove, propane heater. $2,500 toward an electric heat pump in hot spot areas (Cumberland & west Courtenay)
Clean BC	Install a heat pump	$1,000 - $3,000
BC Hydro	Install a heat pump	$1,000 - $2,000

Regional Airshed Committee

In 2020, a regional airshed committee was established by the CVRD. A report summarizing the first year of the Regional Airshed Committee is provided in Attachment 7. The vision of the airshed committee is: The Comox Valley has clean air supporting the health of all residents. The airshed committee is led by the Comox Valley Air Quality Coordinator, and is composed of a steering committee, and a roundtable membership. The City of Courtenay is an active participant on the airshed steering committee and roundtable, along with individuals representing the CVRD, the Town of Comox, the Village of Cumberland, the Ministry of Environment, Island Health, and Vancouver Island University. The vision statement is supported by the following goals:

1. Achieve measureable reductions in fine particulate matter levels
    a. Reduce emissions from existing residential wood burning appliances
    b. Transition away from biomass heating systems
    c. Eliminate burning of yard waste in residential neighbourhoods
    d. Promote and advocate for alternative to open burning outside of residential neighbourhoods.
2. Effective coordination of efforts
3. Educate and engage the community

Working groups composed of both roundtable and steering committee members were established to identify actions to achieve the goals. These actions form the basis of the Airshed Protection Strategy, which will be available for public review in January 2022. Once the Airshed Protection Strategy is finalized in the spring of 2022, it will be ready for implementation.

RECOMMENDATIONS:

It is recommended that the City of Courtenay continue to support the development of the Regional Airshed Protection Strategy. Council will have an opportunity to provide feedback on the strategy, during the review process in January 2022. Once the Regional Airshed Protection Strategy is finalized, staff will evaluate the implications of implementation, and seek council approval for implementation in Spring 2022.

FINANCIAL IMPLICATIONS:

There are no financial implications at this time, with the exception of staff time to contribute to the review and finalization of the Regional Airshed Protection Strategy. The financial implications associated with implementation will be considered once the strategy is finalized, and presented to council for approval.

ADMINISTRATIVE IMPLICATIONS:

Engineering Services is an active participant on the regional airshed committee, and has been involved in the development of the regional airshed protection strategy to date. Approval of this staff report will maintain the involvement of Engineering Services.

ASSET MANAGEMENT IMPLICATIONS:

There are no asset management implications at this time. Once the Airshed Protection Strategy is finalized, asset management implications will be considered.

STRATEGIC PRIORITIES REFERENCE:

The City of Courtenay's 2019-2022 Strategic Priorities include six themes and 28 priorities. The local implementation of regional airshed actions aligns with the priorities listed below.

We proactively plan and invest in our natural and built environment

- ▲ Look for regional infrastructure solutions for shared services
- ● Make progress on the objectives of the BC Climate Action Charter
- ●▲ Advocate, collaborate and act to reduce air quality contaminants
- ●▲ Support social, economic and environmental sustainability solutions

We continually invest in our key relationships

- ●■ Consider effective ways to engage with and partner for the health and safety of the community
- ▲■ Advocate and cooperate with local and senior governments on regional issues affecting our community

The City of Courtenay defined Strategic Priorities for 2021-2022. This Regional Air Quality Initiative was identified as a priority for both Engineering Services, and Advocacy and Partnerships.

OFFICIAL COMMUNITY PLAN REFERENCE:

The development of the Wood Smoke Bylaw Options aligns with the following policies described in the Official Community Plan.

10.3 Policies and Objectives

Objective 5: To protect a representative variety of Courtenay's natural heritage and to maintain, and where necessary enhance, water and air quality, healthy soils and all species native to Courtenay, with an emphasis on rare and endangered species, sensitive ecosystems and essential ecosystem functions.

6. The City will continue to support community based air quality research and monitoring initiatives including monitoring of green house gas emissions.

REGIONAL GROWTH STRATEGY REFERENCE:

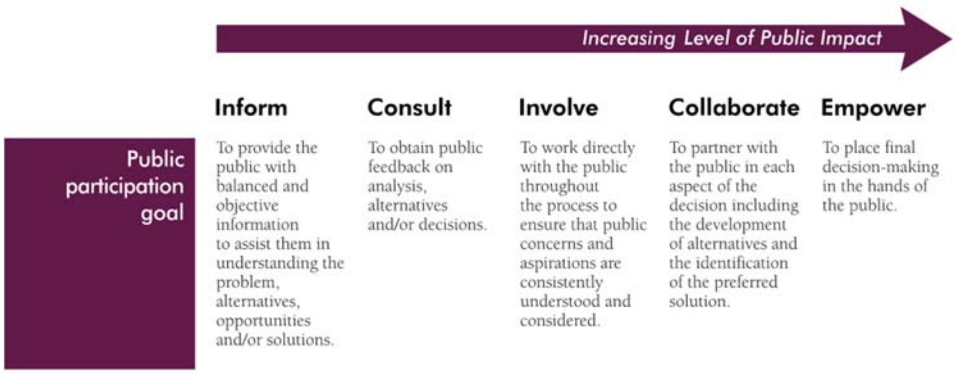
The development of the Wood Smoke Bylaw options is aligned with "Goal 7: Public Health and Safety". The Regional Growth Strategy (RGS) notes that exposure to air pollutants has increased, and with it childhood asthma rates. It also noted that chronic diseases like cardiovascular and respiratory disease, diabetes and cancer, are all on the rise in the CVRD. The RGS speculated that the increase in chronic disease could be related to increasing risk factors, like the lack of physical activity and obesity. The elevated concentrations of fine particulate matter were not listed as a risk factor in the RGS, however medical professionals have established air pollution as a risk factor in the development of chronic cardiovascular and respiratory diseases. No policies supporting Goal 7: Public Health and Safety are provided in the RGS.

The development of this bylaw is also aligned with "Goal 8: Climate Change" in the RGS. Supporting policies:

- 8A-5 Local governments should develop GHG reduction strategies for the operation, maintenance and construction of their buildings in the Comox Valley.
- 8E-1 Encourage efforts to increase the use of cost competitive renewable energy.

CITIZEN/PUBLIC ENGAGEMENT:

Stakeholder engagement has been facilitated by the Regional Airshed Committee, which **collaborated** and **involved** the public and key stakeholder groups based on the IAP2 Spectrum of Public Participation: https://iap2canada.ca/Resources/Documents/0702-Foundations-Spectrum-MW-rev2%20(1).pdf



OPTIONS:

Option 1: THAT based on the December 6, 2021 staff report "Air Quality and Wood Smoke in the Comox Valley" Council approve OPTION 1, and direct staff to:

1. Represent the City of Courtenay at Regional Airshed Committee meetings; and
2. Support the development of a Regional Airshed Protection Strategy.
3. Send correspondence to the regional district encouraging them to adopt regulatory bylaws for the Electoral Areas to limit activities that contribute to poor air quality in the region. This includes: bylaws limiting the installation of new woodstoves, restrictions on backyard burning and non-agricultural or forestry related land clearing burning.

Option 2: Refer back to Staff for further review.

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Reviewed by:

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Concurrence by:

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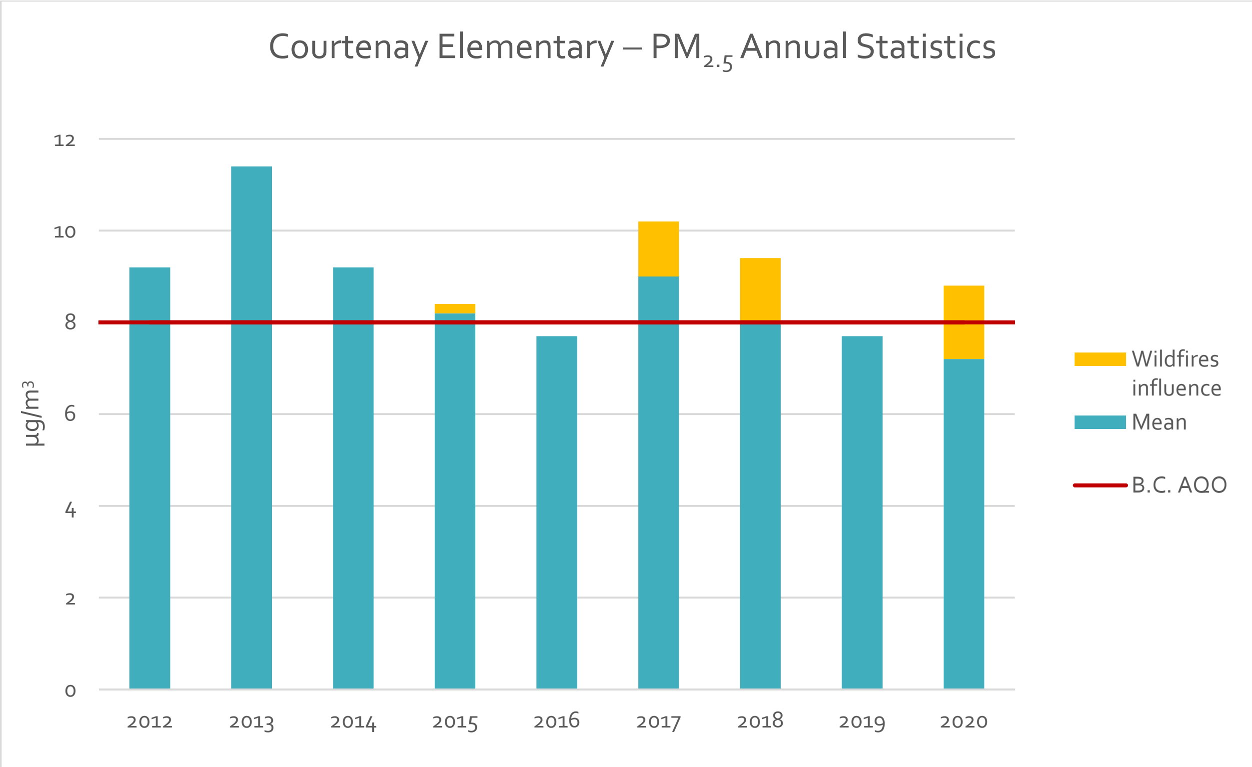
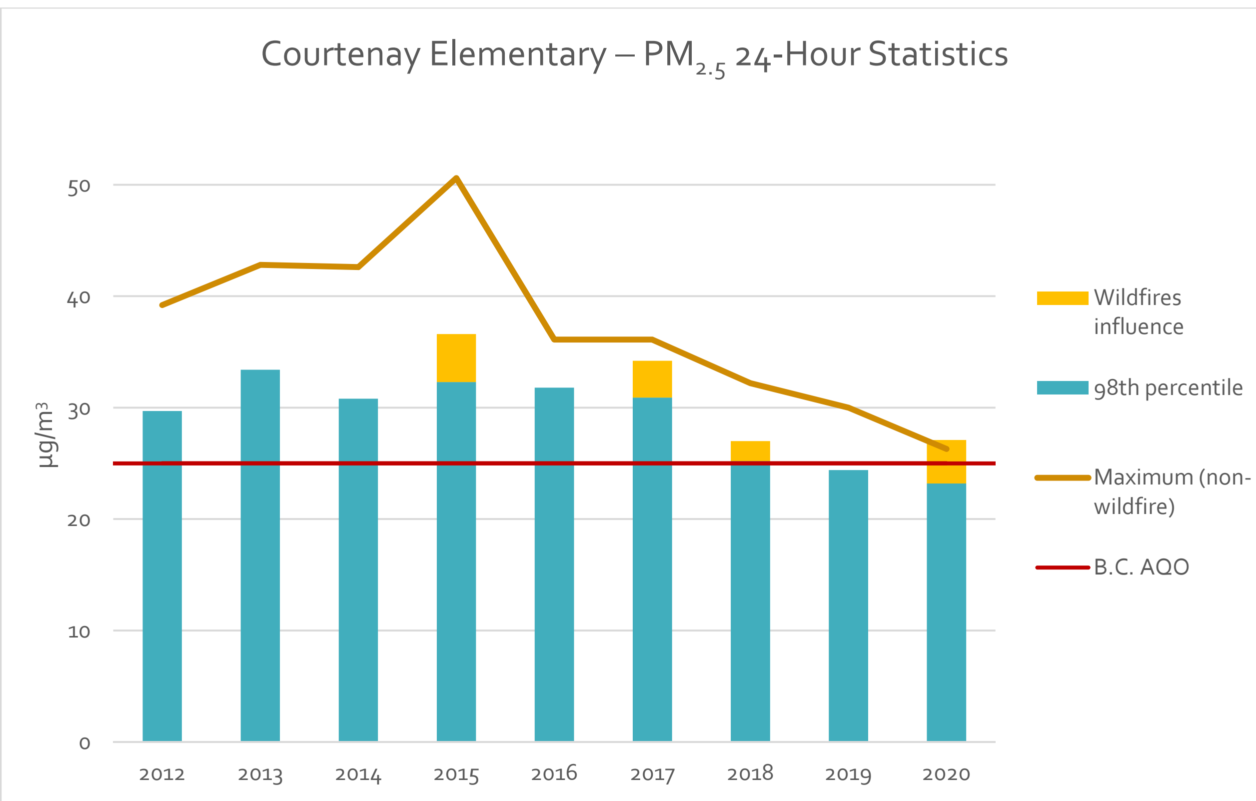
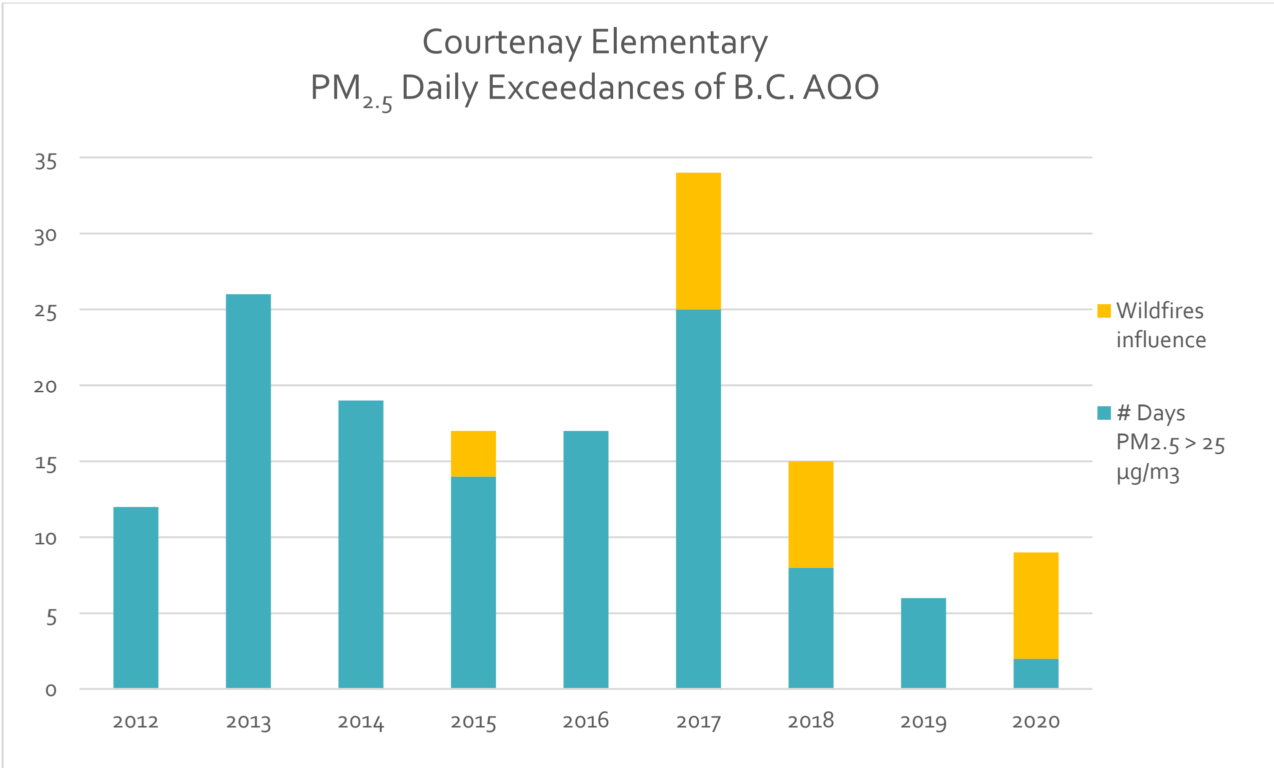
ATTACHMENTS:

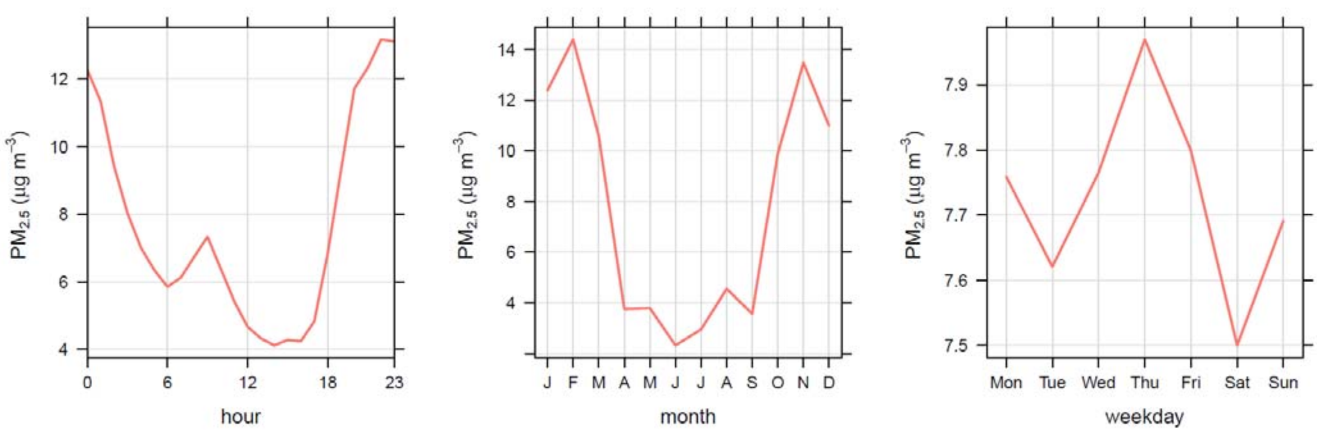
Attachment #1:	Ministry of Environment, Key Findings from $PM_{2.5}$ Stationary Monitoring at Courtenay Elementary
Attachment #2:	Particulate Matter Emissions Inventory for the Comox Valley 2015 Base Year.
Attachment #3:	Home Heating and Air Quality Survey Report for the Comox Valley
Attachment #4:	Monitoring Residential Woodsmoke in British Columbia Communities
Attachment #5:	Assessment of EPA's Residential Wood Heater Certification Program. Test Report Review: Stoves and Central Heaters
Attachment #6:	Comox Valley Regional District, Bylaw Review Summary
Attachment #7:	Regional Airshed Roundtable Year 1 Report, Comox Valley Regional District





Attachment 1: Ministry of Environment, Key Findings from $PM_{2.5}$ Stationary Monitoring at Courtenay Elementary


Courtenay Elementary
PM2.5 Daily Exceedances of B.C. AQO
35
30
25
20
15
10
5
0
2012
2013
2014
2015
2016
2017
2018
2019
2020
Wildfires influence
Days PM2.5 > 25 µg/m3


PM2.5 (µg m-3)
hour
0
6
12
18
23
month
J F M A M J J A S O N D
weekday
Mon Tue Wed Thu Fri Sat Sun

BRITISH COLUMBIA | Ministry of Environment and Climate Change Strategy

ATTACHMENT 2

Foreword – Road Dust Emissions Inventory Uncertainties and Contributions to $PM_{2.5}$ in the Comox Valley

Road dust is not an important source of fine particulate matter ($PM_{2.5}$) in the Comox Valley. Ambient measurements of $PM_{2.5}$ show that concentrations are low during the warm/dry periods of spring and summer (when road dust impacts would be expected) and elevated during the cool/wet fall and winter periods primarily due to sources of wood smoke[1] such as open burning and residential wood heating.

To clarify, the road dust emissions estimates presented in the emissions inventory report entitled "Particulate Matter Emissions Inventory for the Comox Valley 2015 Base year" (RWDI 2017) are based on methods that include a large degree of uncertainty. For this inventory, a provincial road dust value taken from a national emissions inventory, was scaled down to the Comox Valley airshed level using predicted fuel-sales as a proxy – this was the best scaling information available for the region. This method resulted in an estimated road dust contribution to $PM_{2.5}$ of 46%. More accurate methods to estimate road dust emissions are based on a number of site-specific variables which are not known with any degree of certainty without extensive field measurements. Because of the large uncertainty in these estimates, road dust emissions are omitted from discussion in the report, as they are not a significant source of $PM_{2.5}$ in this area.

A better estimate of road dust contributions to fine particulate matter ($PM_{2.5}$) comes from a method called "ambient particle speciation," which measure the actual composition of air samples in some detail. Canada-wide studies[2] have determined that road dust can contribute between 3% and 9% of the $PM_{2.5}$ mass, and that this is restricted to periods after spring thaw when ground up traction material on paved surfaces is available for re-entrainment. For example, a particle speciation study in the interior town of Golden BC[3] found that road dust contributed up to 9% of the $PM_{2.5}$ mass (maximum contributions after spring thaw), while open burning and residential heating contributed > 70%. The estimate of 46% in the Comox Valley Emissions Inventory is, therefore, extremely inconsistent with results obtained elsewhere through more precise methods.

Earle Plain

Air Quality Meteorologist

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[1] Plain, E. (2016). Patterns of Air Quality and Meteorology in Courtenay BC 2011-2016. BC Ministry of Environment and Climate Change Strategy.
[2] Ewa Dabek-Zlotorzynska, et al. (2010). Canadian National Air Pollution Surveillance (NAPS) PM2.5 speciation program: Methodology and PM2.5 chemical composition for the years 2003-2008. Atmospheric Environment, Vol. 45, Issue 3, January 2011.
[3] Evans G, and C. Jeong (2007). Data analysis and source apportionment of PM2.5 in Golden, British Columbia using Positive matrix Factorization (PMF).

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Particulate Matter Emissions Inventory for the Comox Valley 2015 Base Year

Final Report

RWDI # 1700243
March 17, 2017

SUBMITTED TO

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EXECUTIVE SUMMARY

RWDI AIR Inc. (RWDI) was retained by the BC Ministry of Environment (BC MOE) to compile a Particulate Matter (PM) emissions inventory for the Comox Valley Regional District (CVRD). In this report, RWDI presents an inventory of particulate matter emissions including total particulate matter (TPM), particulate matter 10 microns and smaller in aerodynamic diameter (PM_{10}) and particulate matter 2.5 microns and smaller in aerodynamic diameter ($PM_{2.5}$) for a 2015 Base year. Emissions were quantified from point (industrial), area, and mobile sources as well as road dust. Specific focus was placed on wood combustion in various forms, including: residential woodstoves for space heating; residential yard waste; shrubs and trees from land-clearing; and, forest harvesting slash burning.

Total PM, PM_{10}, and $PM_{2.5}$ in the CVRD are estimated to be 875, 707, and 592 tonnes, respectively, excluding road dust. Emissions of TPM, PM_{10}, and $PM_{2.5}$ by source and source sector are shown in Table 1.

Fugitive road dust is estimated to contribute 92% of the total PM, 78% of the PM_{10}, and 46% of the $PM_{2.5}$ in the region. However, most fugitive road dust is in the coarse (>44 µm) size fraction (Pace, 2005) and thus settles out of the air in close proximity (e.g., meters to tens of meters) to the emission source (Desert Research Institute, 2000).

When excluding road dust sources from the emission summary, the key sources of TPM in the region are open burning (48%), and space heating (25%), followed by agricultural (10%) and mobile (9%) sources. Industrial sources make up less than 1% of the TPM in the region. Emissions of PM_{10} follow similar patterns to TPM in the CVRD. There are more significant differences in the contribution from different source types to $PM_{2.5}$ emissions. Dominant sources of $PM_{2.5}$ in the region are open burning (45%), space heating (35%), and mobile sources (12%).

Table 1: Particulate Matter Emissions for the CVRD

Emission Source			2015 Emissions (tonnes per year)		
			TPM	PM_{10}	$PM_{2.5}$
Point	Industrial Sources		1.6	0.6	0.2
	Point Subtotal		***1.6***	***0.6***	***0.2***
Area	Space Heating	Natural Gas - Residential	1.2	1.2	1.2
		Natural Gas - Commercial/Industrial	1.0	1.0	1.0
		Propane	0.2	0.2	0.2
		Wood	225.6	213.0	212.8
		Heating Oil	0.5	0.5	0.5
		Space Heating Subtotal	***228.5***	***215.9***	***215.7***
	Agricultural	Synthetic Fertilizer Application	0.2	0.1	0.03
		Tilling	35.5	35.5	7.5
		Harvesting	0.3	0.3	0.05
		Wind Erosion	51.1	25.6	3.8
		Livestock movements	4.1	1.2	0.2
		Crop Residue Burning	0.9	0.8	0.8
		Agricultural Subtotal	***92.1***	***63.6***	***12.4***
	Open Burning	Provincially Regulated – Pile	348.9	247.8	215.9
		Provincially Regulated – Area	57.5	42.4	36.7
		Municipally Regulated – Pile	6.2	4.8	4.1
		Recreational Fires	0.01	0.01	0.009
		Regional/Municipal - Backyard Burns	17.2	17.2	17.2
		Wildfire	3.5	2.6	2.4
		Open Burning Subtotal	***433.4***	***314.8***	***276.2***
	Miscellaneous	Meat Cooking	15.5	15.5	15.5
		Cigarettes	0.5	0.5	0.5
		Dry Cleaning	0.01	0.01	0.01
		Crematorium	0.01	0.01	0.01
		Structural Fires	0.3	0.3	0.3
		Miscellaneous Subtotal	***16.4***	***16.4***	***16.4***
	Area subtotal		***770.3***	***610.7***	***520.7***
Mobile	On-road	Light-duty	11.6	11.6	10.8
		Heavy-duty vehicles	10.4	10.4	10.0
	Non-road vehicles		34.1	33.7	32.6
	Marine Vessels		19.4	19.4	17.8
	Aircraft		3.3	3.3	3.0
	Mobile Subtotal		***78.7***	***78.3***	***74.1***
Fugitive Dust	Industrial Sources		3.7	1.1	0.1
	Construction Operations		23.3	23.3	4.7
	Landfills		22.8	12.6	8.4
	Fugitive Dust Subtotal		***49.8***	***36.9***	***13.1***
Total (no road dust)			***900.5***	***726.5***	***608.1***
Paved and unpaved roads			11,087.3	2,615.9	522.6
Total (with Road dust)			***11,987.8***	***3,342.4***	***1,130.7***

Notes: Totals may not equal the sum of components due to rounding.

CONSULTING ENGINEERS & SCIENTISTS

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Tables

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1 INTRODUCTION

The BC Ministry of Environment (BC MOE) retained RWDI AIR Inc. (RWDI) to provide an air emissions inventory of particulate matter (PM) in the Comox Valley Regional District (CVRD). This region encompasses the City of Courtenay, the Town of Comox, Village of Cumberland, CVRD Areas A, B and C, and all First Nations within these geographic areas. The PM inventory included all relevant emission sources in the region including point, area, and mobile sources as well as road dust for the Base Year 2015. Emissions were computed for total particulate matter (TPM), particulate matter 10 microns and smaller in aerodynamic diameter (PM_{10}) and particulate matter 2.5 microns and smaller in aerodynamic diameter ($PM_{2.5}$).

There is very little industry in the Comox Valley. The emissions inventory therefore focused on developing robust estimates from the area source category. Specific focus was placed on wood combustion in various forms, including: residential woodstoves for space heating; residential yard waste, shrubs and trees from land-clearing; and, forest harvesting slash burning.

2 PARTICULATE MATTER EMISSIONS ESTIMATION METHODS

Particulate matter emissions in the CVRD arise from industrial, mobile and area sources as well as road dust.

Industrial facilities in the CVRD include the following:

- Cement facilities;
- Concrete facilities; and
- Asphalt facilities.

Area sources include the following:

- Space heating;
- Open burning;
- Agricultural activities; and
- Miscellaneous sources.

Agricultural area sources include:

- Wind erosion and tilling of soils;
- Harvesting of crops;
- Agricultural open burning;
- Dust from livestock; and
- Synthetic fertilizer application.

Open burning sources include:

- Burning activities regulated and tracked (through permit or other means) by provincial and local authorities; and
- Wildfires that are not deliberately set.

Mobile sources of PM include:

- On-road vehicles;
- Off-road vehicles;
- Aircraft;
- Marine vessels; and,
- Rail sources.

Typically, emissions are expressed as a base quantity or 'activity' multiplied by an emission factor. The accuracy of the calculation thus hinges on both the accuracy of the base quantity data available and the latest scientific data to support the emission factors. A general emission equation is shown below.

$$Emissions = Base\ Quantity\ x\ Emission\ Factor$$

The specific emission equations, base quantities and emission factors used for each of the emission sources are listed in the sections below.

2.1 Industrial Sources

A search of BC MOE emission database revealed that three facilities had air discharge authorization for PM in the CVRD. Two of these facilities (Trueline Masonry and Landscape Products Ltd. and Hyland Precast Inc.) are cement and concrete manufacturing plants. one facility (Tayco Paving Co. Ltd) is an asphalt manufacturing plant.

Both Trueline Masonry and Landscape Products Ltd. and Hyland Precast Inc. only had allowable discharges for TPM. As no additional information was available for the $PM_{2.5}$ and PM_{10} fractions, only TPM is presented for these facilities. Tayco Paving reported air releases of PM to the 2014 National Pollutant Release Inventory (NPRI) from stack, storage and handling, fugitive, and road dust sources. For consistency with the rest of this report, the fugitive dust from roads from this facility are presented separately from the other industrial point source emissions. As the actual emissions for the other two facilities were not available, a conservative estimate was calculated using the maximum allowable discharges from their permits. The TPM emissions from industrial sources in the BC MOE authorization database and reported to the NPRI in 2014 are shown in Table 2.

Table 2: Particulate Matter Emissions from Industrial Sources in the Authorization Database and Reported to the NPRI in 2014 (tonnes per year)

Emission Source		2014 Emissions (tonnes per year)		
		TPM	PM_{10}	$PM_{2.5}$
Point	Tayco Paving Company	1.51	0.65	0.23
	Trueline Masonry and Landscape Products Ltd.	0.01	-	-
	Hyland Precast Inc.	0.07	-	-
	Point subtotal	***1.59***	***0.65***	***0.23***
Fugitive Dust	Industrial Sources Tayco Paving Company	3.74	1.06	0.11
	Fugitive Dust subtotal	***3.74***	***1.06***	***0.11***
Total		***5.33***	***1.71***	***0.34***

2.2 Area Sources

Area sources within the CVRD include space heating, agricultural sources, and open burning. Particular attention was given to developing estimates of emissions from residential woodstoves, residential and agricultural backyard burning, and land-clearing burning.

2.2.1 Space Heating

Particulate emissions from space heating result from the combustion of natural gas, propane, heating oil or wood for residential, commercial and industrial buildings. The Community Energy and Emissions Inventory of CEEI (Ministry of Environment, February 2014) estimates the energy use and greenhouse gas emissions from residential, commercial and industrial buildings by community. The CEEI directly obtains natural gas, propane (for some regions) and electricity data from the major utilities. Total consumption is estimated by region using the number of dwellings and average consumption by dwelling type. The consumption of heating oil, propane, and wood is estimated from the difference of the expected total energy consumption minus the actual reported by natural gas and electricity and piped propane utility providers. The latest CEEI report for 2010 was used for the space heating calculations. In addition, RWDI conducted a phone and email survey to collect sales volumes of propane, heating oil and wood used in residential and commercial/industrial space heating in the CVRD. Information on the data collection from fuel suppliers is discussed in the sections below.

2.2.1.1 Natural Gas Consumption

The CEEI obtains natural gas usage directly from utility providers. The values for residential and commercial consumption in the CVRD from the 2010 CEEI report were used. These values were then multiplied by the natural gas heating value (1,050 BTU/ft^3) from AP-42 Appendix A (US EPA, 1995) and the TPM emission factor from AP-42 Chapter 1, Section 4 on Natural Gas Combustion (US EPA, 1998). The amount of natural gas consumed and the relevant emission factors are listed in Table 3. All particulate matter from natural gas combustion is assumed to be less than 1.0 micron, consistent with the guidance from AP-42.

Table 3: Particulate Matter Emissions from Natural Gas Combustion (tonnes per year)

Building Type	Usage (GJ)	Emission Factor (kg/GJ)		
		TPM	PM_{10}	$PM_{2.5}$
Residential	379,654	0.0031		
Commercial	309,409			

2.2.1.2 Propane Consumption

RWDI attempted to contact five propane companies in the CVRD by phone and email. Two were distributors and three were suppliers. Of these, two did not respond and two declined to provide information. However, one provider who did not provide data (claiming confidentiality issues) confirmed that sales have remained constant over the last few years. They also confirmed that the 2010 CEEI consumption value for the CVRD was still a reasonable estimate for 2015.

The amount of propane from the 2010 CEEI report was multiplied by the propane heating value (94,000 BTU/gal) from AP-42 Appendix A (US EPA, 1995) and the TPM emission factor for commercial boilers from AP-42 Chapter 1, Section 5 on Liquefied Petroleum Gas Combustion (US EPA, 2008). Only a TPM emission factor was published; however, all the PM is assumed to be less than 1.0 µm. Emission factors from propane combustion are listed in Table 4.

Table 4: Particulate Matter Emissions from Propane Combustion (tonnes per year)

Boiler Type	Usage		Emission Factor ($kg/10^3$ L)		
	(GJ)	(L)	TPM	PM_{10}	$PM_{2.5}$
Commercial	71,153	2,717,742	0.084		

2.2.1.3 Heating Oil Consumption

RWDI attempted to contact two furnace oil providers in the CVRD. Emails were sent to both companies; however, neither responded. To calculate emissions from heating oil, the 2010 CEEI consumption value was multiplied by the distillate oil (No. 2 oil) heating value (140,000 BTU/gal) from AP-42 Appendix A (US EPA, 1995) and filterable PM emission factor for residential furnaces from AP-42 Chapter 1, Section 3 on Fuel Oil Combustion (US EPA, 1999). All PM was assumed to be less than 2.5 microns in diameter. Emission factors from heating oil combustion are listed in Table 5.

Table 5: Particulate Matter Emissions from Heating Oil Combustion (tonnes per year)

Firing Configuration	Usage		Emission Factor (kg/1000L)		
	(GJ)	(L)	TPM	PM_{10}	$PM_{2.5}$
Residential Furnace	412,618	10,581,884	0.048		

2.2.1.4 Residential Wood Burning

Prior research and monitoring efforts in the Comox Valley have suggested that residential wood burning is a considerable source of PM in the CVRD. As with all sources, the emission estimates are only as good as the quality of the base quantity data available. Unfortunately, unlike other fuel sources, consumption of wood is difficult to track accurately. Retail suppliers have no requirement to track or report volumes sold, and as there are a limited number of suppliers they are not inclined to share proprietary information publically. In addition, wood is freely available from many local and untraceable sources.

There are a few documents which can provide some information to help to quantify the amount of wood consumed in the CVRD as listed below.

- The 2010 Community Energy and Emissions Inventory (CEEI) (Ministry of Environment, February 2014)
- An Inventory of Wood-burning Appliance Use in British Columbia (Mustel Group Market Research, March 2012)
- Residential Wood-Burning Emissions in British Columbia (BC Ministry of Water, Land, and Air Protection (WLAP), May 2005)
- Wood Stove Inventory and Behaviour Analysis (Envirochem Services Inc., December 2012)

The first three reports all provide different methodologies and different values which can be used to calculate the wood consumed in the CVRD. A methodology to calculate the wood consumption using data from each of the first three reports is provided below along with a comparison of the results and presentation of the final approach used to calculate emissions. The fourth document is a summary of all residential burning surveys completed in BC to date (at the time of writing).

The 2010 CEEI (Ministry of Environment, February 2014) estimated the amount of heating oil, delivered propane and wood used for space heating in the CVRD by assuming average fuel consumption amounts by dwelling type and number of dwellings and subtracting the use of electricity, natural gas, and piped propane in the region. The CEEI estimated that 494,412 gigajoules of energy was obtained from wood in the CVRD.

The energy consumed in the CEEI was provided in gigajoules and was converted to tonnes of wood using Equation 1 and assuming a moisture content (MC) of 18% as per the Residential Wood Burning Report (WLAP, 2004)

Equation 1: Wood Consumption Conversion (from gigajoules to tonnes)

$$Wood\ Consumed\ (tonne) = Energy\ from\ Wood\ Consuption\ (GJ) \div \left(19.2 - (0.2164 \times MC)\right)$$

The quantity of wood consumed in 2010 using the CEEI as a raw data source is shown in Table 6 and Figure 1.

The BC MOE retained the Mustel Group to conduct a telephone survey of wood burning appliance use in BC in 2012 (Mustel Group Market Research, March 2012). The results from this survey included a detailed breakout of the number of survey respondents who use a wood burning appliance for a number of regions across BC. It was found that 20% of survey respondents in the Comox Valley use wood appliances, and 36% of the respondents in the entire “West Coast Region” (equivalent to Vancouver Island outside of other communities surveyed) use wood appliances. The report also collected information on the percentage splits of four major appliance types: wood stoves (63%); wood fireplaces (45%); wood burning central heat (3%); and, pellet stoves (5%). The Mustel Group also collected information on the amount of wood and pellets burned annually by household. BC statistics reports 29,231 households in the CVRD in 2015. The quantity of pellets and wood used in 2015 were estimated from the data in the Mustel Group report and are shown in Table 6 and Figure 1.

The British Columbia Ministry of Water, Land and Air Protection (WLAP) (BC Ministry of Water, Land, and Air Protection (WLAP), May 2005) completed a detailed emissions inventory for PM from wood burning equipment across the province in 2004. The WLAP report included a telephone survey of wood burning appliance use in British Columbia. The WLAP report used the survey results to quantify the amount of wood (and wood pellets) burned in each of 12 types of appliances for two regions on Vancouver Island: the Capital Regional District, and Other Vancouver Island. The total number of households in the Other Vancouver Island region at the time of the survey and the number of households in the CVRD in 2015 were used to estimate of the amount of wood and pellets burned in the CVRD (assuming 2004 behaviours). The quantity of pellets and wood used in 2015 estimated from the 2004 WLAP are shown in Table 6 and Figure 1.

In addition to the three methodologies for calculating wood consumption from the three documents described above, RWDI attempted to contact four firewood sales providers in the CVRD. Three providers could not be reached (unavailable due to full voicemail boxes, closed websites, etc.). One provider responded but declined to provide data due to confidentiality issues but confirmed that sales have increased approximately 20% since 2010 and confirmed the CEEI estimate of energy consumed from burning firewood (494,412 GJ) for residential heating in 2010.

Table 6: Comparison of Estimated Wood Consumed for Space Heating in the CVRD (tonnes)

Study Used to Estimate Wood Consumption	Wood Consumed in CVRD (tonnes)	
	Wood	Pellet
2010 CEEI	32,304	
Mustel 2012 - "West Coast" (36% wood appliance use)	25,788	3,604
Mustel 2012 - "Comox Valley" (20% wood appliance use)	14,413	2,014
WLAP 2004 (Provincial wood stove emissions inventory)	25,680	521

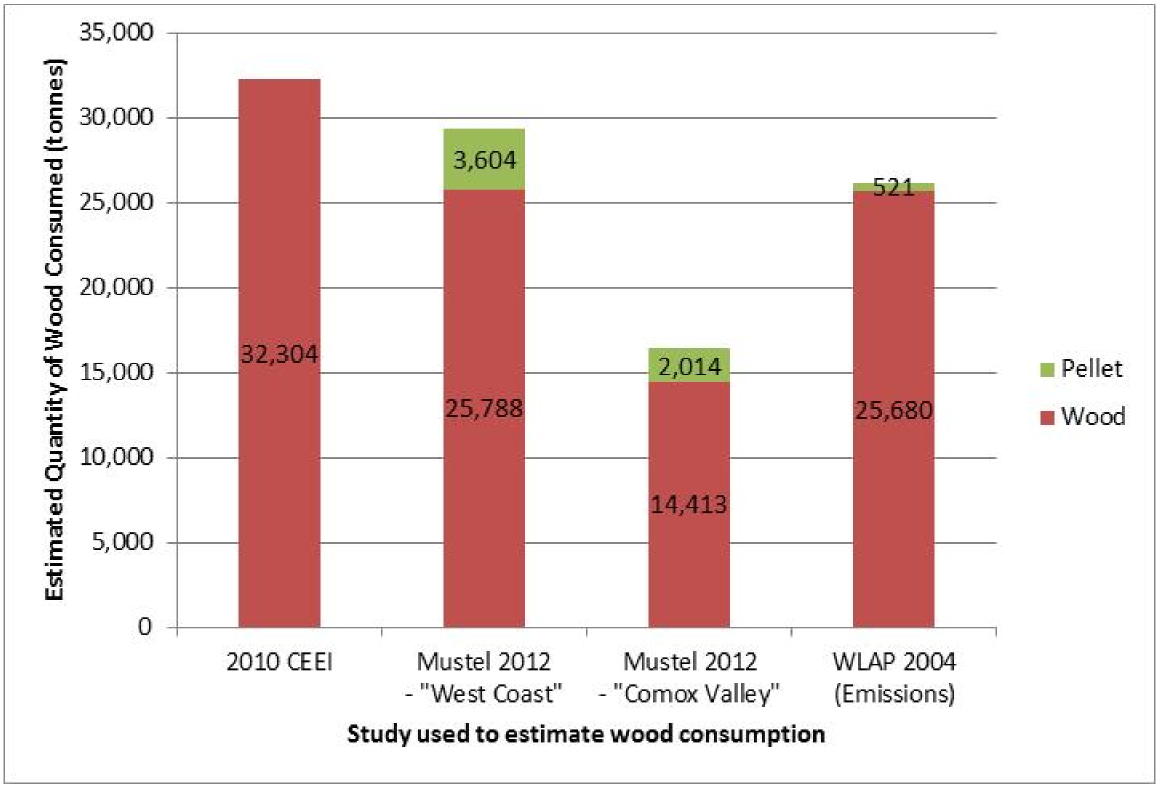

Figure 1: Estimated Quantity of Wood Consumed Using Different Studies

For this emissions inventory, it was assumed that 36% of households in the CVRD burned wood as per the Inventory of Wood-Burning Appliance use in the West Coast in 2012 (Mustel Group Market Research, March 2012). According to the Mustel Group report, 5% of wood-burning households burn pellets. Thus for simplicity, it was assumed that the remainder of households burning wood (95%) have cord wood burning appliances.

The methodology from the Residential Wood Burning Report (BC Ministry of Water, Land, and Air Protection (WLAP), May 2005) was used to estimate emissions from residential wood burning for space heating. The emission equation for PM from residential wood burning for space heating is shown in Equation 2.

Equation 2: Particulate Matter Emission Equation for Residential Wood Burning

$$PM = Wood\ Consumed\ (tonne) \times Percent\ of\ Applicance\ Type_{Other\ Vancouver\ Island}\ (\%) \times EF_{PM}\left(\frac{kgPM}{tonne\ wood}\right)$$

Emissions from wood burning equipment are dependent on the type of appliance and technology used. As part of the detailed Residential Wood Burning Report (BC Ministry of Water, Land, and Air Protection (WLAP), May 2005), the amount of wood consumed by 11 types of technology was collected by survey across the Province.

The percentages of wood consumed by each appliance technology type for "Other Vancouver Island" (which excluded the Capital Regional District), excluding pellet stoves in 2004 is provided in Table 7. Results from the 2012 Mustel Survey (Mustel Group Market Research, March 2012) were used to allocate the total wood burned into each of the 11 technology types. The 2012 survey did not collect data for each of the 11 technology types, but rather provided the province-wide percentages of technology in larger groupings. The results of the 2004 and 2012 studies were used in combination to distribute the assumed cord wood consumption into 11 technology types, presented in Table 8.

The amount of wood burned per household was calculated from the average West Coast household use (2.2 cords/year/household), cord volume (2.27 m^3/cord) and wood species obtained from the Wood Stove Inventory and Behaviour Analysis Report (Envirochem Services Inc., December 2012). Densities for the BC wood species were obtained from the Residential Wood Burning Report (BC Ministry of Water, Land, and Air Protection (WLAP), May 2005) and used to calculate an average wood density. The amount of residential wood burned in the CVRD was determined by multiplying the amount of wood burned per household by the amount of wood burning households in the CVRD. Of those households assumed to burn wood, 95% were assumed to burn wood logs, and 5% were assumed to burn wood pellets. Finally, the amount of wood (25,788 tonnes wood logs) was multiplied by the percentage of each appliance type and appliance specific emission factors.

For pellet stoves, the same methodology was adopted. The amount of pellets burned per household was calculated from the average West Coast household use (78.3 bags/year/household) and bag weight (40 lbs/bag) obtained from the Wood Stove Inventory and Behaviour Analysis Report (Envirochem Services Inc., December 2012). To determine the amount of pellets burned in the CVRD, the average household amount was multiplied by the amount of wood burning households in the CVRD and assuming 5% of those households burned pellets. The amount of pellets (3604 tonnes) was then multiplied by the emission factors for pellet stoves.

Emission factors for each appliance type were obtained from the Residential Wood Burning (BC Ministry of Water, Land, and Air Protection (WLAP), May 2005) and shown in Table 9.

Table 7: Percentage of Wood Burning Appliance Types (%) from WLAP, 2004

Appliance Type	Fireplace; Advanced	Fireplace; Conventional Without glass doors	Central Furnace/Boiler (inside)	Central Furnace/Boiler	Central Furnace/Boiler (outside)	Fireplace Insert; Advanced Technology	Fireplace Insert; Catalytic	Fireplace Insert; Conventional	Woodstove; Advanced	Woodstove; Catalytic	Woodstove; Conventional	Pellet
% of Appliance Type	2%	14%	4%	0%	0%	2%	1%	9%	36%	5%	26%	-

Table 8: Percentage of Wood Burning Appliance Types (%) from Mustel, 2012 and WLAP, 2004

Appliance Type	Fireplace; Advanced	Fireplace; Conventional Without glass doors	Central Furnace/Boiler (inside)	Central Furnace/Boiler	Central Furnace/Boiler (outside)	Fireplace Insert; Advanced Technology	Fireplace Insert; Catalytic	Fireplace Insert; Conventional	Woodstove; Advanced	Woodstove; Catalytic	Woodstove; Conventional	Pellet
% of Appliance Type	7%	7%	2%	0%	1%	13%	1%	9%	51%	2%	7%	-

Table 9: Wood and Pellet Emission Factors (kg/tonne)

Appliance Type	Fireplace; Advanced	Fireplace; Conventional Without glass doors	Central Furnace/Boiler (inside)	Central Furnace/Boiler	Central Furnace/Boiler (outside)	Fireplace Insert; Advanced Technology	Fireplace Insert; Catalytic	Fireplace Insert; Conventional	Woodstove; Advanced	Woodstove; Catalytic	Woodstove; Conventional	Pellet
TPM Emission Factor	5.1	19.3	14.1	14.1	14.1	5.1	5.1	14.4	5.1	5.1	24.6	1.2
PM_{10} Emission Factor	4.8	18.5	13.3	13.3	13.3	4.8	4.8	13.6	4.8	4.8	23.2	1.1
$PM_{2.5}$ Emission Factor	4.8	18.4	13.3	13.3	13.3	4.8	4.8	13.6	4.8	4.8	23.2	1.1

2.2.2 Agricultural Sources

Particulate matter is produced from agricultural activities including the addition of synthetic fertilizers, tilling and harvesting of crops, wind erosion on fields, livestock husbandry, and the use of agricultural on- and non-road vehicles and equipment. Agricultural non-road vehicles and equipment is discussed further in section 2.3.2.

The Canadian Census of Agriculture provides the land in crops by crop type and the head of livestock (on a particular date) by Census Consolidated subdivision (CCS) every five years. The most current Census of Agriculture is from 2011, the 2016 Census data are not expected to be available until 2017 at the earliest. The base quantities used for the emissions from agricultural sources in this inventory were extracted from the 2011 Census of Agriculture for the CCSs for Comox Valley: Comox Valley A (5926021), Comox Valley B (Lazo North) (5926022), and Comox Valley C (Puntledge - Black Creek) (5926024). Census consolidated subdivisions (CCSs) within the CVRD are shown in Figure 2.

MAP 2A

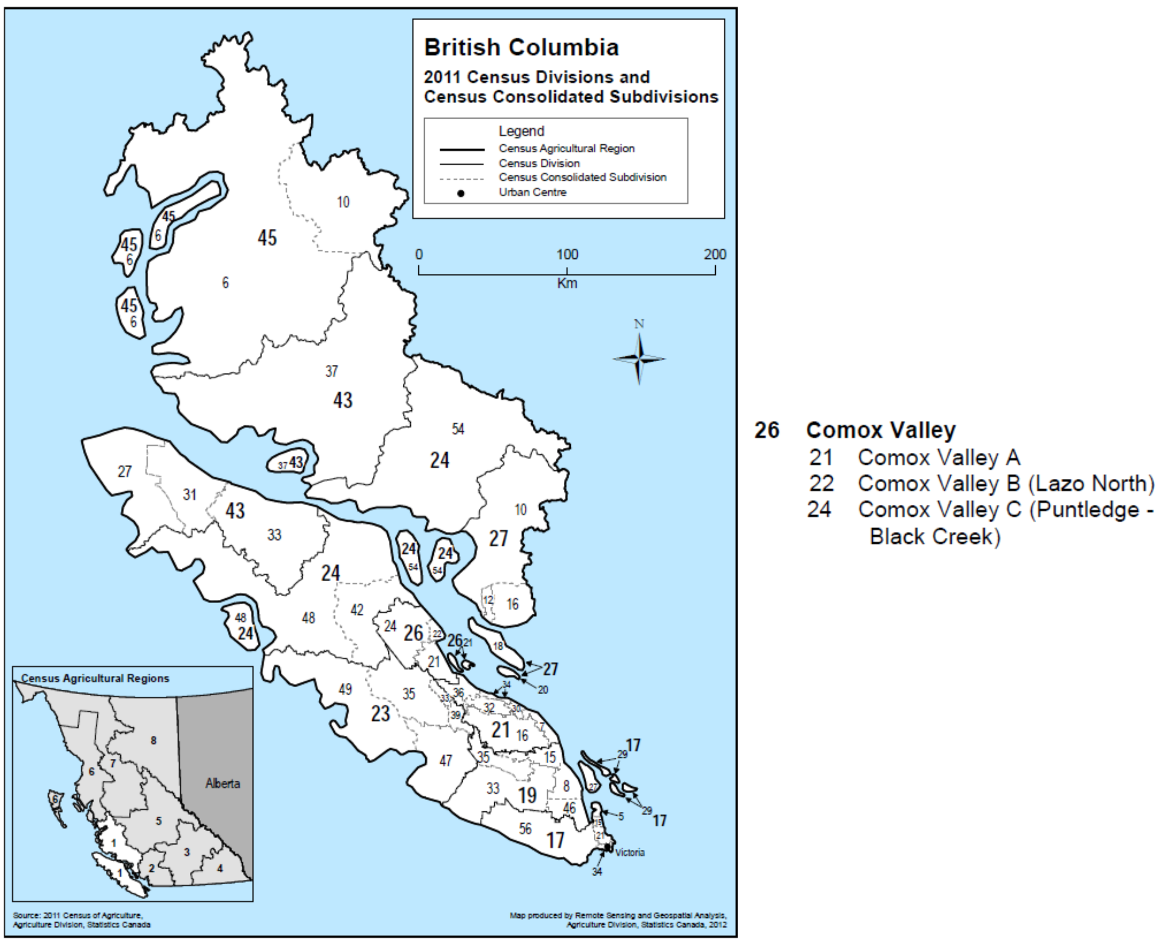

Figure 2: BC Census Division 1 (Vancouver Island-Coast) Showing Consolidated Subdivisions and the CVRD.

2.2.2.1 Synthetic Fertilizer Application

Particulate emissions were based on the method used by Environment Canada to calculate PM emissions from fertilizer application as part of the national emissions inventory. The emissions of PM are based on the quantity of fertilizer applied with global emission factors that account for the handling and storage as well as the spreading of fertilizers (Environment Canada, 2006). The general emission equation is shown in Equation 3. PM emission factors per tonne of fertilizer applied are shown in Table 10. The amount of fertilizer applied (summed per crop type) is equal to the area of land per crop multiplied by a fertilizer application density which varies by crop. The amount of fertilizer applied per crop uses the method developed by Sheppard *et al.* (Sheppard, Bittman, & Bruulsema, 2009) and is described further in Appendix 1. The area in each crop type by CCS is also shown in the Appendix.

Equation 3: Particulate Matter Emissions from Fertilizer Application

$$PM\ Emissions\ (kg) = Area\ of\ land\ per\ crop\ (hectare) \times Amount\ of\ Fertilizer\ applied\ per\ crop\ \left(\frac{kg}{ha}\right) \times PM\ Emission\ Factor\ \left(\frac{kg}{tonne}\right)$$

Table 10: Particulate Matter Emission Factors for Fertilizer Application

Pollutant	Emission Factor (kg/t Fertilizer)
TPM	2.23
PM_{10}	1.09
$PM_{2.5}$	0.31

2.2.2.2 Tilling

Particulate matter is released from the disturbance of soils during the tilling of fields and harvesting of crops. The EPA method for quantifying PM emissions from agricultural tilling activities was used with local improvements (Poon & Robbins, 2006). Tilling emissions are dependent on crop-specific and region-specific factors. Crop-specific factors including the area tilled and the number of tills per year (often expressed as the years between renovations). Region-specific factors include the moisture reduction factor (an expression of the local precipitation pattern) and the local silt content.

The general emission equation is shown in Equation 4. Emissions of TPM, PM_{10}, and $PM_{2.5}$ are calculated per crop type and per season. Emissions are based on the crop area (in hectares), the number of tillings (passes), and an emission factor calculated specifically for the region and season. The area per crop for each CCS is shown in Appendix 1.

Equation 4: Tilling Emission Equation

$$Emissions\ per\ crop\ per\ season_{\ (PM, PM_{10}, PM_{2.5})} = Area\ per\ crop\ (ha) \times Number\ of\ tillings\ per\ crop\ and\ per\ season \times Emission\ Factor_{(PM, PM_{10}, PM_{2.5})} \times Tillage\ Factor(unitless)$$

The number of tills per crop is based on the census agricultural region and the month. The number of tills (passes) for each region has been developed with expertise from Ministry of Agriculture staff as part of the BC Agricultural Air Emissions Inventory (RWDI, 2014). The detailed methodology for the number of tills per crop is shown in Appendix 1.

The tillage emission factor equation is shown in Equation 5. The base equation includes an empirically derived constant (5.38) multiplied by a moisture reduction factor, particle size multiplier, and the silt content. The particle size multiplier is used to estimate the fraction of TPM that is PM_{10} or $PM_{2.5}$. The particle size multiplier is typically assumed to be 0.21 for PM_{10} and 0.042 for $PM_{2.5}$.

Equation 5: Tilling Emission Factor Equation

$$Emission\ Factor_{(PM, PM_{10}, PM_{2.5})} = 5.38 \times Moisture\ reduction\ factor\ per\ season \times Particle\ size\ multiplier_{\ (PM, PM_{10}, PM_{2.5})} \times Silt\ content\ per\ region\ (\%)^{0.6}$$

The moisture reduction factor reflects the precipitation accumulation which decreases the likelihood of particles becoming airborne. Moisture reduction factors were generated by month for each of the eight agricultural regions (based on the Census of Agriculture regions) for the detailed agricultural emissions inventory for the Ministry of Agriculture (MoA). The moisture reduction factors for Vancouver Island – Coast was used for the CVRD and are shown in Table 11.

Table 11: Moisture Reduction Factors for Tilling Emission Factor Equation

Month	Moisture Reduction Factor (unitless)
January	0.00
February	0.00
March	0.00
April	0.20
May	0.50
June	0.50
July	0.75
August	0.50
September	0.50
October	0.00
November	0.00
December	0.00

The silt content is a percentage based on typical soil type. The silt content values for each CCS were developed using data from the Soil Landscapes of Canada version 3.2, developed by Agriculture and Agri-Food Canada and shown in Table 12.

Table 12: Silt Content by CCS

CCS	Silt Content (%)
Comox Valley A	35.0
Comox Valley B Lazo North	43.6
Comox Valley C Puntledge - Black Creek	48.4

2.2.2.3 Harvesting

Particulate emissions from crop production arise from soil cultivation and harvesting. Emissions depend on crop, soil type, cultivation method, and weather conditions before and while working. Environment Canada's national air emissions inventory includes emission quantities and methods for agricultural tilling and wind erosion, but does not specifically include particulate emissions from harvesting.

The emission method from the BC Agricultural Air Emissions Inventory (RWDI, 2014) was used for this inventory. The general emission equation is shown in Equation 6. It is assumed that each crop is harvested only once annually. The PM_{10} emission factors are shown in Table 13. The California Air Resources Board $PM_{2.5}$ to PM_{10} ratio of 0.15 for agricultural harvesting (Countess Environmental, 2006) was used to estimate $PM_{2.5}$. Total PM was assumed to equal $PM_{10.}$ The area by crop type is provided in provided in the detailed method in Appendix 1.

Equation 6: PM_{10} Emissions from Agricultural Harvesting

$$Emissions_{PM_{10}}(kg) = Annual\ crop\ area\ (ha) \times Number\ of\ harvests\ \times Emisison\ factor\ \left(\frac{kg}{ha}\right)$$

Table 13: PM_{10} Emission Factors for Harvesting by Crop Classification Groupings

Crop Classification Category Groupings	PM_{10} Emission Factor (kg/ha)
Corn	0.12
Grass/hay/alfalfa	0.25
Cereal, grain and oilseed	0.47
Pasture	0.00
Peas/beans/early potatoes	0.31
All other vegetables	0.03
Turf	0.00
Tree fruits vines and berries	0.01

2.2.2.4 Wind Erosion

Particulate emissions also result from wind erosion of tilled agricultural lands. Particulate emissions from wind erosion of agricultural lands were calculated using the Wind Erosion Equation (WEQ) shown in Equation 7. The WEQ relies on crop-specific and region-specific factors. Crop specific factors include the surface roughness factor, the unsheltered field width factor and the vegetative factor. Crop-specific factors as developed for the BC Agricultural Air Emission inventory (RWDI, 2014) were used. Region-specific factors including the soil erodibility and climatic factor were developed for the Comox Valley.

Equation 7: Wind Erosion Equation

$$Emissions\ Factor_{PM_{10}}\ \left(\frac{ton}{acre\ year}\right) =$$
$$\mathrm{A}[Total\ suspended\ particulate\ portion\ (0.025)]\ \times I\ \left[Soil\ Erodibility\ \left(\frac{ton}{acre\ year}\right)\right] \times$$
$$K\ [Surface\ roughness\ factor]\ \times C\ [Climatic\ factor]\ \times L'^{[Unsheltered\ field\ width\ factor]} \times$$
$$V'[Vegetative\ cover\ factor]$$

Total PM was broken out into PM_{10} and $PM_{2.5}$ size fractions using factors from the WRAP Fugitive Dust Handbook (Countess Environmental, 2006). The PM_{10}/TPM ratio for wind erosion is 0.5; the $PM_{2.5}/PM_{10}$ ratio is 0.15.

A detailed description of the development of the parameters K, C, L' and V' is provided in Appendix 1. Total PM, PM_{10}, and $PM_{2.5}$ emissions were calculated using the monthly emission factors generated from Equation 7 multiplied by the total area per crop. The area of each relevant crop was taken from the 2011 Census of Agriculture and is shown in Table 14.

Table 14: Crop Area by CCS for Wind Erosion Calculations

Wind Erosion Crop Grouping	Census Table	Census Fields	Crop Area (hectares)		
			Comox Valley A	Comox Valley B Lazo North	Comox Valley C Puntledge - Black Creek
Alfalfa	Hay and field crops 2011	Alfalfa_and_alfalfa_mixtures_hectares	284	83	197
Barley	Hay and field crops 2011	Barley_hectares	0	n/a	84
Grain Hays	Hay and field crops 2011	Mixed_grains_hectares Canola_rapeseed_hectares Flaxseed_hectares All_other_tame_hay_and_fodder_crops_hectares	n/a	183	1977
Potatoes	Hay and field crops 2011	Potatoes_hectares	1	n/a	n/a
Vegetables	Vegetables excluding greenhouse	Total vegetables excluding greenhouse vegetables_hectares	19	28	n/a

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2.2.2.5 Livestock movements

Particulate emissions from animal production result from animal housing and moving facilities. The emissions methodology for PM from cattle, swine, poultry and horses was selected from the "A Review of Agricultural Air Emissions Estimates for the Lower Fraser Valley of British Columbia" (Poon & Robbins, 2006). The transfer of methodology from the LFV to CVRD assumes that agricultural livestock production operates similarly in both regions. The number (head) of livestock was taken from the 2011 Census of Agriculture and is shown in Table 15.

Table 15: Number of Livestock by CCS

Livestock	Number of Livestock (head)		
	Comox Valley A	Comox Valley B Lazo North	Comox Valley C Puntledge – Black Creek
Horses	74	19	255
Swine	97	71	603
Poultry	3,857	1,232	18,586
Cattle	48	63	112

The recommended method for deriving emissions from cattle assumes that only cattle in beef feedlots generate significant PM and that the best conservative estimate of the number of cattle in beef feedlots is based on the number of beef steers. The number of steers was taken from the 2011 Census of Agriculture and is shown in Table 15.

The published PM_{10} emission factor is 11 kg/1000 head/day, with particle size multipliers of 3.0 for TPM and 0.15 for $PM_{2.5}$ resulting in the emission factors shown in Table 16. A climate correction factor of 0.572 was generated for the Comox Valley which is equal to fraction of days with less than 2.0 mm of rain in the region.

Equation 8: Particulate Matter Emissions from Cattle

$$PM_A = \frac{Number\ of\ Steers}{1000\ head} \times EF_{PM10,daily} \times Particle\ size\ multiplier_A \times climate\ correction\ factor \times days\ in\ feedlots\ (365)$$

Table 16: Particulate Matter Emission Factors for Cattle

Pollutant	Effective Emission Factor (kg/1000 steer/day)
TPM	33
PM_{10}	11
$PM_{2.5}$	1.65

The recommended methodology for calculating emissions for swine uses Equation 9 with a TPM emission factor of 1.854 mg/hr/kg swine. PM_{10} to TPM and $PM_{2.5}$ to TPM ratios of 0.5 and 0.1 were used. The mass per animal is shown in Table 17.

Equation 9: Particulate Matter Emissions from Swine

$$PM = Number\ of\ swine\ (head) \times Mass\ per\ animal\ (\frac{kg}{head}) \times EF_{PM,hourly} \times Hours\ per\ year\ (8760) \times Particle\ size\ conversion$$

Table 17: Assumed Mass of Animal (Swine)

Census Livestock Category		Number of head	Mass per head kg/head
Swine	Boars_number	9	230
	Sows_and_gilts_for_breeding_number	80	170
	Nursing_and_weaner_pigs_number	270	47
	Grower_and_finishing_pigs_number	412	47

The recommended method for estimating emissions from poultry depends on the length of production cycle and varies for pullets and laying hens versus broilers, turkeys, and other poultry. The emission estimation method was varied between layers (pullets under 19 weeks intended for laying, laying hens19 weeks and over, and layer and broiler breeders) and non-layers (broilers roasters and Cornish, turkeys, and other poultry). The emissions from layers were calculated by bird type using Equation 10. The number of livestock, TPM emission factors, PM_{10} to PM and $PM_{2.5}$ to PM ratios, and hours per production cycle for layers is shown in Table 18.

The emissions from broilers (non-layers) were calculated by bird type using Equation 11. The number of livestock, PM emission factors, PM_{10} to TPM and $PM_{2.5}$ to TPM ratios, and hours per production cycle for broilers (non-layers) is shown in Table 19.

Equation 10: Particulate Matter Emissions from Poultry Layers

$$PM = Number\ of\ birds\ (head) \times Mass\ per\ animal\ (\frac{kg}{head}) \times EF_{PM,production\ cycle}\ (\frac{\frac{mg}{hr}}{kg\ bird}) \times Hours\ of\ production\ per\ year\ (8760) \times Particle\ size\ conversion$$

Equation 11: Particulate Matter Emissions from Poultry Broilers (non-layers)

$$PM = Number\ of\ birds\ (head) \times Mass\ per\ animal\ (\frac{kg}{head}) \times EF_{PM,production\ cycle}\ (\frac{\frac{mg}{hr}}{kg\ bird}) \times Hours\ of\ production\ per\ day\ \times (Days\ of\ production + days\ of\ cleanout) \times cycles\ per\ year \times Particle\ size\ conversion$$

Table 18: Emission Equation Factors for Poultry Layers

Census Livestock Category		Number of head	Mass per head kg/head	EF for production cycle mg/hr/kg	Hours per production hr/yr
Poultry	Pullets under 19 weeks, intended for laying (63)	1605	0.75	1.266	8760
	Laying hens, 19 weeks and over (64)	5215	1.8	1.266	8760
	Layer and broiler breeders (pullets and hens) (65)	333	1.8	1.266	8760

Table 19: Emission Equation Factors for Poultry Broilers (non-layers)

Census Livestock Category		Number of head	Mass per head kg/head	EF for production cycle mg/hr/kg	hours/day hr/day	days production days	cleanout days per cycle days	cycles per year cycles/year
Poultry	Broilers, roasters and Cornish (66)	11870	1	5.61	24	40	2	6.5
	Turkeys (67)	2067	4.9	5.61	24	75	2	3.5
	Other poultry	2585	1.8	5.61	24	75	2	3.5

The recommended method for quantifying emissions from horses separates the animals into those in riding rings versus those in paddocks. This method uses the total number of horses from the Census of Agriculture and assumes a split between horses in riding rings (75%) and horses in paddocks (25%). The assumed splits are based on data from the Lower Fraser Valley with an assumption that the split is similar in the CVRD. The general emission equation is shown in Equation 12 and the emission factors are shown in Table 20.

Equation 12: Particulate Matter Emissions from Horses

$$Emissions\ (kg) = Number\ of\ horses(head) \times EF(\frac{kg}{head})$$

Table 20: Particulate Matter Emission Factors for Horses

Pollutant	Horse Emission Factor (kg/head)	
	Paddocks	Riding Rings
TPM	2.15	1.61
PM_{10}	0.72	0.54
$PM_{2.5}$	0.11	0.08

2.2.2.6 Crop Residue Burning

Open burning is one disposal option for excess vegetation (crop residue) from crop production. Emissions are based on an assumption of the amount of crop residue produced, the proportion of this residue which is disposed of by incineration, and an emission factor. Emissions from the burning of crop residue were calculated using Equation 13. The amount of crop residue produced is calculated using the land area in crops (by crop category) and an assumed rate of residue production (Fuel Loading) per crop type.

Equation 13: Agricultural Waste Burning Equation

$$Emissions\ (kg) = Crop\ area\ (hectares) \times Fuel\ Loading\ \left(\frac{tonne\ residue}{hectare}\right) \times Percentage\ of\ dry\ crop\ residue\ burned\ (\%) \times Emission\ Factor\ \left(\frac{kg}{tonne\ residue}\right)$$

Crop residue production (fuel loadings) were assigned by crop category. The percentage of dry crop residue burned in various regions across the province was developed as part of the BC Agricultural Air Emissions Inventory to be 0.5%. PM emission factors per crop were selected from the California Air Resources Board and grouped into crop categories relevant to BC (California Air Resources Board, 2014). Emission factors and fuel loadings per crop type are shown in Table 21.

Table 21: Crop Residue Burning Emission Factors and Waste Production Rates

Land Cover Category	Emission Factors (kg/tonne)			Fuel Loading (tonnes/hectare)
	TPM	PM_{10}	$PM_{2.5}$	
Corn	5.8	5.7	5.4	9.4
Field Crops - Vegetables	8.7	8.5	8.2	4.7
Orchard Crops	4.0	4.0	3.7	5.1
Vine Crops	3.2	3.2	3.0	4.7
Field Crops - Hay	8.7	8.5	8.2	4.7
Grapes	3.2	3.2	3.0	14.0

The crop area by crop type was taken from 2011 Census of Agriculture for the census consolidated subdivisions (CCSs) within the CVRD. The total area in hectares for each crop category and for each CCS in the CVRD are shown in Appendix 1.

2.2.3 Open Burning

Open burning is a significant source of PM emissions in BC (Environment and Climate Change Canada, 2016). This source can be divided into three sub categories: prescribed & pile burning (land clearing and forestry operations); backyard burning; and, forest fires.

2.2.3.1 Prescribed & Pile Burning

Open burning is a common practice in British Columbia due to the needs of forest management and also disposal of debris related to logging activities and land clearing. Particulate matter emissions from open burning depend on the amount and type of waste burned. Open burns are categorized by their size and nature per the BC Wildfire Regulation, as described in Table 22.

The Ministry of Forest, Lands and Natural Resource Operations (FLNRO) maintains an Open Fire Tracking System (OFTS) through their Wildfire Branch. This inventory keeps track of Category 3 (Pile) and Category 4 (resource management) burns in British Columbia through the issuance of Burn Registration Numbers (BRNs). The BRN data recorded through the Wildfire Branch in the OFTS are the most complete record of open burning activities available in the Province, and thus, were adopted as the activity data for this particular emissions inventory.

Table 22: BC Wildfire Regulation Open Fire Categorization

Open Fire Category	Description
Category 1 (Camp Fires and Backyard Burns)	An open fire that meets both of the following requirements: a) the open fire burns material in one pile no larger than 0.5 m in height and 0.5 m in width; and b) the open fire is lit, fuelled or used: i. by any person for a recreational purpose, or ii. by a first nation for a ceremonial purpose.
Category 2	An open fire, other than a camp fire, that: a) burns material in one pile not exceeding 2 m in height and 3 m in width, b) burns material concurrently in 2 piles each not exceeding 2 m in height and 3 m in width; or c) burns stubble or grass over an area that does not exceed 0.2 ha.
Category 3	An open fire that burns a) material concurrently in 3 or more piles each not exceeding 2 m height and 3 m in width, b) material in one or more piles each exceeding 2 m in height or 3 m in width, c) one or more windrows, or d) stubble or grass over an area exceeding 0.2 ha.
Category 4 (Resource Management Open Fire)	An open fire that: a) burns unpiled slash over an area of any size, or b) is not a campfire or a category 2 or 3 open fire and is lit, fuelled or used for silviculture treatment, forest health management, wildlife habitat enhancement, fire hazard abatement, ecological restoration or range improvement.

Source: Government of British Columbia, 2005.

The OFTS BRN data were obtained from the Ministry for the 2015 calendar year. The records include both pile (in number of piles/windrows) and area (in hectares) burn registrations. The amount of material burned can be estimated using either the number of piles or the area of the burn. The emissions equations for regulated burns by number of pile or by area burned areas are shown in Equation 14 and Equation 15.

Equation 14: Regulated Pile Burn Emissions

$$\text{Pile Burn Emission (kg)} = \text{Emission Factor (kg/tonne)} * \text{Net Mass Per Pile (tonnes)} * \text{Number of Piles} / 1{,}000$$

Equation 15: Regulated Area Burn Emissions

$$\text{Area Burn Emission (kg)} = \text{Emission Factor (kg/tonne)} * \text{Fuel Loading (tonnes / hectare)} * \text{Burn Area (hectares)} / 1{,}000$$

The province-wide OFTS BRN data was filtered for regulated burns in the CVRD (using associated latitude / longitude coordinates in ArcGIS) and to remove duplicate entries, resulting in 40 regulated burns in the CVRD in 2015.

For pile burning, a method to categorize the pile burns into different pile classes was adopted from a 2010 BC MOE emissions inventory (McCormick, 2013). The first step of this method was to produce a frequency distribution for the categorization of different pile classes.

Break points were identified at 5 piles and fewer, 5 to 10 piles and more than 10 piles. Pile classes were assigned C (Very Dirty), B (Dirty) and A (Clean), respectively. Pile class statistics within the area of interest are presented in Table 23 and Figure 3. An additional 13 BRN records were classified as area burns.

In addition to the OFTS BRN data, the Denman Island and Cumberland Fire Service areas reported 10 permits for land-clearing each. These additional 10 permits were assumed to be class C piles with an average of 2.25 piles per permit (equal to the number of piles per permit from the BRN data).

Table 23: Pile Burn Statistics from 2014 OFTS BRN Data

Pile Class	Number of BRN Records	Total Number of Piles	Percent of BRNs	Percent of Total Pile Burns	Description
Class A	16	1,620	59%	97%	> 20 piles / BRN
Class B	3	40	11%	2%	5-19 piles / BRN
Class C	8	18	30%	1%	1-5 piles / BRN
Class C from Fire Service District Permits	20*	45	n/a	n/a	Assumed 2.25 piles / Permit

*Both the Denman and Cumberland Fire Services reported 10 permit each for landclearing

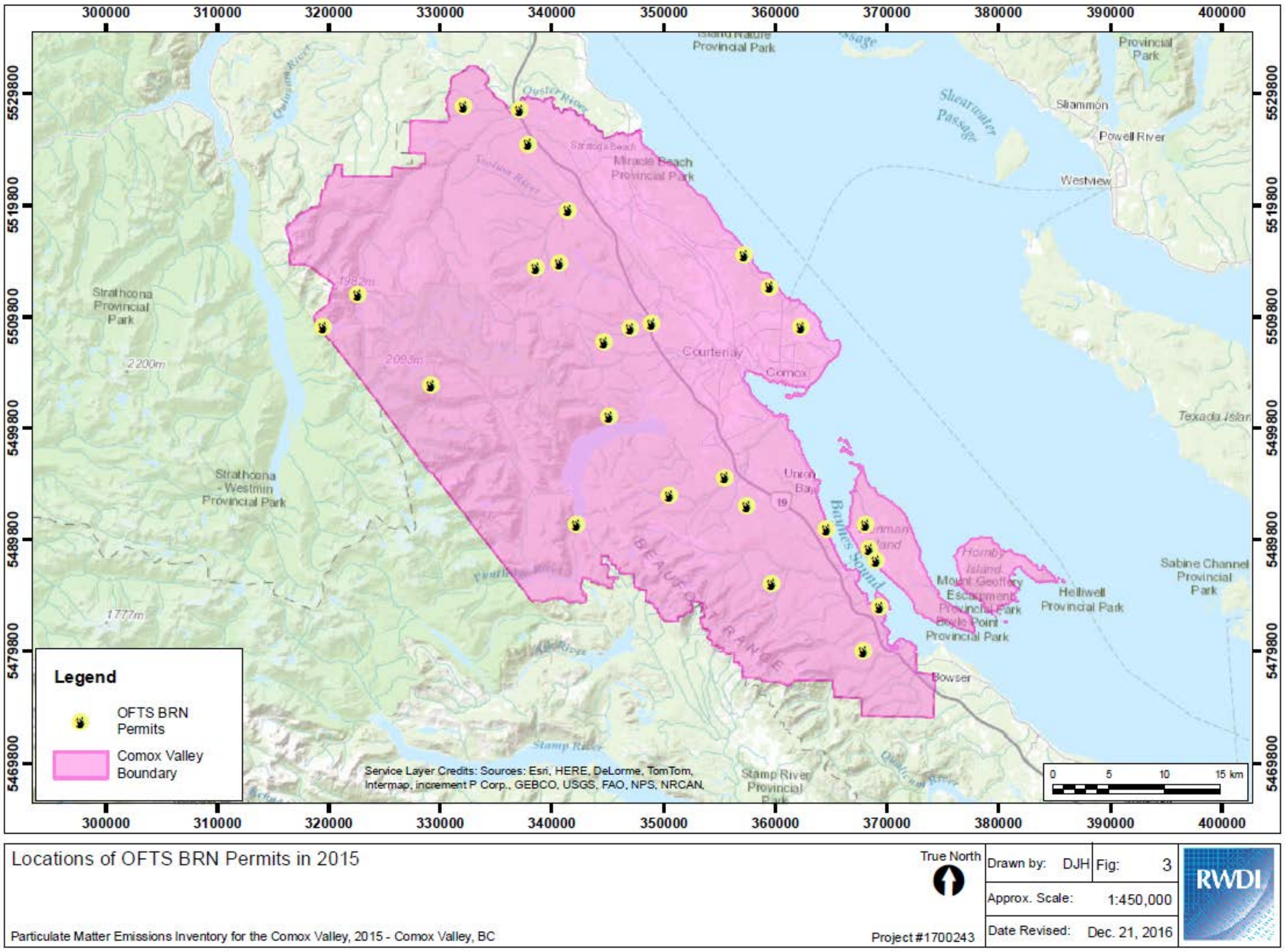

Figure 3: Locations of OFTS BRN Permits in 2015

2.2.3.2 Pile and Area Burn Assumptions

Assumptions were made for pile and area open burns to estimate the amount of material burned as a necessary input for emission calculations. Assumptions for the different pile classes were adapted from the 2010 BC MOE emissions inventory report (McCormick, 2013) and are presented in Table 24. Piles were assumed to be parabolic in shape, with a packing ratio that varied based on the class of pile due to the assumption that operators doing larger numbers of pile burns are typically better at making tight, organized piles. The wood density value is an average calculated from several tree species commonly found in BC forests.

Table 24: Pile Burn Size and Net Mass Assumptions

Pile Class	Pile Height (m)	Pile Width (m)	Pile Volume (m^3)	Packing Ratio	Consumption Factor	Wood Density (lb per ft^3)	Wood Density (kg per m^3)	Net Mass per Pile (tonnes)
Class A	6.0	9.0	190.85	0.25	0.9	27.7	444.63	19.09
Class B	6.0	9.0	190.85	0.15	0.9	27.7	444.63	11.46
Class C	6.0	9.0	190.85	0.10	0.9	27.7	444.63	7.64

The only assumption required for area burns was an estimate of the fuel loading value, which is the estimated number of tonnes of material per hectare. A value of 7.2 tonnes per hectare value was adapted from the US EPA's AP-42 Chapter 2, Section 5 on Open Burning (US EPA, 1992). Most 'area burns' in the area of interest were assumed to be resource management burns due to their Category 3 or 4 classifications. As such, the material burned is assumed to be wild grasses and shrub / brush mix. To represent this type of burn material, the fuel loading value for the refuse category "Weeds – Unspecified" was adopted for area burns.

2.2.3.3 Emission Factors

The final emission factor used in the calculation of PM emissions from both pile and area open burn is 0.63 kg per tonnes of mass consumed and is shown in Table 25. This emission factor for burns was referenced from the Metro Vancouver 2005 Lower Fraser Valley Air Emissions Report, Table B.1.2.1 for Burning for the Prescribed Burning category (MV 2010).

Table 25: Open Burning Emission Factors (kg per tonne of mass consumed)

Burn Type / Class	TPM	PM_{10}	$PM_{2.5}$
Class A	11.0	7.8	6.8
Class B	13.5	10.0	8.5
Class C	18.0	14.0	11.9
Area	8.0	5.9	5.1

2.2.3.4 Backyard burning

Backyard burning refers to the burning of clean, untreated wood or other organic materials on residential properties. For this inventory, backyard burning includes Category 1 (camp fires and backyard burns) and Category 2 open fires under the backyard burning category. Category 1 and Category 2 open fires can be regulated and/or tracked by regional and municipal authorities. Fire Chiefs from the local fire districts were contacted to obtain information regarding burning behavior in their respective areas. Each Fire District was asked to provide the number of fire permits issued in 2015 and the number of fires suspected to be lit without a permit. The survey also asked whether backyard burning is banned for part or all of the year. A copy of the survey is provided in Appendix 2.

In the rural areas of the CVRD, it is common practice to burn residential yard waste such as brush, grass clippings or leaf litter. Backyard burning is banned in the City of Courtenay, the Town of Comox and the Village of Cumberland. The Village of Cumberland passed a bylaw on February 27, 2017 to prohibit yard waste fires, previously there had been a spring yard waste burning period. Occasionally household garbage may be burned;

however, it has not been included in this emissions inventory as it is on the prohibited items list of the Open Burning Smoke Control Regulation, and is considered a rare practice.

The CVRD also provided data from Comox Valley Waste Management Centre regarding the amount and types of material collected as well as collection data for the City of Courtenay. The average burnable waste generated per capita was calculated for the City of Courtenay, Comox, and Cumberland for 2015 using the sum of wood, grass, organics and yard waste collected and is shown in Table 26.

Table 26: Yard, Wood, Grass & Leaves and Organic Waste Generated in the Comox Valley by Community

Community	Population	Waste Collected (tonnes)	Waste Generation Rate (kg per capita)
Comox	13,627	1697	124.6
Courtenay	25,744	2365	91.9
Cumberland	3,398	343	100.9

The average of yard waste generation rates for the City of Courtenay (91.9 tonnes/person) was used to estimate the total waste generated in rural areas. This waste generation rate was multiplied times the population in rural areas including Cumberland, and the electoral areas (25,812 people) (Comox Valley Regional District, 2013). The actual amount of waste collected in the rural areas, provided by the CVRD was subtracted and the remainder was assumed to be burned. The values are presented in Table 27.

Table 27: Yard Waste Generated, Collected and Burned (tonnes per year)

2011 CVRD Population	25,812	people
Yard Waste Generation	91.9	kg/capita/year
Estimated Waste Generation	2,371	tonnes/year
Actual Waste Collected	522	tonnes/year
Estimated Yard Waste Burned	1,849	tonnes/year

Using the data from the Comox Valley Waste Management Centre, percentages of the materials collected were calculated and multiplied by the amount of material burned and the PM emission factors from AP-42 Chapter 2, Section 5 on Open Burning (US EPA, 1992). The quantities burned and PM emission factors from backyard burning are listed in Table 28. As the majority of particulate matter is submicron in size (US EPA, 1992), the TPM is equal to the PM_{10} and $PM_{2.5}$ amounts.

Table 28: Particulate Matter Emission Factor and Material Quantities from Backyard Burning

Material	US EPA Category	TPM EF (kg/tonne)	Percentage of Material Collected (%)	Quantity of Material Burned (tonnes)
Yard Waste	Unspecified Weeds	8	81%	1492
Clean Wood Waste	Unspecified forest residue	8	7%	136
Cut Grass & Raked Leaves	Unspecified Leaves	19	12%	221

To verify the amount of waste burned, RWDI contacted nine fire districts and obtained information regarding the number of permits issued in 2015. Each permit was assumed to represent 1.5 piles since most people burn one to two piles per permit. Additionally, the number of fires without a permit (as estimated by each Fire District) was included and assumed to represent a single fire. The amount of material burned was calculated using the same assumptions as opening burning for Class C (1-5 piles) in Table 24 but the pile size was changed to a maximum of 2 m x 3 m as per the BC Wildfire regulation for Category 2 burns (Government of British Columbia, 2005). The estimated amount of material burned is presented in Table 29. This amount (1000 tonnes) is similar in magnitude to the yard waste estimated using the data from CVRD (1849 tonnes), and thus, the emissions from backyard burning are assumed to be reasonable.

Table 29: Estimated Amount of Backyard Burn Material (tonnes per year)

Fire Type	Number of Permits*	Number of Fires	Amount of Material Burned in 2015 (tonnes)
Backyard Burn Permit	1436	2154	460
Burns without a Permit	*	865	195
Recreational Fires	385	385	0.8
Landclearing Fires**	20	45	344
		Total Amount Burned	***999.8***

*The number of fires without a permit was provided by survey with each fire district, thus there is no value for the number of permits
**Emissions from landclearing fires are addressed in section 2.2.3.1 and these amounts have been added into Table 23

2.2.3.5 Wildfire

The BC Wildfire Service collects and publishes several types of data on current and historical wildfires throughout the province. They also published a dynamic list and interactive map of all current wildfires larger than 0.01 hectares for the current year (May 2016-May 2017) for each Fire Service Area. A filter of the Coastal Fire Centre current wildfire list for fire areas 7 and 8 resulted in a list of 6 fires totaling 43.8 hectares, all of which were outside of the Comox Valley.

The BC Wildfire service also produces GIS files with the point locations and sizes (polygons) for wildfires in 2016. The point locations file listed 1,049 individual fires in the province, but the size file only lists sizes for 214 fires. When compared to the Comox Valley, the point locations file listed 10 wildfires, but none of these fires were listed in the size file, meaning the corresponding size of each fire is unknown.

In addition, the BC Wildfire Service publishes historical wildfire data including locations, size, and data in GIS format to the end of 2014. This data source listed two wildfires with a total of 5.3 hectares burned in 2014. This dataset, being the most complete set of recent data, was used for determining emissions from wildfires.

Wildfire emission factors were calculated from data obtained from Wildfire CAC Emission Inventory for 2011 report (McCormick, 2012). The estimated amount (in tonnes) of TPM, PM_{10} and $PM_{2.5}$ emitted were divided by the total area burned for the Coastal Region. The effective emission factors for the Coastal Region and the corresponding emissions estimated for wildfire burns in the CVRD are presented in Table 30.

Table 30: Effective Emission Factors for Wildfire Burning in the Coastal Region (kilogram per hectare)

Emission Factor (kg/ha)		
TPM	PM_{10}	$PM_{2.5}$
667	481	444

2.2.4 Miscellaneous Sources

Miscellaneous sources of PM include meat cooking, cigarettes, dry cleaning, crematoria, and structural fires. PM emissions from the BC emissions inventory (Environment and Climate Change Canada, 2016) were scaled to the CVRD using human population. PM emissions from the BC emissions inventory are shown in Table 31. Population was taken from BC Statistics (BC Statistics, 2016), the 2014 population for BC used was 4,638,415, and the population for the CVRD for 2015 was 64,634.

Table 31: 2014 BC Emissions from Miscellaneous Sources

Emission Source			2014 BC Emissions (tonnes per year)		
			TPM	PM_{10}	$PM_{2.5}$
Area	Miscellaneous	Meat Cooking	1,114.0	1,114.0	1,114.0
		Cigarettes	39.0	39.0	39.0
		Dry Cleaning	1.0	1.0	1.0
		Crematorium	1.0	1.0	1.0
		Structural Fires	22.0	22.0	20.0
		Miscellaneous subtotal	***1,177.0***	***1,177.0***	***1,175.0***

2.3 Mobile

Mobile emission sources include on-road vehicles, non-road equipment, marine vessels, locomotives and aircraft. Direct PM emissions from mobile transportation sources are a small portion of the TPM in BC at less than 1% (Environment and Climate Change Canada, 2016).

PM emissions from the BC emissions inventory (Environment and Climate Change Canada, 2016) were scaled to the CVRD using appropriate surrogate data for all mobile sources except marine transportation. Mobile emissions for all of BC are shown in Table 32.

The emission amounts in Table 32 were scaled down to the CVRD region using surrogate data from the 2010 CEEI, the 2011 Census of Agriculture and Statistics Canada. The specific surrogates used for each emission source by the categories used in the 2014 BC air emissions inventory are shown in Table 33. The surrogates used for each mobile emission source are also further discussed in the following sections.

Table 32: Province-Wide (BC) Mobile Source Emissions for 2014

Emission Source				2014 BC Emissions (tonnes per year)		
				TPM	PM_{10}	$PM_{2.5}$
Mobile	On-road	Light-duty	Light-duty diesel trucks	36	36	35
			Light-duty diesel vehicles	33	33	32
			Light-duty gasoline trucks	297	297	273
			Light-duty gasoline vehicles	255	255	235
			Motorcycles	3	3	3
		Heavy-duty vehicles	Heavy-duty diesel vehicles	1181	1181	1146
			Heavy-duty gasoline trucks	61	61	56
	Non-road vehicles		Off-road use of diesel	1225	1225	1200
			Off-road use of gasoline/LPG/CNG	579	557	524
	Marine Vessels		Marine Transportation	2599	2495	2296
	Aircraft		Air Transportation	218	218	196

Table 33: Mobile Emission Scaling Surrogates

Emission Source			BC 2014 Category	BC Value	Comox Valley Value	Scaling Surrogate Name		Surrogate Data Source
Mobile	On-road	Light-duty	Light-duty diesel trucks	73,198,229	1,369,459	Diesel (litres)	Light Trucks, Vans, SUVs	CEEI, 2010
			Light-duty diesel vehicles	35,730,800	1,096,181	Diesel (litres)	Small Passenger Cars	
			Light-duty gasoline trucks	2,404,995,683	40,157,147	Gasoline & hybrid (litres)	Light Trucks, Vans, SUVs	
			Light-duty gasoline vehicles	1,803,891,002	34,484,704	Gasoline & hybrid (litres)	Small Passenger Cars	
			Motorcycles	14,451,157	305,713	Gasoline (litres)	Motorcycles, Mopeds	
		Heavy-duty vehicles	Heavy-duty gasoline trucks	1,212,620,517	9,794,534	Diesel (litres)	Bus	
							Commercial Vehicles	
							Motorhomes	
							Tractor Trailer Trucks	
			Light-duty diesel trucks	341,375,603	4,715,081	Diesel, hybrid, other (litres)	Bus	
							Commercial Vehicles	
							Motorhomes	
							Tractor Trailer Trucks	
	Non-road vehicles		Off-road use of diesel	62,900	1,188	Number Owned & Leased	Total Farm Machinery	Census of Agriculture, 2011
			Off-road use of gasoline/LPG/CNG					
	Non-road vehicles		Off-road use of diesel	13,125,233	147,338	Dollar Value $	Total Building Permits, 2015	BC Statistics
			Off-road use of gasoline/LPG/CNG					
	Aircraft		Air Transportation	1,398,732	21,124	Number	Total, itinerant and local movements (3)	Statistics Canada

2.3.1 On-road vehicles

The 2014 BC emissions inventory estimates for on-road vehicles were scaled from a BC total to the CVRD using the predicted fuel consumption from the 2010 CEEI reports for BC. Fuel consumption by thirteen vehicle class and fuel type combinations from the CEEI were mapped to seven mobile source categories from the BC inventory. Each of the seven mobile source categories was scaled from the Provincial to regional total individually.

2.3.2 Non-road equipment

Non-road equipment can be further divided by sector of use including: agricultural; construction; industrial; commercial; lawn and garden equipment; and, recreational off-road vehicles. However, results from the FVRD have indicated that agricultural and construction equipment contributes to over 85% of the PM from all non-road sources (RWDI, 2016). The 2014 BC emissions inventory estimates for non-road vehicles were therefore scaled to the CVRD using appropriate scaling factors derived from surrogate data for agricultural and construction equipment. BC emissions from non-road equipment were assumed to be split between agriculture and construction at 50% share per sector. Each of these emissions were then downscaled to the CVRD using the surrogates listed in Table 33. The number of vehicles owned and leased as reported to the 2011 Census of Agriculture by census consolidated subdivision (CCS) was used to scale the non-road agricultural equipment emissions. The 2015 annual dollar value in building permits was used to scale the non-road construction equipment emissions.

2.3.3 Marine Vessels

Particulate emissions are expected to be produced by ferries, recreational vessels and fishing vessels in the Comox Valley. For this study, emission estimates from marine vessel movements in 2015 were provided by Environment and Climate Change Canada (ECCC) from earlier results output from the prototype Marine Emission Inventory Tool (MEIT v4.1). It should be noted that the values provided from MEIT have not been fully validated (per ECCC). Emissions from MEIT were provided for the region shown in Figure 4. Emissions over this area are shown in Table 34.

Table 34: Marine Emission Inventory Tool Emissions[1] for the CVRD[2]

Emission Source	2015 MEIT Prototype Emissions (tonnes per year)		
	TPM	PM_{10}	$PM_{2.5}$
Marine Vessels	19.4	19.4	17.8

1. Emissions were extracted from a MEIT prototype and have not been validated yet
2. Emissions from MEIT were provided for a region bounded by a latitude range of -125.555 and a longitude range of -124.570 and 49.921 and 49.404.

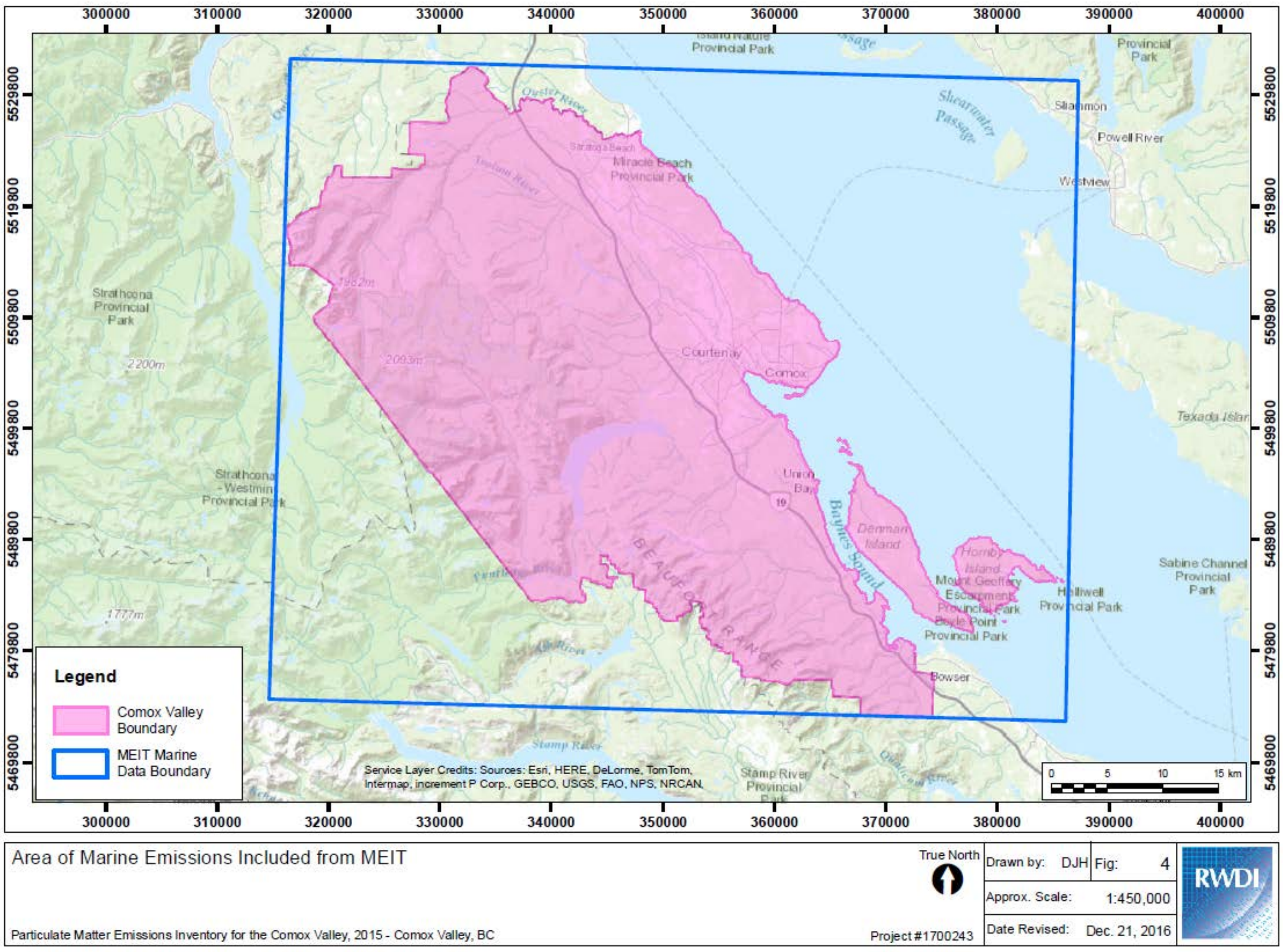

Figure 4: Map of Marine Emissions Included from MEIT

2.3.4 Locomotives and Rail Equipment

All railways within the geographic scope of this project were closed prior to 2011 resulting in zero PM emissions from this source.

2.3.5 Aircraft

RWDI obtained the number of Landings and Take-offs (LTOs) for civilian and military aircraft at the Comox Valley Airport in 2015 from the Royal Canadian Air Force's 19 Wing Comox AFB. A representative from the Comox Valley Airport confirmed that although aircraft movements vary from year to year, traffic did not increase significantly in 2015. Two smaller commuter and recreational airports were contacted by email for information but neither responded. Canada wide aircraft movements were also collected from Statistics Canada for 2014 and are listed in with the Comox totals in Table 35.

Table 35: Total Aircraft Landings and Take-offs (LTOs)

Region	2015 LTOs
Canada	6,085,333
British Columbia	1,398,732
Comox	21,124

The BC emission estimates from aircraft were downscaled to the CVRD using the total aircraft movements from the Comox Valley Airport and the total for all airports in BC as reported by Statistics Canada (Statistics Canada, 2016).

2.4 Fugitive Dust

Fugitive dust emissions result from mobile equipment operating on dust emitting surfaces such as from paved and unpaved roadways, industrial areas, and landfills. Fugitive dust sources included in this section are associate with industrial sources, construction operations, and landfills. Fugitive dust from paved and unpaved roads has been included in a separate section. Emission estimates for fugitive dust from roads are typically large, however, as noted previously, most fugitive road dust is in the coarse (>44 μm) size fraction (Pace, 2005) and thus settles out of the air in close proximity (e.g., within 100 meters) of the emission source (Desert Research Institute, 2000).

2.4.1 Industrial sources

Tayco Paving Company was the only industrial facility within the CVRD to report emissions of fugitive dust to the NPRI in 2014 as shown in Table 36.

Table 36: Fugitive Dust PM Emissions from Industrial Sources reported to the NPRI in 2014

Emission Source			2014 Emissions (tonnes per year)		
			TPM	PM_{10}	$PM_{2.5}$
Fugitive Dust	Industrial Sources	Tayco Paving Company	3.74	1.06	0.11

2.4.2 Construction Operations

Fugitive dust from construction operations were calculated using the method described in Metro Vancouver's 2005 Emission Inventory (Metro Vancouver, 2007), which contains monthly emission factors for 6 different building types. Emission factors were multiplied by the number of dwellings or value of construction built, the assumed number of months of construction, and an average size of building as shown in Table 37. The number of dwellings or value of construction built for each of the 6 building types was extracted from the 2015 Building Permit data from BC Statistics (BC Stats, 2016) as shown in Table 38.

Table 37: Factors for Emissions of Construction Dust

Item	Unit	Conversion Factor (ha/unit)	Duration	Adjusted EF (tonnes TPM and PM_{10}/ha-month)	Adjusted EF (tonnes $PM_{2.5}$/ ha-month)
Single-detached	Dwellings	0.067	4.2	0.014	0.0028
Duplex/Row	Dwellings	0.067	4.2	0.014	0.0028
Apartment	Dwellings	0.02	12	0.049	0.0098
Commercial	$ million	0.55	11	0.085	0.017
Industrial	$ million	0.55	11	0.085	0.017
Institutional	$ million	0.27	11	0.085	0.017

Table 38: Building Permits in Comox Valley Regional District in 2015

Building Types (Units)	Value or Number of Buildings Permitted
Industrial ($000)	4,478
Institutional and Government ($000)	43,070
Commercial ($000)	13,905
Residential Units (total #)	370
Residential Units -single dwelling (#)	163
Residential Units- Row (#)	3
Residential Units- Apartments (#)	195

2.4.3 Landfills

Emissions of fugitive dust from landfills from the BC emissions inventory (Environment and Climate Change Canada, 2016) were scaled based on the total volume of waste predicted and reported from the CEEI for 2010. The 2014 BC emissions inventory reported: 192,022 tonnes of TPM; 57,635 tonnes of PM_{10}; and, 11,542 tonnes of $PM_{2.5}$ for all of BC. The CEEI estimated that 2,386,715 tonnes of solid waste was produced in BC in 2010, and 44,224 tonnes of solid waste was produced in the CVRD in 2010.

2.5 Road Dust

Road Dust emissions are presented in a separate section of this report, in keeping with current emission inventory trends. Fugitive dust from paved and unpaved roads results from traffic movements which suspend material into the atmosphere. Current methods for estimating emissions of road dust include a large degree of uncertainty as estimates are based on a number of site-specific variables which are not known with any certainty without extensive field measurements. Particulate matter that is suspended on roads is typically crustal matter of larger size fractions (e.g., > 44 µm). The largest particles tend to settle out within the first 100 m of the roadway, which provides inherent mitigation of about 75% of emissions (Desert Research Institute 2000). For this reason, road dust emissions are typically highly conservative.

Emissions from paved and unpaved roads were provided by the BC emissions inventory (Environment and Climate Change Canada, 2016) in three categories: tire wear and brake lining; dust from paved roads; and, dust from unpaved roads (see Table 39). The 2014 BC emissions inventory estimates for paved and unpaved roads were scaled from a BC total to the using the predicted fuel consumption from the 2010 CEEI reports for BC as shown in Table 40. Fuel consumption for all vehicle classes and all fuel type combinations from the CEEI were summed to Provincial and regional totals and used to scale emissions from tire wear and brake lining and dust from paved roads. Consumption of diesel fuel was used to scale dust from unpaved roads.

Table 39: 2014 BC Road Dust Emissions

Emission Source	BC 2014 Emission Category	2014 BC Emissions (tonnes)		
		TPM	PM_{10}	$PM_{2.5}$
Paved & Unpaved Roads	Tire wear & Brake Lining	772	772	189
	Dust from Paved Roads	551,352	105,677	25,350
	Dust from Unpaved Roads	347,436	118,543	17,118
Total Road Dust		**899,560**	**224,992**	**42,657**

Table 40: Road Dust Emission Scaling Surrogates

Emission Source	BC 2014 Emission Category	Fuel Consumption (L)		Fuel Type Included
		BC	Comox Valley	
Paved & Unpaved roads	Tire Wear & Brake Lining	5,894,855,894	83,962,333	All fuel
	Dust from Paved Roads			
	Dust from Unpaved Roads	1,321,549,546	12,260,174	Diesel fuel

3 RESULTS

3.1 All Sources

Emissions of TPM, PM_{10}, and $PM_{2.5}$ by source and source sector for 2015 for the CVRD are shown in Table 41. Annual emissions of TPM, PM_{10}, and $PM_{2.5}$ from all sources (excluding road dust) are estimated to be 901, 727, and 608 tonnes, respectively. The relative proportions of TPM, PM_{10}, and $PM_{2.5}$ by major emission source category excluding fugitive dust are shown Figure 5, Figure 6 ,and Figure 7, respectively.

Table 41: Particulate Matter Emissions for the CVRD

Emission Source			2015 Emissions (tonnes per year)		
			TPM	PM_{10}	$PM_{2.5}$
Point	Industrial Sources		1.6	0.6	0.2
	Point Subtotal		***1.6***	***0.6***	***0.2***
Area	Space Heating	Natural Gas - Residential	1.2	1.2	1.2
		Natural Gas - Commercial/Industrial	1.0	1.0	1.0
		Propane	0.2	0.2	0.2
		Wood	225.6	213.0	212.8
		Heating Oil	0.5	0.5	0.5
		Space Heating Subtotal	***228.5***	***215.9***	***215.7***
	Agricultural	Synthetic Fertilizer Application	0.2	0.1	0.03
		Tilling	35.5	35.5	7.5
		Harvesting	0.3	0.3	0.05
		Wind Erosion	51.1	25.6	3.8
		Livestock movements	4.1	1.2	0.2
		Crop Residue Burning	0.9	0.8	0.8
		Agricultural Subtotal	***92.1***	***63.6***	***12.4***
	Open Burning	Provincially Regulated - Pile	348.9	247.8	215.9
		Provincially Regulated - Area	57.5	42.4	36.7
		Municipally Regulated - Pile	6.2	4.8	4.1
		Recreational Fires	0.01	0.01	0.009
		Regional/Municipal - Backyard Burns	17.2	17.2	17.2
		Wildfire	3.5	2.6	2.4
		Open Burning Subtotal	***433.4***	***314.8***	***276.2***
	Miscellaneous	Meat Cooking	15.5	15.5	15.5
		Cigarettes	0.5	0.5	0.5
		Dry Cleaning	0.01	0.01	0.01
		Crematorium	0.01	0.01	0.01
		Structural Fires	0.3	0.3	0.3
		Miscellaneous Subtotal	***16.4***	***16.4***	***16.4***
	Area Subtotal		***770.3***	***610.7***	***520.7***
Mobile	On-road	Light-duty	11.6	11.6	10.8
		Heavy-duty vehicles	10.4	10.4	10.0
	Non-road vehicles		34.1	33.7	32.6
	Marine Vessels		19.4	19.4	17.8
	Aircraft		3.3	3.3	3.0
	Mobile Subtotal		***78.7***	***78.3***	***74.1***
Fugitive Dust	Industrial Sources		3.7	1.1	0.1
	Construction Operations		23.3	23.3	4.7
	Landfills		22.8	12.6	8.4
	Fugitive Dust Subtotal		***49.8***	***36.9***	***13.1***
Total (no road dust)			***900.5***	***726.5***	***608.1***
Paved and unpaved roads			11,087.3	2,615.9	522.6
Total (with Road dust)			***11,987.8***	***3,342.4***	***1,130.7***

Notes: Totals may not equal the sum of components due to rounding.

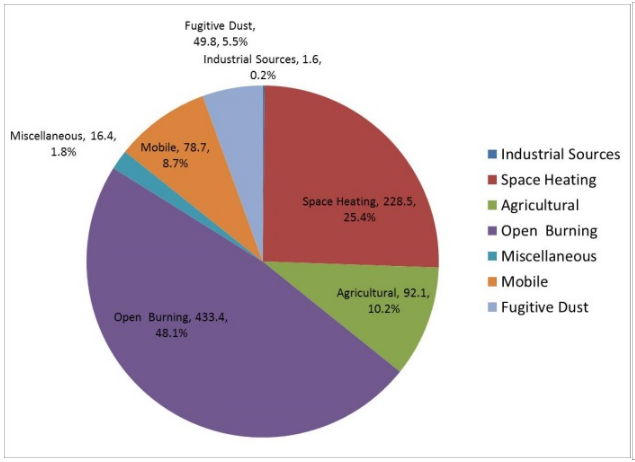

Figure 5: TPM Emissions for the CVRD, tonnes (not including Road Dust)

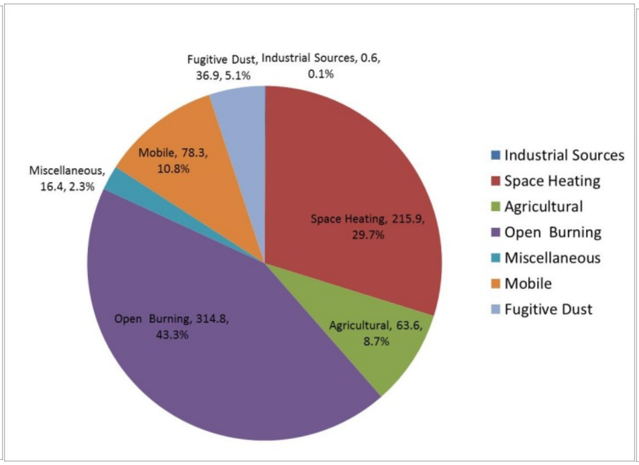

Figure 6: PM_{10} Emissions for the CVRD, tonnes (not including Road Dust)

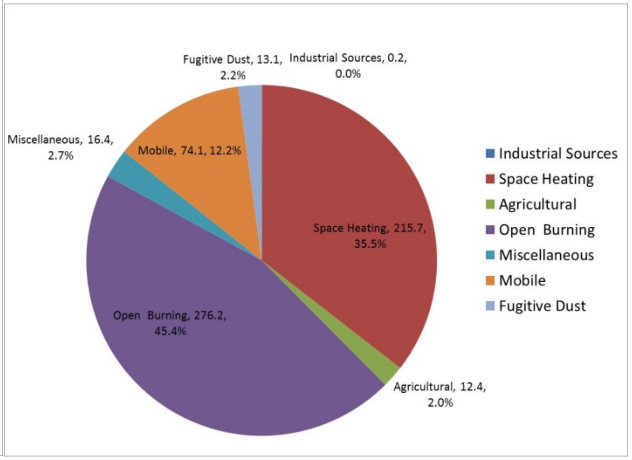

Figure 7: $PM_{2.5}$ Emissions for the CVRD, tonnes (not including Road Dust)

3.2 Industrial Sources

Emissions from industrial sources are shown in Table 42.

