COLUMBIA RIVER GORGE VISIBILITY AND AIR QUALITY STUDY

"Strawman" Study Plan

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1. INTRODUCTION

This "strawman" workplan for a Columbia River Gorge air quality and visibility study was prepared to assist in the development of an overall work plan for the Columbia River Gorge Air Quality Project. This project includes a series of steps from scientific investigation through development of a comprehensive regional air quality strategy to implementation of the regional strategy. This strawman workplan focuses on the scientific investigation component of the overall work plan.

NOTE: This strawman plan is not complete. A budget has not yet been developed. Also, a section of meteorology for the study area has not yet been written. The section on data analysis and modeling also needs additional work.

The overall work plan is being developed under the auspices of the Columbia River Gorge Commission. The commission was established pursuant to the federal legislation Columbia River Gorge National Scenic Area Act (1986). The National Scenic Area Act has two purposes:
1. To protect and provide for the enhancement of the scenic, cultural, recreational and natural resources of the Gorge; and
2. To protect and support the economy of the Gorge by encouraging growth to occur in existing urban areas and by allowing future economic development outside these areas if it is compatible with the first purpose.

The Columbia River Gorge Commission was created by an inter-state compact. Twelve voting members are appointed by the governors of Oregon and Washington and the six counties within the Columbia River Gorge National Scenic Area. One non-voting Forest Service member represents the U.S. Secretary of Agriculture. The Gorge Commission has several responsibilities under the National Scenic Area Act, including planning for the Scenic Area, implementing the Columbia River Gorge Scenic Area Management Plan and monitoring and hearing appeals of land-use decisions.

In May 2000 the Commission adopted an amendment to the Gorge Management Plan that calls for the protection and enhancement of Gorge air quality. The amendment directed the states of Oregon and Washington, working with the U.S. Forest Service and the Southwest Clean Air Agency and in consultation with affected stakeholders to develop a work plan. The purpose of the work plan, among other things, is to establish timelines for the gathering and analysis of necessary Gorge air quality data and, ultimately, for the development and implementation of an air quality protection strategy.

1.1 Goals and Objectives

This study plan will be incorporated into the above work plan and is intended to describe a study that would lead to a general understanding of the sources of aerosols and visibility, and other air quality components such as effects on cultural resources, agricultural health, ecosystem disturbance, and ozone effects on vegetation and humans. in the Scenic Area. It includes identification of model development and evaluation needed for assessment of future emission scenarios to be developed under the overall work plan. It also acknowledges that long-term monitoring needs to be done to evaluate trends and effects of emissions scenarios to be implemented under the overall work plan.

The goals of the study are to characterize current visibility and meteorological conditions in the Scenic Area, identify sources affecting air quality and visibility in the Scenic Area, and to develop and apply models to assess changes in air quality and visibility within the Scenic Area due to changes in emissions. In order to determine the important physical processes that must be captured by models, a substantial monitoring component for the study is proposed. The monitoring component of the study will:

- lead to the understanding of the physical processes at work, i.e. the development of conceptual models, a major objective of the study
- help identify sources, source categories and source regions that affect air quality and visibility in the Scenic Area
- provide direct input to mathematical models by data, including
  1) wind data from radar wind profilers and radiosondes
  2) boundary conditions for aerosols and gases
- provide data for model evaluation.

In a simple situation such as flat terrain, an isolated point source, and clear skies, model application and monitoring programs would be relatively straightforward. However, in the Scenic Area, there is highly complex terrain, substantial moisture, including fog and low clouds. There are also significant uncertainties in emissions inventories. Thus, a robust monitoring program is proposed that will help determine what the important processes are that the models must simulate, provide information for model input and evaluation, and to help in the evaluation and further development of the emissions estimates for sources of important chemical compounds. For example, if in-gorge sources are most important, detailed modeling within the gorge would be critical, with outside sources handled with boundary conditions (provided by measurements). If cloud-water chemistry processes are very important, then models that have sophisticated cloud-chemistry mechanisms would be needed.

Some modeling will be helpful in developing the conceptual models, such as confirmation of general flow directions that can be used to evaluate the reasonableness of receptor models, for example. **Modeling tools meeting a major goal of the study, i.e. assessment changes of future air quality with various emissions scenarios, will be finalized after the conceptual models have been developed.**

Figure 1-1 is a coarse map showing the general location and boundaries of the Scenic Area. A more detailed map appears in section 2 (Figure 2-1). The Scenic Area map only hints at the complexity of the terrain in the area. The Columbia River cuts a channel up to about 1200 meters deep through the Cascade Mountains. Side canyons with rivers flowing into the Columbia River further complicate the terrain. Limited information about how the terrain affects the airflow through the gorge will be presented in section 2.

Figure 1-1. Location map of Columbia River Gorge National Scenic Area

1.2 Guide to study plan

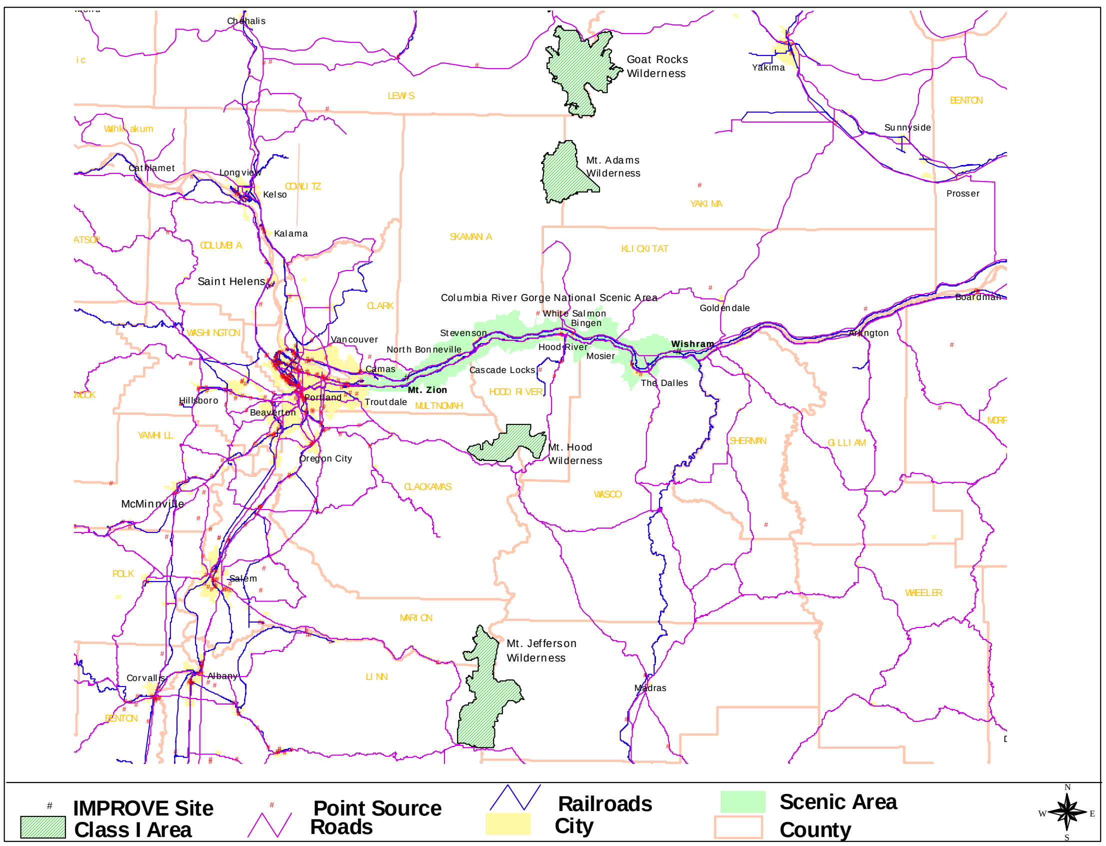
Section 2 summarizes existing knowledge of emissions, meteorology, and aerosol, and visibility for the area. Section 3 presents a series of hypotheses based on review of existing data, and the additional information needed to help confirm or refute these hypotheses. Alternately, the hypotheses can be considered as a series of important questions that need to be answered to understand source-receptor relationships and visibility in the Scenic Area. In section 4, the proposed measurements program is presented, with components added in order of priority. Section 5 describes data analyses and modeling components of the proposed study. Section 6 outlines data management procedures and section 7 discusses quality assurance needs. Section 8 recommends a program management structure. Budget estimates are given in Section 9. References are presented in Section 10.

