Attachment B

Puget Sound Ports Air Quality Health Impacts Study
WSU Scope of Work

Background:

In 2007, the Ports of Tacoma, Seattle, and Vancouver B.C. came together to create the Northwest Ports Clean Air Strategy (NWPCAS), a join initiative to reduce air pollutant and greenhouse gas (GHG) emissions from port operations[1]. In 2015, the Northwest Seaport Alliance (NWSA) was formed and was included as a member of the strategy. The ports developed the strategy in collaboration with government agencies, including the EPA and Washington State department of Ecology. The strategy sets overarching emission reduction targets for the ports in addition to activity-based targets for each emission sector encompassed in port operations. The NWPCAS is updated every five years to realign the targets with the latest science and technology, industry best practices, regional, national, and international policy, and port, community, and agency priorities. The ports are currently beginning the process of updating the NWPCAS for years 2020 and beyond. As part of this update process, the Northwest Seaport Alliance is looking to employ state-of-the-art scientific methods to better understand the health impacts of port-related emissions in the Puget Sound Airshed to inform targets, goals, and methods if the new NWPCAS.

Study Overview and Goals:

The Laboratory for Atmospheric Research (LAR) at Washington State University (WSU) operates the AIRPACT numerical air quality forecast system for the Pacific Northwest. This system uses state-of-the-art meteorological and chemical transport models to simulate ozone, PM2.5, numerous air toxics, and related precursors and products on a one-hour time step over a 4 km x 4 km gridded domain covering Idaho, Oregon, Washington and peripheral areas. The AIRPACT framework is ideally suited, particularly after suitable modifications, to quantify the exposure of the population to port related air emissions, within the Puget Sound Airshed.

To accomplish this, WSU proposes creating a PORTS modeling framework, based upon AIRPACT, with a high-resolution model domain (1.3 km x 1.3 km grid cells) centered on the Puget Sound Airshed. The PORTS modeling system will be used to simulate the concentrations of important air pollutants based on emissions from port-related sources. The 1.33-km domain (Figure 2) will be 'nested' within the AIRPACT 4-km domain; AIRPACT 4-km results will provide initial conditions and boundary conditions for the PORTS simulations. The overarching study design is to isolate emissions from operations related to Puget Sound Area Ports involved in the NWPCAS update and to use these port specific emissions in PORTS to assess pollutant concentrations within the Puget Sound Airshed both for annual average and maximum short-term concentrations. A subsequent modeling exercise will assess the population's exposure to these air pollutants, using the BenMap health impact tool [2]. These exposure effects will be evaluated for each source type individually, as well as in aggregate, with the goal of assessing the spatial

[1] EPA. Northwest Ports Clean Air Strategy. https://www.epa.gov/ports-initiative/northwest-ports-achievements-reducing-emissions-and-improving-performance
[2] EPA. BenMAP. https://www.epa.gov/benmap/benmap-downloads

distribution of pollutant concentrations as well as developing an airshed scale exposure metric for assessing the relative impacts of each source.

Summary of Tasks and Responsibilities:

1. Adapt emissions inventory to create PORTS inputs.

WSU, Washington State Department of Ecology (WSDOE), and NWSA will share in this task. Washington State Department of Ecology will update the AIRPACT emissions inventory to include vessel emissions estimates from the recently completed Puget Sound Maritime Emissions Inventory (PSEI)[3]. Other sources (locomotives, heavy-duty on-road vehicles, and cargo handling equipment) will be modeled by scaling the existing AIRPACT emissions inventory for the appropriate source types. NWSA will work with WSU to determine the scaling factors for port facilities. Once the emissions are finalized, WSU will create emission maps that NWSA can review and can use to inform the early NWPCAS update process.