Table 42: Particulate Matter Emissions from Industrial Sources

Emission Source		2015 Emissions (tonnes per year)		
		TPM	PM_{10}	$PM_{2.5}$
Point	Tayco Paving Company	1.51	0.65	0.23
	Trueline Masonry and Landscape Products td.	0.01	-	-
	Hyland Precast Inc.	0.07	-	-
Total		***1.59***	***0.65***	***0.23***

3.3 Area Sources

Emissions from area sources by source and type are shown in Table 43. Emissions from wood used for space heating and provincially regulated pile burns make up the majority of the area source emissions, contributing 25% and 48% of the TPM, respectively. The relative proportions of TPM, PM_{10}, and $PM_{2.5}$ emissions from area sources by emission source category are shown Figure 8, Figure 9, and Figure 10, respectively

Table 43: Particulate Matter Emissions from Area Sources

Emission Source			2015 Emissions (tonnes per year)		
			TPM	PM_{10}	$PM_{2.5}$
Area	Space Heating	Natural Gas - Residential	1.2	1.2	1.2
		Natural Gas - Commercial/Industrial	1.0	1.0	1.0
		Propane	0.2	0.2	0.2
		Wood	225.6	213.0	212.8
		Heating Oil	0.5	0.5	0.5
		Space Heating Subtotal	***228.5***	***215.9***	***215.7***
	Agricultural	Synthetic Fertilizer Application	0.2	0.1	0.03
		Tilling	35.5	35.5	7.5
		Harvesting	0.3	0.3	0.05
		Wind Erosion	51.1	25.6	3.8
		Livestock movements	4.1	1.2	0.2
		Crop Residue Burning	0.9	0.8	0.8
		Agricultural Subtotal	***92.1***	***63.6***	***12.4***
	Open Burning	Provincially Regulated - Pile	348.9	247.8	215.9
		Provincially Regulated - Area	57.5	42.4	36.7
		Municipally Regulated - Pile	6.2	4.8	4.1
		Recreational Fires	0.01	0.01	0.009
		Regional/Municipal - Backyard Burns	17.2	17.2	17.2
		Wildfire	3.5	2.6	2.4
		Open Burning Subtotal	***433.4***	***314.8***	***276.2***
	Miscellaneous	Meat Cooking	15.5	15.5	15.5
		Cigarettes	0.5	0.5	0.5
		Dry Cleaning	0.01	0.01	0.01
		Crematorium	0.01	0.01	0.01
		Structural Fires	0.3	0.3	0.3
		Miscellaneous Subtotal	***16.4***	***16.4***	***16.4***
	Area Subtotal		***770.3***	***610.7***	***520.7***

Note: Totals may not equal the sum of components due to rounding.

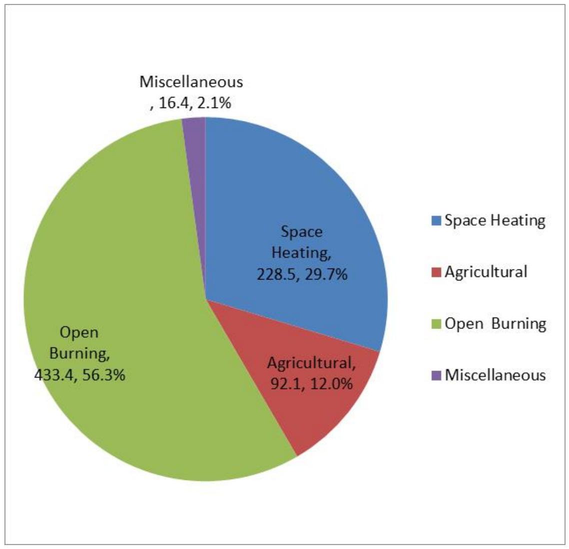

Figure 8: TPM Emissions from Area sources in the CVRD, tonnes

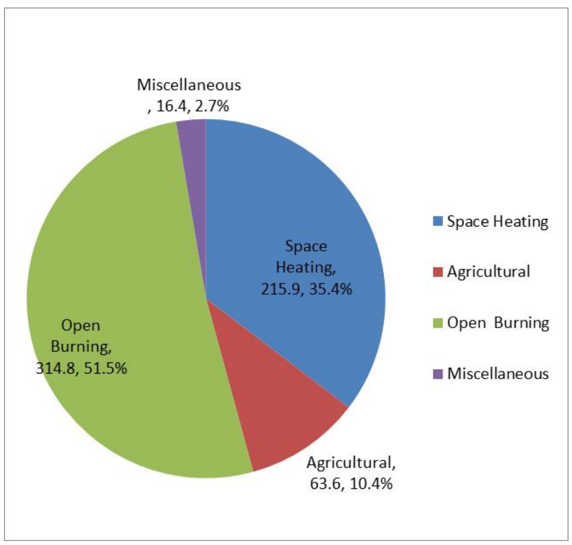

Figure 9: PM_{10} Emissions from Area Sources in the CVRD, tonnes

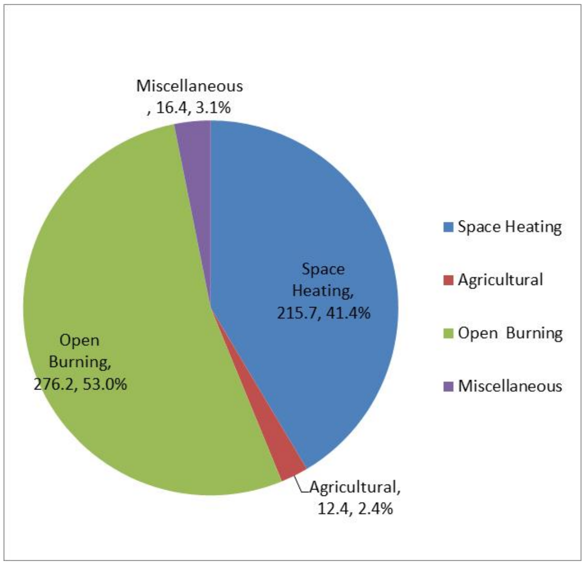

Figure 10: $PM_{2.5}$ Emissions from Area Sources in the CVRD, tonnes

3.3.1 Space Heating

Space heating emissions by fuel type are shown in Table 44, Emissions from wood burning equipment are listed in Table 45.

Table 44: Particulate Matter Emissions from Space Heating Sources by Fuel Type

Emission Source		2015 Emissions (tonnes per year)		
		TPM	PM_{10}	$PM_{2.5}$
Space Heating	Natural Gas - Residential	1.2	1.2	1.2
	Natural Gas - Commercial/Industrial	1.0	1.0	1.0
	Propane	0.2	0.2	0.2
	Wood	225.6	213.0	212.8
	Heating Oil	0.5	0.5	0.5
	Space Heating Total	***228.5***	***215.9***	***215.7***

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Table 45: Particulate Matter Emissions from Wood Burning Equipment (tonnes per year)

Appliances Type	Fireplace; Advanced	Fireplace; Conventional Without glass doors	Central Furnace/Boiler (inside)	Central Furnace/Boiler	Central Furnace/Boiler (outside)	Fireplace Insert; Advanced Technology	Fireplace Insert; Catalytic	Fireplace Insert; Conventional	Woodstove; Advanced	Woodstove; Catalytic	Woodstove; Conventional	Pellet	Total Wood burning Equipment
TPM	9.5	34.4	8.5	0.1	2.2	17.2	1.6	34.0	66.8	2.0	44.9	4.3	***225.6***
PM_{10}	9.0	33.0	8.0	0.1	2.0	16.2	1.5	32.1	62.9	1.9	42.3	4.0	***213.0***
$PM_{2.5}$	9.0	32.8	8.0	0.1	2.0	16.2	1.5	32.1	62.9	1.9	42.3	4.0	***212.8***

Note: Totals may not equal the sum of components due to rounding.

3.3.2 Agricultural Sources

Emissions from agricultural sources are shown in Table 46.

Table 46: Particulate Matter Emissions from Agricultural Area Sources by Emission Sources and CCS

Emission Source			2015 Emissions (tonnes per year)		
			TPM	PM_{10}	$PM_{2.5}$
Agricultural	Synthetic Fertilizer Application	Comox Valley A	0.04	0.02	0.01
		Comox Valley B Lazo North	0.03	0.01	0.00
		Comox Valley C Puntledge - Black Creek	0.14	0.07	0.02
	Synthetic Fertilizer Application Subtotal		***0.21***	***0.10***	***0.03***
	Tilling	Comox Valley A	7.71	7.71	1.62
		Comox Valley B Lazo North	5.65	5.65	1.19
		Comox Valley C Puntledge - Black Creek	22.14	22.14	4.65
	Tilling Subtotal		***35.50***	***35.50***	***7.45***
	Harvesting	Comox Valley A	0.10	0.10	0.02
		Comox Valley B Lazo North	0.04	0.04	0.01
		Comox Valley C Puntledge - Black Creek	0.16	0.16	0.02
	Harvesting Subtotal		***0.31***	***0.31***	***0.05***
	Wind Erosion	Comox Valley A	5.83	2.91	0.44
		Comox Valley B Lazo North	5.49	2.74	0.41
		Comox Valley C Puntledge - Black Creek	39.82	19.91	2.99
	Wind Erosion Subtotal		***51.13***	***25.57***	***3.83***
	Livestock movements	Comox Valley A	0.71	0.22	0.03
		Comox Valley B Lazo North	0.56	0.19	0.03
		Comox Valley C Puntledge - Black Creek	2.79	0.83	0.13
	Livestock movements Subtotal		***4.07***	***1.24***	***0.20***
	Crop Residue Burning	Comox Valley A	0.17	0.17	0.16
		Comox Valley B Lazo North	0.08	0.08	0.07
		Comox Valley C Puntledge - Black Creek	0.61	0.60	0.57
	Crop Residue Burning Subtotal		***0.86***	***0.85***	***0.81***
Agricultural Total			***92.08***	***63.55***	***12.37***

Note: **Totals may not equal the sum of components due to rounding**

3.3.3 Open Burning

Emissions from open burning sources are shown in Table 47 and illustrated in Figure 11.

Table 47: Particulate Matter Emissions from Open Burning Sources by Emission Sources and CCS

<table>
<tr><th colspan="3" rowspan="2">Emission Source</th><th colspan="3">2015 Emissions (tonnes per year)</th></tr>
<tr><th>TPM</th><th>PM_{10}</th><th>$PM_{2.5}$</th></tr>
<tr><td rowspan="14">Open Burning</td><td rowspan="4">Provincially Regulated - Pile</td><td>Class A</td><td>340.2</td><td>241.3</td><td>210.3</td></tr>
<tr><td>Class B</td><td>6.19</td><td>4.58</td><td>3.89</td></tr>
<tr><td>Class C</td><td>2.47</td><td>1.92</td><td>1.64</td></tr>
<tr><td>Provincially Regulated - Pile Subtotal</td><td>348.9</td><td>247.8</td><td>215.9</td></tr>
<tr><td rowspan="2">Provincially Regulated - Area</td><td>Area</td><td>57.5</td><td>42.4</td><td>36.7</td></tr>
<tr><td>Provincially Regulated - Area Subtotal</td><td>57.5</td><td>42.4</td><td>36.7</td></tr>
<tr><td>Municipally Regulated - Pile</td><td>Municipally Regulated - Pile Subtotal</td><td>6.2</td><td>4.8</td><td>4.1</td></tr>
<tr><td>Recreational Fires</td><td>Recreational Fires Subtotal</td><td>0.01</td><td>0.01</td><td>0.009</td></tr>
<tr><td rowspan="4">Backyard Burning</td><td>Yard Waste</td><td>11.9</td><td>3.77</td><td>3.77</td></tr>
<tr><td>Clean Wood Waste</td><td>1.1</td><td>0.04</td><td>0.04</td></tr>
<tr><td>Cut Grass & Raked Leaves</td><td>4.2</td><td>0.14</td><td>0.14</td></tr>
<tr><td>Backyard Burning Subtotal</td><td>17.2</td><td>3.9</td><td>3.9</td></tr>
<tr><td rowspan="2">Wildfire</td><td>Wildfire subtotal</td><td>3.53</td><td>2.55</td><td>2.36</td></tr>
<tr><td>Wildfire Subtotal</td><td>3.53</td><td>2.55</td><td>2.36</td></tr>
<tr><td colspan="3">Open Burning Total</td><td>433.4</td><td>314.8</td><td>276.2</td></tr>
</table>

Note: Totals may not equal the sum of components due to rounding.

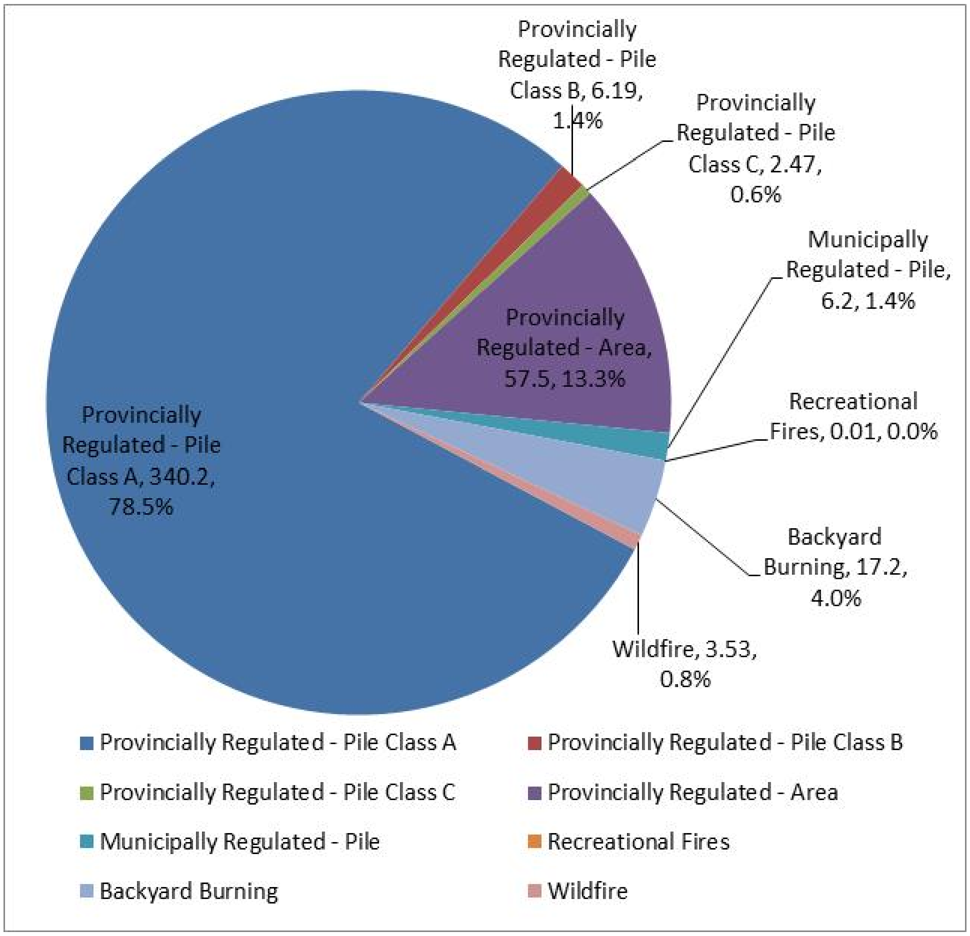

Figure 11: Particulate Matter Emissions from Open Burning Sources in the CVRD, tonnes

3.3.4 Miscellaneous Sources

Emissions from miscellaneous sources are shown in Table 48.

Table 48: Particulate Matter Emissions from Miscellaneous Sources

Emission Source		2015 Emissions (tonnes per year)		
		TPM	PM_{10}	$PM_{2.5}$
Miscellaneous	Meat Cooking	15.5	15.5	15.5
	Cigarettes	0.5	0.5	0.5
	Dry Cleaning	0.0	0.0	0.0
	Crematorium	0.0	0.0	0.0
	Structural Fires	0.3	0.3	0.3
	Miscellaneous Subtotal	***16.4***	***16.4***	***16.4***

3.4 Mobile

Emissions from mobile sources by source are shown in Table 49. Emissions from mobile sources collectively contribute only 7.4% of the TPM in the CVRD (excluding fugitive dust).

Table 49: Particulate Matter Emissions from Mobile Sources

Emission Source			2015 Emissions (tonnes per year)		
			TPM	PM_{10}	$PM_{2.5}$
Mobile	On-road	Light-Duty	11.58	11.58	10.75
		Heavy-Duty Vehicles	10.38	10.38	10.03
	Non-Road Vehicles		34.07	33.66	32.56
	Marine Vessels		19.4	19.4	17.8
	Aircraft		3.29	3.29	2.96
	Mobile Subtotal		***78.7***	***78.3***	***74.1***

3.5 Fugitive Dust

Emissions from fugitive sources by source are shown in Table 50.

Table 50: Particulate Matter Emissions from Fugitive Dust Sources

Emission Source		2015 Emissions (tonnes per year)		
		TPM	PM_{10}	$PM_{2.5}$
Fugitive Dust	Industrial Sources	3.7	1.1	0.1
	Construction Operations	23.3	23.3	4.7
	Landfills	22.8	12.6	8.4
	Fugitive Dust Subtotal	***49.8***	***36.9***	***13.1***

Note: Totals may not equal the sum of components due to rounding.

3.6 Road Dust

Emissions of from road dust are shown in Table 51. Emissions from fugitive dust (shown in Table 52) contribute to 93% of the TPM, 80% of the PM_{10}, and 47% of the $PM_{2.5}$.

Table 51: Particulate Matter Emissions from Fugitive Dust Sources

Emission Source		2015 Emissions (tonnes per year)		
		TPM	PM_{10}	$PM_{2.5}$
Road Dust	Paved & Unpaved Roads	11,087.3	2,615.9	522.6

Table 52: Particulate Matter Emissions from Fugitive Dust and Other Sources

Emission Source	2015 Emissions (tonnes per year)		
	TPM	PM_{10}	$PM_{2.5}$
Point	1.6	0.6	0.2
Area	770.3	610.7	520.7
Mobile	78.7	78.3	74.1
Fugitive Dust	49.8	36.9	13.1
Total (no Road dust)	***900.5***	***726.5***	***608.1***
Road Dust	11,087.3	2,615.9	522.6
Total (with Road dust)	***11,987.8***	***3,342.4***	***1,130.7***

Note: Totals may not equal the sum of components due to rounding.

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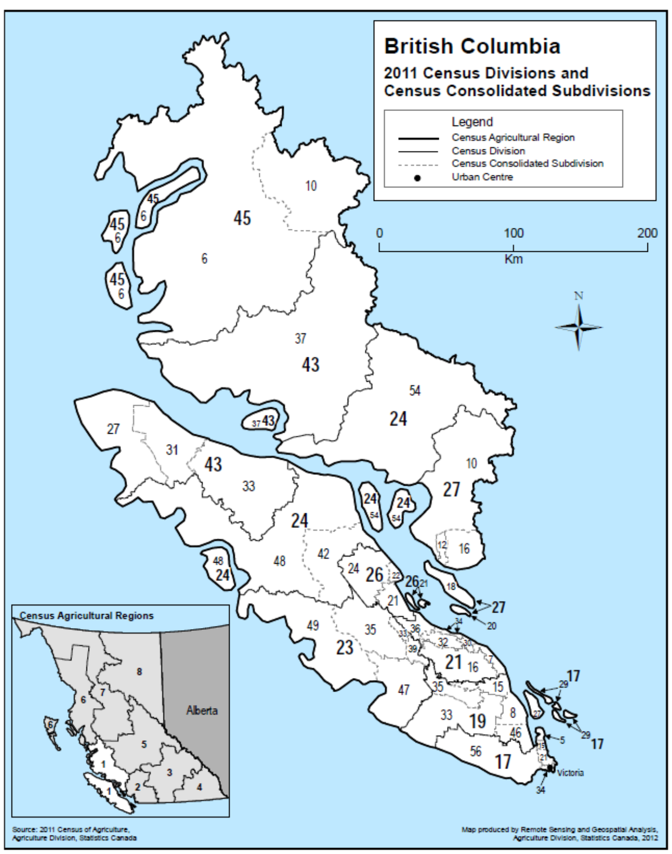
APPENDIX 1: DETAILED AGRICULTURAL EMISSIONS INVENTORY METHOD

4.1 Agricultural Sources

Particulate matter is produced from agricultural activities including the addition of synthetic fertilizers, tilling and harvesting of crops, wind erosion on fields, livestock husbandry, and the use of agricultural on- and non-road vehicles and equipment. Agricultural non-road vehicles and equipment has been discussed in section 2.3.2.

The Canadian Census of Agriculture provides the land in crops by crop type and the head of livestock (on a particular date) by Census Consolidated subdivision (CCS) every five years. The most current Census of Agriculture is from 2011, the 2016 Census data are not expected to be available until 2017 at the earliest. The base quantities used for the emissions from agricultural sources in this inventory were all extracted from the 2011 Census of Agriculture for the CCSs for Comox Valley: Comox Valley A (5926021), Comox Valley B (Lazo North) (5926022), and Comox Valley C (Puntledge - Black Creek) (5926024). Census consolidated subdivisions (CCSs) within the CVRD are shown in Figure 12.

MAP 2A



26 Comox Valley
- 21 Comox Valley A
- 22 Comox Valley B (Lazo North)
- 24 Comox Valley C (Puntledge - Black Creek)

Figure 12: BC Census Division 1 (Vancouver Island-Coast) Showing Consolidated Subdivisions and the CVRD.

4.1.1 Synthetic Fertilizer Application

Particulate emissions were based on the method used by Environment Canada to calculate PM emissions from fertilizer application as part of the national emissions inventory. The emissions of PM are based on the quantity of fertilizer applied with global emission factors that account for the handling and storage as well as the spreading of fertilizers (Environment Canada, 2006). The general emission equation is shown in Equation 16. PM emission factors per tonne of fertilizer applied are shown in Table 53. The amount of fertilizer applied (summed per crop type) is equal to the area of land per crop multiplied by a fertilizer application density which varies by crop.

Equation 16: Particulate Matter Emissions from Fertilizer Application

$$\begin{aligned} PM\ Emissions\ (kg) &= Area\ of\ land\ per\ crop\ (hectare) \times Amount\ of\ Fertilizer\ applied\ per\ crop\ \left(\frac{kg}{ha}\right) \\ &\times PM\ Emission\ Factor\ \left(\frac{kg}{tonne}\right) \end{aligned}$$

Table 53: Particulate Matter Emission Factors for Fertilizer Application

Pollutant	Emission Factor (kg/t Fertilizer)
PM	2.23
PM_{10}	1.09
$PM_{2.5}$	0.31

A detailed method for estimating monthly emissions of ammonia from fertilizer application was developed by Sheppard *et al.* (Sheppard, Bittman, & Bruulsema, 2009). This method includes calculating the fertilizer application rate for 37 different crop types by four different fertilizer solution groupings (15 of these crop types are relevant to the CVRD). The work completed by Sheppard *et al.* (Sheppard, Bittman, & Bruulsema, 2009) used fertilizer sales data from the Canadian Fertilizer Institute (CFI) to partition nitrogen fertilizer amounts into four main forms: urea, nitrogen solutions (typically urea ammonium nitrate), anhydrous ammonia, and ‘others’. The fertilizer application rate by census crop and fertilizer type are shown in Table 54 and the crop area by CCS is shown in Table 55.

Table 54: Fertilizer Application Density by Census Crop and Fertilizer Type

Census Field	Fertilizer Application Rates (kg/ha)			
	Anhydrous	Other	UAN	Urea
Alfalfa_and_alfalfa_mixtures_hectares	0.28	0.54	0.00	1.44
Blueberries_total_area_hectares	26.24	50.43	0.02	134.36
Carrots_hectares	31.46	60.47	0.02	161.12
Census_All_131_Barley_hectares	21.08	40.52	0.01	107.95
Corn_for_silage_hectares	14.07	27.05	0.01	72.07
Fall_rye_hectares	10.39	19.98	0.01	53.23
Green peas_hectares	15.73	30.24	0.01	80.56
Mixed_grains_hectares	17.30	33.26	0.01	88.62
Other vegetables 48_hectares	13.62	26.19	0.01	69.77
Potatoes_hectares	20.20	38.82	0.01	103.43
Raspberries_total_area_hectares	19.07	36.66	0.01	97.68
Spring_rye_hectares	10.39	19.98	0.01	53.23
Spring_wheat_excluding_durum_hectares	21.39	41.12	0.01	109.56
Sweet corn_hectares	35.11	67.49	0.02	179.82
Tomatoes_hectares	41.85	80.45	0.03	214.35

Table 55: Crop Area by CCS and Crop Type

Census Crop	Crop Area by CCS (ha)		
	Comox Valley A	Comox Valley B Lazo North	Comox Valley C Puntledge – Black Creek
Alfalfa_and_alfalfa_mixtures_hectares	284.0	83.0	197.0
All_other_tame_hay_and_fodder_crops_hectares	412.0	183.0	1977.0
Blueberries_total_area_hectares	4.0	2.0	15.0
Carrots_hectares	1.0	1.0	0.0
Census_All_131_Barley_hectares	0.0	30.0	84.0
Corn_for_silage_hectares	74.7	0.0	261.3
Fall_rye_hectares	23.0	0.0	23.0
Forage_seed_for_seed_hectares	0.0	0.0	243.0
Green peas_hectares	1.0	0.0	0.0
Mixed_grains_hectares	5.0	0.0	0.0
Oats_hectares	4.8	0.0	14.3
Other vegetables 48_hectares	7.0	1.0	3.0
Potatoes_hectares	1.0	26.9	67.1
Raspberries_total_area_hectares	1.0	1.0	10.0
Spring_rye_hectares	13.0	0.0	0.0
Spring_wheat_excluding_durum_hectares	0.0	0.0	1.0
Sweet corn_hectares	11.5	3.5	4.0
Tomatoes_hectares	1.0	0.0	1.0

The method used by Environment Canada is based on a technique for Phosphorous-based fertilizers developed in 1973. Environment Canada is one of the few agencies that incudes PM from fertilizer application in their emissions inventory. The US EPA currently states that “emission factors are not presently available for PM” (*from fertilizer application*) (US EPA, 1995).

4.1.2 Tilling

Particulate matter is released from the disturbance of soils during the tilling of fields and harvesting of crops. The EPA method for agricultural tilling was used with local improvements (Poon & Robbins, 2006). Tilling emissions are dependent on crop-specific and region-specific factors. Crop-specific factors including the area tilled and the number of tills per year (often expressed as the years between renovations). Region-specific factors include the moisture reduction factor (an expression of the local precipitation pattern) and the local silt content.

The general emission equation is shown in Equation 17. Emissions of PM, PM_{10}, and $PM_{2.5}$ are calculated per crop type and per season. Emissions are based on the crop area (in hectares), the number of tillings (passes), and an emission factor calculated specifically for the region and season. The area per crop for each CCS is shown in Table 56.

Equation 17: Tilling Emission Equation

$$Emissions\ per\ crop\ per\ season_{\ (PM,PM_{10},PM_{2.5})} =$$
$$Area\ per\ crop\ (ha) \times Number\ of\ tillings\ per\ crop\ and\ per\ season\ \times Emission\ Factor_{(PM,PM_{10},PM_{2.5})} \times$$
$$Tillage\ Factor(unitless)$$

Table 56: Crop Area by CCS and Crop Type for Tilling and Harvesting

Census Crop	Crop Area by CCS (ha)		
	Comox Valley A	Comox Valley B Lazo North	Comox Valley C Puntledge – Black Creek
Alfalfa_and_alfalfa_mixtures_hectares	284.0	83.0	197.0
All_other_tame_hay_and_fodder_crops_hectares	412.0	183.0	1977.0
Apples_total_area_hectares	12.0	7.0	4.0
Beets_hectares	0.0	1.0	0.0
Blueberries_total_area_hectares	4.0	2.0	15.0
Broccoli_hectares	0.0	2.0	0.0
Cabbage_hectares	0.0	0.3	0.7
Carrots_hectares	1.0	1.0	0.0
Cauliflower_hectares	1.3	0.7	0.0
Census_All_131_Barley_hectares	0.0	30.0	84.0
Census_All_131_Total_corn_44_hectares	74.7	0.0	261.3
Cherries_sweet_total_area_hectares	0.0	0.3	1.7
Corn_for_silage_hectares	74.7	0.0	261.3
Cranberries_total_area_hectares	5.3	16.0	10.7
Cucumbers_hectares	0.0	0.0	1.0
Dry onions yellow Spanish cooking etc _hectares	1.0	0.0	0.0
Fall_rye_hectares	23.0	0.0	23.0
Forage_seed_for_seed_hectares	0.0	0.0	243.0
Grapes_total_area_hectares	7.0	13.0	5.0
Green peas_hectares	1.0	0.0	0.0
Lettuce_hectares	2.4	0.6	1.0
Mixed_grains_hectares	5.0	0.0	0.0
Oats_hectares	4.8	0.0	14.3
Other vegetables 48_hectares	7.0	1.0	3.0
Other_field_crops_46_hectares	2.3	0.0	0.8
Other_fruits_berries_and_nuts_total_area_47_hectares	14.0	2.0	42.0
Pears_total_area_hectares	2.0	2.0	1.0
Peppers_hectares	0.0	0.0	1.0
Plums_and_prunes_total_area_hectares	1.0	2.0	0.0
Potatoes_hectares	1.0	26.9	67.1
Pumpkins_hectares	2.0	0.7	0.3
Raspberries_total_area_hectares	1.0	1.0	10.0
Saskatoons_total_area_hectares	0.5	0.0	0.5
Shallots and green onions_hectares	0.0	0.4	0.6
Spinach_hectares	0.8	0.3	0.0
Spring_rye_hectares	13.0	0.0	0.0
Spring_wheat_excluding_durum_hectares	0.0	0.0	1.0
Squash and zucchini_hectares	1.0	1.0	1.0
Strawberries_total_area_hectares	2.0	0.0	2.0
Sweet corn_hectares	11.5	3.5	4.0
Tomatoes_hectares	1.0	0.0	1.0
Total vegetables excluding greenhouse vegetables_hectares	19.0	28.0	16.0
Total_area_of_fruits_berries_and_nuts_hectares	43.0	57.0	85.0
Total_rye_45_hectares	0.7	0.0	0.3
Total_wheat_43_hectares	0.0	0.0	2.0

The number of tills per crop is based on the census agricultural region and the month. The number of tills (passes) for each region has been developed with expertise from Ministry of Agriculture staff as part of the BC Agricultural Air Emissions Inventory (RWDI, 2014). The number of tills per month is shown in Table 57, no tilling is done in January or December. The number of tills per season were provided by BC Ministry of Agriculture staff and divided over the months within the season or year. The tillage factor is assumed to 100% minus the percentage of area managed with no-till or zero-till practices. For the CVRD, the tillage factor was set to 76%.

Table 57: Tilling Practices per Season by Crop Category for Vancouver Island

Census Crop	Number of Tills per month								
	February	March	April	May	June	July	August	September	October	November
Alfalfa_and_alfalfa_mixtures_hectares	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.13	0.13	0.13
Apples_total_area_hectares	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Apricots_total_area_hectares	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Asparagus non-producing_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Asparagus producing_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Beets_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Blueberries_total_area_hectares	0.22	0.22	0.22	0.22	0.00	0.00	0.00	0.00	0.00	0.00
Broccoli_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Brussels sprouts_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Buckwheat_hectares	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.50	0.50	0.50
Cabbage_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Canary_seed_hectares	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.13	0.13	0.13
Canola_rapeseed_hectares	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.50	0.50	0.50
Caraway_seed_hectares	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.50	0.50	0.50
Carrots_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Cauliflower_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Celery_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Census_All_131_Barley_hectares	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.50	0.50	0.50
Census_All_131_Total_corn_44_hectares	0.75	0.75	0.75	0.75	0.00	0.00	0.00	0.25	0.25	0.25
Cherries_sour_total_area_hectares	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Cherries_sweet_total_area_hectares	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Chick_peas_hectares	1.25	1.25	1.25	1.25	1.00	1.00	1.00	0.00	0.00	0.00
Chinese cabbage_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Cucumbers_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Dry onions yellow Spanish cooking etc hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67

Census Crop	Number of Tills per month									
	February	March	April	May	June	July	August	September	October	November
Dry_field_peas_hectares	1.25	1.25	1.25	1.25	1.00	1.00	1.00	0.00	0.00	0.00
Dry_white_beans_hectares	1.25	1.25	1.25	1.25	1.00	1.00	1.00	0.00	0.00	0.00
Durum_wheat_hectares	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.13	0.13	0.13
Fall_rye_hectares	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.50	0.50	0.50
Flaxseed_hectares	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.50	0.50	0.50
Grapes_total_area_hectares	0.22	0.22	0.22	0.22	0.00	0.00	0.00	0.00	0.00	0.00
Green and wax beans_hectares	1.25	1.25	1.25	1.25	1.00	1.00	1.00	0.00	0.00	0.00
Green peas_hectares	1.25	1.25	1.25	1.25	1.00	1.00	1.00	0.00	0.00	0.00
Lentils_hectares	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.50	0.50	0.50
Lettuce_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Mixed_grains_hectares	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.50	0.50	0.50
Mustard_seed_hectares	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.50	0.50	0.50
Oats_hectares	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.50	0.50	0.50
Other vegetables 48_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Other_dry_beans_hectares	1.25	1.25	1.25	1.25	1.00	1.00	1.00	0.00	0.00	0.00
Other_field_crops_46_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Other_fruits_berries_and_nuts_total_area_47_hectares	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Peaches_total_area_hectares	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Pears_total_area_hectares	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Peppers_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Plums_and_prunes_total_area_hectares	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Potatoes_hectares	1.25	1.25	1.25	1.25	1.00	1.00	1.00	0.00	0.00	0.00
Pumpkins_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Radishes_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Raspberries_total_area_hectares	0.30	0.30	0.30	0.30	0.19	0.19	0.19	0.65	0.65	0.65
Rutabagas and turnips_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67

Census Crop	Number of Tills per month									
	February	March	April	May	June	July	August	September	October	November
Shallots and green onions_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Soybeans_hectares	1.25	1.25	1.25	1.25	1.00	1.00	1.00	0.00	0.00	0.00
Spinach_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Spring_rye_hectares	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.13	0.13	0.13
Spring_wheat_excluding_durum_hectares	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.50	0.50	0.50
Squash and zucchini_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Sugar_beets_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Sweet corn_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Tomatoes_hectares	1.50	1.50	1.50	1.50	0.50	0.50	0.50	0.67	0.67	0.67
Total_rye_45_hectares	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.50	0.50	0.50
Total_wheat_43_hectares	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.50	0.50	0.50
Triticale_hectares	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.50	0.50	0.50
Winter_wheat_hectares	0.63	0.63	0.63	0.63	0.00	0.00	0.00	0.50	0.50	0.50

The tillage emission factor equation is shown in Equation 5. The base equation includes an empirically derived constant (5.38) multiplied by a moisture reduction factor, particle size multiplier, and the silt content. The particle size multiplier is used to estimate the fraction of PM that is PM_{10} or $PM_{2.5}$. The particle size multiplier is typically assumed to be 0.21 for PM_{10} and 0.042 for $PM_{2.5}$.

Equation 18: Tilling Emission Factor Equation

$$\begin{aligned} \mathit{Emission\ Factor}_{(PM, PM_{10}, PM_{2.5})} &= 5.38 \times \mathit{Moisture\ reduction\ factor\ per\ season} \times \mathit{Particle\ size\ multiplier}_{(PM, PM_{10}, PM_{2.5})} \\ &\times \mathit{Silt\ content\ per\ region}\ (\%)^{0.6} \end{aligned}$$

The moisture reduction factor reflects the precipitation accumulation which decreases the likelihood of particles becoming airborne. Moisture reduction factors were generated by month for each of the eight agricultural regions (based on the Census of Agriculture regions) for the detailed agricultural emissions inventory for the MoA. The moisture reduction factors for Vancouver Island – Coast was used for the CVRD and are shown in Table 58.

Table 58: Moisture Reduction Factors for Tilling Emission Factor Equation

Month	Moisture Reduction Factor (unitless)
January	0.00
February	0.00
March	0.00
April	0.20
May	0.50
June	0.50
July	0.75
August	0.50
September	0.50
October	0.00
November	0.00
December	0.00

The silt content is a percentage based on typical soil type. The silt content values for each CCS were developed using data from the Soil Landscapes of Canada version 3.2, developed by Agriculture and Agri-Food Canada and shown in Table 12.

Table 59: Silt Content by CCS

CCS	Silt content (%)
Comox Valley A	35.0
Comox Valley B Lazo North	43.6
Comox Valley C Puntledge - Black Creek	48.4

4.1.3 Harvesting

Particulate emissions from crop production arise from soil cultivation and harvesting. Emissions depend on crop, soil type, cultivation method, and weather conditions before and while working. Environment Canada's national air emissions inventory includes emission quantities and methods for agricultural tilling and wind erosion, but does not specifically include particulate emissions from harvesting.

The emission method from the BC Agricultural Air Emissions Inventory (RWDI, 2014) was used for this inventory. The general emission equation is shown in Equation 19. It is assumed that each crop is harvested only once annually. The PM_{10} emission factors are shown in Table 60. The California Air Resources Board $PM_{2.5}$ to PM_{10} ratio of 0.15 for agricultural harvesting (Countess Environmental, 2006) was used to estimate $PM_{2.5}$. And total PM was assumed equal to $PM_{10.}$ The area by crop type is provided inTable 56.

Equation 19: PM_{10} Emissions from Agricultural Harvesting

$$Emissions_{PM_{10}}(kg) = Annual\ crop\ area\ (ha) \times Number\ of\ harvests\ \times Emisison\ factor\ \left(\frac{kg}{ha}\right)$$

Table 60: PM_{10} Emission Factors for Harvesting by Crop Classification Groupings

Crop Classification Category Groupings	PM_{10} Emission Factor (kg/ha)
Corn	0.12
Grass/Hay/Alfalfa	0.25
Cereal, Grain & Oilseed	0.47
Pasture	0.00
Peas/Beans/Early Potatoes	0.31
All Other Vegetables	0.03
Turf	0.00
Tree Fruits Vines & Berries	0.01

4.1.4 Wind Erosion

Particulate emissions result from wind erosion of tilled agricultural lands. Particulate emissions from wind erosion of agricultural lands were calculated using the Wind Erosion Equation (WEQ) shown in Equation 20. The WEQ relies on crop-specific and region-specific factors. Crop specific factors include the surface roughness factor, the unsheltered field width factor and the vegetative factor. Crop-specific factors as developed for the BC Agricultural Air Emission inventory (RWDI, 2014) were used. Region-specific factors including the soil erodibility and climatic factor were developed readily for the Comox Valley.

Equation 20: Wind Erosion Equation

$$Emissions\ Factor_{PM_{10}}\ \left(\frac{ton}{acre\ year}\right) =$$
$$\mathrm{A}[Total\ suspended\ particulate\ portion\ (0.025)]\ \times I\ \left[Soil\ Erodibility\ \left(\frac{ton}{acre\ year}\right)\right] \times$$
$$K\ [Surface\ roughness\ factor]\ \times C\ [Climatic\ factor]\ \times L'^{[Unsheltered\ field\ width\ factor]} \times$$
$$V'[Vegetative\ cover\ factor]$$

Total PM was speciated to PM_{10} and $PM_{2.5}$ using factors from the WRAP Fugitive Dust Handbook (Countess Environmental, 2006). The PM_{10}/PM ratio for wind erosion is 0.5. The $PM_{2.5}/PM_{10}$ ratio for windblown fugitive dust is 0.15.

As an aid in understanding the mechanics of this equation, the soil erodibility factor or “I”, may be thought of as the basic erodibility of a flat, very large, bare field in a climate highly conducive to wind erosion (i.e., high wind speeds and high temperature with little precipitation). This factor was initially established for the WEQ for a large, flat, bare field in Kansas that has relatively high winds along with hot summers and low precipitation. The parameters K, C, L’ and V’ may be thought of as reduction factors for a ridged surface, a climate less conducive to wind erosion, smaller-sized fields, and vegetative cover, respectively, to adjust the equation for applicability to field conditions that differ from the original Kansas field.

Individual land parcels were assigned soil textural classes (Table 61) using a standard soil texture triangle, shown in Figure 13 (Soil Classification Working Group, 2013) and soil erodibility factor, “I”, using GIS. The percentage of particles in three size groupings: silt, sand and clay were extracted from Agriculture and Agri-Food Canada’s Soil Landscapes of Canada National Soil DataBase (Agriculture and Agri-Food Canada, 2010). Area-weighted erodibility factors, “I”, were determined in GIS for each of the three CCSs and are shown in Table 61.

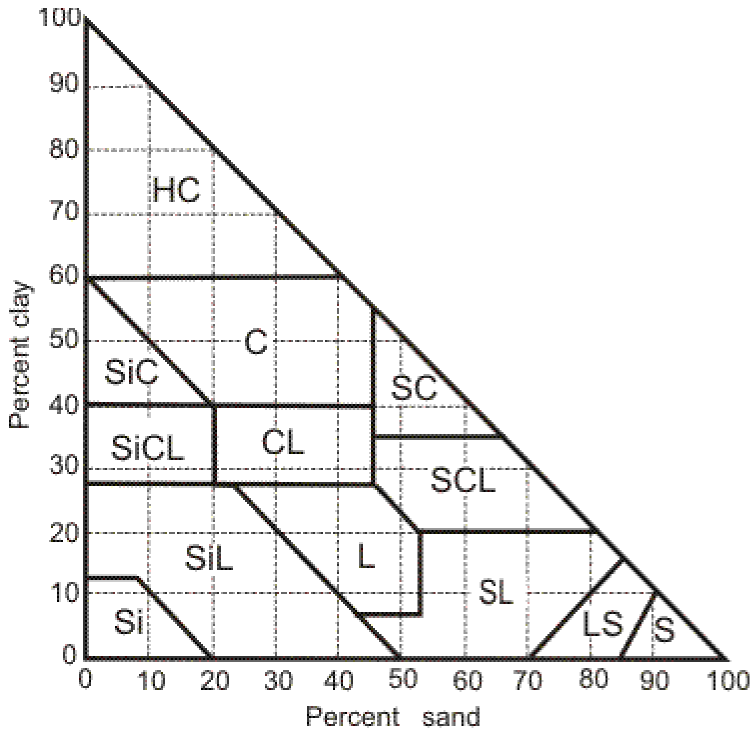


Figure 13: Soil Texture Triangle

Table 61: Soil Erodibility, I, for Various Soil Textural Classes

Predominant Soil Textural Class	Erodibility (tons/acre-year)
Sand	220
Loamy Sand	134
Sandy Loam, Clay, Silty Clay	86
Loam, Sandy Clay Loam, Sandy Clay	56
Silty Loam, Clay Loam	47
Silty Clay Loam, Silt	38

Table 62: Erodibility Factor, I per CCS

CCS	Erodibility factor (tons per year)
Comox Valley A	84
Comox Valley B Lazo North	65
Comox Valley C Puntledge - Black Creek	56

The surface roughness factor (K), unsheltered field width (L'), and vegetative cover (V') were assigned by crop type using values developed by the US EPA (US EPA, 1974), as shown in Table 63.

Table 63: Wind Erosion Variables by Crop (USA EPA, 1974)

Crop	K	L, ft.	V, lb/acre	L*, ft.
Alfalfa	1	1000	3000	250
Barley	0.6	2000	1100	500
Beans	0.5	1000	250	250
Corn	0.6	2000	500	500
Grain Hays	0.8	2000	1250	500
Oats	0.8	2000	1250	500
Potatoes	0.8	1000	400	250
Rye	0.6	2000	1250	500
Vegetables	0.6	500	100	125
Wheat	0.6	2000	1350	500

Monthly climatic factors, C, were taken from the BC Agricultural Air Emissions Inventory (RWDI, 2014) for Vancouver Island - Coast and are shown in Table 64.

Table 64: Wind Erosion Equation, Monthly climatic factor, C

Month	Climatic Factor, C
January	0
February	0
March	0
April	0.01
May	0.02
June	0.04
July	0.14
August	0.06
September	0.01
October	0
November	0
December	0

Total particulate matter (PM), PM_{10}, and $PM_{2.5}$ emissions are calculated using the monthly emission factors generated from Equation 7 multiplied times the area per crop. The area of each relevant crop was taken from the 2011 Census of Agriculture and is shown in Table 65.

Table 65: Crop Area by CCS for Wind Erosion Calculations

Wind Erosion Crop Grouping	Census Table	Census Fields	Crop Area (hectares)		
			Comox Valley A	Comox Valley B Lazo North	Comox Valley C Puntledge – Black Creek
Alfalfa	Hay and field crops 2011	Alfalfa_and_alfalfa_mixtures_hectares	284	83	197
Barley	Hay and field crops 2011	Barley_hectares	0		84
Grain Hays	Hay and field crops 2011	Mixed_grains_hectares		183	1977
		Canola_rapeseed_hectares			
		Flaxseed_hectares			
		All_other_tame_hay_and_fodder_crops_hectares			
Potatoes	Hay and field crops 2011	Potatoes_hectares	1		
Vegetables	Vegetables excluding greenhouse	Total vegetables excluding greenhouse vegetables_hectares	19	28	

4.1.5 Livestock Movements

Particulate emissions from animal production result from animal housing and moving facilities. The emissions methodology for PM from cattle, swine, poultry and horses was selected from the "A Review of Agricultural Air Emissions Estimates for the Lower Fraser Valley of British Columbia" (Poon & Robbins, 2006). The transfer of methodology from the LFV to CVRD assumes that agricultural livestock production operates similarly across the West Coast of BC. The number of livestock was taken from the 2011 Census of Agriculture and is shown in Table 66.

Table 66: Number of Livestock by CCS

Livestock	Number of Livestock (head)		
	Comox Valley A	Comox Valley B Lazo North	Comox Valley C Puntledge – Black Creek
Horses	74	19	255
Swine	97	71	603
Poultry	3,857	1,232	18,586
Cattle	48	63	112

The recommended method for cattle assumes that only cattle in beef feedlots generate significant PM and that the best conservative estimate of the number of cattle in beef feedlots is based on the number of beef steers. The number of steers was taken from the 2011 Census of Agriculture and is shown in Table 66

The published PM_{10} emission factor is 11 kg/1000 head/day, with particle size multipliers of 3.0 for PM and 0.15 for $PM_{2.5}$ resulting in the emission factors shown in Table 67. A climate correction factor of 0.572 was generated for the Comox Valley which is equal to fraction of days with less than 2.0 mm of rain in the region.

Equation 21: Particulate Matter Emissions from Cattle

$$PM_A = \frac{Number\ of\ Steers}{1000\ head} \times EF_{PM10,daily} \times Particle\ size\ multiplier_A \times climate\ correction\ factor \times days\ in\ feedlots\ (365)$$

Table 67: Particulate Matter Emission Factors for Cattle

Pollutant	Effective Emission Factor (kg/1000 steer/day)
PM	33
PM_{10}	11
$PM_{2.5}$	1.65

The recommended methodology for swine uses Equation 22 with a PM emission factor of 1.854 mg/hr/kg swine. PM_{10} to PM and $PM_{2.5}$ to PM ratios of 0.5 and 0.1 were used. The mass per animal is shown in Table 68.

Equation 22: Particulate Matter Emissions from Swine

$$PM = Number\ of\ swine\ (head) \times Mass\ per\ animal\ (\frac{kg}{head}) \times EF_{PM,hourly} \times Hours\ per\ year\ (8760) \times Particle\ size\ conversion$$

Table 68: Assumed Mass of Animal (Swine)

Census Livestock Category		Number of head	Mass per head kg/head
Swine	Boars_number	9	230
	Sows_and_gilts_for_breeding_number	80	170
	Nursing_and_weaner_pigs_number	270	47
	Grower_and_finishing_pigs_number	412	47

The recommended method for poultry depends on the length of production cycle and varies for pullets and laying hens versus broilers, turkeys, and other poultry. The emission method varied between layers (pullets under 19 weeks intended for laying, laying hens19 weeks and over, and layer and broiler breeders) and non-layers (broilers roasters and Cornish, turkeys, and other poultry). The emissions from layers were calculated by bird type using Equation 10. The number of livestock, PM emission factors, PM_{10} to PM and $PM_{2.5}$ to PM ratios, and hours per production cycle for layers is shown in Table 69.

The emissions from broilers (non-layers) were calculated by bird type using Equation 24. The number of livestock, PM emission factors, PM_{10} to PM and $PM_{2.5}$ to PM ratios, and hours per production cycle for broilers (non-layers) is shown in Table 70.

Equation 23: Particulate Matter Emissions from Poultry Layers

$$PM = Number\ of\ birds\ (head) \times Mass\ per\ animal\ (\frac{kg}{head}) \times EF_{PM,production\ cycle}\ (\frac{\frac{mg}{hr}}{kg\ bird}) \times Hours\ of\ production\ per\ year\ (8760) \times Particle\ size\ conversion$$

Equation 24: Particulate Matter Emissions from Poultry Broilers (non-layers)

$$PM = Number\ of\ birds\ (head) \times Mass\ per\ animal\ (\frac{kg}{head}) \times EF_{PM,production\ cycle}\ (\frac{\frac{mg}{hr}}{kg\ bird}) \times Hours\ of\ production\ per\ day \times (Days\ of\ production + days\ of\ cleanout) \times cycles\ per\ year \times Particle\ size\ conversion$$

Table 69: Emission Equation Factors for Poultry Layers

Census Livestock Category		Number of Head	Mass per Head kg/head	EF for Production Cycle mg/hr/kg	Hours per Production hr/yr
Poultry	Pullets under 19 weeks, intended for laying (63)	1605	0.75	1.266	8760
	Laying hens, 19 weeks and over (64)	5215	1.8	1.266	8760
	Layer and broiler breeders (pullets and hens) (65)	333	1.8	1.266	8760

Table 70: Emission Equation Factors for Poultry Broilers (non-layers)

Census Livestock Category		Number of Head	Mass per Head kg/head	EF for Production Cycle mg/hr/kg	Hours/Day hr/day	Days Production Days	Cleanout Days per Cycle Days	Cycles per Year Cycles/Year
Poultry	Broilers, roasters and Cornish (66)	11870	1	5.61	24	40	2	6.5
	Turkeys (67)	2067	4.9	5.61	24	75	2	3.5
	Other poultry	2585	1.8	5.61	24	75	2	3.5

The recommended method for horses separates the animals into horses in riding rings and in paddocks. This method uses the total number of horses from the Census of Agriculture and assumes a split between horses in riding rings (75%) and horses in paddocks (25%). The assumed splits are based on data from the Lower Fraser Valley with an assumption that the CVRD has similar splits. The general emission equation is shown in Equation 25 and the emission factors are shown in Table 71.

Equation 25: Particulate Matter Emissions from Horses

$$Emissions\ (kg) = Number\ of\ horses(head) \times EF(\frac{kg}{head})$$

Table 71: Particulate Matter Emission Factors for Horses

Pollutant	Horse Emission Factor (kg/head)	
	Paddocks	Riding Rings
PM	2.15	1.61
PM_{10}	0.72	0.54
$PM_{2.5}$	0.11	0.08

4.1.6 Crop Residue Burning

Open burning is one disposal option for excess vegetation (crop residue) from crop production. Emissions are based on an assumption of the amount of crop residue produced, the proportion of this residue which is disposed of by incineration, and an emission factor. Emissions from the burning of crop residue were calculated using Equation 26. The amount of crop residue produced is calculated using the land area in crops (by crop category) and an assumed rate of residue production (also called the fuel loading) per crop type.

Equation 26: Agricultural Waste Burning Equation

$$Emissions\ (kg) = Crop\ area\ (hectares) \times Fuel\ Loading\ \left(\frac{tonne\ residue}{hectare}\right) \times Percentage\ of\ dry\ crop\ residue\ burned\ (\%) \times Emission\ Factor\ \left(\frac{kg}{tonne\ residue}\right)$$

Crop residue production (fuel loadings) were assigned by crop category. The percentage of dry crop residue burned in various regions across the province was developed as part of the BC Agricultural Air Emissions Inventory to be 0.5%. PM emission factors per crop were selected from the California Air Resources Board and grouped into crop categories relevant to BC (California Air Resources Board, 2014). Emission factors and fuel loadings per crop type are shown in Table 72.

Table 72: Crop Residue Burning Emission Factors and Waste Production Rates

Land Cover Category	Emission Factors (kg/tonne)			Fuel Loading (tonnes/hectare)
	PM	PM_{10}	$PM_{2.5}$	
Corn	5.8	5.7	5.4	9.4
Field Crops - Vegetables	8.7	8.5	8.2	4.7
Orchard Crops	4.0	4.0	3.7	5.1
Vine Crops	3.2	3.2	3.0	4.7
Field Crops - Hay	8.7	8.5	8.2	4.7
Grapes	3.2	3.2	3.0	14.0

The crop area by crop type was taken from 2011 Census of Agriculture for the census consolidated subdivisions (CCSs) within the CVRD. Crop areas for specific crop fields and tables were grouped into crop categories matching the emission factors as shown in Table 73. The total area in hectares for each crop category and for each CCS in the CVRD are shown in Table 74.

Table 73: 2011 Census Tables and Fields per Crop Categories

Land Cover Category	Census Table	Census Fields	
Orchard Crops	Fruits Berries Nuts	Apples_total_area_hectares	Cherries_sour_total_area_hectares
		Pears_total_area_hectares	Peaches_total_area_hectares
		Plums_and_prunes_total_area_hectares	Apricots_total_area_hectares
		Cherries_sweet_total_area_hectares	
Grapes	Fruits Berries Nuts	Grapes_total_area_hectares	
Corn	Hay and Fieldcrops	Total_corn_44_hectares	
Field Crops - Vegetables	Vegetables excluding greenhouses	Total vegetables excluding greenhouse vegetables_hectares	
Field Crops - Hay	Hay and Fieldcrops	Total_wheat_43_hectares	Alfalfa_and_alfalfa_mixtures_hectares
		Oats_hectares	All_other_tame_hay_and_fodder_crops_hectares
		Barley_hectares	Forage_seed_for_seed_hectares
		Mixed_grains_hectares	Potatoes_hectares
		Total_rye_45_hectares	Mustard_seed_hectares
		Canola_rapeseed_hectares	Sunflowers_hectares
		Soybeans_hectares	Canary_seed_hectares
		Flaxseed_hectares	Ginseng_hectares
		Chick_peas_hectares	Buckwheat_hectares
		Lentils_hectares	Sugar_beets_hectares
		Dry_field_peas_hectares	Caraway_seed_hectares
		Dry_white_beans_hectares	Triticale_hectares
		Other_dry_beans_hectares	Other_field_crops_46_hectares
Vine Crops	Fruits Berries Nuts	Strawberries_total_area_hectares	Blueberries_total_area_hectares
		Raspberries_total_area_hectares	Saskatoons_total_area_hectares
		Cranberries_total_area_hectares	Other_fruits_berries_and_nuts_total_area_47_hectares

Table 74: Crop Area by Crop Category and CCS

CCS	Land Cover Category						Fuel Loading (tonnes/ hectare)
	Corn	Field Crops - Vegetables	Orchard Crops	Vine Crops	Field Crops - Hay	Grapes	
Comox Valley A	74.7	19	15	26.8	707.4	7	9.4
Comox Valley B (Lazo North)	0	28	11.3	21	322.9	13	4.7
Comox Valley C (Puntledge - Black Creek)	261.3	16	6.6	80.2	2584.7	5	5.1

APPENDIX 2: FIRE SURVEY REQUEST

Questions	Response
Does your fire service area allow open/backyard burning at some point during the year (or is it completely banned)?	*Yes/No*
If yes, please continue	
Does your fire service area allow open/backyard burning **without** a permit?	*Yes/No*
If so, which months is this allowed?	*Provide a range of months*
Can you estimate the amount of burning that occurs **without** a permit during this time?	*Use whatever description is most useful (e.g. "about twice the amount that occurs in months requiring permit", "about 100 fires", etc.)*
Does your fire service area issue permits for open/backyard burning?	*Yes/No*
If yes, during what months are these permits issued	*Provide a range of months*
If yes, how many permits were issued in **2015**?	*If exact values are not available please provide an estimate of the typical number of permits issued.*
If yes, how many permits were issued in **2014**?	*If exact values are not available please provide an estimate of the typical number of permits issued.*
Does this fire service area have any other specific burning requirements?	*e.g. restrictions on pile size, ventilation index, etc.*
Approximately how many complaints or reports of illegal burning do you receive per year?	
Given your experience, can you estimate about how many piles (with and without permit) are burned in your fire service area annually?	*Burns without permit:*
	Burns with permit:
Do you have any additional comments or insights on burning behaviours in your fire service area?	

What types of material do you typically observe being burned in your fire service area? (check all that apply and write in additional)	*Yes* ✓	*No* ✓
Wood or wood by-products (brush, waste wood)		
Grass or leaf litter (leaves, clippings, old grass)		
Landclearing (trees, bushes, fields)		
Agricultural waste (crop cover, trimmings/prunings)		
Residential garbage (including newspaper and cardboard)		
Hazardous domestic waste (plastics, paint, rubber)		
Other (please specify): ______________________________		

ATTACHMENT 3

HOME HEATING AND AIR QUALITY SURVEY REPORT FOR THE COMOX VALLEY

Report prepared for:
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Comox Valley
REGIONAL DISTRICT

Report prepared by:
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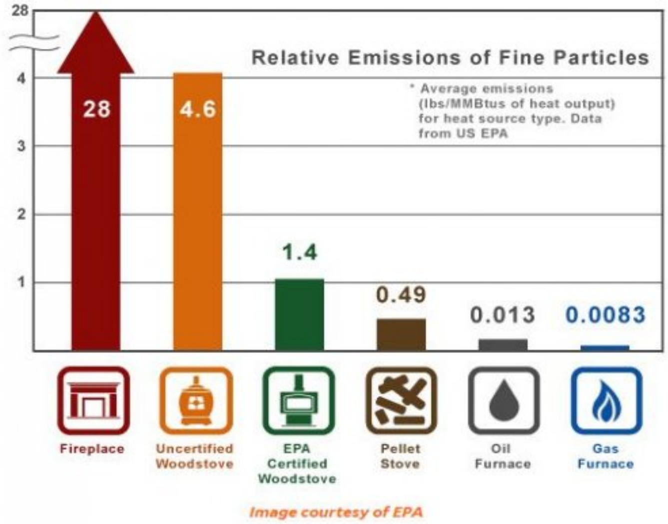
2 - INTRODUCTION

The need to design and administer a home heating and air quality survey came as a response to recent studies indicating that 36% of fine particulate matter (PM2.5) is from space heating in the Comox Valley, particularly from wood heating, and that there is a correlation between high levels of PM2.5 and respiratory and cardiovascular health issues [1]. Mobile monitoring [2] and data from the air quality monitoring station at Courtenay Elementary showed that the level of fine particulates PM 2.5 were above applicable standards several times in the past two years, causing the issuance of seven air quality advisories in 2017 alone. A recent study by Island Health (presented by Sarah Henderson) has shown that these advisories correlate with an increase in doctor visits and the prescription of Salbutamol, a medication typically prescribed to treat asthma [1].



According to the Environmental Protection Agency (EPA), EPA certified wood stoves emit 70% less fine particulates than uncertified wood stoves. Pellet and gas stoves further reduce emissions while heat pumps emit zero fine particulates.

In an effort to reduce wood smoke pollution during the winter months and reduce the number of air quality advisories, the Comox Valley Regional District (CVRD) has been running the Wood Stove Exchange program since 2016 (with a trial year in 2011), which aims to exchange non-EPA certified wood stoves in the Comox Valley with new CSAB415/EPA-certified wood stoves.

Qualifying residents received a $250 rebate, and 140 residents have participated to date. In the past two years, additional funding has been introduced to further incentivize the removal of non-certified wood burning appliances all together by replacing them with either a pellet or gas heating appliance ($600 rebate), or an electric air-source heat pump ($1000 rebate), as long as the applicant meets the eligibility criteria (that wood must be the applicant's primary heating source, the stove must be in usable condition and it must not be EPA certified).

For more information on the Woodstove Exchange Program, visit www.comoxvalleyrd.ca/woodstove.

There are 29,573 private dwellings occupied by usual residents within the Comox Valley Regional District and municipal boundaries according to the 2016 Census Profile Data [3], however there is no data showing the number or age of residential wood stoves.

To assist with long-term planning of the Wood Stove Exchange Program, the purpose of the survey was to:

1) Understand how residents heat their homes (what percentage is heated by wood);
2) Identify the level of knowledge around smart wood burning practices;
3) Identify resident's level of awareness regarding air quality and health in the Comox Valley.

This document presents the findings from the home heating and air quality survey conducted in Comox Valley between February 22 and April 8, 2018.

3 - SUMMARY OF FINDINGS

The summary of findings highlights information presented in this report.

TYPES OF HEATING SOURCES

a) The primary heating source is electricity, accounting for 52% of respondents home heating (205), with 19% using electric baseboards, 22% having ducted heat pumps, 6% using ductless heat pumps and 5% using an electric furnace.

b) 1 in 5 respondents use wood as their primary heating source (82), 17% (66) use it as their secondary heating source and 8% use wood as their additional heating source for a total of 149 respondents (38%).

c) In the rural areas, the percentage of respondents that have wood stoves is higher than in the urban centers. 50% of the primary heating in Area C (Black Creek) is with wood stoves, and accounts for 40% of the primary heating in Area B (Lazo North), and 30% of the primary heating for Area A (Baynes Sound).

d) 11 respondents use oil as their primary heating source, and are eligible for heat pump rebates available through EfficiencyBC (up to $2,350 in the Comox Valley). Visit efficiencybc.ca for more information.

AGE OF HEATING SOURCES

a) 60% of respondents (231) say their primary heating source is 10 years old or newer, while 12% (47) say it is 24 years or older.

b) Only 6 respondents (1.5%) indicated that their wood-burning appliance (used as a primary heating source) is older than 24 years, meaning these appliances are likely not EPA certified and respondents would qualify for the current Wood Stove Exchange Program. Of those 6 respondents, 3 were from Area C, and 3 were from Area A, Area B and Cumberland, respectively, and all 6 would like to switch to a cleaner heating source if money were no object.

c) None of the 11 respondents with wood heated outbuildings reported having wood burning appliances older than 24 years old.

PREFERENCE TO HEATING THEIR HOMES

a) Two-thirds of respondents (249) would like to change their heating source. One-third (126) of respondents wouldn't change how their homes were heated, one-third (127) would install a heat pump, and the remaining third would choose a variety of options, the third highest being install a furnace (gas or electric) (40).

b) Three-quarters of the respondents that use wood as their primary heating source (61), would prefer a different heating source, with the highest choice being a heat pump (30). Wood burning respondents indicated that their primary reason for not making this switch was because it’s too expensive to do so.

WOOD BURNING PRACTICES

a) Half of the wood burning respondents (74) burn between 0-2 cords per year, 35% (52) burn 3-4 cords per year, 11% (16) burn 5 or more cords per year and 5% (7) do not know how many cords they burn.

b) 84% store their firewood on their property at least six months before burning, with nearly half of respondents (49%) storing it for over one year.

c) 88% (131) always stack their wood under a sheltered area with sufficient airflow on at least three sides.

d) The most popular way respondents obtain their firewood is by ordering it from Craigslist, Kijiji, Facebook or the newspaper (43%, 64).

e) Two-thirds of respondents (67%, 100) indicated that the number one reason they burn wood is to be able to heat their homes if there was a power outage. The second and third main reason for burning wood was because it is cheaper than all other heating sources (62%), and they enjoy the ambiance it provides to their home (62%). Of the respondents that burn wood as their primary heating source (82), the main reason for burning wood was because it was cheaper than other heating sources like electricity or gas (73%, 60). Heating their home if there was a power outage was the second most important reason, chosen by 70% of respondents (57).

f) Nearly half of wood burning respondents (67) indicated that the number one downside to burning wood is that it is too messy, and nearly one third (31%, 44) think it is too much work. 28% (39) thought there was no downside at all.

g) Only 1 in 10 respondents use a moisture meter to ensure their woods moisture content is below 20%.

PERCEPTIONS OF AIR QUALITY AND HEALTH

a) 93% of respondents (362) can smell smoke in the Comox Valley on occasion during the winter months., only 7% of respondents (28) say they never smell wood smoke during the winter months.

b) Two-thirds of respondents (264) believe smoke from residential burning affects the air quality in their neighbourhoods. 27% believe it affects their neighbourhood daily, 22% said often and 19% said occasionally.

c) Although nearly all respondents (94%) believe exposure to residential wood smoke affects people's health, just over half (57%) are concerned that smoke from residential wood smoke is affecting their personal health or their family's health. One-third of respondents (121) do not believe wood smoke affects their health or their family's health.

d) One-third of respondents (129) find out about air quality advisories through local newspaper or radio, and all other respondents (192) receive this information in a wide variety of forms.

e) 17.5% of respondents (68) do not receive or seek notification when an air quality advisory is issued.

f) 4 out of 5 respondents are aware of the Wood Stove Exchange Program and the rebates available for exchanging a non-EPA certified wood burning appliance with an EPA certified wood stove or insert ($250 rebate), a pellet or gas stove ($600 rebate) or an air-source heat pump ($1000). This high level of awareness could be because the survey link was hosted on the Wood Stove Exchange Program webpage.

g) Half of the respondents (194) believe smoke for residential wood burning is the biggest contributor to poor air quality in the Comox Valley, while the remaining half believes it is open burning (18%), vehicle emissions (15%) or a variety of other emission sources.

4 - METHODOLOGY

The purpose of the survey was to identify the age and number of current state of wood-burning appliances and to understand behaviours and perceptions around wood smoke and health in order to inform future air quality management actions.

To assist with long-term planning of the Wood Stove Exchange Program, the purpose of the survey was to:

1) Understand how residents heat their homes (what percentage is heated by wood);
2) Identify the level of knowledge around smart wood burning practices;
3) Identify resident's level of awareness regarding air quality and health in the Comox Valley.

4.1 DESIGN

The survey was designed to include all residents in the Comox Valley regardless of whether they used wood heating. Air quality affects everyone, so besides understanding how residents heated their home, the CVRD wanted to capture a strong representation of the population's impression of air quality in the Comox Valley.

Similar surveys were reviewed for Smithers [4] and Vanderhoof [5] to understand the scope, questions asked and distribution methods.

Image above: Poster and flyer distributed during distribution.

Breathe Clean Air Comox Valley, a local non-profit concerned with the impact of wood smoke on health was also consulted during the development of the survey questions.

INCENTIVE

An incentive of a $250 Gift Card to Quality Foods was offered as a prize draw to entice participation. Entering the prize draw and providing contact information was optional for respondents. A Union Bay resident won the prize, selected randomly from the draw entries after the closing date.

The complete survey can be found in Appendix A.

4.2 DISTRIBUTION

The survey was administered between February 22 and April 8, 2018 in a variety of ways; focusing on online marketing, direct invitation, local media and community awareness and engagement. The CVRD chose to purse the following distribution methods:

ONLINE MARKETING

- Live survey link from February 22 – April 8 through Checkbox.com
- CVRD's Wood Stove Exchange Program webpage updated to invite viewers to take the survey
- Several social media updates through the CVRD Facebook page
- Asked the City of Courtenay, Town of Comox and Village of Cumberland to post on their website, share in their newsletter and sharing it on social media (the press release was posted on the City of Courtenay's webpage and shared through social media)

DIRECT INVITATION

- Promotion through Breathe Clean Air's eNewsletter (99 people), website and social media
- Direct email to 2017 draw entries with valid email address (83 people)
- Direct email to past Wood Stove Exchange Program participants with valid email addresses (36 people)
- 2400 'Clean Air for Our Community' brochures were updated and hand delivered to hotspots identified during the Mobile Air Quality Monitoring Report [2]

LOCAL MEDIA

- News release issued February 28 regarding the wood stove exchange program and the survey
- Print advertisements in the Comox Valley Record on March 20 and 22

COMMUNITY AWARENESS AND ENGAGEMENT

- Survey Graphic on CVRD lobby TVs with link to take the survey
- 30 posters distributed around community notice boards in Cumberland, Courtenay and Comox
- Hosted a booth at the following events to answer questions about the Woodstove Exchange Program, give out ¼ page flyers with the survey link and ask people to complete the survey on an iPad:
    - Quality Foods, Courtenay, Feb. 28 (7 completed on iPad, 35 took flyer)
    - Comox Valley Farmers Market, March 10, (7 completed on iPad, 58 took flyer)
    - Breathe Clean Air Forum, March 14 (8 completed on iPad, 30 took flyer)
    - Quality Foods, Comox, March 23 (4 completed on iPad, 24 took flyer)
    - Comox Mall, April 6 (4 completed on iPad, 25 took flyer)

5 - FINDINGS

There were 389 valid responses to the Home Heating and Air Quality survey collected over the six week time distribution period. The average statistically significant response rate was within +/- 4.94% based on 389 valid responses recorded.[1]

The following section presents the data collected from the survey, in the order it was presented in the survey. The survey can be viewed in Appendix A.

5.1 DEMOGRAPHICS

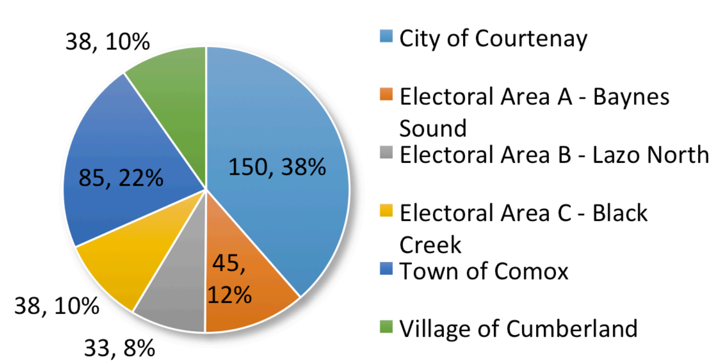
Respondents were able to choose their geographical location from a drop down menu, as well as enter their postal code. The majority of residents were from the V9N area, indicated within the red border on the map below.

Image above: Postal code bubble chart

Image left: Indication of the geographical area of the majority of survey respondents (outlined in red).

Of the 389 respondents, the majority were from the City of Courtenay (38%) followed by the Towne of Comox (22%), with 10% from the Village of Cumberland, 12% from Area A (Baynes Sound (Including Royston, Union Bay, Fanny Bay, Denman and Hornby Island), 8% from Area B (Lazo North), 10% from Area C (Puntledge/Black Creek (Including Merville, Kitty Coleman, Oyster River and Mount Washington). 4 respondents data was removed because they indicated they were from outside the Comox Valley.

Figure 1. Demographics of survey respondents (n=389).



[1] *A margin of error of 5% or below is considered normal. The confidence level of 95% is an industry standard, meaning the survey will be accurate 19 times out of 20. The degree of accuracy of questions that received a lower response rate or polled from a smaller sample have a lower degree of accuracy [6].*

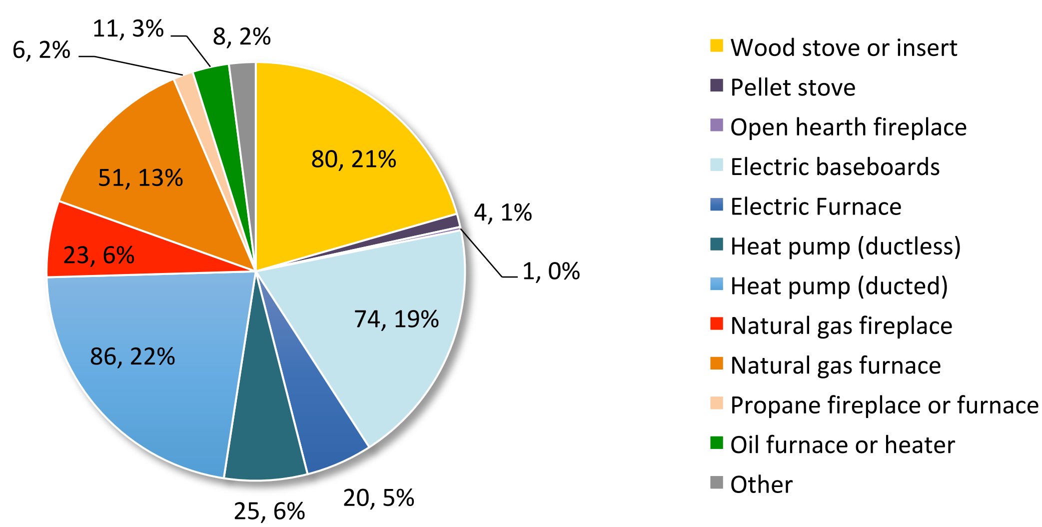
5.2 HOW RESPONDENTS HEAT THEIR HOMES

Respondents were asked what they consider to be their home's primary heating source (used for more than 50% of their home's heating) during the winter months. Respondents could choose one option that best applies.

PRIMARY HEATING SOURCE

The majority of respondents (52%, 202) indicated that their main heating source is electricity, either with a heat pump (22% ducted and 6% ductless), electric furnace (5%) and electric baseboard heating (19%). Those burning wood as their primary heating source (21%) indicated they are doing so with a wood stove or insert, one respondent indicated they use an open-hearth fireplace as their main source of heat and no respondents indicated they use a wood furnace. 19% of respondents use natural gas as their main heating source, either from a furnace (13%) or fireplace (6%). Propane heating (2%) and oil (3%) make up the remaining primary heating sources, with the majority of respondents that chose 'Other' (2%) using a boiler system.

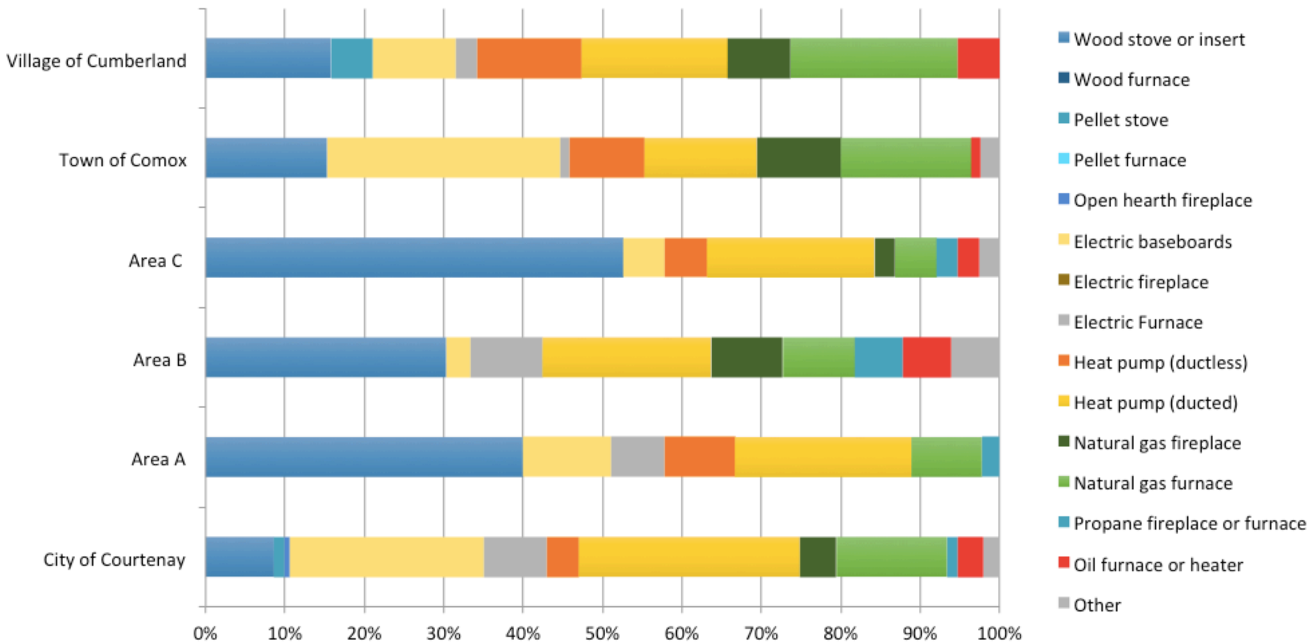
Figure 2. Percentage of type of primary heating source indicated by respondents (n=389).



OIL HEATING: It is worth noting that 11 respondents use oil as their primary heating source. These residents are eligible for heat pump rebates available through EfficiencyBC (up to $2,350 in the Comox Valley). Information is available at https://efficiencybc.ca.

To further break down each type of primary heating source, figure 3 shows the percentage of each heating source by area within the Comox Valley. In the rural areas, the percentage of respondents that have wood stoves is higher than in the urban centers. 50% of the primary heating in Area C (Black Creek) is with wood stoves, and wood heating accounts for 40% of the primary heating in Area B (Lazo North), and 30% of the primary heating for Area A (Baynes Sound).

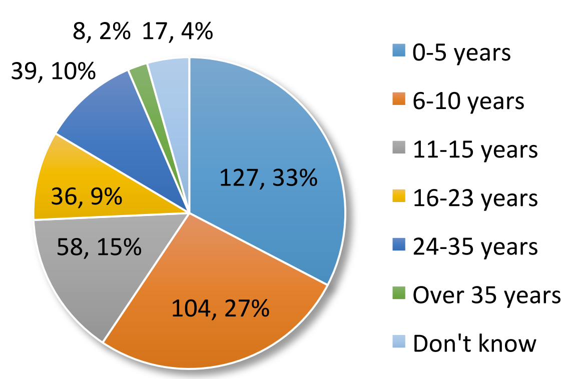
Figure 3. Percentage of total for each type of primary heating source by area (n=389).
The number of respondents is shown for each type of heating source for each area.



AGE OF PRIMARY HEATING SOURCE

Respondents were asked the age of their primary heating sources to assess efficiency and identify how close respondents might be to finding a replacement for their aging heating sources. 60% (231) have a heating source that is 10 years old or newer, while only 12% (47) have a primary heating source that is 24 years or older.

Figure 4. Age of primary heating source (n=389).



AGE OF WOOD BURNING APPLIANCES

With respect to wood stoves, current EPA certification began in 1994. Wood stoves older than 24 years are likely not meeting any emissions standards and should therefore be decommissioned.

12% of all respondents indicated that their primary heating source was older than 24 years, however only 1.5% (6) indicated that their wood-burning appliance, used as their primary heating source, is older than 24 years. Another 1.5% (6) of respondents indicated their wood burning appliance, used as their secondary heating source, is older than 24 years. Therefore, a total of 3% of all respondents potentially using a non-EPA certified wood burning appliance.

4% of respondents don't know how old their primary heating source is, in which case the number of respondents with non-EPA certified wood burning appliances may be higher than indicated.

SECONDARY HEATING SOURCE

When looking at secondary heating sources, 23% of the total number of respondents indicated they did not have a secondary heating source. Of the remaining 301 respondents, wood accounts for 17%, electric options account for 38% and natural gas options account for 19%. Table 1 shows the number of each type of primary and secondary heating sources indicated by respondents.

Table 1. Percentage comparison of respondents with each type of heating source indicated as primary and secondary (n=389).

Type of Heating System	Number Primary Heating Type	Percent Primary Heating Type	Number Secondary Heating Type	Percent Secondary Heating Type
Wood stove or insert	82	21%	59	15%
Wood furnace	0	0%	1	0%
Open hearth fireplace	1	0%	6	2%
Pellet stove	4	1%	0	0%
Electric baseboards	74	19%	90	23%
Electric fireplace	0	0%	14	4%
Electric Furnace	20	5%	23	6%
Heat pump (ductless)	25	6%	5	1%
Heat pump (ducted)	86	22%	14	4%
Natural gas fireplace	23	6%	61	16%
Natural gas furnace	51	13%	13	3%
Propane fireplace or furnace	6	2%	13	3%
Oil furnace or heater	11	3%	2	1%
Other	6	2%	5	1%
Don't know	0	0%	0	0%
No other heating sources			84	23%
Total	**389**	**100%**	**389**	**100%**

21% use wood as their primary and 17% use wood as their secondary heating source.

52% use electricity as primary and 38% as their secondary heating source.

19% use natural gas as primary and 19% as their secondary heating source.

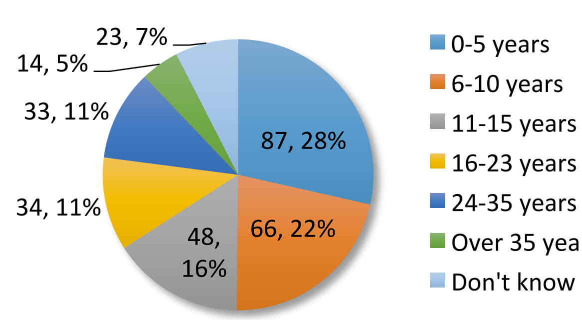
Those that chose "Other" as their secondary heating source indicated they use propane catalytic, natural gas hot water baseboard heaters, radiant electric ceiling, electric boiler and an electric radiator.

AGE OF SECONDARY HEATING SOURCE

Respondents were asked the age of their secondary heating sources to assess efficiency and identify how close respondents might be to finding a replacement for their aging heating sources.

50% of respondents (153) indicated that their secondary heating source was 10 years old or newer, while 16% stated it was 24 years or older. As noted above, only 6 of these respondents have a wood stove burning appliance that is 24 years or older.

Figure 5. Age of secondary heating source (n=305). Figure excludes respondents that indicated they have no other heating source.



ADDITIONAL HEATING SOURCE

40% of respondents (150) identified that they had an additional heating source, which was identified as electric (15%), natural gas (6%), propane (3%), wood (5%), pellet (1%), or other (6%). Those that chose "Other" showed a variety of options ranging from in-floor heating, to solar, to boilers.

Table 2. Type of additional heating system (n=384, 5 respondents skipped this question).

Type of Heating System	Number Additional Heating Type	Percent Additional Heating Type
Wood stove or insert	21	5%
Wood furnace	1	0%
Open hearth fireplace	10	3%
Pellet stove	3	1%
Electric baseboards	32	8%
Electric fireplace	15	4%
Electric Furnace	0	0%
Heat pump (ductless)	2	1%
Heat pump (ducted)	7	2%
Natural gas fireplace	19	5%
Natural gas furnace	4	1%
Propane fireplace or furnace	10	3%
Oil furnace or heater	1	0%
Other	22	6%
Don't know	3	1%
No other heating sources	234	60%
Total	**384**	**100%**

8% use wood as an additional heating source.

15% use electricity as an additional heating source.

6% use natural gas as an additional heating source.

60% do not have an additional heating source.

The age of the additional heating source was not asked in the survey.

WOOD HEATED OUTBUILDINGS

Only 11 respondents (3%) indicated they had one or more wood-heated outbuildings, however all but two respondents indicated that their wood-heating appliance was less than 23 years old, therefore they were using EPA certified wood stoves. The additional two respondents did not know the age of their outbuilding's wood stove, therefore we cannot identify whether they are using a certified model or not. Data for other means of heating outbuildings was not collected.

5.3 RESPONDENT'S PREFERENCE TO HEATING THEIR HOMES

Respondents were asked, "If money were not object, what would be your preferred way to heat your home?"

This question was asked to identify whether residents were happy with their current heating systems or if they would like to change it, and if so, what would be their preferred option. One-third (32%) of respondents wouldn't change how their homes were heated, one-third (33%) would install a heat pump, and the remaining third (34%)

would choose a variety of options, the third highest being install a furnace (gas or electric). Table 3 shows the number and percent of each preferred heating type.

Table 3. Respondent's preferred way to heat their home if money were no object (n=389).

Answer	Number	Percent
I wouldn't change anything about how my home was heated	126	32%
Heat pump (electric)	127	33%
Furnace (gas or electric)	40	10%
Other	34	9%
Electric fireplace	20	5%
Wood stove/insert	15	4%
Pellet stove	8	2%
Don't know	7	2%
Electric baseboards	6	2%
Wood furnace	5	1%
Gas fireplace	1	0%
Total	**389**	**100%**

The 34 respondents that chose 'other' chose solar (16), geothermal (4), in-floor heating (2), natural gas heat pump, more insulation, and a combination of systems (10).

PREFERENCES FOR WOOD STOVE USERS

Of the 82 respondents that use wood as their primary heating source, 75% (61) would prefer a different heating source, with half of those respondents (30) wanting a heat pump. 8 respondents would install a furnace, 5 would install a gas stove, 2 would get a new wood stove/insert, 2 want solar, and 5 would get a pellet stove. The remaining 10 respondents include all other heating sources including those noted as "other".

5.4 WOOD BURNING PRACTICES

Of the total respondents, 149 (38%) indicated that they burn wood for home heating (primary, secondary and additional heating sources). 240 respondents (62%) do not burn wood. The following responses are related to wood burning practices indicated by respondents.

NUMBER OF CORDS OF WOOD BURNED EACH YEAR

Respondents that burn wood were asked how many cords they use per year. Of these 149 respondents, 50% (74) burn between 0-2 cords per year, 35% (52) burn 3-4 cords per year, 11% (16) burn 5 or more cords per year and 5% (7) do not know how many cords they burn.

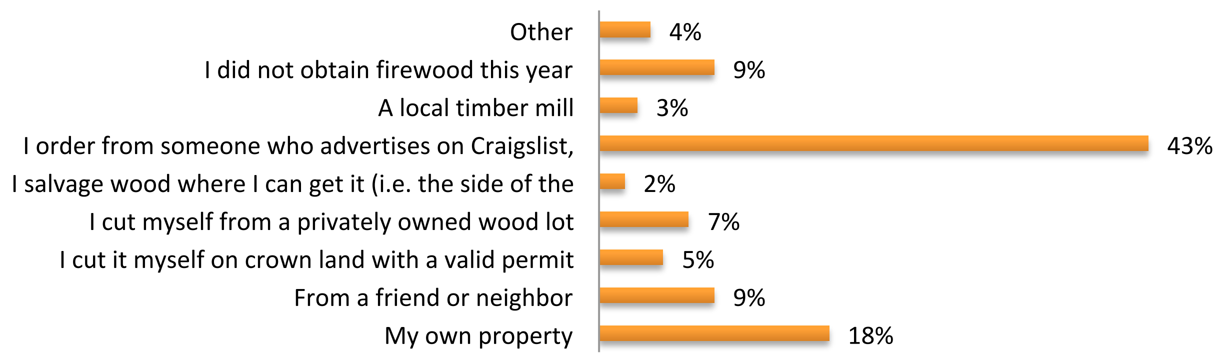
Table 4. Number of cords respondents burn per year.

Number of Cords	Count	Percent
0-1	27	18%
1-2	47	32%
3-4	52	35%
5-6	13	9%
7 or more	3	2%
Don't know	7	5%
Total	**149**	**100%**

WHERE RESPONDENTS OBTAIN THEIR FIREWOOD

43% (64) obtain their firewood from Craigslist, Kijiji, Facebook or the newspaper. See figure 6 below for the other ways in which respondents obtain their firewood.

Figure 6. Where respondents obtain their wood (n=149).



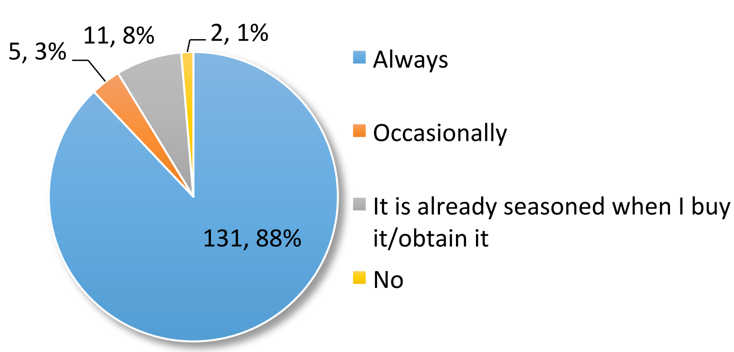
The 4% of respondents that chose 'Other' indicated that they take wood off slash piles, obtain wood from a fencing company, obtain wood from arborist clients, purchase it, or work with a group of friends and logging truck to obtain and split wood.

The (9%) of respondents that chose 'I did not obtain firewood' may have already had firewood on their property from the year before, were away for the winter, or used a different heating source than their primary source and did not need to obtain more wood.

WOOD STORAGE

When respondents that burn wood were asked if they stack their wood under a sheltered area with sufficient air flow on at least three sides, 88% (131) said always, 3% (5) said occasionally, 1% (2) said no, and 7% (11) said the wood was seasoned when they obtained it.

Figure 7. Number of respondents that stack their wood under a sheltered area with sufficient air-flow on three sides (n=149).



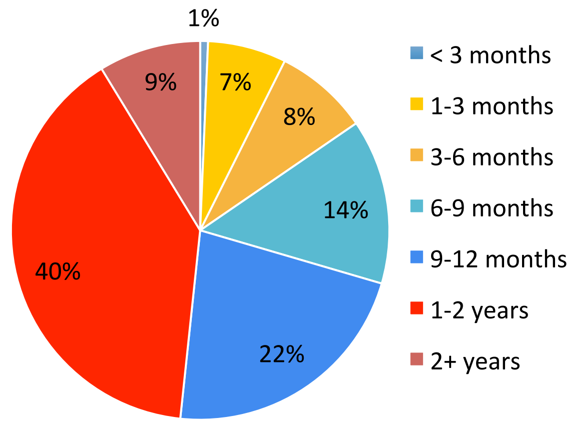
LENGTH OF TIME FIREWOOD IS STORED

Respondents were then asked how long the wood was on their property before it was burned. This question helped to clarify respondent's impressions of what it means to "season their wood".

The BC Ministry of Environment recommends wood be cut, split and dried for a minimum of six months before burning, preferably in the spring to burn in the fall/winter [7].

84% of wood burning respondents follow the above recommendation and store their firewood on their property at least six months before burning, with nearly half of respondents (49%) storing it for over one year.

Figure 8. Amount of time respondents store their firewood before burning (n=149).



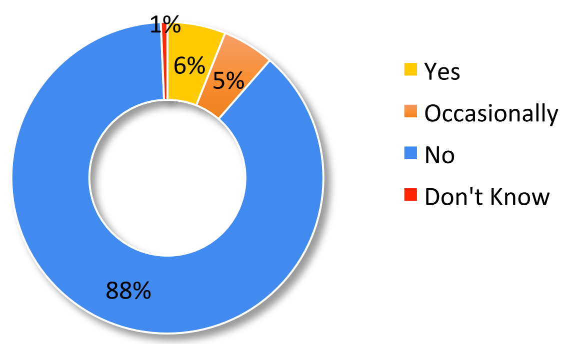
MOISTURE CONTENT OF FIREWOOD

Respondents that burn wood were asked if they use a moisture meter to test the moisture content of their wood before burning it. A moisture meter is a digital device that provides a percentage moisture content reading of the wood.

BC Ministry of Environment recommends that the moisture content be 20% or less to reduce smoke [7].

88% of respondents (131) do not use a moisture meter, 11% always or occasionally do, and 1% does not know if they use a moisture meter at home.

Figure 9. Percentage of wood burning respondents that use a moisture meter to test their wood's moisture content before burning (n=149).

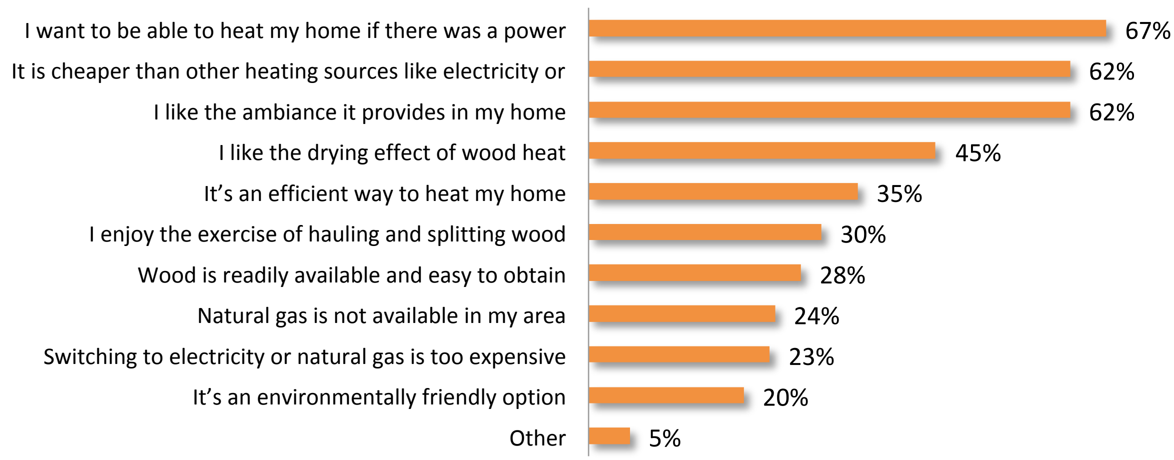


PROS AND CONS TO BURNING WOOD

Wood burning respondents were asked, "For what reasons do you use wood to heat your home?" Respondents were able to choose all answers that apply, and 600 responses were selected.

Two-thirds of respondents (67%, 100) indicated that the main reason they burn wood is to be able to heat their homes if there was a power outage. Nearly two-thirds (62%, 94) respectively indicated that the next most important reason for burning wood was because it is cheaper than all other heating sources, and they enjoy the ambiance it provides to their home. See figure 10 for all responses.

***Figure 10. Pros: Reasons respondents heat their homes with wood (n=149)*.**

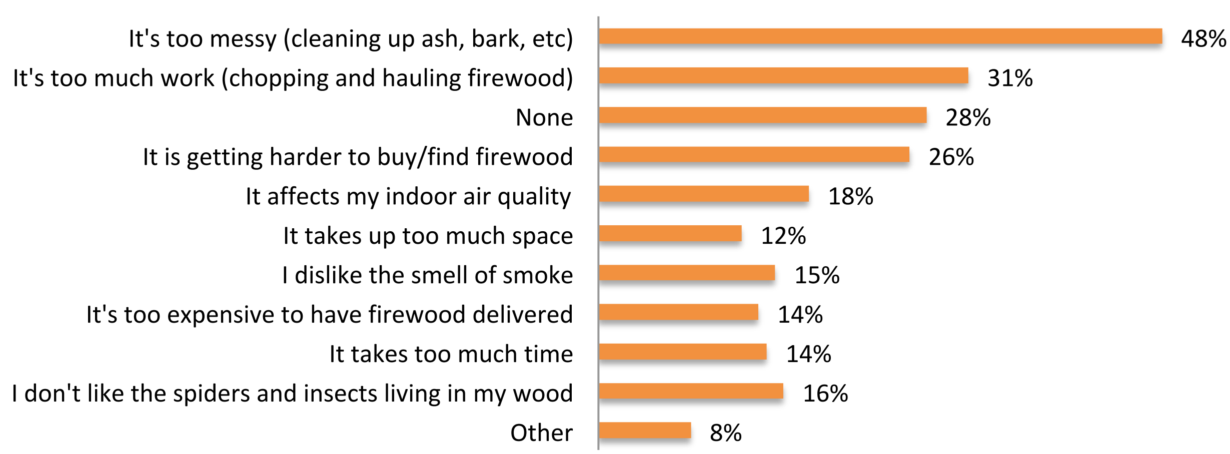


The 5% (8) respondents that chose 'Other' noted the following reasons for burning wood; "it clears debris I can't otherwise burn outside", "I can cook food if there's a power outage", "heat pumps are not efficient lower than -1 or 2 degrees", "using deadfall on my property reduces wildfires", "it's the only heating source in my outbuilding" (2) and "I don't use it at this time".

140 of the 149 respondents that burn wood answered the question, "are there any reasons you dislike burning wood to heat your home?" Respondents were allowed to choose all that apply, and 322 responses were chosen. Nearly half (48%, 67 respondents) indicated that wood as a heating source was too messy, and nearly one-third (31%, 44) thinks it is too much work. On the other hand, 28% (39) answered "none". 9 respondents did not answer the question. See figure 11 for all responses.

Of the respondents that burn wood as their primary heating source, the top reason for burning wood was because it was cheaper than other heating sources like electricity or gas (73%, 60 respondents). Heating their home if there was a power outage was the second most important reason, chosen by 70% of respondents (57).

Figure 11. Cons: Reasons respondents do not like using wood to heat their homes (n=140).



Those that chose 'Other' stated; "it pollutes the outside air" (7), "it affects the neighbors", "it's the only option for my outbuildings" (2), and "I dislike the social pressure to move away from wood heating".

5.5 IMPRESSIONS OF AIR QUALITY IN THE COMOX VALLEY DURING THE WINTER MONTHS

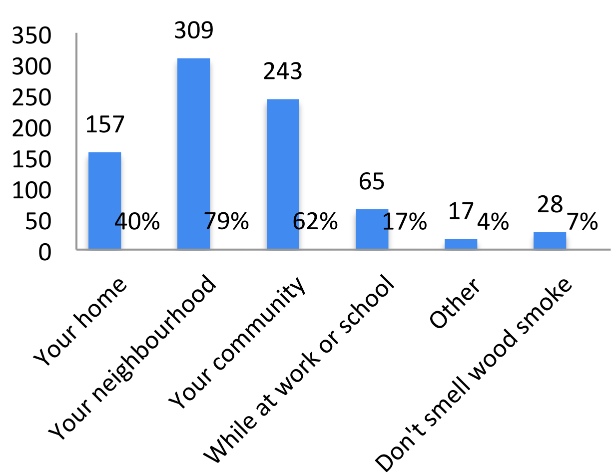
Respondents were asked a series of questions to identify their level of awareness of wood smoke in the winter months and what their beliefs are when connecting wood smoke to health.

AWARENESS OF THE PRESENCE OF WOOD SMOKE

A strong indicator of whether someone's health is being affected by wood smoke is by being able to smell smoke. The question was asked, "On occasion during the winter months, can you smell wood smoke in a) your home, b) your neighbourhood, c) your community, d) at work or school, e) other, or f) I don't smell wood smoke."

Respondents were able to choose all that apply. Respondents chose a total of 819 responses. 79% of respondents (309) could smell smoke on occasion in their neighbourhood, 62% said they could smell it in their community (243), and 40% said they could smell smoke in their homes on occasion during the winter (157). Only 7% (28) said they couldn't smell smoke in the winter months, therefore 93% do smell wood smoke on occasion in the Comox Valley in the winter months.

Figure 12. Location(s) respondents can smell wood smoke on occasion during the winter months (n=389).

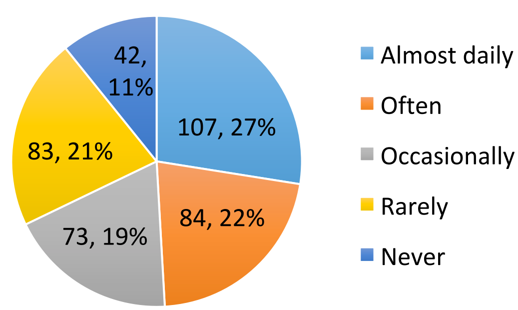


The 17 respondents that chose "Other" stated; they could smell the smoke in their or their children's hair/clothing (2), in the forest trails surrounding the community (5), when visiting a different part of the community (i.e. family members home or specific location) (6) noting locations in Cumberland, Comox and Courtenay, everywhere (3), and in their car.

CONNECTING WOOD SMOKE TO AIR QUALITY

When asked how often smoke from residential burning affects the air quality in respondents' neighborhoods during the winter months, nearly half said often (27%, 107) or almost daily (22%, 84), 19% said occasionally (73) and less than one-third of respondents (32%) said wood smoke rarely or never affects air quality in their neighborhoods (125).

Figure 13. How often respondents believe smoke from residential burning affects the air quality in their neighbourhood (n=389).

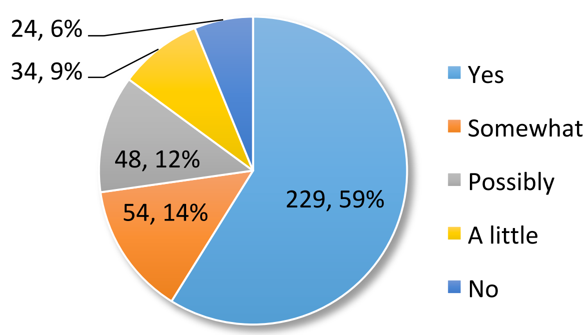


79% of respondents said they can smell wood smoke on occasion in the Comox Valley, but only 67% noted that the wood smoke affects air quality on occasion in their neighbouhoods.

CONNECTING WOOD SMOKE TO HEALTH

94% of respondents (365) believe exposure to residential wood smoke affects human health, with nearly three quarters of respondents (73%, 283) stating yes or somewhat, and 9% (24) stating it may affect health 'a little'.

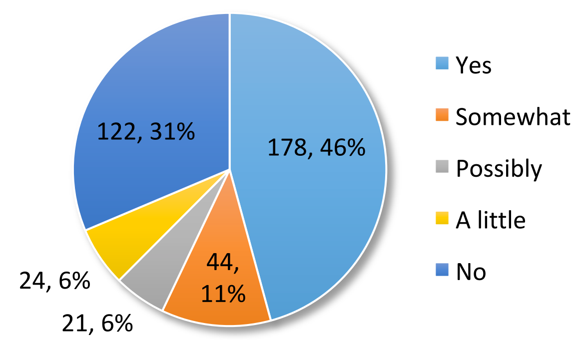
Figure 14. Number of respondents that believe exposure to residential wood smoke affects human health (n=389).



Although nearly all (94%) respondents believe exposure to residential wood smoke affects people's health, just over half (57%) stated in the following question that they are concerned that smoke from residential wood smoke is affecting their health or their family's health.

Nearly one-third of respondents (31%) do not believe wood smoke affects their health or their family's health.

Figure 15. Number of respondents concerned that wood smoke affects their health or their family's health (n=389).



For this question, the answer option "Possibly" was changed to "Possibly, although it can be hard to tell if it's a cold or allergies." The intention of changing this wording was to help respondents link the typical signs of wood smoke exposure to their personal health experiences in the winter months. However only 6% of respondents (21) chose this answer.

AWARENESS OF THE WOOD STOVE EXCHANGE PROGRAM

Respondents were asked, "Are you aware that the Comox Valley Wood Stove Exchange Program is providing rebates to exchange old, non-EPA wood stoves with new certified wood stoves ($250 rebate), gas or pellet stoves ($600 rebate) or heat pumps ($1000 rebate)?" 4 out of 5 respondents answered 'yes' (215), while 19% (74) answered 'no'.

Figure 16. Awareness that the Comox Valley Wood Stove Exchange program is providing rebates to exchange old non-EPA certified wood stoves.

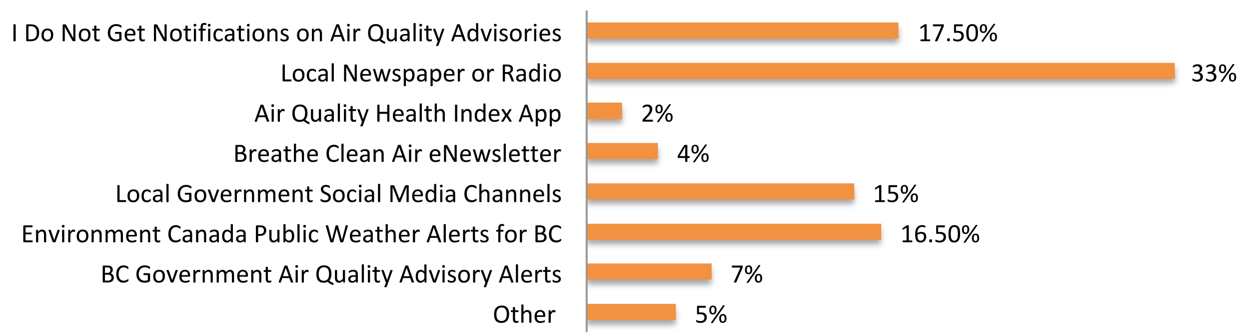
The high rate of awareness could be due to the fact that the survey link was hosted on the Wood Stove Exchange Program webpage.

AIR QUALITY ADVISORIES

In 2017, there were seven air quality advisories issued in the Comox Valley, accounting for 17 days in which the air quality exceeded the provincial 24-hour PM2.5 limit.

Respondents were asked how they found out about these air quality advisories. 17.5% of respondents (68) do not get any information regarding air quality advisories. One third of respondents (129) hear about them through the local newspaper or radio, and the remaining 50% of respondents find out a variety of ways. See figure 17 below.

Figure 17. How respondents hear about Air Quality Advisories in the Comox Valley (n=389).

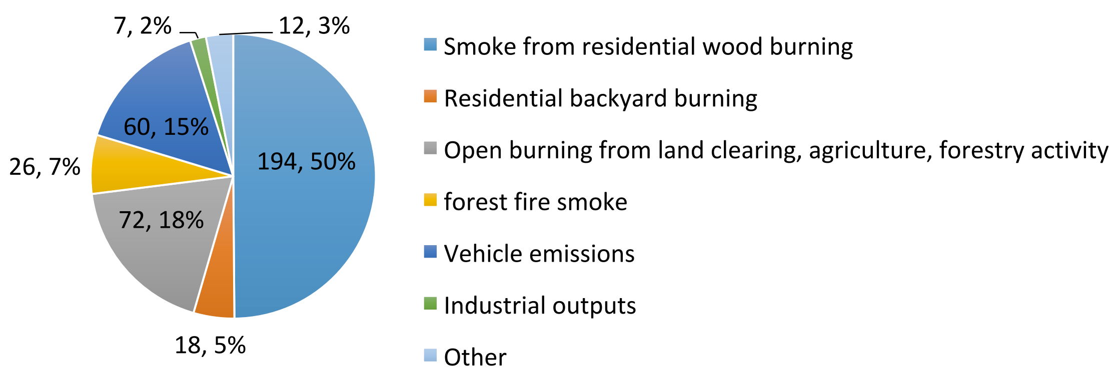


Of the 5% of respondents (21) that chose "Other", the responses to the above question were: Facebook (8), the sight/smell (3), through word of mouth (3), multiple sources (3), signs in town, the Weather Network App, local government website or CBC.

LOCAL AIR POLLUTION SOURCES

Respondents were asked to what they think is the largest contributor to air pollution in the Comox Valley. Half of respondents (194) believe it is from smoke from residential wood burning. The remaining half of respondents answers are split between the other choices, with the next largest choice (18%) being open burning from land clearing, agriculture and forestry activity (72 responses).

Figure 18. Perceptions of the biggest contributor to poor air quality in the Comox Valley in the winter months (n=389).



Of the 12 respondents that chose 'Other', responses were, "I do not think there is an air quality problem in the Comox Valley (7), the Compost facility, the valley air circulation, neighbors burning toxic material like garbage and plastic, and "there are multiple sources of air pollution," (2).

5.6 ADDITIONAL COMMENTS

40% of respondents (154) had additional comments. All comments are provided in Appendix B. A summary of the top five issues identified from the additional comments were:

1. **More education is needed to ensure the entire population is aware of the health effects of wood smoke in the Comox Valley.** The comments show many personal stories about respondents being affected by wood smoke and/or the shock of poor air quality upon moving to the Comox Valley vs. others not believing wood smoke is an issue with local air quality.

2. **A set of common rules and regulations (i.e. bylaws) around wood burning for the entire air shed, including land clearing is a necessity.** Many believe that burning wood should not be allowed in densely populated areas.

3. **Many respondents indicated their disapproval how the current Wood Stove Exchange Program provides a rebate for a wood stove to wood stove exchange.** A number of respondents believe that funds should be used for cleaner burning options only and incentives should include other clean burning options (such as solar, geothermal, boiler systems and other electric/gas technologies), not just gas or pellet stoves and heat pumps.

4. **The largest barrier to moving away from a wood stove to cleaner burning option is the cost.** Comments show respondents believe the cost of switching to a cleaner heating source is too high. Additional comments question the suggested cleaner-burning option's efficiency or indicate options such as natural gas are not available in their area.

