Washington State Regional Haze State Implementation Plan

Appendix C

Additional Information for Interagency Monitoring of Protected Visual Environment Sites that Monitor Visibility for Washington's Mandatory Class I Areas

This appendix contains additional information for the 6 IMPROVE sites that measure visibility impairment for the 8 mandatory Class I Areas in Washington. The supplemental information includes nearby populations, industrial centers, and wind patterns.

Olympic IMPROVE Site: OLYM1

Nearby Population/Industrial Centers and Local Sources

Because of the size of the National Park, different areas may be affected by different sources. For the northeastern National Park area, where the OLYM1 monitoring site is located, nearby industrial and urban emission sources that most immediately affect the area are in Port Angeles, 35 km (20 mi) west, emissions from which may include residential woodstove emissions. Other portions of the eastern National Park area are across Puget Sound from the Seattle metropolitan area 50 km (30 mi) to the east and downwind for prevailing west wind conditions. For the western Park area including the Coastal section, there are no additional large source areas, although there may be timber and shipping related industries.

Wind Patterns

Prevailing winds at well-exposed locations near the northwestern U.S. coast are generally from the north or northwest throughout the year and especially in the summer months, a consequence of the semi-permanent high pressure that lies off the Pacific Coast. Southerly and easterly winds can occur during the winter, when the Pacific High moves southward and weakens. This pattern is indicated in monthly Quillayute Washington wind roses for summer months, which show the prevalence of westerly coastal winds. Winter Quillayute Washington wind roses may be more influenced by local diurnal flows as air drains to the west off the slopes of the Olympic range in the absence of strong opposing western synoptic flow.

The Olympic Mountains present an unusual near-circular obstruction to westerly winds, which consequently tend to divide at low levels and flow to the north and south, converging on the lee side, where the OLYM1 IMPROVE site is located. At times, channeling and compression of westerly winds the Strait of Juan de Fuca can result in high speed “Strait Winds”. Rising motions above the low-level convergence zone produce clouds and precipitation that may affect eastern portions of Olympic National Park to some extent. Near the IMPROVE site, resulting westerly flow is from the direction of Port Angeles 35 km (20 mi) west of the site. In the western National Park area and the Coastal area there will be a more direct effect from the ocean including periodic sea and land breezes. These areas are also sheltered and generally upwind from anthropogenic sources around Puget Sound that have more direct impact on eastern Park areas.

Potential local transport routes towards the OLYM1 site include transport or anthropogenic components from the west, the direction of Port Angeles. Transport from the heavily populated Seattle area on the east side of Puget Sound may occur during infrequent easterly wind conditions.

Inversions/Trapping

Temperature inversions are relatively common in the greater Puget Sound area that includes northeastern National Park locations represented by OLYM1. In wintertime, the common situation is a surface based radiation inversion that can persist until ventilated by an incursion of marine air from the Pacific. In the extended summer months, May to October, the common inversion condition over the eastern Pacific is a subsidence inversion caused by the persistent sub-tropical high-pressure system. Typical inversion heights are 300 to 600 m (1,000 to 2,000 ft), and the OLYM1 monitoring site may be near this height much of the time. In western National Park areas the summertime subsidence inversion, aided by a diurnal sea/land breeze is likely, more so than the wintertime surface inversion.

North Cascades IMPROVE Site: NOCA1

Nearby Population/Industrial Centers

The northern Puget Sound area near the mouth of the Skagit River is ~ 100 km (60 mi) west of the NOCA1. The city of Seattle is 160 km (100 mi) southwest.

Wind Patterns

Synoptic winds in the region are generally westerly, with more northwesterly flow during the summer when the Pacific High is off the coast of northwestern U.S., and more westerly flow during the winter when the Pacific High has retreated southward. This pattern can be seen in monthly Seattle Washington wind roses although these surface wind patterns may differ somewhat from upper level winds because of terrain effects. During the winter, with high pressure over the Great Basin and Idaho and low pressure west of the Cascades easterly gradient (synoptic) flow is common.

The NOCA1 IMPROVE site is within the upper Skagit River channeled flow regime, with westerly channeled upvalley flow enhanced at times by prevailing westerly synoptic flow.

Inversions/Trapping

Locally, the NOCA1 site is in a lower valley location and may at times be within valley trapping inversions that do not extend to higher National Park elevations. On a larger scale, inversion breakup and vertical mixing during periods of weak synoptic forcing could at times bring urban emissions from Seattle and northern Puget Sound 100 to 160 km to the west into the area. Mixing heights calculated for Salem Oregon (Ferguson and Rorig, 2003), a maritime location similar to the Seattle and Puget sound region, show winter heights generally below 300 m (1,000 ft), which would prevent urban emissions from reaching the NOCA1 site elevation, but Spring and summer Salem mixing heights frequently reach to 1,500 m or higher which could allow Puget Sound urban emissions to mix to the NOCA1 elevation. Resulting transport to NOCA1 could result from concurrent afternoon up valley flow or from entrainment of emissions near the mixing height into higher level air flow, and subsequent transport to the monitoring site.