2. Run AIRPACT and PORTS framework simulations to estimate concentrations.

Once the emissions inventory files have been created, WSU will run the AIRPACT and PORTS frameworks to estimate the regional concentrations of the pollutants of interest (DPM, $PM_{2.5}$, ozone, and other air toxics if applicable). AIRPACT runs will be needed to provide: 1) initial conditions for the start of each month of PORTS simulations, 2) daily boundary conditions for PORTS runs. In order to develop source attribution results, one base case PORTS simulation will be conducted with all port sources included; then additional individual attribution runs will be completed where emissions from the five source categories are zeroed out. Subtracting an attribution run from the matched base case run will yield a difference for each pollutant of interest, showing the portion of each pollutant attributable to that source. This approach, known as the 'brute force' technique, we believe will be more efficient in terms of computer resources than other approaches such as the Direct Decoupled Method which is designed for source-specific sensitivity analyses. Results will be provided graphically for each source category as well as for all port related sources combined, and data files will be generated that provide the required input for BenMAP. Model simulations will be completed for one month of each season and those four months used to estimate annual average concentrations for each pollutant as well as the domain maximum 1-hour concentrations. This approach is used in place of complete year-long simulations to reduce the computing resource requirements to a level where multiple runs can be completed for source attribution purposes.

3. Regional Exposure Analysis

PORTS results for pollutant concentrations associated with each source type will be correlated spatially with population to estimate exposure based on census block populations. WSU will develop an appropriate exposure metric and/or simply use the population

[3] Starcrest, 2018. Puget Sound Maritime Air Emissions Inventory. https://pugetsoundmaritimeairforum.org/2016-puget-sound-maritime-air-emissions-inventory/

multiplied by the average concentration in each census block. This exposure analysis will be performed for each source type and summed for the entire model domain, to determine the relative exposure levels of different pollutants for each source. WSU will also apply the BenMap model using the attribution results to assess different health outcomes associated with the simulated exposure rates.

Deliverables:

Completion Date: December 31, 2018

- Produce emission maps for each source and primary pollutant to be used in stakeholder discussions.

Completion Date: May 31, 2019

The deliverable from WSU to NWSA is a final report detailing the methods, results, and conclusions of the study as follows:

- Description of all modeling methods used.
- Map graphics showing gridded emissions for each pollutant and source category.
- Map graphics that show the resulting annual average and maximum air pollutant concentrations for each air pollutant and source category.
- Metrics that quantify the Puget Sound Population's exposure to each air pollutant and the corresponding health risk (i.e. concentration x population exposed, acute and chronic health risk metrics).
- Analysis of results identifying which sources pose the largest risk to public health.
- Analysis of results characterizing the composition of secondary pollutants and which sources are most significant.
- Characterization of port related emissions in context of other emissions.

WSU will also provide the model output results in the file format for BenMAP.

Overview of Proposed Methodology:

The PORTS framework will be employed to assess the impacts of port-related air pollution on the Puget Sound Airshed. The following is a high-level summary of the methodology to be followed.

<u>Sources to be Modeled:</u>

The Puget Sound area ports have 5 major sources of air pollutant emissions to be modeled. Emissions from the following sources will be included in the study.

- Ocean going vessels (OGVs) – the ocean-going vessel category consists of large vessels that carry cargo through the open ocean. This includes auto carriers, bulk carriers, containerships, general cargo vessels, passenger cruise vessels, refrigerated vessels (reefers), and roll-on/roll-off (Ro-Ro) vessels.

- Harbor craft – for the ports, the harbor craft category includes assist tugboats used for helping OGVs maneuver in the harbor during arrival and departure.

- Cargo handling equipment (CHE) – cargo handling equipment is non-road equipment used to move cargo (containers, general cargo, and bulk cargo). Examples of cargo handling equipment include: forklifts, yard trucks, rubber tired gantry cranes, and straddle carriers.

- Locomotives – the locomotive category includes switching locomotives, used to sort rail cars on marine terminals and related intermodal yards, and line-haul locomotives, used for transporting cargo trains to their destination on the rail network.

- Heavy duty on-road vehicles – the heavy-duty category includes heavy duty (semi) trucks used to transport port related cargo. Busses used for transporting passengers for cruise terminals at Port of Seattle are also included, but represent a very small fraction of emissions.