5. **More education is needed on smart wood burning practices.** Comments around storage, burning dry wood, knowing the temperature of the fire and knowing/maintaining individual stoves are all noted.

It is clear that there are several barriers to a) understanding the health effects of wood smoke, b) making the switch to a cleaner burning option and c) using proper burning techniques. The recommendations section touch on these identified barriers and propose solutions to resolving these issues.

6 - DISCUSSION OF FINDINGS

HOME HEATING SOURCES

The types of heating sources used in the Comox Valley varies widely, with just over half of the respondents using electricity as their primary heating source, mostly using baseboards and heat pumps. 38% of the total respondents burn wood, with 21% using wood as their primary heating source. These percentages change based on the physical location, with higher rates reported in the rural areas than in Comox, Courtenay and Cumberland. Assuming this data is representative of the entire Comox Valley, the number of homes burning wood as their primary heating source could potentially be 6,200 homes, and up to 11,000 homes including those that burn wood as their secondary and additional heating sources. A residential property survey would need to be completed to confirm these numbers.

In an effort to identify how many non-EPA certified wood stoves there may still be in the Comox Valley, the question of “age of heating source” was asked, rather than “is your wood stove EPA approved”. This also identified the age of all heating sources, with the assumption that the older the heating source, the closer the homeowner may be to upgrading to a newer (cleaner) option.

12% of all respondents have a heating source older than 24 years, and only 3% (12 respondents) have wood burning appliances that are older than 24 years, meaning these appliances are likely not EPA certified. The Wood Stove Exchange Program current states that to be eligible for a rebate, residents must use wood as their primary heating source and the appliance must not be EPA certified. With only 6 of these 12 respondents indicating that they burn wood as their primary heating source, there may be several hundred uncertified stoves left in the Comox Valley. Program eligibility criteria may need to be reassessed to target these remaining homes and to continue to incentivize the shift away from wood as a primary heating source.

During the development of the survey questions, it was identified that there may be several uncertified wood stoves in outbuildings such as heated shops or garages. However none of the 11 respondents with wood heated outbuildings reported having wood burning appliances older than 24 years old; therefore it can be assumed that all appliances are currently EPA certified. Future planning will focus on home heating rather than heating outbuildings.

Overall, two-thirds of respondents want to change their heating source, and half of those respondents would install a heat pump if money were no object. Interestingly, 75% of respondents that burn wood as their primary heating source, would like to change their heating source, and the majority of them would install a heat pump if they could afford it.

WOOD BURNING PRACTICES

Reported wood burning practices were for the most part following the recommended smart burning practices from the Ministry of Environment [7], however only 1 in 10 use a moisture meter to ensure their wood’s moisture content is under 20%. 84% store their firewood on their property at least six months before burning, with nearly half of respondents (49%) storing it for over one year, and 88% always stack their wood under a sheltered area with sufficient air flow on at least three sides.

There are several pros and cons to burning wood. The survey aimed to identify what respondents liked and disliked about using wood as a heating source, to assist in future planning and marketing efforts. The main reasons identified were: 1) to be able to heat their home if there was a power outage, 2) because it is cheaper than all other heating sources, and 3) enjoying the ambiance it provides to their home. When looking at the data from those that burn wood as their primary heating source, the top reasons for burning wood were 1) because it was cheaper than other heating sources like electricity or gas (73%), followed by being able to heat their home if there was a power outage (70%).

In terms of reasons for disliking using wood as their main heating source, nearly half of wood burning respondents indicated that the number one downside to burning wood was that it is too messy, and nearly one third think it is too much work. 28% thought there was no downside at all.

PERCEPTIONS OF AIR QUALITY AND HEALTH

The majority of respondents are aware that there is an air quality issue during the winter months and that wood smoke affects people's health. Nearly all respondents can smell smoke on occasion during the winter months (93%), therefore they are noticing wood smoke and therefore breathing it into their lungs. Although nearly all respondents (94%) believe exposure to residential wood smoke affects people's health, just over half (57%) are concerned that smoke from residential wood smoke is affecting their personal health or their family's health. One-third of respondents do not believe that wood smoke is a health risk or his or her health personally, or to his/her family.

In 2017, there were 17 days when fine particulate matter levels (PM 2.5) exceed the applicable Canadian Ambient Air Quality Standards (CAAQS). Residential wood burning in the fall and winter are the largest contributors to this issue when weather conditions resulted in temperature inversions that trapped pollutants such as PM 2.5 at ground level. Half of the respondents believe smoke for residential wood burning is the biggest contributor to poor air quality in the winter months, while the remaining half believe its open burning (18%), vehicle emissions (15%) and a variety of other emission sources. The answers to this question (including those noted in "other") show that where people live and the time of year will dramatically effect these perceptions of air pollution sources, and more general awareness and education may be needed.

There are many different ways to learn about air quality advisories in the Comox Valley, and from the survey data, there is no main method in which respondent's find out about these advisories. 17.5% of respondents do not receive or seek out any information about air quality advisories. There may be opportunity to improve this alert system in an effort to inform residents more consistently and effectively regarding air quality advisories.

Awareness levels are high regarding the Wood Stove Exchange Program. 4 out of 5 respondents stated they were aware of the Wood Stove Exchange Program and the rebates available for exchanging a non-EPA certified wood burning appliance with a certified wood stove/insert ($250 rebate), a pellet or gas stove ($600 rebate) or heat pump ($1000). The online survey link was hosted on the wood stove exchange program webpage, which may have resulted in increase awareness of the program amongst survey participants.

7 - CONCLUDING REMARKS

The survey successfully brought to light several key points that can be used to assist the long-term planning of the Wood Stove Exchange Program, and gave residents a means to express their opinions on the issue of air quality. 40% of respondents provided comments including personal stories, opinions, ideas and actions that have been used to define the recommendations in the following section.

There is sufficient data showing that smoke from residential wood burning is affecting the air quality in the Comox Valley and the health of the community. But the discussion remains open as to what to do to reduce the amount of wood smoke from residential wood burning. Current efforts have been focused on education of smart wood burning practices and reducing the number of non-EPA certified wood stoves. However without air pollution reduction goals, measurable targets and an implementation plan, it is difficult to decide what the best next step may be to have a larger impact on reduction of wood smoke in the winter months. The recommendations in the following section pull key points from the survey data as well as from the comments section to provide discussion points for the consideration of stakeholders including municipal and provincial staff, and local elected officials.

8 - RECOMMENDATIONS

The following recommendations are proposed solutions to the issues identified in the survey data and additional comments. This list is meant to further discussion around air quality improvements in the Comox Valley.

1. Of the one-third of respondents that indicated wood was their primary heating source, 12 respondents (3% of total respondents) indicated that their stove may be non-EPA, based on the age of the appliance. Therefore, to further reduce residential wood smoke in the Comox Valley, it is recommended that the CVRD discuss the feasibility of opening up the Wood Stove Exchange Program to homes with EPA certified wood burning appliances as their main heating source. However, residents would only be eligible for exchange of their EPA certified wood stove to a cleaner burning option (pellet stove, gas stove or heat pump).

2. Continue to partner with Island Health, the BC Ministry of Environment and the BC Lung Association to further support education on how wood smoke affects people's health, showcasing regional data. Use marketing language that connects the symptoms of wood smoke inhalation with the problem.

3. Provide an infographic on the pros and cons of each home heating source as it relates specifically to the Comox Valley to assist homeowners in making informed decisions about exchanging their wood-burning appliance for a cleaner burning option. Provide typical costs for annual electricity/gas prices for homes with an average or typical EnerGuide Rating for this area.

4. 13 respondents use oil as their primary heating source. Target these residents with information regarding the EfficiencyBC Program, which could provide residents up to $2,350 in the Comox Valley. Information is available at http://efficiencybc.ca.

5. Currently, one permanent air quality monitoring station is located in the Comox Valley at Courtenay Elementary School and a temporary air quality monitoring station was recently deployed in Cumberland for a one-year period. Consider the installation of additional monitoring stations in the Comox Valley, including Cumberland, Comox, and east Courtenay.

6. Encourage Comox Valley local governments to implement a bylaw that restricts the use of non EPA-certified wood stoves, burning wood with moisture content higher than 20%, and burning wood in any capacity on poor venting days. Broadly communicate the bylaw, providing a phone number and web page so it is easy to find out if it is a safe day to burn. Communicate a hotline to call to report burning on poor venting days, triggering a bylaw officer to visit the resident in question to investigate. The first step will be to provide education regarding the bylaw and how to identify when it's safe to burn, as well as alternatives to burning wood. Review bylaws for Prince George, Kelowna and Smithers.

7. Consider implementing yard waste pick up in rural areas of the CVRD to reduce backyard burning. Qualicum Beach does seasonal yard waste pick up, and the amount that can be picked up is based on size of property. See https://www.qualicumbeach.com/chipping-program. Identify whether the fire departments can get involved, to collect and chip yard waste one weekend each season. Consider restrictions on backyard burning in future bylaws, with priority to rural areas in close proximity to densely populated urban areas.

8. Establish a formal air quality working group in the Comox Valley, similar to the programs in Prince George, Port Alberni and Cowichan Valley. Input would be sought from local government officials, scientists, provincial support and local citizens and non-profit groups. The group would outline the goals and priorities of the community, backed by provincial and regional scientific data and should include resources dedicated to implementing the prioritized action plan.

9. Promote the EfficiencyBC Program to provide residents that want to upgrade their heating system with a qualified professional regarding the best retrofit options for their home to reduce wood smoke and improve their home's EnerGuide rating. Give priority to residents using the Wood Stove Exchange Program rebates for gas stoves or heat pumps.

10. Develop a set of criteria to identify homes that are large contributors to air pollution with regards to wood smoke. Set up a small number of "home heating retrofit grants" to assist these residents that show financial need as their primary reason for not switching to cleaner heating sources.

11. Consider working with the Provincial Government on providing a text-based alert system to deliver air quality advisories to resident's mobile devices, similar to the CVRD's get notified system that currently advises residents about boil water advisories. The Provincial Government has been working on this system specifically for air quality with Smithers through Ben Weinstein.

9 - REFERENCES

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10 - APPENDIX A – SURVEY QUESTIONS

Wood Stove Exchange Program – Residential Home Heating and Air Quality Survey
Distribution: February-March 2018

Survey Questions

As part of the 2018 wood stove exchange program, the Comox Valley Regional District is conducting a residential home heating and air quality survey.

The purpose of this survey is to understand how residents heat their homes and to better understand their perceptions of local air quality and wood burning practices.

The information collected on this form is gathered under the authority of Section 26 (c) of the Freedom of Information and Protection of Privacy Act and will be used solely for planning future air quality programs. The information will be available to the public upon request in a summarized format. The summary will be shared with the BC Ministry of Environment & Island Health. Should you have any questions about the collection and use of this information, please contact Vince Van Tongeren by emailing communityservices@comoxvalleyrd.ca or by calling 250-334-6038.

Please take 10 minutes to complete the survey to the best of your knowledge. Upon completion, you can enter to win a $250 Gift Card to Quality Foods in Courtenay or Comox.

From the drop down menu, please choose the area of the Comox Valley in which you reside: (View Map [http://www.comoxvalleyrd.ca/assets/Community/Documents/CVRD_Map.pdf])

- City of Courtenay
- Town of Comox
- Village of Cumberland
- Electoral Area A – Baynes Sound (Including Royston, Union Bay, Fanny Bay, Denman and Hornby Island)
- Electoral Area B – Lazo North
- Electoral Area C – Puntledge/Black Creek (Including Merville, Kitty Coleman, Oyster River and Mount Washington)
- I live outside the Comox Valley

1. Please enter your Postal Code (i.e. V3V 3V3): [Insert text box]

2. What do you consider to be your home's primary heating source (used for more than 50% of your home's heating) during the winter months? (Choose one that best applies)

- Wood stove or insert
- Wood furnace
- Pellet stove
- Pellet furnace
- Open hearth fireplace
- Electric baseboards
- Electric fireplace
- Heat pump (ductless)
- Heat pump (ducted)
- Natural gas fireplace

- Natural gas furnace
- Propane fireplace or furnace
- Oil furnace or heater
- Other
- Don't know

3. Approximately how old is this heating appliance?

- 0-5 years
- 6-10 years
- 11-15 years
- 16-23 years
- 24-35 years
- Over 35 years
- Don't know

4. What would you consider to be your secondary heating source (used for less than 50% of your home's heating) during the winter months? (Choose one that best applies)

- Wood stove or insert
- Wood furnace
- Pellet stove
- Pellet furnace
- Open hearth fireplace
- Electric baseboards
- Electric fireplace
- Heat pump (ductless)
- Heat pump (ducted)
- Natural gas fireplace
- Natural gas furnace
- Propane fireplace or furnace
- Oil furnace or heater
- Don't know
- Other (please explain) [Insert text box]
- No other heating sources

[If chose 'No other heating sources' skip to Q7]

5. Approximately how old is this heating source?

- 0-5 years
- 6-10 years
- 11-15 years
- 16-23 years
- 24-35 years
- Over 35 years
- Don't know

6. Do you have any other heating sources in your home? (Choose all that apply)

- Wood stove or insert

- Wood furnace
- Pellet stove
- Pellet furnace
- Open hearth fireplace
- Electric baseboards
- Electric fireplace
- Heat pump (ductless)
- Heat pump (ducted)
- Natural gas fireplace
- Natural gas furnace
- Propane fireplace or furnace
- Oil furnace or heater
- Don't know
- Other (please explain) [Insert text box]
- No other heating sources

7. Do you have any wood-heated outbuildings (such as a shop, garage or shed)?
    - Yes
    - No
    - Don't know

[If chose 'Yes', show Q8, otherwise skip to Q9]

8. Approximately how old is your wood-burning appliance in your outbuilding?
    - 0-5 years
    - 6-10 years
    - 11-15 years
    - 16-23 years
    - 24-35 years
    - Over 35 years
    - Don't know
    - Other (please explain) [insert text box]

9. If money were no object, what would be your preferred way to heat your home? (Please choose one that best applies)
    - I wouldn't change anything about how my home is heated
    - Furnace (gas or electric)
    - Heat pump (electric, ducted or ductless)
    - Electric baseboards
    - Electric fireplace
    - Gas fireplace
    - Pellet stove
    - Wood furnace
    - Wood stove/insert
    - Don't know
    - Other (please explain) [Insert text box]

10. Approximately how many cords of wood do you burn on average each year to heat your home or outbuilding(s)? (One cord is equivalent to 4'x4'x8' of stacked split wood)

- I don't burn wood
- 0-1
- 1-2
- 3-4
- 5-6
- 7 or more
- Don't know
- Other (specify amount of bundles, truck loads, etc.) [Insert text box]

[If answered 'I don't burn wood' skip to Q17]

11. Where do you typically obtain your wood? (Choose the best answer)

- My own property
- From a friend or neighbour
- I cut myself on crown land with a valid Firewood Permit
- I cut myself from a privately owned wood lot
- I salvage wood where I can get it (i.e. side of the road)
- I order from someone who advertises on Craigslist, Kijiji, Facebook or the newspaper
- A local timber mill
- Outside of the North Vancouver Island area
- Purchase pellets from a local distributor or order online
- Other (please describe) [insert text box]
- I did not obtain wood this year (please explain) [insert text box]

12. Do you stack your wood under a sheltered area with sufficient airflow on at least three sides to reduce the moisture content (i.e. season your wood)?

- Always
- Occasionally
- It is already seasoned when I buy/obtain it
- No

13. How long is your firewood on your property before you burn it?

- Less than 1 month
- 1-3 months
- 3-6 months
- 6-9 months
- 9-12 months
- 1-2 years
- More than 2 years

14. Do you use a moisture meter to test the moisture content of your wood before burning it? (A moisture meter is a digital device that provides a percentage moisture content reading of the wood.)

- Yes
- Occasionally
- No
- Don't know

15. For what reasons do you burn wood to heat your home? (Choose all that apply)

- It is cheaper than other fuel sources like electricity or gas
- I like the ambiance it provides in my home
- Switching to electric or gas options are too expensive
- Natural gas is not available in my area
- I like the drying effect of wood heat
- Wood is readily available and easy to obtain
- If there is a power outage, I want to be able to heat my home
- It is an efficient way to heat my home
- It is an environmentally friendly option
- I enjoy the exercise of hauling and splitting wood
- Other (please explain) [Insert text box]

16. Are there any reasons you dislike burning wood? (Choose all that apply)
    - None, I love burning wood
    - It’s too physically challenging (chopping and hauling wood)
    - It’s messy (cleaning up ash, wood chips, bark, etc.)
    - I dislike the smoke-smell
    - It affects my indoor air quality
    - It takes too much time
    - It takes up too much space
    - I don’t like the spiders and insects living in my wood storage area
    - It’s too expensive to have wood delivered
    - It is getting harder to buy/find
    - Other (please explain) [Insert text box]

17. On occasion during the winter months, can you smell wood smoke in…(Choose all that apply)?
    - Your home?
    - Your neighbourhood?
    - Your community?
    - While at work or school?
    - Other (please explain) [Insert text box]

18. How often does smoke from residential burning affect air quality in your neighbourhood during the winter months? (Choose the answer that best applies)
    - Almost daily
    - Often
    - Occasionally
    - Rarely
    - Never

19. Do you believe that exposure to residential wood smoke affects people’s health?
    - Yes
    - Somewhat
    - Possibly
    - A little
    - No

20. Are you concerned that your health or your family’s health might be affected by wood smoke in the Comox Valley?
    - Yes

- Somewhat
- Possibly, although it can be hard to tell if it's a cold or allergies
- A little
- No

21. In 2017, there were seven air quality advisories. How do you find out about local air quality advisories?
    - Local government social media channels
    - Local newspaper or radio
    - Breathe Clean Air eNewsletter
    - BC Government Air Quality Advisories Alerts
    - Environment Canada Public Weather Alerts for BC
    - Air Quality Health Index App
    - I do not get Air Quality Advisories
    - Other (please explain) [Insert text box]

22. What do you think is the biggest contributor to poor air quality in the Comox Valley?
    - Smoke from residential wood burning
    - Residential backyard burning
    - Open burning from land clearing, agriculture or forestry slash
    - Vehicle emissions
    - Industrial outputs
    - Other [Insert text box]

23. Are you aware that the Comox Valley Wood Stove Exchange Program is providing rebates to exchange old, non-EPA or CSA certified wood stoves with new certified wood stoves ($250 rebate), gas or pellet stoves ($600 rebate) or heat pumps ($1000 rebate)?
    - Yes
    - No

24. Any other comments or suggestions regarding home heating or local air quality? [Insert large text box]

25. Would you like to receive an email with more information about the Wood Stove Exchange Program or smart burning practices? Your contact information will not be associated with individual results or used in any other way.
    - Yes
    - No

[If 'Yes', provide an enter email address box with a submit button and a caption that says, "Please provide your email address below"]

Thank you for taking the time to complete our survey. To be entered to win a $250 gift card to Quality Foods, please enter your name and phone number below. This information will only be used to contact the winner, and will not be associated with individual results or used in any other way.

Name: ________________________
Phone: ________________________

Thank you for submitting your survey. Please only submit one survey per household.

Review these links for more information about Smart Burning Practices and the Residential Wood Stove Exchange Program.

Smart Burning Practices <https://www2.gov.bc.ca/gov/content/environment/air-land-water/air/air-pollution/smoke-burning/wood-burning-appliances/burning-wood>

Wood Stove Exchange Program <www.comoxvalleyrd.ca/woodstove>

11 - APPENDIX B – ADDITIONAL COMMENTS

Additional comments are presented in the order in which they were received. These comments have been given a basic spell check, but are otherwise unedited. Those in bold are related to the top five additional comments noted in section 5.5.

1. **Mail direct to residents to educate them about the hazards of outdoor burning (venting index) and burning wet wood 2. Probably out of CVRD mandate, but encourage infrastructure to allow gas heat infrastructure to be built.** I spoke with Gas and the main pipe isn't all that far away. I think some collaboration may be possible? (No way for gas heat without a pig tank in my area)
2. Please encourage/educate on responsible wood stove use, and wood storage, but do not ban wood stoves entirely. A relatively small number of irresponsible wood burners could be significant contributors to air quality issues.
3. We have recently installed a wood stove insert with a catalytic converter that burns the gas a second time. Even with 2 heat pumps in the home, one ducted and one non-ducted, the home gets chilly when the outside temperature drops below -3 degrees. **Your survey is not taking into consideration the need to burn wood as a second heating source in order to maintain comfort levels even if it is not the main source of heat.**
4. Our neighbour burns wet wood with an old stove. It belches smoke all the time. **If there were a cheap way for her to upgrade it would benefit the whole community.** My parent had to move from Royston to the city due to air quality issues from wood smoke, which triggered asthma attacks. The days of belching smoke from old stoves should be over.
5. I am aware of the rebates but I am not willing to convert my home heating to another carbon producing source such as heat pump or natural gas. **Why aren't you offering incentives to convert to solar which is a much greener option? I would consider changing over and getting rid of my wood stove if you offered a rebate to go solar!!**
6. Forest fires and agricultural/industrial burning is the problem. NOT residential wood stoves.
7. The compost facility on Knight Road is overpowering. It assaults you when you get off a plane at the airport. Also often makes spending time in our yard unbearable.
8. **Heat pumps are supposed to all that. But they are very expensive, what good is a furnace that switches completely to electric as soon as it gets cold. As well they are totally not reliable, they break down almost on a yearly basis, about the time you really need it. (Yes I did have it serviced in the summer)**
9. I've never once noticed a change in air quality when the advisories come out.
10. Get rid of wood burning
11. We only use wood if there is prolonged power failure. Only twice in the last 10 years. Where we are we get more smell from the dairy farm on Marsden than smoke in the winter. Three or four times per year we will have an out door fire for hot dogs and marshmallows made up of dry hard wood bits from the shop.
12. I would like to see more area's (all in fact) be connected to natural gas. We purchased our home with a top of the line heat pump but if it had not been here we would be burning a lot more wood to stay warm as the cost of electricity is far to high and we don't have natural gas in our neighbourhood, which would be the far less expensive and environmentally sound way to go. **I would love to see the CVRD work with Terresen [FORTIS] to bring natural gas to all its residents.**
13. I wish that there were a bylaw that required either removal or upgrading of old stoves when homes are bought and sold in the valley.

14. We need to get aggressive about removing old inefficient stoves. **I would also love to see more information about what is the best type of energy source for our area. In terms of environmental impact (i.e.: impact of hydro vs. gas vs. efficient wood stoves). We are at a point with our home where we want to make changes but I find myself unable to find good scientific based info on what's the best thing to do.**

15. **Even with the rebate it is thousands to convert!** We switched to electric forced air because wood was impossible to find!!

16. I live in Courtenay in Crown isle where the air is clean cause most people burn gas. However I border on the Comox regional district on Idiens and the rural street next to us has many wood burners who constantly pollute our air some nonstop all winter.

17. I find the [air] quality acceptable

18. Wood providers should be licenced and a level of quality control of their product to be sold - does not matter how high the EPA of the wood appliance is if the wood being burned is not properly seasoned and stored for the burning season. Back yard burning should not be permitted - a yard waste pick up could and should be considered for the rural areas

19. **We got a quote for gas hook-up. It was $40,000!!** It is 2 blocks, maybe, to the hook-up!!!

20. I was shocked by the air quality when I moved here a few years ago. It is so unfair that we can't use our own yard when our neighbour is burning (in their relatively new stove) or can't go for a walk in our neighbourhood once the stoves start up. We've had to buy air purifiers for inside our home, as we often smell smoke. We are worried that our health is being affected and have considered moving. And I have talked to many others that have similar concerns. **Educating people on how to burn better or putting in new stoves (like the one my neighbour already has) just isn't going to make much of a difference.** Burning in a town just impacts way too many people.

21. Air quality in the Comox Valley is terrible in the winter. I am frequently forced to stay indoors as spending time outside results in coughing and a sore throat. Politicians need to do more than providing rebates for wood stove upgrades--it's not working. Air quality is getting worse every year and it is largely caused by wood stoves. This is the issue I will be basing my vote on in the upcoming elections.

22. If electricity were cheaper you wouldn't have as many homes heated with wood.

23. Why do people who choose the cleanest environmental way to heat their home **get charged so much for electric consumption**? The people who heat their home with gas or wood don't often go into the second step of electricity cost, but yet cause the environment the most damage. Those who heat with electricity go into the second step often in winter months. We are getting screwed by the government and B.C. Hydro.

24. As you drive home from work from and you come up the hill on Royston Road you can see the billowing clouds of smoke coming from Cumberland. Soon it will be upon us, again. We look over the Comox bay and all you see is the smoke sitting above the water. We sit in our hot tub for short periods of time because of the smoke filled air. We often are overtaken by the odours of burning garbage and wood that has creosote on it. Local homes are not burning fires correctly. **Wet wood and fires not hot enough**. Good luck on working in the yard on weekends due to back yard burning. Good luck with trying to solve this problem...

25. The worst smoke is from people banking their stoves overnight or over the day time and a **lot of people seem to think it makes sense to burn wet wood.** You can exchange stoves all you want but if people burn wet wood or don't know how to use them properly (modern efficient stoves are not designed for "banking") you won't solve anything. I hope you understand there are only a very few people responsible for the issue. Anyone who lives in west Courtenay and walks around regularly in the daytime could point

out the half dozen or so worst perpetrators. **Until you are willing to deal one on one with people who are the worst offenders you will accomplish nothing.**

26. There are many times when we can not leave the house because of the extremely heavy smoke from people burning in their yards and or heating their homes with inefficient wood burning heating sources. We are considering moving to somewhere with cleaner air. Maybe out of province.
27. We have just moved to the Comox Valley from just outside Hamilton ON, and are shocked by the poor air quality, which is far worse than anything caused by Hamilton's steel mills. We are incredulous that people in an urban environment are still allowed to primarily heat with wood. It is like we are still living in the 19th century.
28. I think some of the poor air quality also comes up the Strait from the Lower Mainland
29. **Would welcome ban on wood burning. Actions taken to date do not appear to have made any noticeable difference.** Wood burning should be banned when temperature inversions are producing air quality issues.
30. Living as we do in Black Creek, poor air quality is usually, but not always, less of an issue as is seen when driving into the downtown Courtenay/Comox area via Hwy 19A, especially during the winter months and more so on a windless or inversion day. Many chimneys along the way producing copious heavy smoke and finally the view of Courtenay from the top of Mission Hill can be pretty alarming as it sits in its thick blanket of smog. **The comfort and affordability of wood heat is understandable but as our density and population grow along with the ever-increasing costs of gas or electric heating, proper education and controls regarding the use of wood burners needs to happen fast!**
31. I am an asthmatic--many days in the winter I cannot walk in my own neighbourhood because of wood burning stoves. Back yard burning is not healthy - **it should be banned 15 km from city limits** -- not from city center. One side of a street can be in the city and they other RD -they should not be able to burn-- but they do. Exchanging one wood stove for another is not the answer. **Help pay for a gas fireplace -- if gas is available in the area or a propane fireplace. Help to pay to install energy efficient electric heat and help to keep the price of electricity down so it is affordable or help pay the bills. Ban all wood burn appliances in all new builds anywhere within 15 km of city limits, and have them removed when a home is sold within city limits. We need to be more proactive. We all need CLEAN AIR!!**
32. Two thoughts: 1. This survey could do well to ask, "do you burn any substance (wood, garbage, other)..." Because someone might answer no to wood, but still be creating a major issue by burning other stuff! 2. **I think garbage burning in Cumberland could potentially be reduced by weekly garbage pick up or an accessible bear-proof dumpster in the village** (i.e., walkable). We don't all have the infrastructure to store garbage inside our homes for up to 13 days at a time, or even compost for up to 6. I can imagine people might feel compelled to burn in these circumstances.
33. How can we get Fortis to expand service in our area? Electric back up for our heat pump can be unreliable in our area, so most folks resort to wood.
34. There should be other options available everywhere in Comox Valley other than any kind of burning, especially opening burning. **Backyard burning and campfire pits should be completely banned and yard pick up should be available.** People state that the smoke sits in the valley because it's the valley, isn't that a good excuse alone to ban or greatly cut back on burning? I lived in Port Hardy for 2 years and the air quality was completely awful so it was disappointing to find Courtenay has issues of its own (especially with no mills or such nearby to pollute the air). I hope City of Courtenay will listen to people's concerns and work hard on making successful changes in this beautiful place.
35. Wood has been used for heating for over a hundred years in this valley. If natural gas were available I would use that instead of wood.

36. **If I didn't have to pay out so much to convert to gas I would in a minute.**
37. **I would like the regional district to set up a registry so that residents can submit their cell number and receive text messages when air quality advisories are issued.**
38. To eliminate them [wood stoves] completely. It is a serious issue.
39. It is a mistake to replace old stoves with new stoves. My health has been impacted since moving here 15 years ago; Asthma, pneumonia, hernia from coughing. I moved here because I am fit and active. I regret moving here for reasons of health. An air filter has eliminated my asthma completely but it is outrageous not to be able to run my hrv or open windows for 6 months of the year. It has been difficult to find a new area locally where attitudes to burning are not archaic but we are leaving Cumberland for an 'out of town' new subdivision with no stoves. This is with regret and considerable inconvenience. If you look at the known effects of smoke on gestating foetuses, on young children and older persons and the levels we are exposed to in residential areas this is not a particularly healthy place to raise a family or get old. **Actually it is a poor place to live for anyone interested in their health.** The sooner people thinking of moving here become aware of health consequences, and the sooner this valley's foul reputation becomes well known and hinders development the sooner something will done about this significant public health issue.
40. **Government reports over the past eight years have shown that the Comox Valley has some of the worst air quality in BC in the winter months and regularly fails to meet provincial and federal air quality objectives. Research shows that wood smoke is extremely harmful to human health. It is time for local government to act.**
41. Local air quality in Cumberland prevents me exercising from October - April, simply walking the dog brings on coughing which affects any exercise I also attempt indoors.
42. I have asthma so wood fire smoke seriously affects me. I have to close all windows and use a high quality air purifier to sleep at night when my neighbours burn wood. Terrible smoke
43. I would love to have a heat pump, but cannot afford one. Even with the rebate, it is so expensive and hydro, even without heating is so high. **(Senior on limited income).**
44. When we moved into our house a wood stove was the primary heating source. Due to concerns about health and maintenance, we removed it and now rely on our 'secondary' heating source - electric baseboards. Gas is not currently available in our neighbourhood and we have been trying to find an economical way to have a heat pump installed, but it is challenging. The wood smoke at times is so thick in our neighbourhood the winter, we can smell it in our house with the windows closed. When you look around, it is typically 4-5 houses that are just pumping the smoke out - to the point where it sometimes looks like the house is on fire. **If wood burning as primary heating including a carbon surcharge - to reflect the 'real' cost of using wood as a heat source - it would not be nearly as appealing a way to heat homes.** The heat pump rebate is a great start, however, it only covers ductless varieties, which as we are finding out are hard to install into small homes. **If there was a rebate that covered ANY head pump conversion that would be more** helpful and accessible to more homeowners.
45. When I moved here 2 years ago from Vancouver I could feel the effect of the poor air quality on my breathing. Very alarming!
46. We intend to switch to a heat pump in the next 2 or 3 years and I support government initiatives to improve air quality. We've changed our burning practices to stop burning during Air Quality Advisories. **We acknowledge it's a serious problem and would like to stop burning, but can't afford to quite yet.**
47. **Ban open burning and non-EPA certified wood stoves, with stiff fines for homes and business in non-compliance.** Explore alternatives to burning for land clearing/agriculture/forestry. The whole region shouldn't have to pay with their health so a small number of businesses and homes can save a few bucks.
48. **Please keep rebates**. Air quality is important. No slash burning for land clearing, insane. Thanks!

49. **In my neighbourhood the worst offender for bad smoke owns a new EPA rated stove. What we need in this valley is not just newer stoves, but better bylaws and enforcement for air quality standards.** I consider smoke from my neighbour to be an extreme nuisance. I literally cannot be outside in my back yard without wearing a mask at times during the winter. The acrid smoke from this new stove is consistently awful from October until April. So for 7 months of the year I am affected by this person's poor burning practices. By anyone's measure, this is not right. Replacing stoves is not the answer. Better bylaws and enforcement against poor burning practices is the most effective means to achieve the goal of clean air in CVRD. The Opacity method is an efficient way to determine how a homeowner is burning their wood, from the opacity of smoke leaving their chimney. This can be done from the street and is easy to document. I feel trapped and hopeless about our local situation. My pleas to our neighbour, to burn dry wood and burn it correctly, fall on deaf ears. **There is nothing I, or many others who suffer the same situation, can do without support from local government. Please, please do something about the air quality in our beautiful valley.**
50. From a view property of the valley, I very seldom can see the effects of wood burning. The air quality monitors being close to the greatest traffic congestion, 17th street Bridge, only increases the air quality concerns. **The valley does have the occasional inversion, which holds smoke, and exhaust in. On these days people should use other sources of heat and drive less.** I do not think that there is an air quality issue in the Comox Valley on normal days.
51. I would like everyone using wood fireplaces to update to the more efficient models but they are not the cause of poor air quality in my area. As a frequent walker, **I am often bothered by vehicle emissions.**
52. I find it difficult to exercise outside or garden in the valley because the smoke affects my breathing- either the wood smoke or backyard burning and sometimes both at the same time. I came to Comox 3 yrs. ago, attracted by the fresh mountain and ocean air and was disappointed to discover the level of air pollution in this otherwise beautiful place. I have a lung disorder that stems from childhood and find the poor air quality negatively impacts my ability to enjoy life here as much as I'd like to. **I may have to leave the valley because of poor air quality.**
53. **I believe that the wood stove burners would use electricity if BC Hydro rates where cheaper.** No one I know is using less than the minimum GJ’s. That is sickening. I would love to know where people can be less than the minimum and not use wood. My condo in Comox was never under the minimum. It faced south - was warmed by the sun all day and surrounded by units on all 4 sides.
54. The only thing I found not on the list is slash pile burning
55. I don't use the wood burner when there's a weather issue (i.e.: depression, high wind, etc.).
56. Please do something about the air quality in this region. I didn’t know it was an issue when my family and I moved to Cumberland and I am considering leaving the valley because of it. It concerns me that this questionnaire is all about “opinions” when in fact there is clear science from which to guide policy changes. Many other communities are managing this issue well, why are we stuck in the dark ages? **Science and progressive public policy please.**
57. I don't feel we should be perusing upgrading people's wood stoves with another wood stove. **We should be encouraging clean heating and a new wood stove is not clean.** Heat pump by far the best followed by gas furnace. Electric baseboards are clean but too expensive to use. **Better rebates for heat pumps and gas furnace and a way to phase out wood. No new wood stove permits would be a start.**
58. **I think that small campfire burns of appropriate material (i.e. clean untreated wood) should be allowed with a proper permit.**
59. Every time there has been an air quality warning, if I look out my window I can see that slash is being burnt on the mountainside. Residential wood stove/backyard burning has almost nothing to do with poor

air quality. I would hate to see new regulations just so the RD can be seen to be doing something when the real problem is in the jurisdiction of the Province. By the way, the **wood I burn in my wood stove comes off of the slash and so has a zero net effect, as it would be burnt anyway on the mountainside.**

60. I would like for people to realize that our country and its citizens have been using wood to heat with since it was founded. The country is covered with forests. There is a lot of deadfall that could be used for home heating and much of that dead fall rots on the forest floors or dries out to provide fodder for forest fires. **To me it makes way more sense to efficiently use this national resource to heat our homes than to let it burn out of control in wildfires and destroy so much,** like the ones that consumed so many hectares of forest last summer. I have lived in and visited many countries around the world, our air quality is excellent compared to all of them, I entertained some German friends this year who told me that Europe is looking at efficient wood burning stoves as one of the best ways to heat a home for the environment. **We have NOTHING to be concerned about in using wood stoves to heat homes.**

61. **Why is solar not on the selection lists for a heating source?** We added solar and would not go back.
62. **Stop people using wood in the city and around the Comox Valley**. Unless they are a long way out of town.
63. I have homes burning wood on both sides of me and one across the street. If my children or I had asthma, I would have to move. The house 2 lots west of me sends a steady stream of wood smoke into the L'Arche Centre. **I've burned wood as a sole heat source for many years and I am not convinced that new certified wood stoves would result in an improvement of air quality.** Burning wet wood with a closed damper will result in heavy smoker regardless of the stove. **Is there research to support the effectiveness of this initiative? I would support paying more tax to support heat pumps and clean methods of heating homes.**
64. The air quality in my neighbourhood is terrible every day in the winter months! I'm really tired of being poisoned by my neighbour's wood smoke.
65. **Stop funding any wood burning appliances and only fund electric or gas heating.** Burning of any wood is harmful to people's health and costs millions of dollars in medication and associated health care costs. **The ONLY reason we kept a wood stove is in case of earthquake in the winter and we lose gas or electricity for a prolonged period.** We NEVER burn any wood for any other reason, as it is not considerate to our neighbours or our community.

66. It's not just the residential wood burning stoves or fireplaces that cause toxic smoke to be breathed, but a lot of homes are also burning their personal garbage producing an ever greater health risk. **I love the warmth of wood heat but its environmental impact is not worth the damage it causes to human health.**

67. Open burning creates awful smoke, but I find it doesn't occur frequently. That said, people should NOT be burning waste, and should take their refuse to the dump! Royston is rural, but our homes are close together around the Laurel Drive / Meredith / Marine Drive area and it's just not appropriate to be open burning with this density. Our house was heated by wood stove until January 2017 when we took possession after purchasing the property. After we moved in - March 2017 - we replaced the old oil furnace with a new gas furnace as the primary heat source. The house inside smelled like campfire - especially in the basement room where the stove was. **We've completed renovated the inside, never use the stove (we have it for emergency preparedness only) and the smell is gone.** Many homes in Royston heat with wood. On the drive to Cumberland up Royston road in winter, you can see thick heavy smoke emanating from a few homes that reduces visibility on the roadway. There were a few evenings where the smoke was mixed with fog and visibility went suddenly to nearly zero. The particulate matter that is emitted from the wood smoke is a concern to me, and the health of my family (and neighbours!). **I understand that a switch to cleaner energy can be expensive, and prohibitive to many. However, I believe that change is needed. Health care costs (publically funded - provincially) will decrease with**

improved air quality, so perhaps the province can help fund the switch to cleaner home heating options. Might save them money in the long run.

68. Since moving to the City of Courtenay (Fitzgerald Ave.) from Vancouver in 2003, the air quality in our neighbourhood has become progressively worse each winter. We have neighbours who have discussed with us that they are converting to wood and pellet stoves to save on Hydro. This winter has been the worst for air quality. Some nights we are unable to keep our bedroom windows open a crack, as the neighbourhood smoke billows into our home. The poor air quality has made it much more difficult to recover from minor colds. It also makes walking our dog around the neighbourhood a very stinky experience as the smoke permeates our clothes and our dogs fur. Breathing while exercising outside is also more difficult. **During foggy days, it impacts visibility to dangerous levels while driving/biking/walking.** One of the reasons our kids no longer attend Courtenay Elem. is because the smoke in the air around the school for days at a time is so heavy. When looking at some of the chimneys in our neighbourhood it is plainly obvious many stoves are not being used properly or they are burning whatever they can, as the smoke is dense and never settles to a low burn. **PLEASE help reverse this situation to healthy levels.**
69. The local air quality during the colder months of the year here in Courtenay is AWFUL due to smoke from residential wood burning stoves. PLEASE make this illegal as it is harming everyone's health!!
70. **I would like to be able to contact someone to complain when the neighbours are burning garbage**!!!!'
71. I'm pleased CVRD is moving ahead in this manner with a survey of home heating usage. **Let's use the information obtained to continue moving ahead with making the air cleaner for all in the Comox Valley!**
72. I am fortunate to live in an area of fairly new homes with no wood stoves so wood smoke is seldom a problem at home. When I visit low lying and older areas sometimes the air is thick with wood smoke and very irritating.
73. Local air quality needs immediate remediation; Smoke from our neighbourhood gets pulled in to our home air through the air intake for our heat pump so we can't even escape the wood smoke indoors! **More information needs to be given to wood burners about the health effects.** At times visibility is reduced to 10ft out our window due to backyard burning by neighbours. Weekly the smoke is bad enough to induce coughing when going outside. Our kids have to come indoors several times a year (where it still smells smoky) because it's so smoky outside.
74. I live on the Courtenay/CVRD boundary yet Fortis quoted $140k to get it close (it would then be another $4-5k to actually get it into the house and useable.
75. I have serious lung issues and have done a lot of research on air quality. I believe ALL smoke is harmful. I also believe exchanging one wood stove for another isn't going to solve our problem. It's like when we were told light cigarettes were less harmful, and the truth was they were just as harmful. I smell smoke Everyday here. If someone is purchasing wood for their stove the average cost is $1200.00 a year. A heat pump cost about $600.00 a year to run. Why can't we have more incentive to exchange wood stoves for a CLEAN way to heat homes and drop the wood stove exchange? So much is being done to clean up our oceans and soil, Why not our air? We all need clean air, PLEASE!!
76. Glad that we do not use our electric baseboard heaters, the heat pumps In Our home, heat it sufficiently.
77. While I have significant concerns about the air quality in the CVRD, I believe that our area on the ocean is not adversely affected. I think the problem is considerably worse in smaller lot subdivisions, and where air is trapped. I think it is crucial for the CVRD to put resources into dealing with this problem. One possibility is to **ban old wood stoves**, **perhaps fine, and require proof of certification.**
78. Air quality seems to be worse in Cumberland than in other parts of Comox Valley

79. Please give us more tools to change from off an outmoded way of heating our homes. Almost no one prefers it but it's still ongoing!
80. I believe education, not regulation, is a far more effective way to ensure we have good air quality in our communities. I also believe we could improve our local air quality if there was perhaps better communication between MoE and MoF when allowing Forestry burns to take place, i.e.; Not allowing multiple burns on low overcast days. Also, giving the general public, better access to pre-burn piles to cut firewood that would then be burned in a much more controlled system (wood stoves), better cured wood and greatly reduced smoke emissions. Banning wood stoves goes against our Human Rights to Life, since fire is what makes us the superior species we are and without it we would not survive. That is a battle you will never win.
81. I am concerned about the poor air quality advisories. It seems that more should be being done about this.
82. **Worst issue in our area is wood burning neighbours who do not burn efficiently or cleanly due to older wood burning units, poor quality or unseasoned wood, damping down air intake to extend burn.** Prevailing wind blows smoke directly into our yard from 3 wood burning neighbours. One member of our household and other neighbours are immunity compromised and I believe the level of wood smoke is hazardous to their health, and is generally hazardous to the entire affected population.
83. **Please move towards phasing out Wood Stove, despite owning one I have ceased using it due to the mediocre air quality of the Comox Valley and the detrimental health effects on our community. I am fortunate enough to be able to afford electric heating but understand that people need financial incentives to be able to transition to other forms of heating.**
84. **Hydro increases should be controlled by gov't**
85. **I don't think we should continue to build homes with wood-burning appliances and I think we should discourage their use in general. On bad air-quality days, I'm not sure wood-burning appliances should be used at all, unless there is no other heat source.** Open burning is a problem as well and not sure it should be permitted at all, there are certainly other options. And there are still many people who don't realize smoke is a health hazard, we need better education/awareness.
86. **Rules for burning must be consistent throughout the CVRD and they must be enforced.** When I ride my bike into the more rural areas there are open fires burning everywhere at all times. This would neither be permitted nor tolerated within the confines of Comox and Courtenay. Yard waste pickup should be provided for all areas of the CVRD if this is not currently the case.
87. **We have stop back yard burning and stop burning wood stoves and fireplaces people leave it smouldering all night and all day when they are at work I wish I knew it was this bad before I moved here**!! I would have never bought in Comox I wish I bought over in Crown isle it's better over there. But I cannot afford to move again!!!!
88. **I moved from Vancouver 3 years ago. I would take wood smoke any day over vehicle emissions and chemical pollution like there is in the city. We moved here so we could find a place to live with a wood stove.** Unfortunately right now we have an oil tank and it is insanely expensive, so a wood stove is a top priority when we buy.
89. I live on 1st St, just up from the Puntledge River, near Arden Rd. Starting in November; you can see the ash falling. Yes, it's that bad. It gathers on cars. It is impossible to keep out of houses. For asthmatics, people with breathing issues, or immune compromised people it is awful. Friends have refused to come and visit when it's particularly bad. The problem is both forestry/agriculture/industry *and* woodstoves. **The woodstoves are made worse by the number of people burning improper wood and garbage. Please do something!**

90. **PLEASE PUT A STOP TO OPEN YARD BURNING! PLEASE! INCLUDING LAND CLEARING! This is a MAJOR problem** especially in the nice spring weather AND IS ALLOWED UNTIL A PROVINCIAL FIRE BAN IS PUT INTO EFFECT! Usually min June! Insane thinking! I'll never understand why it's even still allowed when all other municipalities have a FULL BAN in place. Much of the CVRD is simple basic residential neighbourhoods close to schools and playgrounds. PLEASE GET THIS ONE SORTED OUT IMMEDIATELY! This past weekend has been a potential CANCER HELL AROUND HERE! It is selfish and inconsiderate not to ban this old fashioned practise
91. I have emphysema and if the air quality doesn't improve in the Comox Valley I may have to move somewhere else, because I have to stay in the house most of the time in the winter due to poor air quality. If I even open my door, smoke from the neighbours' woodstoves gets into my house.
92. The dry season in summer when backyard fires are not allowed is the only time of year the air quality in our neighbourhood is good. It's the wood stoves all winter and then on any nice day fall or spring, **the backyard burning starts and spoils our outdoor time. The smoke makes me feel positively ill. Please make it stop!**
93. **We do not support the Wood Stove Exchange Program, as it does not and will not improve AQ in any significant way.** The health risks both short and long-term are well documented and within 3 years of living here I was diagnosed with asthma triggered by wood smoke and know far too many others with respiratory problems that either appear or worsen here. More needs to be done now. **Clearly, wood-burning appliances must not be allowed in populated areas. The CVRD needs to do far more public education and develop specific tactical strategies to help transition homeowners and neighbourhoods and communities from wood burning to gas or electric that will not impact the health of the majority of people who live here.**
94. I'm asthmatic, in our area the air quality in the winter is often so poor I do not go outside for a walk or exercise as it negatively affects my breathing and I'm forced to use a puffer. **Unfortunately it has been my experience that most homeowners who use a wood stove to heat, really do not care about their PM2.5 emissions and the effect it has upon the health of others.** Forest Industry slash burning is another major contributor. Yes there are restrictions on when and how far away they have to be from built up areas, however in the Comox Valley during the cooler/cold months we often have inversions which trap the emissions and they stay for long periods of time. **There are some hard and unpopular decisions that need to be made to safeguard the health of our citizens. 1. Mandatory removal of all wood stoves within 3 years, credits/rebates made to facilitate the transfer to "clean" heating; 2. Penalty for non-compliance after the 3-year deadline; 3. Slash burning to be confined to much more restrictive conditions, i.e. only during certain time frames and weather conditions and further away from built-up areas.** Yes, there will be a large outcry from both the forest industry and the people who burn would and do not want to change. Change is never easy but it is needed. The science backs it up. Let's roll up our sleeves and do the right thing!
95. **There are people in the region (including my neighbourhood) who do not appear to know the best way to store and burn wood in their woodstoves**. This results in excess smoke, which permeates the neighbourhood.
96. My husband has asthma and has great difficulty with the smoke from wood fires. We moved to the Valley thinking the air here would be clean and were shocked to discover when winter came that so many people here are burning wood. It's a huge problem for us and we suspect many other people.
97. **Wood fired pizza ovens and bakeries also impact air quality in my urban area.**
98. Before moving to town this past year, we always heated our home with a woodstove. We never had a problem with smoke problems simply because we only burned dry wood. **We are not against woodstoves,**

but something should be put in place to ensure people use only dry wood and have an up to date woodstove in place

99. I believe that there should be a balance. I have been reducing the amount that I use my stove to better the air quality in my neighbourhood. **I think that burning green wood is one of the biggest issues that the valley faces. If I had a heat pump I would use my wood stove only for special occasions but would want to retain the stove for power outages.**

100.**I think we need to do more to get people to update their wood stoves. I believe they can be very clean source with newer technology out.** I do not believe people have an efficient set up. Having an efficient stove can result in no smoke and clean burn.

101.Home businesses involving burning or smoking materials should not be allowed in residential areas.

102.Eliminated rebates for wood stove to EPA wood stove (they both dump particulates into the air), ban new installation of wood stoves in new homes, create an incentive to decommission wood stoves, incentives for solar panels.

103.**All burning of wood, either inside a home or outside, should be completely banned immediately.** This is a well known health hazard and is costing us both lives and money for treatment. The greater good of the majority should dictate the end of this wood burning legacy. I regard wood burning in the same light as smoking.

104.Winter air quality can be bad. I have a heart condition and it definitely affects me. I would really like to see wood burning for heat in residential areas phased out as quickly as possible.

105.1) Some people have constantly smoky fires. There is a difference between start up smoke and damped down smoky fires. A small fine similar to a parking violation would be good to see against problem smokers. It's the problem smokers that give woodstoves a black eye. 2) We have an outdoor wood boiler, it works amazing. I run a hot fire once or twice a day and the water jacket surrounding the burn chamber soaks up the heat and stores it long after the fire has died out. The hot water is plumbed thru my house and supplies all heat required. A quick check of my chimney showed ZERO carbon build up in the chimney pipe. I smoke for 1-5 minutes on start up, and then the exhaust is clear. There is a fan supplying forced air to the fire for combustion. - **These stoves are brilliant; I would like to see more public education towards this style of stove.**

106.**It is appalling that nothing has been done so far to mitigate the smokiness that is a daily occurrence from at least November to now March 19/18, and still continuing**); I complained about it in 2016, to VIHA, CVRD, and the City of Courtenay, as others have, and it has not changed. **It is obvious that some in our neighbourhood burn wet, green, unseasoned, or treated wood, burn other substances besides wood in their stoves, do not know how to build a proper fire, or all of the above.** It is obvious from the visual smoke and smell in the air that others in the Comox Valley also are ignorant of how they are affecting the health of everyone who lives here, or simply do not care. The rebate program obviously has not worked. Other communities have strict by-laws, which restrict wood stoves and fireplaces, in order to improve air qualities, and enforce those laws. Why don't we? We are even worse off than many of those communities because we live in a Valley!

107. Have you sent a press release to the newspaper to get people to participate? Have you placed ads in the newspaper to do the same? What is the response rate? I can imagine it is extremely low. Will you do a door-to-door study in areas? Will you distribute a flyer with information about the harmful effects of wood smoke, and information on the survey? Wood is a dirty fuel. Wood is a solid mass that releases massive amounts of particulates - and **there is NO KNOW SAFE LEVEL FOR PM2.5 (PARTICULATES 2.5 MICRONS AND SMALLER). There is no justifiable rationale for burning wood in communities. You don't smell toxins coming out of gas furnace chimneys.** I have had three heart incidents since moving to valley.

The first was a heart attack in February 6 years ago the second 2 years ago. Both required expense trips to Victoria for stents. The third was this year and it looks like it will now be bypass surgery. All three occurred in February, at the peak of wood smoke burning, after several months of exposure. The source of the smoke? One neighbour who burns wet wood. The cost to the medical system in the 10s of thousands of dollars. The cost to me in lost work will be months. The neighbour does not care about my health or any of her neighbour's health. She has told me that. This attitude is at the heart of the problem. **If mayors, councillors and staff do not take action to stop wood burning in our communities, each person is endorsing the use of a toxic fuel and responsible for harm to the citizens. You are either in favour of a healthy community with quality breathable air, or you are against having a healthy community who due to your inaction are forced to breathe toxic pollution.** Children from pre-birth to their late teens are especially vulnerable as they are still developing. The impact may take years to show up so politicians and staff may choose to deny the association and not take responsible proactive action. The consequence can be cancer, just as with second hand cigarette smoke. Seniors are also vulnerable. But no one escapes the damage. Research has shown even young healthy adults are affected. I know two people who have had to move because of wood smoke. The cost to them is over $10,000 each just in real estate fees. And still they may not be safe as they are still in the valley. We may also be forced to move. With family here, there are not many options. A woman I know in Crown Isle developed asthma after arriving and tests have shown it is caused only by wood smoke. And this is in Crown Isle where there is no wood burning. The smoke is from outside the Crown Isle development. The worst particulates are the ultra fine ones, below 0.3 microns and **even expensive HEPA filters won't remove the smallest and most dangerous particles. So what are homeowners to do? The particulates will get into the house. Modern houses even are required by building code to have ventilation systems that pull in outside, polluted wood smoke.**

108. In the survey you make no mention about solar heating and no mention of energy saving programs (e.g. energy audits) to lessen harmful emissions.
109. **Ideally if any wood stove exchange program could somehow be mandatory, or if a bylaw were enacted to enforce cleaner wood burning options**, that would help to drag the Comox Valley (probably kicking and screaming) into the 21st century. One can hope!
110. **We burn only DRY wood in a Pacific Energy Super 27, which is 81.6% efficient. I think that it is time to put a 5-year deadline on people burning wood in older inefficient wood stoves. Coupled with that I would 'definitely' make financial 'help' available for any older people who just might not be able to afford upgrading their stove. Basically we need to get rid of the inefficient older wood stoves by making them illegal - if need by doing home inspections. People would change quicker if they couldn't get insurance because their wood stove was not an acceptable heating appliance.**
111. We live on 5 acres. Use a Pacific Energy stove. Highly efficient.
112. **The region should offer significant incentives to switch from woodstoves to cleaner heating sources (e.g., heat pumps). See the incentives on Gabriola Island as an example.**
113. Once a year I'd like to be able to burn my yard waste for one day.
114. I agree that there are too many inefficient wood stoves/fireplaces being used but question whether the incentive program is working. We have personally upgraded to a more energy-efficient boiler in another home, have had a heat pump installed at our current home to replace in-ceiling radiant heat, and yet have never qualified for any rebates. **So it kind of seems like the programme is set up to reward irresponsible people.** Also, survey does not explicitly ask if homeowner's wood burning stove is EPA certified (ours is). Is that based purely on age of unit?
115. Tell me more about the heat pump rebate. I have asthma and dislike the smoke. **Understand lots of strings attached for the rebate program.**

116.The Question re contributors to poor air quality should be a 'choose all that apply' I would list two addition sources of concern: toxic VOC from laundry vents and Forest fires.

117. My partner and I are adversely affected by wood stove smoke in the winter months. It makes it very difficult to be able to have clean air come in a home in the winter time, and we are often affected physically by the wood smoke. **If it were a perfect world, people would know how to properly use wood for heat. Unfortunately due to many circumstances, that is not possible. Hopefully the wood stove exchange program will help towards this. It would be nice if it eliminated the need for wood stoves altogether.**

118. The air quality in this valley is abysmal. I am an active, fit professional in my early 40s and I have to purposefully stay inside on weather inversion days because my lungs have become sensitive to wood smoke over the last 2 years (we moved here 9 years ago). From my house above Goose Spit, I can literally see the pall of smoke over Royston, Cumberland and Courtenay on these days. **We really need the local governments to step up and have some sort of mandatory wood stove upgrade program and not just an incentive.**

119.People need better education/understanding of pressure systems when it comes to backyard burning as well as the types of material that they burn in their backyard burns.

120.**People here are as attached to their right to burn wood as Americans are to the Second Amendment. I have to keep my windows closed basically November thru March--almost half the year. It is too bad that each one believes his burning practices are uniquely flawless.** One of my neighbours swears she has the most state of the art, clean-burning fireplace possible. Yet she has smudge coming out of her chimney all day, and I've seen her firewood--it's wet. It was delivered wet, and it's stored outside under an overhanging porch roof. Not much protection in wind-driven rain. My next door neighbour has his woodpile on the ground, under a tarp--hardly rainproof in this climate. Those new certified wood stoves offered in the rebate program are not that helpful. People who heat with firewood keep a slow burn going at night, so it's not a clean hot burn. And there is no control over what type of material they are burning. I do like the Montreal rules, which is no wood burning in the city, UNLESS there is an emergency power failure in winter.

121.CVRD has different rules for open burning than the City of Courtenay. Since we are within the same air shed, the rules should be standardized.

122.The smell of wood smoke reminds me of my childhood home and campfires. I know now that is a good way to heat being a dry even warming heat when using the correct wood but can be awful and annoying with unseasoned wood. **With the population going up daily in the Comox Valley, we cannot sustain wood heat without hurting the young, weak or elderly.** The valley is like a huge bowl with one side opened to the sea so unless the winds are correct, the smoke stays in the valley as a huge grey cloud. You can see it well when coming down Ryan Road on a bad advisory day or when forest fires are raging on the western side of Canada and the USA. I hate to see it go but it is time like rotary phones and 100-watt light bulbs.

123. Every contributor cited above is a combination for the poor air quality and Comox Valley has the worst quality air in BC. **Every political decision-maker at all level and all the citizen have a responsibility to offer and maintain a better air quality. It's not a choice, it is a civic duty**. **And if some citizen lacks money to convert for a less polluted system, the government in collaboration with BC Hydro, Gas or propane should plan a program to help them. Wood stove, residential backyard burning, outdoor wood fire are not an option it must be banned.**

124.The use of older wood stoves is also a big reason for air quality and owners burning wood and material other than dry seasoned wood...How to ban the use of old wood stoves is the question.

125. Please encourage replacement of wood-burning sources of heat. Toxic smoke should not be allowed to be emitted into the atmosphere, affecting all of us. If encouragement or education is ineffective, ban wood-burning sources of heat, giving a period of time to replace. For the good of the health of all citizens, including those with wood stoves.
126. I am well aware that the burning of wood for home heating has a negative effect on air quality. I think much of the air quality issues in the Comox Valley could be solved by eliminating slash pile burning on privately owned timber lands AND by residents using proper burning techniques (only burning dry, seasoned wood in hot fires). A properly burning fire in almost any wood stove, regardless of its age, will produce almost no smoke. We always burn hot fires that produce little to no smoke. If it's too hot in the house, we open windows. The same technique holds true for backyard burning. A hot fire, properly tended to will not produce much smoke. **Has the CVRD considered providing a wood storage facility where resident could purchase properly seasoned, dry wood to burn?** This would solve many of our community's air quality problems. With natural gas unavailable to many residents, heating with electricity is not a viable financial option for our family and many others. **We have also not considered upgrading our wood stove to a heat pump because the cost is prohibitive even with the available $1000 rebate.**
127. **We burn dry wood and know how to burn it as cleanly as our non-EPA certified woodstove is able. We want to use the Exchange Program rebate to help cover the cost of an EPA certified woodstove.** We can't afford to buy it for at least a year or two. However, hundreds of woodstoves like ours do not decrease the Comox Valley's air quality like the atrocious open air slash burning that forest companies are permitted to do. Most recently, less than a kilometer away from city limits, with the wind blowing it right through the Village...When this burning occurs and I have a cold, I develop asthma and I am forced to use an inhaler.
128. I take issue with the way 2 of your questions are worded above: 1)"Do you believe that wood smoke affects peoples' health?" It's not a matter of what I believe. **This is not a subjective matter. There is science & health studies backing up the facts that particulates from burning wood are hazardous for our lung health.** 2) "What do you think is the biggest contributor....”? Again it's not what we subjectively think. With proper testing it could be proven which are the biggest contributors.... there’s probably a few and put together they are big contributors. I advise that you word your surveys more carefully.
129. Nothing you can do about forest fire smoke. Definitely incentivizing people to alternate heat sources other than wood is the way to go, but should probably be organized as a larger package since a full switch would require renovations rather than just the purchase of an alternative heat source. Perhaps the province/fed might have additional rebates or tax exemptions that align with this program that could be packaged together and showcased over the next 3-5 years. Perhaps a 0.1% (random number) municipal tax break could be offered to those making the "greener" choice as well. Just ideas :) Thanks!
130. We don't have a wood stove. My neighbours do, and the air stinks all winter long. If I open the window the smoke smells come in. My son got asthma a few years ago and I am confident it is linked to the appalling air quality created by my neighbours' smoky woodstoves. I don't know if there is any enforced cleaning schedule? I am actually selling my house this year, and I will be moving to an area without wood stoves.
131. We traded our wood stove for a new gas fireplace at the end of last year, but unfortunately we were not eligible for the rebate because our stove was too new. It would be nice to offer people a rebate for exchanging even newer stoves with a cleaner source.
132. Considerations should be given to inversions, dryness of firewood, and physical location, e.g. .a low-lying valley area.

133. **We upgraded from an inefficient open fireplace to a catalytic wood insert 2 years ago and were told the rebate didn't apply to us. I think the rebate should apply to anyone upgrading from an inefficient wood burner to a more efficient stove.**
134. **I am tired of living in an area with such poor air quality in the winter. IT IS UNHEALTHY!! And I am tired of people being allowed to burn wood for their own comfort - and what I see in my neighbourhood is NOT from necessity - while many of us suffer discomfort and health problems. That is crazy. Part of the culture here of entitlement - like water - and nature - there for our use - and abuse. Please step up to the plate and do what is necessary to help protect the health of all of us actually.**
135. Re: local air quality. **A major contributing factor that significantly affects air quality in my neighbourhood comes from lead paint** that neighbours sand from old doors, windows, trailers, etc. using power equipment. This creates dust with lead and other toxic chemicals in it. I have approached a neighbour and requested that the sanding be done in such a way as to prevent its spread throughout the neighbourhood- (request ignored). The dust is being inhaled by adjacent neighbours and children and others walking by. Also it settles in the soil and is absorbed by plants e.g. vegetables. I would like to see stricter bylaws and penalties pertaining to sanding lead containing paints (and other toxic chemicals) put in place. Regarding wood smoke. Perhaps some kind of regulations requiring WETT certification occasionally**. Even though my stove is an older model, it is high efficiency and was WETT certified a couple of years ago. Another idea might be to have mandatory information sessions on how to properly burn firewood to reduce the amount of smoke produced. I burn my fires very hot and produce very little smoke.** Perhaps require a permit to use a woodstove, dependent on having attended the session AND having WETT certification. The open burning from land clearing and agriculture or forestry activity creates much more smoke and resultant pollutants in the valley than woodstoves and should be banned. If the wood that was being burned were made available for woodstove burning, there would be much less total smoke produced (as it would be seasoned first and burned in a much more efficient manner). It is difficult to decide what type of fuel to use for heating as they all create problems for the environment. All the new natural gas demands on Vancouver Island come from fracked gas, which pollutes ground water and contributes to earthquake damage. BC's newest source of electricity (Site C dam) comes at a huge cost to the environment with the flooding of prime agricultural land. Wood stoves could arguably contribute the least to environmental damage IF managed properly. David Suzuki uses woodstoves to heat his home and I imagine that he has done a lot of research in this area. Thank you for the opportunity to participate in this survey.
136. Ban open burning!
137. **I wish more people would use a temp meter on their wood stove so they would burn hotter fires with less smoke and creosote. You should advertise this as a good option to reduce smudge fires, which produce the worst toxic smoke.** Maybe the new stoves should not be able to shut down all the way so they can't burn so low producing so much smoke.
138. I have immune issues and got infections and health issues from the wildfires last summer.
139. **I moved from Noel ace to get away from wood smoke, I had cancer and my neighbour burner beachside. Now I'm by the old hospital and the air coming out of there is toxic.**
140. On 9 acres so not affected by smoke
141. Air quality really needs to be improved with significant rewards for going away from wood heating. More regulations needed for open burning and forestry and industrial, "farming" burning.... More places needed to be set up for detecting air quality around more areas! More publishing of results...
142. Ban wood stoves -- every other heat source is regulated and users pay taxes, including carbon taxes, on those sources. Wood stoves are unregulated and one of the very few things in residences that are not

regulated -- we have bylaws regarding pets, noise, lawn care, garbage disposal, occupancy, water and electricity usage. But individuals can burn wood without any regulation, without concern to their neighbours, or to polluting the environment. If you can regulate and monitor everything we do, then something can be done to eliminate wood smoke.

143. We moved here from the lower mainland 6 months ago; It was a decision that wasn't taken lightly due to the knowledge of the air quality issue. I hope we haven't made the wrong decision........... **Other "valleys" have improved their air quality issue, there should be NO reason for Comox valley to not clean up their act. Worse air quality IN THE COUNTRY in this day and age is ridiculous and MUST be taken seriously.** Your local mayor and council seem to have their hands in the sand. I'm not eager to get asthma or worse in my retirement years because the powers that be don't seem to give a damn about their community. **Make a total ban on in home burning, back yard burning (implement better recycling and composting plans).** Lumber company burning should be mandated for outlying areas only on a very strict minimal basis. Just because we live in a VALLEY, doesn't mean we have to choke. I moved to Comox Valley 3 years ago for the weather, scenery, outdoor life etc. only to find that the air here is polluted for half the year beyond anything I have ever seen in any other location in Canada. As a retired Medical Doctor I am dumbfounded that these conditions have been allowed to continue in the face of the well known health risks that residents are being subjected to, in particular children and the elderly. The Comox Valley is (I believe) relying to an increasing degree economically on retirees coming and living here. However if the word gets out that people may want to think twice about air conditions here with respect their health the trend may be negatively impacted. I certainly would not recommend it to any of my previous patients with respiratory or heart problems. We need to get into the 21st century and deal decisively with this problem. **Half measures like switching to high efficiency wood stoves, which still pollute are not good enough. Subsidization to switch heating sources should be aimed at electricity, natural gas, or oil heating not wood heating. I believe people should be given a 5 yr. period in which to switch to one of these alternative heating sources, subsidize them if need and they continue to burn wood after that they should then be fined.** The excuse that people continue to burn wood because it is cheaper in no way gives them the right to continue to pollute the air and cause unnecessary health problems for citizens of the Comox Valley We no longer heat with coal, insulate with asbestos and tolerate smoking in public places, **We have strict antipollution requirements for our vehicles and have taken lead out of gasoline and we should no longer tolerate this unnecessary air pollution with its health risks. The elected officials in the Comox Valley need to have the fortitude to deal with this head on and protect the health of their citizens, as is their duty**
144. I think both residential wood burning as well as backyard burning and open burning (land clearing etc.) are all a factor in the poor air quality that we sometimes have in the Comox Valley. There is a nearby home that burns wood for heat all through the winter and it really is noticeable, plus all the other homes burning plus the outdoor burning. . We had a wood stove in our home and we removed it shortly after we bought the house. We replaced it with a ductless heat pump and updated our older electric baseboard heaters for more efficient supplemental heat when we need it.
145. We have our beautiful home up for sale, because we are developing allergies to the constant back yard burning, wood stove burning and also burning from a shed where a home-based business is operating. We have made enemies by politely complaining about the smoke that our neighbours create from the above.
146. **3 neighbours burn green, wet wood in brand new stoves and always damp down the stove to save wood causing constant toxic smoke.**
147. This is serious. We have several friends who are seriously affected by the poor air quality, particularly in winter.

148. Wood stoves should be banned in the City NOW because it affects so many people. Bylaws regarding noxious fumes and burning wet wood are not enforced at all. People (even with brand new wood stoves) burn wet wood and damp down the stove (to save wood) causing constant billows of toxic smoke affecting every one else.
149. Carbon Tax on wood stove use...
150. If they can give rebates to people to STILL keep burning wood (and it won't make much difference, because the new 'state of the art' fireplaces still belch out smoke) I wish they could match that with home air filters for the rest of us who are suffering.
151. The local air quality is terrible in the winter, and something really needs to be done about it. Ways to tackle this could be: **- Don't let wood stoves/fireplaces be put into new builds/developments. - More public awareness of when air quality advisories are in place -More public awareness of the negative health effects of wood smoke**. - This article offers some sound advice: http://breathecleanair.ca/was-2-5-million-on-wood-stove-exchange-worth-it/
152. Stop funding the purchase of new wood stoves. If the owner burns wet wood or finished wood, the problem remains. Please ban all back yard burning in the CVRD. All burning causes health problems and just one person can ruin the day for a whole neighbourhood.
153. Since pour air quality is well known, why is open burning still allowed? And maybe the rebates should be higher and concentrate more on replacing wood furnaces with gas heat, not wood stoves.
154. It is my opinion that residential outdoor burning of garden refuse should be banned in the Comox Valley.

ATTACHMENT 4

Monitoring Residential Woodsmoke in British Columbia Communities

by

Matthew Wagstaff

B.Sc., The University of British Columbia, 2014

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE AND POSTDOCTORAL STUDIES

(Occupational and Environmental Hygiene)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

August 2018

The following individuals certify that they have read, and recommend to the Faculty of Graduate and Postdoctoral Studies for acceptance, a thesis/dissertation entitled:

Monitoring Residential Woodsmoke in British Columbia Communities

submitted by	Matthew Wagstaff in partial fulfillment of the requirements for
the degree of	Master of Science
in	Occupational and Environmental Hygiene

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Abstract

Wood burning is a common home heating method in many communities in British Columbia and an important source of fine particulate matter ($PM_{2.5}$) air pollution. During winter months communities impacted by residential woodsmoke experience high concentrations of $PM_{2.5}$, at levels that have been associated with a wide range of health effects. Characterising levels of woodsmoke within and between communities can support air quality management and reduction of exposures.

This project tested novel methods to measure the relative levels and spatial variability of residential woodsmoke $PM_{2.5}$ using fixed and mobile optical instruments. The methods were applied during the winter heating season (January 5th to March 2nd, 2017) across three communities identified to be impacted by residential woodsmoke from fixed-site monitoring data, and three paired communities without routine monitoring.

Continuous monitoring was performed for two weeks at fixed monitoring stations in each monitored community to compare the optical instruments with established methods used to measure $PM_{2.5}$ and woodsmoke. This was combined with nightly mobile monitoring using the same optical instruments, alternating between driving routes around the paired monitored and unmonitored communities to create detailed maps describing woodsmoke levels and variability.

The nephelometer (B_{sp}) and aethalometer (*delta C*) tested at the fixed-site were strongly correlated with conventional methods of measuring $PM_{2.5}$ (beta attenuation monitor and filter-based) and woodsmoke (levoglucosan). Comparisons between the instruments during mobile monitoring clearly identified times and areas where woodsmoke was dominating $PM_{2.5}$ concentrations.

Mobile monitoring indicated considerable spatial variation across all communities and identified hotspot areas with consistently elevated concentrations of both $PM_{2.5}$ and woodsmoke. The spatial variance of $PM_{2.5}$ concentrations was significantly greater than the temporal variance during 71% of the runs, demonstrating the importance of understanding

spatial variability when monitoring the air quality impacts of woodsmoke. Strong woodsmoke impacts were found in each community. In general, the unmonitored communities had $PM_{2.5}$ concentrations that were similar to or higher than their partnered monitored communities, despite having smaller sizes and populations.

The development of this approach allows for detailed and cost-effective characterisation of woodsmoke in monitored and unmonitored communities, which could inform source control efforts in many Canadian communities.

Lay Summary

Wood burning is used to heat many homes in British Columbia (BC). However, residential wood burning can degrade community air quality, and cause negative health effects. This project tested a mobile monitoring method to map air quality around BC communities, and to understand the contributions of residential woodsmoke. Testing was conducted between January and March 2017 in three pairs of communities on the coast, in the mountains, and in the northern interior. The instruments used in the mobile monitoring compared well to conventional methods for measuring woodsmoke, while mobile measurements identified specific times and areas within each community where woodsmoke caused degraded air quality. The maps showed clear variation in the air quality within each community, including smoke hotspots. This mobile monitoring method will allow for detailed and cost-effective understanding of woodsmoke in communities concerned about the air quality impacts of residential wood burning.

Preface

The testing of the mobile monitoring method using both a nephelometer and aethalometer, along with temporal comparison of these instruments with filter-based measurements of $PM_{2.5}$ and levoglucosan concentrations at BC Ministry of Environment and Climate Change Strategy (ENV) monitoring stations was originally proposed to me by my supervisors and collaborators. However, I contributed to writing a proposal which led to project funding from the Clean Air Research Agenda at Health Canada. Details of the study such as locations and timelines of the fixed monitoring campaign, along with the specific methods used in mobile monitoring were planned and decided upon by myself and my co-supervisors Drs. Michael Brauer and Sarah Henderson.

Field data collection was almost exclusively carried out by myself, apart from some support from ENV technicians in accessing the monitoring stations in each of the three locations and the initial placing of the fixed site equipment. I was fully responsible for instrument preparation and calibration prior to field monitoring in each region, daily filter changes and instrument checks at the monitoring stations, and I performed all mobile monitoring alone. Data collected by ENV monitors at these stations were also accessed and used in this study.

Gravimetric filters collected in the field campaign were analysed for $PM_{2.5}$ and levoglucosan concentrations at the UBC Occupational and Environmental Hygiene lab by its manager, Matty Jeronimo. All further data analysis was conducted by myself, with specific decisions on analysis supported by my supervisors.

Results of this research have been made public in community-specific reports and will be published in the peer-reviewed literature in the future.

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List of Abbreviations

BAM = Beta attenuation monitor

BC = British Columbia

B_{sp} = Particle light scattering (measurement reported by a nephelometer)

°C = Degrees Celsius, measure of temperature

CARA = Clean Air Research Agenda at Health Canada

CCD = Courtenay and Cumberland monitoring route

CCX = Courtenay and Comox monitoring route

CSA = Canadian Standards Agency

ENV = The British Columbia Ministry of Environment and Climate Change Strategy

EPA = United States Environmental Protection Agency

Mm^{-1} = Inverse mega-meters, reporting units of B_{sp}

m/s = Metres per second, measure of wind speed

PM = Particulate matter

$PM_{2.5}$ = Fine particulate matter (particulate matter with an aerodynamic diameter of less than 2.5 microns)

R^2 = Coefficient of determination

SD = Arithmetic standard deviation

UBC = The University of British Columbia

Z = Mean z-score

μg/m^3 = Micrograms per cubic meter, measure of concentration

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I would like to first thank my co-supervisors Dr. Michael Brauer (UBC) and Dr. Sarah Henderson (UBC and the BCCDC) and express my sincere gratitude for their support and guidance throughout this project; I could not have asked for better supervisors.

In addition to my supervisors, I would also like to express my thanks to the following people:

- My committee member Arvind Saraswat (ENV).
- The main collaborators on the CARA funded project: Nina Dobbin (Health Canada), Natalie Suzuki (ENV), and Dr. Scott Weichenthal (McGill).
- The UBC Occupational and Environmental Hygiene Lab Manager Matty Jeronimo for lab analysis, support and instrument troubleshooting.
- The BC Ministry of Environment staff in each region for the invaluable support I received during my field work: Chris Marsh, Graham Veale, Lorne Nicklason, Earle Plain, Lee Loran, Ben Weinstein and Gail Roth.
- Community members in each region who provided feedback on monitoring routes.
- Members of the Brauer/Henderson lab group for troubleshooting support.
- Kathleen McLean (BCCDC) for developing an automated app that will allow future users of this mobile method to easily map their data.

Finally, and most importantly I would like to thank both my parents for their never-ending support, and especially Dallas who I would not have been able to complete this project without! From digging through snowbanks to help set up the equipment in Whistler, right through to reading this thesis for clarity, she was there every step of the way.

Chapter 1: Introduction

1.1 Residential Woodsmoke in British Columbia

Approximately 10% of British Columbia (BC) homes outside of the Metro Vancouver area use wood as their primary source of fuel during the heating season, with a further 20% burning wood in the home at least some of the time (1). Wood is plentiful and inexpensive in many parts of the province, which makes it an attractive heating option when compared with alternatives such as natural gas, electricity, or heating oil. However, air emissions from burning wood are much higher and more variable than emissions from other types of fuels. Woodsmoke is a complex mixture of gases and particles, the specific composition of which depends on multiple factors including the wood species, its water content, and the combustion temperature (2). From a human health perspective, the most important products of incomplete combustion are fine particulate matter ($PM_{2.5}$), oxygenated organics (e.g. aldehydes), hydrocarbons (e.g. polycyclic aromatic hydrocarbons), and carbon monoxide (3).

There are three main types of wood burning appliances used for residential heating in BC: indoor stoves; indoor fireplaces; and outdoor boilers. Each type has a range of emission profiles depending on its design and the behaviour of its users. A BC Ministry of Environment and Climate Change Strategy (ENV) report from 2012 on the use of wood burning appliances in the province found that woodstoves were most common (58% of users), followed by open fireplaces (42% of users), which typically generate more smoke than burning in a closed stove (1,4). By regulation, smoke emissions from modern stoves are lower than emissions from older stoves when the newer technology is correctly used (5). However, comparisons of emissions between modern and older stoves have been mixed during indoor air quality studies because other factors affect the smoke emitted into the indoor environment, such as the user behaviour and fuel properties (6,7). The ENV has been operating a woodstove changeout program over the past decade to encourage the use of cleaner burning technology, and a recent provincial survey found that 40% of respondents using fireplaces and 71% of respondents using wood stoves were aware that their appliances were certified as low emissions (1). While not explicitly stated, the certification of these appliances is likely based on the standards set by the Canadian Standards Association (CSA) or the US Environmental Protection Agency (EPA) before 1994. The provincial 1994 Solid Fuel Burning Domestic Appliance Regulation prevented the sale or re-sale of any appliances that did not meet these standards after November 1, 1994 (8). This regulation was updated in November 2016, to improve the standards so that nearly all wood burning appliances sold in BC must now be certified to meet either the new lower emissions standards set by the EPA in 2015, or the equivalent standards set by the CSA in 2010, which represent a 40% reduction to the standards set in 1992 (9). The updated regulation also specifies what fuels may be burnt in wood burning appliances and contains provisions regarding the sale and installation of outdoor wood boilers. These regulations only apply to the sale of new appliances; existing wood stoves and fireplaces are not affected.

Further regulation of wood burning appliance use falls to individual municipal governments, where the scope and strength of regulations can vary considerably from very limited, to more involved regulation. One example of municipal regulations is the *City of Duncan's Wood Burning Appliances and Air Quality Bylaw No.3089, 2013* which requires the removal of all existing non-certified woodburning appliances during the transfer of any property, restricts the use of all wood burning appliances when a provincial Air Quality Advisory is in effect (with the exception of homes with no alternative heating method) and requires new constructions with wood burning appliances to also install a secondary space heating method (10).

1.2 **Ambient Air Quality Impacts**

Woodsmoke is complex, but its impacts on ambient air quality are typically seen in routine monitoring of $PM_{2.5}$ concentrations during the heating season. Although $PM_{2.5}$ measurements reflect contributions from all sources, the impacts of woodsmoke are made evident by a diurnal pattern with higher concentrations in the mornings and evenings when residents are more likely to be at home and when the atmospheric mixing height is reduced (11,12). Residential woodsmoke can lead to episodes of severely degraded air quality, especially in valleys where nighttime temperature inversions are common and woodsmoke can be trapped (13). Estimates suggest that smoke from residential wood burning is the second largest anthropogenic contributor to $PM_{2.5}$ emissions in BC following road dust, contributing approximately 15% of total emissions and exceeding emissions from all transportation and industry sectors (14). Smaller, more rural communities are more affected than the larger urban areas (1). As a result of residential woodsmoke, several communities in BC fail to meet the annual $PM_{2.5}$ air quality objective of 8 $\mu g/m^3$ set by the provincial government (15).

The location of residential woodsmoke emissions is an important consideration with respect to community exposures. Residential woodsmoke is emitted from many small point sources directly within communities where people spend the majority of their time. The distribution and relative size of the point sources across a community combined with topographical features and meteorological conditions can lead to high spatial variability across small areas. These factors can create hotspots where $PM_{2.5}$ concentrations are elevated above background levels. Previous mobile monitoring campaigns in northern and coastal BC have measured and mapped this spatial variability across many communities (16–19).

Despite being an important source of $PM_{2.5}$ in BC, residential woodsmoke is relatively under-regulated compared with mobile and industrial emissions. While evidence such as emissions inventories and temporal patterns in air quality monitoring data suggests that woodsmoke degrades air quality in many areas during the winter, municipalities that hold the power to pass new or stricter regulations are often hesitant to take further action without empirical evidence that smoke is affecting local air quality (20).

1.3 **Health Impacts**

Exposure to ambient $PM_{2.5}$ has been associated with a wide range of acute and chronic health outcomes, particularly cardiovascular and respiratory morbidity and mortality (21,22). Globally, an estimated 3.2 million deaths can be attributed to ambient $PM_{2.5}$ exposures, of which 2.1 million would be avoided if the World Health Organisation guideline for annual average $PM_{2.5}$ of 10 $\mu g/m^3$ was met worldwide (23). There is currently no evidence for a threshold level below which no adverse health effects occur; even at relatively low concentrations $PM_{2.5}$ pollution has a significant burden on health (24). Therefore, regions that have relatively clean air can still benefit when $PM_{2.5}$ emissions are further reduced (23).

Although much of the evidence on the health effects of $PM_{2.5}$ exposure comes from urban environments where industrial and mobile sources may dominate, there is a growing body of literature specific to woodsmoke. The most comprehensive review of available literature concluded that woodsmoke $PM_{2.5}$ appears to have acute and chronic health effects that are similar to $PM_{2.5}$ from other combustion sources (3). Evidence for the respiratory outcomes has been stronger and more consistent than evidence for the cardiovascular outcomes, but the most recent review highlighted multiple studies that show improvements in cardiovascular indicators when woodsmoke exposure was reduced (25).

A more targeted review of the physiochemical properties of woodsmoke $PM_{2.5}$ from residential wood burning has also been conducted. It considers how the particles change under various combustion conditions and over time, and the potential significance of the observed changes in terms of health effects (26). The review concluded that particles produced during inefficient combustion (typical of fireplaces and older wood stoves) have a larger organic component and likely have higher lung deposition efficiencies. Particles produced during efficient combustion (typical of the more advanced wood and pellet stoves) tend to be dominated by the inorganic component, which deposits less efficiently in the respiratory tract due to rapid coagulation of the particles. However, the high water solubility of the inorganic fraction may play an important role in biological effects at the cellular level (26). Recent research has also shown that the lung toxicity and mutagenic potency of $PM_{2.5}$ created by wood burning varies with different wood species and in different combustion conditions (27).

In addition to the health effects observed in the general population, studies have suggested that some groups may be more susceptible to the effects of ambient $PM_{2.5}$ exposure (22). Individuals suffering from pre-existing conditions such as diabetes and chronic respiratory or cardiovascular diseases are more susceptible (28), while the elderly are at higher risk of hospitalisation and death. Children also face higher risk because their respiratory systems are developing and they breathe more air relative to their body weight (22). These populations are also likely to spend the majority of their time within a community, potentially in close proximity to emission sources, and where hotspots of elevated $PM_{2.5}$ concentrations may be present.

1.4 Limitations of Existing Monitoring

Regulatory air quality monitoring networks, such as the BC network operated across the province by ENV and Metro Vancouver, collect valuable data, but have two major limitations with respect to monitoring residential woodsmoke:

1. They cannot provide source-specific information
2. They cannot provide spatially resolved information

The instruments installed for regulatory assessment of air quality are chosen to monitor the criteria air pollutants (such as $PM_{2.5}$), but no source-specific information is collected. Therefore, the data from these networks can identify communities that have relatively high $PM_{2.5}$ concentrations, but they cannot provide direct information on which sources are responsible for the higher concentrations. Routinely measured $PM_{2.5}$ cannot be used in isolation to accurately characterise the air quality impacts of residential woodsmoke. Because combined contributions from all sources are measured, more source-specific information is needed to understand the independent impacts of woodsmoke in affected communities. To date there is no systematic best practice for conducting woodsmoke monitoring in Canadian communities with or without regulatory $PM_{2.5}$ stations, though many elements of such a system have been tested within the BC context.

The second limitation is spatial resolution on both regional and local scales. From an economic standpoint, the number of fixed monitoring stations that can be installed and maintained is limited. On a regional scale, this means that larger communities are prioritised, and smaller communities have limited or no data. On a local scale, this means that most monitored communities (excluding large cities) have a single monitoring station installed at a location that is chosen to be approximately representative of the average air quality.

This lack of spatial resolution is especially important in the case of residential woodsmoke. On the regional scale, smaller and more rural communities generally have higher rates of residential wood burning (due to a lack of alternative heating options), which may result in higher $PM_{2.5}$ concentrations; however, there is no means to quantify this impact without available monitoring data. On a local scale, residential woodsmoke is emitted from many small point sources across a community. The distribution and relative size of these point sources (due to type and quality of wood burning appliance, burning habits etc.) combined with topographical features and meteorological conditions can lead to high spatial variability and dramatically different air quality, even across small areas. Because a single monitoring station will only collect data at a single point within the airshed, it can only provide a small piece of the picture in terms of the air quality experienced across an entire community. If the purpose of the station is to be representative of the community and capture the average exposure, the location may be biased high or low. Even if the location of the station is representative of average conditions across the community, the station will not be capturing certain areas which may have much higher exposures, and we will not have an accurate picture of the true exposures that the entire population experience.

1.5 Measurement Strategies for Residential Woodsmoke

Ambient $PM_{2.5}$ is composed of particles from multiple sources, making it challenging to estimate the contribution from woodsmoke alone. Five approaches to this challenge are described below.

1.5.1 Surveys and Emissions Inventories

Emissions inventories and surveys are commonly conducted by various levels of government to estimate total emissions of air pollutants and the contributions of various sources. This information can be used to understand the importance of different pollutant sources and prioritise areas for improvement. For example the 2016 Canadian Air Pollutant Emissions

Inventory estimated that approximately 15% of total $PM_{2.5}$ emissions in BC were created by residential wood burning, ranking ahead of all anthropogenic sources except road dust (14).

1.5.2 Studying Temporal Patterns

Identifying temporal patterns in routine air quality monitoring data that are indicative of residential wood burning is a novel approach proposed by Hong et al (20). An algorithm was developed to retrospectively classify days as smoke-impacted using hourly $PM_{2.5}$ and daily temperature data. Three parameters were established for the algorithm: sufficient variability in daily 1-hour $PM_{2.5}$ concentrations; daily temperatures cold enough to require home heating; and a low ratio of daytime to nighttime mean $PM_{2.5}$ concentrations, which is indicative of the higher usage of woodstoves during the evening and early morning hours due to colder temperatures and more residents being at home. Values were established for each of these parameters using data from known smoke-impacted days in Courtenay, BC identified using levoglucosan measurements from another study (29). This method was then applied to rank 23 communities in BC by their annual number of smoke-impacted days, and three of the top-ranked communities were chosen as the target monitored communities for this thesis.

1.5.3 Source Apportionment Using Tracer Compounds

Chemical tracers are useful tools to identify and quantify the contribution of specific pollutants. The tracer most commonly used to identify woodsmoke is levoglucosan (1, 6-anhydro-b-D-glucopyranose). This compound is specific to the source because it only forms during the combustion of cellulose, which occurs at temperatures greater than 300°C (30). It is also one of the most abundantly produced organic compounds in woodsmoke (4) and is stable when emitted (31). However, levoglucosan is not a perfect tracer because the emissions can vary with fuel type (wood species) and combustion efficiency (4).

1.5.4 Source Apportionment Using Optical Properties

The optical properties of woodsmoke can also be used to differentiate it from $PM_{2.5}$ generated by other sources. Studies comparing $PM_{2.5}$ from woodsmoke with that from vehicle exhaust suggest that woodsmoke PM absorbs more light in the UV and blue wavelengths whereas vehicle exhaust absorbs light from UV through infrared (32,33). Using these differences in absorbance, dual- or multi-wavelength aethalometers can be used to help distinguish woodsmoke $PM_{2.5}$ from other sources (13).

The difference between absorption of light at 370 nm (known as UVC because it measures ultraviolet absorption) and 880 nm (known as BC because it measures absorption by black carbon) wavelengths is known as *delta C* and is used as a woodsmoke indicator. This difference is specific to biomass combustion because the organic aerosol components of woodsmoke absorb more light at 370 nm relative to 880 nm, which does not happen with $PM_{2.5}$ generated by other sources (34,35). *Delta C* is also strongly correlated with levoglucosan concentrations in ambient $PM_{2.5}$ (36). Using a dual- or multi-channel aethalometer in this way is more cost-effective and simpler than monitoring chemical tracers, and can provide much greater temporal and spatial resolution.

1.5.5 Measuring Spatial Patterns

Residential woodsmoke emissions can have high spatial variability across BC communities because it is emitted from many small point sources that are unevenly distributed across the community. Spatial patterns can therefore be useful when evaluating the contribution of residential woodsmoke to overall $PM_{2.5}$. For example, consistently elevated $PM_{2.5}$ concentrations in residential areas are likely created by residential wood burning. Several studies have employed mobile monitoring as a method for mapping woodsmoke hotspots in both rural and urban environments (16,17,19,37), and some have also evaluated the utility of multi-wavelength aethalometers for this purpose (13). Mobile monitoring is a relatively economical and flexible method for measuring particle concentrations at high spatial resolution across various terrains, land use areas, and pollutant gradients.

1.6 Project Overview

This project was designed to develop a new, cost-effective method that can be used to address the two identified limitations of existing air quality monitoring networks with respect to residential woodsmoke: (1) they cannot provide source-specific information and (2) they cannot provide spatially resolved information. This method combines mobile monitoring with a nephelometer to address the lack of spatial resolution and a multi-wavelength aethalometer to address the lack of source-specific information. The method was tested by applying it across three communities with monitoring stations known to be impacted by residential woodsmoke (referred to as the “monitored communities” throughout this thesis), and three nearby unmonitored communities (referred to as the “unmonitored communities” throughout this thesis).

To evaluate the effectiveness of these instruments and assess the contribution of residential woodsmoke to $PM_{2.5}$ concentrations in the three monitored communities, the testing of the mobile method was combined with additional monitoring at the fixed site monitoring stations. The two types of optical instruments were temporarily installed and levoglucosan samples were collected to compare results with the regulatory data from the beta attenuation monitors (BAM) operated by ENV.

1.6.1 Project Objectives

The primary objective of this thesis was to develop a systematic and cost-effective method for assessing woodsmoke in both monitored and unmonitored communities across Canada. This required comparison of methods for measuring total $PM_{2.5}$ with methods for establishing the woodsmoke contribution to total $PM_{2.5}$. It also required testing the approach in both monitored and unmonitored communities. This was important because the method could be a valuable tool to characterise woodsmoke impacts across the many smaller Canadian communities that currently have no permanent air quality monitoring.

The secondary objective of this thesis was to collect total $PM_{2.5}$ and woodsmoke contribution data in six specific BC communities, of which three were monitored and three were unmonitored. Mobile monitoring was conducted to estimate both total $PM_{2.5}$ and woodsmoke concentrations across each community with high spatial resolution to create detailed air quality maps. These maps were then used to estimate the contribution of woodsmoke to $PM_{2.5}$ patterns, identify hotspot neighbourhoods, and assess the representativeness of available monitoring station locations.

1.6.2 Research Questions

A series of research questions was used to support each of the two objectives:

Method development questions:

1. Can a single-channel nephelometer be used to estimate total $PM_{2.5}$ concentrations?
2. Can a dual-channel aethalometer be used to estimate woodsmoke concentrations?
3. Can the two optical instruments be used together to estimate woodsmoke contribution to $PM_{2.5}$ concentrations?
4. What information can mobile monitoring add to the understanding of woodsmoke in communities?
5. Is there value in using an aethalometer in addition to a nephelometer during mobile monitoring?

Community-specific questions:

1. What did we learn about woodsmoke in the monitored communities?
2. What did we learn about woodsmoke in the unmonitored communities?
3. What did we learn about the spatial patterns across each community?

Chapter 2: Methods

2.1 Site Selection

Three communities with ENV monitoring stations known to be impacted by residential woodsmoke were identified and each paired with a nearby, unmonitored community. Previous work conducted by Hong et al. had ranked 23 BC communities by the number of days identified as woodsmoke-impacted, with Houston, Courtenay, Port Alberni, Vanderhoof, and Whistler ranked as the most affected (20). From these five communities, three were selected from different regions: Courtenay from the Vancouver Island region; Vanderhoof from the northern interior region; and Whistler from the coast mountain region. To demonstrate the utility of the mobile monitoring method, it was important to test the method in unmonitored communities where woodsmoke was likely to be an important source. Therefore, three nearby unmonitored communities were selected to pair with each of the monitored communities. Cumberland was paired with Courtenay, Fraser Lake was paired with Vanderhoof, and Pemberton was paired with Whistler (Figure 2-1).

One driving route for the mobile monitoring was created for each community in the Whistler / Pemberton and Vanderhoof / Fraser Lake route pairs. However, due to the proximity of communities in the Comox Valley, the town of Comox was also included in the driving routes in this region. One route covered most of Courtenay (area southwest of the Courtenay river) and the unmonitored community of Cumberland, while the second route covered Comox, the rest of Courtenay (area northeast of the Courtenay river), and parts of the Comox Valley Regional District. These two routes are referred to as the Courtenay-Cumberland and Courtenay-Comox routes respectively throughout this thesis, and together as the Courtenay-Cumberland / Courtenay-Comox route pair.

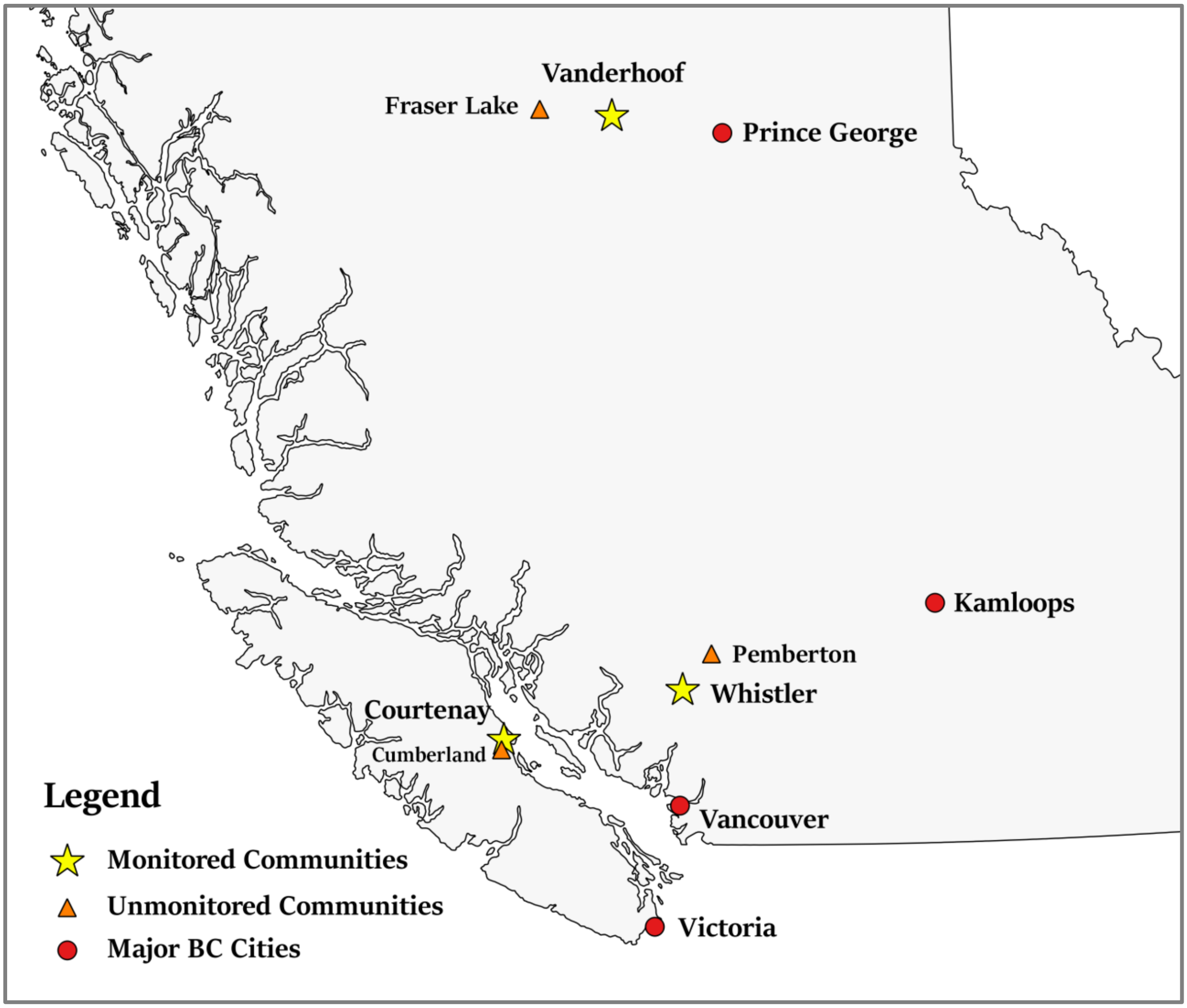


Figure 2-1: Locations of study communities in British Columbia.

2.2 Timeline of Field Monitoring

Field monitoring was conducted over three 2-week periods from January-March 2017 (Table 2-1), when average temperatures are typically low and use of wood for home heating is high. Fixed location monitoring was conducted at the monitoring stations for the entire 2-week period in each of the monitored communities. Mobile monitoring was performed in the monitored community and the nearby unmonitored community on alternating nights, for a total of seven nighttime runs on each route. Two daytime runs were also conducted on each route for comparison (*Appendix B – List of Mobile Monitoring Runs*). The nighttime mobile monitoring runs were started at approximately 21:00 each evening, when woodsmoke is likely to be the dominant source of $PM_{2.5}$ and less traffic is present on the roads.

Table 2-1: Field monitoring timeline.

Community Pair *(*indicates the monitored community)*	**Start Date**	**End Date**
Whistler* and Pemberton	5th January 2017	19th January 2017
Courtenay* and Cumberland	24th January 2017	7th February 2017
Vanderhoof* and Fraser Lake	16th February 2017	2nd March 2017

2.3 **Equipment Overview**

Four types of monitoring equipment were used in this project and are briefly explained here.

2.3.1 ENV $PM_{2.5}$ Monitoring Instruments

The BC air quality monitoring network primarily uses beta attenuation monitors (BAM) to measure $PM_{2.5}$ concentrations at monitoring stations across the province. These instruments collect 1-hour samples of $PM_{2.5}$ on a glass filter tape and estimate the total mass by measuring the difference in beta attenuation through the filter before and after the sample collection. The airflow rate through the filter tape is recorded and used to convert the beta attenuation to an average $PM_{2.5}$ concentration over the hour.

2.3.2 Nephelometers

Nephelometers are single-wavelength optical instruments that estimate particulate matter concentrations in real-time by measuring light scattering by particles in sample air (Figure 2-2). The instrument measures total light scattering (B_{scat}), but routine calibration allows the instrument to correct for the effect of Rayleigh scattering by gases and report only the scattering caused by particles. This is known as B_{sp}, where *"sp"* refers to light scattering by particles, and has been strongly correlated with $PM_{2.5}$ concentrations (38). This measure is reported in units of inverse Mega-meters (Mm^{-1}).

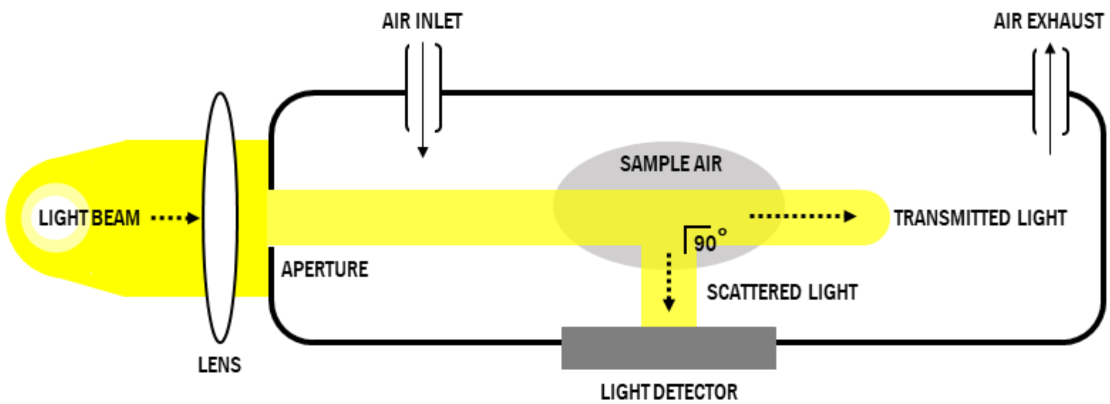


Figure 2-2: Nephelometer function diagram.
Single-wavelength light is shined through the air sample, and the amount of light that is scattered by particles in the air is measured by the light detector.

During this project two nephelometers were used: (1) an Ecotech M9003 was installed alongside the ENV monitoring equipment at the fixed stations in the monitored communities; and (2) an Ecotech Aurora 1000 was used in the mobile monitoring vehicle. Each instrument used 525 nm light sources. Both instruments were operated with inlet heaters to keep the relative humidity in the sample air below 60%, which reduces the potential for light scattering by water droplets. No size selective inlets were attached to the nephelometer sample lines because light scattering is dominated by very fine particles (aerodynamic diameters between 0.1 and 1 µm) and larger particles have a minimal contribution (39).

2.3.3 Aethalometers

Fast response multi-wavelength aethalometers can provide more information about the chemical composition of a $PM_{2.5}$ sample than BAMs or nephelometers. To collect data on $PM_{2.5}$ only, a size selective cyclone is attached to the air inlet tubing to filter out larger particles. The aethalometer then deposits $PM_{2.5}$ from sample air onto a quartz filter tape and shines multiple wavelengths of light through the sample every second to measure the proportion of each wavelength that is absorbed by the sample. The previously described *delta C* is used to indicate woodsmoke. Because aethalometers are primarily used to measure black carbon concentrations, the instrument internally converts absorbance measurements to concentrations of particles absorbing at each wavelength. Therefore, *delta C* is reported as the difference in concentration of particles absorbing at 370 nm and particles absorbing at 880 nm in units of micrograms per cubic metre (µg/m^3).

Two aethalometers were used in this project to measure *delta C*: a Magee Scientific AE21 (loaned to the project by ENV) was installed alongside the ENV equipment at the fixed stations in the monitored communities; and (2) a Magee Scientific AE33 (purchased for this project and future research with funds from the BC Lung Association) was used in the mobile monitoring vehicle.

As filter-based optical measurements are affected by mass loading, where instrument response decreases with increased loading on the filter (40), both instruments systematically pause measurements and advance the filter to a clean section whenever measurements reach a maximum absorbance. Because this effect is incremental, the data is impacted between tape advances. The data from the older AE21 model must be manually corrected for this issue, while the AE33 was designed to overcome this issue internally in real-time using the patented DualSpot™ method (41).

2.3.4 Harvard Impactors

Impactors are used to filter air and collect particulate matter of a known size (in this case $PM_{2.5}$) on a Teflon filter for further analysis. Impactors operate at a specific flow rate of air at which the inertia of particles larger than the desired size will cause them to impact on a plate when passing through the Impactor, leaving only the particles of the desired size in the airstream passing through the Teflon filter. Impactors are used in conjunction with a calibrated air pump that maintains a constant air flow rate and reports the total volume of air that passed through the filter over the operational period. By weighing the sample filters before and after sampling, the mass of $PM_{2.5}$ that has been deposited on the filter can be calculated and then converted into an average concentration during sampling. These filters can also be chemically analysed for compounds of interest such as levoglucosan.

2.4 **Fixed Site Monitoring**

2.4.1 Instrument Data Collection

In each of the three monitored communities (Whistler, Courtenay, and Vanderhoof) an Ecotech M9003 nephelometer and a Magee Scientific AE21 aethalometer were installed and operated on the roofs of the ENV fixed stations alongside the ENV monitoring equipment for a 2-week period. Each instrument was housed in a weatherproof Pelican case to protect it from low temperatures and wintertime precipitation (Figure 2-3). The AE21 was operated with a BGI SCC 1.829 cyclone to remove particles larger than 2.5 microns from the sample air, with a Magee water trap also connected to the sample inlet tubing to reduce humidity in the sample airflow and protect the instrument from water damage. Both instruments were set to record data at the highest possible temporal resolution, 1-minute averages for the M9003 nephelometer and 5-minute averages for the AE21 aethalometer. Both instruments were calibrated following instructions from their manufacturers prior to transportation to each site.

Figure 2-3: Study fixed-site equipment in Whistler.
The BC Ministry of Environment (ENV) monitoring instruments are stored in the white housing with the sample inlets and small weather station attached to the top. The M9003 nephelometer was installed in the black pelican case to the right, with the sample inlet protruding from the top of the case. On the left, a blue tarpaulin covered the pelican case housing the AE21 aethalometer with its sample inlet attached to the side of the ENV housing. The two Harvard Impactors with their air pumps, power supplies, and back-up batteries were in individual protective cases (Figure 2-4) installed on the wooden frame. The inlets for all instruments were configured to sit as closely to the same height as possible.

Two Harvard Impactors with attached air pumps were also used to collect 24-hour $PM_{2.5}$ samples on Teflon filters (37mm with PTFE Membrane) for each day of monitoring at the fixed sites (Figure 2-3 and Figure 2-4). The OMNI 400 air pumps used with the impactors were calibrated to a flow rate of 10 L min^{-1} using a MesaLabs Defender 520 DryCal before each 24-hour filter sample was started, and the flow rate was re-measured after each 24-hour period. The start and stop times, average flow rate, and total air volume were recorded for each sample. The Harvard Impactors, filter cassettes, and impaction plates were cleaned between each use, and clean mineral oil was applied to the impaction plates just prior to the installation in the impactors.

Four impactors were rotated to expedite changeovers and minimise time lost between 24-hour periods. Two clean impactors were assembled with a clean filter indoors, so that the two used impactors could be quickly swapped with clean impactors on each day of sampling. Filters were stored in individual petri dishes and transported in the upright position between leaving from and returning to the UBC Occupational and Environmental Hygiene Lab where they were weighed and analysed. Each petri dish was labelled with a filter identification code, and a matching ID sticker was removed from the petri dish and affixed to the impactor while the filter was in use. The same sticker was used to seal the petri dish when the filter was removed from the used impactor. This ensured filters were not misidentified or misplaced. Filters were changed at approximately 16:00 each day in Whistler, but this was then changed to approximately 12:00 for the Courtenay and Vanderhoof stations.

Figure 2-4: Harvard Impactor.
Harvard Impactor installed in protective Pelican case with OMNI 400 air pump, power supply, and back-up battery during monitoring.

2.4.2 Filters and Levoglucosan Analysis

The 37mm Teflon filters used to collect the 24-hour $PM_{2.5}$ samples in the Harvard Impactors were weighed in the climate- and humidity-controlled balance room at the UBC Occupational and Environmental Hygiene Lab before and after sampling, along with two field blanks per location. The total $PM_{2.5}$ mass was calculated as the weight difference of each filter pre- and post-sampling. The total volume of air sampled was calculated from the active time and average flow rate of the pump that was attached to the filter and used to calculate the average $PM_{2.5}$ concentration for the approximately 24-hour sampling period. This was performed for all filters, and the average daily $PM_{2.5}$ concentration was calculated by taking the average of the two filters collected on each day.

One of each daily pair of filters was also analysed for levoglucosan mass by gas chromatography–mass spectrometry (GC/MS) at the UBC Occupational and Environmental Hygiene Lab (*Appendix C – Levoglucosan Analysis Procedure*). Combining these results with the total volume of air sampled by the pump attached to the filter, the average levoglucosan concentration for each approximately 24-hour period was calculated. The second filter from each day was sent to the University of Toronto for analysis of the oxidative potential of the sample as part of a linked Health Canada study.

2.5 **Mobile Monitoring**

A thorough mobile monitoring protocol was created for use in this study and future work (*Appendix A – Woodsmoke Mobile Monitoring: Full Protocol*). A brief review of the methods covered by the protocol is provided here.

2.5.1 Route Creation and Monitoring Schedule

One driving route was created for each community that started and ended at the ENV monitoring station in that community pair. These routes were designed to cover the entire area in as much detail as possible within a reasonable driving time. Feedback from community groups was solicited and used to ensure the routes focused on the residential areas of interest to each community. The routes were designed to facilitate smooth data collection by looping around blocks and avoiding U-turns to prevent stop-and-go driving. These routes were programmed into a GPS navigator device (Garmin Nuvi 2497 using Garmin Basecamp software) to give directions to the driver during monitoring runs and to ensure that routes were accurately repeated.