Calculated Fall Salem mixing heights were typically 300 to 600 m, lower than in the spring and summer but occasionally high enough to bring valley emissions to the NOCA1 site elevation.

Regionally, summertime subsidence inversions associated with the establishment of the semi-permanent Pacific high-pressure system could result in regional aerosol buildup over periods of days. Subsidence inversion heights are typically at elevations of 2,000 to 3,000 m (6,000 to 10,000 ft), well above the NOCA1 IMPROVE site. With weak northwesterly winds, Puget Sound emissions can become trapped against the Cascades and/or pushed up the Skagit River valley towards the NOCA1 IMPROVE site. Highest regional aerosol concentrations may occur during summertime stagnation and subsidence inversion periods in conjunction with western wildland fires.

Snoqualmie Pass IMPROVE Site: SNPA1

Nearby Population/Industrial Centers

The Seattle metropolitan area and Puget Sound source region is about 50 km (30 mi) west of SNPA1 at its closest point, and 1,000 to 1,100 m (3,200 to 3,600 ft) lower in elevation. The city of Seattle is 70 km (40 to 45 mi) west northwest of the monitoring site. East of the Cascades, the cities of Wenatchee and Yakima are near 150 km (90 to 100 mi) to the east and southeast respectively.

Wind Patterns

Synoptic winds in the region are generally westerly, with more northwesterly flow during the summer when the Pacific High is off the coast of northwestern U.S., and more westerly flow during the winter when the Pacific High has retreated southward. This pattern can be seen in monthly Seattle Washington wind roses although these surface wind patterns may differ somewhat from upper level winds because of terrain effects. During the winter, with high pressure over the Great Basin and Idaho and low pressure west of the Cascades easterly gradient (synoptic) flow is common. The SNPA1 IMPROVE site is located near the crest of the Cascades and may be exposed to airflow over the Cascades and to aerosols transported from upwind sources by upper level winds. Although it is above valley elevations to the west, SNPA1 may at times see diurnal up valley transport from the Seattle area via the South Fork of the Snoqualmie River. If it occurs, such flow transport would show a diurnal pattern of aerosol characteristics.

Inversions/Trapping

Locally, the SNPA1 site is at a ridge crest location and probably above trapping inversions that may develop at valley bottom locations east and west of the Cascade crest. On a larger scale, inversion breakup and vertical mixing during periods of weak synoptic forcing could at times bring urban emissions from the Seattle and Puget Sound source region 50 to 75 km (30 to 50 mi) west of Wilderness boundaries to western Wilderness and SNPA1 elevations. Mixing heights calculated for a similar maritime location at Salem, Oregon (Ferguson and Rorig, 2003) show winter heights generally below 300 m (1,000 ft), which would prevent urban emissions from reaching the SNPA1 site elevation, but Spring and summer Salem mixing heights frequently

reach to 1,500 m or higher which could allow urban emissions to arrive at SNPA1. This could result from concurrent afternoon up valley flow or from entrainment and transport by higher level flow. Fall mixing heights are typically 300 to 600 m, lower than in the spring and summer but occasionally high enough to bring valley emissions to the SNPA1 site elevation.

Regionally, summertime subsidence inversions associated with the establishment of the semi-permanent Pacific high-pressure system could result in regional aerosol buildup over periods of days. Subsidence inversion heights are typically at elevations of 2,000 to 3,000 m (6,000 to 10,000 ft), well above the SNPA1 IMPROVE site. With weak northwesterly winds, Puget Sound emissions can become trapped against the Cascades and possibly impact lower crest elevations such SNPA1. Highest aerosol concentrations may result during summertime stagnation and subsidence inversion periods in conjunction with western wildland fires.

Mount Rainier IMPROVE Site: MORA1

Nearby Population/Industrial Centers

The small community of Ashford (pop ~300) is located about 6 km (3.7 mi) east of the site. The nearest major population center is Tacoma, some 50 to 60 km (~ 35 mi) due northwest. Washington State Highway 706, a main entrance to the National Park from the west, goes through the valley within 1 km of the monitoring site.