2. **SUMMARY OF EXISTING KNOWLEDGE**.

This section presents an overview of background information regarding, emissions, meteorology, air quality, and visibility in the Scenic Area. Additional information is contained in the documents: “Some Characteristics of Aerosols and Haze, Aerosol Transport and Emissions Sources Affecting the Columbia River Gorge NSA” prepared by the Washington State Department of Ecology and the Oregon Department of Environmental Quality and “On the Composition and Patterns of Aerosols and Haze Within the Columbia River Gorge: September 1, 1996- September 30, 1998” by Core (2001).

2.1 Emissions

Figure 2-1 is a location map showing the Scenic Area, nearby Class I areas and major cities, highways, railroads, and point sources.



Note that the Portland, Oregon/ Vancouver, Washington urban area (population about 1.8 million) is located immediately to the west of the Scenic Area. The Centralia power plant, with 1996 emissions of 78,000 tons of SO_2, or 47% of the point source SO_2 emissions in EPA Region 10 (Oregon, Washington, Idaho, Alaska) (USEPA,2001) is located at the north edge of the map, just above Chehalis. The Centralia powerplant is scheduled to have 90% controls on one unit by December 2001, and 90% control on Unit 2 by December 2002. The Boardman powerplant, located about 100 Km east of the

Scenic Area had SO_2 emissions of 16,578 tons and NO_X emissions of 8949 tons in 1999 (Oregon Department of Environmental Quality). Sources within the gorge include small aluminum smelters, cities of The Dalles, and Hood River, highways, ships, and 2 railroads. Up the Columbia River from the scenic area are the Tri-cities (Richland-Pasco-Kennewick), Yakima, and Spokane (of potential interest mainly in winter). Also to be considered, particularly in summer, are emissions from the Willamette Valley, Longview, the Seattle metropolitan area, and possibly sources to Vancouver, British Columbia. Emissions maps prepared by the Washington Department of Ecology and Oregon Department of Environmental Quality are shown in Figures 2.2-2.5. The Washington emissions are allocated to grid cells 5 Km on a side.

Additional information regarding the state of the emissions inventories in Washington and Oregon is shown below (source: Washington DOE and Oregon DEQ).

Emissions Inventory Gaps – Washington

Sources Not Inventoried On a Statewide Basis

Point source stack parameters (available for many sources, but not all)
Asphalt paving
Non-residential fuel combustion
Residential non-wood fuel combustion
Agricultural burning (all types)
Landfills
POTWs
Industrial wastewater
Construction site emissions
Restaurant grills
Locomotives
Aircraft
Ships
Saltwater associated emissions

Sources Requiring Updates

Residential woodstoves
Some categories of surface coating
Surface cleaning
Dry cleaning
Structure fires
Wildfires
Residential outdoor burning
Land clearing burning

Some Information Available, But Further Research Needed

Ammonia sources
PM size distributions (PM2.5)
Spatial surrogates
Temporal profiles
PM and VOC speciation profiles

Current Washington Inventory Improvement Projects

Emission data for the following categories are being refined under a grant from EPA.

Locomotives
Residential woodstoves
Residential outdoor burning
Ships
Biogenics

Emissions Inventory Gaps - Oregon

Categories Not Inventoried

Railroads
Paved/Unpaved Roads
Agricultural Tilling/ Field Plowing
Airports
Orchards Heating/Orchard Pruning Burning
Fallow Fields
Restaurant Emissions (broiling and deep fat frying)
Wind Blown Dust
Construction Land Clearing

Categories Needing More Detailed Inventory

On-Road Mobile
Forest Wild Fires
Prescribe
Agricultu

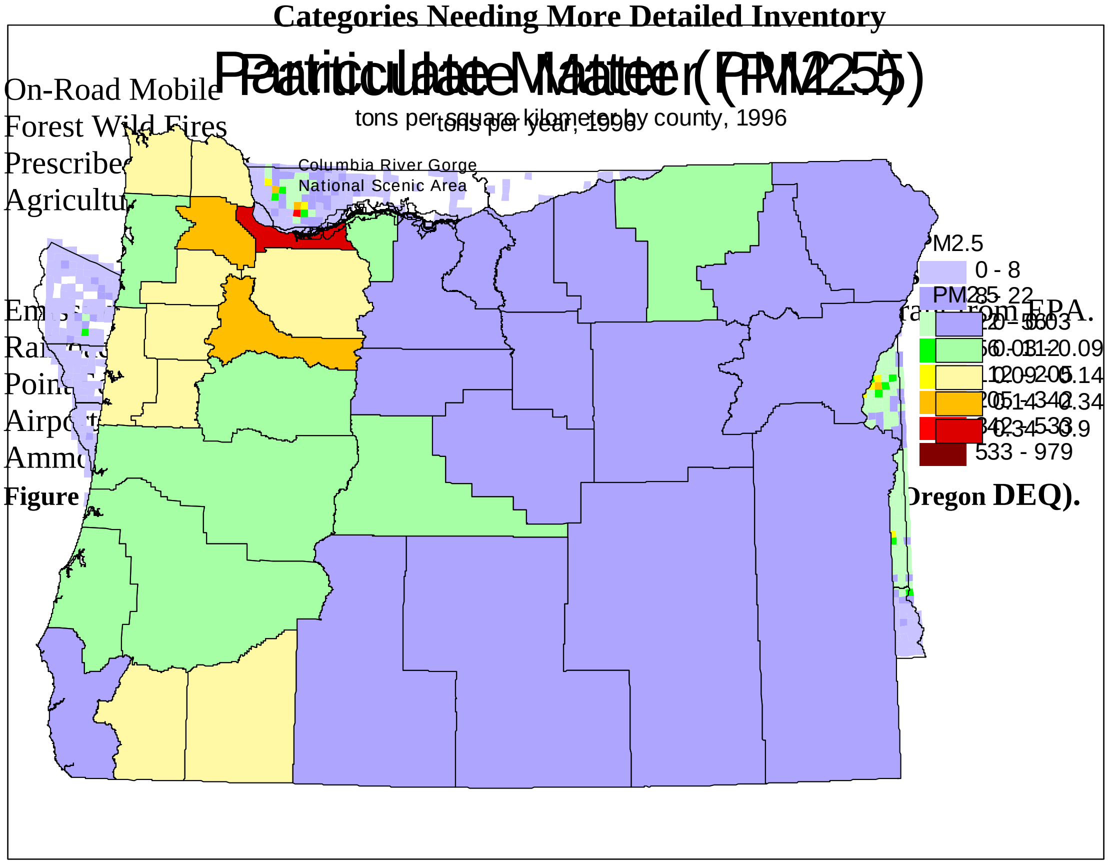
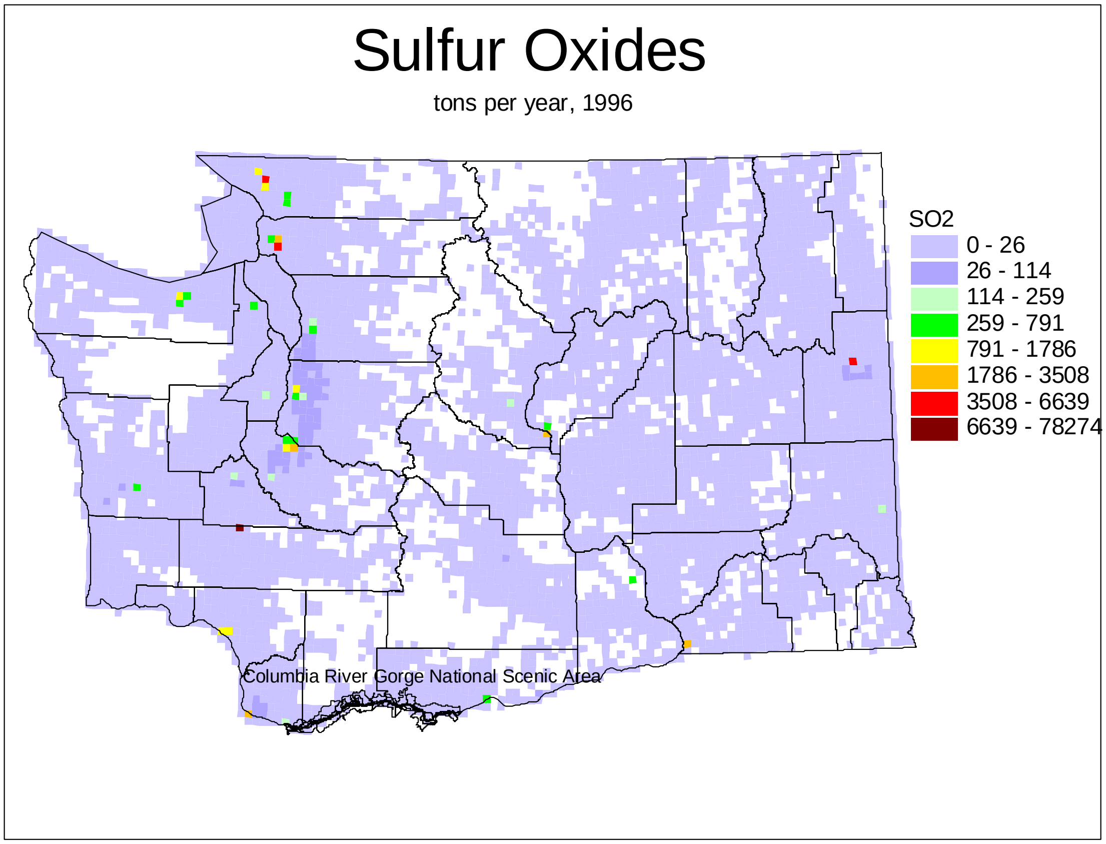