The mobile monitoring was performed in conjunction with the fixed site monitoring, alternating each night between the monitored community route and the paired unmonitored community route. Each route was driven on seven nights starting at approximately 21:00, and twice during daytime periods (*Appendix B – List of Mobile Monitoring Runs*). Routes took between two and a half, and four hours to complete.

To limit the effects of repeating temporal patterns on the mobile monitoring data, routes were scheduled to be driven in alternating directions, forward and reverse, so the same sections of the route were not sampled at the same time each night. The paired community routes were alternated to increase the probability of sampling under similar weather conditions on each route. For example, the weather conditions during the Whistler / Pemberton route pair were more likely to be similar between the two routes if they were driven on alternating evenings rather than if the Whistler route was driven for seven consecutive nights, followed by the Pemberton route for seven consecutive nights.

2.5.2 Equipment Set-Up and Operation

Both the Aurora 1000 nephelometer and the AE33 aethalometer were installed on the rear seat of a vehicle (Figure 2-5). They were powered using a 12V power inverter connected to the vehicle 12V outlet.

Figure 2-5: Monitoring instruments installed in mobile vehicle.
Magee AE33 Aethalometer (foreground) and Ecotech Aurora 1000 Nephelometer (background) installed on rear seat of vehicle for mobile monitoring.

The sample inlet tubing of both instruments was passed through the rear window and attached to the side of the vehicle on the opposite side from the exhaust to limit self-contamination of data. A BGI SCC 1.829 cyclone was attached to the aethalometer inlet line to remove particles larger than $PM_{2.5}$ from the sample air. This cyclone has a shield covering the air inlet, which was attached to the vehicle at the front of the rear window orientated approximately 30° from upright to prevent precipitation from falling into the inlet, and to prevent air from being forced into the inlet due to the motion of the vehicle. A plastic funnel was connected to the end of the nephelometer sample tubing and attached behind the rear window orientated approximately 30° below horizontal. Again, this was to prevent precipitation from entering the inlet tubing and airflow from being forced into the opening. The attachment location of the inlets was chosen to increase the width of bends in the sample tubing and minimise particles being removed from the airflow by impacting on the tubing walls. The window opening around the inlet tubing was sealed using foam and duct tape to prevent moisture entering the vehicle and limit heat escape (Figure 2-6 and Figure 2-7).

Figure 2-6: Vehicle prepared for mobile monitoring.
The aethalometer cyclone inlet is attached above the rear window and the nephelometer sample tubing is attached with a funnel behind the rear window.

Figure 2-7: Orientation of sample inlets.
Inlets were attached to the exterior of the mobile monitoring vehicle. Cyclone connected to AE33 sample tubing was attached to the rear window orientated approximately 30° above horizontal. A funnel was connected to Aurora 1000 sample tubing and attached to the rear of the vehicle at approximately 30° below horizontal.

The AE33 aethalometer records data at 1-second intervals, but the Aurora 1000 can only save to its internal logger at 1-minute intervals. To improve the temporal and spatial resolution of the monitoring, a laptop was used to save live 1-second data from the Aurora 1000 to a text file through a serial connection and the Windows HyperTerminal program. This allowed us to collect 1-second measurements from both instruments. The 1-second nephelometer data were lost from two runs (one nighttime run on the Vanderhoof route, and one daytime run on the Courtenay and Comox route) due to errors in the laptop connection. These runs were excluded from further analyses.

A GPS datalogger (GlobalSat DG-100) was also used in the vehicle to record its location at 1-second intervals. In order to match the instrument data to the GPS location, the instrument clocks were reset to the accurate time prior to each mobile run. While monitoring, the vehicle was driven at approximately 30 km/h whenever safe (higher speeds were necessary on most highways to avoid obstructing traffic), which equates to instrument measurements approximately every 8.3 meters.

Throughout the monitoring run the laptop was also used to record relevant notes about the sampling and specific events that might affect the data. These notes files were used to keep a record of: the start and end times of the monitoring run; the driving direction of the route (forwards or reverse); and a qualitative assessment of weather conditions along with the current temperature from the vehicle readout. Notable events during the monitoring run were also recorded along with their times, such as: having to wait at a railway crossing; driving behind a large vehicle kicking up visible road dust; or driving through a visible smoke plume.

2.6 **Data Cleaning**

All data cleaning, analysis, and map production were performed using the R statistical computing environment (42). Data collected by the AE21 aethalometer installed at the fixed monitoring stations were first corrected using the WUAQL AethDataMasher software (Version 7.1) created by George Allen et al. (43). This process removes the ‘spot loading effect’ that affects data collected by older aethalometer models, and smooths values across the gaps during which the instrument is paused for tape advances. In addition, negative values can occur when the instrument is exposed to a very low concentration immediately following a very high concentration. These were replaced with the closest positive reading as per the data cleaning protocol used by ENV. If no positive values were reported within a 30-minute period of a negative reading (six measurements for the AE21, which had a 5-minute averaging period), the value was set to missing. Negative values from the mobile AE33 aethalometer were set to missing if no positive values were reported within a 30-second period (30 measurements for the AE33, which had a 1-second averaging period). This stricter limit was used on the mobile data to prevent values from being incorrectly attached to locations.

Data collected by the mobile aethalometer, nephelometer, and GPS prior to the run start times (while the vehicle and instruments warmed) were removed to ensure data were consistent between runs. This was done by cropping the data from the mobile instruments using the run start and stop times recorded in the field notes file for each run. Data from all instruments were then matched using the measurement time for each record, which connected GPS coordinates to each 1-second measurement by the mobile instruments. The 1-second mobile values were then matched to the 1-hour fixed site values, providing complete data for further analyses.

2.7 Fixed Site Analyses

2.7.1 Temporal Matching Between Fixed Location Instruments

Following the field monitoring campaign, the 1-hour average $PM_{2.5}$ data recorded by the ENV BAM instruments were retrieved from the BC Air Quality online database along with other air quality and meteorological data recorded at the fixed monitoring stations (44). The 1-minute and 5-minute averages from the M9003 nephelometer and the AE21 aethalometer, respectively, were converted to 1-hour averages to match the $PM_{2.5}$ data from the BAM instruments. Along with the 1-hour data from the BAM instruments, the nephelometer and aethalometer data were also converted to 24-hour averages to match the levoglucosan and $PM_{2.5}$ concentrations from the 24-hour filter samples.

Because the first filter samples (February 17th) in Vanderhoof only covered a 19-hour period due to delays in set up of the instruments, this day was excluded from analysis of the 24-hour average data, leaving 14 days of filter measurements for each of Whistler and Courtenay, and 13 for Vanderhoof. Vanderhoof data from this period were still included in the analysis of 1-hour averages of the other instruments. Data were also missing for the BAM and nephelometer during part of the day on February 4th in Courtenay due to a suspected power cut at the monitoring station. Therefore, analyses including 24-hour averages of those instruments only cover 13 days in Courtenay.

2.7.2 Exploration of Temporal Patterns

To explore the long-term patterns over the 2-week period at each fixed monitoring site, time series plots were created showing the 24-hour averages of the data from each of the five methods: (1) $PM_{2.5}$ concentrations measured by the ENV BAMs; (2) B_{sp} measured by the nephelometer; (3) *delta C* measured by the aethalometer; (4) $PM_{2.5}$ measured on the filter samples; and (5) levoglucosan measured on the filter samples. To allow for comparison of instrument responses, the 24-hour averages of each instrument were plotted on separate scales from zero to the max daily average observed during the whole monitoring campaign. To explore the average daily patterns observed in each community, the average value of each of the three temporally-resolved instruments (BAM, nephelometer, and aethalometer) was calculated for each hour of the day across the two-week period in each community. These results were then plotted as time series following the same methods used for the 24-hour averages to compare the relative responses of the instruments.

2.7.3 Instrument Comparisons

Relationships between the methods used at the three fixed sites were compared using scatter plots and simple linear regression. While it was possible to analyse the relationships between all of the five methods, the specific combinations below were chosen to address specific objectives.

2.7.3.1 Comparison of B_{sp} with Established $PM_{2.5}$ Measures

To compare the nephelometer measurements with more established and direct $PM_{2.5}$ measurements, 1-hour B_{sp} averages from the fixed M9003 nephelometer were compared with 1-hour averages from the ENV BAMs. This linear relationship for each community was used to convert the mobile Aurora 1000 nephelometer B_{sp} values to $PM_{2.5}$ concentration estimates for the maps of each route. In addition, 24-hour average B_{sp} values were compared with the $PM_{2.5}$ concentrations calculated from the filter samples.

2.7.3.2 Comparison of Woodsmoke-Specific Measures

To assess the ability of the dual-channel aethalometer to specifically measure woodsmoke, the 24-hour averages of the *delta C* measurements from the AE21 were compared with levoglucosan concentrations measured on the filter samples.

2.7.3.3 Woodsmoke Contribution Analysis

To estimate the contribution of residential woodsmoke to total $PM_{2.5}$ concentrations, multiple relationships were explored. The chemical tracer method was explored by examining the relationship between levoglucosan and total $PM_{2.5}$ concentrations recorded on the filters. The optical method was also explored by examining the relationship between *delta C* as reported by the AE21 aethalometer and B_{sp} as reported by the M9003 nephelometer.

We also used data from the optical methods to explore whether the relationship between *delta C* and B_{sp} differed during times of day when woodsmoke was expected to be a more or less dominant source of total $PM_{2.5}$. The data were split into nighttime hours (17:00 – 9:00) when residents are more likely to be at home and operating their wood burning appliances, and daytime hours (9:00 – 17:00) when residents are more likely to be away from their homes.

2.8 Mobile Data Analysis and Map Production

The relationship between the two mobile instruments was also used to explore the influence of residential woodsmoke on $PM_{2.5}$ concentrations using time series plots, scatter plots, and simple linear regression. Similar to the night and day comparison of the fixed site data, the relationship between the mobile instruments was also compared during the daytime (N=4) and nighttime (N=14) monitoring runs in each of the three regions to see how the relationship differed during times when woodsmoke was expected to be more or less dominant.

To address the secondary objective of this thesis, average spatial patterns of estimated B_{sp} and *delta C* were calculated and mapped across each monitoring route. A simple averaging of the raw data across the monitoring runs would be heavily impacted by temporal differences between the monitoring nights. To avoid this, the spatial patterns from each mobile run were first extracted by calculating the relative z-score for each measurement. The z-score of an observation is defined as its relative location within the distribution of all observations, expressed as multiples of the standard deviation between the observation and the mean of the distribution. Because data collected by the mobile instruments were lognormally distributed for each run, the data from each instrument were first log-transformed to more closely approximate a normal distribution prior to the z-score calculation. As such, all map legends are on an exponential scale. In addition, data from different areas connected by long, uninhabited sections of highway on the Pemberton and Fraser Lake routes were first cropped to remove these sections, ensuring that z-scores were only calculated based on the inhabited areas of the monitoring routes. Because the route to Fraser Lake passed through the smaller community of Fort Fraser and the neighbourhood of Engen, these were included in the route.

Raster grids were then created for each location covering the extent of the route, at a spatial resolution of 33.33 m^2. Raster layers were calculated for each monitoring run where all z-scores that were recorded within each raster cell were averaged, and the raster grid was then focally smoothed using the surrounding 3x3 matrix of cells weighted by the number of measurements within each cell. This resulted in each cell having a weighted average representation of the surrounding 100 m^2 area. Finally, to calculate the average spatial pattern across the route during the nighttime monitoring, the matching raster cells of the layers from each run were averaged, with a requirement for each cell to have measurements from at least five runs. When mapping these average patterns, each raster cell was shaded according to its calculated z-score, using an eight-bin scale with equal break points from less than -1.5 to greater than +1.5.

To examine the location of the fixed monitoring stations relative to the spatial pattern across each route, the calculated z-score of the closest cell to the station was extracted. This value was converted to an estimate in the original units of each instrument, and the same was done for the break points on the z-score scale. These estimates were generated by determining which instrument values would be equal to the z-score in the distribution of the data from all the runs used in the map. For easier interpretation of the map created using the nephelometer data, the estimates of equivalent B_{sp} were converted to a $PM_{2.5}$ concentration estimate using the community-specific linear relationship established between the fixed 1-hour nephelometer B_{sp} and ENV BAM $PM_{2.5}$ measurements. This conversion was included because users are more familiar with $PM_{2.5}$ concentrations from air quality reports, objectives, and advisories than they are with B_{sp} values. The *delta C* values reported for the aethalometer map were used as relative values because there is no clear conversion to a woodsmoke $PM_{2.5}$ concentration. Further reasoning behind this decision is discussed in Section 4.4.

To add context to the spatial maps, average temperatures, $PM_{2.5}$ concentrations, and wind speeds along with wind roses were calculated using the ENV data from the monitoring stations during each nighttime monitoring run using the 1-hour averages between 20:00 and 01:00. Meteorological data during the final night trip on the Courtenay and Comox route was not available online and so the averages for this route are based on the other six nighttime runs.

2.8.1 Comparison of Spatial and Temporal Variance

To contrast spatial and temporal components of air quality variability, the spatial variance captured by the mobile aethalometer and nephelometer were compared with the temporal variance captured by the aethalometer and nephelometer at the fixed locations. The 1-second data from each mobile instrument were first averaged to match the 1-minute period for the fixed nephelometer and the 5-minute period for the fixed aethalometer. The mobile data were then adjusted for temporal variability at the fixed location over the duration of the drive to extract just the spatial variability (Equation 2-1). Similar methods have been used in previous research to adjust mobile monitoring data for short-term temporal trends during monitoring runs (16,17). The spatial variance in the mobile data for each monitoring run was then compared with the temporal variance in the fixed location data during that run using a Fligner-Killeen test for homogeneity of variance (45). The Fligner-Killeen test was chosen for its robustness to non-normal data and an alpha level of $p < 0.05$ was used to assess significance.

Equation 2-1: Equation for adjusting mobile measurements for short-term temporal trends at the fixed location, where 't' is the time-specific value of the mobile measurement (MobileRaw) or smoothed 15-minute running mean of the fixed site (FixedRunning) data, and 'run' is the mean of the fixed site measurements (FixedRaw) over the duration of the monitoring run.

$$MobileAdjusted_t = \frac{MobileRaw_t}{FixedRunning_t / FixedRaw_{run}}$$

Chapter 3: Results

3.1 Summary of Temporal Patterns in the Monitored Communities

The average conditions measured at the three monitoring stations during the field campaigns were variable across the monitored communities (Table 3-1). Temperatures were lowest in Whistler and highest in Vanderhoof, but $PM_{2.5}$ concentrations, levoglucosan concentrations, B_{sp}, and *delta C* were considerably higher in Courtenay than in the other two communities.

Table 3-1: Average conditions at the three monitoring stations during the field monitoring campaign.
Mean (SD) presented for each measure. BAM acronym refers to the beta attenuation monitors operated by the BC Ministry of Environment and Climate Change Strategy.

	BAM $PM_{2.5}$ *($\mu g/m^3$)*	**Filter $PM_{2.5}$** *($\mu g/m^3$)*	**Levoglucosan** *($\mu g/m^3$)*	**B_{sp}** *(Mm^{-1})*	***delta C*** *($\mu g/m^3$)*	**Temperature** *(°C)*	**Wind Speed** *(m/s)*
Whistler ***5th Jan 2017 – 19th Jan 2017***	11.1 (8.9)	5.3 (3.3)	0.36 (0.31)	25.9 (29.5)	0.57 (0.79)	-5.8 (5.1)	0.7 (0.6)
Courtenay ***24th Jan 2017 – 7th Feb 2017***	16.4 (14)	13.4 (6.8)	1.31 (0.76)	70.6 (71)	1.2 (1.44)	3.9 (2.6)	1.1 (0.8)
Vanderhoof ***16th Feb 2017 – 2nd Mar 2017***	9.4 (8.4)	9.3 (4.7)	0.26 (0.19)	35.9 (37)	0.46 (0.57)	4.9 (4.3)	1.3 (0.8)

High temporal correlation was observed between all measurements taken at the fixed monitoring stations in the three monitored communities (Figure 3-1). The three total $PM_{2.5}$ measures (BAM, filter, and B_{sp}) produced similar daily patterns, as did the woodsmoke-specific measures (levoglucosan and *delta C*). In Whistler, the relative 24-hour averages of the BAM $PM_{2.5}$ were consistently higher than the filter $PM_{2.5}$ and the nephelometer B_{sp}. This was not observed in the other communities (Figure 3-1 and Table 3-1). In Vanderhoof, the two woodsmoke-specific measures were consistently lower than the total $PM_{2.5}$ measures, but still followed the same patterns across days (Figure 3-1). The highest values for each method were measured in Courtenay, where air quality advisories were issued during the sampling when the 24-hour average $PM_{2.5}$ concentrations measured by the BAM surpassed the provincial objective of 25 µg/m^3.

The hourly data showed a diurnal pattern in each community, with smaller peak values in the morning (at 08:00 or 09:00), lower values in the afternoon (reaching daily minimums between 13:00 and 17:00), and then larger peak values at night (Figure 3-2). While this pattern was present in all three communities, the diurnal peaks in Courtenay were more pronounced compared with the other communities. Here, the average morning and night $PM_{2.5}$ peaks were approximately 16 µg/m^3 and 23 µg/m^3 higher, respectively, than the average afternoon low of 5 µg/m^3. The range of $PM_{2.5}$ concentrations in both other communities was approximately 10 µg/m^3.

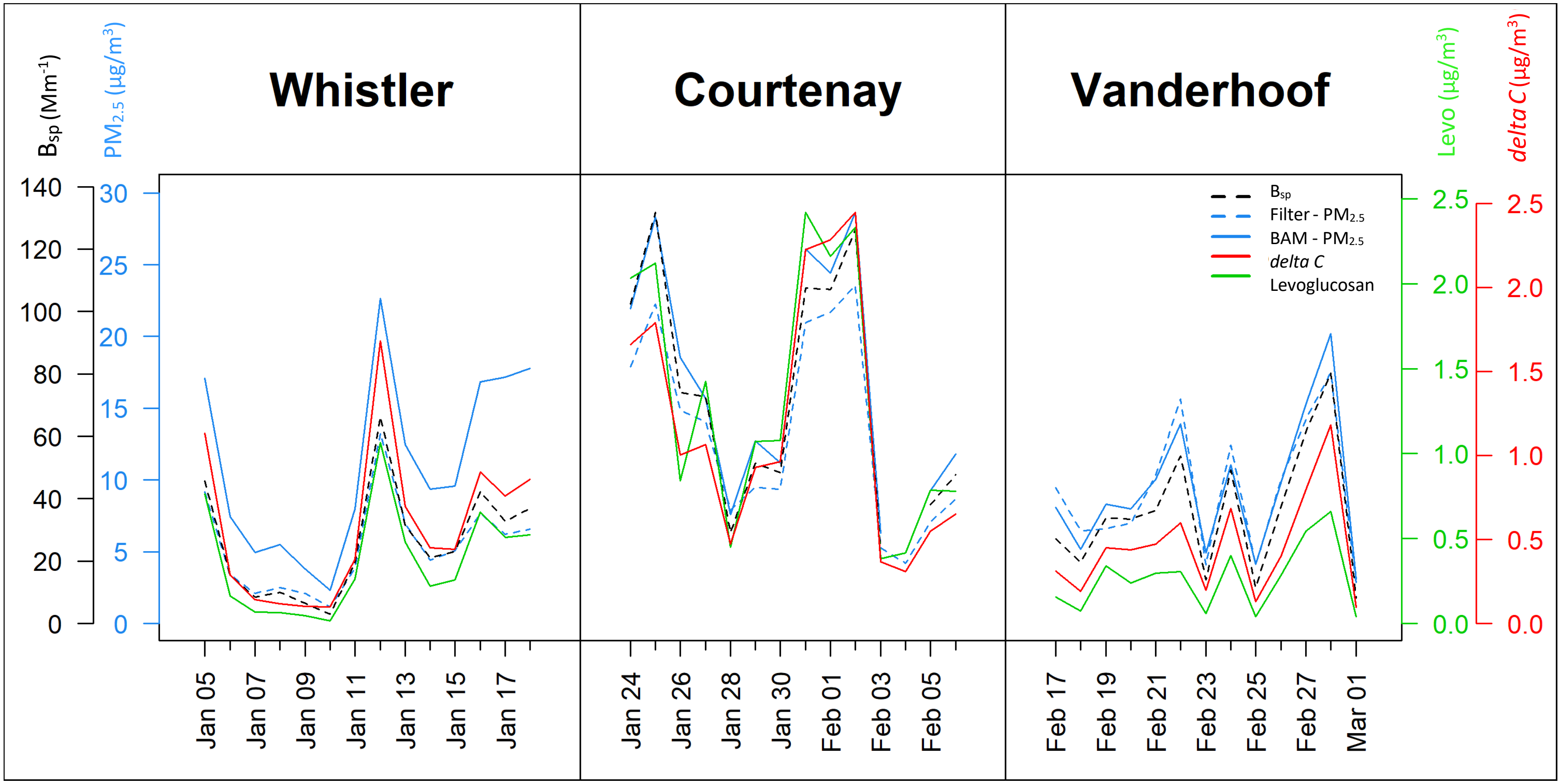


Figure 3-1: Time series plot showing 24-hour average values of the five monitoring methods operated at the monitoring stations.
The two y-axes for the three total $PM_{2.5}$ measures are shown on the left (B_{sp} measured by the nephelometer, and $PM_{2.5}$ concentrations measured by the BC Ministry of Environment beta attenuation monitors (BAM) and filter samples), while the two y-axes for the woodsmoke-specific measures are shown on the right (levoglucosan concentrations from filter samples, and *delta C* measured by the aethalometer). Each of the four y-axes are scaled from zero to the max value measured on that scale across the six weeks of field monitoring.

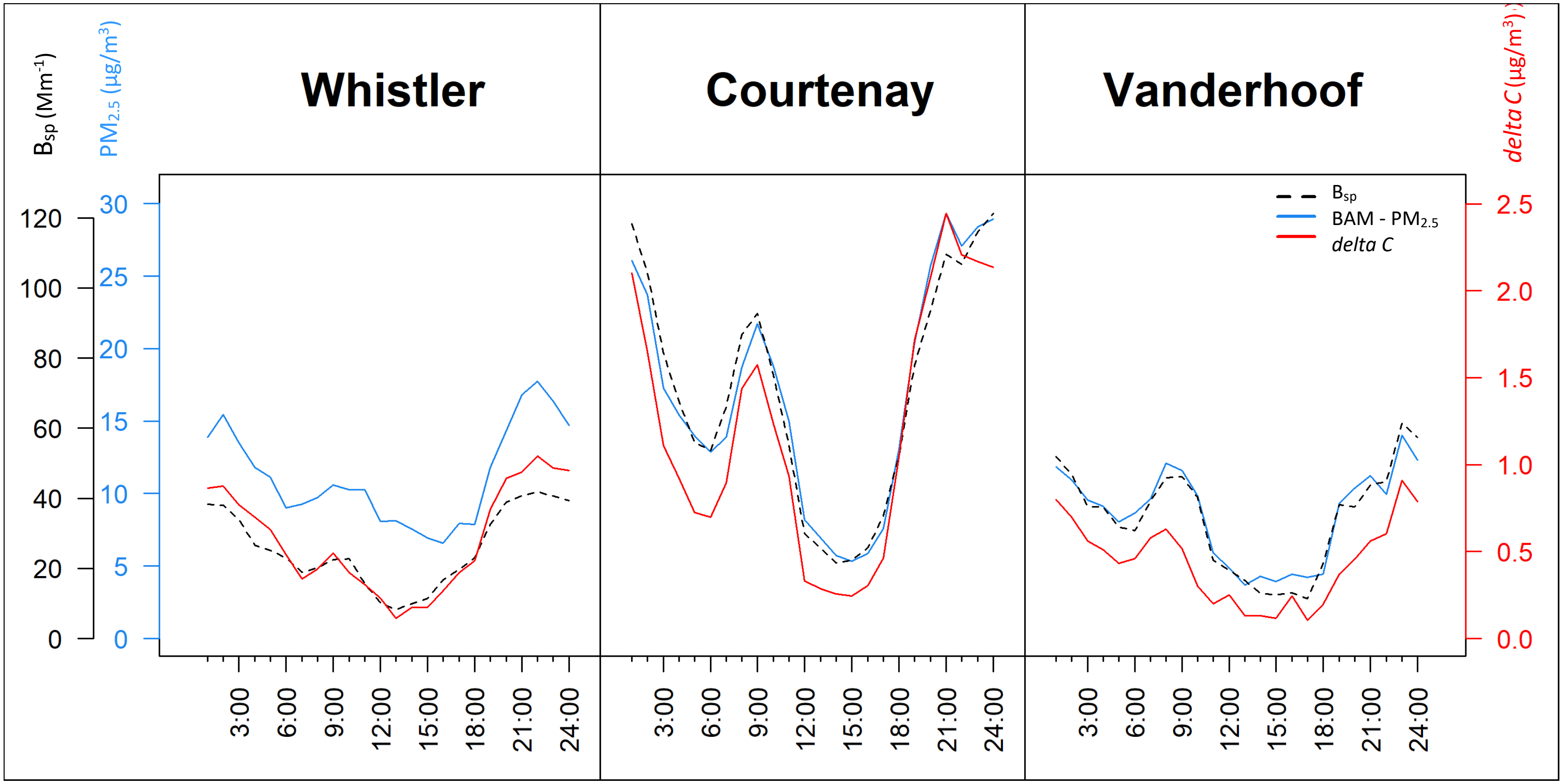
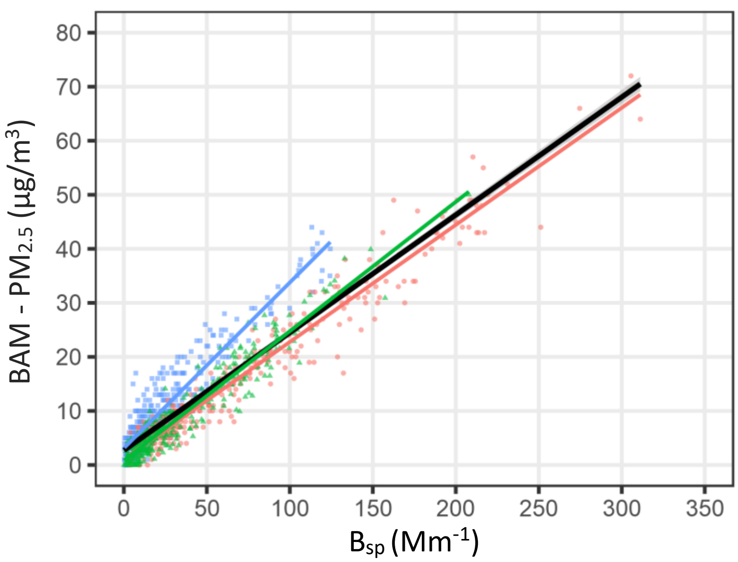


Figure 3-2: Time series plots showing the average daily patterns measured by the fixed site instruments during the monitoring campaign in each of the three monitored communities.

The two y-axes for the total $PM_{2.5}$ measures are shown on the left (B_{sp} measured by the nephelometer, and $PM_{2.5}$ concentrations measured by the BC Ministry of Environment beta attenuation monitors (BAM)), while the y-axis for the woodsmoke-specific indicator *delta C* measured by the aethalometer is shown on the right. Each of the four y-axes are scaled from zero to the max value measured on that scale across the six weeks of field monitoring.

3.2 Comparison of $PM_{2.5}$ Measures at the Fixed Sites

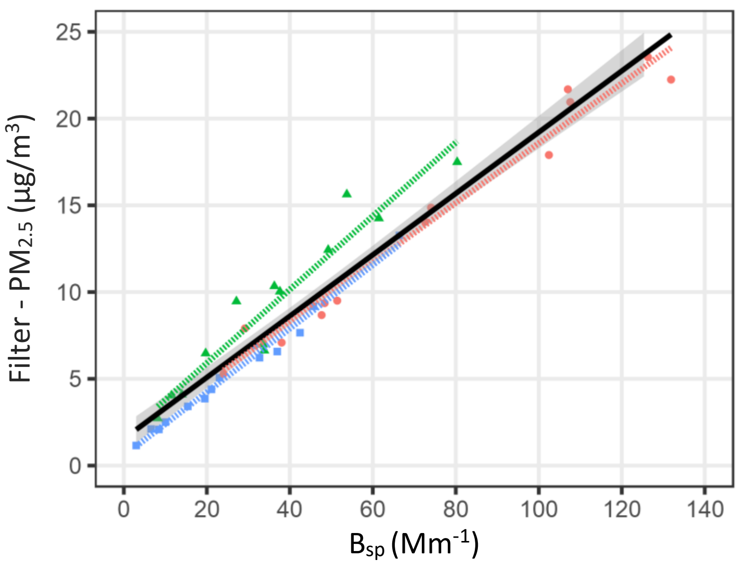
Strong correlation was observed between 1-hour average B_{sp} measurements from the M9003 nephelometer and BAM $PM_{2.5}$ concentrations, with a coefficient of determination (R^2) of 0.88 across all locations (Figure 3-3). However, the linear relationship varied between communities, with a greater slope found in Whistler (0.31 $\mu gm^{-3}/Mm^{-1}$) than in Courtenay (0.22 $\mu gm^{-3}/Mm^{-1}$) and Vanderhoof (0.24 $\mu gm^{-3}/Mm^{-1}$). The three community-specific relationships were used to convert mobile B_{sp} values to $PM_{2.5}$ estimates for mapping of the nephelometer results.



Location	Slope	Int	R^2
Whistler	0.31	3.1	0.88
Courtenay	0.22	1.1	0.95
Vanderhoof	0.24	0.82	0.91
Overall	0.22	2.7	0.88

Figure 3-3: Scatterplot comparison of calculated hourly averages of B_{sp} as measured by the nephelometer and the $PM_{2.5}$ concentrations reported by the beta attenuation monitor (BAM) at each monitoring station. Linear regression lines are shown for each location with the slope, intercept and R^2 values presented in the accompanying table. Colour of points and linear regression lines indicates location and the 95% confidence interval is shown around the linear relationship calculated using the overall data.

Strong correlation was also observed between the 24-hour average B_{sp} measurements and the filter-based $PM_{2.5}$ concentrations, with an R^2 of 0.94 across all locations (Figure 3-4). The relationship between the nephelometer data and the filter $PM_{2.5}$ measurements was more consistent between communities than the relationship between the nephelometer and BAM instruments. Specifically, the B_{sp} in Whistler had stronger correlation with the filter-based $PM_{2.5}$ than with the BAM measurements (R^2 = 0.99 compared with 0.88). Although both the BAM and filter-based measurements reflect total $PM_{2.5}$ concentrations, the slopes of the relationships across all sites differed slightly. Overall, there was a lower slope of 0.18 µgm^{-3}/Mm^{-1} for the filter-based relationship with B_{sp}, compared with 0.22 µgm^{-3}/Mm^{-1} for the BAM relationship.

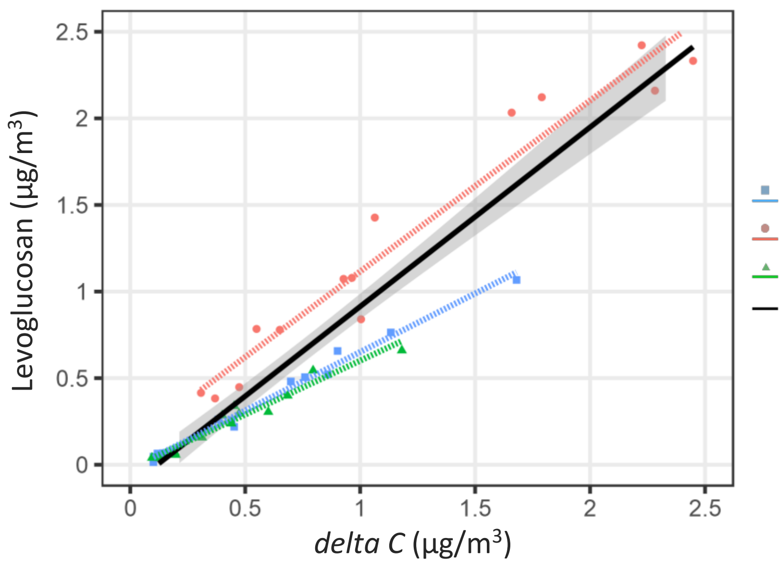


Location	Slope	Int	R^2
Whistler	0.18	0.57	0.99
Courtenay	0.17	1.3	0.97
Vanderhoof	0.21	1.7	0.91
Overall	0.18	1.5	0.94

Figure 3-4: Scatterplot comparison of the calculated 24-hour averages of B_{sp} as measured by the nephelometer and the 24-hour average $PM_{2.5}$ concentrations measured by the filter samples at each monitoring station. Linear regression lines are shown for each location with the slope, intercept and R^2 values presented in the accompanying table. Colour of points and linear regression lines indicates location and the 95% confidence interval is shown around the linear relationship calculated using the overall data.

3.3 Comparison of Woodsmoke-Specific Measures at the Fixed Sites

When comparing *delta C* with levoglucosan concentrations (Figure 3-5), very strong correlation was observed in each of the three communities, with community-specific R^2 values of at least 0.95 and an overall R^2 of 0.90. While a one-to-one linear relationship was observed when considering data across all three sites, there were differences in the slope of the relationship between communities. The measured relationships in Whistler and Vanderhoof were similar (slopes of 0.68 and 0.62 µg/m^3 of levoglucosan per µg/m^3 *delta C*, respectively), but the slope of the relationship between the methods was steeper in Courtenay (0.99 µg/m^3 of levoglucosan per µg/m^3 *delta C*).

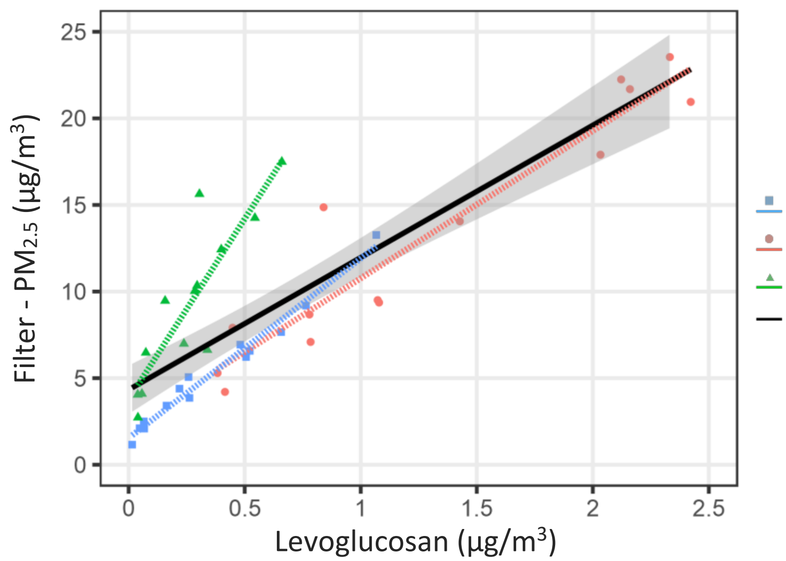


Location	Slope	Int	R^2
Whistler	0.68	-0.03	0.99
Courtenay	0.99	0.13	0.95
Vanderhoof	0.62	-0.02	0.95
Overall	1.00	-0.12	0.90

Figure 3-5: Scatterplot comparison of the two woodsmoke-specific measures, calculated 24-hour averages of *delta C* as measured by the aethalometer, and the 24-hour average levoglucosan concentrations measured by the filter samples at each monitoring station.
Linear regression lines are shown for each location with the slope, intercept and R^2 values presented in the accompanying table. Colour of points and linear regression lines indicates location and the 95% confidence interval is shown around the linear relationship calculated using the overall data.

3.4 Comparison of Woodsmoke and Total $PM_{2.5}$ Measures at the Fixed Sites

Strong correlation was found between woodsmoke-specific methods and total $PM_{2.5}$ concentrations using both the chemical tracer levoglucosan (Figure 3-6) and the optical *delta C* (Figure 3-7). Correlation between the filter measures was stronger in Whistler and Courtenay (R^2 of 0.98 and 0.90, respectively) and levoglucosan accounted for approximately ten percent of the $PM_{2.5}$ mass on the gravimetric filter samples in these regions. Levoglucosan accounted for approximately five percent of the $PM_{2.5}$ in Vanderhoof, and the relationship had relatively weaker correlation (R^2 = 0.76) suggesting that woodsmoke contributed less to $PM_{2.5}$ concentrations relative to the other communities.

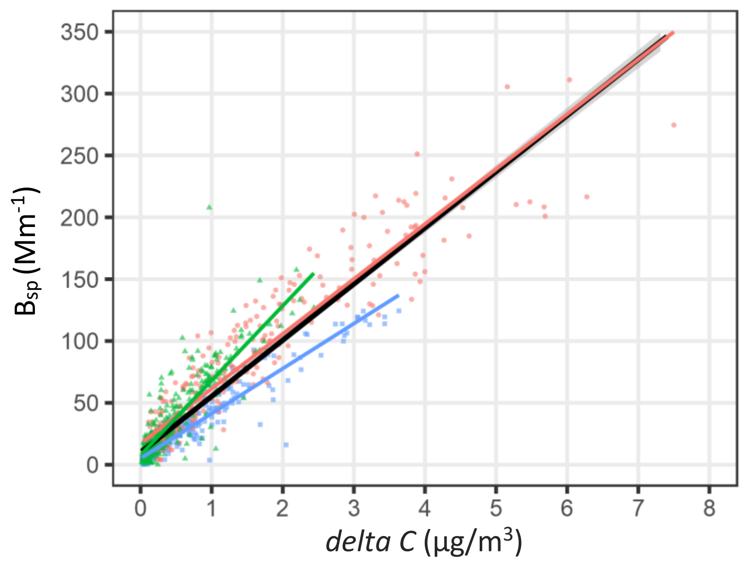


Location	Slope	Int	R^2
Whistler	10	1.50	0.98
Courtenay	8.5	2.30	0.90
Vanderhoof	21	3.80	0.76
Overall	7.6	4.30	0.73

Figure 3-6: Scatterplot comparison of the two measurements made from the daily filter samples; woodsmoke tracer levoglucosan concentrations against total $PM_{2.5}$ concentrations.

Linear regression lines are shown for each location with the slope, intercept and R^2 values presented in the accompanying table. Colour of points and linear regression lines indicates location and the 95% confidence interval is shown around the linear relationship calculated using the overall data.

Similar patterns were found in the relationships between the 1-hour averages of the optical measurements at the fixed sites (Figure 3-7). Whistler and Courtenay again showed strong correlation between the *delta C* and B_{sp} measurements (R^2 of 0.91 and 0.89, respectively). However, Courtenay had a steeper slope than Whistler (44 $Mm^{-1}/\mu gm^{-3}$ in Courtenay compared with 36 $Mm^{-1}/\mu gm^{-3}$ in Whistler). In Vanderhoof, the relationship had a relatively higher slope and weaker correlation compared with the other communities (60 $Mm^{-1}/\mu gm^{-3}$, $R^2 = 0.77$).



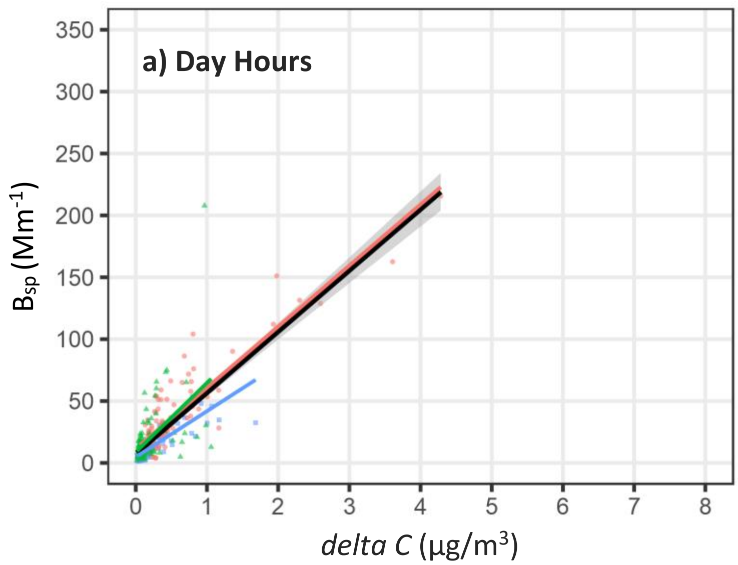
Location	Slope	Int	R^2
Whistler	36	5.10	0.91
Courtenay	44	17.0	0.89
Vanderhoof	60	7.90	0.77
Overall	45	9.90	0.86

Figure 3-7: Scatterplot comparison of 1-hour averages of the two optical instruments installed at the fixed locations; woodsmoke *delta C* as measured by the aethalometer, against B_{sp} measured by the nephelometer. Linear regression lines are shown for each location with the slope, intercept and R^2 values presented in the accompanying table. Colour of points and linear regression lines indicates location and the 95% confidence interval is shown around the linear relationship calculated using the overall data.

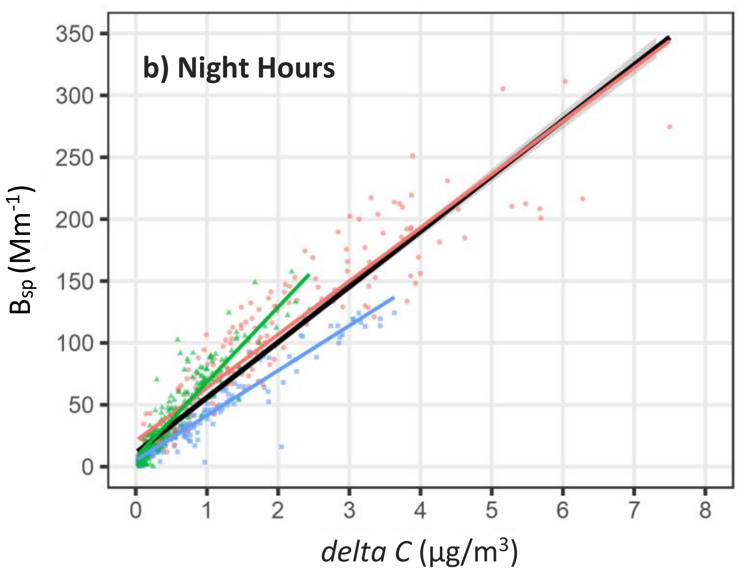
3.4.1 Daily Differences in Woodsmoke Contribution

Correlation between optical measures of woodsmoke and total $PM_{2.5}$ was stronger during nighttime hours (between 17:00 and 09:00) than during daytime hours (between 09:00 and 17:00) (Figure 3-8). While the equation of the overall linear relationship remained similar, the correlation across the three fixed stations decreased from 0.87 at night to 0.66 during the day. This followed the expected pattern as residential wood burning was expected to be more prevalent during the night hours.

While all three community-specific relationships between *delta C* and B_{sp} showed weaker correlation during the day than at night, the differences in the relationship varied. The daytime relationship in Courtenay was very similar to the nighttime relationship (R^2 = 0.83 compared with 0.88), while it was slightly weaker in Whistler (R^2 = 0.71 compared with 0.92) and considerably weaker in Vanderhoof (R^2 = 0.25 compared with 0.86). The equations of the linear relationships remained similar in each community (Figure 3-8).



	Location	Slope	Int	R^2
	Whistler	37	4.80	0.71
	Courtenay	49	11.0	0.83
	Vanderhoof	56	8.70	0.25
	Overall	49	7.50	0.66



	Location	Slope	Int	R^2
	Whistler	36	5.20	0.92
	Courtenay	43	21.0	0.88
	Vanderhoof	61	7.70	0.86
	Overall	45	11.0	0.87

Figure 3-8: Scatterplot comparison of 1-hour averages of *delta C* and B_{sp} measured at the monitoring stations during: a) Day Hours between 09:00 and 17:00, and b) Night Hours between 17:00 to 09:00.
Linear regression lines are shown for each location with the slope, intercept and R^2 values presented in the accompanying table. Colour of points and linear regression lines indicates location and the 95% confidence interval is shown around the linear relationship calculated using the overall data.

3.5 Comparison of Woodsmoke and Total $PM_{2.5}$ Measures during Mobile Monitoring

Scatter plots comparing the *delta C* woodsmoke indicator and the B_{sp} $PM_{2.5}$ indicator measured during mobile monitoring show variable relationships between the three regions and between the 13-14 nighttime and 3-4 daytime runs (Figure 3-9). Stronger correlation was observed during the nighttime runs than during the daytime runs in each region as expected, with R^2 values of 0.66 compared with 0.49 on the Whistler / Pemberton route pair, and 0.75 compared with 0.48 on the Courtenay-Cumberland / Courtenay-Comox route pair. The relationships were weaker on the Vanderhoof / Fraser Lake route pair with an R^2 value of 0.36 during the nighttime, and no correlation during the daytime (R^2 = 0.0006). The scatterplots for this region show that high B_{sp} at times of low *delta C* were responsible for the weaker relationship, especially during the daytime monitoring runs (Figure 3-9). They also show that the highest values measured by both instruments were typically much lower during the daytime runs than during the nighttime for all communities. The one exception was the B_{sp} measurement during the daytime monitoring runs on the Vanderhoof / Fraser Lake route pair, where very high values were measured.

Although the *delta C* and B_{sp} measurements were correlated, scatterplots show unexplained variability between the two instruments even during nighttime runs. For example, a time series comparison of the two instruments during two runs on the Fraser Lake route shows extreme differences in correlation (Figure 3-10). During the nighttime run there is clear correlation between the two instruments with both instruments responding to the same plumes over time. In contrast, the daytime plumes measured by the nephelometer show no similar response from the aethalometer.

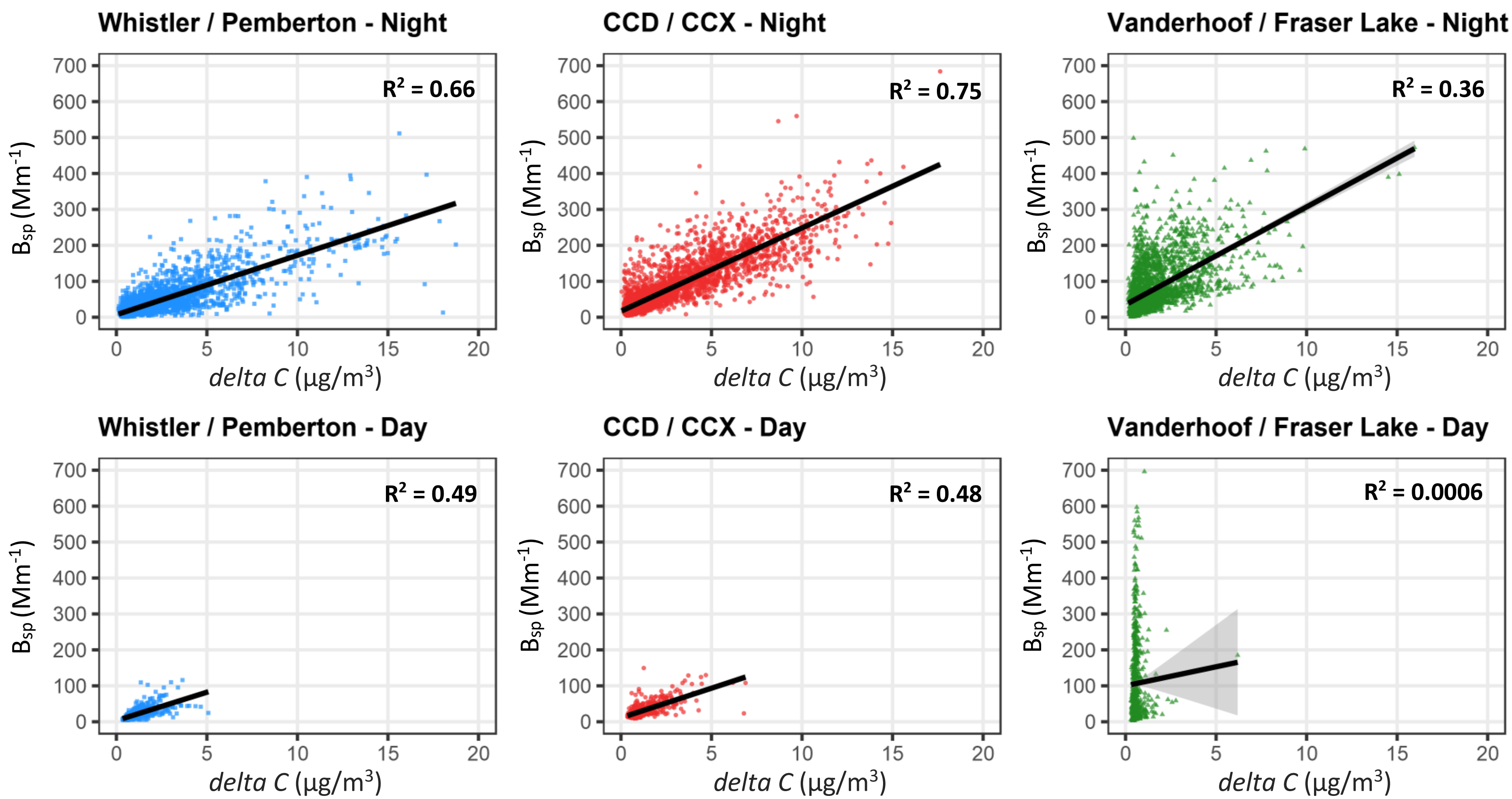


Figure 3-9: Scatterplot comparisons of 1-minute averages of the *delta C* woodsmoke indicator and the B_{sp} total $PM_{2.5}$ indicator measured by the mobile instruments during the monitoring runs.

One plot is shown for each route pair (Whistler / Pemberton, Courtenay-Cumberland (CCD) / Courtenay-Comox (CCX), and Vanderhoof / Fraser Lake) during nighttime monitoring runs in the upper row of plots, and daytime monitoring runs in the lower row of plots. All plots are shown on the same axes scales with three extreme B_{sp} measurements not shown during one Vanderhoof daytime run, and two extreme *delta C* measurements not shown during one Fraser Lake night run. These extreme measurements are included in the linear regressions shown.

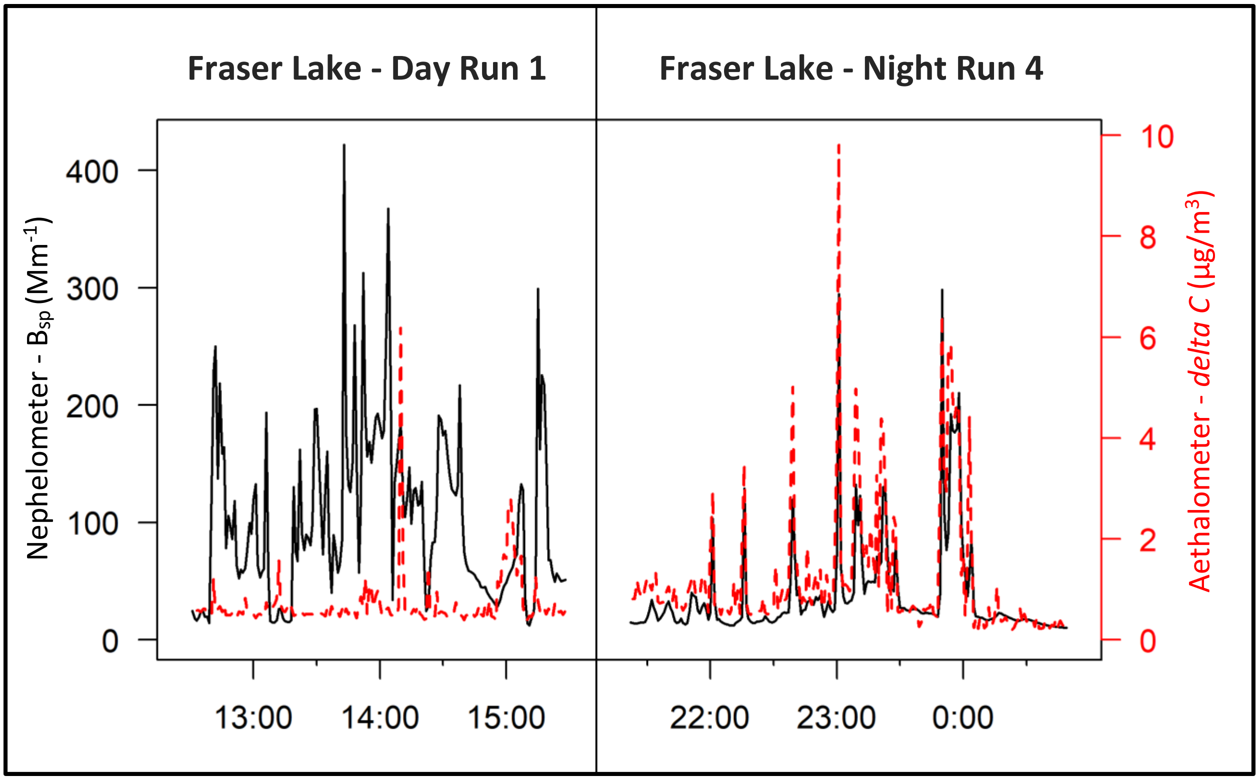


Figure 3-10: Time series comparing responses of the mobile aethalometer and nephelometer during two monitoring runs of the Fraser Lake route.

The y-axes for both instruments are plotted from zero to the maximum value observed during both runs. The first day run on the Fraser Lake route (Day Run 1, February 22nd, 2017) shows an example of low correlation between the two mobile instruments, while Night Run 4 (February 23rd, 2017) is an example of high correlation between instruments.

3.6 **Average Conditions During Mobile Monitoring Runs**

The mobile monitoring routes were alternated each night between the monitored and unmonitored communities to capture similar conditions, but there were still differences in each community pair (Table 3-2). Conditions on the Whistler and Pemberton monitoring nights were the most similar with average temperatures of -6.6 and -6.2 °C, respectively, and calm winds. These conditions favour high use of wood burning appliances and limited venting of emissions from the area. Winds were primarily from the southeast (Figure 3-11). The $PM_{2.5}$ concentrations measured by the ENV BAM on the Pemberton nights were slightly higher than those on the Whistler nights (16.3 μg/m^3 compared with 14.1 μg/m^3).

Large differences were observed between the nights on which the Courtenay-Cumberland and Courtenay-Comox routes were monitored. Average temperatures were similar (3.2 and 3.8 °C), but higher wind speeds and lower $PM_{2.5}$ concentrations were reported by the ENV instruments during the Courtenay-Comox nights (1.3 m/s and 20.6 μg/m^3) compared with the Courtenay-Cumberland nights (0.7 m/s and 31.3 μg/m^3). The nighttime wind direction in this region was predominantly from the west (offshore winds). One exception to this pattern was observed during a Courtenay-Comox run, when stronger winds were measured from the southeast (Figure 3-11).

Wind speeds and temperatures were both higher on average during the monitoring of Vanderhoof and Fraser Lake, which likely contributed to the lower average $PM_{2.5}$ concentrations in this region. The averages of all monitoring station measurements were slightly higher during the Vanderhoof nights compared with the Fraser Lake nights (Table 3-2). Winds during the Vanderhoof nights were predominantly from the west, while wind directions were variable on the Fraser Lake nights (Figure 3-11). There was one run on each route with high wind speeds and very low $PM_{2.5}$ conditions (3.4 m/s and 0.44 μg/m^3 during the first Vanderhoof nighttime run, and 2.5 m/s and 1.8 μg/m^3 during the seventh Fraser Lake nighttime run).

These differences in conditions between route pairs must be considered when comparing maps of the paired route maps. They are especially important when comparing the Courtenay-Cumberland / Courtenay-Comox route pair, because the fixed site $PM_{2.5}$ concentrations were more than 50% higher during the Courtenay-Cumberland nights compared with the Courtenay-Comox nights.

Table 3-2: Average conditions at the monitoring stations during the nighttime monitoring runs on each route. Values calculated using the 1-hour averages of the fixed nephelometer and aethalometer along with the BC Ministry of Environment measurements of $PM_{2.5}$ with the beta attenuation monitors (BAM $PM_{2.5}$) and meteorological data between the hours of 20:00 and 01:00.

Monitoring Route	**B_{sp}** *(Mm^{-1})*	***delta C*** *($\mu g/m^3$)*	**BAM $PM_{2.5}$** *($\mu g/m^3$)*	**Temp** *(°C)*	**Wind Speed** *(m/s)*
Whistler	37	0.9	14.1	-6.6	0.6
Pemberton	43	1.1	16.3	-6.2	0.7
Courtenay-Cumberland	145	2.7	31.3	3.2	0.7
Courtenay-Comox	86	1.6	20.6	3.8	1.3
Vanderhoof	62	0.9	14.1	5.2	1.3
Fraser Lake	46	0.6	11.2	4.4	1.0

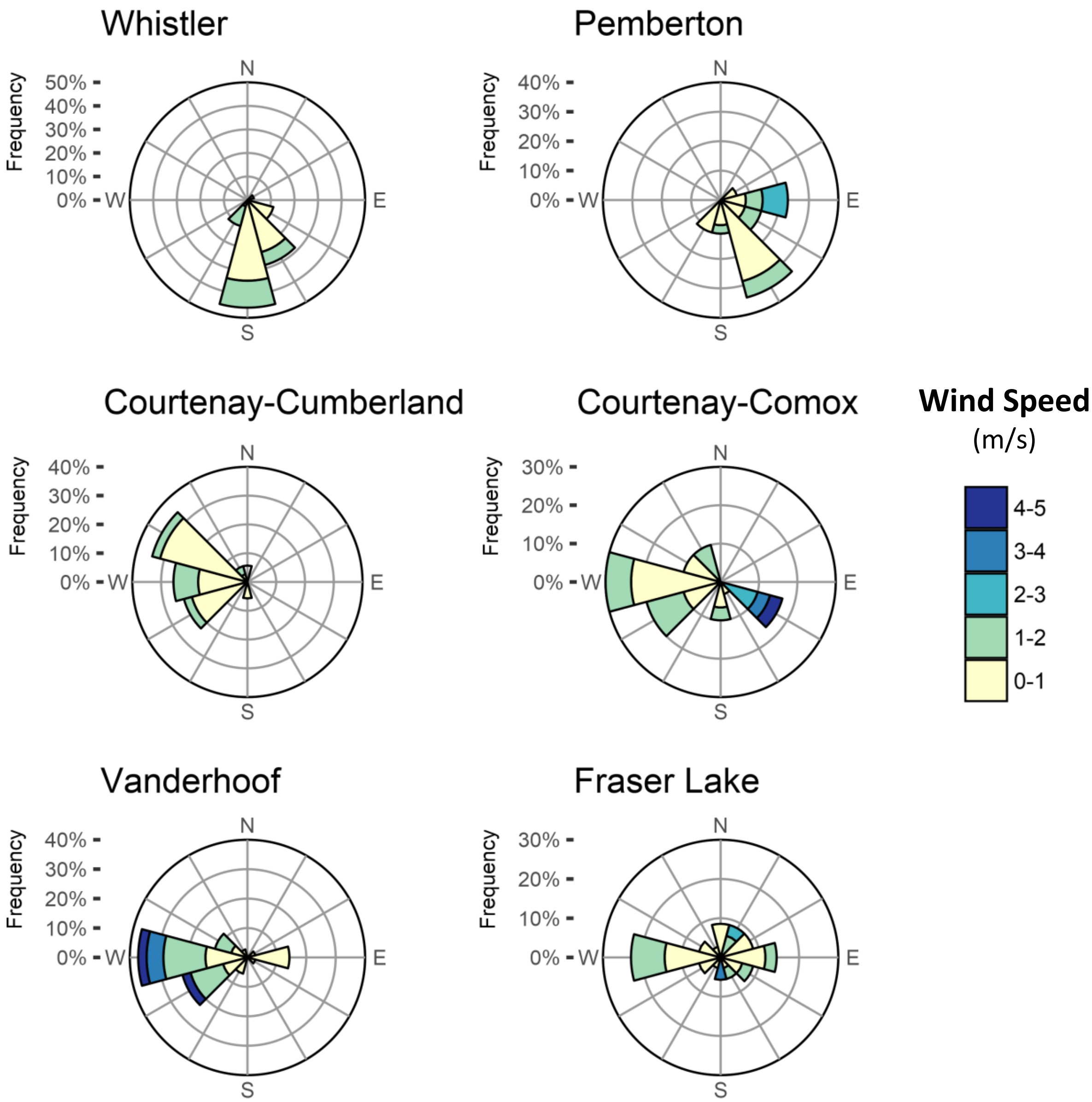


Figure 3-11: Wind roses during the nighttime runs on each route.
Wind data collected at the monitoring stations by the BC Ministry of Environment (ENV).

3.7 **Route Average Maps**

The maps that were created to show the average spatial patterns measured across each community during winter nights are presented in this section. The spatial patterns measured in this study are only relevant to the winter heating season as meteorological patterns may differ by season and other sources may be more prominent in other seasons. Maps labeled 'A' in Figure 3-12 through Figure 3-17 show the average patterns of B_{sp} measured by the nephelometer as an indicator of total $PM_{2.5}$ concentrations, while maps labeled 'B' show the average patterns of the woodsmoke indicator *delta C* measured by the aethalometer. In general, the average patterns measured by both instruments show similar patterns on each route, supporting the expectation that woodsmoke is the dominant $PM_{2.5}$ source in these communities during winter nights.

3.7.1 Whistler and Pemberton Routes

Measurements from the Whistler route show smoke hotspots to the west of the fixed monitoring station and along the east side of Alta Lake, with lower values measured on the west of Alta Lake and in the southwest of the map (Figure 3-12). Measurements from the Pemberton route show hotspots throughout the area, particularly in southeastern Pemberton, the southern parts of Mount Currie, and in the Xit'olacw area to the northeast (Figure 3-13). The B_{sp} measurements at the location of the fixed Whistler monitoring station were slightly lower than the average across the Whistler route with a mean z-score (Z) of -0.14. They were much lower than the average across the Pemberton route (Z = -0.87), with the $PM_{2.5}$ estimate at the fixed-site around half that of the route average. The *delta C* measurements close to the fixed station followed a similar pattern, with mean Z of -0.16 and -0.35 on the Whistler and Pemberton routes, respectively. Substantial variability was observed across both routes. For the Whistler route, the highest averages on the nephelometer map were up to four times higher than the average at the fixed monitoring station, and for the Pemberton route they were up to ten times higher. On the aethalometer maps the highest averages were up to five and six times higher than the averages at the fixed monitoring station for the Whistler and Pemberton routes, respectively.

3.7.2 Courtenay-Cumberland and Courtenay-Comox Routes

The aethalometer and nephelometer route average maps for the Courtenay-Cumberland route show similar smoke hotspots, particularly in the centre and southeast of Courtenay and the northeast of Cumberland (Figure 3-14). The northeast of Courtenay and north of Royston both had higher relative *delta C* than B_{sp} values, suggesting more woodsmoke impact in these places. Meanwhile, there were relatively lower *delta C* values than B_{sp} values observed along the highway between Courtenay and Cumberland, suggesting more impact from non-woodsmoke sources. Measurements from the Courtenay-Comox route show hotspots around the Courtenay monitoring station and in the northwest of the route, with slightly higher relative values also in the main residential area of Comox (Figure 3-15). The *delta C* map shows similar patterns to the nephelometer map, but there appears to be less variation from the mean with large areas of the map falling in the middle of the z-score scale (Figure 3-15).

Both the B_{sp} and *delta C* levels around the Courtenay fixed station were higher than the average across the Courtenay-Cumberland route (Z = 0.41 and 0.38, respectively) and much higher than the average across the Courtenay-Comox route (Z = 1.82 and 1.04, respectively) during the monitoring period. Even still, higher values were observed across the routes with $PM_{2.5}$ estimates up to 1.6 and 2.2 times higher, and *delta C* estimates up to 2.2 and 1.4 times higher than those at the monitoring station on the Courtenay-Cumberland and Courtenay-Comox routes, respectively.

3.7.3 Vanderhoof and Fraser Lake Routes

Measurements from the Vanderhoof route show hotspots in the northwest and northeast (just south of the Nechako river), and in the neighbourhoods north of the Nechako river (Figure 3-16). The hotspots in the northwest of the map and northwest of the central area of Vanderhoof were more pronounced on the nephelometer map compared with the aethalometer map. Very high B_{sp} levels were measured in some sections of the Vanderhoof route, with the highest estimated $PM_{2.5}$ up to 18 times higher than those around the fixed site. Nephelometer measurements on the Fraser Lake route showed hotspots in the north and west of Fraser Lake, as well as the western end of Fort Fraser (Figure 3-17). When contrasting against the aethalometer map, the hotspots are less pronounced in Fraser Lake with lower relative values, but the hotspot in Fort Fraser had higher z-scores. Differences are also observed on the Vanderhoof segment of the route, with lower relative *delta C* values along the highway section, compared to the relative nephelometer measurements. The $PM_{2.5}$ estimates calculated for the fixed Vanderhoof station were lower than the averages across both the Vanderhoof route (Z = -0.61) and the Fraser Lake route (Z = -0.65). However, the station fell closer to the centre of the *delta C* distributions, slightly above the average of the Vanderhoof route (Z = 0.09) and slightly below the average of the Fraser Lake route (Z = -0.22).

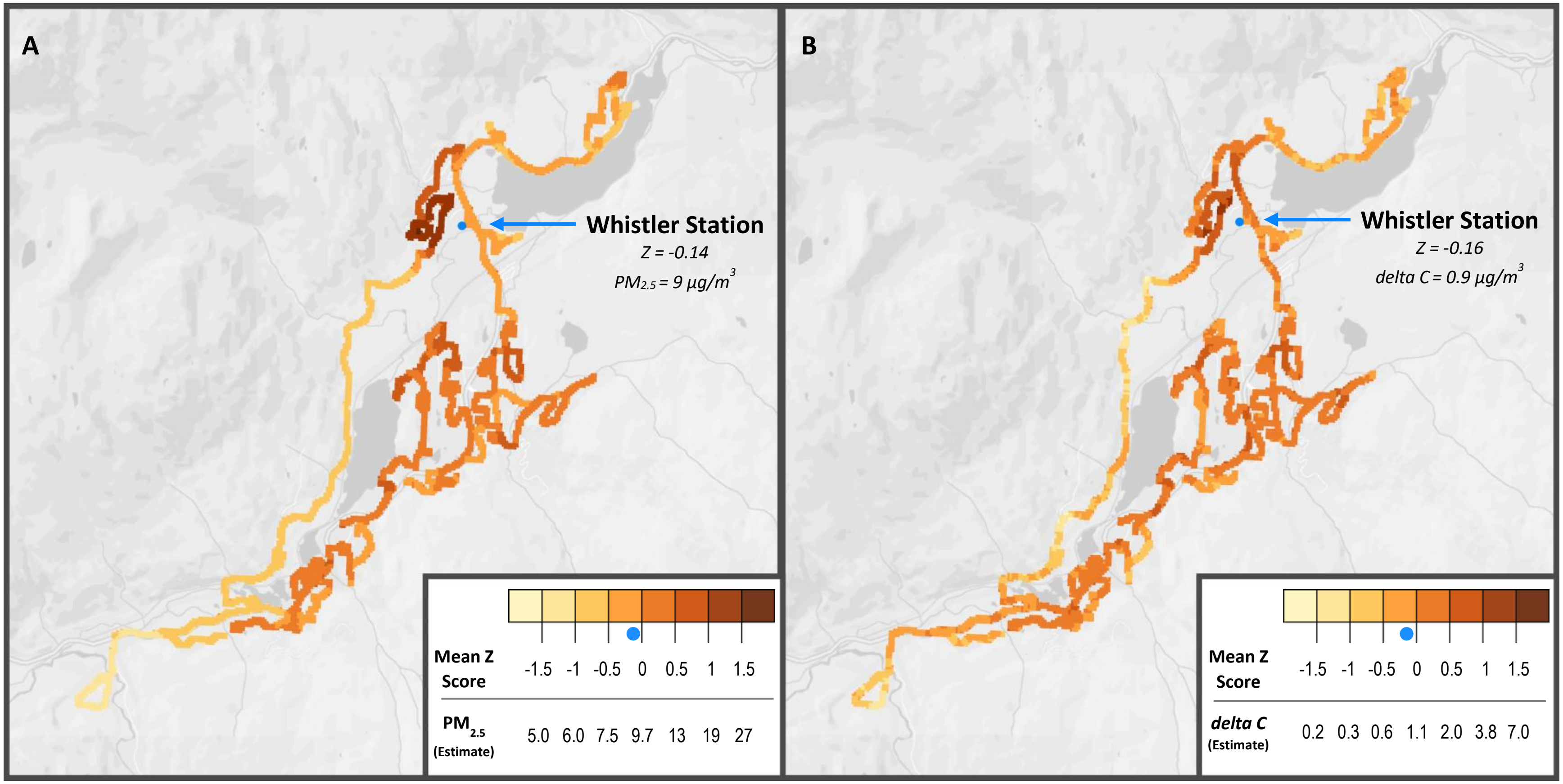


Figure 3-12: Route average maps of the seven nighttime runs across the Whistler route.
Map A shows the average spatial $PM_{2.5}$ patterns estimated from B_{sp} measured by the nephelometer. Map B shows the average spatial patterns of *delta C* measured by the aethalometer. The route is shaded based on average z-score, showing the relative average values of each variable during the nighttime monitoring runs. The location of the Whistler monitoring station is identified by the blue circle with the average z-score of the closest cell. The z-score break points between shading bins along with the mean z-score measured at the fixed site location are converted to $PM_{2.5}$ and *delta C* estimates (in units of µg/m^3) for the nephelometer and aethalometer data respectively.

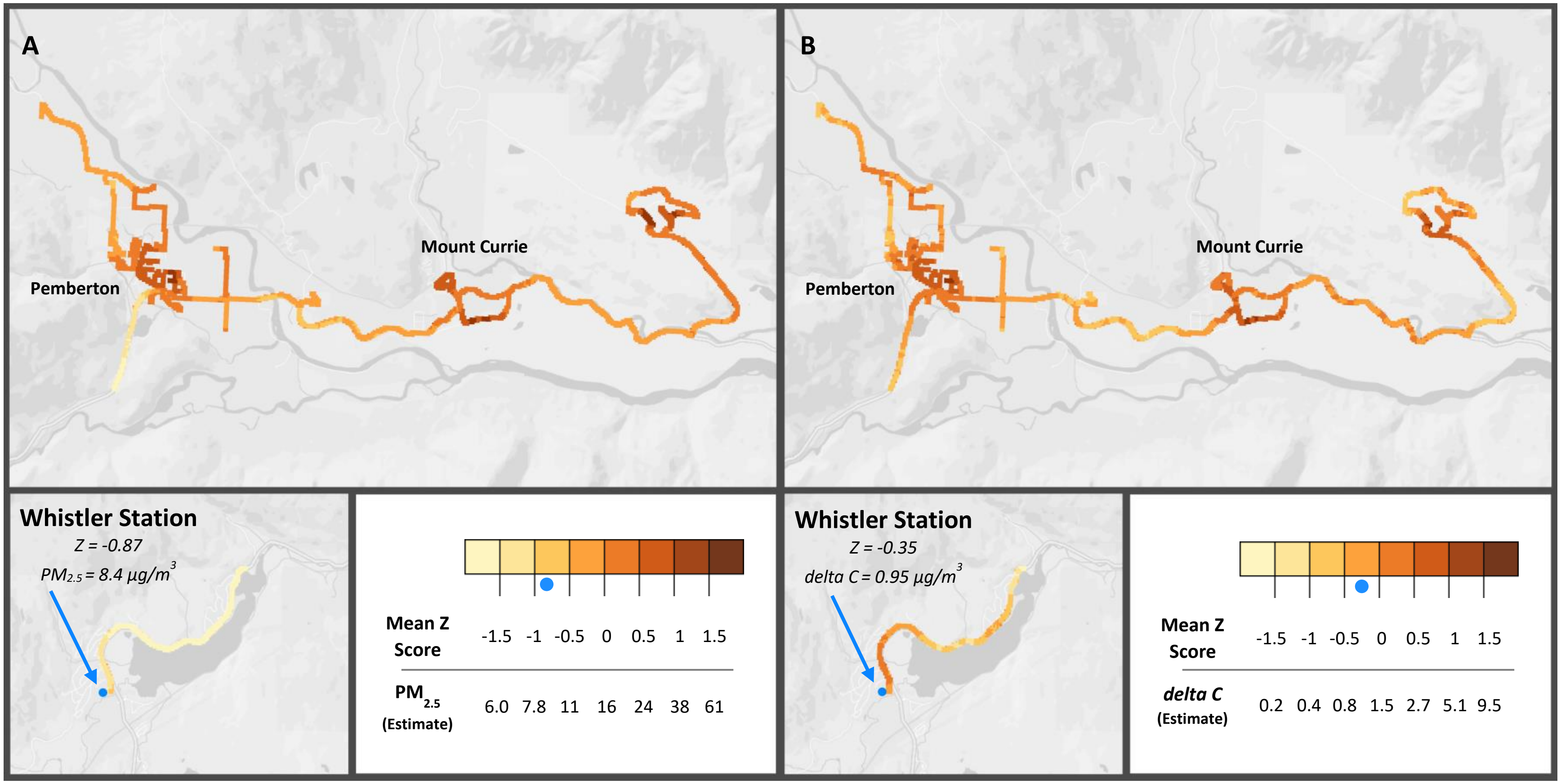


Figure 3-13: Route average maps of the seven nighttime runs across the Pemberton route.
Map A shows the average spatial $PM_{2.5}$ patterns estimated from B_{sp} measured by the nephelometer. Map B shows the average spatial patterns of *delta C* measured by the aethalometer. The route is shaded based on average z-score, showing the relative average values of each variable during the nighttime monitoring runs. The uninhabited highway section of the route between Whistler and Pemberton was removed prior to calculation of z-scores and is also cropped from this map. The location of the Whistler monitoring station is identified by the blue circle with the average z-score of the closest cell. The z-score break points between shading bins along with the mean z-score measured at the fixed site location are converted to $PM_{2.5}$ and *delta C* estimates (in units of $\mu g/m^3$) for the nephelometer and aethalometer data respectively.

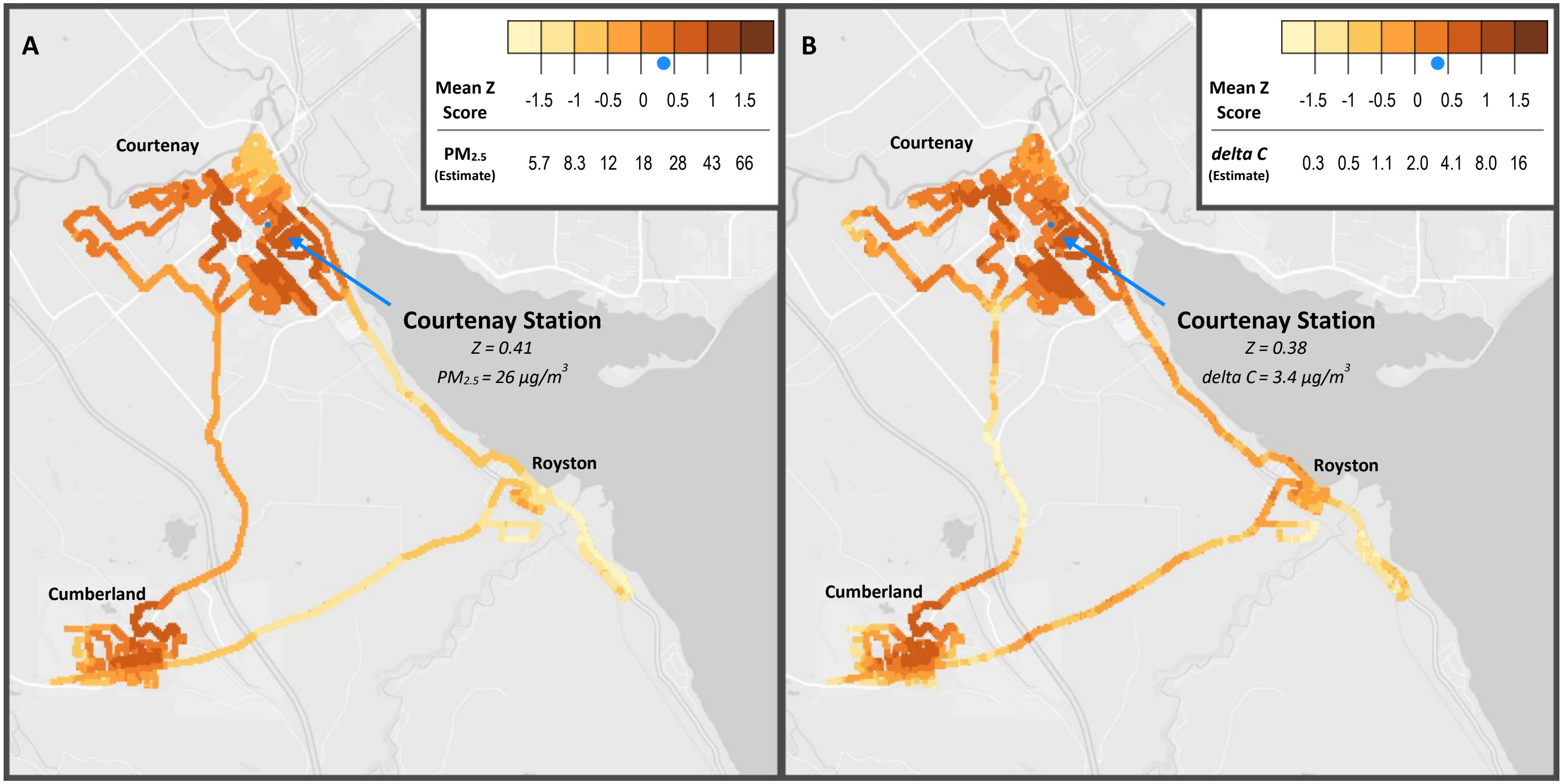


Figure 3-14: Route average maps of the seven nighttime runs across the Courtenay-Cumberland route.
Map A shows the average spatial $PM_{2.5}$ patterns estimated from B_{sp} measured by the nephelometer. Map B shows the average spatial patterns of *delta C* measured by the aethalometer. The route is shaded based on average z-score, showing the relative average values of each variable during the nighttime monitoring runs. The location of the Courtenay monitoring station is identified by the blue circle with the average z-score of the closest cell. The z-score break points between shading bins along with the mean z-score measured at the fixed site location are converted to $PM_{2.5}$ and *delta C* estimates (in units of $\mu g/m^3$) for the nephelometer and aethalometer data respectively.

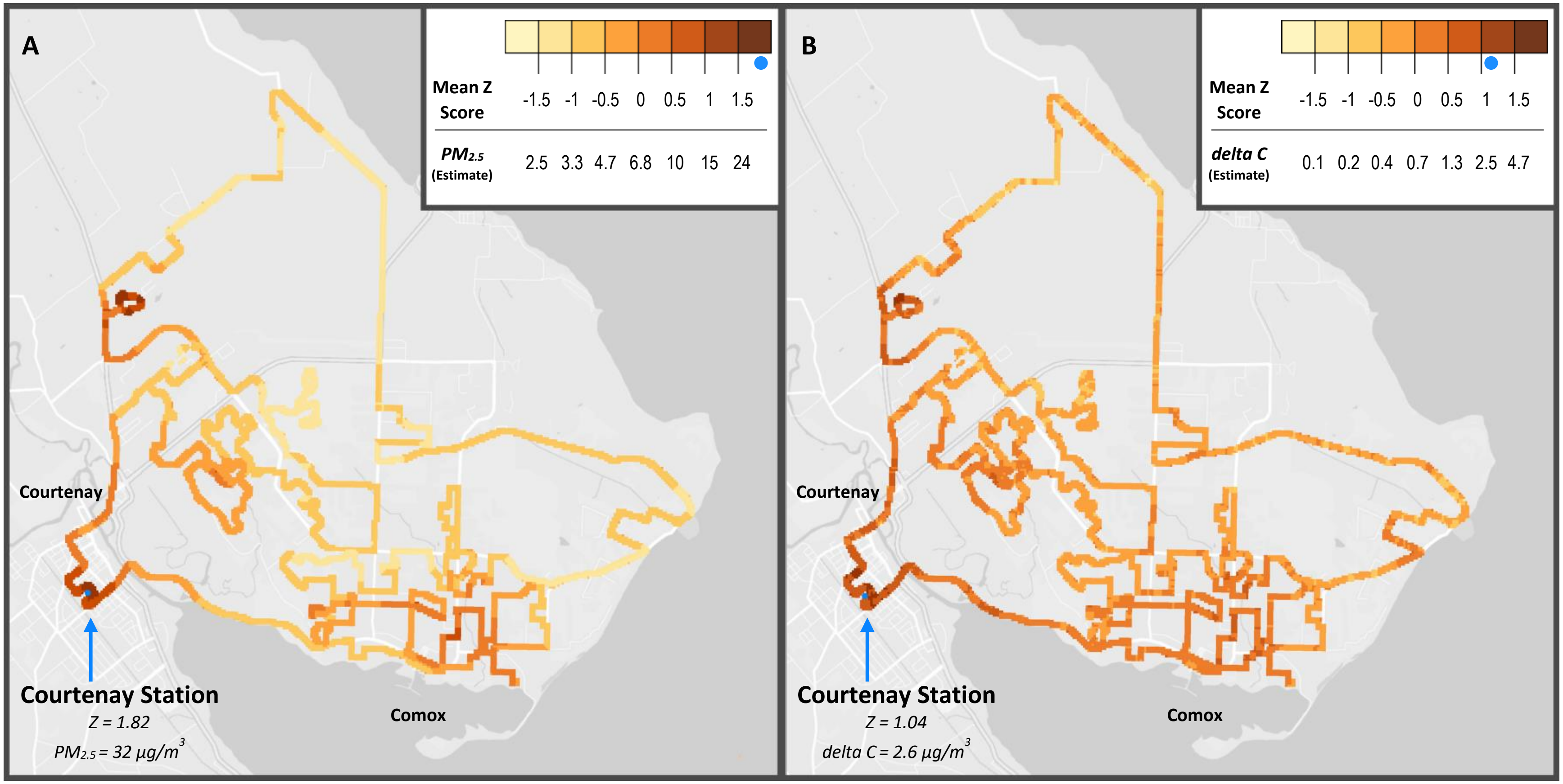


Figure 3-15: Route average maps of the seven nighttime runs across the Courtenay-Comox route.
Map A shows the average spatial $PM_{2.5}$ patterns estimated from B_{sp} measured by the nephelometer. Map B shows the average spatial patterns of *delta C* measured by the aethalometer. The route is shaded based on average z-score, showing the relative average values of each variable during the nighttime monitoring runs. The location of the Courtenay monitoring station is identified by the blue circle with the average z-score of the closest cell. The z-score break points between shading bins along with the mean z-score measured at the fixed site location are converted to $PM_{2.5}$ and *delta C* estimates (in units of $\mu g/m^3$) for the nephelometer and aethalometer data respectively.

Figure 3-16: Route average maps of the six nighttime runs across the Vanderhoof route.
Map A shows the average spatial $PM_{2.5}$ patterns estimated from B_{sp} measured by the nephelometer. Map B shows the average spatial patterns of *delta C* measured by the aethalometer. The route is shaded based on average z-score, showing the relative average values of each variable during the nighttime monitoring runs. The location of the Vanderhoof monitoring station is identified by the blue circle with the average z-score of the closest cell. The z-score break points between shading bins along with the mean z-score measured at the fixed site location are converted to $PM_{2.5}$ and *delta C* estimates (in units of µg/m^3) for the nephelometer and aethalometer data respectively.

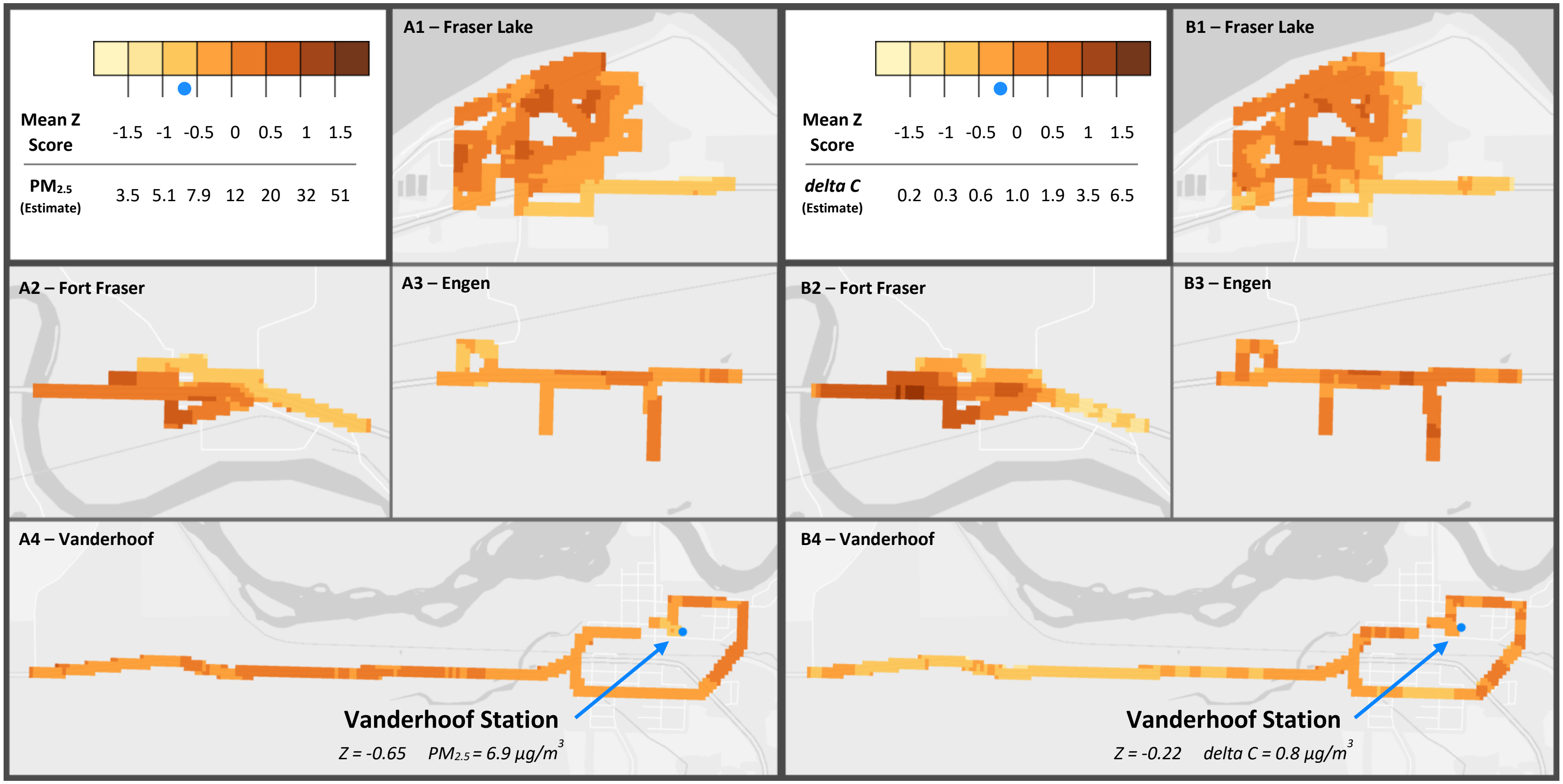


Figure 3-17: Route average maps of the seven nighttime runs across the Fraser Lake route.
Maps A1-4 show the average spatial $PM_{2.5}$ patterns estimated from B_{sp} measured by the nephelometer. Maps B1-4 show the average spatial patterns of *delta C* measured by the aethalometer. The route is shaded based on average z-score, showing the relative average values of each variable. Segments 1-4 show the four inhabited areas of the route used to calculate z-scores (mostly uninhabited sections of highway between these areas were removed prior to analysis). Segment 4 is presented on a smaller scale than segments 1-3 due to the relative sizes of communities. The Vanderhoof monitoring station is identified by the blue circle with the average z-score of the closest cell. The z-score break points between shading bins along with the mean z-score measured at the fixed site location are converted to $PM_{2.5}$ and *delta C* estimates (in units of µg/m^3) for the nephelometer and aethalometer data respectively.

3.8 **Comparison of Spatial and Temporal Variance**

The spatial variance measured during the nighttime mobile monitoring runs was significantly greater than the temporal variance measured by the fixed site instruments over the same time period in 71% of cases for B_{sp} and in 83% of cases for *delta C* (Table 3-3). Temporal variance was significantly greater than spatial variance in the B_{sp} data in 15% of runs, while this was true for *delta C* during only one of the 41 runs across all routes. No significant difference in variance was found in 15% of the runs when comparing the data from both instruments.

The results differed by monitoring route. The spatial variance across Whistler and across Pemberton was significantly greater than the temporal variance in 3 of 7 and 6 of 7 runs, respectively, for B_{sp}. For *delta C* this was true in 5 of 7 cases for each route. The temporal variance was significantly greater than the spatial variance in B_{sp} for 2 of 7 and 1 of 7 of the Whistler and Pemberton routes, respectively, while the temporal variance in *delta C* was never significantly greater than spatial variance on either route. The spatial variance across the Courtenay-Cumberland and Courtenay-Comox runs was significantly greater than the temporal variance in 5 of 7 and 3 of 7 runs, respectively, for B_{sp} and in 7 of 7 and 4 of 7 runs, respectively, for *delta C*. The temporal variance was not significantly greater than the spatial variance on any Courtenay-Cumberland runs when comparing either instrument. For the Courtney-Comox route the temporal variance was significantly greater during 2 of 7 and 1 of 7 runs for B_{sp} and *delta C,* respectively. Across the Vanderhoof and Fraser Lake routes, all routes showed significant differences between temporal variance and spatial variance. Across both routes, the temporal variance was only greater than the spatial variance during 1 of 6 Vanderhoof runs for B_{sp}, and all other comparisons showed significantly greater spatial variance.

Table 3-3: Results of the Fligner-Killeen test for homogeneity of variance used to compare the spatial variance measured during the nighttime mobile monitoring runs, and the temporal variance measured at the fixed location during the same time period.

Results show the number of monitoring runs per route that were found to have significantly greater spatial variance, no statistically significant difference in variance, or significantly greater temporal variance for each instrument comparison. An alpha level of p = 0.05 was used to determine significance.

		Nephelometer $PM_{2.5}$ Indicator			Aethalometer Woodsmoke Indicator		
Route	**No. Runs**	**Greater Spatial**	**No Significance**	**Greater Temporal**	**Greater Spatial**	**No Significance**	**Greater Temporal**
Whistler	7	3	2	2	5	2	-
Pemberton	7	6	-	1	5	2	-
Courtenay-Cumberland	7	5	2	-	7	-	-
Courtenay-Comox	7	3	2	2	4	2	1
Vanderhoof	6	5	-	1	6	-	-
Fraser Lake	7	7	-	-	7	-	-
SUM	41	29	6	6	34	6	1
FRACTION		0.71	0.15	0.15	0.83	0.15	0.02

Chapter 4: Discussion

The primary objective of this study was to test a cost-effective method designed to monitor levels and spatial variability of residential woodsmoke across communities. The secondary objective was to apply the method in woodsmoke-impacted communities to explore spatial patterns of total $PM_{2.5}$ and woodsmoke across these areas. The optical instruments used to measure total $PM_{2.5}$ and woodsmoke were compared with more established approaches at three fixed locations. The mobile monitoring method was applied across three monitored communities and three nearby unmonitored communities. This chapter first discusses research questions pertaining to the primary objective of testing this method, before discussing the results across the communities and finally making conclusions on the ability of the method to monitor residential woodsmoke.

4.1 **Summary of Key Findings**

4.1.1 Primary Objective - Testing the Mobile Monitoring Method

The two optical instruments performed well when compared with more established methods of monitoring $PM_{2.5}$ and woodsmoke concentrations at the fixed sites. Mobile monitoring using these instruments was able to capture considerable spatial variation across the communities. Comparisons of the mobile instruments show the woodsmoke-specific *delta C* measurements by the aethalometer added clarity to the total $PM_{2.5}$ patterns measured by the nephelometer, and identified areas impacted by woodsmoke.

4.1.2 Secondary Objective - Community-Specific Findings

High correlation was observed between all measures of both woodsmoke and total $PM_{2.5}$ concentrations supporting the a priori expectation that the $PM_{2.5}$ in the monitored communities was driven by residential wood burning during winter nights. This conclusion was strengthened by the strong diurnal patterns observed, which is typical of woodsmoke-impacted communities. Spatial variability was significantly greater than temporal variability in 29 and 34 out of 41 runs for B_{sp} and *delta C* respectively, highlighting the need for spatial monitoring of woodsmoke. Despite their smaller sizes and populations, concentrations of total $PM_{2.5}$ and woodsmoke in the three unmonitored communities were similar to, and in some areas higher than, those measured in the nearby monitored communities.

4.2 Can a Single-Channel Nephelometer be Used to Estimate $PM_{2.5}$ Concentrations?

A single-channel nephelometer was used in the mobile monitoring to estimate total $PM_{2.5}$ concentrations in real-time with high temporal resolution. Because the nephelometer does not measure $PM_{2.5}$ concentrations directly, the performance of this instrument was compared with $PM_{2.5}$ measurements from BAMs and gravimetric filter samples at fixed locations in the three monitored communities. In general, the nephelometer performed well as a proxy for $PM_{2.5}$ measurements, with strong correlation observed at all three locations between the 1-hour B_{sp} and BAM $PM_{2.5}$ (Figure 3-3), and between the 24-hour B_{sp} and filter-based $PM_{2.5}$ (Figure 3-4). These results suggest that the nephelometer light scattering measurements can be used to estimate total $PM_{2.5}$ concentrations during mobile monitoring.

However, the relationship between B_{sp} and BAM $PM_{2.5}$ was not entirely consistent, and the linear relationship between the instruments in Whistler had a 50% steeper slope than observed in Courtenay and Vanderhoof (Figure 3-3). Previous research has shown that the relationship between particle light scattering and $PM_{2.5}$ concentrations should be established on a site- and season-specific basis (38,46). Chow et al. compared nephelometers (a similar model to the M9003 used in this research) with $PM_{2.5}$ filter measurements at sites across California and found the relationship varied between sites during the winter, with average light scattering coefficients (B_{sp} divided by $PM_{2.5}$ concentrations) similar to the relationships observed between the B_{sp} and filter-based $PM_{2.5}$ measurements reported here (46).

While the relationship between the nephelometer and BAM differed in Whistler, the relationship between the nephelometer and filter-based measurements of $PM_{2.5}$ were more consistent between the communities. As seen in Table 3-1, the average $PM_{2.5}$ concentrations measured by the BAM in Whistler were double the average filter-based $PM_{2.5}$ concentrations, while these methods were more similar in Courtenay and Vanderhoof.

One possible explanation for differences seen between communities could be the average size fraction of the particles observed in each region. Light scattering measured by the nephelometer is dominated by the smallest particles (~0.1 – 1.0 µm) (39) and so the instrument is less responsive to larger particles in the $PM_{2.5}$ size range. In contrast, BAM measurements may be slightly affected by particle properties such as density, but more accurately respond to the full range of particles smaller than 2.5 µm. Filter-based measurements are indiscriminate of specific size range, because they simply measure the total mass of all particles collected below the size cut point of the collection device (in this case the Harvard Impactor removed any particles larger than 2.5 µm). Differences in the size range or density of particles observed in each airshed could therefore impact the observed relationships between the measurement methods. However, there is no clear reason why the average size of particles would be larger or have higher density in Whistler than in the other communities.

While the nephelometer performed well as a proxy measurement for $PM_{2.5}$ overall, because of the observed differences between communities in the relationship between the nephelometer and BAM hourly measurements, the region-specific relationships were used to convert the results of the spatial maps created using the mobile nephelometer measurements into $PM_{2.5}$ estimates during this project. In future research we would also suggest using region-specific relationships wherever possible when converting B_{sp} to equivalent $PM_{2.5}$ concentrations to account for the potential differences between regions.

4.3 **Can a Dual-Channel Aethalometer be Used to Estimate Woodsmoke Concentrations?**

The mobile method tested in this thesis used an aethalometer to collect source-specific information about total $PM_{2.5}$, specifically by measuring the woodsmoke signal known as *delta C*. Strong correlation was observed between the optical and chemical tracer methods of measuring woodsmoke at the monitoring stations in each of the three airsheds, showing that *delta C* measurements were comparable with the more established method of measuring levoglucosan concentrations (Figure 3-5). Once again, the relationship between the two measures was not consistent across the three regions. While the relationships measured in

Whistler and Vanderhoof were similar (slopes of 0.68 and 0.62 respectively), the relationship between the two methods in Courtenay was steeper (slope of 0.99). Although levoglucosan is commonly used as a chemical tracer for woodsmoke, it is not necessarily released at a consistent emission factor, and the amount of levoglucosan formed during combustion can vary based on factors such as combustion temperature, the wood type, and moisture content (4,47). If consistent differences in average combustion factors exist between Courtenay and the other two locations this could be responsible for the different relationship observed between the two woodsmoke methods.

Previous research comparing the use of *delta C* and levoglucosan has also shown differences in this relationship by location. Wang et al. measured both during winter months in Rochester, NY and reported a slope of 0.17 (levoglucosan over *delta C*) with strong correlation (R^2 = 0.89) (36), compared with the overall slope of 1.0 (R^2 = 0.90) reported here. Harrison et al. found the slope of relationships to be 0.22 at a rural site and 0.15 at an urban site in the United Kingdom, but with much weaker correlation in both cases (R^2 of 0.25 for both) (48). While both studies reported lower slopes than found in the three BC communities, they also measured much lower *delta C* and levoglucosan values. The mean levoglucosan and *delta C* concentrations measured at the three locations in this study ranged from 0.26 to 1.3 $\mu g/m^3$, and 0.46 to 1.2 $\mu g/m^3$ respectively. In comparison, the maximum 24-hour average measurements of levoglucosan and *delta C* by Wang et al. were approximately 0.1 and 0.5 $\mu g/m^3$ respectively, with most measurements much lower (36), and the 90th percentiles of levoglucosan measurements reported by Harrison et al. were only 0.14 at the rural site and 0.07 at the urban site (*delta C* values were not reported by this study) (48). These differences in the *delta C* to levoglucosan relationship between locations and studies could be caused by the varying emission factor of levoglucosan based on average combustion conditions.

During the monitoring in Vanderhoof and Fraser Lake, high levels of road dust were visibly observed, adding another source of $PM_{2.5}$. This is an annual occurrence in parts of the province where the winters are typically colder, and snow blankets the ground for longer periods. When the winter snow first melts after being on the ground for a long period, traction material that was laid on the roads during the winter is exposed and can then be aerosolised by road traffic. The presence of road dust in the Vanderhoof / Fraser Lake route pair presented the opportunity to examine the specificity of the *delta C* measurement for woodsmoke. During the monitoring runs conducted on these routes, passing vehicles visibly aerosolised road dust and the nephelometer B_{sp} readings spiked while the aethalometer readings did not respond. This is evident in the comparison of a daytime and nighttime run on the Fraser Lake route (Figure 3-10). Because there were considerably more vehicles on the road during the daytime run, many spikes are observed in the B_{sp} time series that can be identified as non-woodsmoke due to the lack of relative *delta C* response. In contrast, very limited traffic was present on the following nighttime run and both instruments respond to most of the observed high concentrations, suggesting the $PM_{2.5}$ in these areas was primarily from a biomass combustion source. This demonstrated the specificity of the *delta C* measure to capture woodsmoke only.

4.4 Can the Two Optical Instruments be Used Together to Estimate Woodsmoke Contribution to $PM_{2.5}$ Concentrations?

In previous research, chemical tracers such as levoglucosan have been monitored and compared with $PM_{2.5}$ concentrations to estimate the contribution of residential woodsmoke (16,17,49). Some studies have also used the aethalometer *delta C* indicator (13,49,50). A number of studies have attempted to establish *delta C* (or other absorption measures by an aethalometer) conversion factors to estimate concentrations of woodsmoke $PM_{2.5}$ (13,49,50). Conversions between levoglucosan concentrations and woodsmoke $PM_{2.5}$ have also been proposed (4,49). However, these conversion factors have ranged from study to study and between locations, possibility due to aforementioned variability in levoglucosan production during combustion. Therefore, the *delta C* measurements made here were left unadjusted and simply used as relative measures of woodsmoke when creating maps of the mobile monitoring data and comparing relationships between measures at the fixed sites.

To explore the contribution of woodsmoke to total $PM_{2.5}$ concentrations, the woodsmoke-specific and total $PM_{2.5}$ measures at the fixed sites were compared. First, using the relationship between the 24-hour filter-based samples (levoglucosan against total $PM_{2.5}$, Figure 3-6), and then using the relationship between the 1-hour averages of the optical measures used in the mobile method (*delta C* against B_{sp}, Figure 3-7). Similar linear correlation was found for both relationships in each community and both relationships also highlighted similar differences between the communities. The relationship in Vanderhoof had a steeper slope and weaker correlation than the other two communities, which was expected given the visible observations of road dust discussed in the previous section.

The higher temporal resolution of the optical instruments compared with the filter-based measurements allowed for the comparison of this woodsmoke to total $PM_{2.5}$ during different periods of the day (Figure 3-8). As expected, correlation between *delta C* and B_{sp} was stronger during nighttime hours, when residents are more likely to be at home and using wood-burning appliances. In general, it was weaker during the daytime hours, when fewer wood-burning appliances are expected to be operating (more residents away from their homes, and higher temperatures) and other PM sources such as traffic emissions may have an increased contribution. This finding was similar when comparing the mobile instruments during daytime and nighttime runs (Figure 3-9).

One notable difference between daytime and nighttime periods was observed in Vanderhoof, where many measurements were recorded with high B_{sp} and relatively low *delta C*, especially during the daytime hours at the fixed site (R^2 = 0.25) and during the mobile runs (R^2 = 0.0006). During daytime it is expected that woodsmoke would be reduced and road dust would be increased based on physical observations and higher traffic levels. Therefore, these findings support the ability of the comparison between the optical methods to identify times when woodsmoke is driving $PM_{2.5}$ concentrations.

While the percent of woodsmoke contribution to $PM_{2.5}$ concentrations was not specifically calculated using the *delta C* and B_{sp} measurements reported here, the study findings demonstrate that pairing of these two optical methods can provide useful semi-quantitative information on the influence of woodsmoke in a region. The similar relationships between *delta*

C, B_{sp}, levoglucosan, and $PM_{2.5}$ measured at the fixed sites also shows that the combined optical methods can estimate woodsmoke contributions with similar results to the chemical tracer method that has been more extensively used in previous research. The measurement of *delta C* also has many advantages over the chemical tracer method, including real-time measurements with high temporal resolution, and elimination of the need for expensive and lengthy laboratory analysis of samples. While there is a large initial cost to purchase an aethalometer, operating costs are minimal.

4.5 **What Information Can Mobile Monitoring Add to the Understanding of Residential Woodsmoke in Communities?**

A consistent finding between the route average maps (Figure 3-12 through Figure 3-17) was that substantial spatial variation was captured by this mobile monitoring method. Spatial variance captured by the mobile monitoring method was significantly greater than temporal variance captured at the fixed monitoring stations during 71% of the nighttime mobile monitoring runs when comparing B_{sp}, and 83% when comparing *delta C* (Table 3-3). This indicates that spatial variation is often more important than temporal variation when assessing community woodsmoke impacts and justifies the need for spatial monitoring to add context to the temporal data collected by routine air quality monitoring. Monitoring at a single location captures only a small piece of the picture in terms of population exposure within a region.

Data collected by well-designed mobile monitoring campaigns can be used to: (1) map the average spatial patterns across a region (such as the maps presented in this thesis Figure 3-12 through Figure 3-17); (2) assess the representativeness of current fixed monitoring locations; and (3) identify hotspots of consistently elevated $PM_{2.5}$ and woodsmoke concentrations.

4.6 **Is There Value in Using an Aethalometer in Addition to a Nephelometer During Mobile Monitoring?**

This study was conducted across regions previously identified as being impacted by residential woodsmoke (20), and during times when woodsmoke was expected to be the dominant $PM_{2.5}$

source. As a result, few differences were found between the average spatial patterns of total $PM_{2.5}$ (as estimated by B_{sp}) and woodsmoke (as estimated by *delta C*) on each of the six monitoring routes (Figure 3-12 through Figure 3-17). Strong correlation was also found between the 1-minute averages of the two mobile instruments during nighttime runs on the Courtenay-Cumberland / Courtenay-Comox and Whistler / Pemberton (Figure 3-9) route pairs. This may suggest that using a nephelometer or aethalometer alone during mobile monitoring may be sufficient to measure spatial patterns during these times when woodsmoke is expected to be the dominant source. However, even in these areas and during these time periods, there was still unexplained variation in this relationship between B_{sp} and *delta C*, supporting the necessity of using both instruments in tandem. This need is more obvious during times when woodsmoke is less prevalent, such as the road dust conditions experienced in Vanderhoof. During the daytime monitoring runs, correlation between the instruments was much lower (Figure 3-9), and without the use of an aethalometer it would not be possible to identify that the high B_{sp} measured in Figure 3-10 was primarily not caused by $PM_{2.5}$ from a woodsmoke source. This specificity of the *delta C* measure is valuable when attempting to measure the impact of residential woodsmoke on air quality, and it should be used in future mobile monitoring of communities where woodsmoke is expected to be a major source.

4.7 What Did We Learn About Woodsmoke in the Monitored Communities?

Results of monitoring at the ENV stations in the three monitored communities show clear patterns supporting the work done by Hong et al. to identify these communities as heavily woodsmoke-impacted during the winter months (20). The diurnal pattern of BAM $PM_{2.5}$ concentrations typically observed during winter months in communities impacted by residential woodsmoke were evident in each community during the sampling (Figure 3-2). In addition, the aethalometer *delta C* closely followed the patterns of the overall $PM_{2.5}$ concentrations. This supports the theory that these diurnal patterns are a result of woodsmoke contributions.

Daily averages of all measures at the monitoring stations (both total $PM_{2.5}$ and woodsmoke-specific) followed the same relative patterns over the monitoring campaign (Figure 3-1). The individual comparisons between them were highly correlated, supporting the assumption that woodsmoke was the dominant source of $PM_{2.5}$ concentrations in these communities during the winter. In Whistler and Courtenay specifically, linear relationships between levoglucosan and $PM_{2.5}$ on the 24-hour filter-based samples, and between the 1-hour averages of B_{sp} and *delta C* had strong correlation ($R^2 \geq 0.89$) (Figure 3-5 and Figure 3-6). The relationships in Vanderhoof followed steeper slopes in both cases (i.e. lower ratio of woodsmoke to $PM_{2.5}$) and had somewhat weaker correlation ($R^2 \sim 0.76$), suggesting woodsmoke was a less dominant source in this community during the monitoring period. Visual observations and reduced correlation during daytime patterns between the fixed and mobile instruments suggested road dust was an important $PM_{2.5}$ source in Vanderhoof during this period (Figure 3-8 and Figure 3-9). Periods earlier in the winter when the ground is snow covered may be less impacted by this source.

The levoglucosan measurements reported here were consistent with those made in other woodsmoke-impacted communities in BC. The average and standard deviation (SD) of levoglucosan measurements in Courtenay (mean = 1.31 $\mu g/m^3$, SD = 0.76 $\mu g/m^3$) were slightly lower than those measured by Weichenthal et al. in the same community during the winter of 2013/14 (mean = 1.6 $\mu g/m^3$, SD = 1.3 $\mu g/m^3$) (51). This same study also measured much lower levoglucosan concentrations in Prince George, BC (the closest large community to Vanderhoof) during the same winter (mean = 0.1 $\mu g/m^3$, SD = 0.1 $\mu g/m^3$). Another study by Millar et al. measured levoglucosan during the winter heating season across a number of small BC communities to the northwest of the Vanderhoof / Fraser Lake route pair, with mean concentrations in these communities ranging from 0.27 $\mu g/m^3$ to 1.29 $\mu g/m^3$ (16). The average concentrations in Vanderhoof (mean = 0.26 $\mu g/m^3$, SD = 0.19 $\mu g/m^3$) were double those measured by Weichenthal et al. (2017) in Prince George, which is a larger and more urban centre, but were similar to the nearby communities measured by Millar et al. (2012). The average concentrations in Whistler (mean = 0.36 $\mu g/m^3$, SD = 0.31 $\mu g/m^3$) were also within this range. All three averages were above the levoglucosan concentrations measured in more urban and less woodsmoke-impacted areas in the cities around greater Vancouver by Larson et al. in the winter of 2004/05 (17).