Pollutants to be Modeled:

The pollutants likely to contribute the greatest health effects from port related emissions are diesel particulate matter (DPM) and fine particulate matter ($PM_{2.5}$). DPM may be treated, in CMAQ, either as a tracer or else as a non-reactive species subject to precipitation scavenging and deposition. In addition, port emissions of nitrogen oxides (NO_x) and volatile organic compounds likely contribute to tropospheric ozone and emissions of NO_x, VOCs, and SO_2 likely contribute to secondary aerosol formation. The model will include emissions of NO_x, CO, SO_2, VOCs, PM_{10}, DPM, and $PM_{2.5}$ from the sources listed above. The project will assess the concentrations of the following pollutants as summarized below for each source type.

- Diesel particulate matter (primary): DPM is known to have significant chronic health risks[4] and has been shown to be the most significant driver of inverse health effects from air toxics in the Puget Sound region[5]. As such, DPM emissions has been the indicator tracked by the port to assess its impact on regional air quality, since the majority of port emissions result from combustion of diesel fuel. DPM will likely account for the majority of the health risk associated with port-related pollution.

- Fine particulate matter (primary and secondary): As a Criteria Air Pollutant, $PM_{2.5}$ also negatively impacts human health. For port-related sources, primary $PM_{2.5}$ is roughly equivalent to DPM, though there are some processes (for example ship boiler

[4] CARB. Overview: Diesel Exhaust and Health. https://ww2.arb.ca.gov/resources/overview-diesel-exhaust-and-health

[5] Puget Sound Clean Air Agency. Tacoma and Seattle Area Air Toxics Evaluation. https://www.pscleanair.org/DocumentCenter/View/145/2010-Tacoma-and-Seattle-Area-Air-Toxics-Evaluation---Full-Report-PDF?bidId=

emissions) that are not counted as DPM and some fraction of DPM particles are larger than the 2.5 micrometers in diameter required to be classified as $PM_{2.5}$. Inclusion of the $PM_{2.5}$ category is mostly to assess secondary particulate matter that results from port-related emissions. Specifically, emissions of nitrogen (NO_x), sulfur (SO_x) and organic (VOCs) compounds are often transformed into particulate matter through atmospheric chemistry. Emissions from shipping have been shown to significantly contribute to secondary aerosol concentrations over land[6]. This analysis will provide a comprehensive assessment of the port's contribution to regional particulate matter.

- Oxides of sulfur (SO_x): Sulphur emissions have traditionally been a point of emphasis for the maritime industry, as shippers tend to use fuels that have higher sulfur content than on-road fuels. This impact was reduced significantly with the introduction of the North American Emissions Control Area (ECA) in 2015, but still may be substantial.

- Benzene/other air toxics: Benzene is an air toxic, has been shown to pose a significant health risk in the Puget Sound Region[5], and is known to be emitted from the combustion of fossil fuels. In addition, other air toxics such as, PAHs, formaldehyde, toluene, and acetaldehyde are known to be emitted during fossil fuel combustion. While these pollutants do pose relevant health risks, analyzing their concentrations may be difficult due to the limited scope of the emissions inventory. VOC emissions were reported in aggregated, meaning that emissions inventory estimates of volatile air toxics would be provided using estimated emission distributions to attribute the bulk VOC emissions. NWSA will make recommendations on whether benzene and other air toxics should be modeled based on the magnitude of their emissions, uncertainty of emission estimates, and computational resources required.

- Ozone: As a major source of NO_x and VOCs, port related emissions may have a significant effect on ground level ozone. The impact on regional maximum ozone concentration will be assessed and graphics and data files will be generated as appropriate.

Modeling Methods for Estimating Concentrations:

WSU will use a modeling framework called PORTS, derived from WSU's AIRPACT framework but operating on a high-resolution domain centered around the Puget Sound Airshed (Figure 1 and Figure 2). PORTS, using CMAQ v5.2, will be used to assess concentrations of DPM, $PM_{2.5}$, other air toxics, and maximum domain ozone concentration that result from the emissions of major port-related sources. Concentrations will be simulated for the Puget Sound Region on a 1.33-km domain. Spatial surrogates for the 1.33-km grid have already been developed by the Washington State Department of Ecology (WSDOE). Source apportionment using a brute force approach, as described above, will be used to determine the concentrations attributable to port-related sources. We will also investigate the feasibility of using the CMAQ Direct Decoupled Method to determine the sensitivity of model results to specific port source

[6] Aksoyoglu et al., 2016. Contribution of ship emissions to the concentrations and deposition of air pollutants in Europe. Atmospheric Chemistry and Physics 16, 1895 – 1906.

types. However, our initial assessment is that DDM requires excessive computer time and it will be more efficient to use the 'brute force' approach.