Figure **Oregon DEQ).**



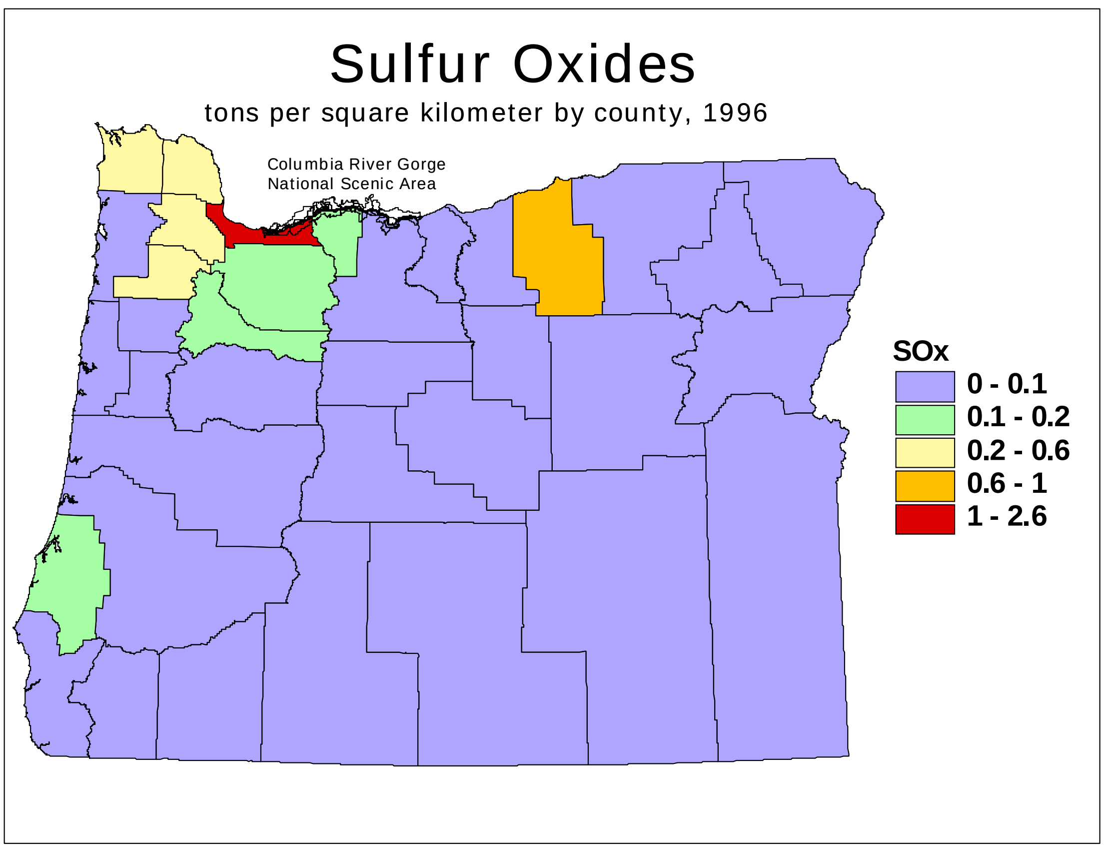
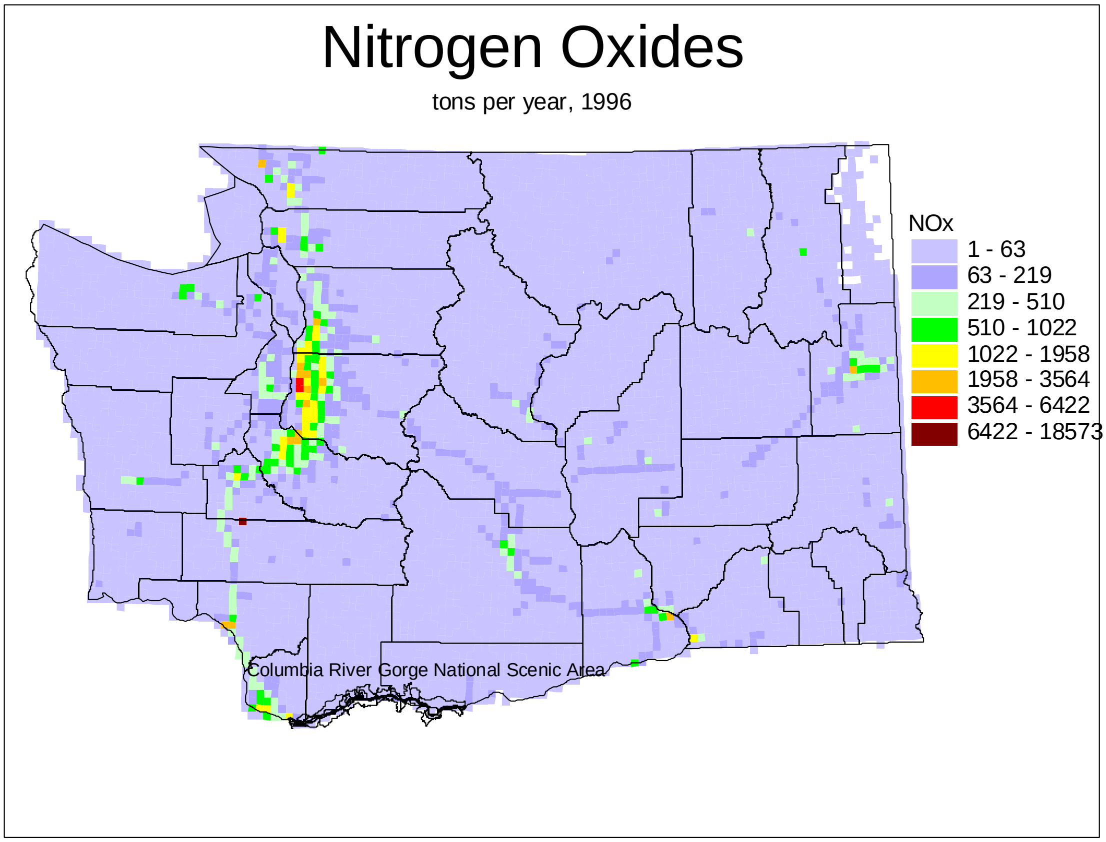


Figure 2-3. SO_X emissions in Washington and Oregon (Washington DOE and Oregon DEQ).