Wind Patterns

Generally, wind directions at the site are channeled to an east/west direction. In absence of synoptic forcing, the site is characterized by mountain/valley circulations, with easterly (from the east) nighttime drainage flow and westerly daytime upslope flow in the valley. The west to east orientation of the valley may serve to enhance synoptic westerly wind flow. Historical data show predominantly east and northeast directional flow during October – December and westerly flow during January – February.

Inversions/Trapping

This valley may be subject to inversion and trapping of pollutants during periods of high pressure and stagnation. In those cases, the monitoring site, located at the bottom of the valley, would be contained within the trapped stable layer.

White Pass IMPROVE Site: WHPA1

Nearby Population/Industrial Centers and Local Sources

The significant population centers and source regions nearest to the Goat Rocks Wilderness and the WHPA1 IMPROVE site are Seattle and the Puget Sound area 100 km (60 mi) to the northwest and Portland Oregon 120 km (75 mi) to the southwest. The Centralia power plant, which has implemented emission controls in recent years, is located near Centralia Washington 100 km due west near the Cowlitz River that has origins in the Goat Rocks Wilderness.

Wind Patterns

Synoptic winds in the region are generally westerly. During the winter, with high pressure over the Great Basin and Idaho and low pressure west of the Cascades easterly gradient (synoptic) flow is common. The WHPA1 IMPROVE site is located near the crest of the Cascades and should be well exposed to these upper airflows and to aerosols transported aloft from upwind sources. Lower Goat Rocks Wilderness elevations may see more typical mountain/valley circulation patterns, especially during periods of weak synoptic forcing, which bring valley air to higher elevations during the day. At WHPA1, aerosols transported with this mountain valley circulation would likely show a diurnal pattern.

Inversions/Trapping

Because of WHPA1's high elevation relative to surrounding terrain it should be generally above surface based valley inversions in Wilderness Area headwaters basins. Summertime subsidence inversions associated with the establishment of the semi-permanent Pacific high-pressure system can result in regional aerosol buildup over periods of days. Subsidence inversion heights are typically at elevations of 2,000 to 3,000 m (6,000 to 10,000 ft), near the WHPA1 site elevation.

Pasayten IMPROVE Site: PASA1

Nearby Population/Industrial Centers

Seattle and Puget Sound source regions are ~ 200 km (120 mi) west of the PASA1 site, on the other (west) side of the Cascade crest. Aerosols may be transported to the monitoring site from the Puget Sound region by upper level (850 mb) westerly winds. Columbia Plateau sources and the Spokane Washington area are close to the PASA1 site. Columbia Plateau sources including agricultural and crustal (dust) components may impact the site during regional summertime stagnation periods when lofted to upper levels on hot afternoons.

Wind Patterns

Synoptic winds in the region are generally westerly, with more northwesterly flow during the summer when the Pacific High is off the coast of northwestern U.S., and more westerly flow during the winter when the Pacific High has retreated southward. Monthly Spokane Washington wind roses indicate this pattern, although wintertime wind directions are more northeasterly, bringing continental air southward with high pressure over the Canadian interior. Note that these surface wind patterns may differ somewhat from upper level winds because of terrain effects. During the winter, with high pressure over the Great Basin and Idaho and low pressure west of the Cascades easterly gradient (synoptic) flow is common. Upper westerly flow may bring Puget Sound area emissions to the monitoring site. With weaker summertime regional pressure gradients, a diurnal pattern may allow Columbia River Basin and Plateau emissions to be lofted to upper levels, including the PASA1 site, during the day and return with down slope flow at night (Ferguson, 1998)

Inversions/Trapping

The PASA1 site is at a ridge top location and should be above local surface based trapping inversions. On a larger scale, persistent low level temperature inversions over the Columbia Basin keep pollutants trapped at low elevations during most of the winter. Mixing heights calculated for Spokane Washington (Ferguson and Rorig, 2003), show winter heights generally below 300 m (1,000 ft), which would prevent urban emissions from reaching the PASA1 site elevation, but spring and summer Spokane mixing heights frequently reach to 1,500 m (4,920 ft), allowing Columbia Basin emissions to reach the PASA1 site elevation of 1,634 m (5,360 ft). Calculated Fall Spokane mixing heights were typically near 900 m, lower than in the spring and summer but occasionally high enough to bring valley emissions to the PASA1 site elevation.

Regionally, summertime subsidence inversions associated with the establishment of the semi-permanent Pacific high-pressure system could result in regional aerosol buildup over periods of days. Subsidence inversion heights are typically at elevations of 2,000 to 3,000 m (6,000 to 10,000 ft), near or above the PASA1 site elevation. Highest regional aerosol concentrations may occur during summertime stagnation and subsidence inversion periods in conjunction with western wildland fires.