Emissions Inventory:

Puget Sound area ports, along with other industry and agency partners, recently completed an emissions inventory for model year 2016 (PSEI)[4]. This inventory surveyed emissions for all maritime-related mobile sources in the Puget Sound area (Table 1). The PSEI emissions data will be used where practicable to develop the emissions inventory file to be used in PORTS. The preferred approach for each emission source is described below.

- Ocean-going vessels: OGV emissions have traditionally been adapted from the PSEI inventory effort to the AIRPACT grid by the WSDOE. The current inventory includes results from the 2011 PSEI. WSDOE staff is currently in the process of updating the AIRPACT inventory to include new emission estimates from the 2016 PSEI. Emissions from grid cells outside the shipping corridor from the strait of Juan de Fuca to the Ports of Tacoma and Seattle (i.e. south of Commencement Bay and north of the strait) may need to be excluded to isolate the ports' influence.

- Harbor vessels: similar to OGVs, the WSDOE is in the process of updating the inventory for assist tugboats. For this analysis, the emissions from assist tugboats should be scaled to include just the responsibilities of the NWSA, Port of Tacoma, and Port of Seattle.

- Cargo Handling Equipment: CHE emissions estimates are provided for each terminal by the PSEI. These will be modeled either by scaling existing non-road emissions estimates in AIRPACT based on the PSEI's emissions estimates, or adding point sources in the port areas for CHE.

- Locomotives: Locomotive emissions estimates will be created for this study by scaling the existing emissions estimates in the AIRPACT system. Two separate scaling factors will be applied. In port areas, where port-related railyards account for most of the traffic, a scaling factor will be developed for the ports' responsibility based on expert knowledge (likely near 100%). For rail network emissions (everywhere else), the ratio of port-related emissions in the PSEI to NEI regional emissions, for those counties included in the PSEI, for line-haul locomotives, will be used to scale emissions.

- Heavy-duty on-road trucks: Truck emissions estimates will be created for this study by scaling the existing emissions estimates in the AIRPACT system. Two separate scaling factors will be applied. In port areas, where port-related trucks account for a larger fraction of total heavy-duty vehicle emissions, a first scaling factor will be developed based on expert knowledge. For network emissions (everywhere else), the ratio of port-related emissions in the PSEI to NEI regional emissions, for those counties included in the PSEI, for heavy-duty diesel trucks, will be used to scale emissions.

Table 1. Total Port-Related Emissions within the Puget Sound Airshed for Port of Tacoma, Port of Seattle, and NWSA, in tons per year.

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM
OGVs	8,635	253	714	257	136	127	129
Harbor	502	16	83	0	16	15	16
Locomotives	1,018	58	195	1	29	27	29
CHE	280	26	154	0	14	13	13
Heavy-duty Trucks	973	51	244	2	47	43	47
Total	11,407	403	1,390	260	242	225	234

Temporal Scale for Model Runs:

Because the pollutants to be analyzed are associated with both chronic and acute health effects, both annual average and maximum contributions will be reported for each source. Annual averages will be estimated by modeling a representative month from each season and extrapolating to the full year.

Model Spatial Scale:

The Puget Sound Airshed as defined in the PSEI is shown in the map below (Figure 1). The light green shaded area below the black dashed line, above the red line indicates the geographical extent of the emissions estimates for the airshed. Though the majority of the population lives to the east of Puget Sound, it is important to model emissions from the Strait of Juan de Fuca, since OGVs are the largest source of air pollutants in the PSEI. A major goal of this study is to understand the importance of these emissions when compared with terrestrial sources. Therefore, emissions will be considered over the entire airshed. Concentrations, at a minimum, should be assessed for the major population centers and along the shipping corridor. The blue outline denotes approximately the areas to be covered by a high-resolution modeling domain to be used for this work. Figure 2 shows WSU's suggested 1.33-km PORTS project domain, which is designed in response to Figure 1, for this work.