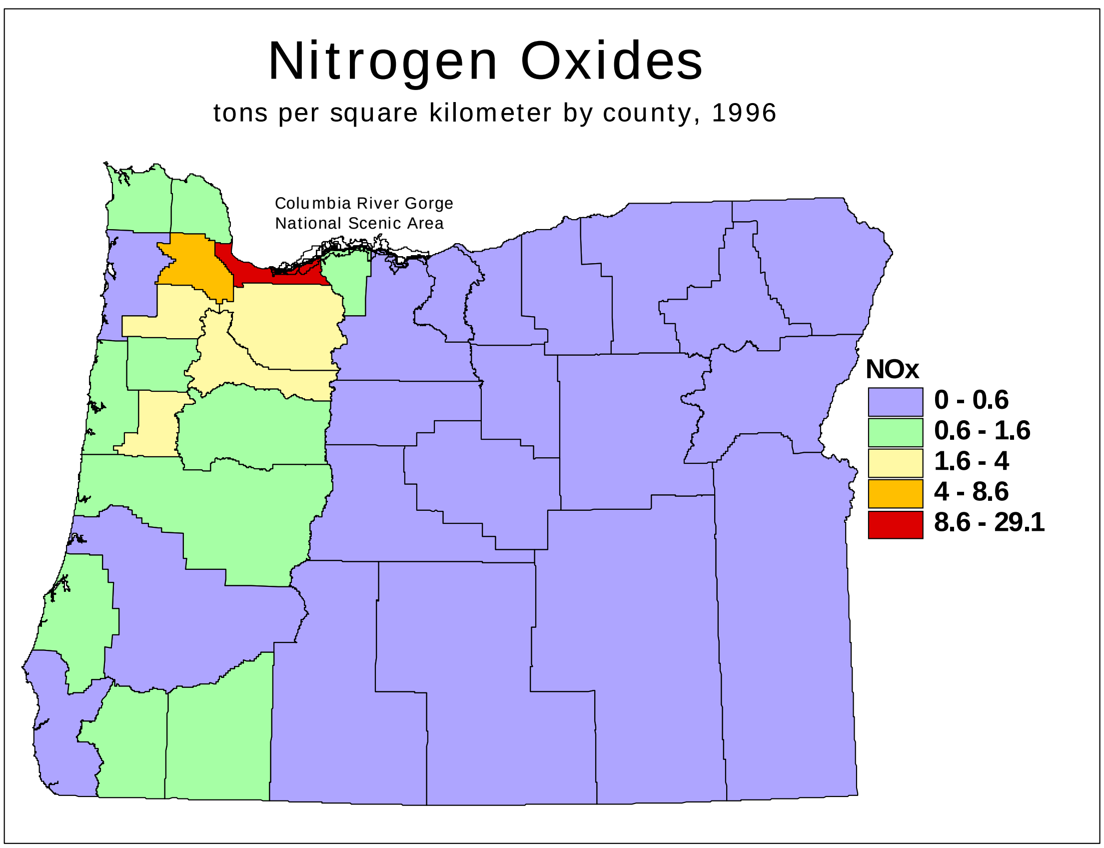
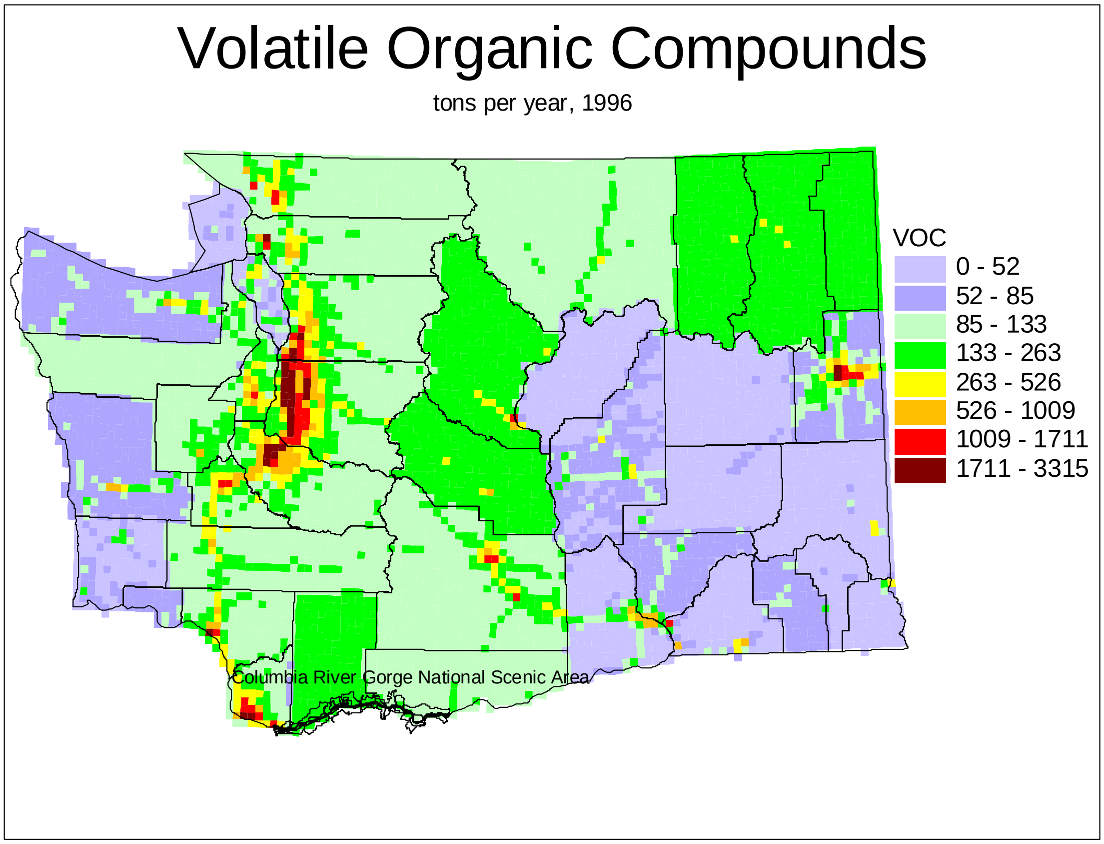


Figure 2-4 NO_X emissions in Washington and Oregon (Washington DOE and Oregon DEQ).



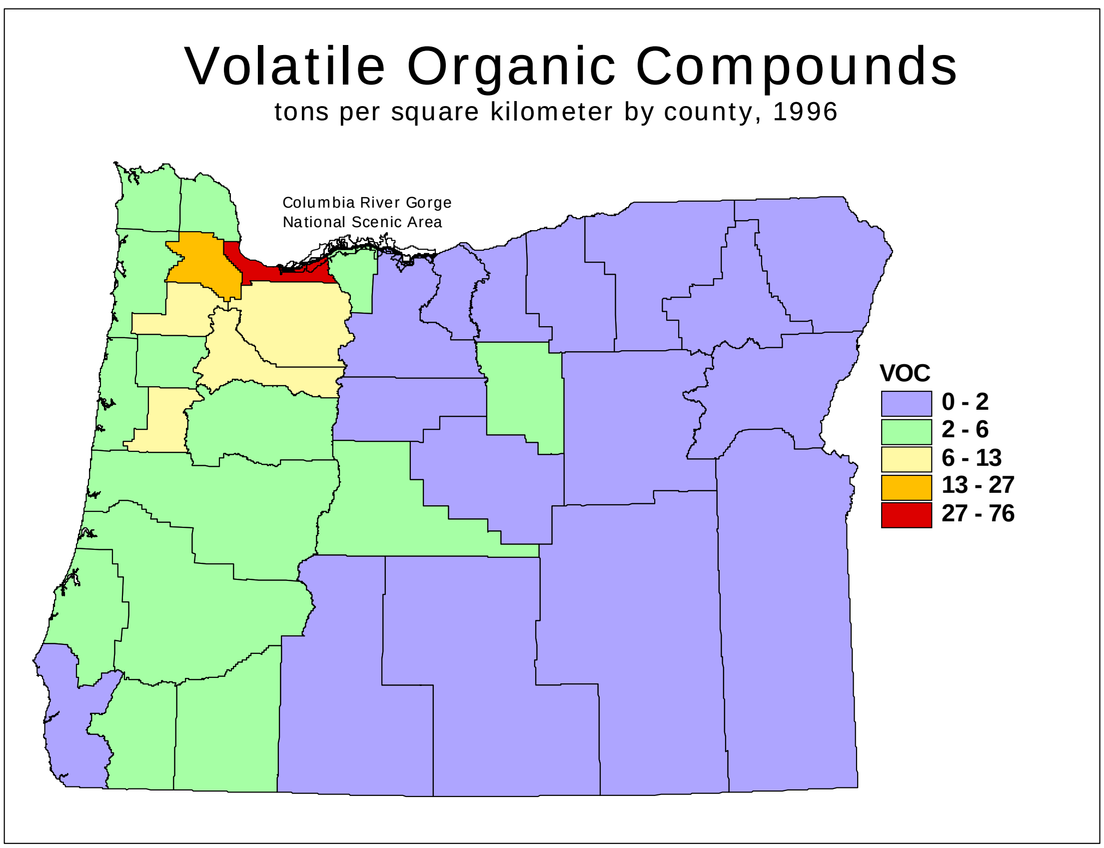


Figure 2-5. VOC emissions in Washington and Oregon (Washington DOE anOregon DEQ).