While the average measurements in Courtenay reported here and by Weichenthal et al (52). have been relatively higher than other measurements across BC, there are still areas where much higher average values have been measured. Bergauff et al. measured average levoglucosan concentrations of 3.0 $\mu g/m^3$ in Libby, Montana in 2004 before a comprehensive woodstove exchange program where approximately 1200 older stoves (in a community of 2700 people) were replaced with certified new stoves or alternative heating options. After the exchange, levoglucosan concentrations had been reduced by 50% with average concentrations of 1.5 $\mu g/m^3$ by the winter of 2006/07 (53). Even following this large air quality improvement, concentrations in Libby, Montana were still similar to the average concentrations that have been measured in Courtenay.

Results of the mobile monitoring showed that residential woodsmoke dominated the spatial variability in $PM_{2.5}$ concentrations as well as the temporal variability. The average route maps calculated for each instrument showed similar patterns for the $PM_{2.5}$ estimates from the B_{sp} measurements and for the *delta C* measurements (Figure 3-12 through Figure 3-17). Representativeness of the monitoring station locations is discussed in the following section.

4.8 What Did We Learn About the Spatial Patterns Across Each Community?

4.8.1 Whistler and Pemberton

The average patterns calculated across Whistler (Figure 3-12) mostly followed the residential areas on both maps, with higher levels observed in the denser area of Whistler to the east of Alta Lake, and lower levels on the west of the lake where there are fewer homes. The location of the Whistler monitoring station was slightly below the average across the Whistler route using both instruments. This was despite being located next to the neighbourhood of Alpine Meadows, which was identified as the clearest hotspot on both maps. However, the wind roses for this monitoring station (Figure 3-11) show winds mainly came from the south and not from the direction of this hotspot. This hotspot is a neighbourhood of relatively older homes and likely has a higher concentration of wood burning appliances. This contrasts with the loop in the far southwest of the route, where the lowest levels were measured in the Cheakamus Crossing neighbourhood. This neighbourhood was developed as a sustainable community for the Vancouver 2010 Winter Olympics and consists of new homes heated by a District Energy System (54). As such, it is unsurprising to find better air quality in this area during these winter evenings. While the winds were relatively calm during monitoring, they were predominantly from the southerly direction, which likely contributed to these lower levels at the south of the map.

The Whistler monitoring station was not representative of the conditions in Pemberton during the monitoring campaign, with higher levels observed across the Pemberton valley during the nighttime monitoring runs (Figure 3-13). As with the Whistler route, substantial variation was observed across the Pemberton route, and three hotspots were identified by both instruments. The first was within the densest part of Pemberton on the west of the maps, while the others were within the Lil'wat First Nation communities of Mt. Currie and Xit'olacw. At the time of writing there are no gas lines connected to the Pemberton valley, so residential heating options in this area are restricted to electric heat, imported propane or fuel oil, and wood burning appliances. This likely leads to higher rates of wood burning for home heating.

4.8.2 Comox Valley Communities

The nephelometer and aethalometer maps showed similar smoke hotspots throughout the Courtenay-Cumberland route, particularly in the centre and southeast of Courtenay and the northeast of Cumberland, both of which are quite dense residential areas (Figure 3-14). Winds during this route were predominantly from the west (Figure 3-11) and may have contributed to the Cumberland values being higher in the eastern part of the community. Similar hotspots were again identified by both instruments on the Courtenay-Comox route, with high concentrations in downtown Courtenay and areas around the monitoring station, along with a small residential area in the northwest of the map (Figure 3-15). A previous mobile monitoring campaign in the Comox Valley in 2009 did not produce average patterns across their monitoring runs, but individual route maps appear to highlight similar hotspots in the centre and southeast of Courtenay, along with the northeast of Cumberland, as well as a similar trend of higher concentrations in Courtenay compared with Comox (18).

The Courtenay monitoring station fell above the averages for both instruments on both routes, especially on the Courtenay-Comox route where the z-scores were 1.82 and 1.04 for the $PM_{2.5}$ and *delta C* maps, respectively. This result suggests that the location of the monitoring station in Courtenay may read higher than many areas across the airshed during winter nights. Despite the relatively high z-scores around the monitoring station, other areas of both routes had even higher average values. Comparing these routes is difficult as they were monitored on different nights with quite different average conditions. However, the higher z-score of the monitoring station on the eastern Courtenay-Comox map relative to the Courtenay-Cumberland map suggests that many areas of the Courtenay-Comox route have lower average concentrations than the areas of the Courtenay-Cumberland route that have relative $PM_{2.5}$ and woodsmoke concentrations greater than at the monitoring station. This highlights the importance of route mapping in the overall method. Because it is difficult to compare directly between routes, monitoring should be designed to cover an entire community of interest as thoroughly as possible.

The high z-scores of the Courtenay monitoring station raise the question of how such locations are identified. Is the objective to provide information about the average exposure of the community? Or is the objective to measure conditions in highly-impacted areas to inform air quality improvements? This method cannot answer these questions, but it highlights the amount of additional information that spatial monitoring can add to temporal monitoring at a single site, which can be invaluable when making decisions regarding regulatory air quality monitoring in an airshed.

4.8.3 Vanderhoof and Fraser Lake

The Vanderhoof maps also showed spatial patterns mostly following the population density in the area, with the less populated outlying areas to the south showing lower z-scores for both instruments (Figure 3-16). Areas north of the highway had higher concentrations than those to the south, and hotspots were visible in the northeast and northwest of the route section south of the Nechako river. The hotspot in the far northwest of the $PM_{2.5}$ map was much less extreme on the *delta C* map. Although woodsmoke from the surrounding homes contributed to the $PM_{2.5}$ measured in this area (as it is slightly elevated on the *delta C* map), this section of road was unpaved, and dust was likely responsible for the $PM_{2.5}$ hotspot. In addition to Fraser Lake, this route covered the smaller community of Fort Fraser and the very small neighbourhood of Engen. The maps from this route show small hotspots in the north and west of Fraser Lake, as well as the western end of Fort Fraser (Figure 3-17). The section of Highway 16 entering and leaving Vanderhoof shows lower z-scores on the aethalometer map, which may indicate that higher values on the nephelometer map were caused by road dust on this section.

Average concentrations at the Vanderhoof station were below the average $PM_{2.5}$ concentrations on both routes, but similar to the average *delta C* values. This difference in z-scores calculated around the monitoring station by the two instruments is not as surprising given the lower correlation between the two instruments during mobile monitoring in this region (Figure 3-9). The $PM_{2.5}$ levels around the station could be lower than the route averages due to very high values calculated in specific areas of the route increasing the route mean, even though the data were log-transformed. The maximum cell values on the map were up to 18 times the cell value at the fixed site on the Vanderhoof route, and five times higher on the Fraser Lake route. The Vanderhoof monitoring station is surrounded by commercial buildings and a school with a large open field, with few residential buildings and wood burning appliances nearby. Even so, the monitoring station fell near the mean of the *delta C* route average map. This finding is likely influenced by the areas included in the route, with the low *delta C* averages of the more outlying areas to the south acting to decrease the route mean. When examining the spatial patterns around the monitoring station more closely, the station location had some of the lowest average *delta C* values in the densest section of the community that is between Highway 16 and the Nechako river. This matches the expectation of lower values around the monitoring station (due to limited wood burning nearby, as described above), and the pattern of concentrations following residential areas as the rest of this area is mostly residential. This again highlights the importance of planning routes that are as representative as possible of the entire community when displaying results on a relative scale.

4.9 What Did We Learn About Woodsmoke in the Unmonitored Communities?

In general, the unmonitored communities had concentrations comparable with and, in some areas, greater than the monitored communities. The average of the $PM_{2.5}$ and *delta C* estimates generated for the maps of the Pemberton and Fraser Lake routes were all higher than the relative values at the location of the monitoring stations in the paired monitored community (Figure 3-13 and Figure 3-17). While Cumberland was not covered by an independent route, the B_{sp} and *delta C* values of the hotspot from the center to the northeast of the community were higher than the average values measured around the Courtenay monitoring station and were comparable with identified hotspots in Courtenay.

Considerable spatial variability in both B_{sp} and *delta C* was also measured across the unmonitored communities. Spatial variance was considerably greater than temporal variance at the nearest monitoring station during six of the seven Pemberton runs when comparing B_{sp} measurements, and five of seven when comparing the *delta C* measurements. The same comparison on the Fraser Lake route found significantly greater spatial variance than temporal variance during all runs for both mobile instruments (Table 3-3). The spatial patterns across the $PM_{2.5}$ and *delta C* maps for each of these unmonitored communities were similar, suggesting woodsmoke was driving $PM_{2.5}$ during these winter nights.

These results show that residential woodsmoke is an air quality concern in unmonitored communities, and that the mobile methods tested here can be used to assess the impacts. Data on the range of values across these communities, the spatial variability, and the $PM_{2.5}$ and woodsmoke hotspots can be particularly valuable for communities without other forms of monitoring.

4.10 **Conclusions on Mobile Method**

The mobile monitoring method developed in this thesis using both a nephelometer and aethalometer effectively captured valuable spatial data on approximate $PM_{2.5}$ concentrations and the contributions of residential woodsmoke across a region. The testing of this method in three community pairs showed that it can be applied to complement existing fixed site monitors or to quickly characterise approximate conditions in otherwise unmonitored areas. Strengths and limitations of the method are discussed below.

4.10.1 Strengths of the Method

This mobile monitoring method has many strengths. First, it was able to capture significant spatial variability with high resolution across the testing communities, such that the average patterns of relative $PM_{2.5}$ and woodsmoke could be mapped. This allowed for the identification of hotspot areas with consistently elevated values. The relatively novel use of a dual-channel aethalometer in mobile monitoring (previously tested by Allen et al. (13)) and the measurement of the woodsmoke indicator *delta C* in addition to B_{sp} can provide strong evidence that woodsmoke is a significant source in a region. Both instruments used in the mobile method were well-correlated with more established measurement methods and the B_{sp} measured by the nephelometer could be converted to estimated $PM_{2.5}$ concentrations based on site-specific relationships.

In addition to providing spatial context around established monitoring stations, the testing of this method in three unmonitored communities showed that it is a good option for characterising $PM_{2.5}$ and residential woodsmoke in such areas. By itself, this method can give an overview of spatial variability across a community, comparing relative patterns of total $PM_{2.5}$ and woodsmoke, and it can provide estimates of the true exposures within these communities. While measurements can only be considered semi-quantitative (as they are only measured over a short time period), data collected in this way could be compared with nearby monitored communities and adjusted using temporal patterns in those areas.

Two other strengths of this method are its lower cost and ease of use compared with chemical analysis and fixed site monitoring. While the initial cost of an aethalometer similar to that used in this mobile method is considerable at approximately $30,000, operating costs of this instrument are negligible. In contrast, analysis of each filter sample for levoglucosan costs $95 per filter. This led to a total cost of approximately $45,000 over the course of this study, greater than the initial cost of the aethalometer (which can continue to be used in future research). Therefore, the aethalometer is a cheaper option to monitor woodsmoke concentrations than levoglucosan, and as shown in this research, can provide comparable results with much greater resolution. Personnel costs are higher for mobile monitoring than fixed site monitoring as a longer time commitment is required each day (approximately three hours per mobile monitoring run, compared to one hour to prepare impactors and change filters at a fixed site). However, the ease of use of the instruments used in this method limited this cost as only one operator was necessary for mobile monitoring runs (in this study I conducted all mobile monitoring alone) and the added benefit of high spatial resolution can be invaluable. The ease of use of the method also presents the opportunity to reduce the cost of the method further by making the method and equipment available for community volunteers to use as part of a citizen science project. Involving community members with air quality monitoring in this way will also increase engagement with air quality issues on a local scale. These strengths make the method an option moving forward to apply in small communities lacking monitoring across Canada.

4.10.2 Limitations of the Method

Due to several limitations of this mobile monitoring method, the values associated with the resulting route average maps are semi-quantitative. Primarily, the method is limited in its inability to monitor whole communities simultaneously. This introduces error into the measurements, because temporal variation cannot be measured by mobile instruments and many other unmeasured variables may affect the data. In the most extreme example, all of the variability measured by the mobile instruments could actually be due to temporal variation rather than spatial differences. Ideally, any such air quality assessment would incorporate both high spatial and high temporal resolution by having many continuous monitors installed across a region. However, this is generally not feasible due to the associated costs of purchasing and operating so many instruments. While the method used here was designed to provide a more cost-efficient option, it is limited by its inability to control for the temporal variation at all measured locations.

Steps were taken during the development of this method to minimise limitations related to temporal variation. First, the monitoring schedule was focused on a specific time of day, and seven monitoring runs were driven on each route to assess average spatial patterns rather than short-term patterns. Second, the driving direction of each route was alternated to reduce the impact of any consistent temporal patterns by averaging these out across multiple trips.

While high spatial resolution can be achieved with the 1-second measurements recorded by the mobile aethalometer, the light scattering estimation of total $PM_{2.5}$ recorded by the nephelometer is limited by instrumental smoothing. The nephelometer used in the mobile monitoring measured light scattering of the current air sample, but it took approximately 23 seconds for the air to be completely replaced. This lag reduces the immediacy of response and naturally smooths the 1-second measurements. However, by recording the raw 1-second readings using a serial connection to a laptop (rather than using the 1-minute averages reported by the instrument), the data were more accurately assigned to the locations at which they were measured before the spatial averaging.

The difference in independence of the individual measurements between the instruments is visible when comparing the final route average maps. Increased variation from cell-to-cell is observed in the aethalometer maps (most clearly seen in straight road sections) compared with the nephelometer maps. Additionally, areas that are high or low on both maps were often more extreme in either direction on the nephelometer maps due to the instrumental smoothing of B_{sp} values. While driving direction was alternated primarily to avoid monitoring the same areas at the same time of day, it also served to reduce the impact of this instrumental smoothing on the nephelometer maps because values were smoothed in each direction from areas with consistently higher or lower readings.

The methods chosen to calculate and represent the route average maps also have a number of limitations. Efforts were initially made to adjust the mobile data for temporal variation at the fixed locations (using methods similar to Equation 2-1), but this approach led to over exaggeration of heavily impacted areas in the route average maps, and there is no evidence to show that the temporal variation at the fixed locations can be extrapolated across the region for this purpose. The method of calculating z-scores for the data recorded by the two instruments during each monitoring run was chosen to extract the relative value of each measurement. Because z-scores are relative values, the route average maps show how each area compares with the rest of the route, which increases the importance of the monitoring route design. Using the z-scores method also required log-transforming the mobile data, which meant the legends of the route average maps are based on an exponential scale and are more difficult to interpret for community members. The calculation of the z-score equivalents for the map legends are only rough approximations, because the reverse calculation was performed on different distributions than were used to calculate the z-scores. Specifically, the z-scores were calculated for each run and then averaged, while the map legends were calculated using the data from all runs. Despite these limitations, the use of z-scores removes the need for a fixed monitor in future applications of this method, increasing the feasibility of its implementation in a wide range of communities.

Chapter 5: Conclusion

This thesis successfully met the primary objective of testing the ability of a cost-effective mobile monitoring method to characterise residential woodsmoke within affected communities. It also met the secondary objective of measuring the average spatial patterns and influence of woodsmoke in three sets of monitored and unmonitored communities in BC.

The method was able to measure spatial variability with high resolution in both total $PM_{2.5}$ using a nephelometer and in woodsmoke using a multi-channel aethalometer. These two instruments performed well when compared with more established methods of monitoring total $PM_{2.5}$ (BAM and filter-based measurements) and woodsmoke (levoglucosan). When used together, they provided valuable information on the relative contribution of woodsmoke to $PM_{2.5}$, both temporally at the fixed site monitoring stations and spatially as part of the mobile method. The mobile method also performed well in unmonitored communities and should be a valuable tool to quickly and cost-effectively characterise air quality for other such communities in the future.

Residential woodsmoke was the dominant driver of $PM_{2.5}$ in each of the community pairs, with strong correlation between relative woodsmoke and $PM_{2.5}$ concentrations both temporally and spatially. Diurnal patterns of $PM_{2.5}$ commonly observed in woodsmoke-impacted communities were evident in the three monitored communities, and the *delta C* measurements indicated that daily peaks were caused by wood combustion. Woodsmoke was somewhat less dominant in Vanderhoof, with more unexplained variation in the woodsmoke-$PM_{2.5}$ relationships than observed in Whistler and Courtenay. This was attributed to the effect of road dust as a secondary major source of $PM_{2.5}$ during the monitoring period. The highest average concentrations of each measurement at the fixed sites were measured in Courtenay, where comparatively high average levoglucosan concentrations have also been measured in previous research (29).

Testing of the mobile method in three unmonitored communities found $PM_{2.5}$ and woodsmoke concentrations comparable with those in the paired monitored communities, despite their smaller sizes and populations. In many areas these concentrations were higher than the concentrations measured at the nearest monitoring stations.

Significant spatial variation measured by the mobile method across each monitoring route showed how one fixed monitoring station in a community is unable to capture the range of air quality experienced within a community at any given time. Spatial variance in total $PM_{2.5}$ concentrations was significantly greater than temporal variance at the monitoring stations during 71% of the nighttime monitoring runs across all routes. For woodsmoke this was true in 83% of cases. This demonstrates the importance of measuring spatial variability when monitoring air quality, especially in communities where residential woodsmoke is an important source, and it justifies the need for spatial monitoring using methods similar to those tested here.

Identification of woodsmoke hotspots can be valuable for communities and those responsible for air quality management. Such data can be used to inform and target the design of source-control efforts to improve air quality in a region. The highly resolved spatial maps achievable with this method could also be combined with health outcomes data in future research.

Following the success of this method in the field monitoring campaign during the winter of 2017, plans were made to make the method and necessary equipment available to community groups across the province. Training materials were created along with computer programs that simplify set-up during monitoring and automatically produce route average maps based on the monitoring data. This makes the method as accessible as possible for users with limited data collection and analyses experience. These tools were successfully trialled with volunteers applying them in both Valemount and Golden during early 2018, with minimal support from project investigators. The methods will be made more widely available to other groups as of winter 2019.

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Appendices

Appendix A **- Woodsmoke Mobile Monitoring: Full Protocol**

Woodsmoke Mobile Monitoring:

Full Protocol

Protocol created as part of an MSc Thesis by: **Matthew Wagstaff**

With support from:

Health Canada

BRITISH COLUMBIA Ministry of Environment and Climate Change Strategy

THE LUNG ASSOCIATION™ British Columbia

Table of Contents

1. Introduction

Smoke from residential wood burning is a leading contributor to fine particulate matter ($PM_{2.5}$) pollution in British Columbia (BC) and has been shown to impact respiratory and cardiovascular health. During the winter heating season, many BC communities often approach and exceed provincial and national standards for $PM_{2.5}$ concentrations due to high rates of wood burning combined with geographic locations where there is a tendency for inversions to form and trap cold stagnant air.

While the BC Ministry of Environment and Climate Change Strategy (ENV) air quality monitoring network collects valuable data of air pollutant concentrations (such as $PM_{2.5}$) at monitoring stations across the province, it is not feasible to install and maintain multiple stations in every community. As a result, no data is collected on air quality in smaller communities, and larger communities typically have data from a single location at most. This is an important limitation as air quality can differ considerably across communities where residential wood burning is prevalent, as there are many small point sources within the community. For example, areas within a community with higher numbers of wood-burning appliances will likely have higher $PM_{2.5}$ levels than other areas with limited wood burning. This spatial variation cannot be captured by the ENV air quality monitoring network and so it is hard to know whether the data collected at each ENV monitoring station accurately represents the air quality levels across that community.

To be able to measure the spatial air quality patterns across communities in the province and add context to data from the ENV network, a mobile monitoring method was developed and tested by researchers at the University of British Columbia with support from Health Canada, the BC Lung Association, and the BC Ministry of Environment.

In addition to measuring air quality patterns across a community with high spatial resolution, the method was also designed for use in small communities that currently lack monitoring stations to obtain a snapshot of air quality patterns in those communities. In these smaller and more rural BC communities, wood burning is typically more prevalent and therefore measuring air quality patterns across these communities is important.

This protocol is designed to help the user implement this method and monitor air quality patterns across their community of interest.

2. Protocol Summary

This protocol is designed to guide the user through conducting a mobile monitoring campaign to measure residential woodsmoke patterns across a community. The protocol will guide you through: planning and preparing for the campaign, operating the instruments, conducting the monitoring itself and finally data management, analysis and interpretation of results.

2.1 Included Equipment

As a registered user of this method you will receive the following equipment necessary to conduct your monitoring campaign:

- **Aethalometer** – Magee Scientific AE33 – *to measure woodsmoke in air samples*
  - Power Cord
  - Air Inlet Tubing and Connectors
  - $PM_{2.5}$ Selective Cyclone
  - Water Trap
  - GPS Receiver and Cords
  - USB Data Stick (containing instrument manuals and for data download)
  - Transportation Case

- **Nephelometer** – Ecotech Aurora 1000 – *to estimate* $PM_{2.5}$ *in air samples*
  - Power Cord
  - Serial Communication Cord and USB Adaptor
  - Air Inlet Tubing and Funnel
  - Transportation Case

- **Vehicle Power Inverter –** Nexxtech **–** *to power the instruments in a vehicle during monitoring*

- **GPS Navigation Device** – Garmin Nuvi 2497 – *to provide driver with route directions*
  - Vehicle Charging Cable
  - Window Holder
  - USB Cable

2.2 Instrument Overview

Two optical instruments are used in this method to collect different data on fine particulate matter ($PM_{2.5}$) in an air sample. A nephelometer measures an estimate of total $PM_{2.5}$ concentrations, while an aethalometer measures the relative amount of woodsmoke in the air. For further information refer to the descriptions below.

Nephelometer – *Ecotech Aurora 1000*

A nephelometer can provide a real-time estimate of the amount of $PM_{2.5}$ in the air by measuring the amount of light scattered by these particles (which is well correlated with the concentration). This effect is what causes the haze associated with smoke and is why visibility is generally reduced on smoky days.

To measure the amount of light scattering, the instrument draws an air sample into a sealed dark container, and then shines a light beam through it with sensors set at an angle to measure scattered light. If there were no particles in the air most of the light would pass straight through, but more and more of the light is scattered in different directions as the concentration of $PM_{2.5}$/number of particles in the air increases. The general concept is illustrated in Figure 1 below.

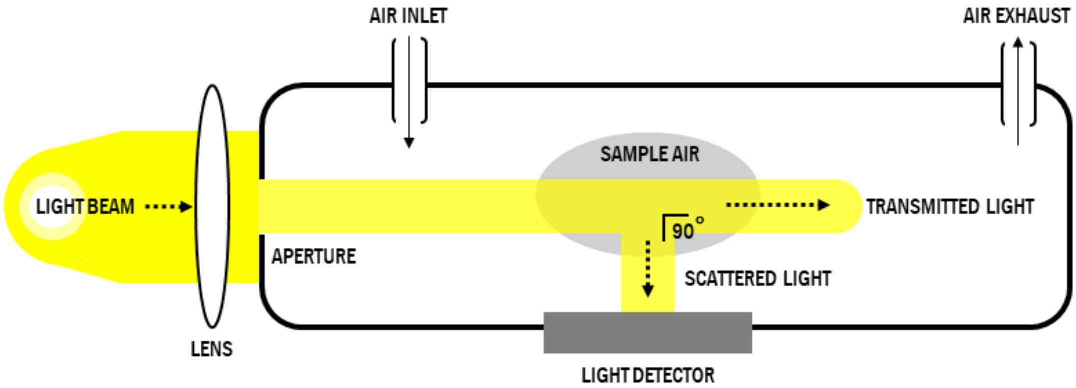


Figure 1: Nephelometer Function Diagram. Light is shined through the air sample, and the amount of light that is scattered by particles in the air is measured.

Aethalometer – *Magee Scientific AE33*

An aethalometer is used to provide more information about the chemical make-up (and therefore the potential source) of a $PM_{2.5}$ sample rather than just measuring the total amount. To collect data on just $PM_{2.5}$ (particles smaller than 2.5µm in diameter), a size selective cyclone is attached to the air inlet tubing to filter out any particles larger than this. The aethalometer deposits $PM_{2.5}$ from sample air onto a quartz filter tape, and then shines multiple wavelengths of light through the sample to measure how much of each wavelength is absorbed by the sample. The differences in absorption at different wavelengths can tell us a lot about the chemical composition and potential source of a sample.

In this case we are interested in the amount of $PM_{2.5}$ that is created by residential wood combustion. While the aethalometer measures absorption of seven wavelengths, we are specifically interested in the difference between the 880nm band (which is known as BC and measures absorption by black carbon), and the 370nm wavelength band (which is known as UVC and measures the ultraviolet absorption). This difference is known as Delta C and has been shown to be a good indicator that the $PM_{2.5}$ sample was likely created by wood burning. Figure 2 below demonstrates this and shows how the aethalometer responds to two different sources of PM. The plot on the right shows a test using a diesel generator as a PM source, and here there is little difference in absorption between the wavelengths (the seven wavelength bands are difficult to see as their values are so close). But when the instrument is measuring PM created by wood burning in the plot on the left, the UV band (shown in red) is significantly higher than the BC band (in grey) at the times when smoke was measured by the instrument, and this difference (shown by the blue arrow) known as Delta C can be measured.

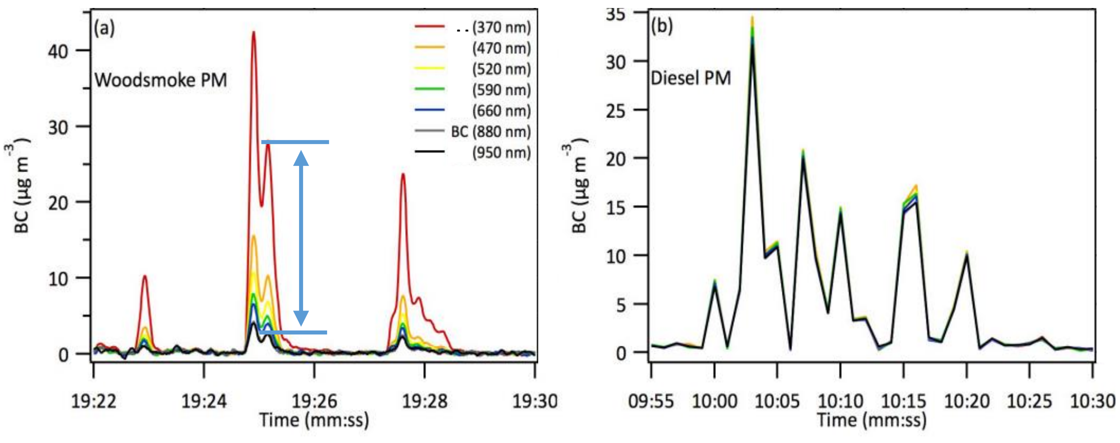


Figure 2: Aethalometer response over time to two different PM sources.

Adapted from: Zhang, K. M., Yang, B., Chen, G., Gu, J., Schwab, J., Felton, D., and Allen, G.: Joint Measurements of PM2.5 and light-absorptive PM in woodsmoke-dominated ambient and plume environments, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2017-213, 2017.

2.3 Monitoring Campaign Overview

For clarity, here is an overview of the steps involved with a monitoring campaign using this method.

1. **Prepare for Monitoring**:
   1.1. Plan monitoring campaign schedule
   1.2. Plan monitoring route
      - Enter monitoring route into Garmin Basecamp software and add to the GPS Navigator
   1.3. Prepare a laptop and data management
   1.4. Set up instruments and confirm settings are correct
   1.5. Check calibrations of instruments
      - Aethalometer – *Stability Test* and *Clean Air Test*
      - Nephelometer – *Zero Check (and Zero Adjust)*
   1.6. Set up a vehicle for the monitoring campaign

2. **Individual Mobile Monitoring Run:**
   2.1. Heat vehicle and instruments
   2.2. Prepare the nephelometer
   2.3. Prepare the laptop connections and notes file
   2.4. Prepare aethalometer and GPS device
   2.5. Start GPS Navigator
   2.6. **Pre-Run Checklist**
   2.7. **Drive the route! – *(the actual monitoring)***
   2.8. End of run – save data and shut instruments down

3. **Post-Monitoring Campaign:**
   3.1. Data download – Nephelometer backup and Air Quality Network
   3.2. Use the Shiny application to map the monitoring data
   3.3. Interpret the maps
   3.4. Return instruments

3. Preparing for Monitoring Campaign

3.1 Planning Monitoring Campaign Schedule

Monitoring of residential woodsmoke should be conducted during the winter months when wood heating appliances throughout a community will be in use. Mobile monitoring runs should be scheduled for evenings when wood heating appliances have been active for a few hours and concentrations will have built up, for example starting around 8-9pm. To limit the effects of other variables, monitoring runs should be scheduled for both weekday and weekend evenings over at least one week and the weather during this period should be recorded. To avoid always monitoring the same areas at the same time, monitoring routes should be driven in alternating directions each evening. Conducting mobile monitoring runs during the day can also collect useful data to compare to the night time results (but this is optional).

To avoid unnecessary complications, inform the local RCMP / Police department of your plans to repeatedly drive slowly along residential streets, include details of your schedule and a vehicle description. Residents may be concerned if they recognise a vehicle slowly driving their small streets every night.

3.2 Planning Monitoring Routes

Planning you monitoring route is a major component of the preparation for a mobile monitoring campaign. Final results will show $PM_{2.5}$ and woodsmoke concentrations relative to other areas on the driving route, and therefore you want to ensure that the route represents the community as much as possible, focusing on more populated areas. To identify important areas to include in routes it is best to make use of multiple information sources such as local knowledge and satellite imagery (eg. Google Earth).

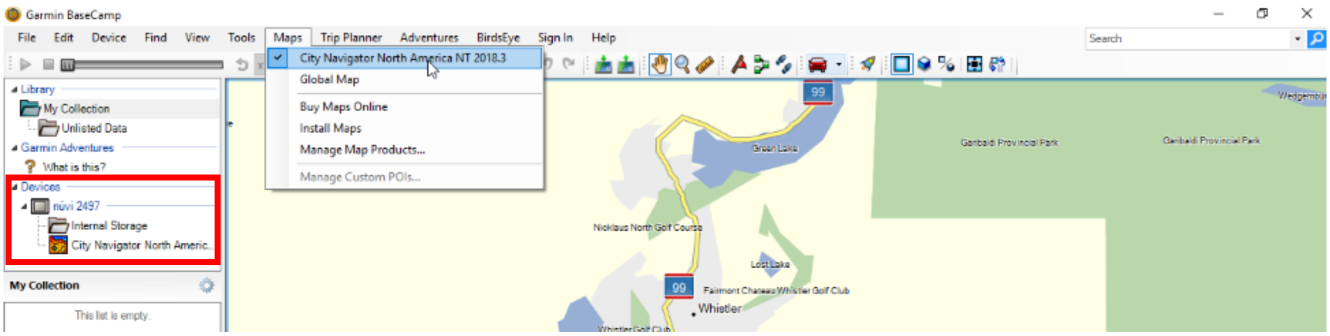
Key considerations when planning monitoring routes:

- Monitoring routes should cover as much of a community as possible within a reasonable time frame to limit variation in conditions (aim for no more than 1.5 hours).
- Try to make routes as continuous as possible (e.g. aim for loops and minimise U-turns) to prevent stop and go driving. Ideally data wants to be collected evenly across the route.
- If there is an air quality monitoring station in the area it is advisable to start and finish the route parked as close to the monitoring instruments as possible to compare data.

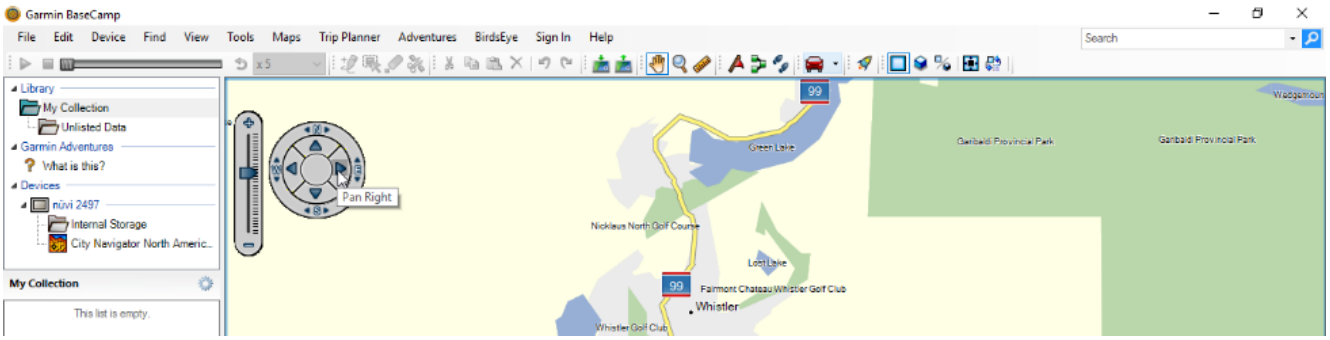
3.3 GPS Navigator Setup – Creating Monitoring Routes

Garmin Basecamp is a free software program that can be used to pre-plan routes that can be saved to a Garmin GPS navigation device to provide the mobile monitoring driver with directions throughout the routes. This software is relatively easy to use and is available for free download at: https://www.garmin.com/en-CA/shop/downloads/basecamp .

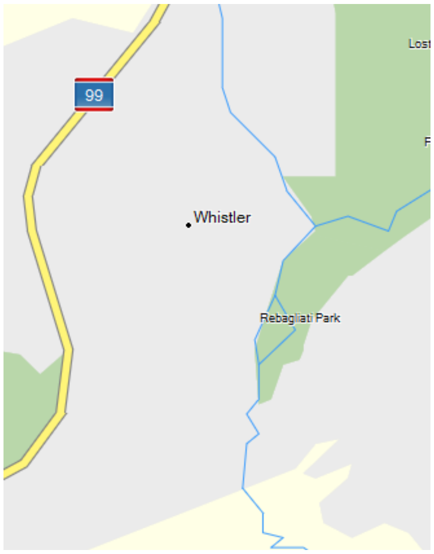
Only very basic maps showing major roads are available in the Garmin Basecamp software and so to be able to see more detail with which to plan routes, it is necessary to first connect a Garmin navigation device to the computer using the included USB cable. When the device is recognized you will see it appear in the upper left-hand panel under devices (in this screenshot the nuvi 2497 within the red box). To ensure the correct map is selected, click on *Maps* in the menu bar and select '*City Navigator…*' .

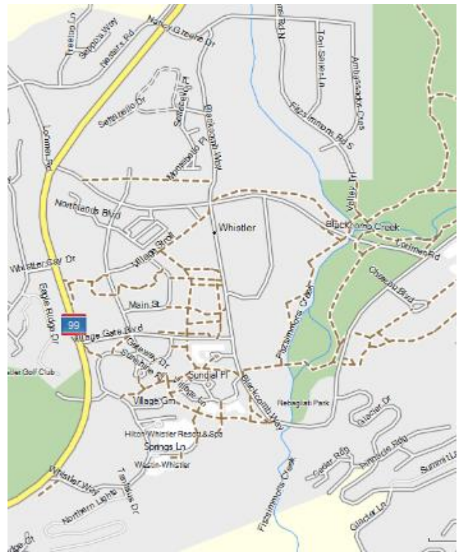


To navigate in the Basecamp software, select the *Pan* icon (image of a hand) in the toolbar to be able to click and drag the map around, or hover the mouse over the blue north arrow in the top left of the map window to bring up the zoom and pan arrow buttons (shown in the screenshot below) which you can use to move the map.

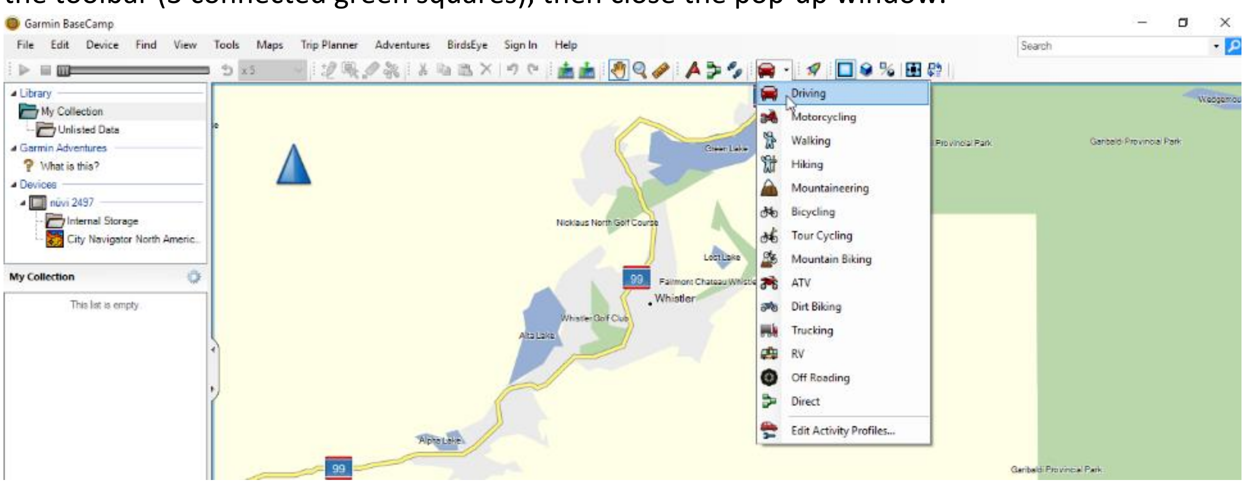


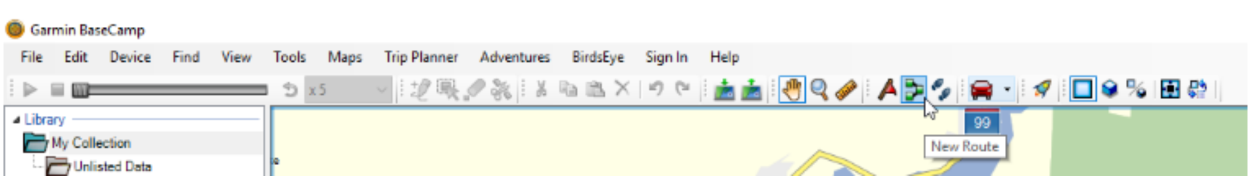
Maps in the Garmin Basecamp software are saved in layers and show more detail as you zoom in. If you are only seeing major roads, zoom in and local roads will appear. The two screenshots below show the difference between a single layer when zooming in (right image is more zoomed in) on Whistler, BC.



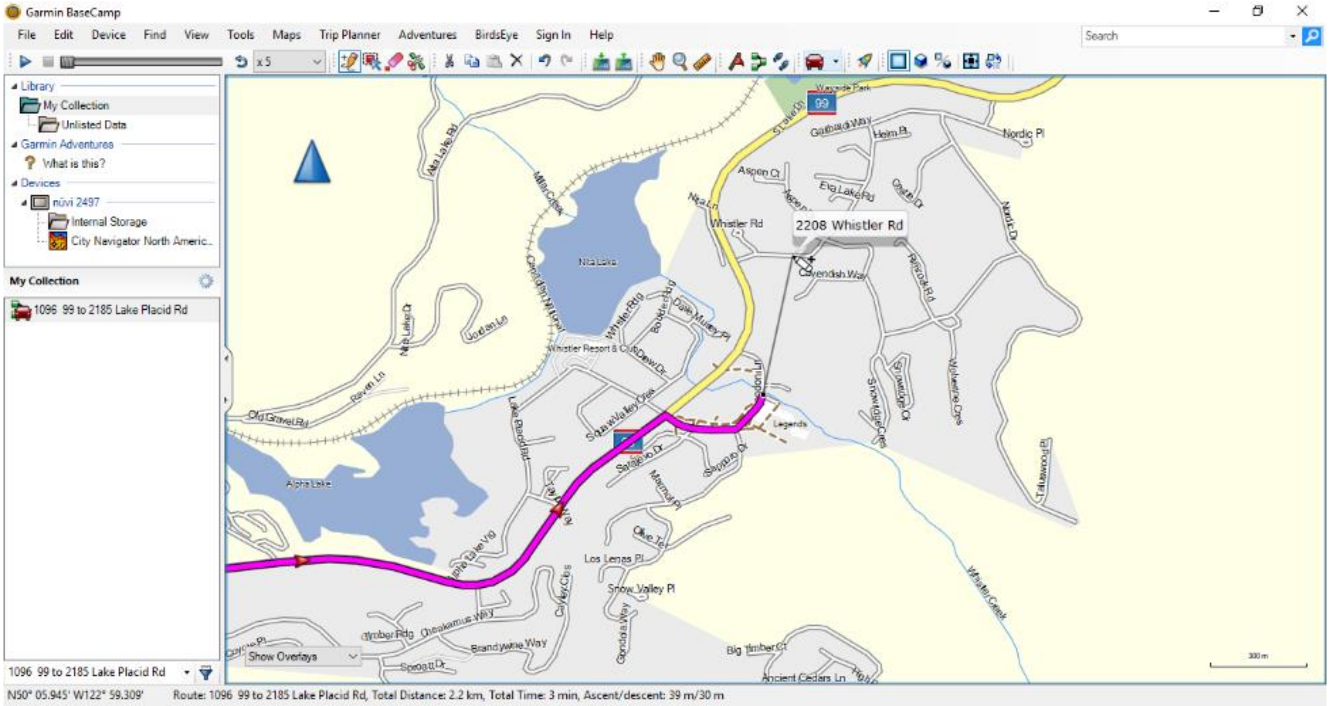


To create a new route, change the *Activity Profiles* button to *Driving,* then select *New Route* in the toolbar (3 connected green squares), then close the pop-up window.

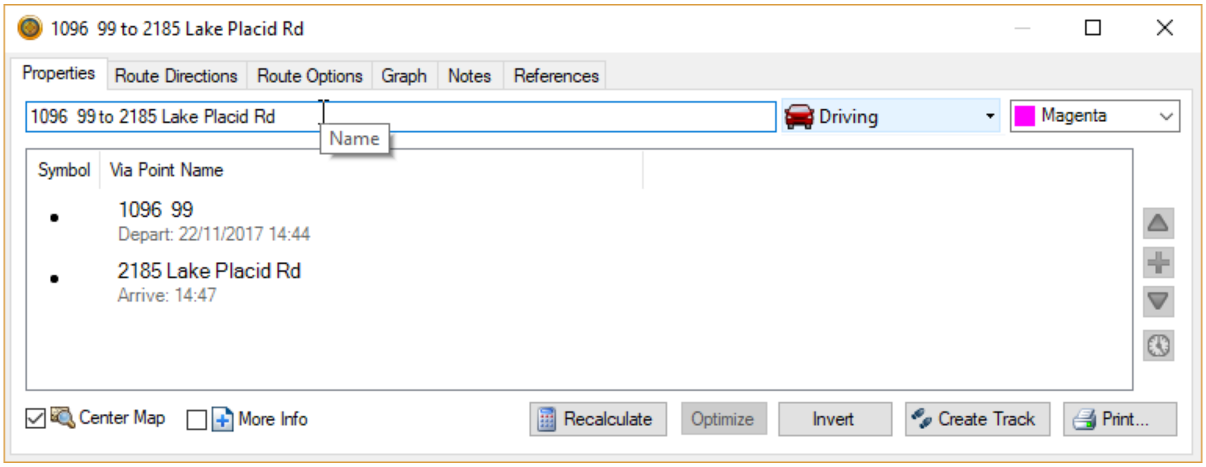




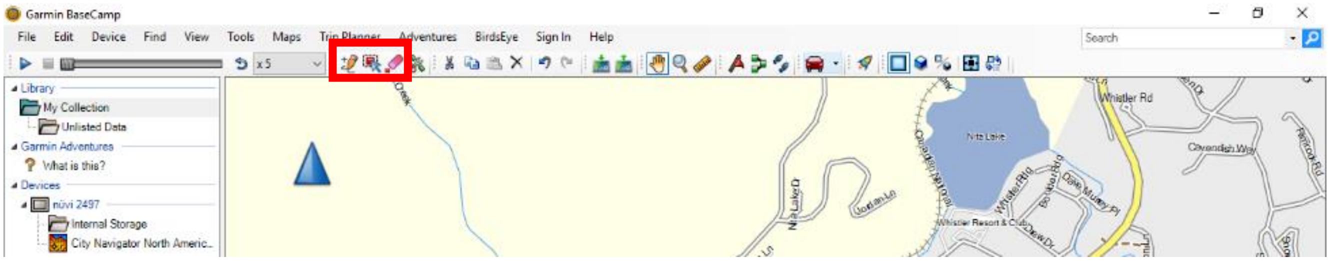
Your mouse cursor will now change to a small pen with a plus sign and you can begin to create your route by adding waypoints to the map by clicking along the roads. The waypoints you add will appear as small black circles on the map, and the Garmin software will automatically calculate the best way between the waypoints and plot this route along with small arrows indicating direction of travel. To move and zoom the map without leaving the route creator mode, you can use the pan buttons in the top left (hover over blue north arrow). Then to leave the route creator mode, just right click.



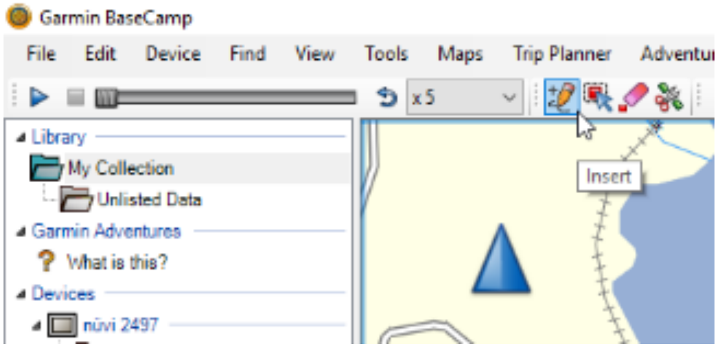
The new route will appear in the lower left toolbar, and double clicking on the route will bring up the properties window where you can rename the route and edit the colour and other properties.



To edit a route and add new points or edit existing points, select the route in this menu and use the three tools in the top toolbar (highlighted by the red square): *Insert, Move Point,* and *Erase.*



Insert will allow you to add new waypoints to the start and end of the route, or between existing waypoints by hovering over the area of interest until it is highlighted and clicking. This will then re-enter the same mode you were in when you first created the route (cursor will be a small pen with a plus sign), and you can add further waypoints.

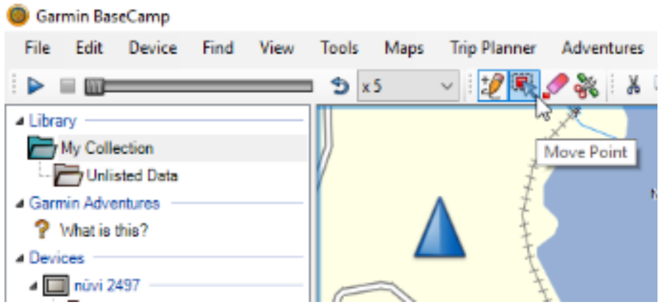


1. Location of Insert Tool

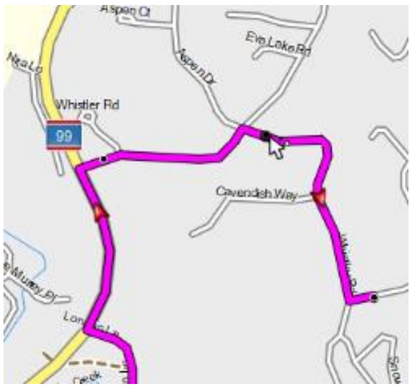
2. Selecting the end of the route to add new waypoints

3. Adding waypoints between existing points to edit the route

Move Point will allow you to click and drag existing waypoints to a new location.



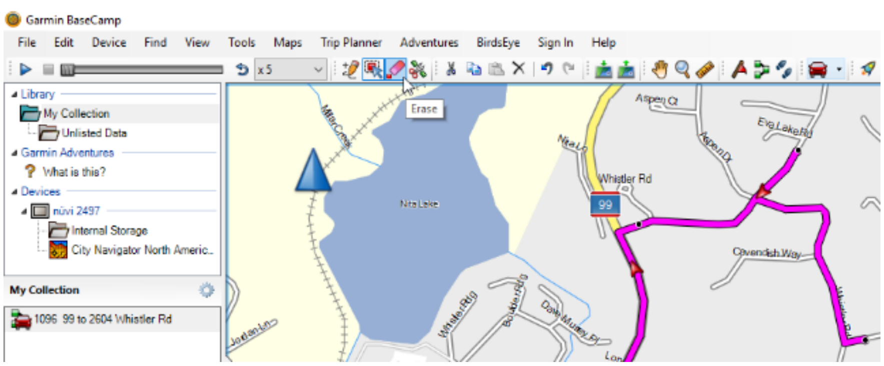
1. Location of Move Point Tool



2. Selecting point to move

3. Dragging waypoint to new location

Finally, the *Erase* tool will allow you to remove existing points. When selected your cursor will change to an eraser and points will be highlighted with a red cross when you hover over them – click to erase.



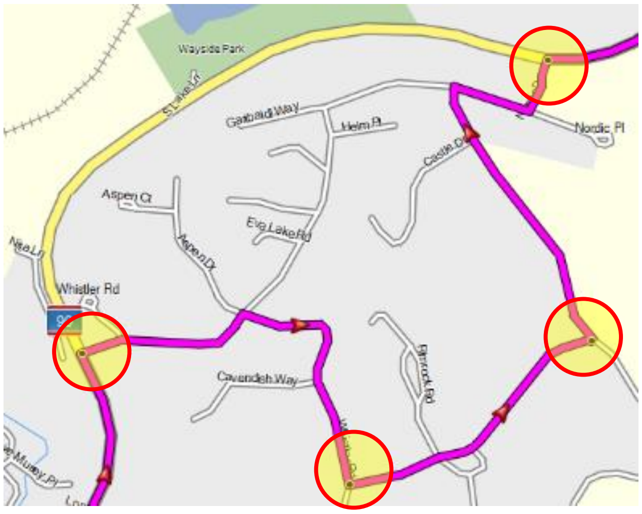
1. Location of Erase Tool

2. Selecting point to delete

Each time you add a waypoint or edit the route, the software will choose the route it thinks is best to connect the waypoints. ***Your goal is to make the software follow the route of your choice with the fewest waypoints***, this simplifies the instructions the device will give the driver.

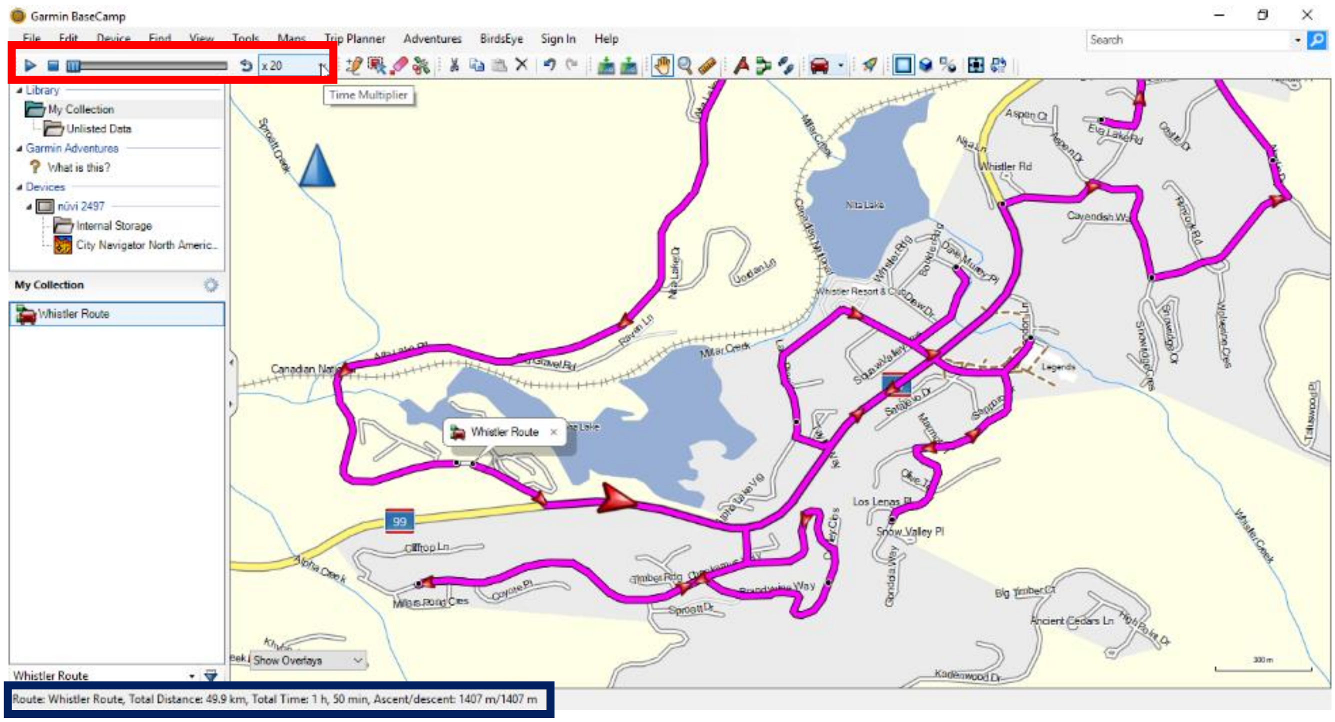
When using the device to navigate a route, the device announces directions until the vehicle reaches the next waypoint. When a waypoint is reached there is a pause in verbal directions until the device recognises that the vehicle has moved past that waypoint. **For this reason, it is important when entering the route into the Basecamp software to place waypoints just after intersections in the direction of intended travel** (as in the example below) rather than directly at the intersection – otherwise the driver won't be told which way to turn until they're already at the intersection.

CORRECT: Black waypoints just after intersections

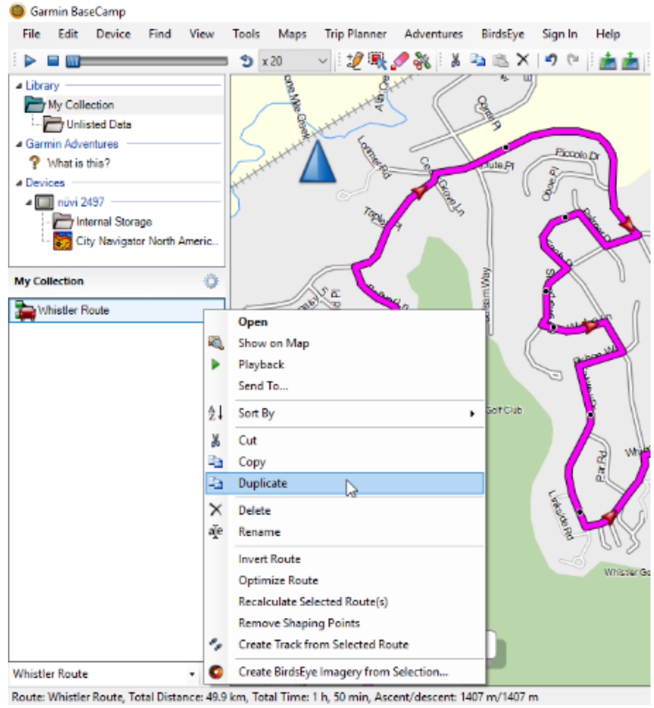


INCORRECT: Black waypoints directly at intersections

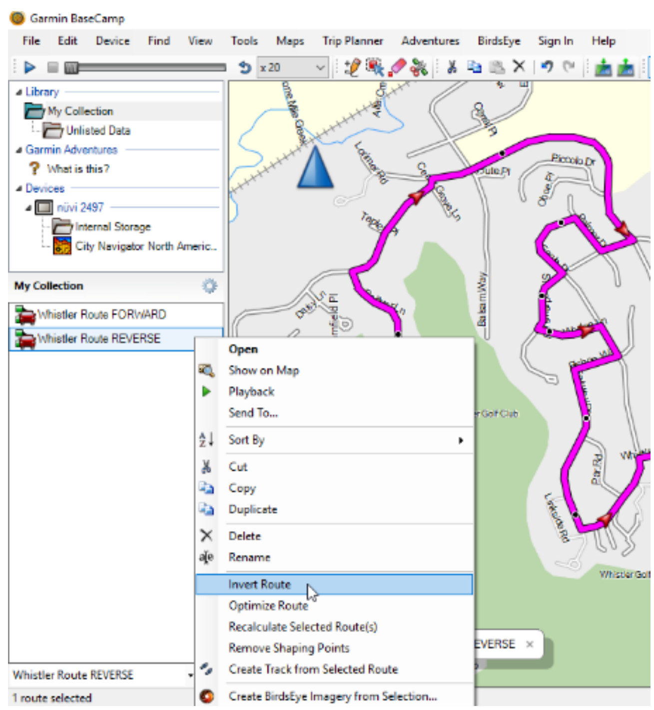
A good way to check your route is working as expected is to use the playback feature. These controls are located in the top left (highlighted here by the red box), and by pressing the play arrow, a large red arrow will appear on the route and follow your directions. There is also a drop-down menu to change the playback speed, and a slider to move ahead in the route. The bottom of the window also presents summary data on the length and estimated drive time of the route (highlighted here by the dark blue box).



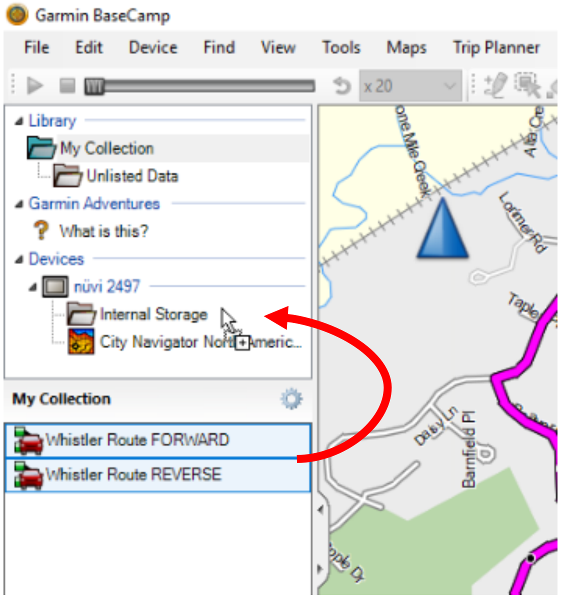
During a monitoring campaign it is important to alternate the direction in which routes are driven, so that each area is not consistently sampled at the same time of night. Therefore, when you have finished designing your route, another version of the route driving in the opposite direction must be created.
To do this, duplicate the finished route in the Basecamp software by right clicking on the route name and selecting *Duplicate.* Then rename the original route as *ROUTE NAME – FORWARD*, and the duplicated route as *ROUTE NAME – REVERSE.*



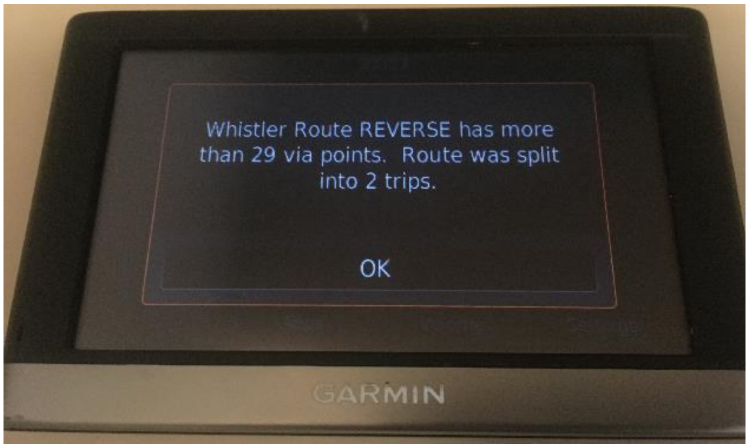
To calculate the reverse route, now right click on the new route and select *Invert Route.* This will instruct the software to calculate the route in the opposite direction through the waypoints. When this is done the route may change a little and you will need to move the waypoints slightly (and potentially insert more between existing waypoints) to make the software choose the intended route. ***Of note here is to move waypoints placed just after an intersection to the other side of the intersection*** (again to ensure the driver is given directions before arriving at the intersection). If there are one-way roads on the route etc. that make it impossible to drive the route exactly in the opposite direction, try to make the forwards and reverse routes as similar as possible.



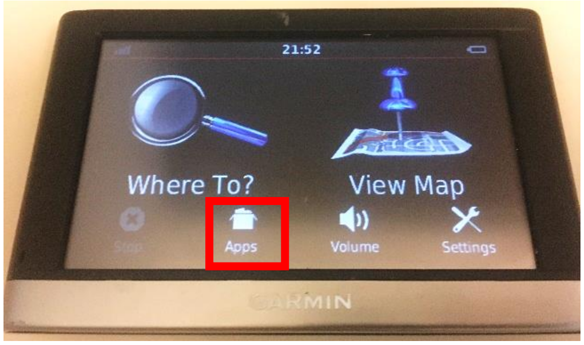
The final step in the Basecamp software is to drag the completed routes from the lower left menu to the GPS Navigator device in the top left menu to save them to the device.

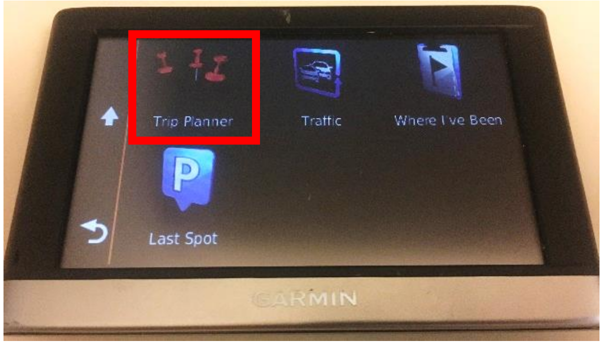


You can then right click on the device name and select 'Eject'. The Garmin navigator device has a limit of 29 waypoints that it can contain in one route, and so when the device is now turned on it will split the route into parts after each 29 waypoints. At the end of each part, the driver will therefore have to quickly pull over and start the next part of the route navigation.

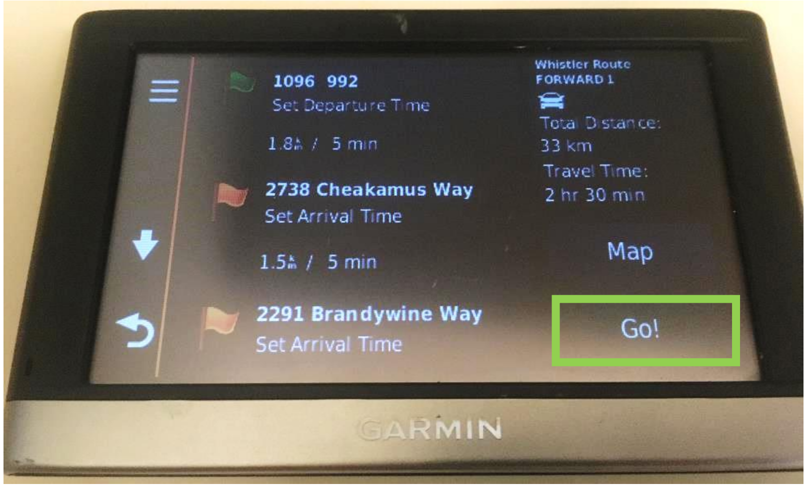


When you are ready to use the route directions you access the pre-programmed trips from basecamp on the device by clicking on *Apps* on the main screen followed by *Trip Planner.*





Finally select the trip of interest to see the trip's information including distance and estimated travel time before hitting *Go!* to start the directions.



3.4 Prepare a Laptop and Data Management

A laptop will need to be used by the co-pilot (or driver if monitoring alone) during monitoring runs. To prepare a laptop, copy the included folder ***'Woodsmoke Mobile Monitoring Materials'*** to the Desktop of your laptop, and check this folder contains the sub-folder ***'Laptop Programs for Monitoring'***.

Data files need to be saved and named in a consistent way to work with the Shiny application. To store the data from your campaign, create an overall folder on your laptop named: *YYYY_MM_LOCATION_MONITORING* using the year and month of your monitoring along with the community name as the location (e.g. 2017_01_WHISTLER_MONITORING). When the monitoring is completed, this folder needs to contain:

1. A completed copy of the ***TripList.csv*** file (a template is included in the '*Woodsmoke Monitoring Materials'* folder).
    a. This file should be filled in using Microsoft Excel to enter the details of each trip, including: ***Date, Route Direction, Start Time and End Time***.
    b. The ***'Date'*** column must be formatted as MM/DD/YYYY. Excel will try to reformat your date column automatically, so to prevent this, enter an apostrophe before the date: i.e. 'MM/DD/YYYY
    c. ***Route Direction*** should equal 'Forwards' or 'Reverse'.
    d. The ***Start Time*** is the time you actually begin driving the route (after all set up and preparation was completed), and the ***End Time*** is when you returned to the same location at the end of the route.
    e. Be careful to **save this file as a comma separated values file (*.csv*)** by using the *Save As* option and choosing from the dropdown menu under the file naming bar. The normal save button will save the file in the default Excel file type (*.xls*).

2. A completed copy of the ***Instrument_Calibrations.xls*** file (also included in the *'Woodsmoke Monitoring Materials'* folder) to keep record of all calibrations and cleaning performed (include date and time along with calibration results for both instruments, such as Zero Check value from the nephelometer).

3. A file containing the nephelometer 1-minute averages as a backup. Download this data at the end of your monitoring as explained in Section 6.1.

4. Most importantly, individual sub-folders for each monitoring trip as described below.

Individual Trip Files

For each trip please save files in the following way:

1. Within the main folder create sub-folders for each trip named: ***TripNo_LOCATION_YYYY_MM_DD*** (e.g. the first trip in Whistler on Jan 5th, 2017 was named Trip1_WHISTLER_2017_01_05)

2. Each trip folder should then contain the following files (how to save these files is explained during the monitoring run instructions):
   - The Notes file named**:** ***TripNo_Notes_YYYYMMDD.txt***
   - The nephelometer file named: ***TripNo_NEPH_YYYYMMDD.txt***
   - The two aethalometer files from the date of the trip with the original naming:
     - ***AE33_AE33-S04-00415_YYYYMMDD.dat***
     - ***AE33_log_AE33-S04-00415_YYYYMMDD.dat***

Here is an example of the folder layout for the first two trips while monitoring in Whistler in January 2017:

2017_01_WHISTLER_MONITORING	
Trip1_WHISTLER_2017_01_05	**Trip2_WHISTLER_2017_01_06**
Trip1_Notes_20170105.txt Trip1_NEPH_20170105.txt AE33_AE33-S04-00415_20170105.dat AE33_log_AE33-S04-00415_20170105.dat	Trip2_Notes_20170106.txt Trip2_NEPH_20170106.txt AE33_AE33-S04-00415_20170106.dat AE33_log_AE33-S04-00415_20170106.dat

3.5 Instrument Checks, Settings and Calibration

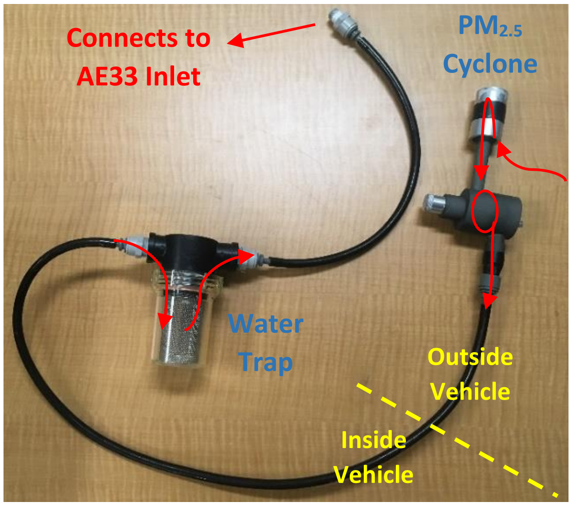
Each instrument needs to be acquired, set up and calibrated in accordance with the manufacturer's procedures. ***If anything is unclear here or you are looking for more information, please refer to the included manufacturer's manuals.***

3.5.1 Aethalometer - Magee Scientific AE33

Instrument Set Up

Included components:

- Magee Scientific AE33 Aethalometer
- Power Cord
- Air Inlet Tubing and Connectors
- $PM_{2.5}$ Selective Cyclone
- Water Trap
- GPS Receiver and Cords
- USB Data Stick (containing instrument manuals and for data download)
- Pelican Transportation Case



To set up the aethalometer sampling line, the $PM_{2.5}$ Selective Cyclone and Water Trap must be connected in sequence to the AE33 air inlet using the included tubing. This sequence is shown in the above photo with the air flow direction shown with red arrows.

The first component of the sampling line is the cyclone which is designed to remove large particulate matter from the air flow. The included cyclone is a BGI SCC 1.829 and is specially designed so that it will remove anything larger than $PM_{2.5}$ from an air stream travelling at a flow rate of 5 liters per minute.

The second component is the water and debris trap which will remove any water from the air stream before it enters the instrument. Be careful when connecting this component as it has a specific direction. There is a raised arrow on the side of the water trap which indicates air flow direction, and so the water trap should be connected with the arrow facing the instrument.

Finally, the tubing itself is made from an anti-static material to limit any smaller particulate matter being removed from the air flow by static forces. To prevent $PM_{2.5}$ from impacting the sides of the tubing and leaving the airflow, keep the tubing as straight as possible with long smooth bends rather than sharp curves.

These components need cleaning periodically so please confirm whether they were cleaned prior to you receiving the equipment. A good way to check is to inspect the silver 'grit pot' on the front of the cyclone, which unscrews from the rest of the cyclone. In the unlikely case that it appears dirty, these components require cleaning. To do this, first separate the sampling line, and then take each component apart (be careful not to lose the o-rings from the cyclone). Each piece (cyclone parts, water trap and tubing) should then be flushed with running water and wiped with a water dampened lint free cloth. The pieces then need be allowed to dry in a warm, dust-free area before reassembly. The components should not need cleaning again during your monitoring campaign.

Instrument Operation

To operate the AE33, **first remove the red inlet/outlet protection screwcaps from the rear of the instrument**. If these are not removed the airflow will be blocked when the pump starts, and this pressure could damage the pump (*NOTE: the instrument fan is noticeably loud, but if the flow is blocked it will be VERY loud*). Connect the power cord to a power source and turn the instrument on using the two power switches (one on the rear next to the power cord and one inside the door of the instrument – the door is opened by pressing the silver button on the front until it pops out to form a handle, and then pulling this handle).

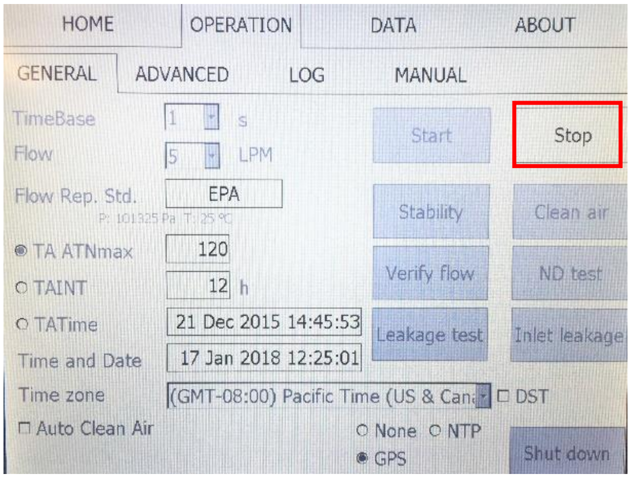
The front screen of the instrument will then illuminate and detail the various electrical checks the instrument performs before starting. When these are complete the screen will switch to the home page and begin to operate. Readings will read '*NA'* for the first few minutes as the filter tape is advanced and the instrument prepares to operate. All further control of the instrument is performed using the touch screen. The headings at the top of the screen are used to switch between settings pages, and for this guide, pages will be identified as the top row option followed by the second row option, for example 'OPERATION/GENERAL'.

The home page is the default screen and shows the live values for Black Carbon and UV Particulate Matter, along with the flow rate, the current timebase setting (which controls whether the instrument is saving 1-second measurements or 1-minute averages), the number of tape advances remaining before a new filter tape is necessary, a status indicator, and finally the current date and time. When the instrument is running, the screen is set to screensaver mode where it will turn dark after a few minutes of inactivity. The usually green status indicator will continue to show on this screen. To wake the display up, simply press the screen.

The status indicator is the most important feature of this home page. A green tick and value of 0 indicates the instrument is running as expected, if the instrument is stopped a red cross will appear, and if there are other issues a yellow exclamation mark will be present. If the value is not 0, you can press the status indicator and another screen will appear explaining what the issue is (as seen to the right – a code of '1' shows the instrument is advancing the filter tape. This is the most common non-zero status). Please contact us for support if this occurs and there is a status update you do not understand.

Instrument status:	1
Operation status:	1 - Tape advance
Flow status:	0 - Flow OK
LED status:	0 - LEDs OK
Chamber status:	0 - Chamber OK
Filter tape status:	0 - Filter tape OK
Settings status:	0 - Settings OK
Tests status:	0 - No test
External device status:	0 - Connection OK
Auto clean air test status:	0 - Status OK or test not run yet
CF card status:	0 - Status OK
Database status:	0 - Status OK

The 3 other tabs at the top of the screen that you can switch between are: *OPERATION*, *DATA* and *ABOUT*. The *OPERATION* screen is used to control the instrument and change settings in the 4 sub-pages, while the *DATA* page has two sub-pages: *TABLE* which shows the live measurements, and *EXPORT* which is used to export data to a USB stick. The final *ABOUT* tab simply shows instrument and user registration details.



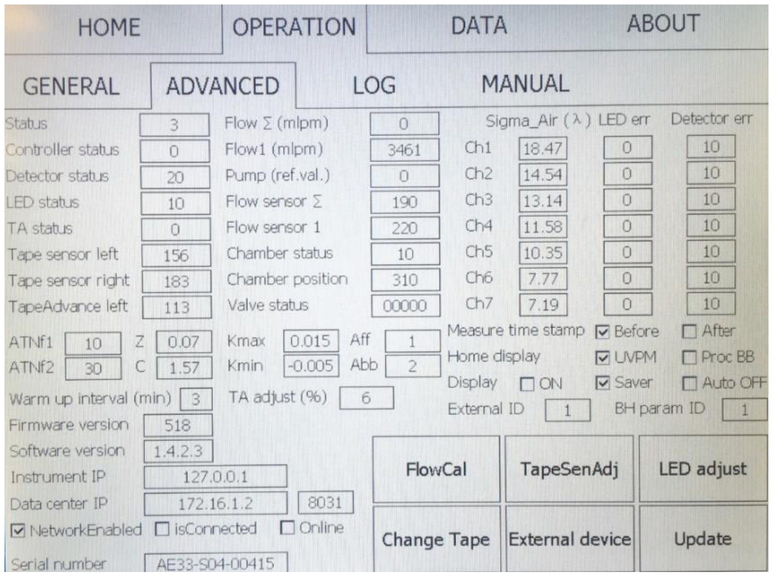
As mentioned, the instrument will begin to operate as soon as it is switched on (unless you choose 'skip to main menu' on the loading screen), and no settings can be changed during operation. To be able to make changes, first stop the instrument using the '*Stop'* button on the top-right of the '*OPERATION - GENERAL'* tab (under the red square in the image to the right). You will notice here that the other options are all greyed out until the instrument stops, and then they will become available.

To turn off the instrument, the instrument must be stopped as explained above, then press *'Shut Down'* at the bottom right of the '*OPERATION-GENERAL'* tab. When the instrument shuts down, use the power switch on the back to complete the process (avoid using the interior power switch, as one is sufficient). Then disconnect the sampling line from the instrument and replace the red protection caps. Whenever you are moving or transporting the instrument, always keep it level with the feet facing down.

Check Instrument Settings

When the instrument is stopped, the settings on the *'OPERATION – GENERAL'* tab should be confirmed to match those in the image above. If there are any differences here, they can be changed by pressing on the option and selecting from the drop-down menus or typing. The *TimeBase* setting of 1-second is important to be able to provide high spatial resolution during the mobile monitoring, and the *Flow* setting of 5 liters per minute is important as this is the air flow rate at which the inlet cyclone will correctly separate $PM_{2.5}$ from larger particulate in the sample air. Finally, the GPS radio button at the bottom should be selected to instruct the instrument to synchronise it's time with the GPS unit (*if this GPS option is not present, please refer to the AE33-GPS Module Implementation Note included with the instrument manuals for the steps to re-connect the GPS device).*

The settings on the '*OPERATION – ADVANCED'* tab (seen below) should be correct when you get hold of the instrument and **should not be changed**. Most of these values indicate the status of various internal sensors. The '*OPERATION - LOG'* tab saves a log of every change to the instrument and may be referenced if you are unsure what the instrument is doing**. Do not use the *'OPERATION-MANUAL'* tab** – this is for Magee Scientific technicians only.



Instrument Calibration Checks

The AE33 is a very stable instrument and most calibration checks do not need to be performed regularly. Chapter 9 of the AE33 manual covers maintenance of the device with a suggested schedule for maintenance checks and clear step by step guides to each procedure (*Note: This suggested schedule is based on the assumption the instrument is running 24/7 and not just for short periods as with our monitoring, so checks do not need to be as frequent*).

The procedure that you are most likely to encounter is if the filter tape runs out during your operation of the instrument. The filter tape in the instrument is held on two spools either side of the optical measurement area and is moved incrementally from left to right during operation. As particulate matter is deposited onto the filter tape, the tape gets darker, and when it gets too dark for more measurements to be taken, the instrument performs a tape advance to move a new clean section of tape under the optical components. Eventually the tape will run out and need to be replaced. The guide for this procedure on page 65 of the AE33 manual is very thorough.

You cannot perform flow checks, calibrations or leakage tests without a professional flow-meter so these procedures should be avoided. However, both a *'Stability Test'* and a *'Clean Air Test'* can be performed without any additional equipment simply by selecting the options on the '*OPERATION – GENERAL'* screen when the instrument is stopped.

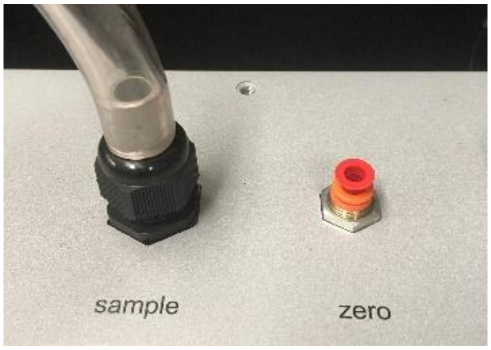
The Stability Test checks the performance of the light source and detector without air flow in the system, while the Clean Air Test is a similar test with the airflow activated but filtered through an internal filter to remove any particles from the air. These two tests should be run prior to the start of monitoring. Set up the instrument indoors when doing this, and each test takes around 20 minutes to run before reporting results to the main screen when they finish. Please record the date and time of each test in the Instrument Calibrations spreadsheet along with the result the instrument gives you (such as *'Stability test results are acceptable'*).

3.5.2 Nephelometer – Ecotech Aurora 1000

Instrument Set Up

Included components:

- Ecotech Aurora 1000 Nephelometer
- Power Cord
- Serial Communication Cord and USB Adaptor
- Air Inlet Tubing and Funnel
- Pelican Transportation Case



There are fewer external components needed to use the nephelometer and so the set up of the instrument is much simpler. The sampling line only consists of tubing to direct air flow from the exterior of the vehicle into the inlet of the instrument (this is the largest of the three inlets on the top of the instrument, and is labeled 'sample' – see above). As this tubing does not have a cyclone or similar component limiting the material entering the tubing, larger dirt and dust particles can impact onto the tubing, and it should be cleaned regularly. Due to the nature of long tubing it is difficult to clean. The most effective method is to clean the tubing either in a shower or outside using a hose. Hold the tube vertically and pour a small amount of dish soap into the higher end, then rotate the tubing to allow the soap to coat the interior walls as it runs down. Now run high-pressure water through the tubing to remove the soap, dirt and dust from the tube. Rotate the tube while doing this to ensure **all** residual soap is removed from the tube. Hang the tube to dry in a warm area. Compressed air can also be used to remove residual water from the tube if necessary. **The tubing must be fully dry before connecting to the instrument.**

Instrument Operation

To operate the instrument, connect a power source and turn on the instrument with the switch on the right side. The nephelometer will first go through some quick checks which are shown on the screen, followed by a short warm up (during which the screen will read *'Inst Warmup Time'*). You will then hear the instrument pump start and the nephelometer will start to take measurements. Normal operation will then begin, and the screen will show the current scattering measurement at the top, along with the sample temperature, relative humidity and pressure readings from the environmental sensors (as seen in the photo below). The row with the headings *ST°C, RH% and BP* will alternate between headings and the current date and time.

The instrument is easy to control. The screen will illuminate when any of the buttons are pressed, and the up and down buttons control the screen contrast while on the main screen (this doesn't need to be changed unless you accidentally turn the contrast all the way down so the values are no longer visible…). To access the menu, press the *enter* or *select* buttons, then use the *up and down arrows* to navigate, and the *enter* or *select* button to enter a menu branch. To go back a level press *page up,* or to finish and return to the main screen press *exit*. To change a setting, highlight the row of interest, press *select* and then use the up and down arrows to switch to the option of choice. Then press the *enter* button to confirm the highlighted choice, or if you need to cancel the change press *exit*. When setting the time, use the *select* and *page up* buttons to move right and left between digits, then use the *up and down arrows* to change the currently highlighted digit.

When you are finished with the instrument simply switch it off using the power switch on the right of the case. Then disconnect the sampling lines and cover the inlets with caps or tape to prevent dirt or dust falling into the instrument. Whenever you are moving or transporting the instrument, always keep it level with the feet facing down.

Check Instrument Settings

Prior to monitoring, verify the following settings are selected in the instrument menu:

Menu Option	Correct Setting	Reason
Under Calibration -> Cal Settings ->		
Auto Cal Intv	Off	*To prevent calibrations starting during monitoring.*
Under Control ->		
Sample Heater	RH	*High humidity can affect nephelometer measurements, and so these commands set the internal air heater to heat the sample air until relative humidity of the sample is less than 60%.*
Desired RH	<60%	
Under Report Prefs ->		
Filtering	Kalman	*Basic unit settings to standardise the data.*
Date Format	Y-M-D	
Temp Unit	°C	
Press. Unit	Mb	
Normalise to	25°C	
Under Serial I/O ->		
MltDr Baud Rt	38400	*These are the communication settings for the instrument's serial ports and must match with a connected laptop for successful data transfer.* *Setting the service port to 'Reading' mode and an output of '1sec' allows us to read and save the live 1 second data directly from the instrument onto a laptop through a serial cord connected to that port.*
Mlt Parity	None	
SvcPt BaudRt	9600	
SvcPt Parity	None	
SvcPort Mode	Reading	
Reading Outp	1 sec	
Under Datalogging ->		
Log Period	1 min	*1 minute is the shortest time averaging period available. This data serves as a backup if there are any issues with the 1 second data captured on the laptop.*

Calibration Checks and Adjustments

The nephelometer works by comparing optical measurements to two calibrated values. The first calibration is a *'Span'* calibration and involves testing the instrument with a standard certified gas - usually high purity carbon dioxide. The second calibration is a *'Zero'* calibration and refers to a measurement of normal air that has been internally filtered to contain zero particles.

The zero calibration is important as the gases that make up air naturally scatter light, and so having this value allows the instrument to remove the impact of these gases from the measurement of the sample. There are two options for each type of calibration: a check, and an adjust. The span and zero checks are used to check the instrument is still measuring expected values when exposed to these controlled samples, and an adjust is to reset the calibration of the instrument if the checks show that this is necessary.

Checking and adjusting the span point requires testing the instrument's response to high purity carbon dioxide and so will be performed between monitoring periods. Please confirm with us that this has been checked recently (In the very unlikely case we ask you to perform a span point calibration yourself, refer to the set up on page 20 of the Aurora manual, and the procedure in the calibration chapter on page 39).

Zero checks are easy to perform as they use a filter built into the instrument to create clean air for the calibration. ***This check should be performed after every few monitoring runs to ensure the instrument is still working as expected***. To perform a zero check, first run the instrument for around 10 minutes to allow the instrument to stabilise, then remove the red cap from the inlet labeled 'zero' on the top of the instrument and use the following menu path: *CALIBRATION -> ACTIVATE CAL -> DO ZERO CHK.* **If you accidentally start a different calibration procedure, turn off the instrument using the power switch and this will prevent settings being changed.**

The test will then begin (you will hear the pump start and the screen will change) and continue until both the minimum calibration time has been reached (default is 15 minutes) and the instrument has achieved 95% stability. When the zero check is finished the instrument will return to normal operation. To check the result of the test, you will have to navigate to CALIBRATION -> PARAMETER and check the updated value alongside LAST ZERO. ***Please record the date/time and new results of any calibration procedures in the Instrument Calibrations Log.***

After any check is performed the results should be compared to Table 5 from the Aurora manual included below. If the LAST ZERO value is above 2, or below -2, then a Zero Adjust should be performed. To do this is similar to the zero check but instead navigate to 'CALIBRATION -> ACTIVATE CAL -> DO ZERO ADJ.'. Again, please record the results from the CALIBRATION -> PARAMETER -> LAST ZERO page. If the value from the zero check is outside 0 ± 4, perform a second zero check before proceeding to confirm this value before contacting us for support. *In the rare case you are testing the Span point, the correct span value for* CO_2 *that should be used for calculating the calibration tolerance is 22.7*Mm^{-1}.

Table 5 Calibration check criteria.

Daily/Weekly Check	Calibration Tolerance	Action required
Zero Check	*±2* Mm^{-}	*Do zero adjust*
	*±4*Mm^{-1}	***Repeat zero check then contact us for support.***
Span Check	*±1% of span point**	*Do full calibration*
	*±5% of span point**	*Invalidate data* *Do full calibration*

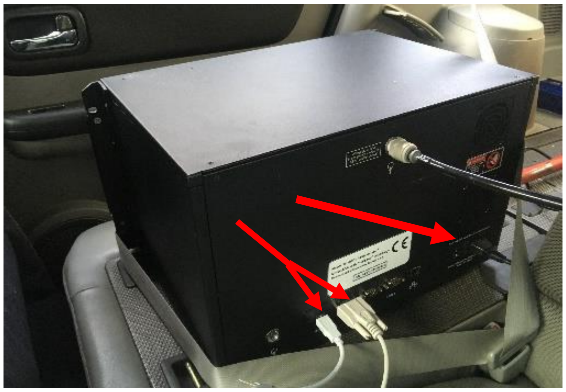
* If calibrating 525nm with FM200, ≈ 220 Mm^{1} @ STP, then the ±5% limit would be ± 11 Mm^{1}. The ±1% limit would be ± 2.2 Mm^{1}.

3.6 Setting Up a Vehicle for Monitoring Campaign

This section covers how to install and connect the instruments in a vehicle ready for mobile monitoring. To prepare a vehicle for mobile monitoring, the two instruments will be placed on the back seat of the vehicle with their air intakes passed through a rear window and attached to the outside of the vehicle (on the opposite side to the vehicle exhaust). Please perform this using the following steps:

1. **Place the AE33 in the rear of the vehicle.**
   - Place the instrument on the same side of the seat as the vehicle exhaust with the screen facing outwards as shown.
   - If the rear seat can fold down flat this works well to place the aethalometer on, otherwise place the AE33 directly on the seat.
   - Secure the instrument using the seat belt or bungee cords.

2. **Connect the cords to the rear of the AE33.**
   - Connect the black power cord at the bottom right.
   - The power cord should be fed to an available 12V socket (use an outlet in the trunk area if possible to keep the front outlet available to power the GPS navigator).
   - Connect the serial and USB cords from the GPS device to the USB and COM1 ports in the bottom left.
   - The GPS receiver (lower right photo) attached to the cords should be passed through to the front of the vehicle and placed on the vehicle dash.
   - ***Do not connect the black inlet tubing (top) to the AE33 yet until starting monitoring.***



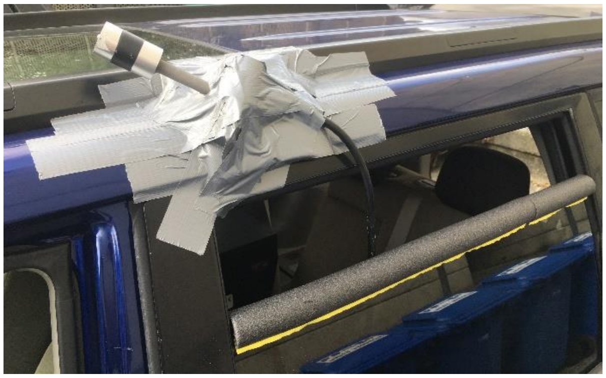
3. **Place the Aurora 1000 in the rear of the vehicle.**
   - The Aurora 1000 should be placed on the opposite side of the seat to the AE33.
   - This instrument generally fits well with the seat in the normal upright position as the seat prevents the instrument falling over.
   - Again secure using the vehicle seat belts or bungee cords.

4. **Connect the Aurora 1000 cords**.
   - Carefully attach the power cord to the power socket on the right side of the Aurora 1000 (this is a 4-pin plug that you will need to line up and then use the outside screw section to secure).
   - Feed the power cord to the 12V power socket.
   - Attach the communication cord with attached USB converter to the top-right port labeled RS232 Service.
   - Feed the communication cord to the front of the vehicle where it will be connected to a laptop during operation.

5. **Place the power inverter by a 12V socket**.
   - Place the power inverter in the rear of the vehicle if possible by a 12V power socket.
   - Plug in the power cords from both instruments.
   - ***The power inverter should <u>NOT</u> be connected to the 12V socket unless the vehicle is running, as it may drain the vehicle battery.***

6. **Prepare the window for attaching the inlets.**
   - Start by half-lowering the rear window on the opposite side to the vehicle exhaust.
   - Line the edge of the window with the foam pipe covering.
   - Close the vehicle door.

7. **Attach the AE33 cyclone to the side of the vehicle.**
   - Due to the shape of the cyclone, it should be positioned on foam at the front of the window facing into the direction of airflow when the vehicle is moving, and slightly upwards (to prevent moisture and other debris entering the air inlet). The smaller silver cylinder should be facing down (held by the hand in this photo).
   - First attach a foam pad to the vehicle (to protect the vehicle from the cyclone) at the front of the rear window using duct tape (seen under the cylone in the photo).
   - Pass the water trap and end of the tubing through the window opening and into the vehicle **(*Do not connect the air inlet tubing to the AE33 yet).***
   - Now tape the cyclone to the vehicle (this is easier with a second person to hold the cyclone while you attach it). To safely secure the cyclone, use longer strips of tape first in a cross pattern across the main body.
   - Then seal over all the foam in the area to limit water, but make sure to not block the area around the inlet.



8. **Attach the Aurora 1000 Inlet.**

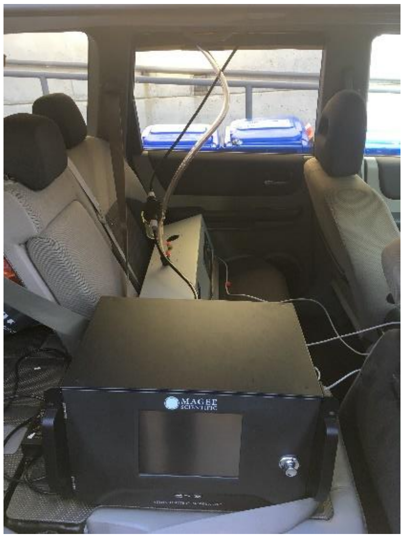
- As there is no cyclone on this inlet and the tubing enters the instrument directly, this inlet should be orientated in the opposite way to the AE33 inlet, by placing it at the rear of the vehicle facing slightly down (approximately 30 degrees below horizontal). This orientation along with the cone attached to the end of the inlet minimises the risk of water and other debris entering the instrument.
- Pass the air inlet tubing for the Aurora through the window into the vehicle.
- Attach some foam to the vehicle to protect the paint, and then attach the cone on top of the foam.
- Make sure to also secure the tubing with tape to prevent it moving around while driving.

9. **Seal the remaining window opening.**

- When both inlets are secured carefully raise the window to minimise the opening but do not squeeze the inlet tubes.
- Seal the remaining window opening and around the two tubes to keep water out of, and heat inside the vehicle. Long strips of tape horizontally across the opening work best, starting at the bottom and working up before sealing around the tubing.
- Do not open this door or adjust this window for the remainder of the monitoring to prevent tearing the inlets from the vehicle or damaging the tubing (a good way to prevent accidentally doing this is to place tape over both the door handle and the window control button).

10. **Attach the air inlets to the instruments.**

- The Aurora inlet tubing simply slides onto the metal sample inlet opening pipe on the top of the instrument.
- The AE33 inlet tubing screws into the opening at the top on the rear of the instrument, and the water trap can sit on the top of the Aurora (as seen in this photo). To screw the inlet in without twisting the inlet tubing, screw the white connector into the instrument, while holding the grey connector (between the tubing and the white threaded connector) still.



Between monitoring sessions disconnect the inlet tubing from both instruments and cover the inlets with tape to minimise any risk of moisture or dust entering the instruments. If temperatures are going to be negative overnight, take the instruments out of the car and bring them inside, otherwise they take a very long time to warm back up when you are ready to monitor. Also if the vehicle is parked in an unsecure location it is advisable to bring the instruments inside overnight. When doing this just disconnect the power and communication cords along with the inlets and leave these cords in place in the vehicle ready for monitoring. Whenever transporting the instruments keep them upright with the feet facing down.

4. Mobile Monitoring Run Preparation

The following is a guide to the individual steps to perform a mobile monitoring run. **Before starting, check there are no reasons to stop the monitoring run until the end (check vehicle gas, laptop is charged, washroom breaks etc).**

4.1 Heat the Vehicle and Instruments

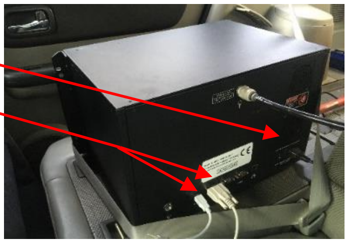
1. Turn on the vehicle and heaters to get the interior to a warm temperature (~20C, this can be done while driving to the start of the route).

IMPORTANT: **If the instruments are turned on right away when cold, humid air may condense on the cold surfaces within the instrument and cause damage.**

For this reason, on cold evenings, the instruments should be removed from the vehicle and brought inside to prevent them getting too cold. This should also be done if the vehicle is not parked in a secure location such as a garage overnight. When doing this, you can disconnect all of the cords from the instruments and leave those in place in the vehicle.

2. If the instruments were removed from the vehicle, place them back in the car as described in Section 3.6 and connect the cords as below:

- Connect the power cord to the rear of the AE33 and connect the GPS Serial and USB cords to the COM1 and USB ports also on the rear.
  DO NOT CONNECT THE INLET LINE YET.



- Connect the power cord to the Aurora 1000, and the serial cord to the '***RS232 Service'*** port.
  DO NOT CONNECT THE INLET LINE YET.

3. Plug the power inverter into the 12V vehicle socket and plug the two instrument power cords into it.

4. **When the instruments are no longer cold to touch**, check the inlet lines are still disconnected from the instruments and turn the instruments on to allow them to sample warm interior air from the vehicle.

- Switch the power switch at the back of the AE33 – the screen will turn on and perform checks, after about 5 minutes it will start recording data.
- Switch the power switch on the right side of the Aurora 1000.

Perform the rest of the set-up work while the vehicle and instruments warm up.

4.2 Prepare the Nephelometer

5. The first step while the nephelometer is heating is to reset the clock to match the aethalometer (AE33). To match the nephelometer (Aurora 1000) data to the GPS location data recorded by the aethalometer, the clocks on the two instruments must match. The aethalometer clock is automatically reset to match the GPS time and so the nephelometer clock needs to be manually set to match this time.

This process is easier with two people. One person will watch the clock on the home screen of the AE33 (through the rear side door), while the other sets the Aurora clock to match. To adjust the nephelometer clock press *'enter'* to access the menu, and then scroll down to ***'ADJUST CLOCK'***. Press *'enter'* to enter this option. Change the date and time to one minute ahead of the AE33 (e.g. if AE33 reads 19:45:27, set Aurora to 19:46:00) by pressing *'enter'* on an option, then using the *'Select'* and *'Page Up'* buttons to move left and right between digits respectively, and the up and down arrows to adjust the currently highlighted digit. When you have the date and time correct, press *'enter'* and move down to highlight the *'Save Time'* option at the bottom of the screen.

When this is ready, the person watching the AE33 screen can count down to the prepared time, and just before the times match, the person operating the Aurora presses *'enter'* on the '*Save Time'* option. The screen will now say *'Setting Clock…'* for a few seconds while the change is saved before returning to the home screen. When this is complete, confirm the two clocks match within a second of one another by each reading out the seconds together (the Aurora only shows the clock on the screen for a few seconds at a time). **If you are not happy with the match, repeat this process as many times as necessary**.

All other settings on the nephelometer should still match the settings described in Section 3.5.2 and the measurements will begin automatically.

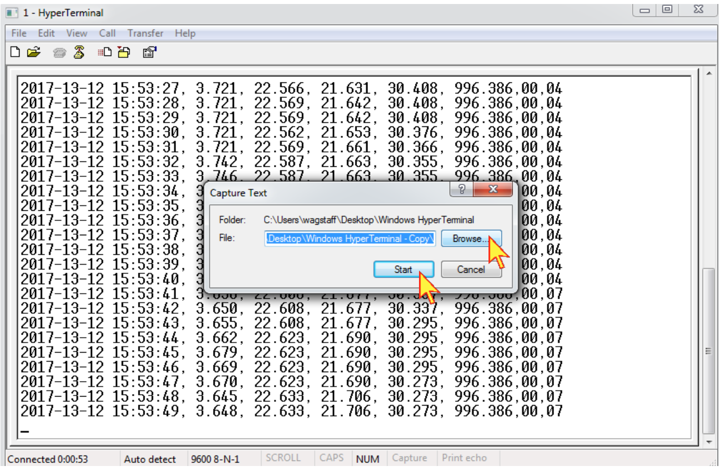
6. Connect the ***'RS232 service'* port** (top right) on the side of the nephelometer to a laptop USB port using the serial cord and USB adaptor.

4.3 Prepare the Laptop

A laptop is used for two things during the trip: saving 1-second data from the nephelometer to a text file using a program called Windows HyperTerminal, and recording and saving important notes about the trip. Two programs have been created to automate both the process of setting up a HyperTerminal connection on the laptop and preparing a notes file in a standard format.

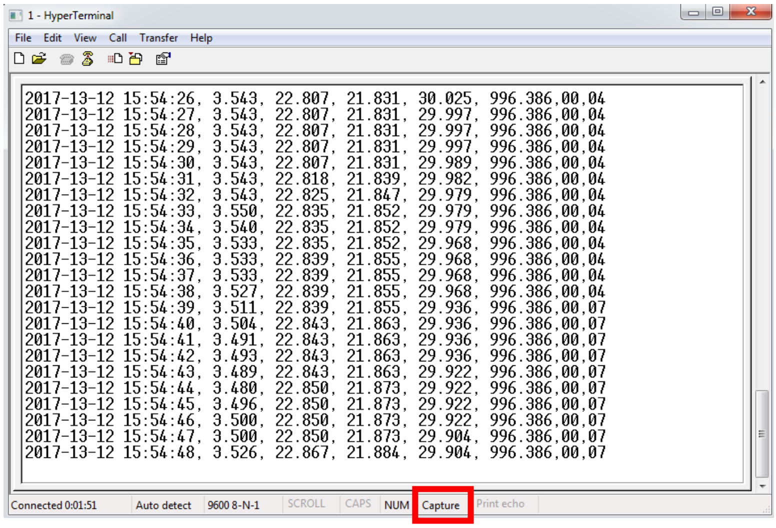
7. When the USB/Serial cord from the nephelometer is connected, open the *'Woodsmoke Mobile Monitoring Materials'* folder, and the *'Laptop Programs for Monitoring'* sub-folder.

8. If using a Windows 10 laptop, run the program called ***'AutomateHyperTerminal-Win10.exe'*** by double-clicking on it, then do not touch the mouse while the laptop automatically goes through the HyperTerminal set up screens and starts the connection for you. If the program is successful you will see live nephelometer data begin to appear in a large window with a smaller window prompting you to 'Capture Text' as seen here. If this does not work, try the second program called '*AutomateHyperTerminal-Win7.exe'*, and if neither work you will have to manually set up the connection yourself as described in the of this guide (this is not a complicated process).



9. If the program was successful, click on '*Browse'* and navigate to the trip folder where you will save the data (this was set up in Section 3.4). Name the file using the format: ***TripNo_NEPH_YYYYMMDD.txt*** (e.g. Trip1_NEPH_20170105.txt) and click save. This will take you back to the 'Capture Text' window where you will click '***Start***'.

10. **To confirm HyperTerminal is now correctly saving the nephelometer data, check the word Capture in the bottom border is bolded** (shown here in the red box – compared to the light grey in the previous screenshot). The live data contains the following columns: *Date, Time, Bscat, Sample Temperature (temperature of the air sample), Enclosure Temperature (temperature of the instrument, Relative Humidity and Pressure* (then placeholders).



Bscat is the back-scattering value measured by the instrument and is well correlated with the $PM_{2.5}$ concentration – therefore this first column following the time contains the values that you are interested in.

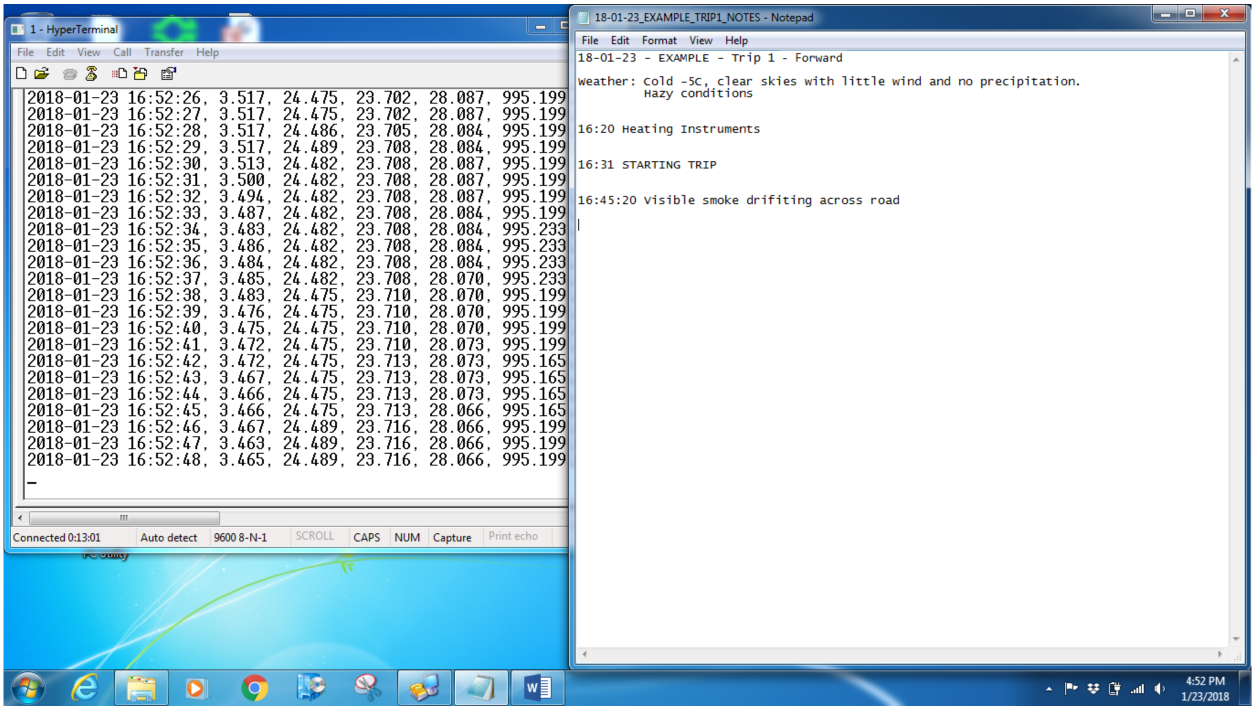
11. To start a new notes file for the trip, run the program called ***'OpenNewNotesFile.exe'*** in the '*Laptop Programs for Monitoring'* folder. This program will ask you for the location name in all capitals (e.g. WHISTLER), the trip number (e.g. 1), and the direction you will be driving the route this time (FORWARDS or REVERSE). Then do not touch the mouse while a new notes file opens and types in these values before prompting you to save the file. Browse to the trip folder and name the file using the format: ***TripNo_Notes_YYYYMMDD.txt*** (e.g. Trip1_Notes_20170105.txt), and choose '*Save'.*

12. Enter the driver and co-pilot names and a short description of the weather (e.g. include the current temperature from the vehicle read out, whether skies are currently clear or cloudy, current precipitation type such as light rain or heavy snow, and windy or calm). Throughout the monitoring run, the co-pilot can record notes on things that impact the trip such as trip delays (due to traffic, having to wait at a train crossing etc.) as well as things that impact $PM_{2.5}$ levels. Things to record here include: driving through a visible smoke plume, driving behind a truck kicking up a lot of road dust etc**. Make sure to include the current time from the HyperTerminal window (to the closest 10 seconds) with each note**. The keyboard shortcut 'ctrl-S' can be used throughout the run to save the file.

IMPORTANT: ALWAYS RECORD THE TRIP START AND END TIMES IN THIS NOTES FILE.

Summary

This screenshot shows how the laptop screen should look during a monitoring run. The HyperTerminal window is showing live 1-second data from the nephelometer, and the Capture icon in the bar at the bottom of the window is black (rather than grey) which confirms this data is being saved. The Notes file is saved (you can tell by the name in the top bar), and contains the date, trip number, direction (Forward here), weather summary and most importantly the start time. There is also an example of something you should take note of here with *"visible smoke drifting across road"* at 16:45:20, as notes like these can help with data interpretation.

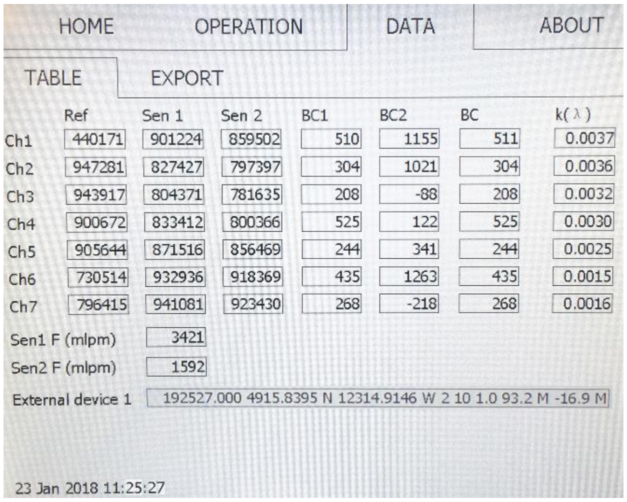


4.4 Prepare the Aethalometer and GPS

13. Place the GPS receiver that is connected to the AE33 (as seen on the right) on the vehicle dashboard where it has a clear view of the sky and will receive the best signal. A very small flashing red LED (shown here by the red arrow) will indicate that it is successfully recording the current location.