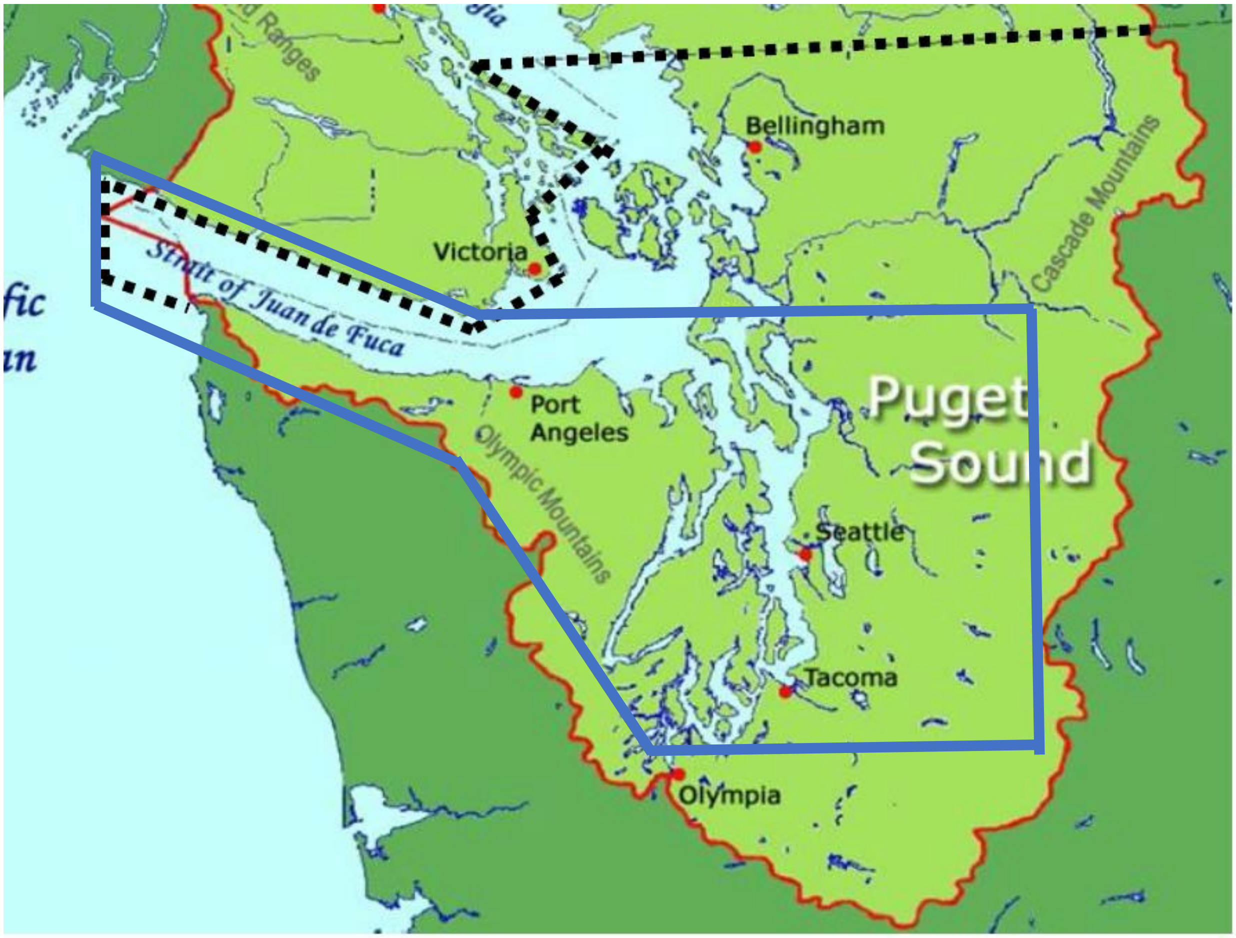

Figure 1. Puget Sound Airshed Boundary

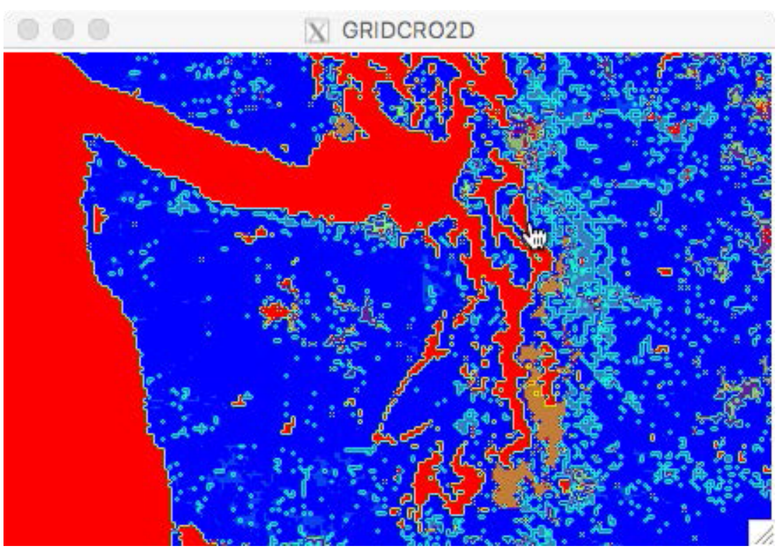

Figure 2. PORTS framework 1.33-km domain for port source modeling.

Research Products:

Within the analysis period, the magnitude and location of the maximum concentration of each pollutant (DPM, $PM_{2.5}$, ozone, and other air toxics if applicable) will be reported and its attribution to each source type. Annual average concentrations associated with each source type will be estimated for each grid cell as well as annual average concentrations for all sources together. Contour maps will be created to illustrate the concentration distribution. Gridded concentration data will be made available in a format appropriate for use in models that assesses community health effects (i.e. BenMAP; WSU has used BenMap in previous research and is familiar with the input requirements).

Health Effects/Exposure Assessment

To assess the impact on public health, annual concentration estimates from AIRPACT for each source type will be combined with population data to determine the exposure of the population. At a minimum, an exposure metric (concentration x population exposed) will be calculated for each census block for each pollutant (DPM, $PM_{2.5}$, and other air toxics if applicable) and the total exposure for the region will be summed. This will allow sources to be compared based on the exposure risk they pose. WSU will apply the BenMap tool to estimate health outcomes associated with the simulated pollutant exposure levels by source category. Contour maps will be created to visually portray the spatial distribution of public health risk for each source.

Project Management and Personnel

Dr. Yunha Lee, Assistant Professor, will serve as the Principal Investigator for the project. Dr. Lee recently joined WSU, initially as a Research Assistant Professor, in 2015 and moved into her current position in 2017. At WSU, she has become a key investigator for AIRPACT modeling work. Dr. Joseph Vaughan, Associate Research Professor, will serve as a co-PI and assist with AIRPACT setup and simulations for the project. Dr. Vaughan has the primary responsibility for daily operation of AIRPACT and has considerable experience in regional air quality modeling for the Pacific Northwest. Dr. Brian Lamb, Regents Professor, will also assist with the overall design and analysis aspects of the project. Dr. Lamb led the development of AIRPACT and has more than three decades of experience with air quality measurements and modeling. Ms. Mashid Etesamifard, PhD graduate student, will play a key role in running the simulations and analyzing the results. Ms. Etesamifard has experience in emissions modeling, is very familiar with AIRPACT operations, and with CMAQ model options, and has recently completed a DDM analysis of ozone source sensitivity for the Kennewick region in Washington state. Mr. Jordan Munson, MS student, will assist with the BenMap applications. Mr. Munson is conducted an evaluation of AIRPACT and is also working on BenMap analyses of long-term AIRPACT simulations.