2.2 Meteorology :TO BE ADDED

2.3 Aerosol and Visibility

Speciated $PM_{2.5}$ measurements have been made routinely at two locations within the Scenic Area, Wishram and Mt. Zion (locations shown in Figure 2-1). The Interagency Monitoring of Protected Visual Environments (IMPROVE) site at Wishram has been operating since June 1993. Measurements at Mt. Zion were made from September 1996 through September 1998 and then suspended. Measurements began again at Mt. Zion in December 1999. Optical measurements included the use of near-ambient Optec NGN-2 nephelometers at Wishram from June 1993- May 2000. The NGN-2 at Wishram was replaced with a Radiance Research nephelometer (humidity maintained at not more than 50% through heating) since June 2000. A Radiance Research nephelometer has been operated at Mt. Zion for the period of record for aerosol data. IMPROVE data is also available from the Mt. Rainier National Park and Three Sisters Wilderness sites.

Most of the summary data shown in this section uses the period of September 1996-September 1998 because data is available from both of the Scenic area sites. The 9/96 – 9/98 period is put into perspective by comparing major components during this period to the entire period of record. With the exception of particulate nitrate (discussed later), this period was similar to the entire period of record.

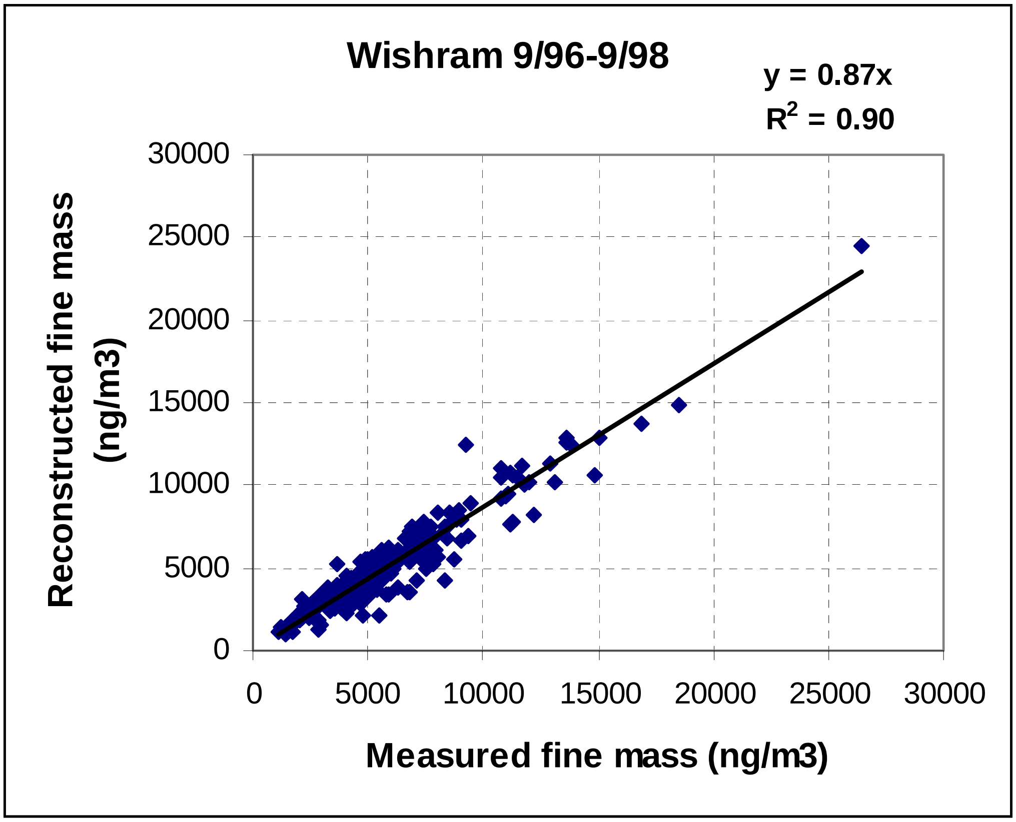
The standard IMPROVE equations (Malm, et. al., 2000) for calculating reconstructed $PM_{2.5}$ mass were used. This includes the following components:

Sulfate assumed to be ammonium sulfate and =4.125*S from particle induced X-ray emission (PIXE) on Teflon filter
Nitrate assumed to be ammonium nitrate and =1.29*$NO3^-$ from ion chromatography on nylon filter
Carbon from Thermal optical reflectance (TOR) on quartz fiber filter
    Organic mass = 1.4*Organic Carbon
    Elemental carbon
Soil=2.2*Al+2.49*Si+1.63*Ca+2.42*Fe+1.94*Ti

PM_{10} mass was measured at Wishram (Teflon filter), but not at Mt. Zion.

As ammonium ion was not analyzed for, it is not known if the sulfate and nitrate were fully neutralized. At times significant concentrations of sodium and chloride ion were reported.

Scatterplots of reconstructed versus measured fine mass for Wishram and Mt. Zion are shown in Figure 2-6. About 90% of the fine mass is accounted for at both sites, and squared correlation coefficients (r^2) are about 0.9. Averaged reconstructed fine mass was 5.3 $\mu g/m^3$ at each site. Annual average reconstructed mass budgets are shown in Figure 2.7. At each site, organic mass is the greatest component, followed by ammonium sulfate, with ammonium nitrate, soil, and elemental carbon much less.