14. The instrument will read *NA's* on the home screen when it is initially turned on as the filter tape is advanced. After about 5 minutes when normal values do appear, check the instrument is running correctly by:

- On the home screen check there are values appearing next to BC and UVPM, and **there is a green tick next to Status and a code of '0'**.
- Press *'DATA'* on the top row of the screen, and then *'TABLE'* on the second row. This opens the Data Table (seen here). Confirm all channel rows are now reading values greater than 0 (during the warm up stage every box on this page will read 0) to check the instrument is operating correctly.
- Also on this page check there is a row present at the bottom labeled 'External device 1' which contains GPS data (as shown to the right). This confirms the GPS is recording a location (GPS data in this field shows UTC time first, the latitude position followed by N, the longitude position followed by W and then other values that show the accuracy of the signal).



AE33 ready for monitoring – DATA/TABLE page showing readings in all cells and valid GPS values in the 'External Device 1' row.

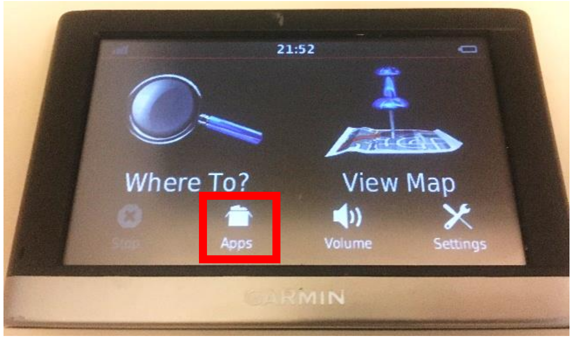
4.5 Start the GPS Navigator

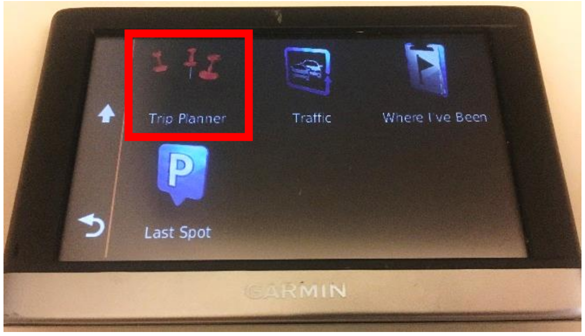
The final device to prepare is the GPS navigator with pre-loaded route directions.

15. If not already in place, attach the GPS holder to the windshield by first pressing it firmly against the glass so the rubber is flush and then using the switch to lock it in place.

16. Turn on the Garmin Navigator device and plug it into the 12V outlet.

17. Start the route directions by choosing *Apps* and then scrolling down with the arrows to choose *Trip Planner*. **Select the pre-loaded route in the correct direction (FORWARDS or REVERSE)** and choose *Go!* to start the directions.





4.6 Connect the Sampling Lines

18. Now the instruments and laptop are ready for monitoring, check the instruments are no longer cold (you can check if they are cold to the touch and also check the temperature readings on the nephelometer in column 5 of the HyperTerminal read out), then you can connect the sample lines to the instrument inlets:

- Slide the plastic tubing onto the metal inlet on the top of the Aurora nephelometer labeled 'Sample'.
- Screw the white threaded connector on the AE33 aethalometer sample line into the inlet at the top of the rear of the AE33**. To remove kinks from the tubing and have the tubing sit as straight as possible, hold the dark grey tubing connector still while screwing in the white connector to the AE33 (this dark grey piece will rotate within the white connector).**

19. Go through the pre-run checklist (Section 5.1), record the start time in the notes file (read the time from the HyperTerminal window) and then begin the run!

Note: This start time is important as it is used to delete the data collected while the instruments warm up inside the vehicle.

5. Mobile Monitoring Run

During the monitoring run the field technician will follow the monitoring route designed for the community as entered in the GPS navigator while occasionally checking all instruments are working as expected. Brief notes will also be taken on special circumstances observed such as heavy traffic or visible smoke that may affect instrument readings

5.1 Pre-Run Checklist

Before beginning a monitoring run please use this checklist to ensure everything is set up correctly for a smooth monitoring run:

1. ***There are no reasons to stop the monitoring run until the end*** (check gas level, that the laptop is charged, no need for a washroom break etc).
2. The two instruments were heated prior to set up (with sampling lines disconnected).
3. **Nephelometer:**
    - Clock has been reset to match the aethalometer
    - Values are appearing as expected on the home screen
    - **Sampling line has been reattached to inlet**
4. **Laptop:**
    - HyperTerminal program is running and 1 second nephelometer data is appearing live on the screen
    - **Capture text has been set up, and the capture text icon is bold in the lower bar**
    - Notes file has been opened and saved ready for notes to be taken throughout the run - Trip number, driving direction and weather summary entered
5. **Aethalometer and GPS:**
    - Green tick and status code of '0' are present on the home screen
    - GPS receiver is placed on the vehicle dashboard and small red LED is flashing
    - Both aethalometer and GPS data are as expected on the '*DATA/TABLE*' page
    - **Sampling line has been reattached to the inlet**
6. **GPS Navigator:**
    - Monitoring route has been selected in the right direction and ready to start
7. Now you can **enter the trip start time on the notes file** and begin the monitoring route!

5.2 Driving Notes

While driving the monitoring route we want to aim for even coverage around the route as much as possible. To achieve this drive at slower than normal speeds (~25-30 km/h in residential areas) but without becoming an obstruction to traffic (i.e. on highways you will have to drive at normal speeds). *Measurements every second at 30 km/h equals approximately one measurement every 8.4 m.*

If there are long pauses in the run for whatever reason (traffic, train crossing, road construction, forgotten bathroom or gas break etc.) be sure to record these in the notes file. Ideally just keep the instruments running, but if you are alone and need to turn off the vehicle you will have to restart the instruments. If the instruments have to be restarted, you will need to start a new HyperTerminal connection between the nephelometer and laptop. Save the new file with the same name format but **ending in NEPH-YYYYMMDD-PART2.txt**.

5.3 End of Run – Data Saving and Instrument Shutdown

At the end of the trip – DO NOT turn off the engine before shutting down the instruments:

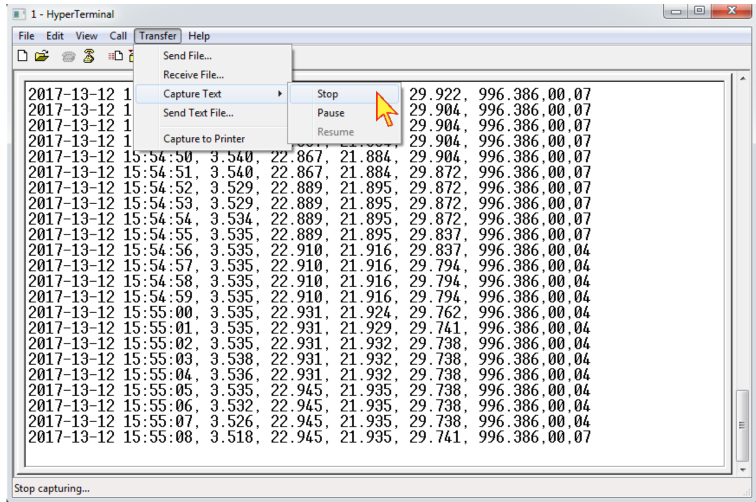
1. Record the stop time and a current weather summary in the notes file – ***check this file is saved before closing.***
2. **Save the HyperTerminal file and end the connection to the nephelometer *(see next page for guide).***
3. **Turn the nephelometer off with the power switch on the side.**
4. **Download data from the aethalometer** by inserting the included USB stick into the front panel, pressing DATA at the top and then EXPORT on the second row down. Touch the date next to from and it should change to the current date, then choose '*ExportToUSB'* for today's files to be copied to the USB.
5. **Shut the aethalometer down using the *'Stop'* and then *'Shut Down'* commands on the *OPERATION/GENERAL* page, before using the power switch on the back.**
6. **Disconnect the sampling lines from both instrument air inlets.**
7. Remove the power transformer from the 12V inlet to prevent it draining the vehicle battery.
8. You're finished!

IMPORTANT NOTE 1*: Make sure to charge the laptop between runs. As there are only two outlets in the power transformer, the laptop must run from battery power during monitoring.*

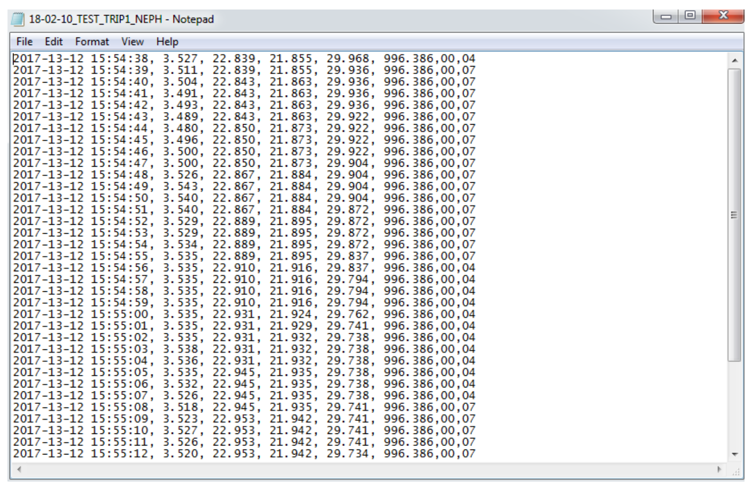
IMPORTANT NOTE 2: *On nights where negative temperatures are expected or if you are parking in an unsecure location, remove all connections from the turned off instruments and cover the inlets. Then bring them inside for the evening (keep the instruments upright and level when moving and storing). This is both more secure and saves you time when waiting for the instruments to heat up the following evening.*

Closing HyperTerminal Connection at End of Run

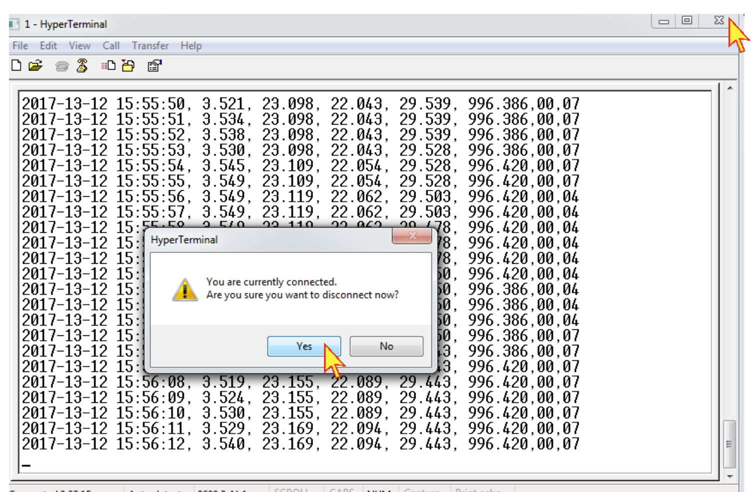
1. **Stop Capturing Text.**
   To stop the text capture, in the top bar select *'Transfer'* -> *'Capture Text…'* -> *'Stop'* as seen to the right.



2. **Check the file.**
   Navigate to the file where the captured text was saved and open it to confirm it was saved as expected.



3. **Close the program to end the connection.**
   When you have ended the text capture and confirmed the file is correct, you can end the connection to the nephelometer simply by closing the program. The program will ask if you want to save the connection – choose NO as this is not possible with this copied version of HyperTerminal.



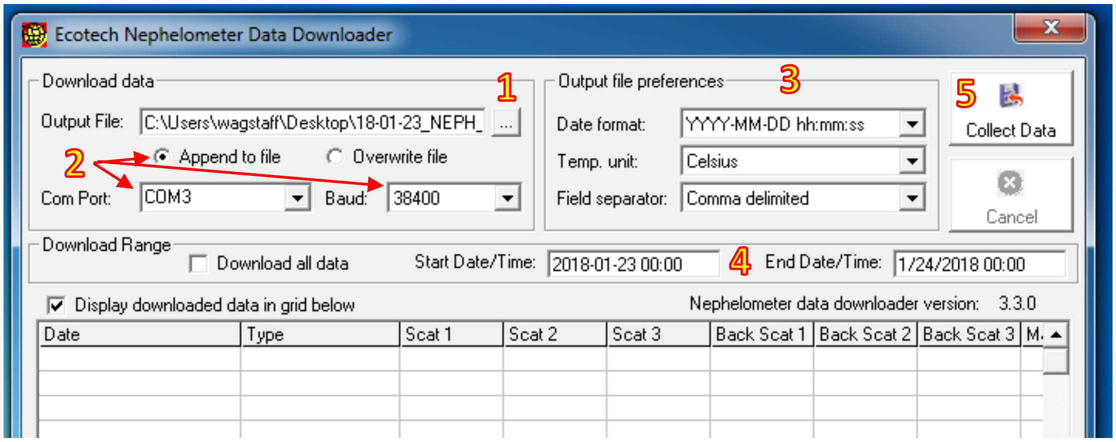
6. Post-Monitoring Campaign

6.1 Download Back-up Data from the Nephelometer

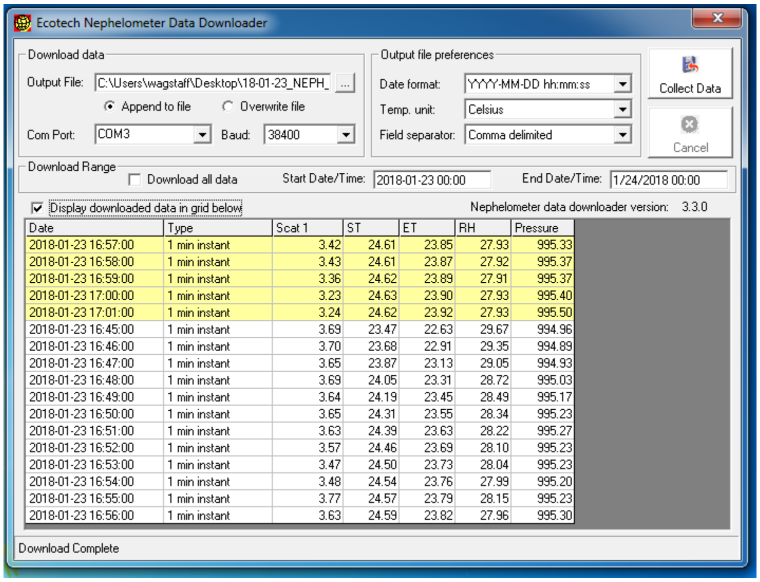
At the end of the monitoring campaign, download the 1-minute average data from the nephelometer onto the laptop as a backup for the 1-second data collected through HyperTerminal during the monitoring. To do this, turn the nephelometer on, and connect the serial cord to the lower '*RS232 multi-drop*' port (rather than the '*RS232 service*' port used during monitoring – shown here on the right).

Open the Ecotech Nephelometer Data Downloader program on the laptop (shown below with numbered steps indicated on the screenshot) and check the following settings:

1. Click on the small box with 3 dots next to the output file to browse for the main monitoring folder and then set the file name as: *YYYY_MM_Location_NEPH_1Min.csv*
2. Below the file name, choose *Append to file,* and check both the COM port matches the port the USB is attached to, and the Baud rate matches the nephelometer settings (should be 38400).
3. To the right under Output file preferences select:
    - Date format = YYYY-MM-DD hh:mm:ss
    - Temp unit = Celsius
    - Field separator = Comma delimited
4. Under *Start Date/Time*, enter the first day of the monitoring campaign. The *End Date/Time* should already be set to the end of the current day.
5. Finally click, *Collect Data* in the top right corner for the laptop to download this data from the nephelometer.



6. As data is downloaded, it will appear in the lower grid, with every 10 1-minute averages switching between yellow and white highlighting. When the download is complete, you can open the file to check it was created correctly and then close the program.



Date	Type	Scat 1	ST	ET	RH	Pressure
2018-01-23 16:57:00	1 min instant	3.42	24.61	23.85	27.93	995.33
2018-01-23 16:58:00	1 min instant	3.43	24.61	23.87	27.92	995.37
2018-01-23 16:59:00	1 min instant	3.36	24.62	23.89	27.91	995.37
2018-01-23 17:00:00	1 min instant	3.23	24.63	23.90	27.93	995.40
2018-01-23 17:01:00	1 min instant	3.24	24.62	23.92	27.93	995.50
2018-01-23 16:45:00	1 min instant	3.69	23.47	22.63	29.67	994.96
2018-01-23 16:46:00	1 min instant	3.70	23.68	22.91	29.35	994.89
2018-01-23 16:47:00	1 min instant	3.65	23.87	23.13	29.05	994.93
2018-01-23 16:48:00	1 min instant	3.69	24.05	23.31	28.72	995.03
2018-01-23 16:49:00	1 min instant	3.64	24.19	23.45	28.49	995.17
2018-01-23 16:50:00	1 min instant	3.65	24.31	23.55	28.34	995.23
2018-01-23 16:51:00	1 min instant	3.63	24.39	23.63	28.22	995.27
2018-01-23 16:52:00	1 min instant	3.57	24.46	23.69	28.10	995.23
2018-01-23 16:53:00	1 min instant	3.47	24.50	23.73	28.04	995.23
2018-01-23 16:54:00	1 min instant	3.48	24.54	23.76	27.99	995.20
2018-01-23 16:55:00	1 min instant	3.77	24.57	23.79	28.15	995.23
2018-01-23 16:56:00	1 min instant	3.63	24.59	23.82	27.96	995.30

6.2 Using Online Shiny Application to Map Your Data

An online application has been created using the Shiny platform to automatically create maps using your data. These maps will show the average spatial patterns across your monitoring route measured with each instrument. To use this application, the data has to be saved in a specific way:

1. Within your overall **YYYY_MM_LOCATION_MONITORING** folder, create a new folder called **SHINY_LOCATION**.

2. Copy and paste the completed ***TripList.csv*** file into this folder.

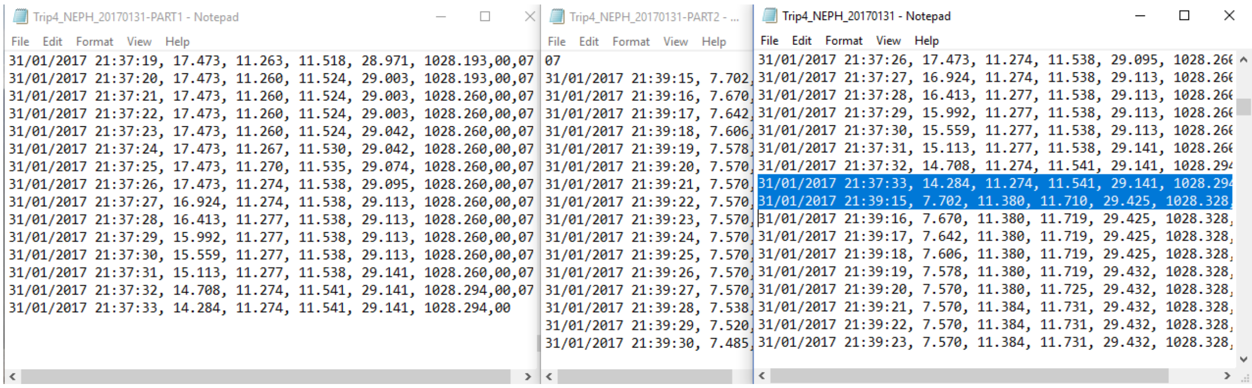
3. Copy and paste all of your individual trip folders into this folder (do not edit or make any changes to the original data files – these should always be kept as is for backup).

4. For each trip, copy and paste the nephelometer file into the **SHINY_LOCATION** folder.

If there were any trips where problems led to multiple nephelometer files being created (for example if you had to stop mid-route), these files have to be combined into a single file for that trip before transferring to the **SHINY_LOCATION** folder. To do this:

- First make sure all the original files are named ending in -PART1, -PART2 etc.
- Open the PART1 file in Notepad (this should be the default program if you just double click on a .txt file to open it). Click *'File'* in the top bar then *'Save As'* to save a copy of this file with the standard naming (***TripNo_NEPH_YYYYMMDD.txt***) with no PART1 etc. into the sub-folder for that trip.
- Now open all further files for that trip in Notepad and manually copy and paste the data from these secondary files into the new file that you just saved. Do this by scrolling to the end of the first file and deleting the last row if it is incomplete, then switch to the PART2 file and delete the first incomplete row there as well. In the PART2 file press ***ctrl-A*** to select all of the data (all rows will highlight blue), and ***ctrl-C*** to copy it. Now return to the first file, place the cursor on a new line ***at the end of the data*** and press ***ctrl-V*** to paste the copied data at the end of the first file. Repeat this process if there are more than two files, copying the data from each file to the end of the newly created overall file.

- The result is shown in the example below (which shows PART1, PART2 and the combined data in the windows from left to right), the final file on the right now looks like a normal file apart from the time break between two rows where no data was recorded (the last row of the original file and the first row of the second file are highlighted here).



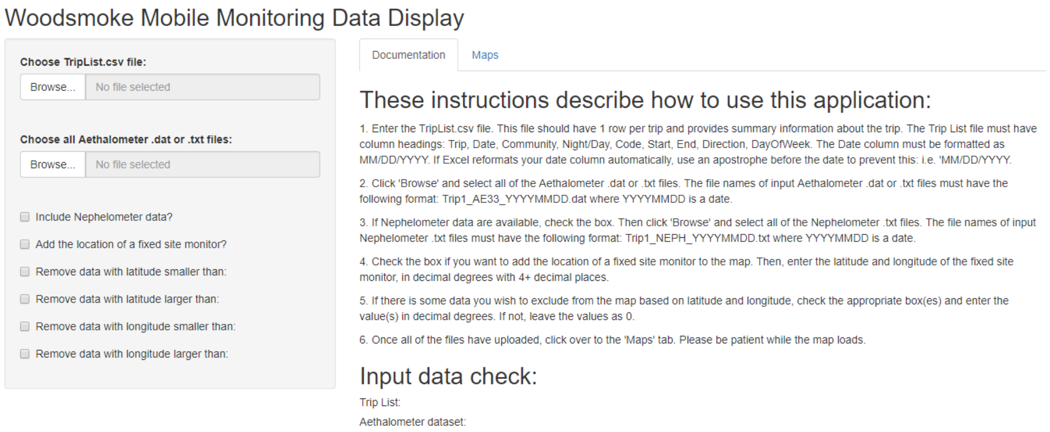
5. Also for each trip copy and paste the aethalometer file (just the larger data file, within the log file) into the **SHINY_LOCATION** folder and rename them in a similar format to the other files as: ***TripNo_AE33_YYYYMMDD.dat***.

If you happened to have any trips that ended after midnight, the aethalometer and GPS data from those trips will be saved in two files as the AE33 instrument saves a new file for each date. Therefore you will have to combine these files in the same way as described above for the nephelometer files, by opening the first file in Notepad, saving a copy named with the format *TripNo_AE33_YYYYMMDD.dat*, and then copy and pasting the data from the second date file into this new file.

6. When this is complete your **SHINY_LOCATION** folder and file names should look like this:

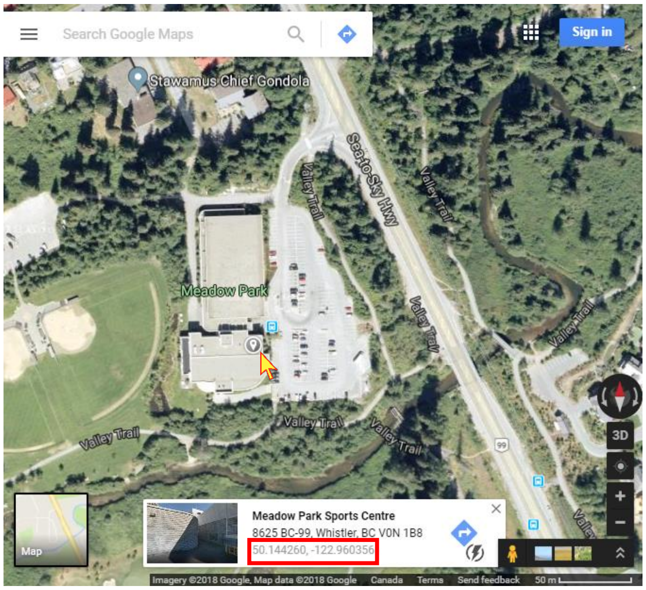
Name	Date modified	Type	Size
Trip1_AE33_20180205	05/02/2018 21:47	DAT File	3,454 KB
Trip1_NEPH_20180205	05/02/2018 21:43	Text Document	283 KB
Trip2_AE33_20180206	06/02/2018 21:38	DAT File	3,205 KB
Trip2_NEPH_20180206	06/02/2018 21:36	Text Document	390 KB
Trip3_AE33_20180207	07/02/2018 21:32	DAT File	3,094 KB
Trip3_NEPH_20180207	07/02/2018 21:31	Text Document	401 KB
Trip4_AE33_20180208	08/02/2018 21:48	DAT File	3,284 KB
Trip4_NEPH_20180208	08/02/2018 21:46	Text Document	409 KB
Trip5_AE33_20180209	09/02/2018 21:33	DAT File	3,226 KB
Trip5_NEPH_20180209	09/02/2018 21:30	Text Document	412 KB
Trip6_AE33_20180208	10/02/2018 21:12	DAT File	2,894 KB
Trip6_NEPH_20180210	10/02/2018 21:10	Text Document	380 KB
TripList	25/05/2018 11:53	Microsoft Excel C...	1 KB

7. To use the Shiny Application, go to: https://kathleenmclean.shinyapps.io/woodsmoke_mobile_monitoring/ and follow the instructions on the right side of the screen.

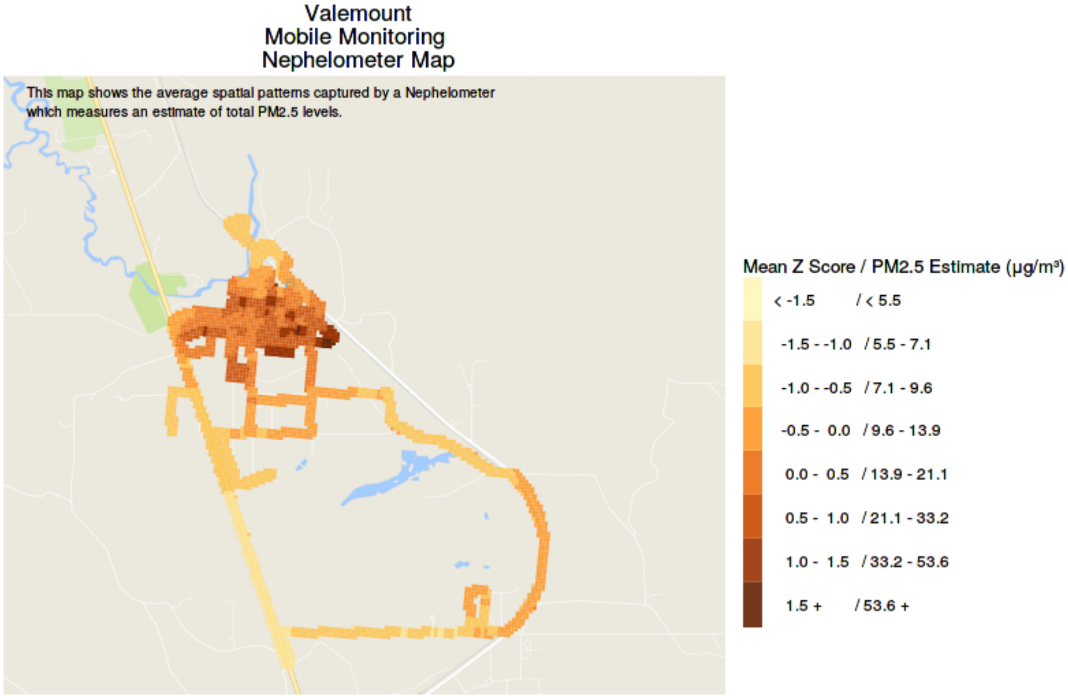


8. The instructions will guide you through the options and uploading your files on the left side of the screen. As files are uploaded, the lower right side of the screen will inform you whether the files were uploaded in the correct format. If any errors are reported here, first check the naming of your files. If there is an error with the ***TripList.csv*** file, also check the format of the Dates within this Excel file are *MM/DD/YYYY* (otherwise the app won't be able to match this file to the instrument data files).

9. If you choose to add the location of a fixed site monitor to the map, the coordinates of your local monitor can be found using Google Maps. If you switch to satellite view in the lower left corner, you can left click on the location of the monitor (the location of the Whistler monitoring station is shown here), and the coordinates will be shown in the pop-up box at the bottom of the page (here in the red box you can see the Latitude = 50.144260, and the Longitude = -122.960356).



10. When you have uploaded your data, switch to the Maps tab at the top of the screen and the maps will load. You can switch between the data from the two instruments ($PM_{2.5}$ estimates from the nephelometer, and woodsmoke specific Delta C from the aethalometer), and adjust the zoom level of the map (11-13 are zoom values determined by Google maps). You can also export the maps as PDFs using the ***Download Map*** option.



6.3 Interpreting the Maps

The maps created by the Shiny application show the average patterns across the monitoring route during your monitoring runs. As the data you have collected is just a snapshot in time, these maps are only semi-quantitative and are intended to identify general patterns and possible hotspot areas.

To create the maps, the app first standardises the data from each trip by converting the measurements to Z scores (also known as 'standard scores'), and then calculates the spatial pattern across the monitoring route during that trip by taking the average of all measurements that fall within each cell of a grid with $100m^2$ cells. Finally, the app calculates the overall average pattern during your monitoring by taking the average of the Z score patterns calculated for each trip, producing a map of average Z scores across the region.

Z scores are a statistical method used to compare values across a range. On this scale a Z score of 0 is equal to the average across the entire monitoring route, and the other values indicate how many standard deviations (a standard measure of variation in the data) each box was away from the total average across the route. For example, an area of the map with a Z score equal to +1 means that box was on average one standard deviation greater than the average during each trip (and so likely has higher $PM_{2.5}$ values on average), while a box with a Z score equal to -1.5 means that area of the map was on average one and a half standard deviations lower than the mean during each trip (i.e. that area had 'cleaner' than average air during the monitoring). These Z scores are calculated on an exponential scale and so the conversions to estimates of standard units alongside the legend are included to help you interpret how much one shade is greater than the shade before. These values are included to add context to the shading and make it easier to understand, but remember that these are estimates and should not be used quantitatively, rather they are included for reference to be able to compare two areas of the map.

6.4 Returning Instruments

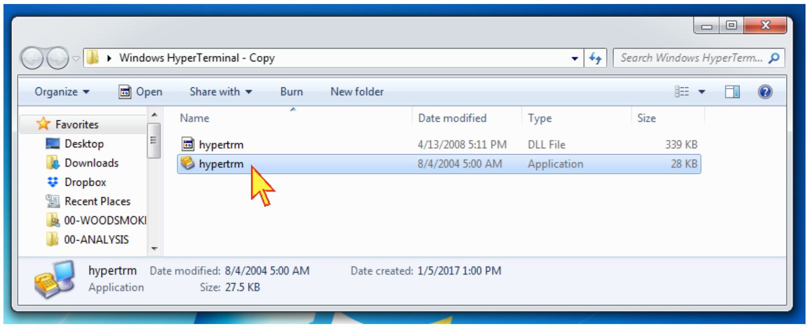
When you have completed your monitoring campaign, please repackage the instruments in the packaging you received them in, ensuring that they are well protected and that the box is labelled for the correct orientation, so that the instruments are kept upright during transportation. All supporting materials including the instrument sampling lines, the aethalometer cyclone, GPS receiver, Garmin navigation device, power cords etc. should be carefully packaged together in the third box. All packages should then be returned to the following address:

Dr. Michael Brauer - Room 370B
School of Population and Public Health
The University of British Columbia
2206 East Mall
Vancouver, BC
V6T 1Z3

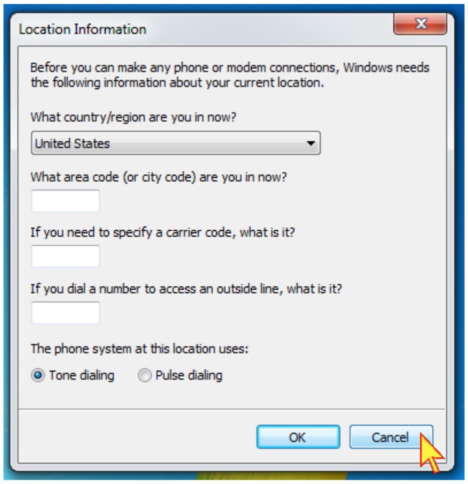
7. Appendix: Manual Set-up of Nephelometer/Laptop Connection

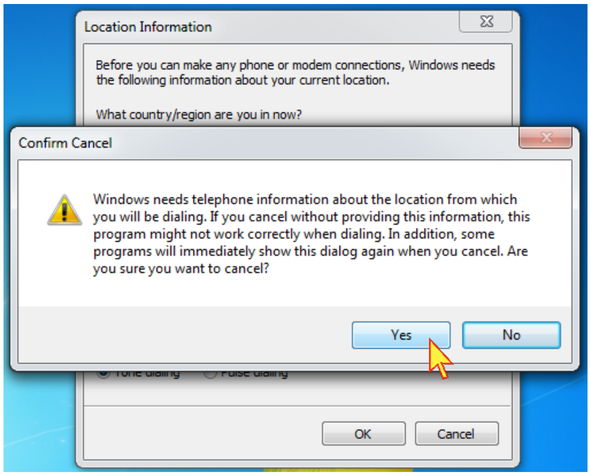
- **Connect the '*RS232 service*' port on the side of the nephelometer to the laptop using the serial cord and USB adaptor**.
- Follow these steps to save live nephelometer data to the laptop using Windows HyperTerminal:

1. **Open Windows HyperTerminal**
   Windows HyperTerminal is a program that came standard on older versions of Windows. The folder you have should contain two files: one with type '*DLL File*' and one with type '*Application*'. Open the application file to run the program.

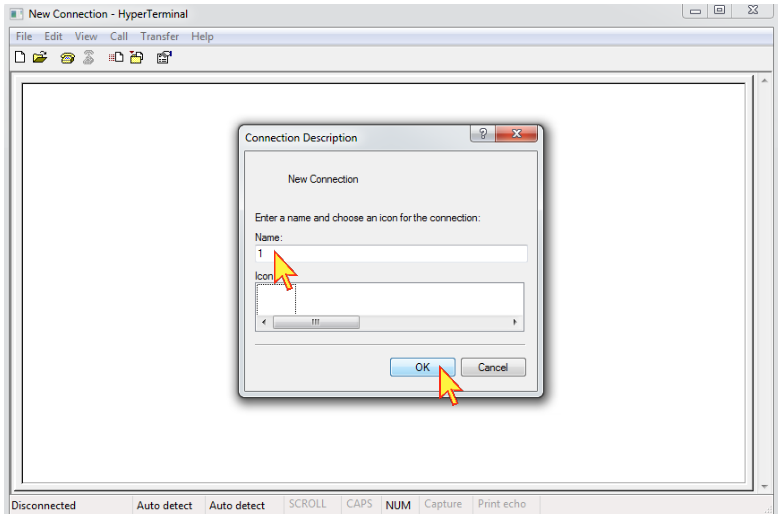


2. **Close the pop-up window asking for location information and then confirm.**

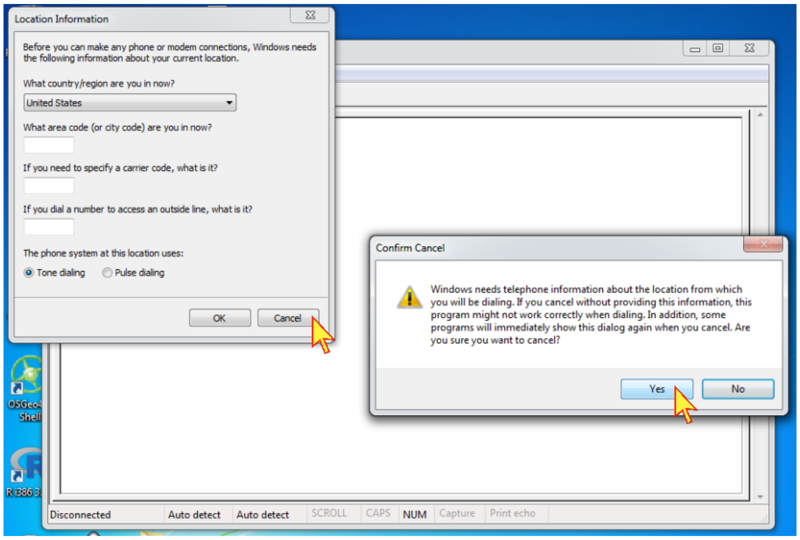




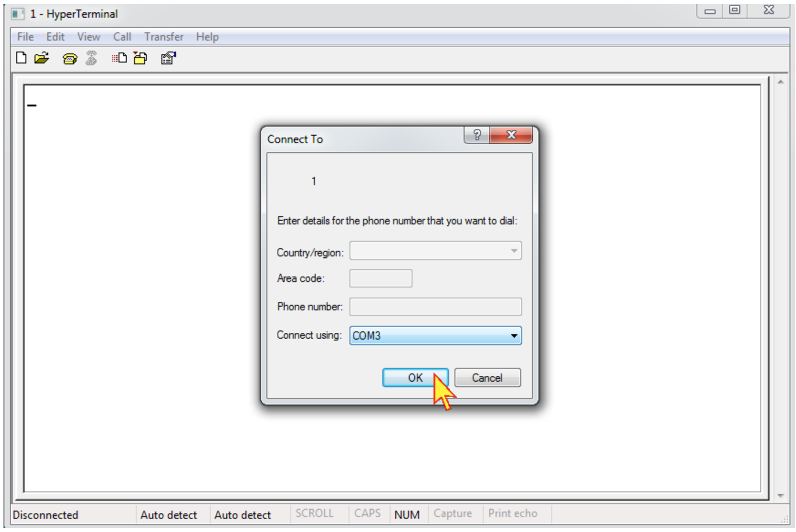
3. **Create a new connection.**
   A new connection box will now pop up. Give an arbitrary name such as ‘1’ to the connection and select ok.



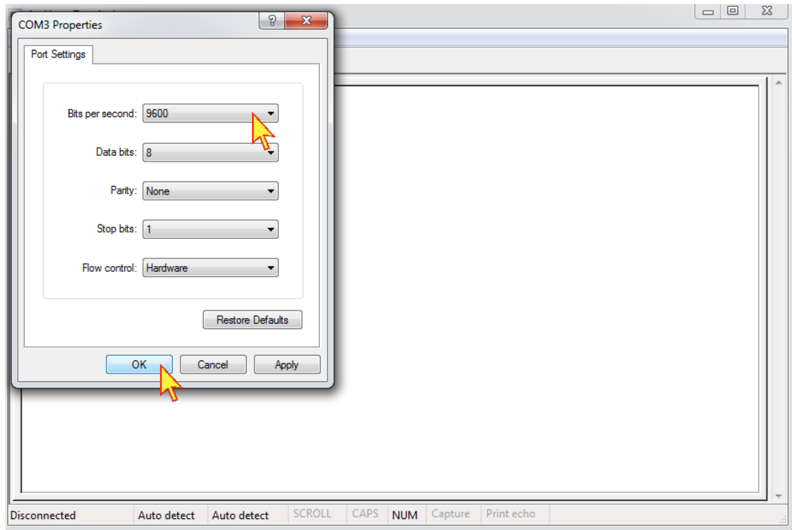
4. **The program will again ask for location information. Cancel again (same as step 2).**



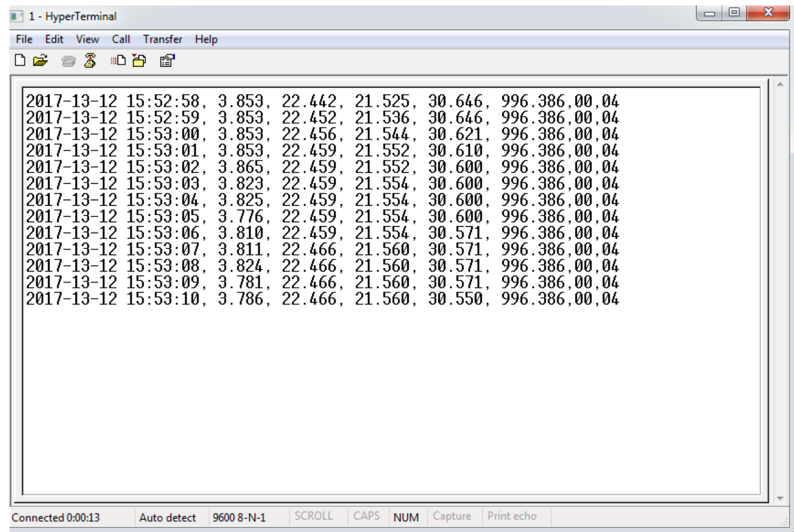
5. **Start a new connection to the nephelometer.**
   This ‘Connect To’ pop-up will appear following the cancellation of the previous windows. The important part here is choosing the correct COM port in the lower drop-down. Typically, the program will automatically select the correct port, but if the next step doesn’t work. You will need to go to the Device Manager to find which USB port is actively connected to the nephelometer and repeat this step.



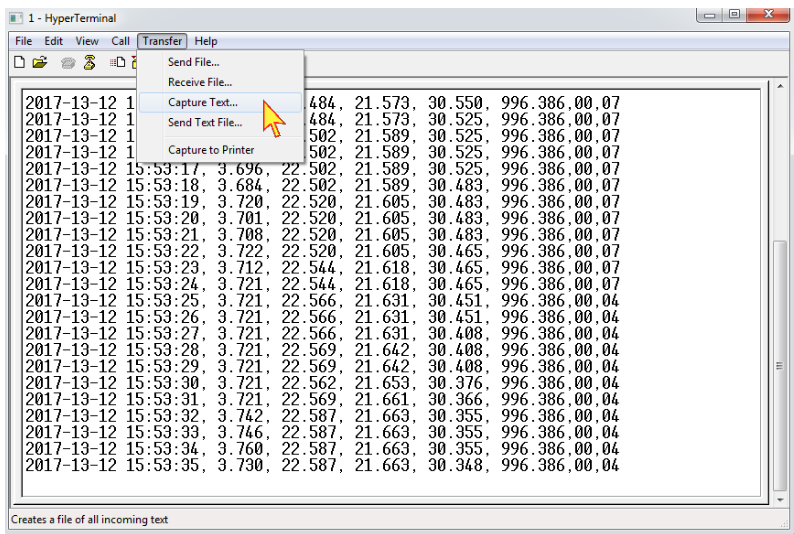
6. **Choose the correct settings for the connection.**
   For HyperTerminal to receive data from the nephelometer, the connection settings here must match the settings on the instrument. The correct settings are shown here – typically the only value that needs to be changed is the '*Bits per second*' to 9600.



7. **The connection will now start.**
   If the connection was successful, live data from the nephelometer will now start appearing on the screen. The columns present are: *Date, Time, Bscat, Sample Temperature, Enclosure Temperature, Relative Humidity* and *Pressure* followed by placeholders*. Bscat* is the back-scattering value measured by the instrument and is well correlated with the $PM_{2.5}$ concentration.

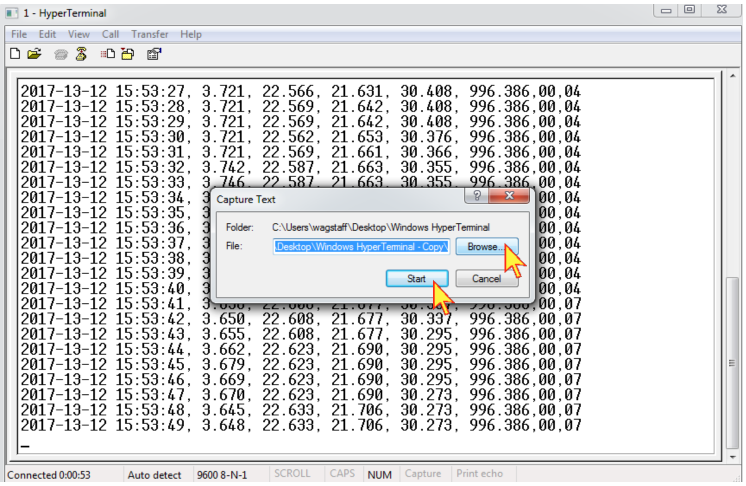


8. **IMPORTANT: Set HyperTerminal to save the incoming data to a text file.**
   Data appearing on the screen is not saved unless you go to the *'Transfer'* menu and select '*Capture Text…*'. If this step is missed there will be no data saved from the monitoring trip.

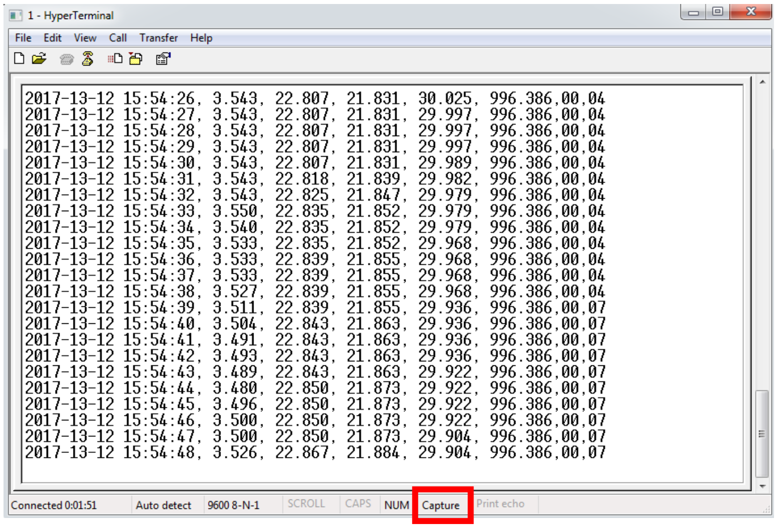


9. Create a file and start saving data.
After selecting '*Capture Text…*' you need to browse to the location you want to save the file and enter the file name as: ***YY_MM_DD_Location_TripNo_NEPH.txt***

Then click *'Start'* to begin capturing the 1-second data from the nephelometer.



10. Confirm data is being saved.
To confirm HyperTerminal is now saving data, the *Capture* word in the bottom border will now be bolded (shown here in the red box – light grey in previous screenshots).
You should also confirm the file has been created by navigating to the trip folder in your file explorer.



Appendix B - List of Mobile Monitoring Runs

Table A-1: List of mobile monitoring runs in the Whistler / Pemberton route pair.

Run #	Date	Driving Route	Night/Day	Code	Route Start	Route End
1	2017-01-05	Whistler	Night	WN1	21:15	00:51
2	2017-01-06	Pemberton	Night	PN1	20:48	00:13
3	2017-01-07	Whistler	Day	WD2	12:08	14:59
4	2017-01-07	Whistler	Night	WN2	20:32	23:45
5	2017-01-08	Whistler	Night	WN3	19:55	23:26
6	2017-01-09	Pemberton	Night	PN2	19:53	23:23
7	2017-01-10	Pemberton	Night	PN3	20:22	23:41
8	2017-01-11	Whistler	Night	WN4	20:48	00:07
9	2017-01-12	Pemberton	Night	PN4	20:19	23:33
10	2017-01-13	Pemberton	Day	PD1	12:00	14:54
11	2017-01-13	Whistler	Night	WN5	20:52	00:11
12	2017-01-14	Pemberton	Day	PD2	11:59	15:09
13	2017-01-14	Pemberton	Night	PN5	20:57	00:28
14	2017-01-15	Whistler	Night	WN6	21:06	00:45
15	2017-01-16	Whistler	Day	WD3	12:17	15:11
16	2017-01-16	Pemberton	Night	PN6	21:03	00:39
17	2017-01-17	Whistler	Night	WN7	21:18	01:02
18	2017-01-18	Pemberton	Night	PN7	21:05	01:05

Table A-2: List of mobile monitoring runs in the Courtenay-Cumberland / Courtenay-Comox route pair.

Run #	Date	Driving Route	Night/Day	Code	Route Start	Route End
19	2017-01-24	Courtenay-Comox	Night	CCX-N1	21:33	01:08
20	2017-01-25	Courtenay-Cumberland	Night	CCD-N1	21:07	00:50
21	2017-01-26	Courtenay-Comox	Night	CCX-N2	21:06	00:50
22	2017-01-27	Courtenay-Cumberland	Night	CCD-N2	21:10	00:45
23	2017-01-28	Courtenay-Comox	Night	CCX-N3	21:15	00:46
24	2017-01-29	Courtenay-Cumberland	Night	CCD-N3	21:22	00:57
25	2017-01-30	Courtenay-Comox	Day	CCX-D1	12:05	15:32
26	2017-01-30	Courtenay-Comox	Night	CCX-N4	21:10	00:38
27	2017-01-31	Courtenay-Cumberland	Night	CCD-N4	21:18	01:07
28	2017-02-01	Courtenay-Comox	Night	CCX-N5	21:11	01:17
29	2017-02-02	Courtenay-Cumberland	Day	CCD-D1	12:27	15:37
30	2017-02-02	Courtenay-Cumberland	Night	CCD-N5	21:20	00:51
31	2017-02-03	Courtenay-Comox	Day	CCX-D2	12:27	16:26
32	2017-02-03	Courtenay-Comox	Night	CCX-N6	20:58	01:07
33	2017-02-04	Courtenay-Cumberland	Day	CCD-D2	12:26	16:20
34	2017-02-04	Courtenay-Cumberland	Night	CCD-N6	21:35	02:01
35	2017-02-05	Courtenay-Comox	Night	CCX-N7	21:09	01:25
36	2017-02-06	Courtenay-Cumberland	Night	CCD-N7	21:12	01:17

Table A-3: List of mobile monitoring runs in the Vanderhoof / Fraser Lake route pair.

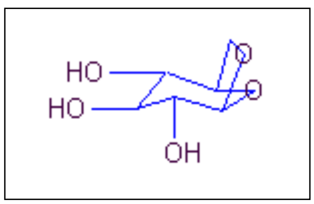
Run #	Date	Driving Route	Night/Day	Code	Route Start	Route End
37	2017-02-16	Vanderhoof	Night	VN1	21:18	23:58
38	2017-02-17	Fraser Lake	Night	FLN1	21:06	00:00
39	2017-02-18	Vanderhoof	Night	VN2	21:14	23:48
40	2017-02-19	Fraser Lake	Night	FLN2	21:18	00:17
41	2017-02-20	Vanderhoof	Night	VN3	21:37	00:19
42	2017-02-21	Vanderhoof	Day	VD1	12:33	15:03
43	2017-02-21	Fraser Lake	Night	FLN3	21:17	00:11
44	2017-02-22	Fraser Lake	Day	FLD1	12:38	15:18
45	2017-02-22	Vanderhoof	Night	VN4	21:16	00:04
46	2017-02-23	Fraser Lake	Night	FLN4	21:28	00:34
47	2017-02-24	Vanderhoof	Night	VN5	21:35	00:22
48	2017-02-25	Fraser Lake	Night	FLN5	21:18	00:15
49	2017-02-26	Vanderhoof	Night	VN6	21:37	00:22
50	2017-02-27	Vanderhoof	Day	VD2	12:36	15:03
51	2017-02-27	Fraser Lake	Night	FLN6	21:24	00:28
52	2017-02-28	Vanderhoof	Night	VN7	21:24	00:14
53	2017-03-01	Fraser Lake	Day	FLD2	12:36	15:06
54	2017-03-01	Fraser Lake	Night	FLN7	21:23	00:17

UBC School of Occupational and Environmental Hygiene (SOEH)			
Determination of Levoglucosan in Atmospheric Fine Particulate Matter by GC/MS			
Creation Date:	07/14/05	Method Version:	SOEH-SOP# A.00.18
Last Update:	01/09/13		

Introduction

Levoglucosan (Figure 1) is a sugar anhydride and is used as a molecular marker for the detection and evaluation for the presence of wood smoke in air. The components detected in wood smoke are numerous: PAH'S, aldehydes, free radicals and methoxylated phenols, but the detection of levoglucosan has proven to be a reliable indicator for wood combustion from residential fireplaces or forest fires.
Solvent extraction of 37 mmor 41 mm teflon filters with ethyl acetate, derivatization of levoglucosan and subsequent GC/MS analysis is a very selective and sensitive quantitative method.

Figure 1: Levoglucosan
1,6-Anhydro-beta-D-glucopyranose (CAS #: 498-07-7)



$C_6H_{10}O_5$ M.W. = 162.142

Apparatus and Chemicals

A. Apparatus:

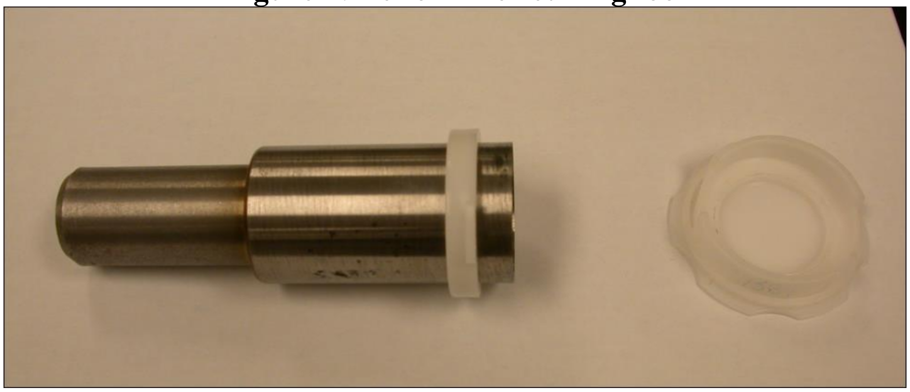
Analytical Instrument:
GC/MS System - Agilent Technologies 5973 GC/MSD

Centrifuge:
Hitachi HiMac centrifuge (CT5DL model)

Sampling Medium:
Gelman Teflo^{TM} W/Ring – PTFE Membrane W/PMP Ring: 2.0 um 37 mm
P/N R2PJ037

Filter Cutting Tool:
[Method 1] Teflon filter cutting tool (see **Figure 2**)
[Method 2] Scissors, scalpel, forceps and Petri dish.

Figure 2: Teflon filter cutting tool



B. Chemicals – Supplier Details

1,6-Anhydro-beta-beta-D-glucopyranose (Levoglucosan) – Sigma-Aldrich P/N 316555-1G (99.9% purity)

1,3,5-Tri-isopropylbenzene (Internal Standard) – Fluka P/N 92075 (97% purity)

7-Dehydrocholesterol (Surrogate) - Sigma-Aldrich

Ethyl Acetate – Fisher analytical grade

MSTFA + 1% TMCS (N-Methyl-N-trimethylsilyltrifluoroacetamide + 1% Trimethylchlorosilane 10 x 1 mL ampules - Pierce Chemicals P/N 48915

Pyridine (ACS grade) – Fluka # 82702 - 99.8% purity

C. Chemicals – Preparation of Stock Solutions

Preparation of Levoglucosan Stock Solution:
Weigh about 0.010 to 0.030 grams an amount of levoglucosan into an aluminium boat and record precisely the final weight. Transfer to a 25 mL volumetric flask and top up with ethyl acetate (depending on sample matrix, this dilution can be altered). Mix vigorously to dissolve all the crystals and to aid solubilization, ultrasonication can assist in this process. Make sure no solid crystals are undissolved. The stock solution can be stored at -80 ºC. Calculate the final concentration in nanograms per microliter (ng/uL) and record the date of preparation.

Preparation of 7-Dehydrocholesterol Surrogate Stock Solution:
Weigh about 0.1 grams an amount of 7-dehydrocholesterol into an aluminium boat and record precisely the final weight. Transfer to a 50 mL volumetric flask and top up with HPLC grade ethyl acetate. Mix vigorously to dissolve all the crystals and to aid solubilizing, ultrasonication can assist in this process. Make sure no solid crystals are undissolved. The stock solution can be stored at -80 ºC. Calculate the final concentration in nanograms per microliter (ng/uL) and record the date of preparation.

Preparation of Tri-isopropylbenzene Internal Standard:
Transfer 5 uL of tri-isopropylbenzene into 25 mL volumetric flask and top up with ethyl acetate. Dilute to an intermediate stock at an appropriate level (5-20 times). Spike 10 uL of this solution into each GC vial after derivatization has been completed.

Sample Preparation Procedure

A. Removal of Teflon portion of the filter

If the entire filter is to be analyzed for levoglucosan, Method 1 should be used. If the filter is to be cut in half (e.g. to analyze one half for levoglucosan and one half for a different analyte), Method 2 should be used.

Method 1
Each teflon filter has an outer plastic ring that maintains the teflon filter's round shape.

Removing the telfon filter material is conducted with a special tool (***Figure 2***) designed to position and cut out the teflon portion and remove the outer plastic ring.

For 37 mm teflon filters place the filter inside a GPM cassette holder and install the support ring.

Snug down the support ring to prevent the filter from rotating during the cutting step.

Insert the cutting tube and rotate with a downward force. This will cut out the teflon portion of the filter.

Using clean forceps transfer the filter to a 4 mL extraction vessel.

Prior to the extraction and derivatization procedures spike each sample with 20 uL of the stock 7-dehydrocholesterol standard (surrogate).

Method 2
If the filter is to be cut in half, this must be done BEFORE removing the outer plastic ring. Using the forceps, grip the filter by the outer plastic ring and hold it above a Petri dish. Use clean scissors to cut the filter in half as accurately as possible.

Place the two filter halves into separate Petri dishes. Using the forceps to brace the outer ring, use the scalpel to carefully cut the filter material away from the ring.

Transfer the filter to a 4 mL extraction vessel.

Prior to the extraction and derivatization procedures spike each sample with 20 uL of the stock 7-dehydrocholesterol standard (surrogate).

B. Extraction and Derivatization

Levoglucosan is light sensitive so take precautions to not expose the sample vials to intense direct light.

Transfer 2 mL of ethyl acetate into the extraction vessel and ultrasonicate for 30 mins.

Centrifuge only if the samples have high suspended particulate matter.

Transfer exactly 100 uL of the final extract into GC vials that have 300 uL inserts installed. Try not to re-suspend the particulates.

Add 15 uL of pyridine and 30 uL of MSTFA + 1% TMCS solution.

Vortex for 10-20 secs and place the samples in a dark location for a minimum of 6 hours to complete the derivatization.

Prior to GC/MS analysis spike 10 uL of tri-isopropyl benzene internal standard into each vial.

GC/MS Conditions

DB-5 (5% phenyl) capillary column 30 meters x 0.25 mm I.D. with 0.25 um film thickness

Temperature Program: 65 ^{o}C (1 min hold) to 310 ^{o}C @ 25 ^{o}C (5 min hold)

Run time (mins): 15 mins

Injection Port Temperature: 290 ^{o}C

Injection Vol (uL): 1 uL

Splitless Injection Time (min): 0.50 min

Inlet Pressure (psi): 10 psi with constant flow

Initial Flow (mL/min): 1.1 mL/min

TABLE 1: Single Ion Monitoring (S.I.M.) for Levoglucosan, Internal Standard and Surrogate

Component	Retention Time (min)	Quan Mass (Q1)	Quan Mass (Q2)	Quan Mass (Q3)	Dwell Time (msec)
Istd	5.681	161.00	189.00	204.00	50
Levoglucosan	7.527	204.00	217.00	333.00	50
Surrogate	13.522	325.00	351.00	456.00	50

Figure 3: S.I.M. Chromatogram of Levoglucosan-TMS, Tri-isopropyl benzene (Istd) and 7-Dehydrocholesterol (Surrogate)

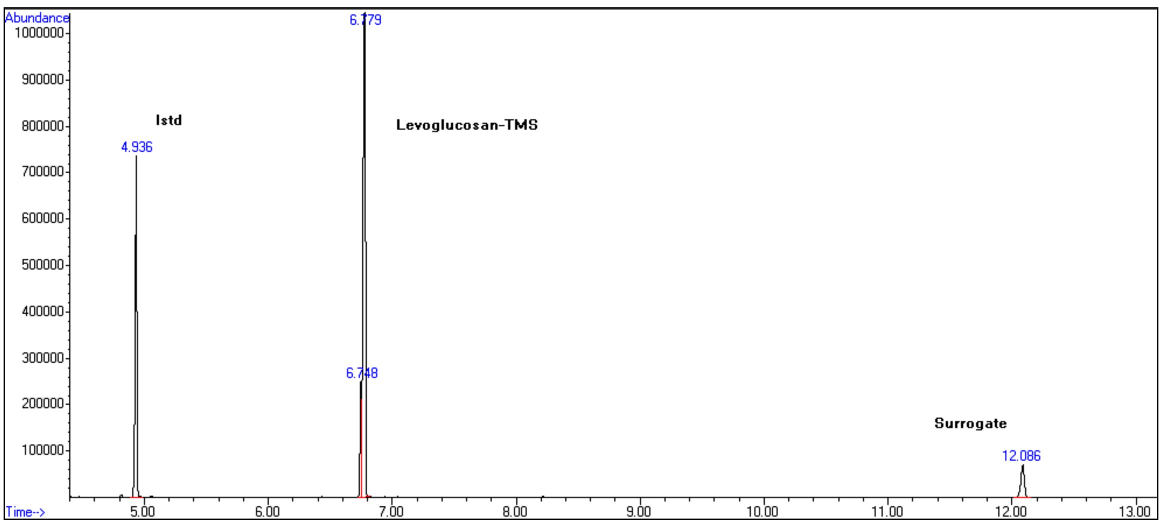


Figure 4: Full Scan Mass Spectrum of the Trimethylsilyl derivative of Levoglucosan

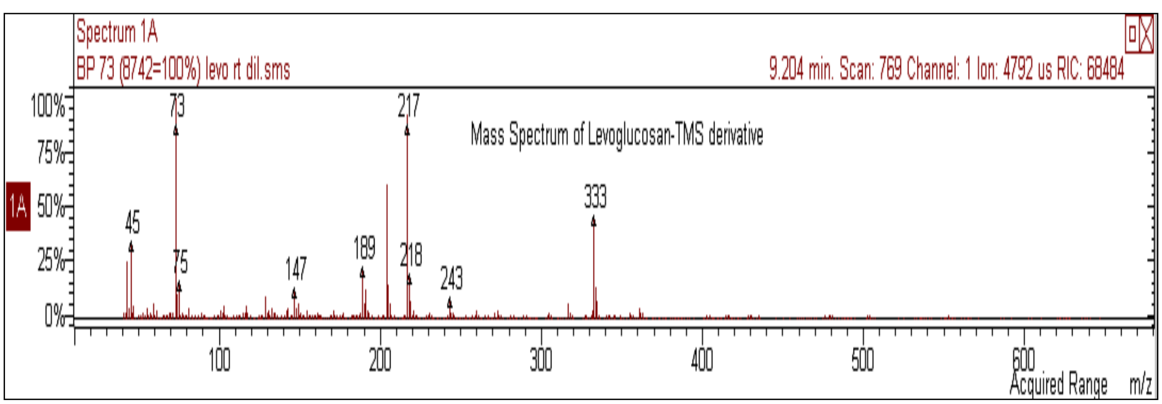
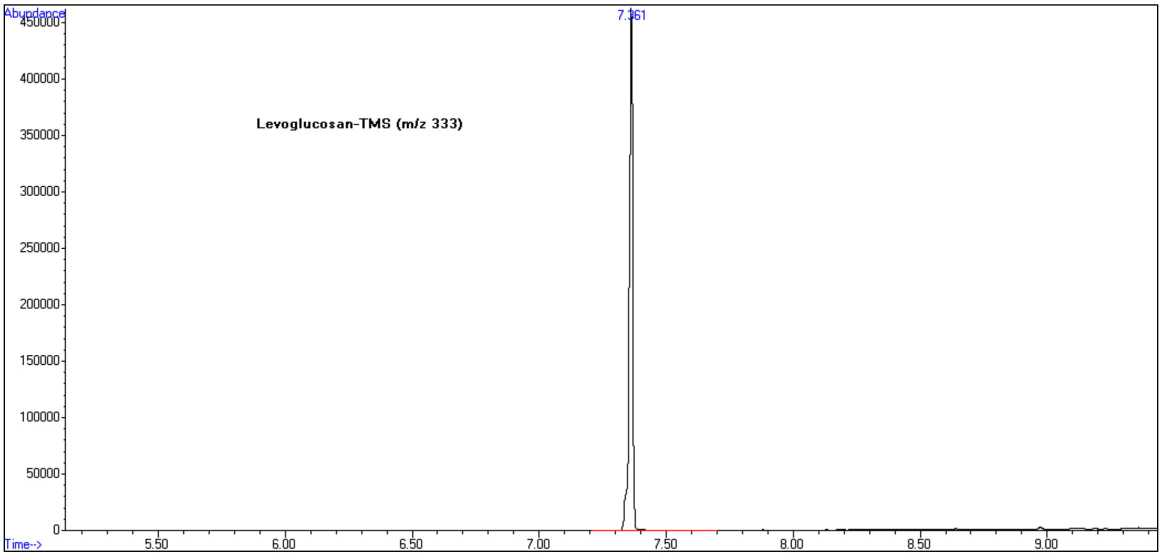


Figure 5: Limited Mass Chromatogram of Quan Ion of Levoglucosan-TMS (m/z 333)



References

Determination of Levoglucosan in Atmospheric Fine Particulate Matter – Christopher Simpson, Russell L.Dills, Bethany S. Katz, and David A. Kalman, Dept of Environmental and Occupational Health Sciences, University of Washington, Technical paper ISSN 1047-3289 J. Air and Waste Management Association 54:689-694

Method Revisions

Revision Number	Author	Date	Description
SOEH-SOP# A.00.16	Timothy Ma	07/14/05	1st Version
SOEH-SOP# A.00.17	Timothy Ma	09/24/08	2nd Version
SOEH-SOP# A.00.18	Jeff Nichol	01/08/13	3rd Version

Appendix D **- R Functions**

This appendix includes important functions created in r for the spatial analysis and mapping performed in this thesis. Required r packages for these functions:

- raster
- sp
- rgdal
- ggmap

1. Example script to create a raster layer to cover a region of interest.

```
#############################################################################
# Script to create a raster layer to cover a community of interest
#   to be used for spatial averaging and smoothing of mobile data
#############################################################################
# Steps taken from example at:
#  http://stackoverflow.com/questions/9542039/resolution-values-for-rasters-i
n-r

# CREATE WHISTLER / PEMBERTON RASTER LAYER #
#  define latitude and longitude boundary box
 xtll <- matrix(nrow = 2, ncol = 2)
 xtll[1,1] <- c(-123.060) # x min
 xtll[1,2] <- c(50.076)   # y min
 xtll[2,1] <- c(-122.636) # x max
 xtll[2,2] <- c(50.351)   # y max

# Convert to SpatialPoints with world epsg:4326
 xtll=SpatialPoints(xtll,CRS("+init=epsg:4326"))

# convert CRS to EPSG:3005 (NAD83/BC Albers)
 spTransform(xtll,CRS("+init=epsg:3005"))
# Take the extent from the previous result and round to nearest 10m
# extent: 1210374, 1239239, 566606.9, 598519.8  (xmin, xmax, ymin, ymax)
 ext = extent(1210370, 1239240, 566600, 598520)

# Determine ncol and nrow by counting the number of rows and columns to make
#     each side of a 3x3 square = approx 100m
 length(1210370:1239239)/(100/3) # ncol = 866
 length(566600:598520)/(100/3)   # nrow = 958

# create raster with these extents, calculated # of columns and under same
# projection
 r.WP = raster(ext, ncol=866, nrow=958, crs="+init=epsg:3005")

rm(ext, xtll)
```

2. Function to spatially average and smooth mobile monitoring results across a raster grid for each monitoring run.

```
###############################################################################
# FUNCTION - Focal.Smoothing.RasterStackTrips(shp, r, variable)
#     - creates a raster stack to hold all individual trip rasters
#     - loops through individual trips in shp and:
#         - overlays raster layer onto SpatialPointsDataFrame with rasterize
#            function
#             - creates 2 rasters, one with raw counts and one with means of
#                all records from within each cell
#             - sets cells with counts less than 1 to NA
#             - multiplies the 2 rasters to obtain a mean*count raster layer
#         - performs focal smoothing on raster layers with focal function
#            using an equally weighted 3x3 box
#            (to create overall effect of 100mx100m)
#         - divides focally smoothed mean*count layer by the focally
#            smoothed count layer to effectively create a raster layer of
#            means focally smoothed using a 3x3 grid weighted by cell counts
#         - adds the trip raster to the raster stack
#     - returns the completed raster stack
#
# ## INPUTS:
# shp = SpatialPointsDataFrame
# r = blank raster layer created to cover the area of interest with cells
#      approximately 33m x 33m
# variable = column name of variable to use for cell means
##############################################################################

Focal.Smoothing.RasterStackTrips <- function(shp,r,variable){

  # create empty raster stack
   s <- stack()

  # loop through individual trips
   for(trip in unique(shp$Trip)){

    # subset trip data
     trip.shp <- shp[which(shp$Trip == trip),]

    # Project spatial data frame to match raster projection of BC Albers
     trip.shp <- spTransform(trip.shp,CRS("+init=epsg:3005"))
```

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```
    ## Use rasterize function to overlay dataframe and produce 2 layers:
    #     1 - r.count - counts the number of records in each cell
    #     2 - r.mean  - takes the mean in each cell
     r.count <- rasterize(x = trip.shp, y = r, field =
       trip.shp@data[,variable], fun = 'count', na.rm = T)
     r.mean <- rasterize(x = trip.shp, y = r, field =
       trip.shp@data[,variable], fun = mean, na.rm = T)

    # Set the cells where there are less than 1 record to NA
     r.mean[which(r.count@data@values < 1)] <- NA
     r.count[which(r.count@data@values < 1)] <- NA

    # multiply the 2 rasters to create a mean*count layer = r.MxC
     r.MxC <- r.mean * r.count

    # Use focal function to perform focal smoothing on the count and
       mean*count layers
    #   (Weighting is with an equally weighted 3x3 grid)
     r.count.SMOOTHED <- focal(r.count, w=matrix(1,3,3), fun=sum, na.rm = T)
     r.MxC.SMOOTHED <- focal(r.MxC, w=matrix(1,3,3), fun=sum, na.rm = T)

    # Divide the smoothed mean*count by the smoothed count layer to
       effectively create a mean layer focally smoothed using a 3x3 grid
       weighted by the cell counts
     r.mean.SMOOTHED <- r.MxC.SMOOTHED / r.count.SMOOTHED

    # add trip name to layer
     r.mean.SMOOTHED@data@names <- trip

    # Add trip layer to the raster stack
     s <- stack(s, r.mean.SMOOTHED)
  }

  return(s)
}
```

3. Function to extract the average spatial pattern across the individual run raster layers.

```r
###############################################################################
# FUNCTION - RasterStack.Average.Pattern(stack, min.trips)
#      - calculates the average pattern of the raster stack
#      - counts how many trips were not NA in each cell and sets the cells in
#            the average layer to NA if this is below the min.trips number
#            (this is to remove cells that were only monitored in 1 of 10
#            trips for example)
#      - returns the completed average pattern raster layer
#
# ## INPUTS:
# stack = raster stack with the indiv trip patterns
# min.trips = minimum number of trips to not equal NA in each cell
##############################################################################

RasterStack.Average.Pattern <- function(stack, min.trips){

  # Calculate the average pattern of the raster stack
   r.avg.pattern <- mean(stack, na.rm = T)

  # Count the number of none NA values in each cell in the raster brick
   rNA <- sum(!is.na(stack))

  # Set the values of cells in the average pattern layer to NA if there were
      not at least the min.trips number of none NA values in the raster brick
   r.avg.pattern[which(rNA@data@values < min.trips)] <- NA

   return(r.avg.pattern)
 }
```

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4. Function to convert the final raster layers to polygons ready for mapping.

```
################################################################################
# FUNCTION - convert.raster.to.polygons(Rast)
#           - converts raster to polygons
#           - transforms to WGS84
#
# ## INPUTS:
# Rast = raster to be converted
###############################################################################

# (Based on: http://stackoverflow.com/questions/33530055/add-raster-to-ggmap-
base-map-set-alpha-transparency-and-fill-to-inset-raster)

convert.raster.to.polygons <- function(Rast){

  # Convert to polygons
   rtp <- rasterToPolygons(Rast)
   rtp@data$id <- 1:nrow(rtp@data)
    # add id column for join data after the fortify

  # project
   projection_wgs84 = CRS("+proj=longlat +datum=WGS84")
   rtp = spTransform(rtp, projection_wgs84)

  # convert to normal dataframe and merge the data to it
   rtpFort <- fortify(rtp, data = rtp@data)
   rtpFortMer <- merge(rtpFort, rtp@data, by.x = 'id', by.y = 'id')

   return(rtpFortMer)
 }
```

5. Function to download base maps from Google.

```
#############################################################################
# FUNCTION - Download.Base.Map(Auto, Data, Center, Zoom)
#
#           - downloads google base map
#           - if auto = T, centers the map on the center of the data
#           - if auto = F, centers map based on variable 'Center'
#
# ## INPUTS:
# Auto = T or F - whether to center based on data or manual
# Data = Data that will be mapped
# Center = Manually defined center to use if Auto = F
# Zoom = zoom level for get_googlemap (usually 11-14)
############################################################################

Download.Base.Map <- function(Auto, Data, Center, Zoom){

  # If Auto = T, define the center for the map request
   if(Auto == T){
     Center <- c(lon = mean(c(min(Data$long, na.rm = T) - 0.01,
                              max(Data$long, na.rm = T) + 0.01)),
                 lat = mean(c(min(Data$lat, na.rm = T) - 0.01,
                              max(Data$lat, na.rm = T) + 0.01)))
   }

  # Download the map with style command to instruct get_googlemap to:
  #     1. Hide road labels
  #     2. Hide administrative labels
  #     3. Hide all points of interest
  #     4. Plot landscape features in a simplified form
  #     5. Hide landscape labels
  #     6. Hide water body labels
  #     7. Hide transit line labels (ferries etc)
   Map <- get_googlemap(center = Center,
                        zoom = Zoom,
                        maptype = "roadmap",
                        color = "bw",
                        scale = 2,
                        style = "feature:road|element:labels|visibility:off&s
tyle=feature:administrative|element:labels|visibility:off&style=feature:poi|e
lement:all|visibility:off&style=feature:landscape|element:all|visibility:simp
lified&style=feature:landscape|element:labels|visibility:off&style=feature:wa
ter|element:labels|visibility:off&style=feature:transit|element:labels|visibi
lity:off")

   return(Map)
 }
```

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6. Function to create maps of final polygons.

```r
################################################################################
# FUNCTION - create.map(Base.Map, Polygons, Pal)
#            - maps and fills polygons that have been pre-binned based
#                  on z-score
#
# ## INPUTS:
# Base.Map = Base map that has already been downloaded
# Polygons = Polygon layer to add to the map
# Pal = Colour palette with hex codes for colour fills
###############################################################################


create.map <- function(Base.Map, Polygons, Pal){

  # create map with base layer
   m <- ggmap(Base.Map)

  # add polygon layer values coloured by Z.bin column with

      transparency (alpha) = 90%, and size = 0 to remove the polygon outlines
   m <- m + geom_polygon(data = Polygons,
                         aes(x = long, y = lat, group = group, fill = Z.Bin),
                         alpha = 0.9,
                         size = 0,
                         show.legend = F)

  # Add colour scale and legend
   m <- m + scale_fill_manual(values = Pal)

  # add themes to simplify the appearance of the map
   m <- m + theme(axis.title=element_blank(),
                  axis.text=element_blank(),
                  axis.ticks=element_blank())