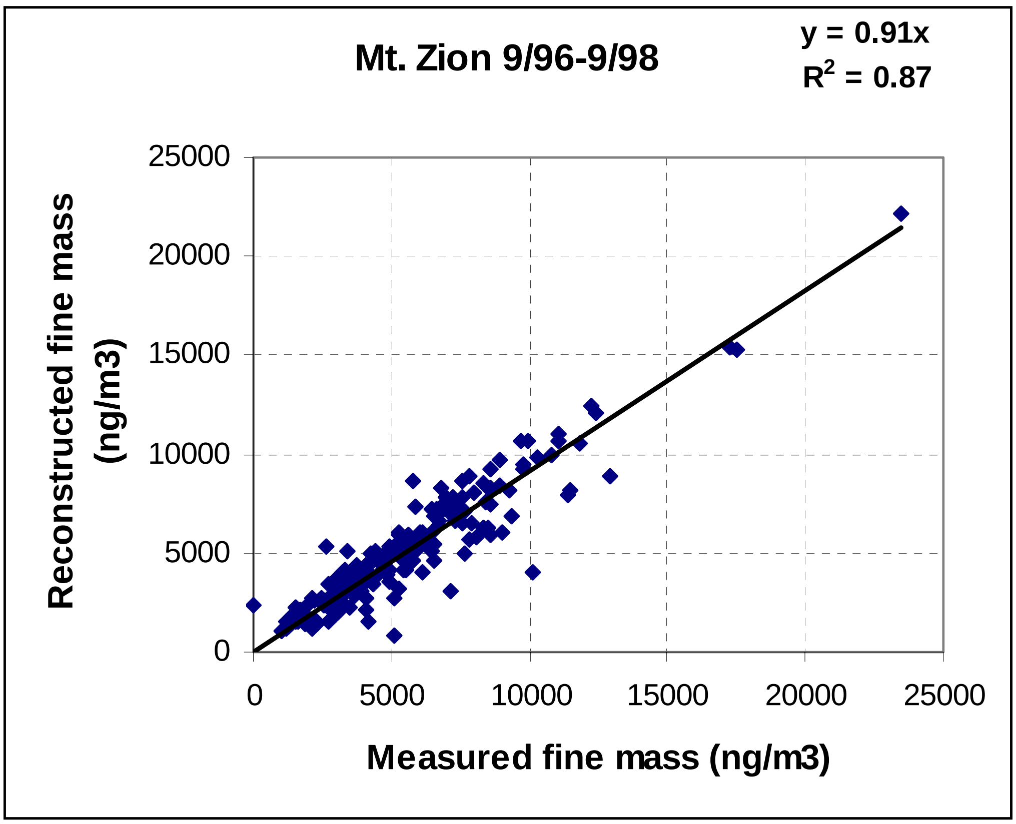
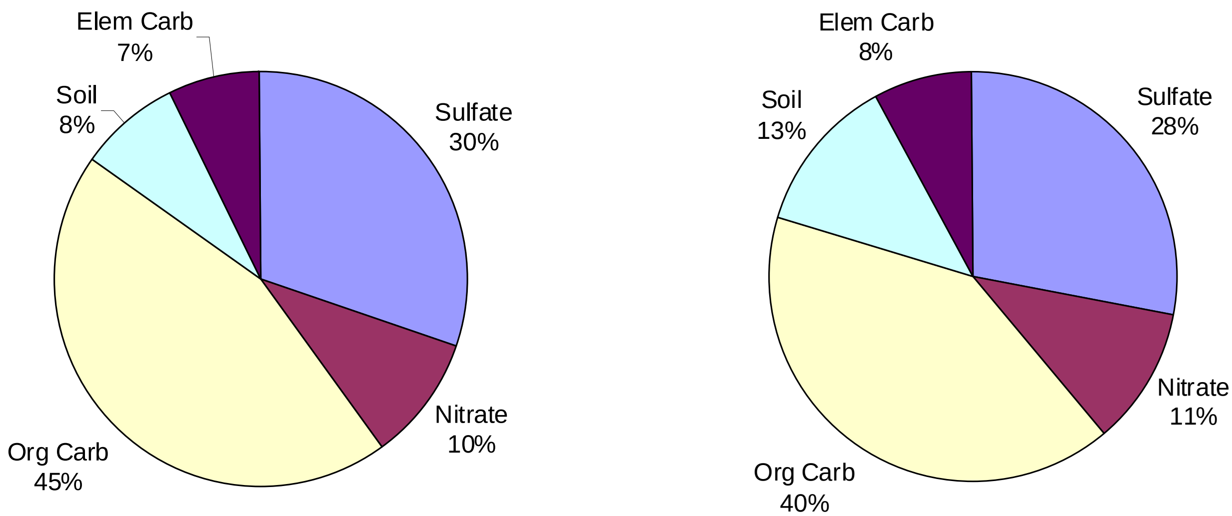


Figure 2-6. Measured versus reconstructed mass, Wishram and Mt. Zion 9/96-9/98.



a) Mt. Zion b) Wishram

Figure 2-7. Annual average reconstructed mass budget a) Mt. Zion; b) Wishram

Monthly averaged component concentrations for the 9/96-9/98 period are shown in Figure 2-8. It should be noted that the monthly averages are based on typically 16-18 values and could be significantly influenced by a single high value. The large soil concentrations in April are from a single day of very high fine soil due to transport of Chinese dust in April 1998. For all components except fine soil, which is higher at Wishram for all months, Mt. Zion has higher concentrations in the summer and Wishram has higher concentrations in winter. As the winds in the gorge are primarily from the west in summer and east in winter, this implies lower concentrations at the downwind canyon site, suggesting that sources outside the gorge are more important than sources within the gorge. Both sites have a fine sulfur peak in July and nitrate peaks in December and January, although the annual curve for NO_3 is flatter for Mt. Zion. Organic mass peaks in the autumn at both sites. Sulfate is moderately correlated between the two sites with an r^2 of about 0.5 for summer (May-September) and Winter (November-March). Organic carbon and elemental carbon are highly correlated between the two sites in summer (r^2= 0.77 and 0.76, respectively), but not well correlated in winter (r^2=0.37 and 0.14), as seen in Figure 2-9.

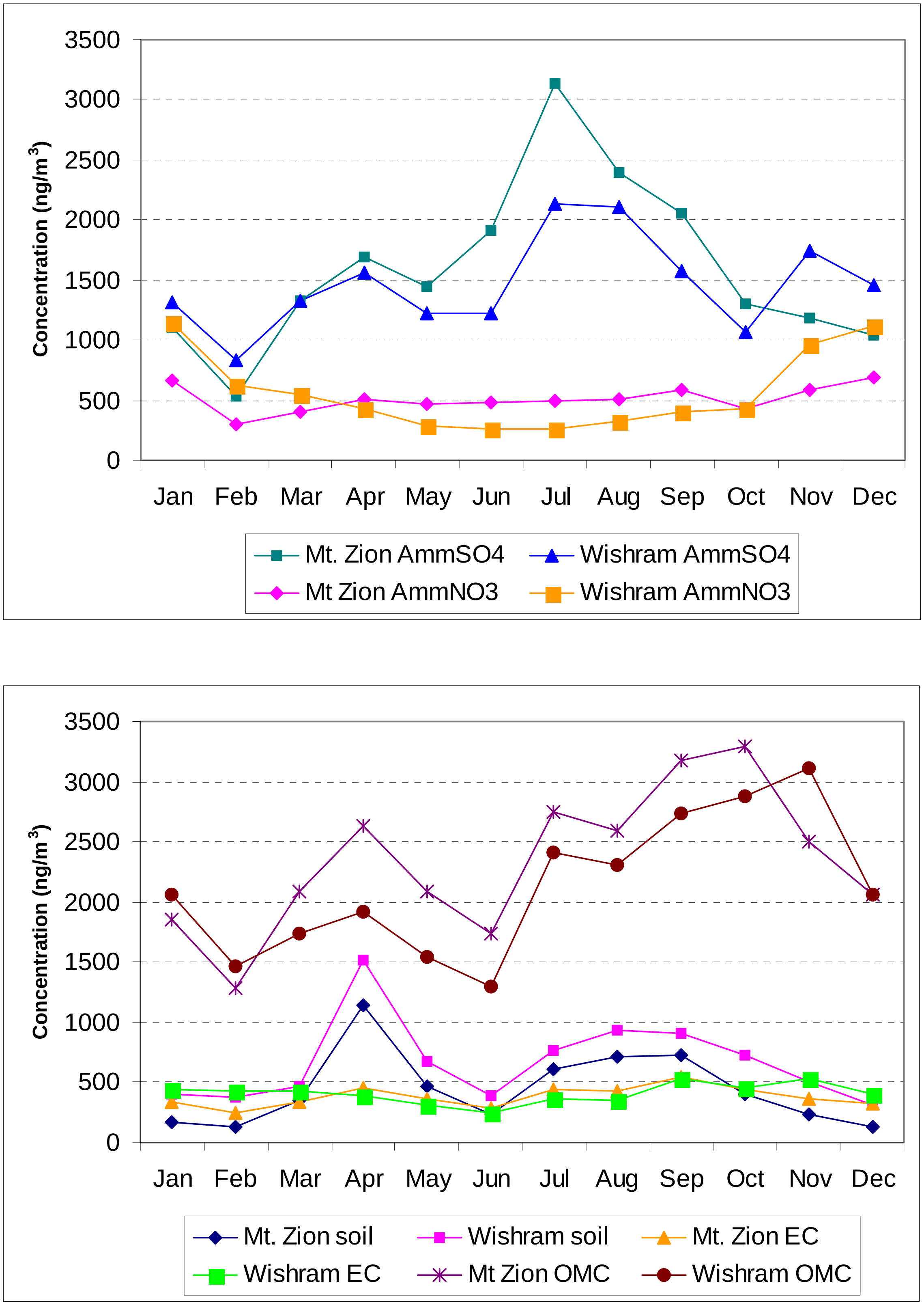


Figure 2.8 Monthly average reconstructed fine mass components Wishram and Mt. Zion, September 1996-September 1998 a) Ammonium sulfate and ammonium nitrate; b) organic mass, elemental carbon, soil.