  # print map
   m
 }
```

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ATTACHMENT 5

2021

Assessment of EPA's Residential Wood Heater Certification Program

Test Report Review: Stoves & Central Heaters

NESCAUM

www.nescaum.org

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ASSESSMENT OF EPA'S RESIDENTIAL WOOD HEATER CERTIFICATION PROGRAM

Test Report Review: Stoves & Central Heaters

Project Manager

Lisa Rector, NESCAUM

Principal Contributors

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Northeast States for Coordinated Air Use Management (NESCAUM)
Boston, Massachusetts

Printed: March 2021

Summary for Policymakers

The Northeast States for Coordinated Air Use Management (NESCAUM) in collaboration with the Alaska Department of Environmental Conservation (ADEC) conducted a review of the US Environmental Protection Agency's (EPA's) program to certify that new wood stoves and central heaters meet air pollution standards. For the over 250 certified wood heaters reviewed, this report finds a systemic failure of the entire certification process, including EPA's oversight and enforcement of its requirements. Wood heater manufacturers and the EPA-approved test laboratories they use for certification testing often deviate from test method requirements and the manufacturers' owner's manual instructions, creating the appearance of artificially lowering emissions in the lab in order to meet the certification standards. The descriptions of the wood heaters given in test reports do not always agree with what the manufacturers advertise in their marketing materials. All test reports have missing data elements.

Many of these discrepancies and omissions are clear violations of EPA requirements. Supposedly independent third-party reviewers are charged with flagging these problems, but do not. In fact, EPA notified the testing labs and third-party reviewers of some of the identified testing issues in 2019, but after that notice, this review found more recent test reports continuing to employ the same practices, and EPA continuing to approve them.

The unavoidable conclusion of this report is that EPA's certification program to ensure new wood heaters meet clean air requirements is dysfunctional. It is easily manipulated by manufacturers and testing laboratories. EPA has done little to no oversight and enforcement. Starting in 1988 when EPA first adopted air pollution standards for new wood stoves, it has never conducted a single audit to verify that a wood heater actually performs consistent with its certification test results, a span of over 30 years.

This raises serious concerns for state and local air quality and public health agencies. These agencies rely on a robust and credible certification program to address air pollution problems and public health harms caused by residential wood combustion. In order to protect public health, the agencies are pursuing policies to incentivize cleaner wood burning devices in communities suffering from high levels of wood smoke pollution. This includes providing financial incentives for the exchange of older devices with cleaner new wood heaters. If EPA's program for certifying wood heaters is not assuring that new devices are in fact cleaner than the ones they are replacing, then these efforts may be providing no health benefits while wasting scarce resources.

At its core, EPA's program as currently run allows the continued sale and installation of high-emitting devices, many of which will be in homes located in overburdened communities already suffering from environmental and other inequities. Once installed, these units will remain in use, emitting pollution for decades to come.

Acknowledgments and Disclaimers

This report was a joint effort between staff at NESCAUM and the Alaska Department of Environmental Conservation. NESCAUM's portion of this work was made possible by funding support provided by the New York State Energy Research and Development Authority (NYSERDA). The opinions expressed in this report do not necessarily reflect those of NYSERDA or the States of Alaska and New York, and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it. Further, NYSERDA, the States of Alaska and New York, and NESCAUM make no warranties or representations, expressed or implied, as to the fitness for a particular purpose or merchantability of any product, apparatus, or service, or the usefulness, completeness, or accuracy of any processes, methods, or other information contained, described, disclosed, or referred to in this report. NYSERDA, the States of Alaska and New York, and NESCAUM make no representation that the use of any product, apparatus, process, method, or other information will not infringe privately owned rights and will assume no liability for any loss, injury, or damage resulting from, or occurring in connection with, the use of the information contained, described, disclosed, or referred to in this report.

NESCAUM would like to thank the following individuals for supporting or providing assistance to this effort:

Mr. Randy Orr, New York State Department of Environmental Conservation; Mr. Kenneth Newkirk, New York State Department of Environmental Conservation; Mr. Marc Cohen, Massachusetts Department of Environmental Protection; Ms. Cindy Heil, Alaska Department of Environmental Conservation; Mr. Steven Hoke, Alaska Department of Environmental Protection; Mr. Nick Czarnecki, Fairbanks North Star Borough; Mr. Steffan Johnson, U.S. Environmental Protection Agency; Mr. Michael Toney, U.S. Environmental Protection Agency; Dr. Rafael Sanchez, U.S. Environmental Protection Agency, and Mr. Patrick Yellin, U.S. Environmental Protection Agency.

NESCAUM is a 501(c)(3) nonprofit association of eight state air quality agencies in the northeast United States whose mission is to provide technical and policy support to the air quality and climate programs of its member states. More information about NESCAUM is available at www.nescaum.org.

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GLOSSARY

Annual Fuel Use Efficiency (AFUE) –The percentage of heat delivered to a home over a year. AFUE differs from "thermal efficiency" in that it assesses performance over a variety of loads and transitional states.

Appliance – A wood heater subject to the Residential Wood Heater (RWH) New Source Performance Standards (NSPS).

ASTM – ASTM International, formerly known as the American Society for Testing and Materials, is an international organization that develops voluntary technical standards.

ASTM 2515 – The ASTM method for measuring particulate matter (PM) in a dilution tunnel. This method is identified as a federal reference method in the RWH NSPS.

ASTM 2618 – The ASTM method for measuring PM emissions from pellet and cordwood boilers. This method is identified as a federal reference method in the RWH NSPS.

ASTM 2779 – The ASTM method for measuring PM emissions from pellet stoves. This method is identified as a federal reference method in the RWH NSPS.

ASTM 2780 – The ASTM method for measuring PM emissions from cordwood stoves burning dimensional lumber. This method is identified as a federal reference method in the RWH NSPS.

ASTM 3053 – The ASTM method for measuring PM emissions from cordwood stoves burning cordwood. This method was approved as a broadly applicable alternative test method for certifications under the RWH NSPS.

CBI – Confidential business information.

Combustion Efficiency – The measure of combustion completeness, how well the appliance burns the fuel. This metric does not reflect the appliance's ability to deliver heat.

CSA B415 – Canadian Standard B415, "Performance Testing Of Solid-Fuel-Burning Stoves, Inserts, and Low-Burn-Rate Factory-Built Fireplaces."

Delivered Efficiency – A measurement of the energy delivered as heat to the building.

HHV – Higher Heating Value of Wood, a measurement of the actual usable energy from the fuel. This value includes the water and hydrogen content of the fuel.

LHV – Lower Heating Value of Wood. This value excludes the water and hydrogen content of the fuel. LHV efficiency values are, on average, 5-10 percent higher than HHV efficiencies.

M5G – The EPA method for measuring PM in a dilution tunnel.

M28 – The EPA method for measuring PM in a dilution tunnel from cordwood stoves using dimensional lumber.

M28 WHH – EPA M28 for Wood-fired Hydronic Heating Appliances.

Nominal Output – The maximum hourly output of an appliance.

New Source Performance Standards, NSPS or RWH NSPS – EPA's "Standards of Performance for New Residential Wood Heaters, New Residential Hydronic Heaters and Forced-Air Furnaces," 89 Fed. Reg. 13672-13753 (March 16, 2015).

RWH – Residential Wood Heating.

Stack Loss Efficiency (SLM) – A measure of efficiency based on fuel input minus all flue gas loss. This measure does not include jacket loss calculations. This is a theoretical calculation of delivered heat.

Thermal Efficiency – Efficiency as determined using the input/output method described in M28 OWHH.

Thermal Storage – A liquid-filled tank that stores excess heat generated by a wood heating appliance.

Executive Summary

In 2015, the U.S. Environmental Protection Agency (EPA) adopted new emission standards for residential wood burning appliances under the Residential Wood Heater New Source Performance Standards (RWH NSPS).[1] These were the first revisions to the standards since 1988, a span of over 25 years, and included consideration of more advanced wood burning technologies and encompassed more wood heater appliance types than under the 1988 standards. The RWH NSPS rule was fully implemented through two steps, with the more stringent Step 2 numerical emission standards going into effect in May 2020.

While the new RWH NSPS requirements were long sought by state and local air quality officials, the final RWH NSPS program as implemented has raised serious concerns about the program's efficacy and the extent to which the updated RWH NSPS will provide in-use emission reductions commensurate with those standards. The 2015 RWH NSPS introduced the use of third-party certifiers accredited by the International Standards Organization (ISO) to implement several critical elements of the new rule, including reviewing certification test reports and conducting compliance inspections. The third-party reviewers are paid by the manufacturers and are often the same companies that perform the certification testing, creating a potential conflict of interest.

Based on these concerns, this study was undertaken to evaluate the effectiveness of the current framework that uses ISO-accreditation and EPA approval to qualify testing labs and an ISO-accredited third-party review to complete a test report review and issue a certificate of conformity, which then becomes part of an application package that goes to EPA's Office of Compliance Assurance (OECA) for review and certification. In this report, results are presented from reviews of available emission certification test reports for almost 250 appliances approved by EPA as compliant with the Step 2 emission standards under the 2015 RWH NSPS. The reviews evaluated (1) completeness of the certification test report data sets, (2) consistency of the EPA-approved test results, and (3) error magnitudes where they can be estimated. The analysis was conducted at the "screening" level, and was intended to identify areas where significant problems exist with the certification testing for which more detailed review by EPA may be warranted. It was not a full and complete review of the test reports, which likely would have revealed many more problems.

The analysis found persistent failures by EPA-approved labs to follow test methods and by third-party reviewers and EPA to identify deficiencies. The review also found a lack of effective oversight and enforcement by EPA. As a result, the existing program

[1] *Standards of Performance for New Residential Wood Heaters, New Residential Hydronic Heaters and Forced-Air Furnaces*, 80 Fed. Reg. 13672-13753 (March 16, 2015).

provides no confidence that new residential wood heaters are performing in a manner that better protects public health than the heaters they replace, and at the level required by federal standards. This has critical implications not only for public health, but also for the perceived cost-effectiveness of investments in residential wood heater change-out programs and tax credits given for the purchase of new wood burning appliances.

The study found that certification laboratories, sometimes at the manufacturer's direction, routinely employ atypical burn practices to improve the emission performance of wood heating devices during certification testing. These unusual practices are not commonly followed by the owners of these appliances after retail sale, and therefore are unlikely to represent actual in-use performance. In June 2019, EPA sent an email to ISO-accredited and EPA-approved labs and third-party certifiers identifying "discrepancies and concerns" it had observed in submitted test reports related to atypical test conditions. The reviewers in this study identified 40 reports certified after EPA sent its email in June 2019. The review found that all 40 of those certified test reports continued to contain at least one of the problematic test practices that EPA had explicitly identified as raising concerns.

There were also instances of prototypes being used for certification testing that are described with different physical parameters (e.g., firebox sizes) than the production models placed into retail sale that they are intended to represent. Different physical parameters between a tested prototype and the model offered for sale can adversely affect conclusions about in-use emissions performance.

In addition to the testing irregularities, this study uncovered a host of attendant issues that further undermine the program's integrity. EPA appears to have not completed any compliance audits in the more than 30 years since the original RWH NSPS rule in 1988. Compliance audits done strategically should be standard practice to verify units in the home perform in a manner consistent with their certification test results completed in the EPA-approved lab. The 2015 RWH NSPS program also lacks transparency as state and local agencies, along with the public, do not have easy access to sufficiently detailed certification test results and enforcement data that could be used to assess appliance performance.

States and communities with wood smoke pollution problems and a desire to reduce air toxics emissions rely on EPA's program to provide air quality improvements. However, EPA's failure to provide oversight and ensure the veracity of certification testing seriously undercuts the integrity of the RWH NSPS program and the likelihood that emission reductions are actually occurring, and sets the course for continued high emissions from new devices for years to come. To address this systemic problem, this study provides a set of recommendations to create a robust and effective RWH NSPS program. Some of the existing program weaknesses can be minimized through a commitment by EPA to enforce current requirements according to the clear language of the RWH NSPS. Others must be addressed through rule changes or as part of the next update to this NSPS, which is due in 2023.

ES-1. Background

Cordwood, pellets, and wood chips are important fuels for primary and secondary residential heating in the United States. According to the U.S. Energy Information Agency (EIA), 12.5 million homes (11 percent of the national total) used wood as an energy source in 2015, mainly for space heating. Wood heating reduces dependence on fossil fuels and promotes a local, indigenous fuel source. However, wood-burning is also a significant source of criteria and toxic air pollutant emissions.

Based on EPA's 2017 National Emissions Inventory (NEI), residential wood combustion emits approximately 340,000 tons of primary $PM_{2.5}$ annually, making it the largest direct source of particulate matter pollution in the country after road dust and fires (wildfire and prescribed).[2,3] Furthermore, a recent study has concluded that the level of wood burning may be significantly higher than represented by the NEI data.[4] These emissions have serious public health consequences, as residential wood heating can account for 10,000 to 40,000 premature deaths annually in the United States.[5,6] In states with large numbers of residential wood heating appliances, this emission source dominates health impacts from air pollution, especially during colder months.

State and local air quality agencies rely on standards and testing through EPA's emission certification program under the 2015 RWH NSPS to reduce emissions from new wood burning devices and to help attain and maintain the fine particulate matter ($PM_{2.5}$) National Ambient Air Quality Standards (NAAQS). Residential wood heating is a primary cause of nonattainment of the NAAQS for $PM_{2.5}$ in some areas. However, the

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[2] US EPA. *2017 National Emission Inventory* (April 2020). Available at: https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data.

[3] Primary PM is emitted directly from the source, as opposed to secondary particulate pollution that is created when sources emit precursor air contaminants, such as oxides of sulfur (SOx), oxides of nitrogen (NOx), volatile organic compounds (VOCs), and ammonia (NH_3), into the atmosphere that through chemical and physical processes form or help form $PM_{2.5}$.

[4] Commission for Environmental Cooperation. *Residential Wood Use Survey to Improve Black Carbon Emissions Inventory Data for Small-Scale Biomass Combustion*, Final Report. CEC, Montreal, Canada, (April 2019).

[5] Penn SL, Arunachalam S, Woody M, Heiger-Bernays W, Tripodis Y, Levy JI. Estimating state-specific contributions to $PM_{2.5}$- and O_3-related health burden from residential combustion and electricity generating unit emissions in the United States, *Environ Health Perspect* 125:324–332 (2017), http://dx.doi.org/10.1289/EHP550.

[6] Ciaizzo F, Ashok A, Waitz IA, Yim SHL, Barrett SRH. Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005, *Atmospheric Environment* 79:198-208, (2013), https://doi.org/10.1016/j.atmosenv.2013.05.081.

true scale of nonattainment is difficult to quantify because there are few regulatory air quality monitors located in rural areas where wood burning is most prevalent.

Residential wood heaters have a long useful life, therefore the benefits of new emission standards accrue slowly. To accelerate the turnover of older higher emitting appliances, government agencies, manufacturers, and nonprofit groups are investing millions of dollars in change-out programs. States and the federal government also offer tax credits that provide consumers with financial incentives to upgrade to new, presumably cleaner-burning wood heaters. In recognition of the public health impacts and financial stakes, this study was undertaken to investigate concerns about efficacy of the testing, review, and certification process adopted in the 2015 rule, and EPA's oversight and enforcement of the overall certification process.

ES-2. Methodology

In undertaking this study, the research team created a list of certification test reports to review using EPA's wood heater database to identify models that had been certified as Step 2 compliant. The team identified 131 cordwood stoves, 96 pellet stoves, and 28 central heating appliances that met these criteria, for a total of 255 devices. The 2015 RWH NSPS requires that a manufacturer post on its website a complete test report and summary report within 30 days of receiving certification, therefore the team attempted to locate all the test reports and post them to a central repository. However, difficulties were encountered finding some of the Step 2 appliance test reports, primarily pellet stove reports. Some manufacturers posted links to incorrect reports. In other instances, the reports could not be found after exhaustive online searches and a detailed review of the manufacturer's website. In some cases, reports were located with assistance from EPA. In total, 13 reports could not be found, and the team was unable to complete reviews of those certification test results.

For the 242 located reports, the next step in the process was to examine applicable regulations and guidance to identify criteria that would serve as the review's foundation. A regulatory basis document was created to catalog the review elements and the applicable regulatory citations. Given the large number of reports to review, the team chose to conduct a screening-level analysis focused on completeness of the reports, elements that could trigger certification revocation procedures, and elements that could trigger compliance audits of the tested devices.

Individual reviewers examined the test reports and entered data from these into a spreadsheet tool, which automatically created a preliminary determination as to whether significant problems existed with the certification testing for specific models based on the number of flags generated by data inputs. The initial reviewer was also able to include notes, comments, and recommendations. The review tool automatically generated warning flags based on data input to allow for objective determinations rather than subjective opinions. Once reviewers completed the data input, the review tool automatically generated summary sheets, which underwent review by a committee comprised of staff from multiple state and local air quality agencies. After assessing the findings, the committee arrived at a final determination on the adequacy of each certification test.

ES-3. Findings

This section summarizes the results of the investigation and provides examples from test reports to highlight the emission ramifications associated with some testing variables and assumptions. The analysis found considerable testing and review irregularities across all three categories of residential wood heating devices: cordwood stoves, pellet stoves, and central heating systems. Similar deficiencies were found on models from all three categories. For the purposes of brevity, this Executive Summary focuses primarily on the cumulative analysis results. Some specific issues with test assumptions and decisions identified through this investigation are highlighted as examples of the larger universe of failures uncovered. Readers are encouraged to review the full report for more scope and detail on the findings for specific aspects of the study.

ES-3.1.1. Cordwood Stove Findings

Reviewers identified 131 cordwood stoves for review. Of the 131 appliances targeted, reports could not be located for two appliances. None of the remaining 129 reports was determined to be complete. On average, the review found 8 revocation elements and 8 audit elements per test report. Deviations included failure to report mandatory elements, improper fueling procedures, and inaccurate firebox measurements.

ES-3.1.2. Pellet Stove Findings

The team identified 96 Step 2 certified pellet stove models to review as part of this research, but 10 test reports could not be found. Of the 86 pellet stove tests reviewed, all contained deficiencies, with an average of four revocation elements and five audit elements per test report. Although the rule requires EPA to review these reports for completeness, not a single report analyzed as part of this study was complete, yet each of these stoves was certified by EPA. Additionally, reports did not include mandatory elements such as PM measurements (6 appliances missing 1-hr filter data) or CO data (8 appliances had no data and 13 tests reported "zero" for CO emissions). Seventy-three percent of test reports contained contradictory information such as the Btu output from high load testing not matching the advertised Btu output.

ES-3.1.3. Central Heating System Findings

Reviewers identified 28 appliances for test report review; 15 cordwood boilers, 8 pellet boilers, 1 chip boiler, and 3 cordwood furnaces. None of the reports contained complete datasets or documented appliance settings to determine how the system operated during certification testing. All central heating unit test reports were incomplete. One test report could not be found. The review found that on average each central heating test report contained 9 revocation criteria flags and 12 audit criteria flags. The amount of data missing from each test report made it impossible to complete a full review of any of the 27 located reports.

ES-4. Recommendations for Program Improvement

A strong and broad response is needed to correct the failures of the RWH NSPS program identified through this study. Some of these program weaknesses can be minimized in the near-term if EPA makes a firm commitment, and follows through in good faith, to fully enforce the existing requirements according to the clear language of the RWH NSPS. Others must be addressed through rule changes.

ES-4.1. Third-Party Review Process

The EPA Inspector General should conduct an investigation of the third-party review system, and the responsible ISO bodies should call for an inquiry into their accreditation processes. EPA-approved laboratories that conduct certification testing should not be eligible to participate in the third-party review process. EPA should initiate action against third-party certifiers that have not adhered to test method and rule requirements. Finally, EPA should reassess the validity and viability of the third-party review process as a cornerstone of this program in the next update to the RWH NSPS.

ES-4.2. Review of Certification Test Results

EPA should conduct a detailed review of the problematic certification test reports identified in this study. The Agency should hold hearings and, where appropriate, revoke certification for models failing to meet the 2015 RWH NSPS rule requirements.

The findings of this report suggest that some manufacturers and EPA-approved laboratories may be "optimizing" certification tests to qualify models as Step 2 compliant by employing methods inconsistent with the approved protocols. At a minimum, models should undergo compliance audits as allowed per 40 CFR § 60.533(n) to verify the ability of production units to meet the emission standards to which the prototype was certified. To date, EPA has not conducted a single compliance audit during the more than 30 years this program has been in place. To address this, EPA should implement routine compliance audits on 10 percent of appliances each year. The audits should begin by targeting stove models that conducted non-representative tests. Appliances should not be allowed to recertify their appliances without retesting. Waiver provisions that allow manufacturers to avoid retesting of appliances should be eliminated. Retesting should require addressing deficiencies identified in the appliance review sheets, and remote witnessing of testing.

ES-4.3. Targeting Public Funding to Appropriate Appliances

Government funds for wood heater change-out programs should be used only for the cleanest appliances with valid test reports. Government agencies and nonprofits funding change-out programs should disqualify units that are certified as Step 2 compliant but fail to meet the rule's requirements. Taxpayer-supported incentive programs, such as the 26 percent federal tax credit created under the BTU Act, EPA Targeted Airshed grants, and state-supported activities, should only apply to those appliances included on the list of approved models developed by the Alaska Department of Environmental Conservation. This currently is the only thorough review of certification test reports applying the 2015 RWH NSPS requirements.

ES-4.4. Improving Certification Test Methods

Current cordwood test methods used to certify residential wood heaters are poorly designed and often lack the specificity to ensure viable and comparable emission results. EPA should revoke or modify problematic test methods. The ASTM 3053 test should be revoked as a Broadly Applicable Test Method. EPA should expedite rulemaking or guidance to close loopholes and reduce deficiencies in ASTM and CSA test methods. Over the longer term, EPA should fully fund efforts to develop new test methods that bring integrity, reliability, and reality to testing outcomes.

ES-4.5. OECA Enforcement and Oversight

EPA should establish residential wood heaters as a high priority enforcement sector and immediately begin a permanent and effective enforcement initiative. EPA should take enforcement action against third-party certifiers that do not adhere to method and rule requirements. Enforcement action should be taken under 40 CFR § 50.535(b) against EPA-approved laboratories that fail to follow required procedures or practices with the goal of assuring lab independence and competence while eliminating coordination between labs and manufacturers that inappropriately "optimize" test results and modify appliances during testing. Finally, EPA should request a revision to ISO procedures to ensure the certification system's integrity and competence.

ES-4.6. Program Transparency

The results of this analysis demonstrate that significant improvements in transparency are needed for the certification and enforcement components of the RWH NSPS. For example, EPA-approved laboratory inspections and compliance assurance activities are treated as confidential business information (CBI). There is no clear justification why these elements would be considered CBI as they do not pertain to typical CBI elements, such as product designs or manufacturing processes. Instead, EPA should eliminate claims of CBI for all compliance assurance monitoring activities. EPA should develop a strategy to ensure all manufacturers post complete non-CBI test reports and take enforcement action against all manufacturers who post incomplete non-CBI test reports, as defined by the rule. EPA should eliminate the use of confidential ISO compliance assurance audits, and all audit findings should be posted on the Enforcement and Compliance History Online (ECHO) database maintained by EPA. EPA should develop and require the use of a standardized certification report template.

ES-4.7. Investigating EPA Program Oversight and Enforcement

The EPA Inspector General or Congress should conduct a review of EPA's OECA and Office of Air Quality Planning and Standards (OAQPS) with a focus on identifying practices to improve Agency oversight and enforcement of the 2015 RWH NSPS program.

ES-5. Conclusions

This study covered 255 Step 2 certified wood heater models (131 cordwood stoves, 96 pellet stoves and 28 central heating appliances) to assess the ability of EPA's program to assure compliance with RWH NSPS regulations. Thirteen of the identified models did not have publicly available certification test reports, as required by the regulations. For the remainder, no report was found to be complete and in full compliance with RWH NSPS requirements. Seventy-two percent of the ISO/EPA certified reports contained issues listed as Criteria for Revocation of Certification under the 2015 RWH NSPS; 24 percent of the test reports were too incomplete to make determinations; and the remaining 4 percent had minor issues.

The third-party certification review process is highly ineffective at identifying and reporting testing irregularities. The documented failures in the third-party process may be due to poor program design, the lack of competency of the groups involved, improper complicity between third-party reviewers and manufacturers, or some combination of the three. Study results also highlight the lack of EPA's use of the auditing program to ensure production models are substantially similar to the prototypes used in certification testing, and that those offered for sale are meeting the applicable emission standards.

This analysis also uncovered a lack of transparency in the RWH NSPS program. Reviewers were often unable to access key data and information on certification testing. An overly broad assertion of confidential business information has removed non-proprietary compliance assurance activities from public review.

Based on the identified shortcomings in this review, the 2015 RWH NSPS certification program fails to assure that new residential wood heaters are uniformly cleaner than past devices before the new standards went into effect. A flawed testing and review system coupled with a historical lack of EPA enforcement of basic program elements work in tandem to undermine the public health goals of the program. The end result is a program devoid of any credibility to ensure that new residential wood heating appliances are meeting federal emission standards, and instead gives every indication that scarce public resources are being misspent on incentive programs meant to encourage the more rapid introduction of cleaner wood burning appliances that truly reduce emissions.

1. INTRODUCTION

In 1988, EPA first established emissions limits for new residential wood heaters (RWH) under the Clean Air Act provisions governing New Source Performance Standards (NSPS). In 2015, EPA updated its original RWH NSPS rule using a two-step process to phase in more stringent emission standards. The initial "Step 1" limits generally aligned with the then-current emissions performance of most covered devices, while more stringent "Step 2" emissions limits took effect for new wood burning appliances sold after May 15, 2020. This was intended to provide manufacturers with a period of several years to design and manufacture cleaner devices.

A wood heater model line is certified as compliant with the RWH NSPS emissions limits if emissions from a prototype appliance, as measured by an EPA-approved testing laboratory, conform to the rule requirements. The 2015 RWH NSPS updates retained key elements of the previous 1988 RWH NSPS rule, allowing manufacturers to test a prototype to certify a model line. However, EPA delegated critical program oversight and compliance assurance activities traditionally performed by EPA to International Standards Organization (ISO) accredited third-party certifiers approved by EPA. Those activities include certification and competency assessments of the EPA-approved test laboratories, review of test reports, and annual inspections to confirm that manufactured appliances reasonably reflect the prototype used for certification testing.

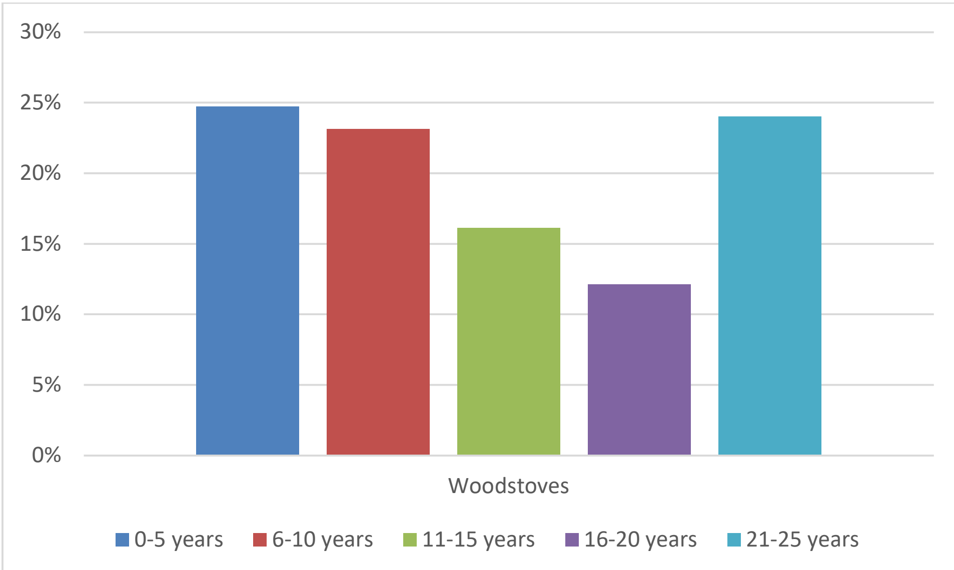
State and local agencies rely on EPA's federal certification program to ensure that new RWH models do not exceed the Step 2 limits in the RWH NSPS. Because there is no mechanism for follow-up assessment of performance in the field, it is essential that the procedures used to certify new wood burning devices accurately reflect emissions under normal use. This is crucial because, once installed, wood burning appliances typically remain in use for decades. A 2018 survey found that almost 25 percent of installed cordwood stoves were more than 20 years old (Figure 1).

In comments to EPA on the proposed 2015 rule, state agencies raised concerns about the third-party review system's efficacy and oversight.[7] In 2018, EPA released an Advanced Notice of Proposed Rulemaking (ANPRM) to solicit additional comments on improving the 2015 RWH NSPS program. Once again, states voiced concerns in comments on that

[7] NESCAUM Comments on Proposed Standards of Performance for New Residential Wood Heaters, New Residential Hydronic Heaters and Forced-Air Furnaces, and New Residential Masonry Heaters [79 Fed. Reg. 6330-6416 (February 3, 2014)], submitted May 5, 2014. Available at https://www.nescaum.org/documents/nescaum-comments-resid-wood-heaters-nsps-20140505.pdf.

ANPRM about the efficacy of the third-party review system and EPA's oversight of that program.[8]

Figure 1. 2018 National Survey - Reported Age of Woodstove[9]



In 2019, the Northeast States for Coordinated Air Use Management (NESCAUM) met with state agencies working on RWH programs. At that meeting, the states requested that NESCAUM undertake a review of certification test reports for appliances certified as meeting the 2015 RWH NSPS Step 2 emissions limits to assess the certification program's efficacy. That review employed procedures similar to those in a study conducted by Brookhaven National Laboratory for the New York State Energy Research and Development Authority (NYSERDA) in 2011 on EPA's Voluntary Hydronic Heater Program.[10] This report presents the results of the NESCAUM review and assesses the rigor of the current regulatory framework used to certify residential wood heating appliances. The report includes information on the following topics:

- the impact of residential wood heating,
- the regulatory structure of the federal RWH certification program,

[8] NESCAUM Comments on Advanced Notice of Proposed Rulemaking for New Source Performance Standards for Residential Wood Heaters, New Residential and Hydronic Heaters and Forced-Air Furnaces [83 Fed. Reg. 61585-61593 (November 30, 2018)], submitted February 12, 2019. Available at: https://www.regulations.gov/document?D=EPA-HQ-OAR-2018-0196-0017.

[9] Commission for Environmental Cooperation. *Residential Wood Use Survey to Improve Black Carbon Emissions Inventory Data for Small-Scale Biomass Combustion*, Final Report. CEC, Montreal, Canada (April 2019).

[10] Butcher, T, *Review of EPA Method 28 Outdoor Wood Hydronic Heater Test Results*, NYSERDA, Albany, NY (2011).

- an overview of test methods used by the certification program,
- the regulatory requirements for certification testing,
- the methodology used to assess program efficacy,
- the findings from the review process, and
- conclusions and recommendations.

2. BACKGROUND ON THE RESIDENTIAL WOOD HEATING SECTOR

2.1. Residential Wood Heating Emissions and Public Health Impacts

Cordwood, wood pellets, and wood chips are important primary and secondary residential heating fuels in the United States. According to the US Energy Information Agency (EIA), 1.8 million US homes use cordwood or wood pellets as their primary fuel. Another 10.3 million households use wood fuels for supplemental heating, which translates into 11 percent of all homes relying on wood as an energy source in 2015. Twenty-five percent of rural households use wood for heating compared with six percent of urban households.

While many view wood as a clean energy source, wood combustion is responsible for a disproportionately large share of pollutant emissions. According to EPA's National Emission Inventory, residential wood heating contributed approximately 340,000 tons of primary $PM_{2.5}$ in the United States in 2017.[11,12] After road dust and fires (wildfire and prescribed), residential wood heating was the largest source of primary $PM_{2.5}$ in the country, exceeding emissions from the highway and off-highway motor vehicle sectors combined (Figure 2).

Wood's importance as a fuel is regional in scale. Areas reliant on home heating oil with forested areas nearby tend to experience higher use.[13] Wood heating is highest in New England, where 21 percent of households use wood.[14] While wood heating may be regional, its impact has national significance. As highlighted in Figures 3 and 4, wood heating emissions were responsible for 98 percent of $PM_{2.5}$ emissions from the residential fuel combustion category. However, wood heating provided only 4 percent of the energy (in British thermal units) used for home heating.

[11] US EPA. *2017 National Emission Inventory* (April 2020). Available at: https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data.

[12] Primary PM is emitted directly from the source, as distinguished from secondary PM, which is formed in the atmosphere by reactions of precursor air contaminants, such as oxides of sulfur (SOx), oxides of nitrogen (NOx), volatile organic compounds (VOCs), and ammonia (NH_3).

[14] EIA, 2020. *Winter Fuels Outlook*. Available at: https://www.eia.gov/outlooks/steo/report/winterfuels.php#:~:text=Wood,as%20a%20supplemental%20heating%20fuel.

Figure 2. Contributions by Source Category to National $PM_{2.5}$ Inventory (2017 NEI)[15]

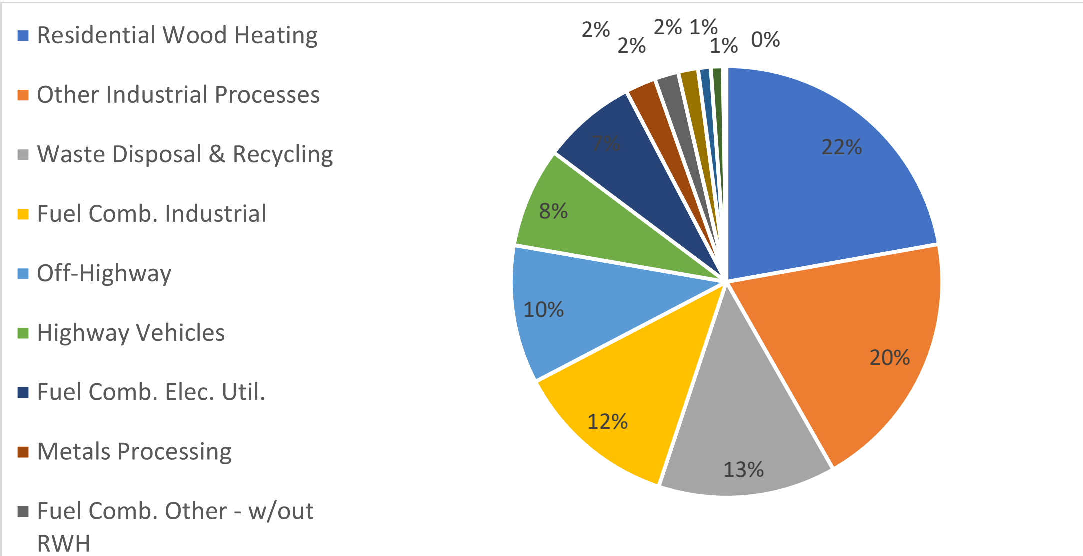
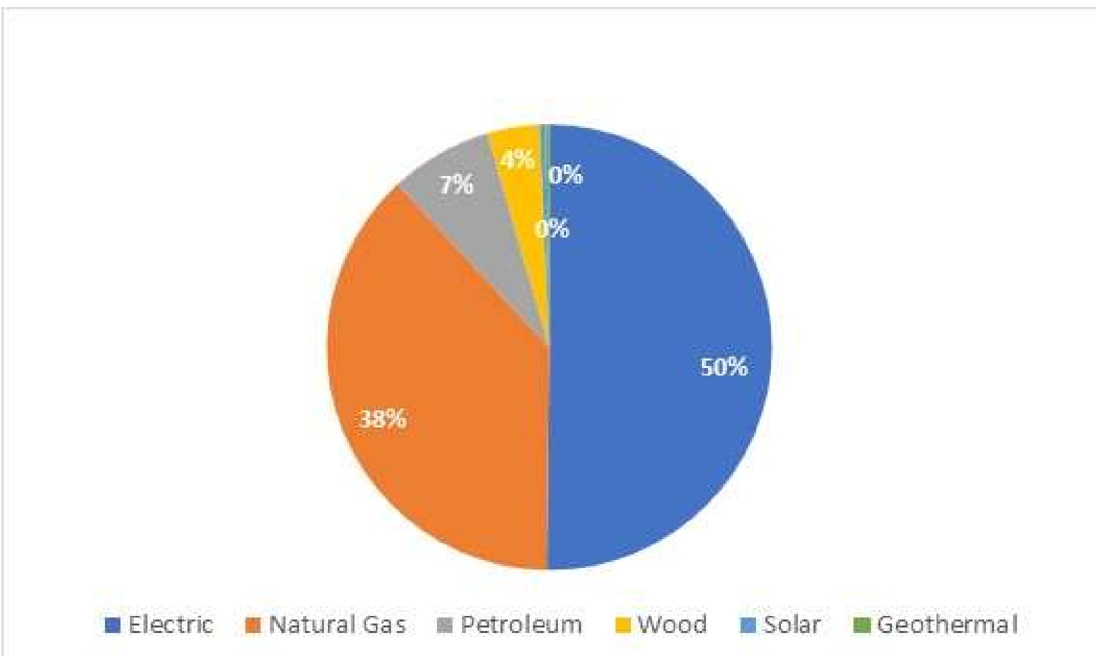
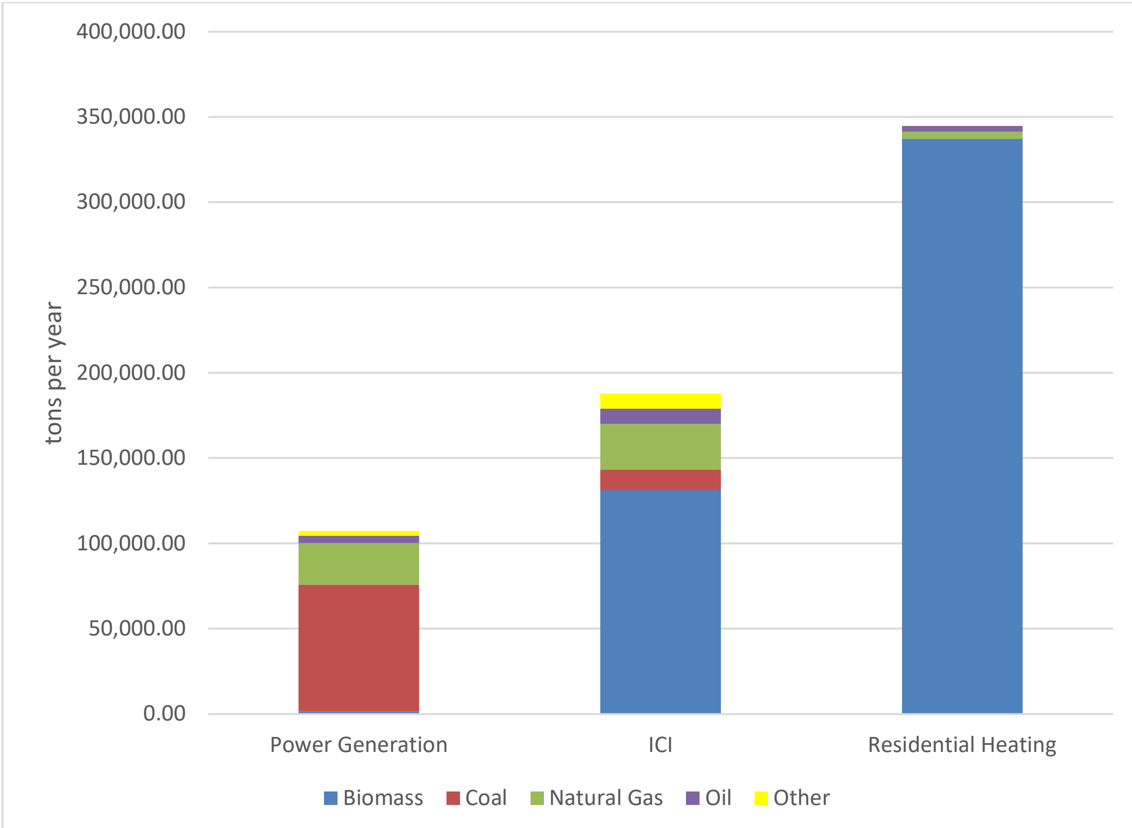


Figure 3. Energy Use for Residential Heating by Fuel Type (BTUs)



[15] US EPA. *2017 National Emission Inventory* (April 2020). Available at: https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data.

Figure 4. Fuel Combustion PM2.5 Emissions by Sector (tons per year)[16]



Exposure to $PM_{2.5}$ in wood smoke is associated with increased risk of respiratory and cardiac mortality, lung function decrements, exacerbation of lung disease, lung cancer, developmental and immunological effects, and premature mortality. A large percentage of the general population is particularly susceptible to those effects, including children, the elderly, and persons with respiratory or heart disease.[17] Studies estimate that RWH air pollutant emissions account for 10,000 – 40,000 premature deaths annually in the US.[18,19]

Wood combustion also emits polycyclic organic matter (POM), benzene, aldehydes, and other air toxics associated with respiratory and carcinogenic effects. EPA estimates that RWH accounts for 44 percent of POM emitted by all stationary and mobile sources and is

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[16] ICI = Industrial, Commercial, and Institutional emission sources.

[17] Naeher LP, Brauer M, Lipsett M, Zelikoff JT, Simpson CD, Koenig JQ, Smith KR. Woodsmoke health effects: a review, *Inhal Toxicol* 19(1):67-106 (2007), doi:10.1080/08958370600985875.

[18] Penn SL, Arunachalam S, Woody M, Heiger-Bernays W, Tripodis Y, Levy JI. Estimating state-specific contributions to $PM_{2.5}$- and O_3-related health burden from residential combustion and electricity generating unit emissions in the United States, *Environ Health Perspect* 125:324–332 (2017), http://dx.doi.org/10.1289/EHP550.

[19] Ciaizzo F, Ashok A, Waitz IA, Yim SHL, Barrett SRH. Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005, *Atmospheric Environment* 79:198-208 (2013), https://doi.org/10.1016/j.atmosenv.2013.05.081.

responsible for 25 percent of the cancer risk and 15 percent of the noncancer respiratory effects attributed to area source air toxics emissions.[20] In states where RWH is more prevalent, this emission source dominates health impacts from air pollution, especially during colder months.

Modeling and monitoring studies have demonstrated that wood smoke is a significant source of the PM measured in ambient air in many United States locations. Studies conducted by the Vermont Department of Environmental Conservation and NESCAUM found that, during the coldest and calmest winter days in Rutland, Vermont, wood smoke accounted for half or more of measured $PM_{2.5}$ levels.[21] A study in rural New York State found that more than 90 percent of carbonaceous $PM_{2.5}$ was associated with wood smoke and that winter nighttime peak $PM_{2.5}$ levels can exceed 100 $\mu g/m^3$.[22] These results are consistent with a field study by NESCAUM in the Adirondacks region that found significant localized pollution from wood burning that is closely associated with the higher population densities of towns and villages.[23] A 2016 study for New York State used modeling to assess wood heating impacts. Results from that study indicated that "a single polluting, wood-burning boiler or stove can lead to pollution levels above health-based air quality standards in the immediate vicinity of the source."[24] Wood smoke issues are not isolated to mountainous areas where valley temperature inversions exacerbate PM emission levels. Studies in Connecticut have found that, on cold winter days when ambient concentrations of $PM_{2.5}$ are elevated, observed wood smoke contributes more than 50 percent of hourly $PM_{2.5}$ concentrations.[25]

Modeling techniques have been used to evaluate the impact of RWH on air quality in locations that lack air quality monitoring data.[26] The results indicate that RWH can cause

[20] US EPA. *National Air Toxics Assessment, 2011 NATA: Assessment Results* (2015). Available at http://www.epa.gov/national-air-toxics-assessment/2011-nata-assessment-results#nationwide.
[21] Allen GA, Babich P, Poirot R. *Evaluation of a New Approach for Real Time Assessment of Wood Smoke PM*, Paper #16. Presented at the Air & Waste Management Association Visibility Specialty Conference on Regional and Global Perspectives on Haze: Causes, Consequences and Controversies, Asheville, NC (October 25-29, 2004).
[22] Graham J, Johnson P. *Assessment of Carbonaceous PM2.5 for New York and the Region*. NYSERDA Report 08-01, Albany, NY (March 2008). Available at http://www.nescaum.org/documents/assessment-of-carbonaceous-pm-2-5-for- new-york-and-the-region/.
[23] Allen GA, Miller PJ, Rector LJ, Brauer M, Su JG. Characterization of Valley Winter Woodsmoke Concentrations in Northern NY Using Highly Time-Resolved Measurements, *Aerosol and Air Quality Research* 11:519–530 (2011), doi:10.4209/aaqr.2011.03.0031.
[24] Weiss L, *et al*. *New York State Wood Heat Report: An Energy, Environmental, and Market Assessment*. NYSERDA, Albany, NY (April 2016).
[25] Connecticut Dept. of Environmental Protection, Bureau of Air Management. *Evaluation of Wood Smoke Contribution to Particle Matter in Connecticut*. Hartford, CT (February 7, 2011). Available at http://www.ct.gov/deep/lib/deep/air/wood_stove_furnaces/ctdep_woodsmokefinalreport.pdf.
[26] Weiss L, *et al.*, *New York State Wood Heat Report: An Energy, Environmental, and Market Assessment*. NYSERDA, Albany, NY (2016).

high ambient $PM_{2.5}$ levels in some locations, even in states that do not have designated $PM_{2.5}$ non-attainment areas.

2.2. Uses of the EPA Certification Program

As discussed in this section, a number of programs rely on the RWH NSPS certification program to identify clean burning appliances needed to meet federal health standards for $PM_{2.5}$ or to address local air pollution concerns.

2.2.1. State and Local Regulations

State and local agencies have developed ordinances and regulations that rely on EPA certification to identify clean RWH devices. Examples of such state actions are provided at: https://www.epa.gov/burnwise/ordinances-and-regulations-wood-burning-appliances.

2.2.2. Tax Incentives and Rebates

Federal, state, and local governments use the EPA certification program as a basis for identifying RWH appliances that are eligible for tax incentives or rebates. These programs cannot achieve optimal emissions reductions if certified stoves do not perform well in the field. Recently, the federal government passed the Biomass Thermal Utilization Act (BTU Act), which gives a 26 percent federal tax credit to any residential wood heating system with an efficiency of 75 percent or more. IRS regulations for this program are not yet in place, but many believe that the EPA database should be the authority to determine which appliances can obtain that tax credit. The following state programs also provide tax incentives or rebates:

- Alabama – 100 percent tax deduction for RWH systems
- Arizona – $500 tax deduction
- Georgia – 100 percent tax deduction for RWH systems
- Idaho – 100 percent tax deduction applied over several years
- Maine – rebates of up to $6,000 for cordwood or pellet boilers
- Maryland – rebates of up to $500 for cordwood stoves and $700 for pellet stoves
- Montana – up to a $1,000 tax credit
- New Hampshire – rebates of 40 percent of the purchase cost ($10,000 cap) for automated wood-fired heating systems
- New York – rebates of $2,000 for pellet stoves and up to $23,000 for boilers
- Vermont – rebates of $6,000 for pellet boilers or furnaces, $650 for pellet stoves

2.2.3. Change-out Programs

Over the past decade, millions of taxpayer and enforcement settlement dollars have supported the purchase of new wood-burning appliances. These programs, which have taken place in many areas of the United States, seek to reduce RWH emissions by replacing older wood-burning appliances with new ones that are NSPS-certified. In the western United States, change-out programs have been used to reduce PM emissions in non-attainment areas. EPA's Targeted Airshed grant program has also spent tens of millions of dollars to support change-outs in a subset of nonattainment areas having the worst levels of $PM_{2.5}$ pollution.

One of the most frequently touted change-out programs took place in Libby, Montana. During 2005 to 2008, every non-EPA-certified stove in that community was replaced. Replacing non-certified stoves with those that had been EPA-certified was expected to reduce this source category's impact by more than 75 percent. However, follow-up studies found that PM emissions from wood heating only declined by 28 percent.[27] Another study of this change-out program found that indoor PM emission reductions across homes and years were variable. A subset of households did not experience any reduction in PM following the change-out, while almost a quarter of the homes measured higher PM levels after than before the change-out.[28] This history indicates that without reliable certification procedures, replacing old stoves with newer models may not result in pollution reduction benefits.

2.3. EPA Certification Process

To obtain EPA certification of a new wood appliance model, the RWH NSPS requires completion of a valid certification test on a prototype of that model, conducted according to the specifications in the rule, that shows compliance with the applicable standard. Before performing the certification test, manufacturers must:

- Secure the services of an ISO-accredited/EPA-approved laboratory to conduct the test.
- Secure the services of an ISO-accredited/EPA-qualified third-party certifier to review the test report.
- Send a 30-day notification to EPA of the intent to test, using the form developed by EPA. The submission must identify the EPA-approved test laboratory, third-party certifier, test methods, model name, and test dates.

After an EPA-approved laboratory conducts the certification test, the test data must be submitted to EPA within 60 days. The manufacturer must then submit the draft test report to an ISO-accredited third-party reviewer for review. The third-party reviewer must

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[27] Ward T, Palmer C, Noonan C. Fine Particulate Matter Source Apportionment Following a Large Woodstove Changeout Program in Libby, Montana, *Journal of the Air & Waste Management Association* 60:688-693 (2010), doi:10.3155/1047-3289.60.6.688.

[28] Noonan C, *et al*. Residential indoor PM2.5 in wood stove home: follow-up of the Libby Changeout Program. *Indoor Air* 22:492-500 (2012), https://doi.org/10.1111/j.1600-0668.2012.00789.x.

review the test report and identify all issues that do not comply with RWH NSPS requirements. If the ISO-accredited third-party reviewer determines that the test was completed according to the RWH NSPS requirements and that the test report is complete, the reviewer issues a certificate of conformity.

Upon receipt of the certificate of conformity, the manufacturer can then submit an application package for certification to EPA's Office of Enforcement and Compliance Assurance (OECA). OECA reviews the submittal to determine that it is complete and accurate. A complete application package includes the following items:

- Certificate of conformity by an ISO/EPA-approved third-party certifier.
- Quality Assurance (QA) plan.
- Full emissions test report from an ISO-accredited/EPA-approved laboratory, including all documentation.
- Model name and design number.
- Engineering drawings and specifications of components that may affect emissions.
- Identification of confidential business information.
- Copy of warranties.
- Statements about stove construction materials; assurance program; sealing and storing the tested unit; manufacturing, labeling and owner's manuals; contracts with an EPA-approved laboratory and third-party certifier and approval to allow those entities to submit information on behalf of the manufacturer; posting of test report on manufacturer's web site; and acknowledgments that the certificate cannot be transferred and that it is unlawful to sell a unit without a valid certificate of compliance.
- Contact information for the manufacturer's responsible representative.
- A statement that the manufacturer has complied with and will continue to comply with all requirements pertaining to the certificate of compliance and that the manufacturer remains responsible for compliance regardless of any error by the EPA-approved test laboratory or third-party certifier.

OECA policy has targeted a timeframe of 90 days to review an application package. The 90-day timeline is a policy decision rather than a regulatory requirement. If, after review, OECA certifies the model line, the RWH NSPS requires the manufacturer to:

- Publicly post the complete non-CBI test report,
- Implement the QA plan via an ISO-accredited/EPA-approved third-party certifier, as detailed in the application, and
- Submit sales data per model, by state, every two years to OECA.

2.3.1. Third-Party Report Review

The requirement for third-party conformance certifications was first introduced in the 2015 RWH NSPS, and EPA must approve the third-party reviewers. The application process includes demonstrating that a nationally recognized accrediting entity has accredited the reviewer to perform certifications and inspections under ISO-IEC Standards 17025, 17065, and 17020.

According to the 2015 RWH NSPS, the third-party certifiers must "[h]ave no conflict of interest and receive no financial benefit from the outcome of certification testing." The company that conducts a certification test, however, is allowed to also provide third-party review services for that test. The role of the third-party reviewer includes:

- Witnessing the test (optional component).
- Reviewing the test report to determine that all requirements of the RWH NSPS related to RWH testing were completed appropriately.
- Issuing a certificate of conformity.
- Conducting compliance assurance inspections to ensure that production models match the prototype that was tested.
- Assessing whether the manufacturer's QA plan meets the requirements of the rule.

Pursuant to the 2015 RWH NSPS, EPA relies heavily on the third-party reviewer to complete comprehensive reviews of test reports. Review of the test report by the ISO-accredited third-party must include confirmation that the following RWH NSPS requirements were met:

- Emissions testing was conducted in accordance with all regulatory requirements.
- The test report is complete and accurate.
- Instrumentation used for testing was properly calibrated.
- Testing data provides sufficient information to confirm that the appliance meets the emission standards listed in the regulation.
- The manufacturer's QA plan is sufficient.

If all of the above conditions are met, the third-party reviewer can issue a certificate of conformity.

2.3.2. Third-Party Compliance Assurance Monitoring Programs

Another new component of the 2015 RWH NSPS is the use of third-party reviewers to conduct QA audits of manufacturing facilities. These inspections are part of the compliance assurance monitoring programs submitted by manufacturers to EPA in the application package for certification. The third-party certifier conducts regular (at least annual) unannounced inspections of the manufacturing facility to ensure that the manufacturer's QA plan is being implemented. Upon completion of the inspection, the third-party inspector must submit inspection reports to the manufacturer and OECA. Inspection reports must identify any deviations from the plan and specify corrective actions.

2.3.3. Approved Laboratories

The 2015 RWH NSPS requires all laboratories conducting certification tests for any appliance regulated under the RWH NSPS to obtain ISO/IEC 17025 accreditation. ISO/IEC 17025 is a quality management program designed to ensure testing laboratories are following proper procedures. To obtain ISO/IEC 17025 accreditation, laboratories must enter into a contract with an ISO accrediting agency and prepare documentation outlining the procedures that the laboratory uses, specific activities the laboratory undertakes, QA plans, and records that provide evidence that QA plans are put into practice.

The ISO accreditor reviews and assesses the documentation supplied by the laboratory and provides a report detailing any corrective action needed. When all needed corrective actions have been completed, the accreditation documents are submitted to a review body for approval. If approved, the laboratory receives a certification of accreditation. Once the laboratory obtains this accreditation, it can apply to the EPA Administrator for approval to conduct testing under the RWH NSPS rule. As part of that application, laboratories must:

- Submit documentation of accreditation under ISO-IEC Standard 17025.
- Agree to participate biennially in an independently operated proficiency testing program with no direct ties to the participating laboratories.
- Agree to allow the Administrator, regulatory agencies, and third-party certifiers access to observe certification testing.
- Agree to comply with calibration, reporting, and recordkeeping requirements that affect approved testing laboratories.
- Agree to perform a compliance audit test (at the manufacturer's expense at the testing cost normally charged to such manufacturer) if the laboratory is selected by the Administrator to conduct the compliance audit test of the manufacturer's model line.
- Have no conflict of interest and receive no financial benefit related to the outcome of testing.

- Agree to not perform initial certification tests on any models manufactured by a manufacturer for which the laboratory has conducted research and development design services within the last five years.
- Agree to seal any wood heater on which it performed certification tests immediately upon completion or suspension of certification testing with a laboratory-specific seal.
- Agree to immediately notify the Administrator of any suspended tests (including the reason(s) why and the projected retest date) and submit the operation and test data obtained for the suspended tests.

EPA certifies laboratories for operation under the RWH NSPS regulation for a five year period. After five years, the laboratory must submit a request for renewal.

2.4. EPA Certification Test Methods

The 2015 RWH NSPS specifies test methods to be used for certifying an appliance's compliance with that regulation. Those methods can be segregated into those that specify pollutant measurement procedures and those that address operation and fueling protocols.

2.4.1. Emission Measurement Methods

EPA references two test methods in the 2015 RWH NSPS for emission measurements:

- ASTM 2515-11 to measure particulate matter emissions.
- Canadian Standards Administration (CSA) B415.10-10 for efficiency, heat output, and carbon monoxide measurement.

2.4.2. Operation and Fueling Protocol for Stoves

EPA's operation and fueling protocols are specific to the type of stove being tested. Cordwood stoves may be tested using either EPA Method 28R, which uses dimensional lumber, or ASTM 3053-17, which uses cordwood. Both methods consist of individual runs that are conducted under steady-state conditions with no replicate testing. Pellet stoves use ASTM 2779-10, which is a single integrated test run. Table 1 summarizes those methods for certifying stoves.

Table 1. Comparison of Key Characteristics of EPA and ASTM Test Methods

Element	EPA M28	ASTM 3053-17	ASTM 2779
Appliance type	Variable & single burn rate stoves	Variable & single burn rate stoves	Pellet stoves
Summary	Four steady state runs at defined load categories	Two steady state load categories (low and medium) and one run with start-up, reload to high fire	One integrated run that encompasses four different fuel loads, coal bed conditions, and heat loads
Operational Parameters			
Number of loading events	1	1 in low and medium runs, 2 in start-up/high run	0
Start-up	No	Yes, combined with high fire	No
High fire	Yes	Yes, combined with start-up	Yes
Medium fire	Two burn rates assessed	Requires a burn setting higher than low but no other requirements	Yes, defined as 50% or less of high fire
Low fire	Yes	Yes	Yes
Replicates	None	None	None
Long charcoal tails	Yes	Yes	No
Precision and variability data	No	No	No
Fueling Parameters			
# of different load sizes by weight	1	2	NA
Fuel load volumes	7 lb/ft^3	10 lb/ft^3 for high; 12 lb/ft^3 for low and medium fire runs	NA
Fuel requirements	Dimensional Douglas fir at a specified moisture content	Any fuel species within allowed specific gravity range at a specified moisture content	No specifications

2.4.3. Operation and Fueling Protocol for Central Heaters

EPA requires the ASTM 2618 operation and fueling protocol in certification tests for cordwood hydronic heaters that do not have external thermal storage. Cordwood hydronic heaters with thermal storage can choose among three different test methods: (1) EPA Method 28WHH, (2) ASTM 2618-13, or (3) EPA Method 28WHH-PTS (for units with partial thermal storage). Pellet boilers without thermal storage must use ASTM 2618-13. Pellet boilers with external thermal storage must use an approved Alternative Test Method (ATM). Furnaces use CSA B415.1-10. Table 2 summarizes key elements of the central heating test methods.

Table 2. Comparison of Test Methods for Hydronic Heaters

	ASTM E2618-13	CSA B415.1-10	EPA M28WHH-PTS
Manual Loaded Fuel: Crib, Cord, or Both	Crib, Cordwood, or Pellet	Crib and Cordwood	Cordwood
Fuel Feed	Both	Both	Manual
PM Measurement Method	Dilution tunnel	Dilution tunnel	Dilution tunnel
PM Measurement	Total PM	Total PM	Total PM
PM Emission Metric	Weighted average or individual run, lb/MMBtu output	Simple average of test runs, lb/MMBtu output	Simple average, lb/MMBtu output
Wood Fuel Species	Any within specified density range	Any within specified density range	white or red oak
Moisture Range (dry basis)	19-25%	18-28%	19-25%
Method of Efficiency Determination	Thermal output	Stack loss method	Thermal output
Burn Rate Categories	Maximum output 25-50% 15-24% < 15%		Maximum output 25-50% 15-24% < 15%
PM Emission Rate (g/hr)	Yes – run average	No	Yes – by phase of burn cycle
Measures Start-up	No	No	Yes
Thermal Storage	Annex that applies to cordwood appliances only	No	Partial
Cold Start	Yes, if used with storage	No	Yes – Cat I and II
Upper Size Limit	No	500,000 Btu/hr	350,000 Btu/hr
Fuel Loading for Handfed Units (minimum)	10 lb/ft^3	10 lb/ft^3	10 lb/ft^3

2.4.4. Alternative Test Methods

Manufacturers can request approval from EPA to use an alternative test method (ATM). ATMs are most often requested if there is no designated test method in the rule that is applicable to the appliance that will be tested. Pellet boilers using thermal storage are an example of an appliance category that requires an ATM.

3. METHODOLOGY

3.1. Study Approach

The project team used an approach similar to that used in a 2011 assessment of EPA's voluntary program for outdoor wood boilers[29] to assess the efficacy of the 2015 RWH NSPS certification program. The study reviewed available certification test reports for appliances certified as compliant with the Step 2 emission standards, evaluating: (1) completeness of the EPA-certified test reports, (2) conformance with test methods, and (3) error magnitudes (where sufficient information was available to estimate this parameter). The review, which is considered to be at the "screening" level, is intended to identify appliance models that have significant certification procedure issues, provide that information to EPA for a more detailed review, and present recommendations for improvements in the certification process.

The first step in the process was to identify the requirements that would constitute a complete certification application package according to the applicable regulations and guidance. This provided the criteria for determining report completeness. A regulatory basis document that compiles the identified review elements and the applicable regulatory citations is on the website https://dec.alaska.gov/air/burnwise/manufacturers-vendors/ maintained by the Alaska Department of Environmental Conservation (ADEC).

Once the team finalized the list of review criteria, an Excel-based tool was created to input test report data and related elements in a standardized format. Because the original Excel spreadsheet was large and complex, Excel summary sheets were created to streamline the review process. The summary sheets, which were used for the reviewers' assessments, pulled information from the original spreadsheet with the previously entered reports. To assess the review tool performance, three people reviewed the same report independently. A comparison of the three different reviews found that all three reviewers identified the same flags. All three reports obtained the same preliminary review determination. One reviewer spent additional time checking calculations in the underlying data. The reviewer who completed those calculations found additional issues. However, it was determined there were not sufficient resources to conduct an in-depth review of each report. Based on this effort's findings, the team agreed that the tool was sufficient to allow multiple people to complete test report reviews. A sample of the summary review sheet is provided in Figure 5.

[29] Butcher, T, *Review of EPA Method 28 Outdoor Wood Hydronic Heater Test Results*, NYSERDA, Albany, NY (2011).

Figure 5. Example of the Review Template for Cordwood Stoves

Cordwood Summary Sheet Template

Summary of Review								
Manufacturer								
Model					Control approach			Non-Catalytic
Prelim review recomm.								
Red flags		Orange flags			Yellow flags			
Final Determination								Basis:
Testing Information	***Determination***							***Notes***
Test method								
Test Lab								
Third-party certifier								
Report certified								
Test Report Elements	***Determination***							***Notes***
Wght Avg PM emissions (g/			PM Highest 1-hr (g/hr)					
Wght Avg HHV Efficiency (%								
Wght Avg CO (g/hr)			Wght Avg CO (g/min)					
Max heat output (Btu/hr)								
Manufacturers Instructions								
Firebox vol. test report								
Firebox dimensions			Longest dim. (in)					
Firebox calculations								
Efficiency calculations								
Burn rate calculations								
Raw data sheets								
Pre-burn completed by								
Pre-burn data								
Lab technician notes								
Doc. of run appropriatenes								
Doc. of run validity								
Doc. of run anomolies								
Doc. of run burn rates								
Photos of the fuel loaded								
Test Run Data	***Determination***							***Notes***
Run #								
Run Category								
Burn rate (kg/hr)								
PM emissions by run (g/hr)								
PM 1-hr filter pull (g/hr)								
Filter data								
Train precision (%)								
Negative weights								
Negs handled appropriately								
Heat output by run (Btu/hr)								
CO by run (g/hr)								
HHV efficiency (%)								
Lowest burn rate tested								
All run data								
Appliance Fueling	***Determination***							***Notes***
Fuel species				Maple				

Log length (in)		
Direction of longest dimens		
Log direction for testing		
Squared (ASTM test only)		
Debarked (ASTM test only)		
Load density (lb/ft3)		
Fuel moisture content load (%db)		
Fuel piece configuration		
Owners Manual Req.	***Determination***	***Notes***
Stack height		
Location recommendation		
Guidance on proper draft		
Fuel loading & reloading		
Fuel selection recomm.		
Improper fuels warnings		
Fire starting procedures		
Proper use of air controls		
Proper operation low		
Ash removal procedures		
Replacement parts		
Federal warning (C or NC)		
Warranty rights		
Catalytst operation		
Cat maintenance procedur		
Determining catalyst det. o		
Reporting	***Determination***	***Notes***
Summary tables complete		
All run data submitted		
Test report complete		
Owner manual complete		
Test dates		
30 Day notice submitted to		
Tested on the proposed dat		
Tested in consecutive days		
60 Day report to EPA		

After completing the review tool, reviewers used EPA's wood heater database (https://cfpub.epa.gov/oarweb/woodstove/index.cfm?fuseaction=app.about) to identify wood burning devices that had been certified as Step 2 compliant. The study identified 255 appliances certified as Step 2 – 131 cordwood stoves, 96 pellet stoves, and 28 central heaters.

The 2015 RWH NSPS rule requires manufacturers to post complete test reports publicly on their company website. The team attempted to locate the test reports for all Step 2 certifications and post them to a central repository but encountered difficulties in obtaining test reports for approximately 20 percent of the appliances. Some websites had links to incorrect test reports. In other instances, the test reports could not be found after exhaustive online searches and a detailed review of the manufacturer's website. In some cases, test reports were located by requesting assistance from OECA.

Individual reviewers examined the test reports and entered data either into the initial spreadsheet or directly into the review tool. The reviewer was also able to enter notes, comments, and recommendations. Reviews were initially entered into the large spreadsheet, and summary report sheets were exported from the review tool. Both the review tool and summary reports automatically generated warning flags, which provide an objective identification of significant problems with the testing or reporting.

A committee, comprised of staff from multiple state and local air quality agencies, met weekly to review summary data. During review meetings, the reviewer presented the findings for each summary sheet, and the committee discussed the results. After reviewing the findings, the committee made a final determination about issues in each report. In some cases, summaries underwent additional review or revisions based on EPA feedback.

In September 2020, manufacturers of room heating appliances were notified that summary sheets had been completed for their certification test reports. The manufacturers were given the opportunity to request a review of the sheets before ADEC publicly posted the information. The initial posting occurred in November 2020, and an update occurred in February 2021. Manufacturers were allowed to address deficiencies identified by reviewers by providing new information to ADEC or by highlighting where the information existed in the report. Manufacturer review only slightly modified review findings. After manufacturers reviewed existing or submitted new data, less than 10 percent of the deficiencies could be resolved.

ADEC maintains a copy of the original review sheet and the updated version. Summary sheets for cordwood stoves and pellet stoves can be found on the ADEC website https://dec.alaska.gov/air/burnwise/manufacturers-vendors/. The information in this report was current as of February 2021. ADEC plans to update the summary sheets as it compiles new appliance reviews and as manufacturers submit revised and additional information. Central heating appliances were not included as part of ADEC's initial regulatory efforts. However, summary sheets and reviews were also completed for these appliances in this study.

3.2. Review Elements

Given the large number of test reports, the team conducted a focused screening-level review. The first step was to determine the completeness of the reports. The second step was to determine the need for follow-up action. Defect and deficiency flags generated by the review were segregated into three categories: (1) required reporting to assess report completeness, (2) revocation elements, and (3) questionable practices that should trigger compliance audits. These review elements were based on the specifications in the RWH NSPS rule and the test methods that the rule references. The regulatory basis for each element is detailed in a report posted by ADEC called "ADEC Regulatory Basis," which can be accessed from the ADEC webpage link given in the above paragraph. Results of appliance reviews can be found in the following Sections 4.1 through 4.3. Reviewers also assessed overarching rule reporting and compliance monitoring components. The results of this effort can be found in Section 4.4.

Based on the identified deficiencies, the study divided test reports into three categories: (1) findings to be submitted to OECA with a request it take action under the revocation of certification provisions in the RWH NSPS [40 CFR § 60.533(l)/60.5475(l)], (2) findings to be submitted to OECA with a request it take action under the audit provisions in 40 CFR § 60.533(n)/60.5475(n), and (3) no action. The following sections detail the review elements that determined categorizing for EPA action or no action.

3.2.1. Report Completeness

Reviewers evaluated reports to determine whether they included the elements required in the RWH NSPS for a complete test report. The required elements, as identified in 40 CFR § 60.537/60.5479, are as follows:

- Full test report
- Raw data sheets
- Laboratory technician notes
- Calculations
- Test results for all test runs
- Discussions of the appropriateness and validity of all test runs, including runs attempted but not completed
- Detailed discussion of:
    - all anomalies
    - whether all burn rate categories were properly achieved
    - any data not used in the calculations
    - for any test runs not completed, the data that were collected, and the reason that the test run was not completed
    - documentation that the burn rate for the low burn rate category was no greater than the rate that an operator can achieve in-home use and no greater than is advertised by the manufacturer or retailer**.**

Reports that contained all the elements listed above were deemed complete. Reports with two or fewer items flagged as missing were determined to be incomplete-minor. Reports flagged for three or more elements were deemed incomplete – major. If no test report could be found for the appliance, the appliance name was sent to OECA.

3.2.2. Recommendation for Action – 40 CFR § 60.533/60.5475(l)

The elements identified in 40 CFR § 60.533(l)/60.5475(l) were reviewed to identify appliances that should be recommended for revocation procedures. The regulatory language states that a revocation determination "will be based on all available evidence, including but not limited to" the specific elements listed in that section. Note that the RWH NSPS does not require a compliance audit to trigger revocation action. Instead, revocation is based on the documentation submitted to EPA. The following elements are listed in those sections as evidence that EPA should consider when making revocation decisions:

- § 60.533/5475(l)(ii) A finding that the certification test was not valid, based on problems or irregularities with the certification test or its documentation. A flag for this criterion was triggered by anomalies or irregularities in the test results. For example, reporting negative emission rates or reporting theoretically impossible efficiency results would trigger a flag under this criterion.

- § 60.533/5475(l)(iii) A finding that the labeling of the wood heater line, the owner's manual, or the associated marketing information does not comply with the requirements of § 60.536/60.5478, which specify that each affected wood heater offered for sale by a commercial owner must be accompanied by an owner's manual that includes the information listed in that section pertaining to installation and to operation and maintenance. That information "must be adequate to enable consumers to achieve optimal emissions performance" and "consistent with the operating instructions provided by the manufacturer to the approved test laboratory for operating the wood heater during certification testing, except for details of the certification test that would not be relevant to the user." Examples of flags generated under these criteria include reports that list firebox volumes, fuel requirements, or heat outputs that differ from those used in the certification test.

- § 60.533/5475(l)(iv) Failure by the manufacturer to comply with reporting and recordkeeping requirements of § 60.5479. An example of flags generated under this reporting criterion would be (1) failure to conduct testing at a burn rate no lower than the homeowner can achieve during in-home use and no greater than advertised by the manufacturer or retailer, (2) failure to measure or report carbon monoxide, (3) failure to measure or report efficiency, or (4) failure to measure or report 1-hour filter values as required under sections § 60.534 or § 60.476.

- § 60.533/5475(l)(vii) Failure of the approved laboratory to test the wood heater according to the specified methods. Examples of flags generated under this criterion include failure to follow procedures specified in the test methods, such as conditioning requirements, burn rate criteria, or train precision, and failure to provide required calculations.

3.3. Recommendation for Action – 40 CFR § 60.533(n)/60.5475(n)

40 CFR § 60.533(n) and § 60.5475(n) provide EPA with the authority to conduct audit tests or to direct the manufacturer to have an audit test performed by an approved laboratory selected by EPA at the expense of the manufacturer. Reviews that did not flag revocation elements but instead identified deficiencies potentially affecting appliance performance or indicated the use of procedures allowed by the test methods but raised questions about test appropriateness were recommended to EPA for action under the audit provisions in 40 CFR § 60.533(n) or § 60.5475(n). These elements may not be directly addressed by test methods or rule requirements but could affect in-use emissions performance.

3.4. Recommendation for No Action

Certification test reports that were determined to be complete and that followed the test method and rule requirements obtained "no action" recommendations.

4. REVIEW FINDINGS

The review team assessed certification test reports for 242 out of 255 room and central heaters approved by EPA as Step 2 compliant. Test reports could not be found for 13 devices. The reports were grouped for analysis by appliance type (room heaters or central heaters), and the room heaters were further divided into two subcategories – cordwood and pellet stoves. This section presents the analysis findings.

4.1. Cordwood Stoves

The team identified 131 cordwood stoves for review, but could not find test reports for two of the stoves. Three PM emissions control approaches are typically employed in cordwood stoves: (1) catalytic controls, (2) non-catalytic controls using secondary combustion to reduce emissions, and (3) a combination of secondary combustion and catalytic controls, typically referred to as the hybrid approach. Eighty-five of the appliances reviewed had non-catalytic controls, thirty-one had catalytic controls, and thirteen used a hybrid approach.

Cordwood stove certification tests can be conducted using either of two test methods: (1) M28R, which is conducted on dimensional lumber fuel, or (2) ASTM 3053-17, which uses cordwood fuel. Sixty of the appliances evaluated used M28R for certification testing, and sixty-nine used ASTM 3053-17. The control approach and test method for two appliances could not be assessed because reviewers could not find their certification test reports on the manufacturers' websites.

4.1.1. Complete Test Reports

The RWH NSPS requires manufacturers to submit "[a]ll documentation pertaining to a valid certification test, including the complete test report and, for all test runs: Raw data sheets, laboratory technician notes, calculations, and test results" as part of the application for a certificate of compliance with that standard [40 CFR § 60.533(b)(5)]. Within 30 days of receiving certification, "the manufacturer must make the full non-CBI test report and the summary of the test report available to the public on the manufacturer's Web site" [40 CFR § 60.537(g)].

For cordwood stoves, the reviewers identified 131 devices certified as Step 2 and were able to obtain test reports for 129 of them. The reviewers assessed report completeness by identifying the number of non-reported elements on the summary sheets. The summary sheets listed 36 reporting elements. Report completeness was based on the number of missing elements. Table 3 provides the findings for some of the critical reporting elements. Based on its assessment, each report was assigned to one of the following five categories:

- *Complete:* All non-CBI elements were included in the report.
- *Incomplete-Minor:* One to three elements (less than 10 percent) were missing from the test report.
- *Incomplete-Major:* Four to ten (10 – 30 percent) elements were missing from the test report.
- *Incomplete-Seriously Deficient:* More than ten elements (>30 percent of the test reports) were missing from the test report.
- *Missing:* Test report could not be obtained by searching the manufacturer's website and by conducting additional web searches.

Table 3. Assessment of Report Completeness – Cordwood Stoves

Report Element		Reported	Not Reported
Raw data sheets	Data for all test runs	52	79
	Manu. instructions	65	66
	Firebox data	56	75
	Required photos	93	38
	Fuel loading	102	29
	Fuel characteristics[30]	100	31
	Fuel loading density	102	29
	Fuel moisture	107	24
	Filter data	99	32
Calculations	Firebox	32	99
	Efficiency	114	17
	Train precision	68	63
Lab technician notes		98	33
Appliance settings		73	58
Heat output		128	3
Burn rate categories		122	9
Discussion of unused data		74	57
Conditioning		85	46
Test location		125	6
Third-party certifier		113	18
Third-party report		85	46

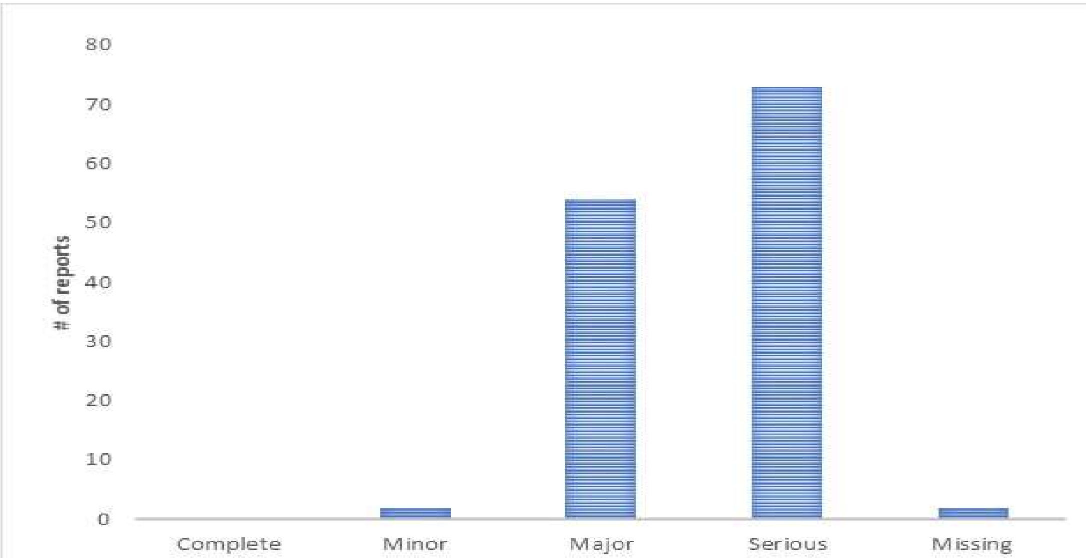
According to the above criteria, none of the 131 identified Step 2 cordwood stoves had complete reports (Figure 6). Two reports had minor deficiencies, 54 reports had major

[30] This element addresses fuel length and for ASTM 3053, the fuel piece characteristics.

deficiencies, and 73 reports had serious deficiencies. Two reports could not be found and were flagged as subject to revocation criteria for lack of public availability.

Of the 129 obtained cordwood stove reports, 13 consisted of only a few pages with little to no information, 21 reports did not include raw datasheets, and 31 reports failed to include laboratory technician notes from the testing.

Figure 6. Cordwood Stove Certification Test Report Completeness



Additional material may have been submitted to EPA OECA as part of the certification application package, but that information was not available to the reviewers. If this additional material was submitted, it illustrates that without access to those elements, states and other parties that rely on EPA's certification process cannot conduct a full review of test results.

We note that during this study, reviewers downloaded different versions of the same test for some appliances, raising concerns about version control and EPA oversight of the data. EPA could resolve this issue by posting the non-CBI reports and all supporting data received as part of certification application packages in a centralized database using its online tools, like the EPA ECHO (Enforcement and Compliance History Online) database. This step would improve access to the complete reports and increase confidence that the reports posted online are the reports EPA reviewed.

4.1.2. Revocation Criteria – Testing Irregularities – Mandatory Reporting Elements

The 2015 RWH NSPS states that a certification can be revoked if EPA finds that the certification test was not valid "based on problems or irregularities with the certification test or its documentation" [40 CFR § 60.533(l)(ii)]. In this study, evaluating testing irregularities included a review of the handling of negative filter weights, as described in this subsection.

Negative Filter Values

ASTM 2515 uses gravimetric analysis to determine PM measurements. Negative filter weights occur when the filter weight after testing is less than the filter weight measured prior to conducting the test. ASTM 3053-17 does not specify how EPA-approved laboratories should handle negative filter values, either in recovery procedures or in calculations. NESCAUM contacted EPA to determine whether guidance had been provided to EPA-approved laboratories regarding proper procedures for addressing negative values. EPA reported that no guidelines had been requested or provided. Because EPA could not provide guidance on this issue, reviewers turned to test methods from the Oregon Department of Environmental Quality (OR DEQ). ASTM 2515, the PM measurement method, is a derivative of EPA Method 5G, which is itself derived from an OR DEQ measurement method. The original OR DEQ method required acetone rinses of the testing train to ensure all particulate materials had been captured. The OR DEQ method clearly articulates that "[t]he blank corrections for the filter and/or rinse samples are '0', if the blank filter or rinse samples yield negative weight gains."[31]

If negative filter weight values were reported, reviewers assessed whether the EPA-approved labs used acetone rinses or other activities to ensure all particulate matter had been recovered. The summary sheet tracked if test reports included negative filter weights. A separate cell tabulated if the negative values were handled appropriately.

Reports were classified as handling negative values appropriately if they indicated that the tester used procedures like acetone rinses to ensure capture of all materials. Reports that assumed negative values were captured elsewhere without identifying any recovery procedures were deemed "handled inappropriately."

Reviewers found that for the 129 located test reports:

- 25 percent (32) of test reports did not provide filter weight information,
- 45 percent (58) reported negative filter weights, and
- 32 percent (41) reported no negative filter weights.

Of the 58 reports with negative filter weights:

[31] Oregon Department of Environmental Quality, *Source Sampling Manual*, Volume 1, revised November 2018, p. C-8.14.

- 9 reports appeared to use recovery methods to assure all materials were included in the filter measurement data.
- 49 reports appear to assume, without confirmation, that the PM filter mass lost was captured elsewhere.

Reports that had negative values and did not report the use of recovery procedures were flagged for revocation criteria. Given the large number of reports with negative values, the lack of EPA guidance on proper procedures for handling negative values is a significant omission in the RWH NSPS program.

4.1.3. Revocation Criteria – Compliance with § 60.536 Requirements

Another revocation criterion specified in the 2015 RWH NSPS is a finding that "the labeling of the wood heater model line, the owner's manual or the associated marketing material does not comply with the requirements detailed in 40 CFR 60.536" [40 CFR § 60.533(l)(ii)]. 40 CFR § 60.536(g)(1) states that information in the owner's manual and associated material "must be consistent with the operating instructions provided by the manufacturer to the approved test laboratory for operating the wood heater during certification testing, except details that would not be relevant to the user." To assess conformance with these requirements, reviewers compared public information published by the manufacturer with the test report information on appliance parameters (firebox volume, heat output, and efficiency ratings) and the manufacturer instructions to the EPA-approved laboratory. The public information reviewed included owner's manuals, product brochures, and websites because "associated marketing materials" are included in this requirement.

Appliance Parameters – Firebox Volume

Firebox volumes are a foundational metric for conducting certification testing. The firebox volume determines the amount of fuel and the log length used for certification testing. Discrepancies in the firebox volume and its required fuel parameters will influence measured PM emissions during testing. Reviewers compared the firebox volume used for certification testing with the firebox volume in manufacturers' marketing materials, including the owner's manual, websites, and product brochures. Of the 129 cordwood stove test reports reviewed:

- 46 percent (59) reported a different firebox volume in marketing materials than the volume reported in the certification test report. 71 percent (42 of the 59) reported differences greater than five percent;
- 11 percent (14) did not list the firebox dimensions in marketing materials or did not report firebox volume in the test report; and
- 43 percent (56) had firebox volumes that matched.

The reviewers categorized the extent of the deviation in firebox volume for appliances with firebox volumes that did not match. Units with variations less than 5 percent were flagged for audit criteria. Appliances with a deviation greater than 5 percent were flagged under revocation criteria.

Appliance Parameters – Heat Output

Heat output is an important metric because the test methods require testing at maximum heat output. When the maximum heat output reported in the manufacturer's materials is greater than the maximum output reported during testing, the certification test may not be adequate or representative. The comparison of the maximum heat output in the certification test report with that listed in the manufacturer's materials found that:

- 75 percent (96) of the appliances reported higher heat output values in the marketing materials than the output reported in the certification testing report,
- 3 percent (4) did not report maximum heat output ratings in the marketing materials, and
- 22 percent (29) had maximum heat output data in the marketing materials that matched the test report.

Appliances were flagged for revocation criteria if the heat output ratings in the manufacturer's materials deviated by more than 10 percent from the heat output achieved during certification testing.

Appliance Parameters – Efficiency

The comparison of efficiency data reported in marketing materials and in certification test reports found that 28 percent (36) of the appliances had conflicting data, 7 percent (9) did not report efficiency information in their marketing materials, and 65 percent (84) had data that matched. Appliances were flagged for revocation criteria if the efficiency ratings in the marketing materials deviated from the average efficiency ratings given in the test reports.

Manufacturer's Instructions to Testing Laboratories

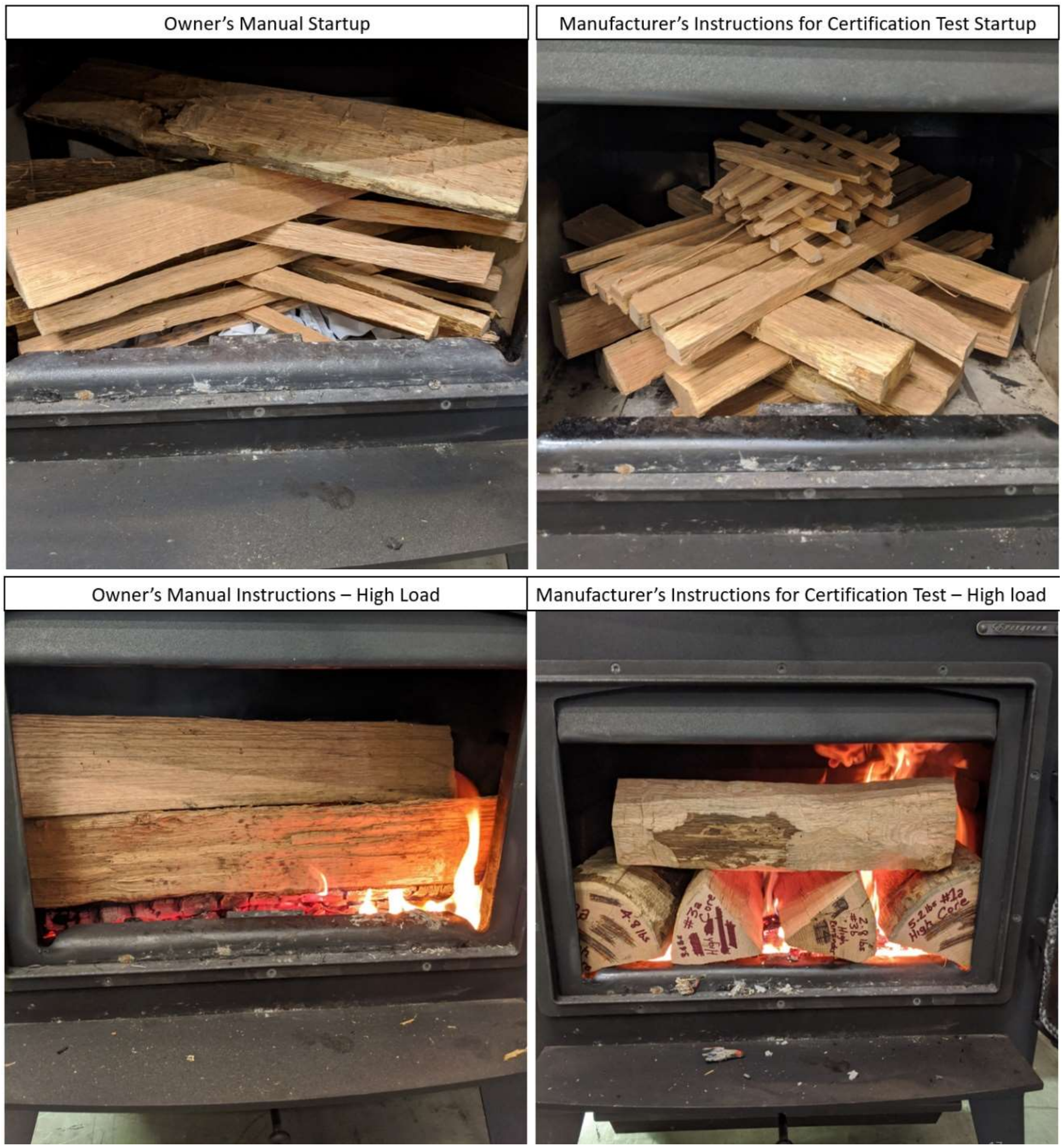
The 2015 RWH NSPS requires the manufacturer's instructions used for certification testing not contradict the operational instructions found in the owner's manual. Specifically, 40 CFR § 60.536(g)(1) states that the information in the owner's manual "must be consistent with the operating instructions provided by the manufacturer to the approved test laboratory for operating the wood heater during certification testing, except details that would not be relevant to the user."

Reviewers compared the manufacturer's instructions to the EPA-approved testing laboratories and the information in the owner's manual for air setting and fuel loading, which are two parameters identified in § 60.536(g). Of the 129 test reports reviewed, 64 test reports (51 percent) did not contain the manufacturer's instructions to the testing laboratory. Reviews assessed fuel loading procedures and air setting data in the 65 reports that had instructions. Areas not considered contradictory instructions were where manufacturers gave specific instructions, such as fuel placement, piece size, and spacing, to the lab but did not include those directions in the owner's manual. Contradictions were identified as lab instructions clearly deviating from instructions in owner's manuals. Issues such as bypass operation and air settings were identified as contradictions. The review found that 39 percent (25) of the test report instructions contradicted the owner's manual instructions. Significantly more reports would be flagged for this criteria if EPA determined that all directions given to the lab by the manufacturer must be included in the owner's manual as instructions.

Assessing the Impact of Contradictory Instructions

NESCAUM tested two medium-sized Step 2 certified stoves to assess the effect of contradictory manufacturer's instructions on emissions measurements (labelled here as "Stove 7" and "Stove 9"). Each stove was tested in two ways: (1) according to the test method used in the certification test and the instructions provided to the certification laboratory, and (2) using the ASTM3053-17 cordwood test and the instructions in the owner's manual. Stove 7 had hybrid (non-catalytic and catalytic) emissions controls and was certified using M28R as emitting less than 1 gram of PM per hour (g/hr). Stove 9 had non-catalytic emission controls and was certified using ASTM 3053-17 at 1.6 g/hr. Figure 7 shows the difference in fuel loading configuration in the two Stove 9 tests.

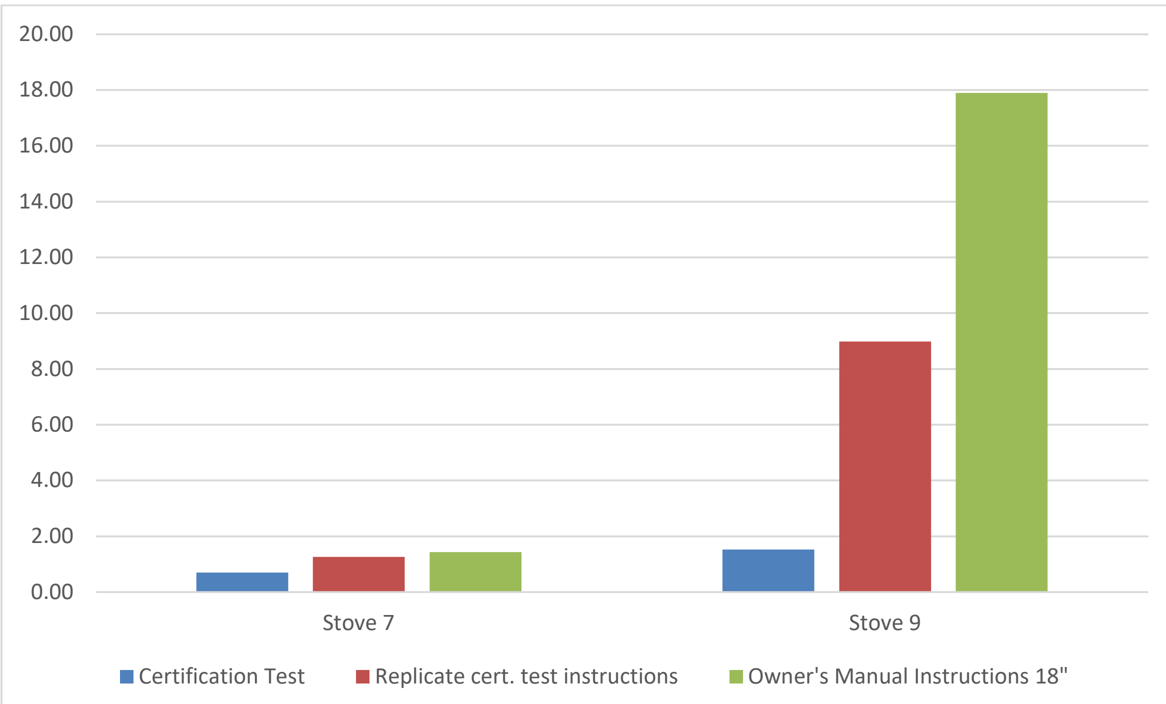
Figure 7. Fuel Loading Configuration – Stove 9



For each of the two stoves, the emission rates reported in the certification test report were compared to those measured in the NESCAUM study test that replicated the certification testing instructions and with the test performed using the instructions in the owner's manual. Those comparisons are shown in Figure 8. For Stove 7, the difference between the certification value and the replicate test, both of which were conducted with the M28R procedures, was less than 0.5 g/hr. Testing Stove 7 with the ASTM 3053-17 cordwood test according to the owner's manual instructions increased emissions by 100 percent from the certified value and 13 percent from the study test that replicated the certification testing procedures for that stove.

Stove 9 showed far more variability, although in that stove, ASTM 3053-17 was used for all tests. In Stove 9, the emission rate in the study test that replicated certification procedures was almost 500 percent of that in the certification test, an increase of more than 6 g/hr. The emission rate in the test performed according to the owner's manual instructions was more than 1,000 percent of the certification value, an increase of 16 g/hr. Results from this analysis indicate the need for consistency in operating instructions. It also highlights the need for EPA to conduct compliance audits to identify stoves, like Stove 9, for which certification results cannot be consistently reproduced.

Figure 8. Comparison of Emissions Rates (g/hr) in Tests on Two (2) Step 2 Certified Stoves



4.1.4. Revocation Criteria – Failure to Follow Test Methods

Failure to follow the test methods specified in 40 CFR § 60.534 is a criterion for revocation under 40 CFR § 60.533(l)(vii). Several elements were evaluated to determine whether certification tests were performed according to the specified methods.

Reporting Elements

Reviewers examined the test reports to determine whether they included the PM emissions in the first hour of the test [40 CFR § 60.534(d)], as well as the efficiency, heat output, and carbon monoxide emissions per CSA B415.1-10 [40 CFR § 60.534(e)] as required in the test methods.

One Hour PM Emission Rates

The RWH NSPS requires reporting the first hour of PM emissions for each test run. The test methods for space heaters require emissions data to be reported in grams per hour and grams per kilogram. Reviewers identified four issues associated with the first-hour reporting requirement: (1) failure to report any first-hour data, (2) failure to report first-hour data for some of the test runs, (3) failure to report the first-hour values in grams per hour or grams per kilogram, and (4) negative PM emission rates for first-hour values. Of the 129 test reports reviewed, 17 reports (13 percent) contained the following issues with the first-hour reporting requirement:

- 13 test reports were missing first-hour values for some runs.
- 4 test reports contained filter weights rather than required reporting metrics.
- 1 report contained negative values for first-hour emission rates.

Appliances were flagged for revocation criteria based on any of the above identified issues.

Efficiency

All test reports reviewed contained efficiency information. However, 19 test reports did not contain the underlying calculations to show how the efficiency value was derived.

Heat Output

Only 1 of the 129 test reports did not contain heat output information.

Carbon Monoxide Emissions

Carbon monoxide (CO) reporting issues were flagged in 10 (8 percent) of the 129 reports reviewed. The RWH NSPS requires reporting of CO data for each run. Reviewers flagged test reports that did not report individual run CO data as subject to revocation criteria.

Fueling Parameters

40 CFR § 60.534 requires conducting certification tests according to the specifications in the approved test methods. The reviewers evaluated the test reports to determine how the fueling specifications, calculations, and appliance conditioning conformed with test method requirements.

Fuel Length

Standardizing fuel length is critical in replicating test results for research or audit purposes. M28R contains specific language concerning the length of the fuel that can be used for testing. ASTM 3053-17 does not contain fuel length requirements, so ASTM 3053-17 tests were not reviewed under this criterion. M28R specifies that

ASTM 2780 must be used to guide fueling protocols. Section 9.4.1.6 of ASTM 2780 states that "each test fuel piece ... shall closely approximate 5/6 the dimensions of the firebox length." The method defines firebox length as "the longest horizontal firebox dimension." To determine whether a test complied with this requirement, the review team identified the longest firebox dimension reported, multiplied by 5/6, and subtracted 1 inch. This calculation was then compared to the fuel length used for testing. If the length of the fuel used was less than the calculated value, reviewers determined that the fuel did not meet the requirements of the test method.

Of the 60 reports reviewed that used M28R as their certification test:

- 50 percent (30) did not meet the method requirements for fuel length.
- 35 percent (20) could not be determined because the report did not contain required reporting elements, such as fuel length (10) or firebox dimensions (10).
- 17 percent (10) complied with the method requirements.

This is a required element in the test method, therefore reports that did not conform to this requirement were identified as subject to revocation criteria. Reports that did not contain sufficient information to make this determination were flagged for audit criteria.

Fuel Shape

Fuel shape assessments were only completed for the 69 test reports using ASTM 3053-17, as fuel shape is not relevant for M28R, which uses dimensional lumber. Section 3.2.3 of ASTM 3053-17 defines the acceptable fuel shape as "typically round wood 12 to 24 inches long that has been split into triangular, half-round, quarter-round, wedge-shaped, or trapezoidal segments." Squared wood is not included in that definition. In 2019, EPA reinforced this requirement in several emails sent to EPA-approved testing labs, which are attached as Appendix A.

Of the 69 ASTM 3053-17 reports reviewed:

- 61 percent (42) used squared wood for more than 50 percent of the pieces.
- 25 percent (17) did not provide sufficient data to make a determination about fuel shape.
- 14 percent (10) contained sufficient data to show compliance with fuel shape requirements.

Test reports that did not comply with method requirements were flagged under revocation criteria. Where there was insufficient information for a determination to be made, the report was flagged for audit criteria.

Train Precision

Section 11.7 of ASTM Method 2515 requires the use of two sampling trains, which are the media collection systems used in the testing. The PM results from the sampling trains are used to calculate two indicators of measurement accuracy and precision. The first indicator, train precision, assesses the PM catch measurements between the two trains. ASTM 2515 specifies that train precision cannot exceed 7.5 percent. The second calculation compares the emission factors in grams per kilogram (g/kg) for the two trains and cannot exceed 0.5 g/kg. The RWH NSPS rule requires a certifier to complete all the test method calculations and include those calculations in the test report.

Reviewers found that 43 percent (56) of test reports did not contain train precision calculations. Failure to report these data limits a reviewer's ability to assess the PM measurement quality in the certification testing. Of the 73 reports that did report train precision, 16 percent (12) exceeded the train precision limitations. None of the tests exceeded the g/kg criterion. Reports that did not complete this calculation or exceeded the 7.5 percent precision requirement were flagged for audit criteria.

Conditioning Requirement

Both ASTM 3053-17 and M28R include specific requirements for conditioning ("aging") of the appliance before conducting certification testing. Failure to follow these conditioning requirements calls into question the validity of a certification test. Section 2.1.4 of M28R specifies that the heater must be operated for a minimum of 50 hours using a medium burn rate prior to beginning the test. M28R/ASTM2780 requires reporting of the following elements concerning conditioning:

- Time and weight for all fuel added (ASTM 2780, Section 9.1.4).
- Flue gas temperature at least once per hour during testing (ASTM 2780, Section 9.1.5).
- For catalytic appliances, hourly catalytic combustor exit temperatures (ASTM 2780, Section 9.1.6).

ASTM 3053-17 includes conditioning requirements that are similar to those detailed in M28R. Section 8.1.4 states that the appliance must be run a minimum of 50 hours at the medium combustion air setting using the fuel specified in section 8.4 [of that method] with a moisture content of 18 – 28 percent dry basis. Like M28R, ASTM 3053-17 also requires reporting of specific elements, including:

- Weight and moisture content for all fuel added.
- Flue temperature recorded at least once during each hour of operation.
- For catalytic appliances, recorded hourly catalytic combustor exit temperature.

Both methods also require reporting of additional information to assure that the medium burn rate and fueling parameters are met.

Of the 129 test reports reviewed:

- 34 percent (44) contained no data on conditioning,
- 50 percent (65) did not contain sufficient data to determine compliance with conditioning requirements,
- 12 percent (16) had data that indicated conditioning requirements may not have been met, and
- 4 percent (4) contained sufficient data to confirm compliance with conditioning requirements.

Most of the reports met the requirement for the number of conditioning hours but did not supply data to assess compliance with fueling and burn rate requirements. Appliances that failed to include any conditioning data were flagged for revocation criteria. Appliances with incomplete data were flagged for audit criteria.

4.1.5. Revocation Criteria – Documentation of Low Burn Rate Testing

40 CFR § 60.534(a)(1) states that "the low burn rate category must be no greater than the rate that an operator can achieve in-home use and no greater than advertised by the manufacturer or retailer." Reviewers analyzed air setting data in the test reports to identify low burn rate settings, and found that many test reports do not clearly identify the air settings. Some stoves appear to have been tested as fully completed appliances with multiple air settings, while other tests appear to have been performed on prototype appliances with a fixed air stop setting. The level of detail provided on settings varies significantly from report to report. Some provide specific air setting measurements, some state that the setting was fully opened or fully closed without further details, and others fail to report any air setting data. Some test reports state that the unit was tested at the low load defined by the manufacturer but do not provide data to support that statement.

The paucity of information about this element in the test reports made it difficult to determine if testing was completed in compliance with the rule requirements and if air settings in production units match the air setting configuration used in the prototype during certification testing. None of the test reports contained sufficient information to allow a clear determination of conformance with the requirement. Test report reviews found that:

- 43 percent (55) of test reports provided information that raised questions whether testing at the lowest setting was conducted or failed to provide supporting information to make a determination.

- 21 percent (27) of test reports provided no statements or data to communicate that testing was conducted at the lowest air setting.
- 36 percent (47) of test reports stated that testing was conducted at the lowest air setting but provided no data to support that statement.

Many test reports include an affirmative statement that they tested at the low burn rate. However, they failed to provide detailed information sufficient to assure compliance. Other reports provided information that raised questions, such as measurement information indicating air settings were not closed or not reporting on all settings. Appliances that made an affirmative statement without data were not flagged but reviewers recommend EPA assess these reports for compliance. Appliances with information that raised concerns were flagged as "could not be determined." This flag requires more information for a complete determination. No report raised a revocation flag as not meeting rule requirements.

4.1.6. Audit Criteria – ASTM 3053 Test Reports

Unlike other test methods, ASTM 3053-17 allows manufacturers to supply instructions to EPA-approved laboratories for key elements of the test. The method:

- Allows the manufacturer to define a usable firebox volume without defining criteria for those determinations. In contrast, M28R requires using the actual dimensions of the firebox with allowances to subtract areas not deemed as useable firebox volume. Firebox volume is a critical component in determining the amount of fuel used in certification testing.
- Provides no requirements for fuel length. This allows the manufacturer to modify fuel lengths to achieve appliance performance that may not reflect homeowner operation.
- Allows manufacturers to specify fuel shape and to debark fuel pieces so that they more closely resemble dimensional lumber than cordwood.
- Allows the manufacturer to provide instructions to the EPA-approved testing laboratory that include specifications for fuel dimensions and loading and spacing configurations that more closely resemble crib wood testbeds than the less-structured loading patterns typical in consumer use.
- Lacks parameters to adequately define the medium burn rate.

Some of these elements have been addressed previously in the discussion of revocation criteria. Additional factors that triggered flags for auditing include fuel length, debarked wood, fuel placement, and delineation between medium and low test runs.

Fuel Length

ASTM 3053-17 does not include fuel length requirements. However, EPA's Clean Air Act National Stack Testing Guidance[32] informs certification testing. Section VII(5) of EPA's guidance recommends testing with expected in-use fuel conditions "that would present the greatest challenge in meeting applicable emissions standards." Furthermore, the guidance states:

- In light of the fact that: (a) **the Act requires that facilities continuously comply with emission limits** [emphasis added]; (b) the NSPS, MACT, and NESHAP programs all require that performance tests be conducted under such conditions as the Administrator specifies; and the NSPS and MACT programs further require that such tests be conducted under representative operating conditions; EPA recommends that performance tests be performed under those representative (normal) conditions that:

    - represent the range of combined process and control measure conditions under which the facility expects to operate (regardless of the frequency of the conditions); and
    - are likely to most challenge the emissions control measures of the facility with regard to meeting the applicable emission standards, but without creating an unsafe condition.

40 CFR § 60.536 also requires that marketing materials and specifically the owner's manual contain information that must be adequate to enable consumers to achieve optimal emissions performance. Based on emission testing conducted by NESCAUM, the use of longer fuel lengths does not improve emissions performance. Therefore the recommendations to use wood in certification testing shorter than detailed in the owner's manual appear to contradict this requirement. Of the 69 tests reviewed using ASTM 3053-17, 84 percent (58) used fuel that was shorter than the maximum fuel length recommended by the manufacturer in the owner's manual or other related marketing materials, and only 8 tests used the same length recommended as a maximum.

As a guide, reviewers also analyzed how many appliances complied with the 5/6 fuel length rule contained in M28R. Using the M28R calculation, the reviewers found that 58 percent (40) of the ASTM 3051-17 tests would not meet the M28R fuel length criterion, and 22 percent (15) did not have sufficient data to make a determination. Reports that did not include fuel length data or used wood deemed too short using the M28R calculation were flagged for audit criteria. Only two cordwood stoves were tested

[32] US EPA. *Clean Air Act National Stack Testing Guidance*. US EPA Office of Enforcement and Compliance Assistance (2009).

with fuel that met the 5/6 guideline and was not shorter than recommended by the manufacturer.

Debarked Wood

Of the 69 ASTM 3053-17 tests reviewed, 90 percent (62) used debarked wood or failed to provide information about whether there was bark on the fuel. This indicates that using debarked wood in the tests is a common practice, but it is not representative of most homeowner fuel use. Reports that did not include pictures sufficient to determine fuel characteristics or used debarked fuel were flagged for audit criteria.

Fuel Placement

Reviewers assessed fuel placement by determining the firebox's longest dimension to apply a typical loading pattern for the stove. If the appliance's longest dimension was its width, the appliance was deemed an east/west stove. If the longest dimension was its depth, it was considered to be a north/south stove. Reviewers then assessed the fuel configuration pictures that must be included in the test reports per ASTM 3053-17 sections 8.5.9.3 and 8.6.9.1. Of the 69 ASTM 3053-17 tests reviewed:

- 51 percent (35) did not load fuel in the configuration typical of homeowner use (e.g., an east/west stove that was fueled north/south or crisscross),
- 6 percent (4) used the expected homeowner configuration, and
- 43 percent (30) did not provide data on fuel placement and did not provide pictures sufficient to determine loading direction.

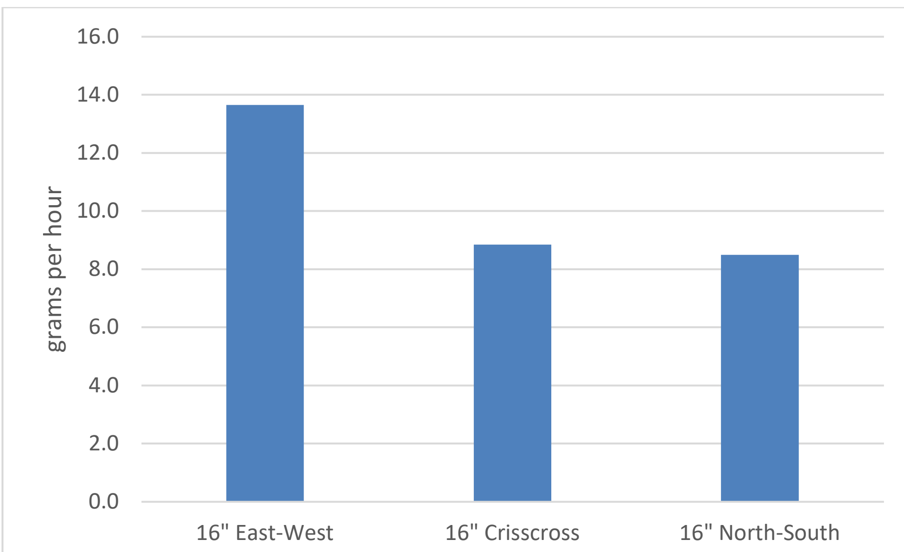
Reports that did not include pictures sufficient to determine fuel loading patterns or used patterns that were not deemed appropriate were flagged for audit criteria.

As part of NESCAUM's test method research, emission testing was completed on a medium-sized, non-catalytic, east/west stove. Testing evaluated the emission impact of the three different fuel configurations found in certification test reports, as shown in Figure 9. For an east/west stove, an east/west fuel configuration would be most representative of in-home use.

Figure 9. Three Common Fuel Loading Configurations for Cordwood Stoves

As shown in Figure 10, using the less representative north/south and crisscross configurations in the east/west stove resulted in lower emissions.

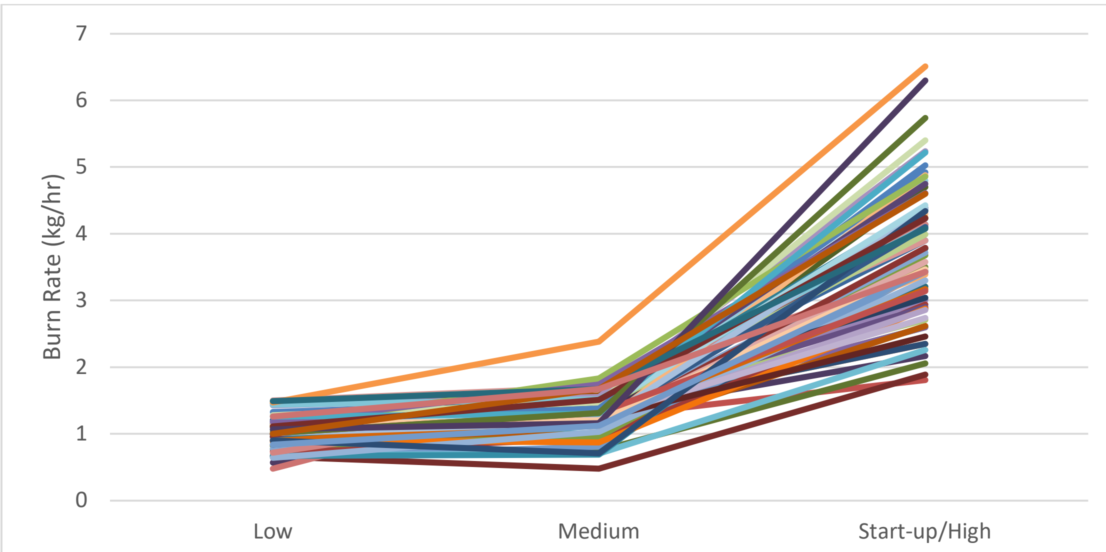
Figure 10. Emission Impact of Fuel Piece Configuration



Delineation Between Low and Medium Runs

ASTM 3053-17 does not include specifications for medium burn rate runs. Instead, it only requires that the appliance be tested at an air setting higher than the one used for the low setting. This is important because the medium and low test runs represent 80 percent of the weighting in calculating the certification value. Because the emission standard metric is in terms of emissions over time (g/hr), practices that extend burn times reduce the emission rate measured in the certification test when recognizing the largest amount of PM emissions occur at the start of the test. Analysis of the 69 ASTM 3053-17 tests found that almost two-thirds (46) of the medium air setting's burn rates were within 0.3 kg/hr of the burn rate for the low burn. This gap is 50 percent less than the typical range EPA provides within M28R for a single burn rate. For example, the range of allowable burn rates in Method 28R for Category 2 is 0.80 to 1.24 kg/hr. Figure 11 shows the burn rates for the low, medium, and high burns in all the ASTM 3053-17 tests. Clearly, the burn rates in the medium burn runs are skewed closer to the low burn rates and are not representative of mid-point testing. In several instances, the medium-fire phase's burn rate was lower than that in the low-fire phase. In some cases, test reports used the same setting, fully closed, for both the low and medium burn, in violation of test method requirements.

Figure 11. ASTM 3053-17 Comparison of Low, Medium, & High Burn Rates



Other Issues Identified with ASTM 3053

In addition to the issues listed above, reviewers identified other irregularities in ASTM 3053-17 test reports, including:

- Review of testing times indicates that ASTM 3053-17 test runs are significantly longer than M28R on similar stoves. Fuel species, fuel loading volumes, and fuel placement parameters can extend testing times, leading to test runs that last two to three times longer than similar M28R runs. NESCAUM research found that 30-50 percent of the testing time was spent burning the last 10 percent of the fuel load, known as the charcoal tail. During this time, no PM emissions occurred. Larger fuel loads further extend the time of the charcoal tail. Extending the burn-times, along with the less stringent emission standard for cordwood testing in the RWH NSPS, may allow manufacturers to meet the emission standard, in g/hr, without optimizing the design of their appliances.
- Reviewers noted that the stoves' average temperature was significantly higher in the low and medium runs of the ASTM 3053-17 tests than in similar appliances

tested using M28R procedures.

- Reviewers noted that some tests reported different species for different burns. Specifically, fuels with lower densities were used for the start-up/high runs, and higher density fuels were used for low and medium runs. Some reports also reported that the test "mainly used X species," indicating that multiple species were used but not reported. Of the 69 appliances that tested with ASTM 3053-17, 13 percent used a mixture of fuel species, and 6 percent failed to report which fuel species was used in testing
- The method states that the emission rate from only one start-up/high fire run is used in the calculation of the certification value, although a start-up/high fire burn precedes both the low and medium burns. Some test reports used the start-up/high fire emission testing from the first day of testing, some used the second day, some averaged emissions of multiple start-up/high fire runs, while others measured emissions on an additional day of testing. Some test reports reported emission measurements for all runs, some claimed to have only obtained measurements for one of the start-up high fire runs, but report data suggested additional data might have been gathered.

Cumulative Analysis of ASTM 3053-17 Deficiencies

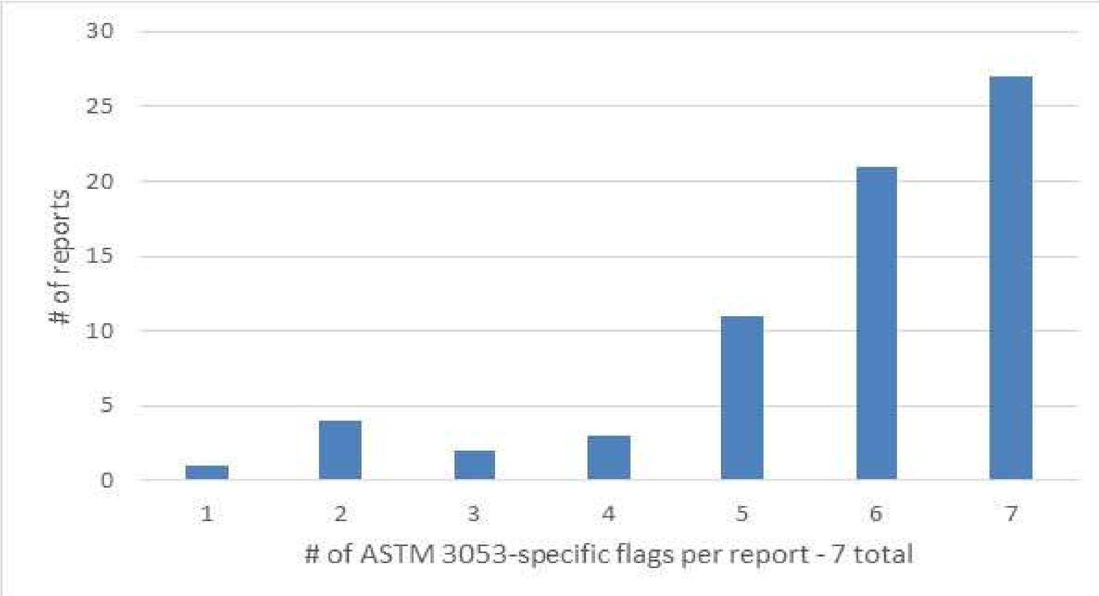
As discussed above, reviewers noted that ASTM 3053-17 tests often included several operational and fueling deficiencies. To assess the cumulative impact of the lack of specificity in the ASTM 3053-17 procedures, reports were reviewed to identify the following seven deficiencies:

1. Wood used was shorter than 5/6 of the longest dimension.
2. Certification testing used shorter wood than the maximum recommended by the manufacturer in the owner's manual or marketing materials.
3. Fuel placement was atypical.
4. Firebox dimensions listed in the test report did not match manufacturer materials.
5. Medium burn rates were within 0.3 kg/hr of low burn rates.
6. Fuel was squared.
7. Fuel was debarked.

As highlighted in Figure 12, all of the ASTM 3053-17 tests had at least one deficiency, and one-third had all seven. Of the 69 ASTM 3053-17 test reports reviewed:

- 96 percent (64) had three or more deficiencies
- 87 percent (59) had five or more deficiencies

Figure 12. Number of ASTM 3053 Deficiencies per Test Report



The incorporation of multiple factors that tend to reduce emissions and that are atypical of in-use stove operation raises questions about the efficacy of the ASTM 3053-17 protocol in assuring compliance with NSPS standards.

We note that beginning in June 2019, US EPA's OAQPS Measurement Technology Group (OAQPS-MTG)[33] sent several emails to ISO-accredited and EPA-approved labs and third-party certifiers raising many of these ASTM 3053 testing issues (*see* Appendix A). In the initial email sent June 13, 2019, OAQPS-MTG stated that it had reviewed certification test reports and identified "discrepancies and concerns" related to testing. These issues included:

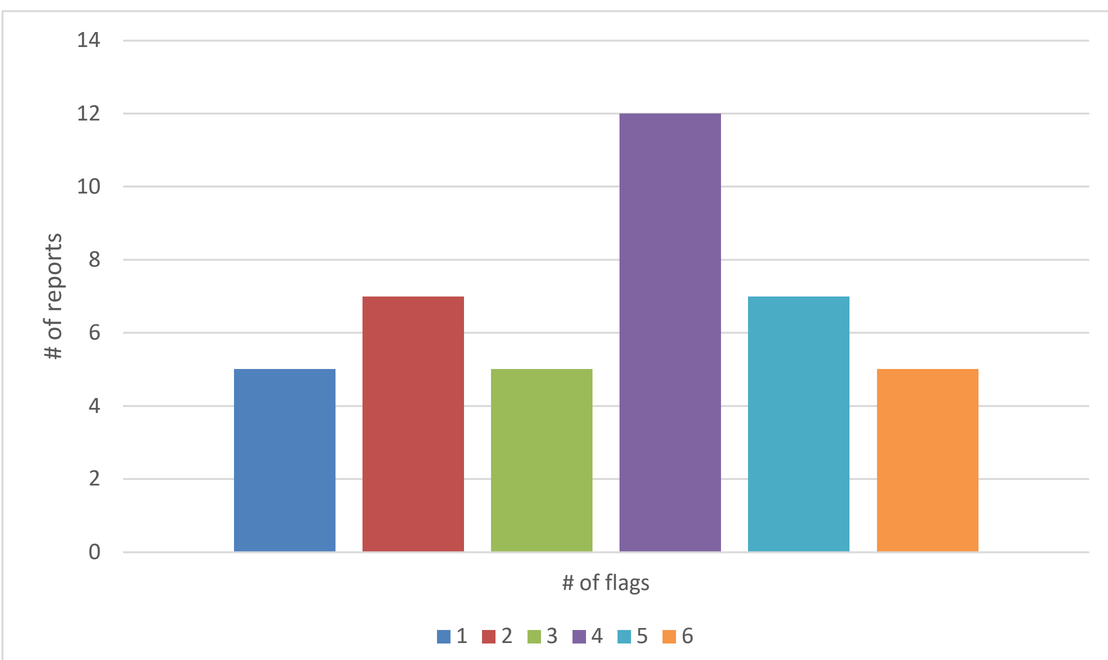
- Lack of reporting on the fuel species used for testing.
- Removing bark from fuel pieces prior to testing.
- Shaping or extreme sorting to constitute preference for a particular shape of fuel or fuel load.
- Loading and lighting of fuel inconsistent with instructions in the appliance owner's manual.
- Using complicated fuel placement instructions that did not reflect homeowner use.
- Manipulating the ash bed.

[33] OAQPS-MTG leads emissions testing requirements. However, a different EPA office handles report certifications. Certification of appliances is the responsibility of EPA's Office of Compliance housed within OECA.

- Failing to meet method-required fuel loading specifications by including shortened fuel pieces, partial loading, or not using the full firebox area to calculate fuel loading.
- Limiting fuel loading during compliance testing.
- Using instructions that expressly override specified sections of the test method or the subpart rule language (inside or outside of the test method requirements).

OAQPS-MTG indicated that manufacturers would need to revise and resubmit corrected compliance test reports where these issues exist. To assess responses, the reviewers for this study looked for updated and revised test reports after the EPA emails were sent, but were unable to locate any. Adding to the difficulty of trying to review subsequently modified test reports is that the EPA OECA Office of Compliance has not issued guidance to require revision tracking of certification reports. Reviewers did identify 40 test reports that the OECA Office of Compliance certified after the OAQPS-MTG June 2019 email, and evaluated those to see if they conformed to the identified issues. Reviewers assessed eight elements, which were all the items in the above bulleted list except the ash bed element, as this proved challenging to review. As shown in Figure 13, all of the 40 reports certified after the 2019 June email contained at least one of the problematic activities that OAQPS-MTG had identified as raising concerns. The number of issues flagged ranged from 1 to 6, with each report having 3.5 flags on average.

Figure 13. Certification Reports that Continued to Include Questionable Activities after June 2019 EPA OAQPS-MTG Email (40 total reports)



4.1.7. Summary of Cordwood Stove Certification Test Reports

Of the 129 test reports reviewed, all contained flags for revocation and audits. On average, each certification test report contained nine missing elements, nine revocation flags, and seven audit flags (Table 4). The findings indicate that issues with cordwood stove certification testing and test reports are widespread and not identified by either ISO third-party reviewers or by EPA OECA.

Table 4. Summary of Cordwood Stove Test Report Reviews Deficiencies

	Missing Report Elements (36 total)	Revocation Criteria Flags (17 total)	Audit Criteria Flags (20 total)
Low	2	3	2
Average	11	8	8
High	24	12	15

4.2. Pellet Stoves

Reviewers identified 96 pellet stoves to review as part of this research. Unlike cordwood stoves, pellet stove emissions are reduced by optimizing combustion of the fuel rather than secondary controls like catalytic or secondary combustion approaches. ASTM 2779 is the only pellet stove test method approved for use under the RWH NSPS. ASTM 2779 is a single test run that allows the appliance to start-up and operate for one hour before starting emission testing. Once emission testing begins, the pellet stove must spend one hour at the maximum setting, two hours at a medium setting, and three hours at the lowest burn rate.

4.2.1. Complete Test Reports

The RWH NSPS requires manufacturers to submit "[a]ll documentation pertaining to a valid certification test, including the complete test report and, for all test runs: Raw data sheets, laboratory technician notes, calculations, and test results" as part of the application for a certificate of compliance with that standard [40 CFR § 60.533(b)(5)]. Within 30 days of receiving certification, "the manufacturer must make the full non-CBI test report and the summary of the test report available to the public on the manufacturer's Web site" [40 CFR § 60.537(g)].

The reviewers assessed report completeness by determining whether the review criteria listed in Table 5 were included in the publicly available test reports. Based on that assessment, each report was assigned to one of the following five categories:

- *Complete:* All non-CBI elements were included in the report.
- *Incomplete-Minor:* One to three elements were missing from the test report.

- *Incomplete-Major:* Four to ten elements were missing from the test report.
- *Incomplete-Seriously Deficient:* More than ten elements were missing from the test report.
- *Missing:* Test report could not be found by searching the manufacturer's website and by conducting additional searches.

None of the publicly available pellet stove certification test reports reviewed were complete. The level of report completeness varied significantly. Of the 96 Step 2 pellet stove certifications identified, 10 percent (10) did not have a publicly available test report, and 15 percent (13) contained less than 20 pages with a deficient amount of data. Table 5 highlights findings from the report completeness review.

Table 5. Assessment of Pellet Stove Report Completeness