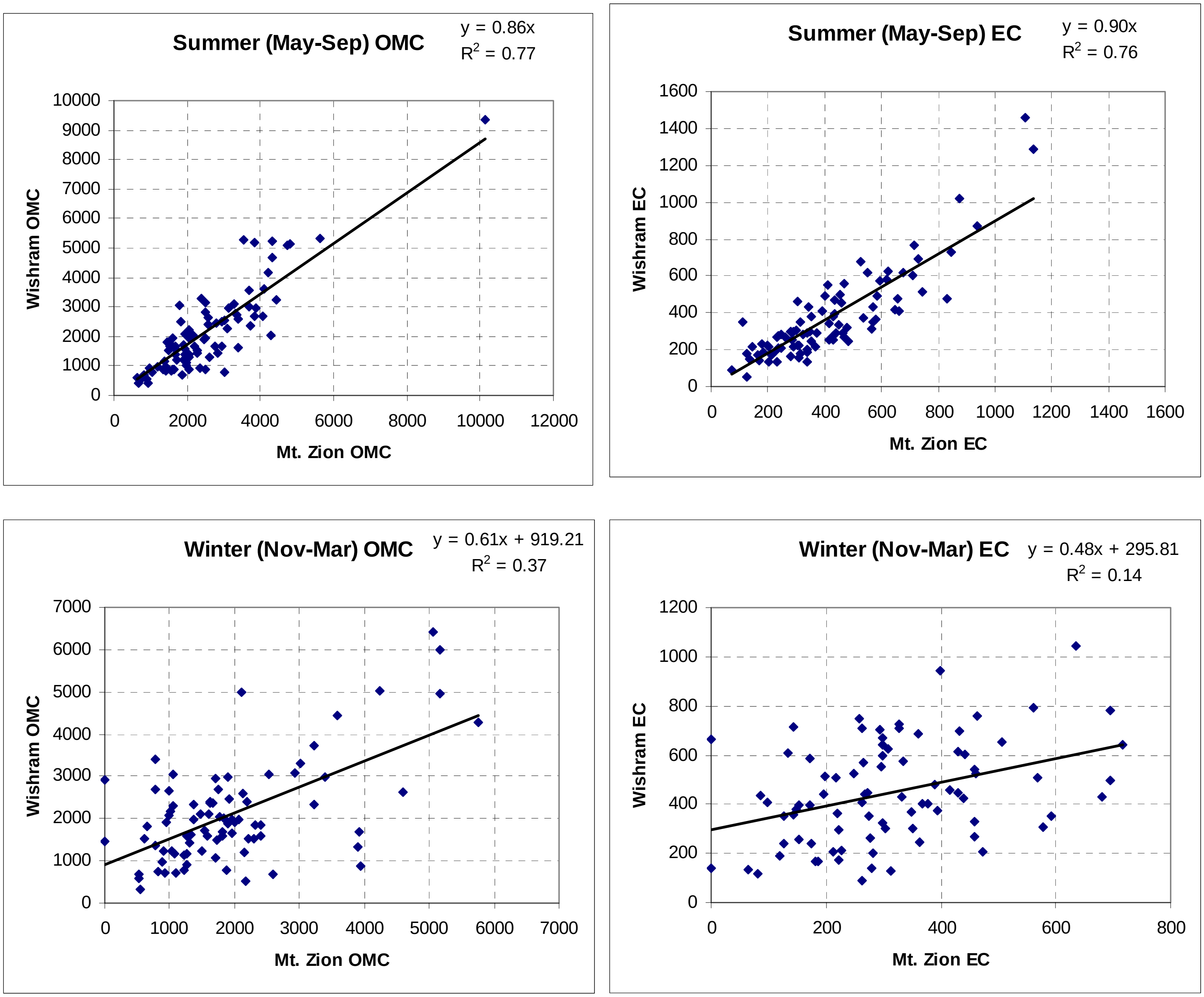


Figure 2-9. Scatterplots of organic mass and elemental carbon for Wishram and Mt. Zion, summer and winter.

<u>Reconstructed fine particle extinction</u>

Reconstructed fine particulate light extinction by month is shown in Figure 2-10. Scattering by coarse mass was not included because coarse mass concentrations are not available for Mt. Zion. The methodology included extinction efficiencies of 10 m^2g^{-1} for elemental carbon, 4 m^2g^{-1} for organic mass, 1 m^2g^{-1} for fine soil and 3 m^2g^{-1}*f(RH) for ammonium sulfate and ammonium nitrate, where f(RH) is a relative humidity growth factor. Daily averaged f(RH) was calculated from hourly f(RH) values for hours with RH of 98% or less. Wishram has higher particle scattering in the months November to February, while Mt. Zion is higher the rest of the year. The considerably higher reconstructed extinction at Mt. Zion compared to Wishram in summer is due to both higher concentrations of most aerosol components and greater water growth of sulfate and nitrate than at Wishram due to higher humidity at Mt. Zion.

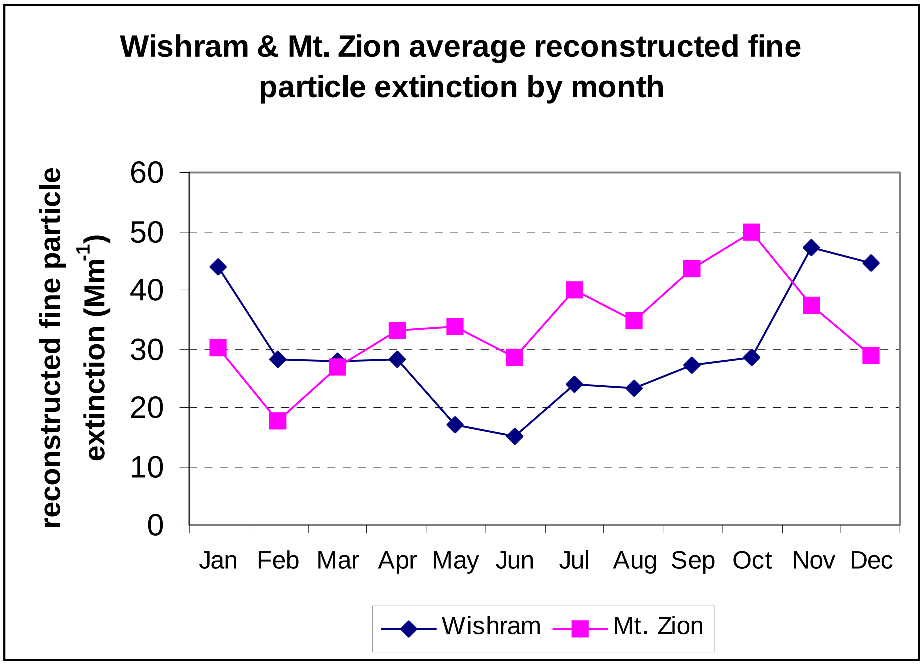


Figure 2-10. Average reconstructed particle extinction by month, Wishram and Mt. Zion 9/96-9/98.

The monthly components of reconstructed extinction for Wishram and Mt Zion are shown in Figures 2-11 and 2-12. Estimated scattering due to dry particles and water growth of sulfate and nitrate is shown separately to emphasize the importance of water growth on scattering in the Scenic Area. At Wishram, it is interesting to note that reconstructed sulfate extinction peaks in winter due to water growth, even though sulfate concentrations are higher in summer. The nitrate extinction is less than 2 mm^{-1} in summer and 12 mm^{-1} in winter at Wishram. Organic aerosol is the greatest single component in summer at Wishram. Mt. Zion has less variation in extinction components during the year as compared to Wishram. This is due to greater aerosol mass in the summer and relatively higher humidity than Wishram in summer (less RH variation than Wishram between summer and winter).