Report Element		Reported	Not Reported
Raw data sheets	Data for all test runs	41	55
	Manu. instructions	67	29
	Appliance setting	77	19
	Fuel characteristics[34]	50	46
	Filter data	61	35
Calculations	Efficiency	67	29
	Burn rate	66	30
	Train precision	39	57
Lab technician notes		66	30
Average heat output		80	16
Heat output range		80	16
Discussion of appropriateness & validity		39	57
Discussion of anomalies		41	55
Discussion of unused data		41	55
Conditioning		52	44
Test location		43	53
Third-party certifier		26	70
30-day notice to EPA		15	81
60-day report to EPA		35	61

More than half of the 86 available test reports did not include the following required elements:

- Sufficient documentation on appliance conditioning to determine compliance with the test method.

[34] This element addresses fuel length and for ASTM 3053 fuel piece characteristics.

- Identification of the company that provided a third-party review of the report and the report from the third-party certifier.
- Complete information on appliance settings for the test.
- Dual-train precision information.
- Pellet analysis.
- Testing location.

Approximately one-quarter of the test reports did not include raw data sheets, technician notes, filter data, burn rate, or the manufacturer's instructions to the lab.

The overall completeness findings, based on publicly available reports, are presented in Figure 14. The review found 10 test appliances with missing reports, 7 appliance reports with minor deficiencies, 35 reports with major deficiencies, and 44 reports with serious deficiencies. Appliances without publicly posted test reports were flagged as subject to revocation criteria.

Figure 14. Pellet Stove Report Completeness Assessment

The review of pellet stove certification test reports found many of the same issues identified with the cordwood stove reports. Some of the omitted elements from the publicly available test reports may have been included in the certification applications submitted to OECA. However, without access to those elements, states and other parties that rely on EPA's certification process cannot conduct a full review of test results.

4.2.2. Revocation Criteria – Testing Irregularities

This section details testing irregularities identified during the report review process. Testing irregularities is a criterion for revocation under 40 CFR § 60.533(l)(ii).

Negative Filter Values

Only 61 of the 86 publicly available reports contained data on filter weights. Of the 61 reports with filter data, 46 percent (28) reported negative filter weights, a percentage similar to the cordwood stoves. As discussed in more detail in Section 4.1.2, ASTM 2515 requires that the filters be weighed before and after testing. Negative filter weights are recorded when the filters weigh less after the test than before the test. Of the 28 test reports with negative filter weights, four indicated the use of recovery methods to ensure all particulate mass was captured for measurement purposes. As noted with the cordwood stoves, EPA has not developed guidance on proper procedures for handling negative filter values despite the high number appearing in test reports. Certification test reports with this flag were listed under revocation criteria.

4.2.3. Revocation Criteria – Compliance with § 60.536 Requirements

Another revocation criterion specified in the 2015 RWH NSPS is a finding that "the labeling of the wood heater model line, the owner's manual or the associated marketing material does not comply with the requirements detailed in 40 CFR 60.536" [40 CFR § 60.533(l)(ii)]. 40 CFR § 60.536(g)(1) states that information in the owner's manual and associated material "must be consistent with the operating instructions provided by the manufacturer to the approved test laboratory for operating the wood heater during certification testing, except details that would not be relevant to the user." To assess conformance with these requirements, reviewers compared the appliance's heat output and efficiency ratings specified in the test report with the manufacturer's information. The public information reviewed included owner's manuals, product brochures, and websites because "associated marketing materials" are included in this requirement.

Appliance Parameters – Heat Output

Heat output is an important metric because the pellet stove test method specifies that the test's high heat segment must be conducted at the maximum heat output the appliance can achieve. Reviewers compared the heat output recorded in the high-fire portion of the ASTM 2779 test with the heat output data found in the manufacturer's materials. (This is not the same as the average heat report element of Table 5.) If the heat output in the manufacturer's materials was ten percent more than the maximum output reported during the high-fire phase of the test, a revocation flag was generated. A flag for this item raises questions about the certification test's adequacy and representativeness.

The comparison of the maximum heat output in the certification test reports with that listed in the manufacturers' materials found that:

- 73 percent (63) of the appliances reported higher heat output values in their marketing materials than achieved during certification testing.
- 9 percent (8) did not report maximum heat output ratings in their marketing materials.
- 17 percent (15) had maximum heat output data that matched their test reports.

The results of this metric were similar to the findings from cordwood stoves.

Appliance Parameters – Efficiency

Reviewers compared the efficiency reported in 86 certification test reports with the efficiency data obtained from the manufacturers' marketing materials. The review found:

- 37 percent (32) of the appliances had conflicting data.
- 34 percent (29) did not report efficiency information in their marketing materials.
- 29 percent (25) had data that matched.

Appliances were flagged for revocation criteria if the manufacturer's materials' efficiency ratings deviated from the average efficiency ratings reported in the test report.

4.2.4. Revocation Criteria – Failure to Follow Test Methods

Failure to follow the test methods specified in 40 CFR § 60.534 is a criterion for revocation under 40 CFR § 60.533(l)(vii). Several elements were evaluated to determine whether certification tests were performed according to the specified methods, as discussed below.

Required Reporting Elements

Reviewers examined the test reports to determine whether they included PM emissions measured in the first hour of the test [40 CFR § 60.534(d)], as well as the efficiency, heat output, and carbon monoxide emissions per CSA B415.1-10 [40 CFR § 60.534(e)] as required in the test methods.

1-hr PM Emission Rates

Of the 86 test report reports reviewed, 15 percent (12) did not fully report first-hour PM emissions. In six of those reports, no first-hour PM emissions were reported. In the other six test reports, additional test runs were completed that were missing the first-hour emissions parameter. Appliances that did not measure or report first-hour PM data were flagged as subject to revocation criteria. Unlike the cordwood stove reports, no pellet stove reports included negative first-hour PM measurements or only filter weights.

Carbon Monoxide (CO) Emission Rates

Of the 86 reports reviewed, 9 percent (8) did not report CO measurements. Of the 78 reports that included CO emissions data, 17 percent (13) stated the CO emissions were zero for the entire test or a portion of the test run. Given the nature of combustion, zero CO emissions are unlikely, and the reports of zero CO raised concerns about measurement accuracy for this pollutant. Appliances that did not measure or report CO emissions or reported a zero-emission rate were flagged as subject to revocation criteria.

Efficiency

All reports contained efficiency data. This reporting element had 100 percent compliance. However, 19 reports failed to provide the underlying calculations to support the reported data.

Average Heat Output and Heat Output Range

Of the 86 reports, 5 did not include average heat output. Six reports did not contain the range of heat outputs. However, all the reports contained either average heat output or the range of heat outputs.

Data from Additional Test Runs

40 CFR § 60.533(b)(5) states that test reports must include any data not used in the calculations and, for any test run not completed, the data collected during the test run and the reason(s) why the test run was not completed. Of the 86 reports, 16 percent (14) reported completing additional test runs. For the 14 tests that completed additional runs, 43 percent (6) had partial data from those test runs but not complete data, and 57 percent (8) did not include any data from the extra test runs. The reviewers flagged under the revocation criteria all certification test reports that did not include complete data from the additional test runs.

Medium Burn Rates

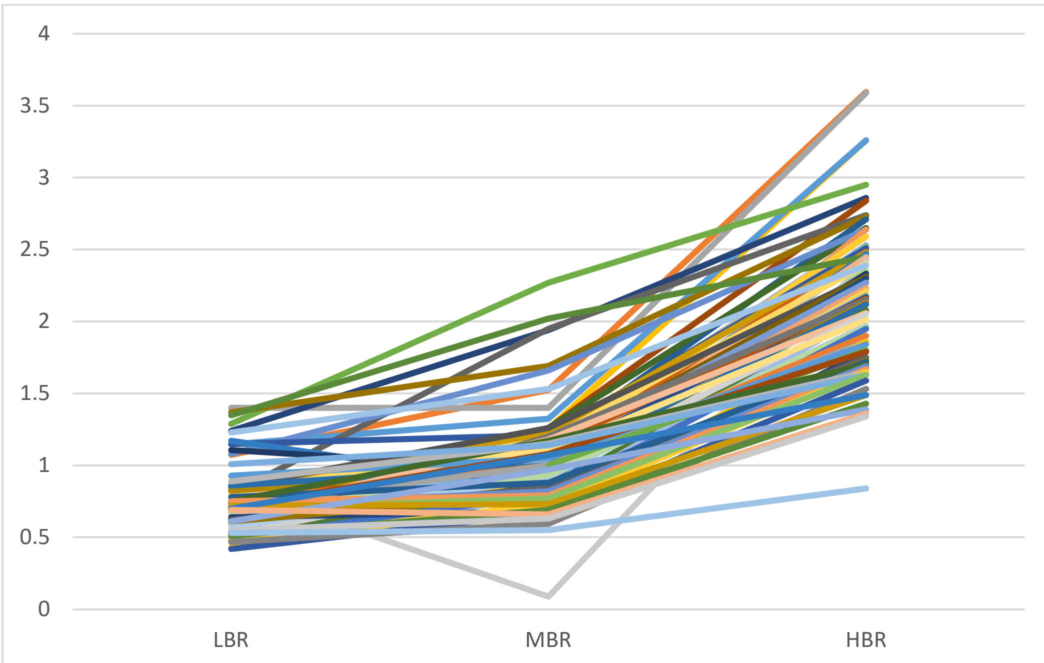
ASTM 2779 section 9.4.1.2 requires that the medium burn rate cannot exceed 50 percent of the high burn rate. Reviewers found that:

- 29.5 percent (26) appliances did not meet this test method requirement.
- 67 percent (57) appliances met the medium burn rate requirement.
- 3.5 percent (3) appliances did not provide data needed to determine compliance.

Appliances that did not meet the medium burn rate requirement were flagged for revocation criteria unless an ATM had been approved by EPA, which was the case for one appliance.

Figure 15 provides an overview of the burn rates for pellet stoves. This figure shows a more linear relationship between low, medium, and high burn rates than those observed for cordwood stoves using ASTM 3053-17.

Figure 15. Low, Medium, High Burn Rates for Step 2 Pellet Stoves



Certification Test Report Review: Conditioning

Section 9.1 of ASTM 2779 requires conditioning of appliances prior to conducting certification testing by operating the appliance for 48 hours at a medium burn rate. Reviewers found in the 86 test reports that:

- 5 percent (4) completed and reported conditioning correctly.
- 41 percent (35) failed to report any conditioning data.
- 43 percent (37) provided data that was insufficient to determine if test method requirements were met.
- 12 percent (10) provided data that indicated conditioning did not meet test method requirements.

Of the 10 reports that contained conditioning data not meeting test method requirements, 5 did not show conformance with medium burn rate requirements and 5 indicated only 10 hours of conditioning occurred. Another 12 reports contained data in the report summary indicating only 10 hours of conditioning had been completed. However, conditioning data was not supplied to confirm those statements. Appliances that did not report or comply with conditioning requirements were flagged for revocation criteria.

While the test method for cordwood stove provides a provision for manufacturers to conduct conditioning, ASTM 2779 provides no such provision, nor could reviewers identify a provision allowing manufacturers to condition pellet stoves before conducting certification testing. Of the 86 reports reviewed, 33 reports stated that the lab completed the conditioning, 17 noted the manufacturer conducted the conditioning, and 36 provided no information on where the appliances were conditioned. Labs are required to report all data obtained from the appliance, so the lack of conditioning data or reporting of who conducted the conditioning suggests that it was done by the manufacturer. Reviewers noted that of the 17 appliances where the manufacturer conducted the conditioning, 7 were completed after the lab indicated it received the appliance.

Multi-Fuel Units

Section 9.4.9 of ASTM 2779 states, "[w]hen alternative fuels are recommended by the manufacturer for use in the pellet heater in the manufacturer's written instructions, conduct a full integrated test run for each of the recommended alternative fuels[.]" Reviewers found that approximately 20 percent of the pellet stoves allow or advertise the use of their appliance with fuels other than wood, such as corn, cherry pits, wheat, rye, and distillers grain. However, certification test reports do not contain testing for those alternative fuels. This deficiency raises concerns about appliance performance when alternative fuels are combusted. Multi-fuel units that did not conduct testing with all the fuels specified in the owner's manual or associated marketing materials were flagged under revocation criteria.

Fueling Parameters

Section 9.3 of ASTM 2779 details requirements for the fuel used in testing. This section includes requirements for analysis of the pellets. According to the test method, all test reports must include the results of an analysis of the higher heating value (HHV) and moisture content of the fuel using specified methods. Units that determine heat output and efficiency using the procedures in section 9.5.1 and Annex 1 of that method must also include ash and ultimate analysis (carbon, hydrogen, nitrogen, and oxygen content) using specified methods. Of the 86 reports reviewed, 49 percent (42) did not include these data. Reviewers also noted that 42 percent (36) did not report the brand or fuel type (softwood, hardwood, mix) of pellet used. Units that did not report the type of pellets used or include analysis of the pellets used in testing were flagged under revocation criteria.

Train Precision

Section 11.7 of ASTM Method 2515 requires the EPA-approved lab to complete two calculations to determine if the precision of the two trains used for PM measurement is sufficient: (1) dual-train precision, which is a comparison of the PM catch in the two trains, cannot exceed 7.5 percent, and (2) the difference in the g/kg measurements for each train cannot exceed 0.5 g/kg. The RWH NSPS requires test reports to include all calculations required by the test method. Additional information on this topic can be found in Section 4.1.4.

The review of pellet stove certification test reports found that 55 percent (47) of the test reports did not include train precision calculations. Failure to report these data limits the reviewer's ability to assess the PM measurement quality. Of the 39 reports that contained train precision information, 15 percent (6) had values that exceeded 7.5 percent. None of the reports violated the g/kg requirement. Units that did not report this calculation or exceeded the 7.5 percent precision requirement were flagged under audit criteria.

4.2.5. Revocation Criteria – Low Burn Rate Testing

40 CFR § 60.534(a)(1) states "the low burn rate category must be no greater than the rate that an operator can achieve in-home use and no greater than advertised by the manufacturer or retailer." Reviewers identified reports where the data indicated the lowest air setting had not been used for the low-fire phase. Many other test reports failed to include data for all air control settings. In these instances, reviewers indicated that compliance with the requirement could not be determined. Reviewers found that:

- 14 percent (12) did not meet the low burn rate requirement.
- 3 percent (3) met the low burn rate requirement.
- 81 percent (70) did not have enough information to determine if the requirement was met.

Test reports where data indicated that testing did not occur at the lowest possible setting or where insufficient data existed to make a determination were flagged under revocation criteria.

4.2.6. Summary of Pellet Stove Certification Test Reports

Of the 86 test reports reviewed, all had at least one element that triggered revocation criteria. As shown in Table 6, on average, each report contained seven revocation criteria flags and five audit criteria flags, and had eleven missing elements. The findings indicate that issues with pellet stove certification testing and test reports are widespread and not identified by either ISO third-party reviewers or by EPA OECA.

Table 6. Summary of Pellet Stove Test Report Reviews Deficiencies

	Missing Report Elements (33 total)	Revocation Criteria Flags (15 total)	Audit Criteria Flags (15 total)
Low	2	3	1
Average	11	7	5
High	29	14	11

4.3. Central Heaters

Wood-fired residential central heating appliances are regulated under Subpart QQQQ of the Part 60 NSPS regulations. While regulated under a different subpart, the requirements for wood-fired central heaters are similar to those used for room heaters. Like room heaters, central heating appliances must be tested using valid certification test procedures, as defined in 40 CFR § 60.5473. That subpart includes the following certification test requirements:

- The Administrator must be notified about the test in accordance with the specifications in 40 CFR § 60.5476(h).
- The test must be conducted by an EPA-approved test laboratory.
- The test must be conducted on a central heater similar to the production model in all material respects that would affect emissions.
- The test must be conducted in accordance with the test methods and procedures specified in 40 CFR § 60.5476.

The team assessed 28 central heaters; 15 cordwood hydronic heaters, 8 pellet boilers, 1 chip boiler, and 3 cordwood furnaces. Certification tests of 9 of the cordwood hydronic heaters, 6 of the pellet boilers, and the chip boiler used ASTM 2618 procedures. Five hydronic heaters were tested according to the EPA M28WHH PTS method. Certification testing of 3 furnaces and 2 pellet boilers used alternative test methods (ATMs). A report could not be found for one cordwood hydronic heater.

4.3.1. Test Report Completeness

Test reports for central heaters were harder to locate on the manufacturers' websites than the stove reports. For 50 percent of the appliances, locating the test reports required contacting EPA. Some manufacturers posted reports at URLs that could not be found by navigating their website or using search engines. This raises questions about the need for a more specific definition of "publicly available."

Reviewers used the list of requirements in the rule as given below to assess the completeness of the posted test reports.

- 40 CFR § 60.5476 discusses general requirements for certification. It states that the manufacturer must "submit a summary and a full test report with all supporting information, including detailed discussion of all anomalies, whether the burn rate categories were properly achieved, and any data not used in the calculations and, for any test runs not completed, the data collected and the reason that the test run was not completed."
- 40 CFR § 60.5475(b)(5) details specific requirements for certification application packages, "including the complete test report and, for all test runs: Raw data sheets, laboratory technician notes, calculations and test results. Documentation must include the items specified in the applicable test methods. Documentation must include discussion of each test run and its appropriateness and validity, and must include detailed discussion of all anomalies, whether all burn rate categories were achieved, any data not used in the calculations and, for any test runs not completed, the data collected during the test run and the reason(s) that the test run was not completed. The documentation must show that the burn rate for the low burn rate category is no greater than the rate that an operator can achieve in home use and no greater than is advertised by the manufacturer or retailer. The test report must include a summary table that clearly presents the individual and overall emission rates, efficiencies and heat outputs."
- 40 CFR § 60.5475(b)(5) specifies that all emission data, including all information necessary to determine emission rates in the format of the standard, cannot be claimed as CBI.
- 40 CFR § 60.5475(b)(12) requires manufacturers to place a copy of the complete certification test report and summary on the manufacturer's website that is available to the public within 30 days of issuing a certificate of compliance.

The RWH NSPS does not specify all the complete test report elements and the summary that must be publicly posted. However, states and other parties that rely on EPA's certification process must have access to all underlying data to conduct a full review of test results.

The level of completeness in the reports varied considerably. None of the certification test reports were complete, and one appliance did not comply with the public posting requirement. Of the 27 reports reviewed, 48 percent (13) were less than 20 pages in length with a deficient amount of data. However, even test reports that had greater information were missing key elements. Table 7 highlights the findings of the completeness determination, and includes the one device with a missing report.

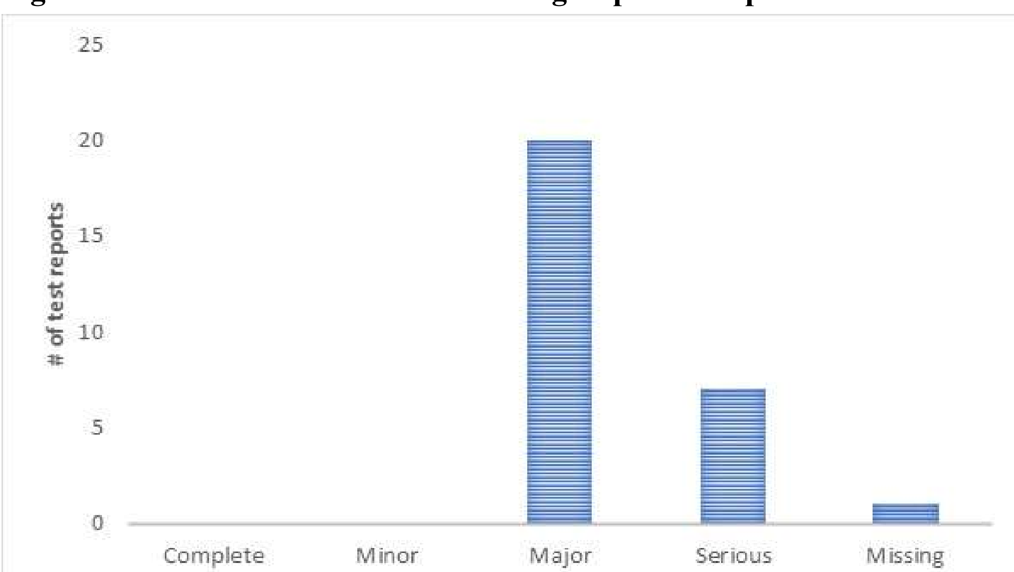
Table 7. Assessment of Report Completeness – Central Heaters

Element	Reported	Not Reported
Instructions to lab on appliance operation	5	23
Raw data	12	16
Lab notes	15	13
Filter data	19	9
Train precision	2	26
Appliance setting	0	28
Burn rate	9	19
Fuel information	9	19
Heat output	27	1
Conditioning	10	18
Photo documentation	7	21

Reports were assigned to one of the following categories based on the report assessments:

- *Complete:* All non-CBI elements were included in the report.
- *Incomplete-Minor:* One to three elements were missing from the test report.
- *Incomplete-Major:* Four to ten elements were missing from the test report.
- *Incomplete-Seriously Deficient:* More than ten elements were missing from the test report.
- *Missing:* Test report could not be found by searching the manufacturer's website and by conducting additional web searches.

Figure 16. Assessment of Central Heating Report Completeness



None of the 27 reports reviewed contained all the data necessary for a complete review. Twenty had three to ten missing elements, seven were missing more than ten elements, and one report could not be located. The appliance for which a report could not be found was flagged under revocation criteria.

4.3.2. Revocation Criteria – Testing Irregularities

The RWH NSPS states that certification for a central heater can be revoked "based on problems or irregularities with the certification test or its documentation" [40 CFR § 60.5475(l)(ii)]. To evaluate testing irregularities, reviewers focused on the handling of negative filter weights. This issue has been discussed in previous sections of this report.

Of the 27 central heating reports reviewed, there was not enough information in 13 test reports to assess this element. Of the 14 certification test reports that included this information, 86 percent (12) reported negative filter weight values. Based on the review, none of the 12 tests that reported negative filter values used recovery procedures to assure that all PM mass had been captured in the weighing process. Further, the negative filter values were not reported in any of the test's summary descriptions in the report.

4.3.3. Compliance with § 60.5478 Requirements

Section § 60.5475(l)(1)(iii) states that a certification can be revoked if EPA determines that "the labeling of the central heater model line, the owner's manual or the associated marketing material does not comply with the requirements of 60.5478." Section 60.5478(f)(1) states that "such information must be consistent with the operating instructions provided by the manufacturer to the approved test laboratory for operating the wood heater during certification testing, except details that would not be relevant to the user." Test reports were assessed to determine whether the laboratory's operational parameters and instructions in the test reports were consistent with those in the manufacturer's materials.

Central Heating Operational Parameters

Unlike the room heaters, reviewers found only limited contradictions between the manufacturer's materials and the testing data. Examples of discrepancies identified included identifying CO emission data as PM results and the reporting of lower heating value (LHV) data without calculating HHV efficiency.

Comparison of Instructions to Laboratories versus Owner's Manual Instructions

Only 5 of the 27 test reports reviewed included the instructions that manufacturers gave to the certification testing laboratory, so it was not possible to make this comparison.

4.3.4. Revocation Criteria – Test Methods

The certification revocation criteria listed in 40 CFR § 60.5475(l)(vii) include the failure of the EPA-approved laboratory to test the central heater using the methods specified in 40 CFR § 60.5476. This section requires that certification tests follow the requirements detailed in the approved methods and specifies that test results must report particulate matter emissions for the test's first hour. Reviewers assessed the reports to determine whether the testing conducted was consistent with the test method requirements

Mandatory Reporting Elements

The rule requires the reporting of first-hour PM emissions, CO, and efficiency. The central heating test methods require reporting of efficiency, heat output, and CO emissions per CSA B415.1-10 [40 CFR § 60.534(e)]. For units testing with ASTM 2618-13, delivered efficiency must also be reported. The reviewers assessed whether those mandatory elements were included in the report's summary data, as discussed below.

First-hour PM Emission Rates

Of the 27 central heating certification test reports reviewed, 8 reports did not contain first-hour PM data. Of the remaining 19 reports, nearly one-third (6) reported negative, first-hour PM emission rates. A negative PM emission rate for the first hour of a test suggests that there were issues with the test. A review of the data found that first-hour values for central heating tests were substantially lower than those for room heating appliances. This finding seems counter-intuitive, as central heating appliances tend to burn more fuel during the initial high-load periods. Additional review of central heating testing should be considered to determine if certification testing follows appropriate protocols for measuring this metric. Appliances that did not report first-hour values or reported negative first-hour values were flagged under revocation criteria.

Appliance Conditioning

ASTM 2618 requires conditioning of appliances at a medium heat draw for 48 hours prior to conducting certification testing (Section 11). However, the method does not define "heat draw" or "medium heat draw." NESCAUM contacted EPA for guidance on this issue and was advised to develop a range somewhere between the lower limit of Category II and the upper limit of Category III testing ranges. Using this approach, reviewers found that of the 27 certification test reports reviewed:

- 7 percent (2) of the appliances appeared to comply with the requirement.
- 7 percent (2) of the appliances appeared not to comply with the requirement.
- 22 percent (6) of the appliances did not have sufficient data in their test reports to determine compliance.

- 63 percent (17) of the appliances did not have conditioning data in their complete test report.

Appliances with reports indicating that the test method's conditioning requirements were not met or which did not have conditioning data in the complete test report were flagged under revocation criteria.

This element highlights a common concern from reviewers regarding the lack of specificity in the test methods. This requirement would benefit from EPA guidance on proper procedures for completing conditioning.

Train Precision

Section 11.7 of ASTM Method 2515 requires the EPA-approved laboratory to complete two calculations to determine if the precision of the two trains used for PM measurement is sufficient: (1) dual-train precision cannot exceed 7.5 percent, and (2) the difference in the g/kg emissions in the two trains cannot exceed 0.5 g/kg. The RWH NSPS requires a test report to include all calculations required by the test method, including these metrics. The reviewers found that 93 percent (25) of the test reports did not contain train precision data. Failure to report these data limits reviewers' ability to assess the data quality of PM measurements. Appliances that did not report train precision information were flagged under revocation criteria.

Efficiency

Section 13.4.5.1 of ASTM 2618-13 states that whenever the efficiency calculated using the stack loss method is lower than the delivered efficiency, the test report must include a discussion of the reasons for those results. The stack loss method calculates the absolute maximum efficiency value that the appliance can achieve during test operations, and the delivered efficiency reports the heat delivered. Theoretically, delivered efficiency cannot exceed the efficiency calculated by the stack loss method unless the boiler is a condensing boiler. Condensing boilers may exceed stack loss efficiency calculations because they capture heat from the flue's water vapor.

Reviewers completed a comparison of stack loss versus delivered efficiency for all appliances. One of the 27 central heating appliances reviewed was a condensing boiler and was excluded from this analysis. Of the other 26 appliances, ten had at least one test run for which the delivered thermal efficiency values exceeded stack loss values. For six of those ten reports, that discrepancy occurred in every test run. Failure to discuss this issue in the test report is a method violation and raises concerns about the test's validity. Appliances that had this discrepancy and failed to address it in the test report were flagged under revocation criteria.

Use of Unapplicable Sections

ASTM 2618 can be used in both cordwood and pellet boiler tests, but the method has separate operational components for each fuel type. Section 12.3 of the method details testing requirements for automatically-fed appliances (pellet or chip boilers). Section 12.2 details operational elements that apply to manually-fed boilers only. The operational components of ASTM 2618 go into greater specificity for manually-fed appliances than automatically-fed appliances. According to Section 12.3, automatically-fed appliances must operate in each test category to use ASTM 2618. Section 12.2 allows manually-fed appliances to conduct two Category 2 tests in lieu of a Category 1 test if the device cannot maintain a fire in Category 1. Section 12.2 also states if an appliance overheats while attempting to operate in any burn category, it cannot use ASTM 2618 for testing.

A reviewer found an automatically-fed appliance used Section 12.2 components to eliminate the requirement to test in Category 1. The reviewer also noted that the appliance overheated in Category 1. It appeared that the appliance used test method practices that were not allowed for the appliance type tested. The review team contacted EPA in September 2020 to determine if an alternative test method had been granted to allow this deviation and learned that no ATM had been given, but the Agency did not explain why it had accepted the appliance's certification test report.

4.3.5. Revocation Criteria – Low Burn Rate Testing Revocation Criteria – Failure to Follow Test Methods

40 CFR § 60.5476) states, "the low burn rate category must be no greater than the rate that an operator can achieve in-home use and no greater than advertised by the manufacturer or retailer." Reviewers found no information in central heating test reports indicating that they had tested at the lowest burn rate. Based on reviews of the test report, reviewers could not confirm compliance with this provision for any test report.

4.3.6. Summary of Central Heating Certification Test Reports

Of the 27 test reports reviewed, each had at least one element that triggered revocation criteria. As shown in Table 8, each test report on average contained nine revocation criteria flags, twelve audit criteria flags, and eight missing elements. This review's findings indicate that issues with central heater certification testing and test reports are widespread and not identified by either ISO third-party reviewers or by EPA OECA.

Table 8. Summary of Central Heating Test Report Review Deficiencies

	Missing Report Elements (33 total)	Revocation Criteria Flags (12-15 total)	Audit Criteria Flags (23 total)
Low	3	4	6
Average	8	9	12
High	12	12	22

4.4. Overarching Issues

In each appliance category, reviewers identified report issues that raised questions about testing integrity. The following section details those elements.

4.4.1. Summary Reports

Reviewers noted that the information contained in the test reports and the associated summaries varied significantly. 40 CFR § 60.533(b)(5) requires that "[d]ocumentation must include discussion of each test run and its appropriateness and validity, and must include detailed discussion of all anomalies[.]" The discussion materials in each of the test reports often failed to call out anomalies. More than 50 percent of the test reports failed to discuss issues encountered in testing. For example, discussions did not report negative filter weights, proportionality issues, train precision deviations, or other issues found in this review. In some cases, the detailed discussion of each run was only a single sentence. Reviewers also noted discrepancies in the data from the summary reports versus the data contained in the raw datasheets. Overall, reviewers noted a lack of reporting of deviations and discrepancies in test report summaries and specific run discussions. This is an area that would benefit from EPA guidance on reporting requirements.

4.4.2. Owner's Manual

40 CFR § 60.536(g) and § 60.5478(f) provide specific information that must be included in the owner's manual. As part of the certification application package, the manufacturer must submit an owner's manual. EPA reviews these manuals to ensure rule requirements are met. Despite EPA review, however, this study found numerous examples of owner's manuals not complying with the rule requirements.

Reviewers identified 16 elements that must be part of the owner's manual. Table 9 summarizes the findings of the review. Approximately 10 percent of the room heater and 37 percent of the central heater owner's manuals could not be found on the manufacturers' websites (a rule requirement), nor were they included in the test reports. On average, cordwood stove owner's manuals had two missing elements, pellet stove owner's manuals had four missing elements, and central heater owner's manuals had one missing element on average. Appliances that did not have owner's manuals available or had deficient owner's manuals were flagged for audit criteria, as these elements can be addressed without retesting.

Table 9. Summary of Missing Owner's Manual Elements

	Cordwood Stoves	Pellet Stoves	Central Heaters
Low	0	0	0
Average	2	4	1
High	14	13	2
No owner's manual found	0% (0)	10% (9)	37% (10)

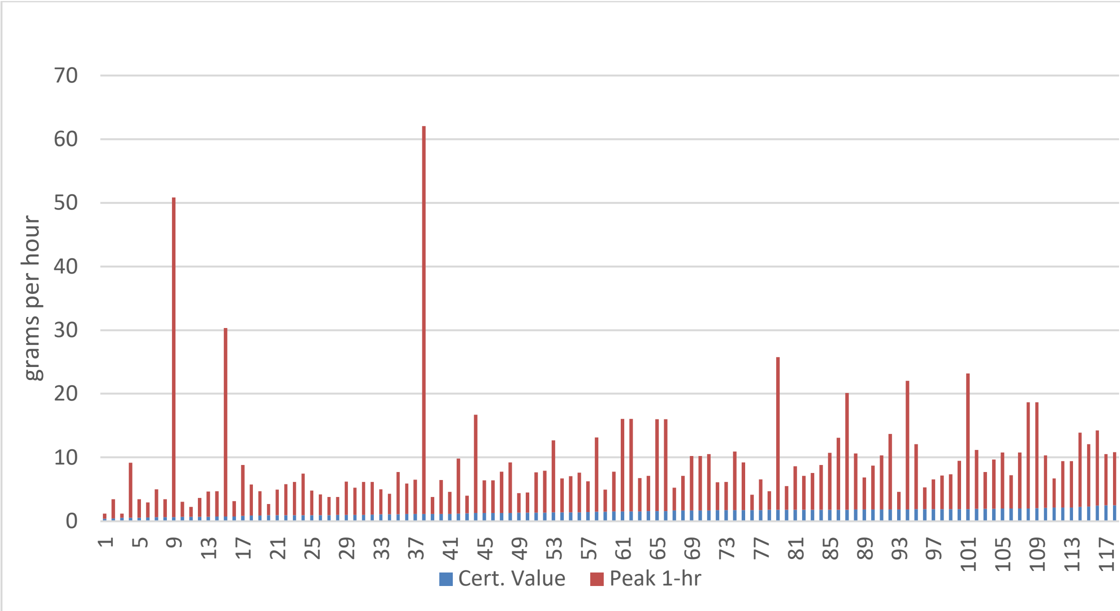
4.4.3. First-hour Values

Reviewers assessed the first-hour metric to determine the performance of the stoves over a short-term period. Reported emission values for certification are the average of multiple runs using average emissions over each individual test run, which can last from 3 to 30 hours or more. Research shows that almost all the emissions from residential wood heating are emitted in the first few hours after fuel loading. Therefore, the first-hour metric provides insights into the ability of an appliance to control for high PM during loading periods.

<u>Space Heaters</u>

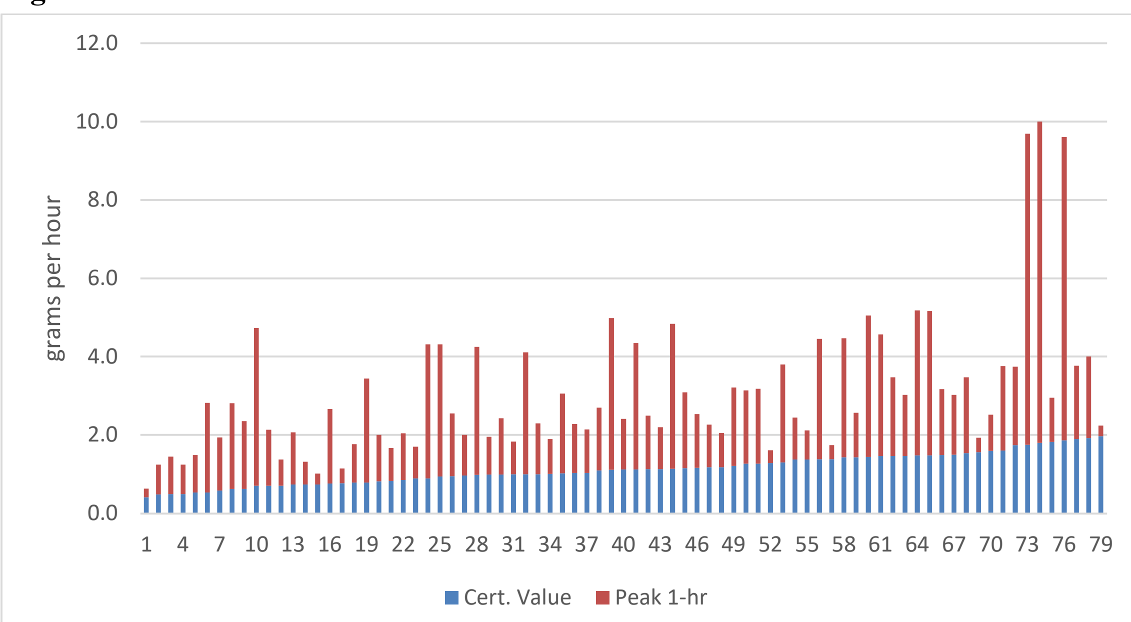
For cordwood stoves, 42 percent (54) had first-hour emission rates that were more than three times higher than the emission standard. On average, first-hour emissions were 616 percent higher than the appliances certification value. The first-hour values ranged from 132 percent to 7,842 percent higher, as shown in Figure 17. Appliances with high first-hour PM values are not necessarily those with higher overall emissions, nor are higher first-hour values associated with a particular control approach (catalytic or non-catalytic).

Figure 17. Certification Values vs. Peak First-hour Values for Cordwood Stoves



Patterns for first-hour PM emission rates for pellet stoves differed from cordwood stoves (Figure 18). Only 15 percent (13) had first-hour emissions three times higher than their average values. On average, first-hour emissions were 175 percent higher than the appliances certification value. The first-hour values ranged from 14 percent to 576 percent higher. Comparing first-hour values for pellet stoves indicates that the first hour of operation may not be the period of highest emission rates.

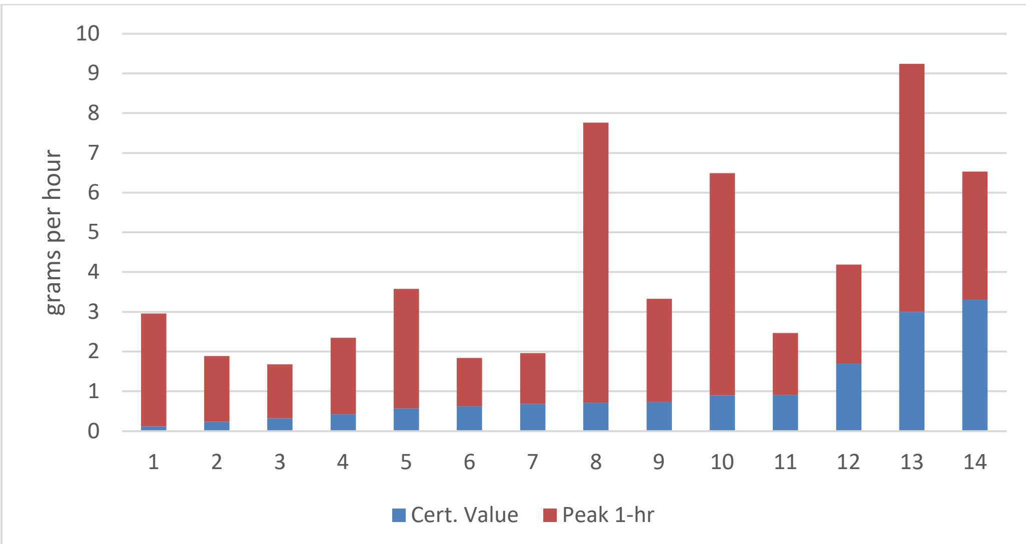
Figure 18. Certification Values vs. Peak First-hour Values for Pellet Stoves



Central Heaters

Reviewers also analyzed first-hour emissions for cordwood and pellet central heaters, as shown in Figure 19. Sixty-four percent (9) had first-hour emissions three times higher than their average values. On average, cordwood central heaters' first-hour emissions were 813 percent higher than the appliances' certification values. The first-hour values ranged from 98 percent to 2,367 percent higher. On average, the first-hour emissions for pellet central heaters were 356 percent higher than the appliances' certification values. The first-hour values ranged from 147 percent to 731 percent higher.

Figure 19. Certification Values vs. Peak First-hour Values for Central Heaters



4.4.4. Audit Criteria – Laboratory Receipt Dates

Under the test methods and rule requirements, test reports need to include the dates of certain events, such as appliance conditioning dates, the date the EPA-approved lab received the appliance, and certification testing dates. Reviewers noted numerous incidents where the dates reported were difficult to reconcile with the timing needed to undertake the steps reported. Examples of contradictory information include:

- The lab completed the conditioning, which requires 48-50 hours of operation, but the lab reported not receiving the unit until the day of or day before testing.
- The lab reported it had completed the conditioning, but the conditioning was completed before the lab reported that it had received the appliance.
- The manufacturer completed the conditioning, but the conditioning was completed after the lab reported that it had received the appliance for certification testing.

These discrepancies raise questions about how the certification test lab defines appliance receipt and what data is gathered during conditioning. Table 10 summarizes the reports with date receipt questions.

Table 10. Summary of Reports with Date Issues

	Room Heaters	Central Heaters
Reports with date issues	76	14
Reports that did not contain date issues	54	3
Reports where determinations could not be made due to missing data	84	10

Reviewers also noted that some appliances seemed to remain at the EPA-approved lab for an extended amount of time – more than a month – before conducting certification testing. Reporting the reason for testing delays in certification test reports would clarify the reason for lags in time between lab receipt and testing.

4.4.5. Audit Criteria – Laboratory Pre-testing

Per 40 CFR § 60.535 and § 60.5477(d)(2)(vi), EPA-approved labs must agree not to perform a certification review on any model from a manufacturer for which the lab conducted research and development design services within the previous five years. The term research is not defined in the rule, but it is generally understood to include gathering information or data on the device's performance.

Reviewers noted numerous examples in certification test reports indicating that the EPA-approved lab conducted pre-testing that could be construed as research, including emission testing, immediately prior to conducting certification testing. This assessment was based on statements in the reports, such as:

- "At the reception of the unit we do preliminary test runs to ensure the unit can reach the limit of the standard. We use those run{s}for aging of the unit."
- "The wood heater has been received in good shape by the carrier. A few screening tests have been done to ensure the repeatability of the results."

Other test reports indicated that the manufacturer ran the appliance in the EPA-approved laboratory facilities to conduct conditioning (i.e., aging) and testing to obtain emission data on the appliance prior to the laboratory conducting the certification test. Reviewers made this determination when the report stated that the manufacturer conducted the conditioning, but conditioning took place after the certification test laboratory received the appliance. Reviewers noted that some conditioning data appeared to resemble certification test loads.

The analysis estimated that 36 to 96 percent of cordwood stoves had EPA-approved laboratory-run tests to confirm emissions performance before the official certification test. The 2015 RWH NSPS stipulates that all testing data obtained by the certification lab must be submitted as part of the test report, whether or not it is used to for certification purposes. Issues with receipt dates, noted above, could be used as a basis for excluding test data. EPA should clarify requirements regarding these elements to assure that certification tests are done appropriately.

4.4.6. Audit Criteria – Appliance Modifications During and After Testing

Review of the reports found evidence that stove design elements were modified during testing or that prototypes tested were not complete models. For example, it appears that several units received at EPA-approved laboratories did not have defined air-stop settings. Reviewers also found examples of EPA-approved laboratories modifying the stop points during the certification test. As noted above, EPA-approved laboratories cannot conduct certification testing for a manufacturer if they have provided research and design services for that manufacturer in the previous five years. EPA should clarify what design and engineering activities EPA-approved laboratories can and cannot undertake prior to certification testing for the 2015 RWH NSPS.

4.4.7. Compliance Assurance Plans

In its certification application, the manufacturer must submit to EPA a compliance assurance plan. This plan must include regular unannounced audits at least once per year. EPA does not conduct the audit visits, as it has delegated inspection activities to the third-party certifiers under the 2015 RWH NSPS. As part of the compliance assurance plan, the third-party certifier must submit reports to EPA within 30 days of conducting an inspection. The reports are required to include deviations from the manufacturer's compliance assurance plan, and if deviations are identified, a plan for corrective action.

Reviewers did not find any information on compliance assurance plans in the publicly posted documentation. Reviewers then reached out to EPA to obtain information on compliance assurance plans, audit reports, and corrective actions. EPA OECA staff informed reviewers that both the plan and the inspection reports are submitted as confidential business information. Reviewers then checked EPA databases that are required to report compliance assurance and inspection activity. Reviewers found no data for these activities in any EPA database they reviewed. Furthermore, reviewers could not find any enforcement activity for this sector as having taken place in the last 20 years.

4.4.8. Compliance Audits

The RWH NSPS rule provides EPA with authority to select appliances for compliance audit testing, which is an available process separate from the revocation criteria. Audit testing is a useful procedural check to verify that production units offered for sale are meeting the emission standards to which the prototype was certified. The process requires the EPA Administrator to notify the manufacturer in writing of the selected heaters/model lines (name and serial number) to test. EPA can also specify the lab that will perform the audit test, which does not need to be the same lab that conducted the selected device's certification test. The manufacturer bears the costs of audit testing. Reviewers examined EPA records and could find no evidence that EPA has ever conducted a compliance audit under either the 1988 or 2015 RWH NSPS.

4.4.9. Sales Reporting Requirements

40 CFR § 60.537(d) and § 60.5479(d) require manufacturers to submit reports to EPA every two years that provide sales for each of their models by state. The rule does not specify that this information is confidential business information (CBI). However, in response to a request from NESCAUM seeking the manufacturer reports, EPA responded that all manufacturers have submitted sales data to EPA OECA as CBI.

NESCAUM also requested sales data aggregated by appliance type (pellet, non-catalytic, catalytic) at the state level. The only information EPA would provide is shown in Figure 20 below. While the release of sales information for individual models may raise CBI concerns, releasing aggregated state sales data for each appliance type would provide significant value for many state programs. Specifically, total sales data by state and by type of stove would help states understand how quickly units are changing over time and what types of appliances are entering their markets. This information also becomes significant in understanding the impacts of model types if they are found to be generally non-compliant under a more rigorous certification program.

Figure 20. Sales Data Supplied by EPA

Wood Appliance Sales Summary

March 9, 2020

Years Reported	**2015-2017**	**% of Market**	**2017-2019**	**% of Market**
Appliance type				
Wood and Pellet Stoves	190,332	98.72	219,537	97.01
HH	1,117	0.58	1,017	0.45
FAF	1,354	0.70	5,756	2.54
Total Units	192,803		226,310	

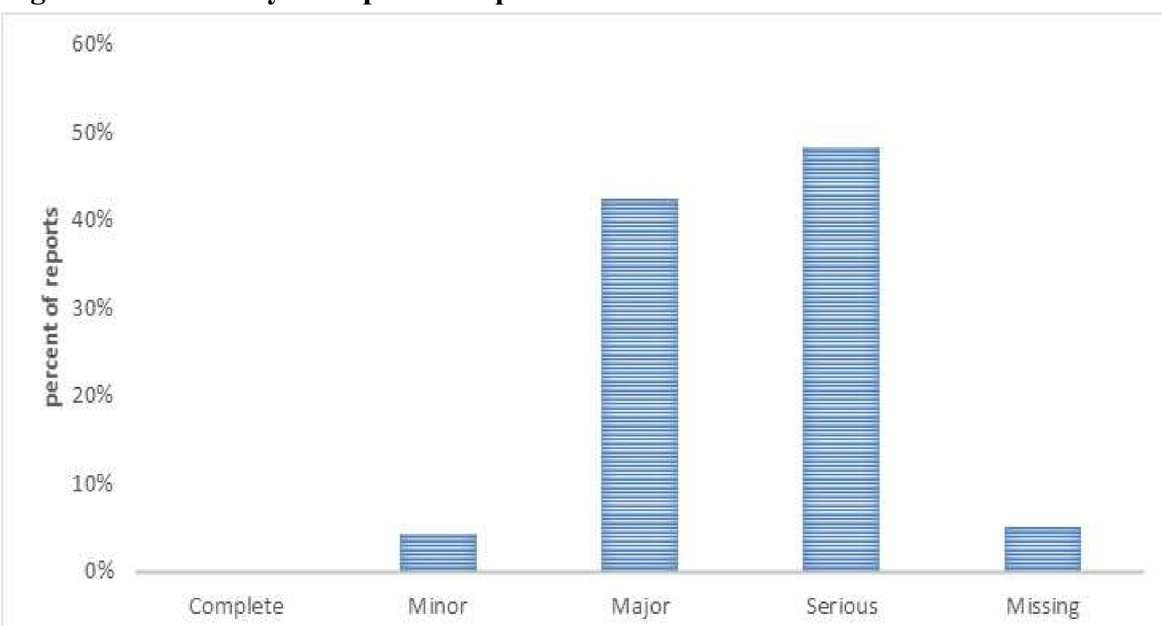
5. RECOMMENDATIONS AND CONCLUSIONS

This study's primary purpose was to evaluate the efficacy of the 2015 Residential Wood Heater NSPS program's third-party system for emission certification testing and review and EPA's oversight and enforcement of this process. The investigation revealed serious and systemic problems throughout the process, from conducting the test to report reviews. The study also identified weaknesses with existing certification test protocols that allow manufacturers and EPA-approved laboratories broad discretion in conducting tests. Those decisions significantly influence measured emissions when testing to certify new residential wood heaters.

5.1. Program Issues

The study attempted to review 255 Step 2 certified wood heater models (131 cordwood stoves, 96 pellet stoves, and 28 central heating appliances) to assess the RWH NSPS program's ability to assure compliance with regulatory emission limits. Reviewers could not find test reports for 13 appliances. Pellet stoves accounted for 10 of the 13 missing reports. Of the remainder of devices, none of their certification reports was found to be complete, and each report contained at least one revocation criteria flag (Figure 21).

Figure 21. Summary of Report Completeness



The study found numerous deficiencies in the test reports, and documented significant deviations from test methods and regulatory requirements. Even when manufacturers submitted additional information for review to address identified deficiencies, the majority of the deficiency flags, whether audit or revocation criteria flags, remained. Table 11 summarizes these findings.

Table 11. Summary of Test Report Review Deficiencies

Deficiency Rates Ranges (avg)	Missing Report Elements	Revocation Criteria Flags	Audit Criteria Flags
		Cordwood Stoves	
Low	2	3	2
Average	11	8	8
High	24	12	15
		Pellet Stoves	
Low	2	4	1
Average	11	7	5
High	29	14	11
		Central Heaters	
Low	3	4	6
Average	8	9	12
High	12	12	22

This analysis found that test methods used to certify residential wood heaters are poorly designed. They lack clarity and specificity for many testing aspects, which reduces testing precision. This analysis shows that manufacturers and EPA-approved laboratories are able to use test method vagaries or voids to employ test strategies that may improve certification testing results but do little to improve appliance performance for consumer use. This undermines the public health and air quality goals of the RWH NSPS program because it allows certification of some units as Step 2 compliant without necessarily incorporating improved design and engineering practices that achieve real-world emission reductions.

The third-party certification review process as conducted was shown to be highly ineffective at identifying and reporting testing irregularities. The study found that third-party certifiers are issuing certificates of conformance for appliances that appear not to meet regulatory test requirements. The documented failures in the third-party process may be due to poor program design, the lack of competency of the groups involved, improper complicity between third-party reviewers and manufacturers, or some combination of the three.

Study results also found that EPA has not used the RWH NSPS auditing provisions to verify that production models are substantially similar to the prototypes used in certification testing, and that those offered for sale are meeting the applicable emission standards. Lack of basic auditing undermines confidence in the RWH NSPS program and its ability to ensure that new residential wood heating appliances are meeting the federal emission standards in the real world.

A major challenge in conducting this study's review of the RWH NSPS program was in obtaining key information from EPA, which demonstrates the need for greater transparency. For example, EPA-approved laboratory inspections and compliance assurance activities are treated as confidential business information (CBI) by EPA and therefore unavailable for public review. By contrast, state and local programs must report all data into EPA's Enforcement and Compliance History Online (ECHO) database and other online reports or dashboards created to assess program efficacy.

These study results provide detailed documentation of the 2015 RWH NSPS program's failures to protect the public from the adverse health effects associated with exposure to wood smoke from new residential wood heaters. Some models certified to the Step 2 standards are not likely to consistently achieve those emission levels when in-use due to a host of weaknesses uncovered with the rule's testing and enforcement elements.

Despite the responsibility and clear authority provided in the Clean Air Act, EPA has failed to effectively enforce the New Source Performance Standards for Residential Wood Heaters requirements. The Agency has not provided the needed oversight, nor has it used the legal remedies provided, including revocation of certificates of conformance or audit testing, to enforce the rule.

5.2. Recommendations for Program Improvement

A strong and broad response is needed to correct the failures of the RWH NSPS program identified through this study. Some of these program weaknesses can be minimized in the near-term if EPA makes a firm commitment, and follows through in good faith, to fully enforce the existing requirements according to the clear language of the RWH NSPS. Others must be addressed through rule changes.

5.2.1. Third-Party Review Process

The EPA Inspector General should conduct an investigation of the third-party review system, and the responsible ISO bodies should call for an inquiry into their accreditation processes. EPA-approved laboratories that conduct certification testing should not be eligible to participate in the third-party review process. EPA should initiate action against third-party certifiers that have not adhered to test method and rule requirements. Finally, EPA should reassess the validity and viability of the third-party review process as a cornerstone of this program in the next update to the RWH NSPS.

5.2.2. Enforcement of Certification Test Results

EPA should conduct a detailed review of the problematic certification test reports identified in this study. The Agency should hold hearings and, where appropriate, revoke certifications for models failing to meet the 2015 RWH NSPS rule requirements.

The findings of this report suggest that some manufacturers and EPA-approved laboratories may be "optimizing" certification tests to qualify models as Step 2 compliant by employing methods inconsistent with the approved protocols. At a minimum, models should undergo compliance audits as allowed per 40 CFR § 60.533(n) to verify the ability of production units to meet the emission standards to which the prototype was certified. To date, EPA has not conducted a single compliance audit during the more than 30 years this program has been in place. To address this, EPA should implement routine compliance audits on 10 percent of appliances each year. The audits should begin by targeting heater models that conducted non-representative tests. Appliances should not be allowed to recertify their appliances without retesting. Waiver provisions that allow manufacturers to avoid retesting of appliances should be eliminated. Retesting should require addressing deficiencies identified in the appliance review sheets, and, given today's communication technologies, remote witnessing of testing.

5.2.3. Targeting Public Funding to Cleanest Appliances

Government funds for wood heater change-out programs should be used only for the cleanest appliances with valid test reports. Government agencies and nonprofits funding change-out programs should disqualify units that are certified as Step 2 compliant but fail to meet the rule's requirements. Taxpayer-supported incentive programs, such as the 26 percent federal tax credit created under the BTU Act, EPA Targeted Airshed grants, and state-supported activities, should only apply to those appliances included on the list of approved models developed by the Alaska Department of Environmental Conservation. This currently is the only thorough review of certification test reports applying the 2015 RWH NSPS requirements.

5.2.4. Improving Certification Test Methods

Current cordwood test methods used to certify residential wood heaters are poorly designed and often lack the specificity to ensure viable and comparable emission results. EPA should revoke or modify problematic test methods. The ASTM 3053 test should be revoked as a Broadly Applicable Test Method. EPA should expedite rulemaking or guidance to close loopholes and reduce deficiencies in ASTM and CSA test methods. Over the longer term, EPA should fully fund efforts to develop new test methods that bring integrity, reliability, and representativeness to testing outcomes.

5.2.5. OECA Enforcement and Oversight

EPA should establish residential wood heaters as a high priority enforcement sector and immediately begin a permanent and effective enforcement initiative . EPA should take enforcement action against third-party certifiers that do not adhere to method and rule requirements. Enforcement action should be taken under 40 CFR § 50.535(b) against

EPA-approved laboratories that fail to follow required procedures or practices with the goal of assuring lab independence and competence while eliminating coordination between labs and manufacturers that inappropriately "optimize" test results and modify appliances during testing. Finally, EPA should request a revision to ISO procedures to ensure the certification system's integrity and competence.

5.2.6. Program Transparency

The results of this analysis demonstrate that significant improvements in transparency are needed for the certification and enforcement components of the RWH NSPS. For example, EPA-approved laboratory inspections and compliance assurance activities are treated as confidential business information (CBI). There is no clear justification why these elements would be considered CBI as they do not pertain to typical CBI elements, such as product designs or manufacturing processes. Instead, EPA should eliminate claims of CBI for all compliance assurance monitoring activities. EPA should develop a strategy to ensure all manufacturers post complete non-CBI test reports and take enforcement action against all manufacturers who post incomplete non-CBI test reports, as defined by the rule. EPA should eliminate the use of confidential ISO compliance assurance audits, and all audit findings should be posted on the Enforcement and Compliance History Online (ECHO) database maintained by EPA. EPA should develop and require the use of a standardized certification report template.

5.2.7. Investigating EPA Program Oversight and Enforcement

The EPA Inspector General or Congress should conduct a review of EPA's OECA and Office of Air Quality Planning and Standards (OAQPS) with a focus on identifying practices to improve Agency oversight and enforcement of the 2015 RWH NSPS program.

5.3. Conclusions

This study covered over 250 Step 2 certified wood heater models (131 cordwood stoves, 97 pellet stoves and 23 central heating appliances) to assess the ability of EPA's program to assure compliance with RWH NSPS regulations. Some of the identified models did not have publicly available certification test reports, as required by the regulations. For the remainder, no report was found to be complete and in full compliance with RWH NSPS requirements. Seventy-two percent of the ISO/EPA certified reports contained issues listed as Criteria for Revocation of Certification under the 2015 RWH NSPS; 24 percent of the test reports were too incomplete to make determinations; and the remaining 4 percent had minor issues.

The third-party certification review process appears highly ineffective at identifying and reporting testing irregularities. The documented failures in the third-party process may be due to poor program design, the lack of competency of the groups involved, improper complicity between third-party reviewers and manufacturers, or some combination of the three. Study results also highlight the lack of EPA's use of the auditing program to ensure production models are substantially similar to the prototypes used in certification testing, and that those offered for sale are meeting the applicable emission standards.

This analysis also uncovered a lack of transparency in the RWH NSPS program. Reviewers were often unable to access key data and information on certification testing. An overly broad assertion of confidential business information has removed non-proprietary compliance assurance activities from public review.

Based on the identified shortcomings in this review, the 2015 RWH NSPS certification program fails to assure that new residential wood heaters are uniformly cleaner than past devices before the new standards went into effect. A flawed testing and review system coupled with a historical lack of EPA enforcement of basic program elements work in tandem to undermine the public health goals of the program. The end result is a program devoid of any credibility to ensure that new residential wood heating appliances are meeting federal emission standards, and that gives every indication that scarce public resources are being misspent on incentive programs meant to encourage the more rapid introduction of cleaner wood burning appliances that truly reduce emissions.

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Appendix A: EPA Emails on Certification Testing

Appendix A: EPA Emails on Certification Testing

Note: The following three email texts sent by EPA are unedited copies of the originals.

Email 1 of 3

From: Johnson, Steffan
Sent: Thursday, June 13, 2019 4:19 PM
To: Alex Tiegs <atiegs@omni-test.com>; 'brian.brunson@intertek.com' <brian.brunson@intertek.com>; 'brian.ziegler@intertek.com' <brian.ziegler@intertek.com>; 'claude.pelland@intertek.com' <claude.pelland@intertek.com>; 'dpower@polytests.com' <dpower@polytests.com>; 'dvoracek@szutest.cz' <dvoracek@szutest.cz>; 'gpiedalue@polytests.com' <gpiedalue@polytests.com>; Henrik Persson <henrik.persson@ri.se>; Jared Sorenson <jsorenson@omni-test.com>; Jes Andersen <jsa@teknologisk.dk>; 'jsteinert@dirigolab.com' <jsteinert@dirigolab.com>; Kelli O'Brian <kelli@clearstak.com>; 'lennart.aronsson@sp.se' <lennart.aronsson@sp.se>; Toney, Mike <Toney.Mike@epa.gov>; 'John Steinert' <john.steinert@pfsteco.com>; 'WTerpstra@PFSCorporation.com' <WTerpstra@PFSCorporation.com>; 'Benjamin.Barker@csagroup.org' <Benjamin.Barker@csagroup.org>; 'Travis.F.Hardin@ul.com' <Travis.F.Hardin@ul.com>; Laura Hinton <lhinton@guardiantestlabs.com>
Cc: Sanchez, Rafael <Sanchez.Rafael@epa.gov>; Lischinsky, Robert <Lischinsky.Robert@epa.gov>; Aldridge, Amanda <Aldridge.Amanda@epa.gov>; Baumgart-Getz, Adam <Baumgart-Getz.Adam@epa.gov>; French, Chuck <French.Chuck@epa.gov>; Boyd, Rochelle <Boyd.Rochelle@epa.gov>; Lowe, Theresa <Lowe.Theresa@epa.gov>; Cozzie, David <Cozzie.David@epa.gov>; Jordan, Scott <Jordan.Scott@epa.gov>; Wayland, Richard <Wayland.Richard@epa.gov>; Hemby, James <Hemby.James@epa.gov

Subject: Reporting Emissions Test Results when using Alt-125, or Alt-127 (ASTM E-3053)
Importance: High

To all EPA Approved Wood Heater Test Laboratories and Third Party Certifiers,

In reviewing some recent test reports that have been submitted to EPA with the intent to certify a wood heater to the Subpart AAA cordwood emissions standard, there are some discrepancies and concerns that we are observing, and we will be asking some manufacturers to revise and resubmit a corrected compliance test report. At least one of these concerns (noted below) is critical and may require re-testing. All of these items are important enough to request a corrected report, and we wanted to let all of you know just why you may be contacted by your client(s) with such a request.

We have seen a number of test reports using the Alternate Test Method and ASTM E-3053 that do not identify the species of cordwood used for the compliance testing. While it is true that the ASTM method allows selection from a wide list of wood species, the test report must identify the species of fuel used. This is specified not in the test method but in the General Provisions to EPA 40, Part 60.8 (f)(2) which governs content that must be included in the test report. Paragraph (iii) of this section reads: *"(iii) Description of the emission unit tested including fuel burned, control devices, and vent characteristics; the appropriate source classification code (SCC); the permitted maximum process rate (where applicable); and the sampling location."*

We are asking that test reports that did not identify the wood fuel species burned during a compliance test submit an amended test report to this Agency. If you are a third party reviewer and have certified such a test report, we request that you include this item, along with other items listed in the General Provisions, in your review checklist.

We have seen some test reports that reference "manufacturer's instructions" for conducting the certification test, yet those instructions were not included in the test report. The requirement to submit this information is to comply with the General Provisions of 60.8(b) and (c). The guiding principle here is that ONLY the EPA Administrator has the ability to modify a test method for any reason, and these manufacturers instructions do NOT supersede the test method. Also, the National Stack Test Guidance Document (available here: https://www.epa.gov/compliance/clean-air-act-national-stack-testing-guidance) clearly states that the emissions test report "*must demonstrate all information from the test lab such that it is a stand-alone document capable of reproducing the entirety of the test results"*. As such, all information pertinent to the operation of the appliance during the testing must be included in the test report (per 40 CFR 60.534). Also, as such instructions are relevant to how the testing was conducted, this documentation is Confidential Business Information (CBI).

We are asking manufacturers that have issued test reports where the manufacturers provided instructions to the test lab regarding appliance operation during the test, and that documentation was NOT included in the emissions test report available to the public, to take corrective action and submit an amended test report to this Agency. If you are a third party reviewer and have certified such a test report, we request that you now include this item, along with other items listed in the General Provisions, in your review checklist.

We have seen some test reports that contain manufacturer's instructions that may run contrary to the test method and rule requirements. Specifically, we have seen instances where manufacturers have directed laboratories to conduct low load testing with air inlet damper settings at "specified distances from fully closed", meaning that the unit may not be getting tested at the lowest operating rate that a homeowner will have access to during the course of normal daily operation. Testing at the lowest setting a consumer will be able to operate the appliance in their home is specifically required in 40 CFR 60.534.

Test labs and third party certifiers who are conducting /observing testing where manufacturers provided such instructions AND where you have knowledge that such devices are capable of combustion with air inlet dampers more fully closed than those setpoints specified by the manufacturer review the rule requirements with their client(s) and either select the lowest available setpoint or modify that stove model to fix the lowest available air inflow setting at that specified point, to remain fixed thereafter. Furthermore, we insist that laboratories and third party certifiers add the requirement(s) of 60.534 to their checklists and take necessary steps to not look past this requirement in the future. Appliance models found to have been tested in this manner and subsequently certified, will need to be reviewed by EPA on a case-by-case basis. As a reminder, third-party certification is an attestation that all testing was conducted as specified in the regulation; certification of testing that does not meet the regulatory requirements may result in loss of EPA Approval status.

We have seen some test reports where cordwood fuel is used to demonstrate compliance, and the dimensions of the "cordwood" very closely match the dimensions of crib fuel. While we recognize that it may happen that occasionally a wood splitter would produce a piece where the minor cross section is nearly equal to the major cross section of the fuel piece, we expect that this happens infrequently and is not normal for every piece in a fuel load.

We ask that labs and third party certifiers use pieces that approximate hand-split fuel and not something that seems to be far more selective. While fuel pieces are 'selected' for the test based on size and weight and, to some extent, dimension, we expect to see fuel loads that are more random (in terms of piece-to-piece comparisons) than not.

As always, thank you for continuing to support the EPA Wood Burning Appliance Certification Program. Please do not hesitate to reach out to us and ask questions, any time, with respect to any certification tesing you are undertaking; we are happy to offer our technical direction to help you, and your clients, meet the subpart AAA and QQQQ regulatory requirements.

Email 2 of 3

Subject: RE: Reporting Emissions Test Results when using Alt-125, or Alt-127 (ASTM E-3053)
From: "Johnson, Steffan" <johnson.steffan@epa.gov>
Date: 7/15/19 11:31 am

CORRECTION TO ITEM 2 BELOW: NO EMISSIONS TEST INFORMATION IS CONFIDENTIAL. The last sentence is intended to read "is NOT Confidential Business Information".
I regret the confusion this may have caused. Such information MUST be included in the non-CBI report.
Sincerely,
Stef Johnson

Email 3 of 3

From: Johnson, Steffan
Sent: Wednesday, December 4, 2019 10:11 AM
To: bdavis@omni-test.com
Cc: Alex Tiegs <atiegs@omni-test.com>; Ken Morgan <kmorgan@omni-test.com>; Boyd, Rochelle <Boyd.Rochelle@epa.gov>; Sanchez, Rafael <Sanchez.Rafael@epa.gov>; French, Chuck <French.Chuck@epa.gov>; Scinta, Robert <scinta.robert@epa.gov>; Jordan, Scott <Jordan.Scott@epa.gov>; Yellin, Patrick <Yellin.Patrick@epa.gov>; Aldridge, Amanda <Aldridge.Amanda@epa.gov>; Baumgart-Getz, Adam <Baumgart-Getz.Adam@epa.gov>; Hemby, James <Hemby.James@epa.gov>; Wayland, Richard <Wayland.Richard@epa.gov>; Lowe, Theresa <Lowe.Theresa@epa.gov>; Lessard, Patrick <Lessard.Patrick@epa.gov>

Subject: RE: Morso Model 5660B Certification Inquiry
From: Toney, Mike <Toney.Mike@epa.gov>
Sent: Tuesday, December 3, 2019 9:13 AM
Dear Mr. Davis,

Mike Toney forwarded your questions below to my attention, and I will endeavor to address your concerns to an appropriate level.

First off, let me be very clear that the Third Party Certification program is intended to function as an "…independent third party accredited under ISO-IEC Standards 17025 and 17065 to perform certifications, inspections and audits by an accreditation body that is a full member signatory to the International Laboratory Accreditation Corporation Mutual Recognition Arrangement and approved by EPA for conducting certifications, inspections and audits" under subparts AAA and QQQQ of US CFR, Part 60. I state this up front to point out that EPA expects that Third Party Certifiers have processes in place that guide them through situations such as the questions you pose below, or the statements made by the manufacturer in the attached letter and instructions. That said, we're all trying to navigate the rule and cordwood compliance testing is relatively new, so I'll try to shed some light on how the Measurement Technology Group views the compliance test process in order to help you in your Determination Guidances. Keep in mind that the final review is conducted by our Office of Enforcement and Compliance Assistance in Washington, D.C., who conducts a 'trust but verify' review of the submitted test report and associated/required materials prior to granting a model Certification; I say that to let you know that what the Measurement Technology Group may view about a particular test question is not the final word on compliance certification.

Let me begin by turning back the clock to the 1988 NSPS rule that established Subpart AAA. Here is an excerpt from the preamble of EPA's 1988 wood heater rule:

"In response to questions received after proposal from accredited laboratories, a provision has been added clarifying the role of wood heater manufacturers during certification testing. This provision limits instructions by the wood heater manufacturer on wood heater operation to written communications prior to the beginning of the

certification test. The only exception as for the manufacturer who observes that the test is being improperly conducted. He may then notify in writing laboratory personnel of the problem(s). All instructions and notifications relating to the certification test shall be reported in the test documentation. Any special instructions are to be consistent with the operating instructions in the owner's manual, except to the extent that they address details of the certification test (e.g. achieving specific burn rates) that would not relevant to homeowner operation. In other words, the wood heater should not be operated during the certification test in a manner significantly different from homeowner operation in order to increase the likelihood of passing."

That statement holds today, under the new NSPS as well as it did in 1988. This means that while a manufacturer may provide input to the test laboratory on operation of the appliance during the certification test, specific instructions that stray from typical homeowner operation, intended to lower the emissions of the appliance solely for the certification test, are not acceptable.

- MTG believes that examples of such instructions with respect to a cord wood compliance test include (but are not limited to):
- Removing bark prior to use as test fuel.
- Shaping or extreme sorting to constitute preference for a particular shape of fuel or fuel load (not to emulate crib fuel or create 'triangular crib fuel').
- Loading and lighting fuel inconsistent with instructions in the appliance owner's manual.
- Complicated fuel placement instructions that would not ever be followed by a home owner.
- Manipulation of the ash bed inconsistent with, or otherwise in addition to, instructions included in the appliance owner's manual, or in a manner that a homeowner is unlikely to ever follow.
- Failure to meet method required fuel loading specifications (shortened fuel, partial loading, or not using the full firebox area to calculate fuel loading).
- Limiting fuel loading during compliance testing that will be easily overridden by a home user seeking a longer burn time.
- Instructions that specifically override specified sections of the test method OR the subpart rule language (inside or outside of the test method requirements).

For reference, we have put together what we feel reasonably describes cord wood fuel: A cross sectional area end view should not form a perfect (or near perfect) square (except occasionally) but to be of a triangular or trapezoid shape with ill regular lines, some curvy some, zig zag. But not all having the same length (pie shape is fine). It is acceptable to have some bark but not having all the bark stripped off. It is not acceptable for a test fuel load to consist of all bark being stripped off of every piece. We expect to have wood pieces that are torsion shaped or pieces that are rounds, semi-rounds, have rounded edges, or are larger at one end and smaller at the opposite end. No fuel load should consist of pieces all chosen to be the same size/shape characteristics.

Regarding the comment that states "we to not read that the procedure we have used is illegal, therefor we must assume that we can use the procedure" is not a statement that we ascribe to be true, on its face. Meaning, that we look for common sense and reasonableness in such interpretations. For example, the method does not say that the lab cannot cube the fuel into square, even chunks. It might burn clean, but would a home owner ever operate the appliance in that manner? No. So, use a reasonableness test when reviewing such procedures and ask yourself if you feel it is reasonable for the manufacturer to assume that such instructions, which should also be included in the operators manual, would be followed by the average homeowner during day to day operations. If yes, then I think you have your answer and, if no, likewise, you have your answer.

I would suggest that you pay close attention to items not included in the test method as well, such as instructions for setting a damper for a low burn rate test. Subpart 60.533(b)(5) has some requirements that must be in the test report and while this is a good checklist, the requirement there for documentation of *"…the burn rate for the low burn rate category must be no greater than the burn rate that an operator can achieve in home use and no greater than is advertised by the manufacturer or retailer…"* is of particular importance. So where you have a manufacturer telling you that *"…the damper setting for the low burn rate test should be set to XX millimeters from a fully closed position…"*, it is of key importance for your process to verify that the aforementioned damper is incapable of being closed further during ANY operation in the home than where it was placed during the compliance test. To clarify, the homeowner shall not be able to burn fuel at a lower rate than the lowest achieved during the compliance test, and this must be documented and such documentation included in the report to EPA.

Regarding your question about the room air blower, MTG feels that it is not a good idea to make assumptions about the impact of the blower when burning crib fuel and apply that directly to a cord wood test.

I hope this is helpful. Should you have questions about certification I would recommend you contact Dr. Rafael Sanchez who is copied on this e-mail.

Very sincerely,

Stef Johnson

Steffan M Johnson | Leader – Measurement Technology Group | US EPA Office of Air Quality Planning and Standards | Air Quality Assessment Division | 109 T.W. Alexander Drive, RTP, NC 27710 | Mail Drop: E-143-02 | Phone: (919) 541-4790 | Cell: (919) 698-5096

ATTACHMENT 6

Location	Building Bylaws			Fire Protection Service Regulations Bylaws			Nuisance Bylaws	
	Bylaw No.	New wood burning appliances prohibited	Permit required to install wood burning appliances	Bylaw No.	Beach fires and campfires prohibited (without a permit)	Open burning permit required (includes backyard burning)	Bylaw No.	Smoke as a Nuisance
CVRD	No. 142		X	No. 528			No. 377	X
City of Courtenay	No. 3001	X		No. 2556	X	X	No. 2987	X
Town of Comox	No. 1472	X		No. 1856	X (Some exceptions)	X	No. 1652	X
Village of Cumberland	No. 1091	X		No. 988	X	X	No. 870	
Rural Cumberland				No. 258		X		
Black Creek				No. 357		X		
Denman				No. 281		X		
Fanny Bay				No. 283		X		
Hornby Island				No. 282		X		
Merville				No. 484				
Mt. Washington				No. 433				
Tsolum Farnham				No. 261		X		
Union Bay				No. 199				

Regional Airshed Roundtable

Year 1 Report

Comox Valley Regional District

May 2021

Submitted to: Comox Valley Regional District

Submitted by: Pinna Sustainability Inc.

TABLE OF CONTENTS

1. Introduction

1.1 Background

Over the last two decades, an increasing body of evidence indicates that wood smoke can be a significant source of air pollution that can have detrimental health effects to humans. This is highlighted for BC's context in a recent report published by the BC Lung Association which stated that wood smoke is a major contributor to air pollution in BC.[1] Wood smoke contains fine particulate matter called $PM_{2.5}$, a pollutant that can cause chronic and acute respiratory and cardiac diseases, especially among children and the elderly. Major sources of $PM_{2.5}$ include using wood stoves to provide heat in homes, open burning to manage debris and reduce fire risk, vehicles and equipment that serve our daily needs, and more.

In an effort to reduce the levels of $PM_{2.5}$, local initiatives have been implemented such as the Comox Valley Regional District's (CVRD) Wood Smoke Reduction Program, bylaw updates by local governments, and education and outreach initiatives by both the CVRD and local advocacy groups. Despite these efforts, local air monitoring results showed no significant improvement.

Recognizing the severity of the issues, and lack of improvements in air quality, in 2019 the CVRD Board included air quality as a key project under the Regional Growth Strategy service. A multi-agency working group developed a framework for moving forward, which included recommending a collaborative approach to air quality improvement and forming a Regional Airshed Roundtable initiative (the Airshed initiative), as laid out in the report, *A Regional Approach to Improve Air Quality: Our Proposal*.

A collaborative approach was chosen because, as described the *Our Proposal* report:

> "The interactions between the causes, impacts, and potential solutions of poor air quality in the Comox Valley are complex. While we know that there are distinct contributors to elevated $PM_{2.5}$ (mainly attributed to wood smoke from residential heating, backyard burning and larger open burns), the pathways to improving air quality touch on personal choice and behaviours, social norms, socioeconomic inequalities, government regulation, the "tragedy of the commons" and cultural values…
>
> **Improving air quality in the region will require us to align our actions across many individuals and organizations, in order to achieve our goals** [emphasis as in original]."

There is a wide variety of stakeholders with different opinions on how to improve air quality within the Comox Valley. The Airshed initiative works to navigate some of the complexities with air quality management through collaboration, communication and a strategic approach.

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[1] BC Lung Association. State of the Air 2017 Report.
https://bc.lung.ca/sites/default/files/State%20of%20the%20Air%202017%20-%20merged.pdf

1.2 Airshed Roundtable Objectives and Process

The Airshed initiative is a three-year, collaborative initiative to form and begin implementation of an Airshed Protection Strategy (Strategy). The Strategy's main aim is to improve air quality in the Comox Valley. As the purpose statement created by the working group that preceded this process states: ***Working together to achieve the best air possible for a healthy Comox Valley***.

"Working together" acknowledges that no one organization is ultimately responsible for clean air, but rather, that many must work together to achieve the desired outcome. Although the CVRD is leading this process, ultimately all participating organizations will play an important role in forming and implementing the Strategy.

"Best air possible" refers to measures in the short, medium and long term, with measurable improvements in daily and annual levels of $PM_{2.5}$, reaching consistently lower levels than the BC standards.

In order to achieve these improvements in air quality through a collaborative approach, the CVRD launched the Airshed initiative in Spring 2020 using the framework proposed by the working group. This involved establishing a Steering Committee, establishing an Airshed Roundtable, and retaining an Air Quality Coordinator. The following section describes these roles.

Objectives for the Airshed initiative and the process itself are broken down by year and are summarized in Figure 1 below.

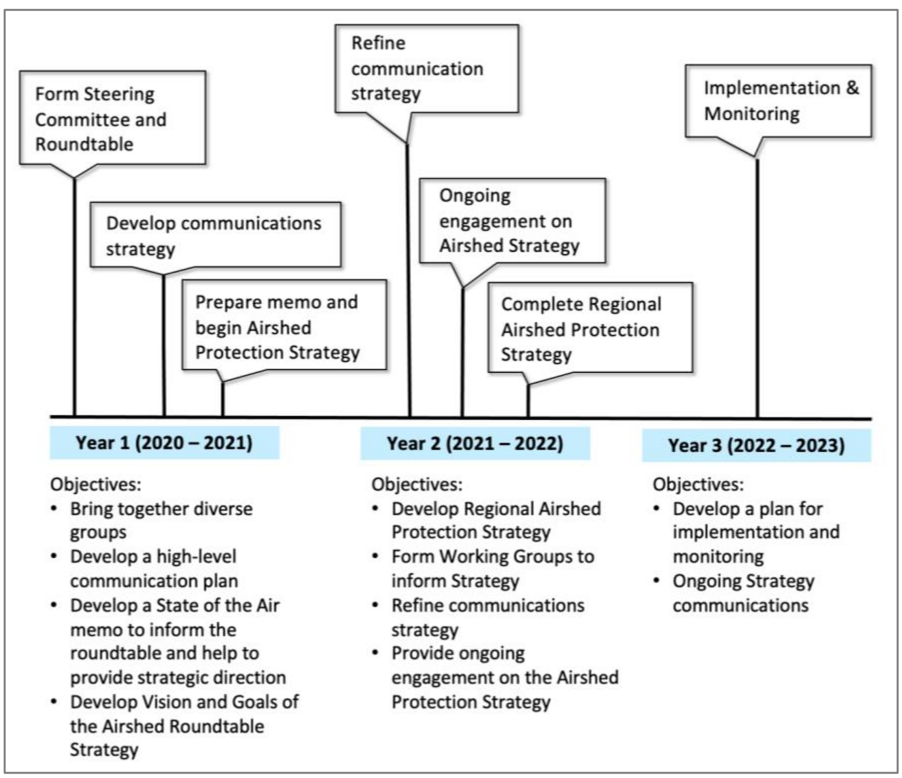

Figure 1: Objectives and process for the Regional Airshed Roundtable by year

1.3 Airshed Initiative Structure and Roles

The Airshed initiative is made up of four entities with different roles. The first group is the **CVRD** who convene the process, obtain and allocate resources, and make the final decisions. The second entity is the **Air Quality Coordinator**, Pinna Sustainability, hired by the CVRD as an external consultant. The Air Quality Coordinator's role is to facilitate process, support strategy development, guide implementation, and establish a process to monitor and report. The Air Quality Coordinator is also responsible for writing the Airshed Protection Strategy based on Steering Committee guidance, Roundtable discussion, and public input.

The third group is the **Steering Committee**, who are made up of government agencies involved in managing air quality. The Steering Committee role is to provide expertise, listen to input, inform recommendations, and champion and support strategies. The Steering Committee meets 8 - 12 times per year, which includes attending the Roundtable meetings.

Finally, the **Airshed Roundtable** is made up of government representatives, non-profit, industry, and members of the public. The Airshed Roundtable role is to identify issues, generate solution ideas, seek common ground, and share information and progress with their networks. The Airshed Roundtable meets 3 - 4 times per year.

Figure 2 displays the above information, along with the role of the **general public**.

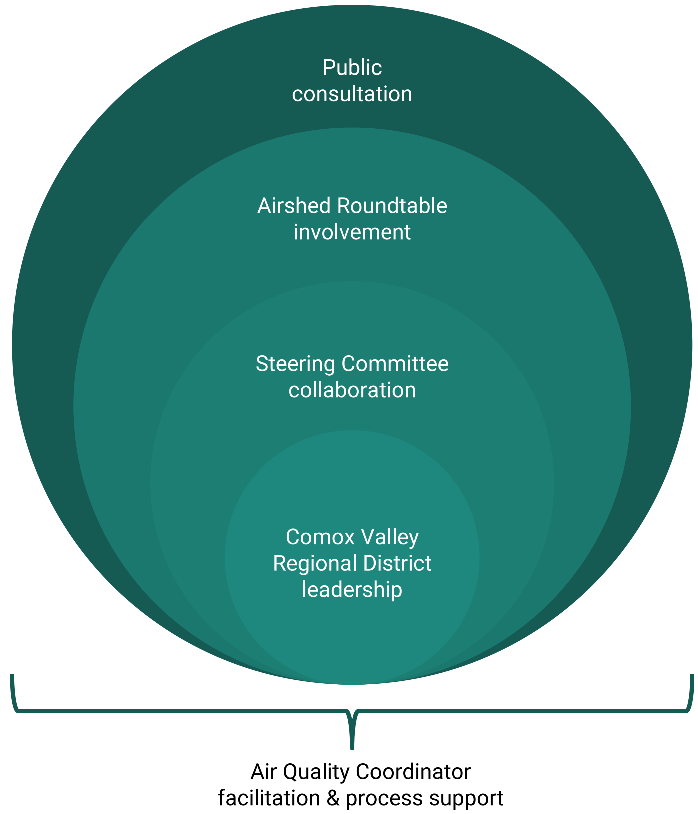

Figure 2: Airshed Protection Strategy group structure

2. Group Formation

One of the first steps in the Airshed initiative was to form the groups responsible for its creation: Air Quality Coordinator, Steering Committee, and Airshed Roundtable. The following section outlines this process.

2.1 Air Quality Coordinator

In April 2020, the CVRD put out a Request for Proposals to hire an Air Quality Coordinator to support the Airshed Roundtable Strategy development. Pinna Sustainability Inc. was awarded the contract in May 2020.

2.2 Steering Committee

The Steering Committee is made up of staff from government agencies and academia who are involved in managing or researching air quality. The following groups were invited to participate in the spring of 2020. Active members of the Steering Committee are in **bold**, while passive members (receive meeting notes and materials) are in *italics*. There are eight active members of the Steering Committee currently.

- **CVRD**
- *Town of Comox*
- **City of Courtenay**
- *Village of Cumberland*
- **BC Wildfire, BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD)**
- **Air Quality Section, BC Ministry of Environment and Climate Change Strategy (ENV)**
- **Vancouver Island Health Authority (VIHA)**
- **Vancouver Island University**
- K'òmoks First Nation

2.3 Airshed Roundtable

Working in partnership with the CVRD, and building upon the suggested stakeholders and representatives outlined in the *Regional Approach to Improve Air Quality: Our Proposal*, the Air Quality Coordinator developed invitations for participation in the Airshed Roundtable.

The following groups were invited to participate in the summer of 2020. Active members of the Airshed Roundtable are in **bold**, while passive members (receive meeting notes and materials) are in *italics*. There are 29 number of active participants in the Airshed Roundtable.

- BC Community Forest Association
- **BC ENV**
- Benett Sheet Metal and Heating
- **City of Courtenay**
- Comox Seniors' Association
- **Comox Fireplace & Patio**
- **Comox Valley Breathe Clean Air**
- **Comox Valley Chamber of Commerce**
- Comox Valley Community Foundation
- **Comox Valley Community Health Network**
- **Comox Valley Nurses for Health & the Environment**
- **Comox Valley Farmers' Institute**
- **Comox Valley Fireplace and Patio**
- Comox Valley Firewood
- **Cumberland Community Forest Society**
- *CVRD's Integrated Regional Transportation Select Committee*
- **Elemental Energy Advisors**
- *Fire Departments (Fire Chiefs Association)*

- First Nations Health Authority
- **FLNRORD**
- **Focused Energy Assessments**
- **Hanock Natural Resource Group**
- **Hearth, Patio, & Barbeque Association of Canada**
- K'ómoks First Nation
- **Manager of Fire Services CVRD**
- **Mid Island Farmers' Institute**
- *Mosaic Forest Management*
- **Norse Heating**
- *Peakflow Energy Solutions*
- School District 71
- **Town of Comox**
- **Vancouver Island University**
- **VIHA (Environmental Health)**
- **VIHA (Public Health)**
- **Village of Cumberland**
- **Six members of the public**

Members of the public were invited to submit a proposal to join the Airshed Roundtable. Six members of the public were chosen by the CVRD based on submissions to join the Airshed Roundtable.

3. Strategy Development Process

Once the Air Quality Coordinator, Steering Committee and Airshed Roundtable were formed, the groups began to meet, build relationships, and begin to develop the Strategy's vision and goals. The date, agenda, and outcome of each meeting during the first year are outlined in the proceeding sections.

3.1 Steering Committee Meetings

Five Steering Committee meetings were held during the first year of the process. The following table provides the date, agenda and outcomes from each meeting.

Date	Agenda	Outcomes
Meeting 1: June 18, 2020 9 members present	• Introductions • Review work completed to date re: air quality • Establish roles and expectations • Review State of the Air Report table of contents • Discuss communications approach • Discuss Roundtable invitations • Next steps	• Updates for Terms of Reference and Guiding Principles document • Updates to State of Air memo table of contents • Confirm Roundtable membership

Meeting 2: August 13, 2020 9 members present	• Review Draft State of the Air Memo • Discuss Roundtable membership procedures • Identify objectives and approach for first Roundtable meeting	• Updates to State of the Air Memo report content • Updates for the Roundtable meeting approach • Members volunteered to present background information at the first Roundtable meeting
Meeting 3: October 14, 2020 8 members present	• Discuss outcomes from Roundtable meeting #1 • Identify objectives and approach for Roundtable meeting #2 • Discuss media approach	• Group happy with first Roundtable meeting • Members volunteered to lead presentations in their topic area of expertise in the next Roundtable meeting (open burning, space heating, and transportation) • Recommendations for media approach
Meeting 4: February 3, 2021 7 members present	• Overview of Roundtable survey input • Review and discuss draft vision and goal ideas developed from the survey input • Discuss feedback obtained from Roundtable members on the Roundtable membership and process, and proposed approach for Roundtable meeting #3 • Proposed updates to the process for Year 2 engagement	• Updates to draft vision and goals document to bring to the Roundtable • In response to feedback from Roundtable participants, discussed and confirmed continuation of the current collaborative format, and endorsed additional communication with Roundtable members as needed to encourage collaboration
Meeting 5: April 13, 2021 7 members present	• Review vision and goal updates based on Roundtable meeting #3 • Working Group proposal as an approach to enable increased discussion among small groups between Roundtable meetings • Roundtable update, including participant process requests • Strategies for Goal 2: Effective coordination of efforts and monitoring	• Endorsed current vision and goals document with minor changes requested • Endorsed proposed Working Group format • Suggested potential public event to highlight links between health and air quality • Strategies section deferred to next meeting due to time limitations

3.2 Roundtable Meetings

Three Roundtable meetings were held during the first year of the Airshed Roundtable process. The following table provides the date, agenda and outcomes from each meeting.

Date	Agenda	Outcomes
Meeting 1: September 15, 2020 30 members present	• Welcome and introductions • Overview of project and process • Expert presentation on Air Quality in the Comox Valley • Facilitated discussion on strengths, barriers, and opportunities • Next steps	• Acquaintance among participating members • List of strengths, barriers and opportunities to bring forward to set the context and to inform development of Strategy vision and goals
Meeting 2: November 19, 2020 30 members present	• Welcome and introductions • Check-in on process and terms of reference • Introduction to collaborative strategy development • Steering committee presentations on 3 topics: Space heating, open burning, and transportation • Break-out groups: informing goal development • Next steps	• Suggested updates to Terms of Reference • Increased awareness of the major sources of air pollution in the region • Input to support development of Strategy vision, goals and values
Meeting 3: March 4, 2020 30 members present	• Welcome and introductions • Steering Committee update • Related initiatives update: Community resiliency investment and FireSmart • Roundtable survey findings • Developing the strategy: draft vision and goals overview • Break-out: Vision discussion • Break-out: Goals discussion • Reconvene and wrap-up	• Detailed input on the vision statement and goals • Informed the identification of guiding principles for the Strategy

3.3 Roundtable Survey and Feedback

Following the second Roundtable meeting, an online survey was implemented to seek feedback from both the Steering Committee and Roundtable members. Primarily the survey sought to collect vision and goal ideas from the two groups, feedback on the Airshed initiative process to date, as well as gauge support for potential Working Groups. The results of the survey helped inform the vision and goals document, as outlined in the next section.

4. Key Outcomes

4.1 Formation of Roundtable and Terms of Reference

One of the first tasks of the Airshed Roundtable was to form a Terms of Reference. Based on the original proposal for this process, as well as consultation with the Steering Committee and CVRD, the Air Quality Coordinator formed a draft Terms of Reference. The Terms of Reference was reviewed and updated based on Steering Committee and Roundtable feedback.

4.2 Communication Plan and Ongoing Communications

A communications plan was drafted and approved by the board in July of 2020. The plan highlights the objectives and proposed formats for communication with select audiences. This includes social media content, CVRD website updates, and board updates. The Airshed Roundtable meeting materials, including presentations, are available to the general public through the CVRD project website. Further, a shared drive has been created for Roundtable members to access meeting materials and related resources.

Throughout the first year, members of the Roundtable provided feedback related to process of the Airshed initiative. The Air Quality Coordinator maintained regular communication with all members, received input, and brought feedback to the Steering Committee during meetings for guidance on how to address feedback and/or adjust the process, as necessary. For example, the Steering Committee proposed that the Air Quality Coordinator have one-on-one meetings with select members of the Roundtable to hear feedback directly and maintain a collaborative environment.

4.3 State of the Air Memo

A State of the Air memo was completed in September 2020 and was written to provide the background to prepare the Airshed Roundtable for participation to develop and implement a Regional Airshed Protection Strategy. This memo summarizes the current state of the air in the Comox Valley (air quality data, pollutant sources, studies and work completed to date), highlights how air pollutant sources are regulated and managed, and provides examples of what an airshed protection strategy may include. It provides members of the Roundtable a common understanding of this information in preparation for collaboratively developing an airshed protection strategy for Comox Valley. Key messages from this memo and the Roundtable discussions will be communicated with the public during the process, and the memo itself has been made available for download on the project website.

4.4 Strategy Vision and Goals

During the first year of the Airshed initiative one of the main tasks was to develop a set of vision and goals for the Airshed Protection Strategy. The process that was used to develop the vision and goals is outlined in Figure 3 below. The vision and goals document is provided as Appendix A.

Figure 3: Comox Valley Airshed Strategy: method for drafting vision and goals

5. Next Steps

The next year of the Airshed initiative will build on the success of the first year to develop the Airshed Protection Strategy. This includes identifying how to achieve the goals laid out in the first year through development of concrete actions.

The CVRD has provided resources to conduct additional engagement in 2021 to support this process. This process will be advanced through smaller Working Groups with select Roundtable and Steering Committee members to take a "deeper dive" into developing strategies in specific topic areas. Working Groups will be tasked with moving from goal to action, including identifying both longer-term and shorter-term actions. The Working Groups will also consider who would be responsible for implementation, and how the goal can be tracked.

Further, the additional resources will be used for a broader education campaign, which will include an online public engagement through the CVRD Connect website.

A schedule for Year 2 tasks is provided in Figure 4 below.

		2021								2022			
		May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Deliverable 1: Airshed Roundtable, Leadership Group and Working Group													
1.1	Steering Committee meetings												
1.2	Roundtable meetings		24th			23rd		25th				24th	
Deliverable 2: Communications													
2.1	Develop communications strategy (1 per year)												
2.2	Communications - general												
Deliverable 3: Prepare and Implement Regional Airshed Protection Strategy													
3.1	Prepare the Regional Airshed Protection Strategy												
Deliverable 4: Funding													
4.1	Apply for relevant grant opportunities to support the work of the Roundtable						As needed						
Deliverable 5: Reporting & Project Management													
5.1	Project management												
5.2	Prepare year end report												
Deliverable 6: Engagement													
6.1	Develop Connect CVRD content												
6.2	Identify collaborative initiatives												
6.3	Host a public online event						Date TBD						
6.4	Working Groups to develop strategies	25-28	7-11	5-9									

Figure 4: Task schedule for Year 2

Appendix A – Vision and Goals

Comox Valley Airshed Roundtable

Draft Vision, Principles and Goals for the Airshed Protection Strategy

May 6, 2021

This document summarizes the current draft Vision, Principles and Goals for the Comox Valley Airshed Protection Strategy. It represents the input and review from Airshed Roundtable members and Steering Committee members. As a next step, members of the Airshed Roundtable and Steering Committee will form working groups to begin identifying strategies to achieve the goals.

Draft Vision Statement

The Comox Valley has clean air that supports the health of all residents.

*Currently, the Comox Valley experiences recurring periods of poor air quality that negatively affect the health of our communities. Achieving this vision is complex and will require **coordinated efforts** from several governments, organizations, industry, and community members. Our actions need to be effective in order to **continually improve air quality**, with an initial focus on reducing **fine particulate matter** – the air pollutant of greatest concern to the health of our Comox Valley communities.*

Draft Strategy Principles

The following principles will guide the development and implementation of the Airshed Protection Strategy:

- **Health protection**: Air pollution disproportionately affects some members of our community. We will work together to ensure the best air possible for all residents in all areas of the valley, focusing on protecting the health of our most vulnerable.
- **Accessible and affordable**: Reducing emissions may involve actions or investments that are not accessible or affordable to everyone. We will work to identify ways to improve access to and affordability of options that help clean our air.
- **Innovative and evidence-based approaches**: Our efforts will be based on the best available science, evidence and practices, and we will build on this information to test innovative approaches to achieve our vision.
- **Minimizing contributions to climate change**: We recognize the urgency of climate change and its potential effects on the health and well-being of our residents. We also recognize that air pollution and climate change are closely linked. Therefore, we will ensure our efforts to minimize air pollution simultaneously minimizing greenhouse gas emissions where applicable.

Draft Goals

1: Achieve measurable reductions in fine particulate matter levels

1A. Reduce emissions from existing residential wood-burning appliances

1B. Transition away from biomass heating systems in residential neighbourhoods

1C. Eliminate burning of yard waste in residential neighbourhoods

1D. Promote and advocate for alternatives to open burning outside of residential neighbourhoods

1E. Reduce emissions from transportation, focusing on sources of $PM_{2.5}$

2: Effective coordination of our efforts

2A. Build partnerships and align efforts across participating organizations

2B. Continually expand our knowledge of local pollution sources and impacts to inform our efforts

3: Educate and involve the community in understanding and reducing the impacts of air pollution

Preliminary sub-goals still in development:

3A. Facilitate a better understanding of the connection between air quality and health

3B. Support knowledge transfer through public events

3C. Support community engagement and links to educational opportunities

CITY OF COURTENAY

BYLAW REFERENCE FORM

BYLAW TITLE
"City of Courtenay Fees and Charges Amendment Bylaw No. 3055, 2021" (Water user fees) "City of Courtenay Fees and Charges Amendment Bylaw No. 3056, 2021" (Sanitary Sewer user fees) "City of Courtenay Fees and Charges Amendment Bylaw No. 3057, 2021" (Solid Waste Collection user fees)
REASON FOR BYLAW
To amend the water, sanitary sewer and solid waste collection user rates for 2022 in accordance with Council resolutions of December 3, 2021.
STATUTORY AUTHORITY FOR BYLAW
Section 194 of the *Community Charter* allows Council to charge a user fee to cover the cost of delivery of a service.
OTHER APPROVALS REQUIRED
STAFF COMMENTS AND/OR REPORTS
The "2022-2026 Water Fund Financial Plan" report was presented to Council on December 3, 2021 and Council approved OPTION 1 and endorsed the proposed increase of 2.0% to water user fees for 2022. The "2022-2026 Sewer Fund Financial Plan" report was presented to Council on December 3, 2021 and Council approved OPTION 1 and endorsed the proposed increase of 7.5% to sewer user fees for 2022. The "2022-2026 Solid Waste, Recyclable and Yard Waste Budgets" report was presented to Council on December 3, 2021 and Council approved OPTION 1 and endorsed the proposed increases of 5% for single residential and multi-residential curbside service and 15% for Institutional, Commercial and Industrial (ICI) and multi-residential apartment and condo non curbside service. Staff prepared the appropriate bylaws incorporating the above rate increases and are presenting it to Council for three readings. The bylaws will be presented for final adoption on January 17, 2022.
OTHER PROCEDURES REQUIRED
December 6, 2021 — A. Bérard Staff Member

THE CORPORATION OF THE CITY OF COURTENAY

BYLAW NO. 3055, 2021

A bylaw to amend City of Courtenay Fees and Charges Bylaw No. 1673, 1992

The Council of the Corporation of the City of Courtenay in open meeting assembled enacts as follows:

1. This bylaw may be cited for all purposes as **"City of Courtenay Fees and Charges Amendment Bylaw No. 3055, 2021."**

2. That "City of Courtenay Fees and Charges Bylaw No. 1673, 1992" be amended as follows:

   (a) That Schedule of Fees and Charges, Section III, Appendix I, "Waterworks Distribution System" be hereby repealed and substituted therefore by the following attached hereto and forming part of this bylaw:

   Schedule of Fees and Charges Section III, Appendix I – Waterworks Distribution System

3. This bylaw shall come into effect upon final adoption hereof.

Read a first time this day of , 2021

Read a second time this day of , 2021

Read a third time this day of , 2021

Finally passed and adopted this day of , 2022

Mayor	Deputy Corporate Officer

SCHEDULE OF FEES AND CHARGES
CITY OF COURTENAY FEES AND CHARGES
AMENDMENT BYLAW NO. 3055, 2021
SECTION III, APPENDIX I

WATERWORKS DISTRIBUTION SYSTEM

1. CONNECTION FEES

(a) Pursuant to Section 3.2 of Water Regulations and Rates Bylaw No. 1700, 1994, and amendments thereto, every applicant shall pay to the City before any work is done on the connection, a connection fee as follows:

Connection Size

Within the City	
Connection from either side of road to property line	
20 millimetres (3/4 inch)	$2,500.00
25 millimetres (1 inch)	$3,500.00
Outside the City	
20 millimetres (3/4 inch) with a minimum charge of $3,500.00	Actual City cost plus 25%

(b) Where a larger connection than those listed above is required, the connection will be installed at City cost plus 25%.

(c) **Water Turn On and Turn Off**

If turn on or turn off is for a purpose other than maintenance or the commissioning of a new service the following fees will apply:

Inside the City	$35.00 for each water turn on or turn off
Outside the City	$55.00 for each water turn on or turn off

(d) **Abandonment Fee**

Fee for disconnecting an abandoned service connection at the water main irrespective of the size of the connection	Actual City cost plus 25%, with a minimum charge of $500.00

2. WATER UTILITY USER RATES

(a) Unmetered Water

The minimum user rate per year or portion thereof for unmetered accounts shall be as follows:

	Bylaw Rates (per annum) **Effective Date January 1, 2022**
Single Family Dwelling	516.17
Multiple Family Dwelling -per unit	436.00
Commercial	493.27
Outside Commercial Users	890.58
Outside Residential Users	890.58

(b) Metered Water

All metered accounts for the quantity of water used each quarter shall be calculated at the following rates:

	Bylaw Rates Effective Date January 1, 2022
Multi-Family Metered	
0 - 48.0 cubic metres	69.84
48.1 - 566.0 cubic metres	1.69
Greater than 566.0 cubic meters	1.36
Commercial Metered	
0 - 48.0 cubic metres	73.81
48.1 - 566.0 cubic metres	1.69
Greater than 566.0 cubic meters	1.36
Regional Standpipe, Regional Playfields	Bulk Water Rate plus 30%
Outside City - Multi-Family Metered	
0 - 48.0 cubic metres	150.31
48.1 - 566.0 cubic metres	2.20
Greater than 566.0 cubic meters	1.75
Outside users - Commercial Metered	
0 - 48.0 cubic metres	150.31
48.1 - 566.0 cubic metres	2.20
Greater than 566.0 cubic meters	1.75
Regional District bulk	1.11
Sandwick - summer only	516.17

(c) Where a meter is found not to register, the charge shall be computed on the basis of the amount of water used during the time the meter was working, or from any other information or source which can be obtained, and such amount so composed shall be paid by the consumer.

(d) Where a commercial or industrial consumer has not been connected to a water meter through non-availability of the water meter or because of special exemption being granted by the City, water charges to the consumer will be computed on the basis of consumption recorded for other similar purposes in the City, or from any other information or source which can be obtained, and such amount so computed shall be paid by the consumer.

(e) Where it has been determined that a water leak has occurred during the last billing period on the buried portion of the service between the water meter and the point where the service pipe enters the building, a maximum one time rebate of 40% of the metered water utility fee to compensate for the water leak will be made at the discretion of the Finance Officer based on the following:

i. The leak occurred on the buried water service;
ii. That a leak of that nature would have caused the volume of excess water usage;
iii. The leak did not occur as a result of negligence of the owner;
iv. The owner has provided satisfactory evidence that the leak has been permanently repaired.

WATER METER RENTALS

a) Water meter fee shall be as follows:

	Bylaw Rates Effective Date January 1, 2022
	Monthly Rates
Up to 3/4"	1.68
1"	4.67
1 1/4" - 1 1/2"	9.31
2"	13.95
3"	23.23
4"	45.96
6"	69.52
8"	92.75
10"	115.97

The above meter fee shall be added to the monthly water rates and will apply both inside and outside the City.

METER READING CHARGE

Each call after the first one of each month if access has not been provided or if readings extra to the quarterly reading are requested $35.00 per call

3. SUPPLY OF WATER FROM FIRE HYDRANTS OR OTHER SOURCE

(a) Water may be supplied from a fire hydrant or other for the use of developers during the course of construction of multi-family, industrial, and commercial developments. The charge for such water usage shall be:

For buildings with a gross floor area up to and including 250 square meters	$250.00
For buildings greater than a gross floor area of 250 square meters	Minimum charge of $250.00, plus $0.10 per square meter for floor area in excess of 250 square meters.

(b) Where water is supplied from a fire hydrant or other non-metered source for other uses, the amount of water supplied will be invoiced in accordance with Section 2 – Water Utility Users Rates – Metered Water.

(c) Charge to service fire hydrant after use:

$95.00 and/or any service costs that may arise from servicing a hydrant in respect of its use.

4. UTILITY BILLING ADJUSTMENTS AND COLLECTION

a) Where a billing error is suspected by the consumer, notification in writing must be made to the City of Courtenay Finance Department within one year of the original billing date for review and consideration. Upon investigation, if it is determined by the City that an error occurred and the consumer has been overcharged, an adjustment will be made to the utility bill in question in an amount to be determined by the City. The City will not provide refunds or adjustments to billing errors made more than two years prior to the date of the notification being received by the City.

b) The rates and charges, enumerated in this Bylaw, are hereby imposed and levied for water supplied or ready to be supplied by the City and for the provision of the service and other water related services. All such rates and charges which are imposed for work done or services provided to lands or improvements shall form a charge on those lands which may be recovered from the Owner of the lands in the same manner and by the same means as unpaid taxes.

CITY OF COURTENAY

BYLAW REFERENCE FORM

BYLAW TITLE

"City of Courtenay Fees and Charges Amendment Bylaw No. 3055, 2021" (Water user fees)
"City of Courtenay Fees and Charges Amendment Bylaw No. 3056, 2021" (Sanitary Sewer user fees)
"City of Courtenay Fees and Charges Amendment Bylaw No. 3057, 2021" (Solid Waste Collection user fees)

REASON FOR BYLAW

To amend the water, sanitary sewer and solid waste collection user rates for 2022 in accordance with Council resolutions of December 3, 2021.

STATUTORY AUTHORITY FOR BYLAW

Section 194 of the *Community Charter* allows Council to charge a user fee to cover the cost of delivery of a service.

OTHER APPROVALS REQUIRED

STAFF COMMENTS AND/OR REPORTS

The "2022-2026 Water Fund Financial Plan" report was presented to Council on December 3, 2021 and Council approved OPTION 1 and endorsed the proposed increase of 2.0% to water user fees for 2022.

The "2022-2026 Sewer Fund Financial Plan" report was presented to Council on December 3, 2021 and Council approved OPTION 1 and endorsed the proposed increase of 7.5% to sewer user fees for 2022.

The "2022-2026 Solid Waste, Recyclable and Yard Waste Budgets" report was presented to Council on December 3, 2021 and Council approved OPTION 1 and endorsed the proposed increases of 5% for single residential and multi-residential curbside service and 15% for Institutional, Commercial and Industrial (ICI) and multi-residential apartment and condo non curbside service.

Staff prepared the appropriate bylaws incorporating the above rate increases and are presenting it to Council for three readings. The bylaws will be presented for final adoption on January 17, 2022.

OTHER PROCEDURES REQUIRED

December 6, 2021

A. Bérard
Staff Member

THE CORPORATION OF THE CITY OF COURTENAY

BYLAW NO. 3056, 2021

A bylaw to amend City of Courtenay Fees and Charges Bylaw No. 1673, 1992

The Council of the Corporation of the City of Courtenay in open meeting assembled enacts as follows:

1. This bylaw may be cited for all purposes as **"City of Courtenay Fees and Charges Amendment Bylaw No. 3056, 2021."**

2. That "City of Courtenay Fees and Charges Bylaw No. 1673, 1992" be amended as follows:

   (a) That Schedule of Fees and Charges, Section III, Appendix II "Sanitary Sewer System" be hereby repealed and substituted therefore by the following attached hereto and forming part of this bylaw:

   Schedule of Fees and Charges Section III, Appendix II – Sanitary Sewer System

3. This bylaw shall come into effect upon final adoption hereof.

Read a first time this day of , 2021

Read a second time this day of , 2021

Read a third time this day of , 2021

Finally passed and adopted this day of , 2022

Mayor	Deputy Corporate Officer

SCHEDULE OF FEES AND CHARGES
CITY OF COURTENAY FEES AND CHARGES AMENDMENT
BYLAW NO. 3056, 2021
SECTION III, APPENDIX II
SANITARY SEWER SYSTEM

1. CONNECTION FEES

(a) Connection Fees

Connection from either side of road to property line

10.16 centimetres (4" inch)	$3,000.00

Where a larger connection than the one listed above is required, the connection will be installed at City cost plus 25%.

(b) Abandonment Fee

Fee for disconnecting an abandoned service connection at the sanitary sewer main irrespective of the size of the connection	Actual City cost plus 25%, min charge $500.00

(c) Connection Charges for Annexed Areas

For owners where commitment letters were issued between 1997 and 2006 quoting a sewer connection bylaw fee of $1,500 (plus a capital contribution fee of $5,000), this bylaw fee amount shall be in effect until October 31, 2007, after which the following schedule of connection fees will apply.

Property Use	Connection Charge		
	Capital Contribution		Connection Fee
	Existing Building	New Development	
Single Family Home OR Duplex	$5,000.00	$5,000.00	Either side of road from main - $3,000.00
Multifamily, Strata OR Apartment OR Mobile Homes	$5,000.00	$5,000.00 for first unit, $2,500.00 per unit for the next five units, $2,000.00 per unit for the next five units, $1,500.00 per unit for the next five units and $1,000.00 per unit for all units thereafter	For a 100 mm diameter connection or the Bylaw rate for larger pipe sizes: Either side of road from main $3,000.00

Industrial OR Commercial OR Public Assembly	$5,000.00	$5,000.00 minimum or the greater amount calculated based on the design sewage flows from the development.	For a 100 mm diameter connection or the Bylaw rate for larger pipe sizes: Either side of road from main $3,000.00

Note: Under the heading of 'Capital Contribution' an 'Existing Building' is defined as a building that existed or a property that had a building permit application in place on or before April 14, 2004. 'New Development' is defined as a property on which a building permit application was made on or after April 15, 2004.

1. SANITARY SEWER USER RATES – APPLIED ON A PER-UNIT/SPACE BASIS

- The minimum user rate per year or portion thereof shall be as follows:

		Bylaw Rates (per annum) **Effective Date January 1, 2022**
Part 1 - Residential Users		
1	Single Family Dwelling	377.97
2	Multiple Family Dwelling -per unit	377.97
3	Mobile Home Park -per space	377.97
4	Kiwanis Village -per unit	377.97

		Bylaw Rates (per annum) Effective Date January 1, 2022
Part 2 - Commercial Users		
1	Hotels and Motels -per unit	152.20
2	Trailer Park and Campsite -per serviced site	78.53
3	Wholesale and Retail Stores	377.97
4	Car Wash	377.97
5	Bus Depot	377.97
6	Funeral Parlour	377.97
7	Garage	377.97
8	Machine Shop and Repair Shop	377.97
9	Bakery	377.97
10	Photographer	377.97
11	Business Office - per office	377.97
12	Professional Office -per office	377.97
13	Barber and Hairdresser	377.97
14	Pool Room and Recreation Facility	377.97
15	Theatre	755.93
16	Department Store	755.93
17	Supermarket	755.93
18	Bowling Alley	755.93
19	Bank	755.93
20	Nursing Home	755.93
21	Cafe and Restaurant (including drive-in or take-out)	755.93
22	Dry Cleaner	755.93
23	Beverage Room	755.93
24	Laundry and Coin Laundry	3,021.21
25	Sawmill	3,765.49
26	Dairy Product Processing Plant	28,041.64
27	Other Commercial Users not enumerated in this schedule	755.93
28	Cheese Processing Plant	6,265.48
Part 3 - Institutional Users		
1	Church	377.97
2	Public Hall	377.97
3	Utility Office	755.93
4	School -per classroom	677.43
5	Regional Recreation Complex	30,078.62
6	Regional District Administrative Office	8,081.29

2. UTILITY BILLING ADJUSTMENTS AND COLLECTION

a) Where a billing error is suspected by the consumer, notification in writing must be made to the City of Courtenay Finance Department within one year of the original billing date for review and consideration. Upon investigation, if it is determined by the City that an error occurred and the consumer has been overcharged, an adjustment will be made to the utility bill in question in an amount to be determined by the City. The City will not provide refunds or adjustments to billing errors made more than two years prior to the date of the notification being received by the City.

b) The rates and charges, enumerated in this Bylaw, are hereby imposed and levied for sewer utility services supplied or ready to be supplied by the City. All such rates and charges which are imposed for work done or services provided to lands or improvements shall form a charge on those lands which may be recovered from the Owner of the lands in the same manner and by the same means as unpaid taxes.

CITY OF COURTENAY

BYLAW REFERENCE FORM

BYLAW TITLE

"City of Courtenay Fees and Charges Amendment Bylaw No. 3055, 2021" (Water user fees)
"City of Courtenay Fees and Charges Amendment Bylaw No. 3056, 2021" (Sanitary Sewer user fees)
"City of Courtenay Fees and Charges Amendment Bylaw No. 3057, 2021" (Solid Waste Collection user fees)

REASON FOR BYLAW

To amend the water, sanitary sewer and solid waste collection user rates for 2022 in accordance with Council resolutions of December 3, 2021.

STATUTORY AUTHORITY FOR BYLAW

Section 194 of the *Community Charter* allows Council to charge a user fee to cover the cost of delivery of a service.

OTHER APPROVALS REQUIRED

STAFF COMMENTS AND/OR REPORTS

The "2022-2026 Water Fund Financial Plan" report was presented to Council on December 3, 2021 and Council approved OPTION 1 and endorsed the proposed increase of 2.0% to water user fees for 2022.

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Staff prepared the appropriate bylaws incorporating the above rate increases and are presenting it to Council for three readings. The bylaws will be presented for final adoption on January 17, 2022.

OTHER PROCEDURES REQUIRED

December 6, 2021

A. Bérard
Staff Member

THE CORPORATION OF THE CITY OF COURTENAY

BYLAW NO. 3057

A bylaw to amend City of Courtenay Fees and Charges Bylaw No. 1673, 1992

The Council of the Corporation of the City of Courtenay in open meeting assembled enacts as follows:

1. This bylaw may be cited for all purposes as **"City of Courtenay Fees and Charges Amendment Bylaw No. 3057, 2021."**

2. That "City of Courtenay Fees and Charges Bylaw No. 1673, 1992" be amended as follows:

   (a) That Schedule of Fees and Charges, Section III, Appendix IV "Garbage Collection Fees" be hereby repealed and substituted therefore by the following attached hereto and forming part of this bylaw:

   "Schedule of Fees and Charges Section III, Appendix IV – Solid Waste Collection Fees"

3. This bylaw shall come into effect upon final adoption hereof.

Read a first time this day of , 2021

Read a second time this day of , 2021

Read a third time this day of , 2021

Finally passed and adopted this day of , 2022

Mayor	Deputy Corporate Officer

1

SCHEDULE OF FEES AND CHARGES
CITY OF COURTENAY FEES AND CHARGES AMENDMENT BYLAW NO. 3057
SECTION III, APPENDIX IV
SOLID WASTE COLLECTION FEES

A.	Dwelling Basis Fee per unit per year -includes recyclables & yard waste pickup	$191.54
	Extra Bag Ticket (50 litre) - each	$3.00
B.	Residential Multifamily, Apartment, Strata per unit per year (Fee for yard waste, recyclables not included)	$168.27
	Additional service fee – yard waste pickup, per unit per year	$22.65

C. Trade Premises (where mixed waste containers are determined to include recyclable materials, the fee imposed shall be two times the regular pickup fee.)

Cans – mixed waste (contains no recyclable material)	**Per Pickup**
1 can or equivalent (1 can = 121 litres)	$3.33
Every additional can or equivalent 121 litres shall be charged at the rate of	$3.33
DCBIA – per unit/premise per year (includes two cans per week plus recyclables/cardboard pickup – this fee is charged to those units that are constrained by space and cannot implement a mixed waste bin or cardboard bin service)	$366.56

Containers - Mixed, Non-compacted (contains no recyclable material)

2 cubic yards	$21.84
3 cubic yards	$32.76
6 cubic yards	$65.52
12 cubic yards	$131.04
20 cubic yards	$218.40
Rate per cubic yard for sizes other than those listed above	$10.92

Compactors – Mixed Waste (contains no recyclable material)	**Per Pickup**
27 cubic yards	$590.32
28 cubic yards	$612.16
30 cubic yards	$655.84
35 cubic yards	$765.04
40 cubic yards	$874.24
For sizes other than those listed above: $590.32 (27 cubic yard base rate) + [(Y – 27) * $21.84 (cubic yard base rate)]	

Refuse to Recycling Centre (no tipping fees)	
DCBIA Recycle Toter Bin	$2.73 per bin
Containers	**Per Pickup**
2 cubic yards	$11.96
3 cubic yards	$17.94
6 cubic yards	$35.88
Sizes other than listed above charged at a rate per cubic yard of	$5.98

Compactors	**Per Pickup**
27 cubic yards	$196.83
30 cubic yards	$218.67
35 cubic yards	$255.14
40 cubic yard	$291.62
For sizes other than those listed above: $196.83 (27 cubic yard base rate) + [(Y – 27) * $11.96 (cubic yard base rate)]	

THE CORPORATION OF THE CITY OF COURTENAY

BYLAW NO. 3021

A bylaw to amend Zoning Bylaw No. 2500, 2007

The Council of the Corporation of the City of Courtenay in open meeting assembled enacts as follows:

1. This bylaw may be cited for all purposes as **"Zoning Amendment Bylaw No. 3021, 2021"**.

2. That "Zoning Bylaw No. 2500, 2007" be hereby amended as follows:

   (a) by rezoning Lot 11, District Lot 158, Comox District Plan VIP73886 (2099 Hawk Drive), as shown in bold outline on **Attachment A** which is attached hereto and forms part of this bylaw, from Residential One Zone (R-1) to Residential One S Zone (R-1S); and

   (b) That Schedule No. 8, Zoning Map be amended accordingly.

3. This bylaw shall come into effect upon final adoption hereof.

Read a first time this 18th day of October, 2021

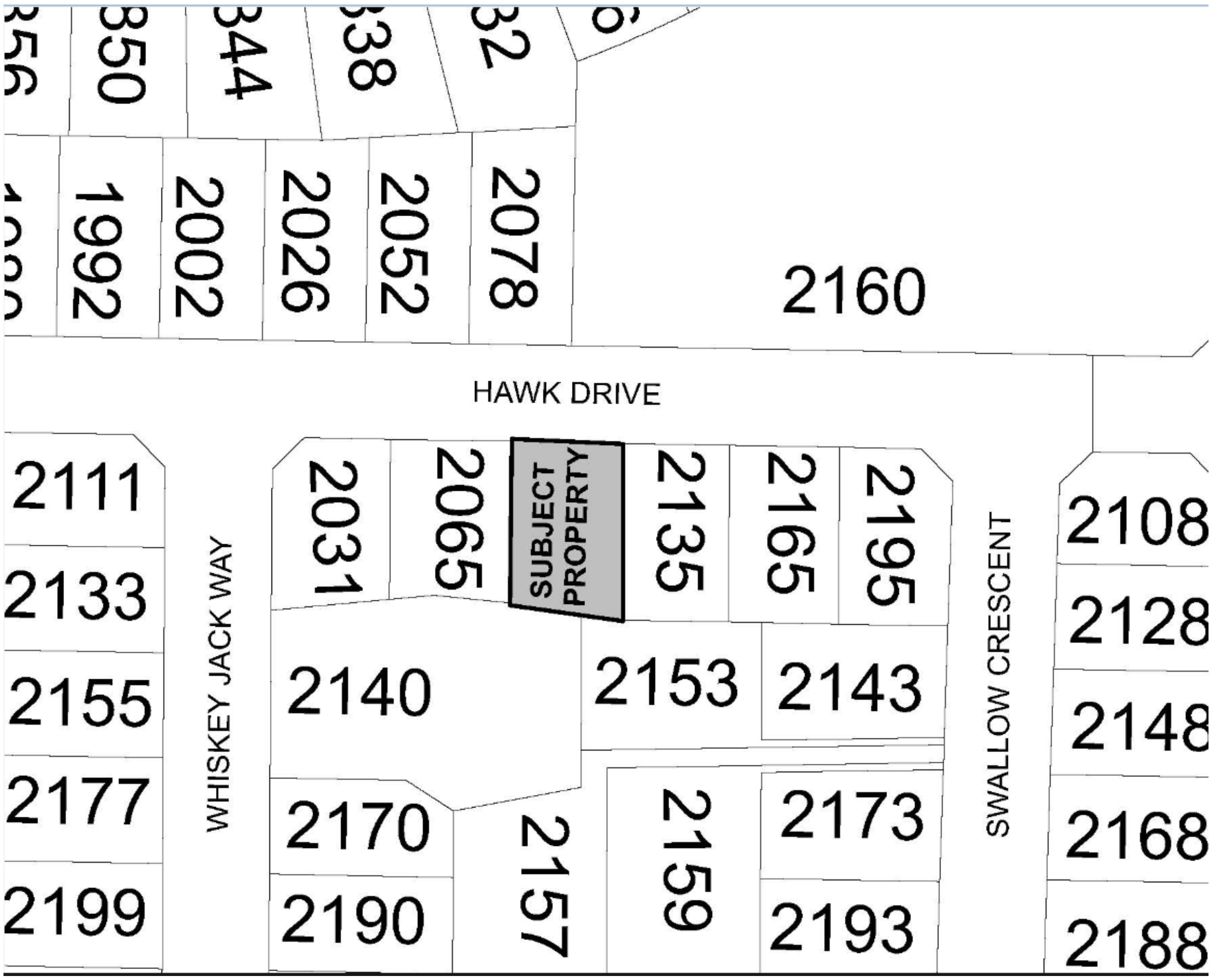
Read a second time this 18th day of October, 2021

Public Hearing notice waiver published in two editions of the Comox Valley Record on the 24th day of November, 2021 and the 1st day of December, 2021 (pursuant to Section 467 of the *Local Government Act*)

Read a third time this day of , 2021

Finally passed and adopted this day of , 2021

Mayor	Corporate Officer



THE CITY OF COURTENAY

ATTACHMENT "A"

Part of Bylaw No. 3021, 2021

Amendment to the

Zoning Bylaw No. 2500, 2007

THE CORPORATION OF THE CITY OF COURTENAY

BYLAW NO. 3043

A bylaw to amend Zoning Bylaw No. 2500, 2007

The Council of the Corporation of the City of Courtenay in open meeting assembled enacts as follows:

1. This bylaw may be cited for all purposes as **"Zoning Amendment Bylaw No. 3043, 2021"**.

2. That "Zoning Bylaw No. 2500, 2007" be hereby amended as follows:

   (a) Amending Section 8.6.1 (5) by adding "notwithstanding any provision of this bylaw, a secondary suite is a permitted use on Lot B, Section 17, Comox District, Plan EPP72243 (1544 Dingwall Road)" and renumbering accordingly.

3. This bylaw shall come into effect upon final adoption hereof.

Read a first time this 15th day of November, 2021

Read a second time this 15th day of November, 2021

Public Hearing notice waiver published in two editions of the Comox Valley Record on the 24th day of November, 2021 and the 1st day of December, 2021 (pursuant to Section 467 of the *Local Government Act*)

Read a third time this day of , 2021

Finally passed and adopted this day of , 2021

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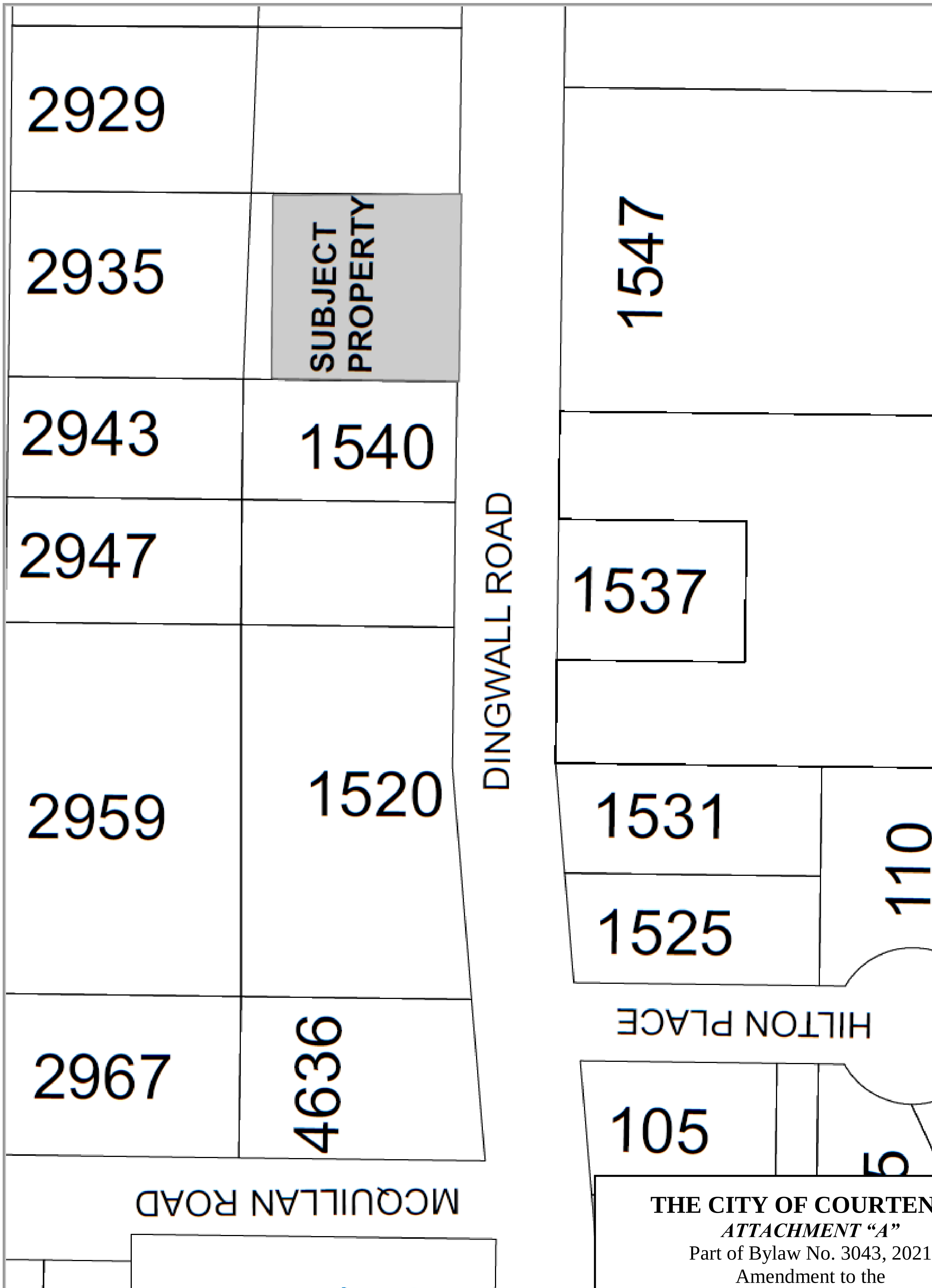
Mayor Corporate Officer

Approved under S.52(3)(a) of the Transportation Act

Ministry of Transportation and Infrastructure
Vancouver Island District



THE CITY OF COURTENAY
ATTACHMENT "A"
Part of Bylaw No. 3043, 2021
Amendment to the
Zoning Bylaw No. 2500, 2007