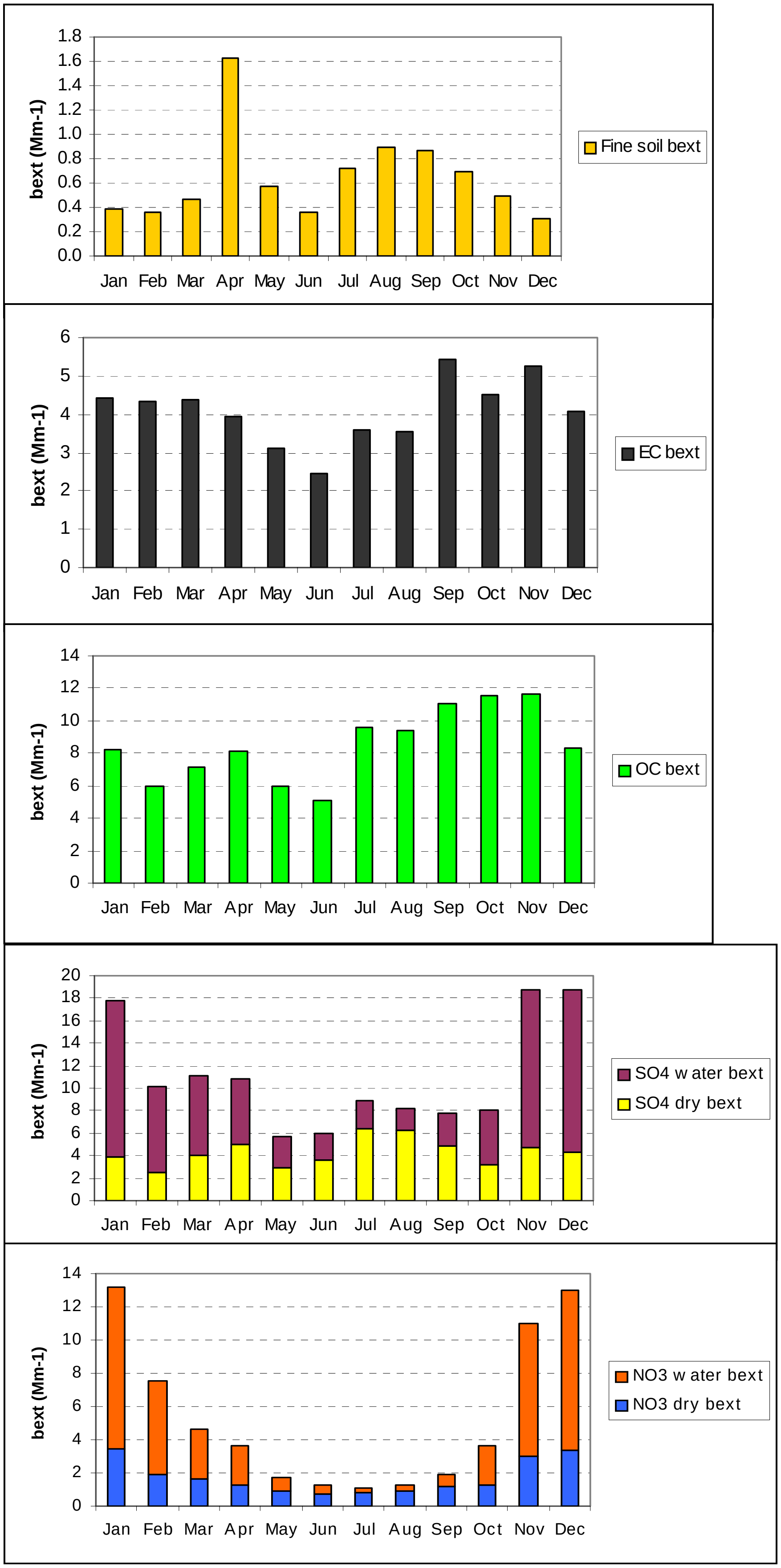


Figure 2-11. Monthly averaged reconstructed particle extinction components, Wishram.

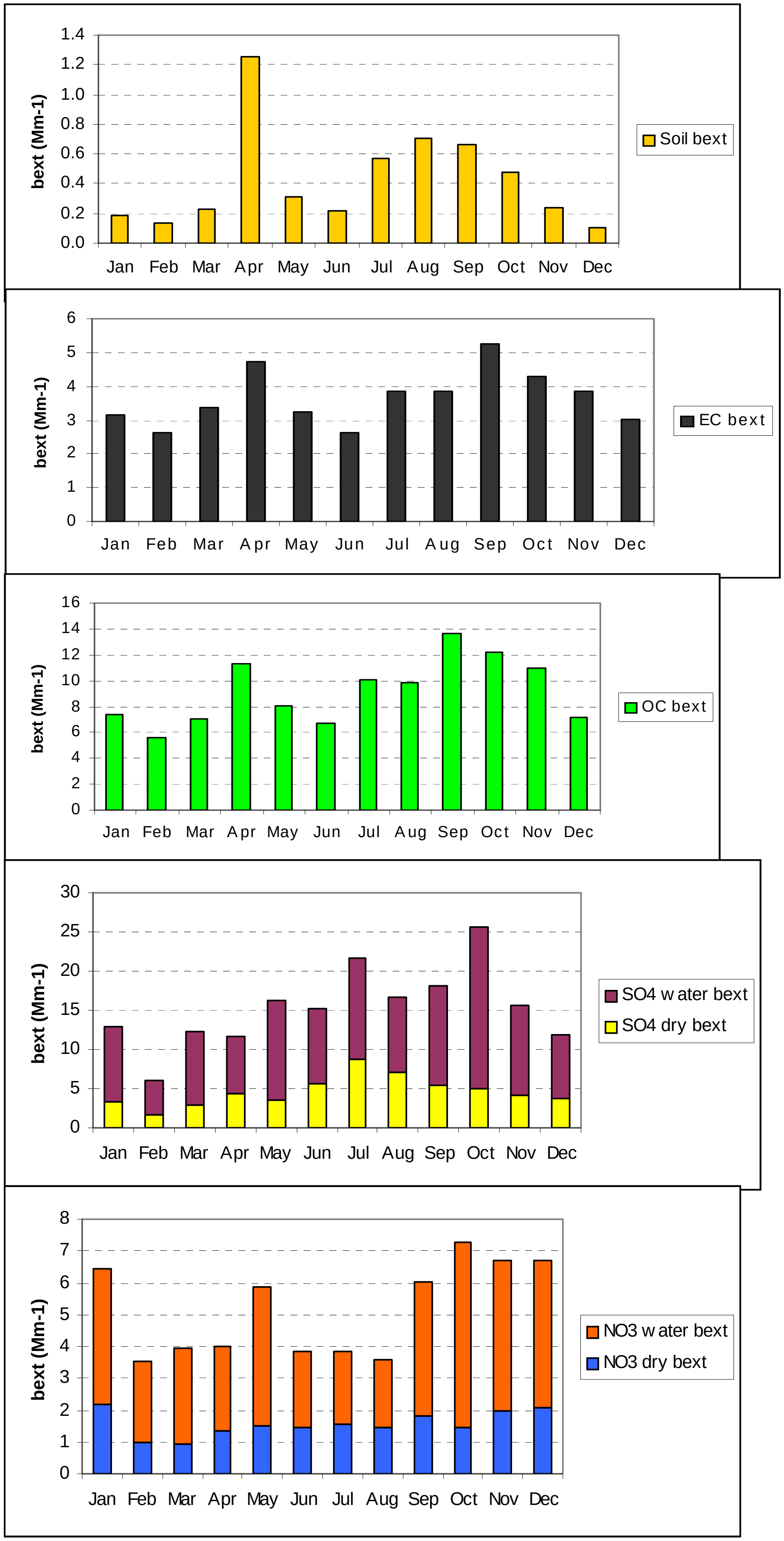


Figure 2-12. Monthly averaged reconstructed particle extinction components, Mt. Zion.

Measured versus reconstructed scattering at Wishram

A scatterplot of measured versus reconstructed particle scattering at Wishram for the period 9/96-9/98 is shown in Figure 2-13. Coarse mass (PM_{10}-$PM_{2.5}$) scattering was included here, with an efficiency of 0.6 m^2g^{-1}. The same data organized by month is shown in Figure 2-14. Here, only hours with measured relative humidity of 90% or less were used with the requirement of at least 12 hours per day of data meeting this limitation. At very high values the nephelometer shows extreme numbers; this was done to avoid using these numbers. It should also be noted that the uncertainty in the RH data is 5%, so a value of 95% could actually be 100% RH.

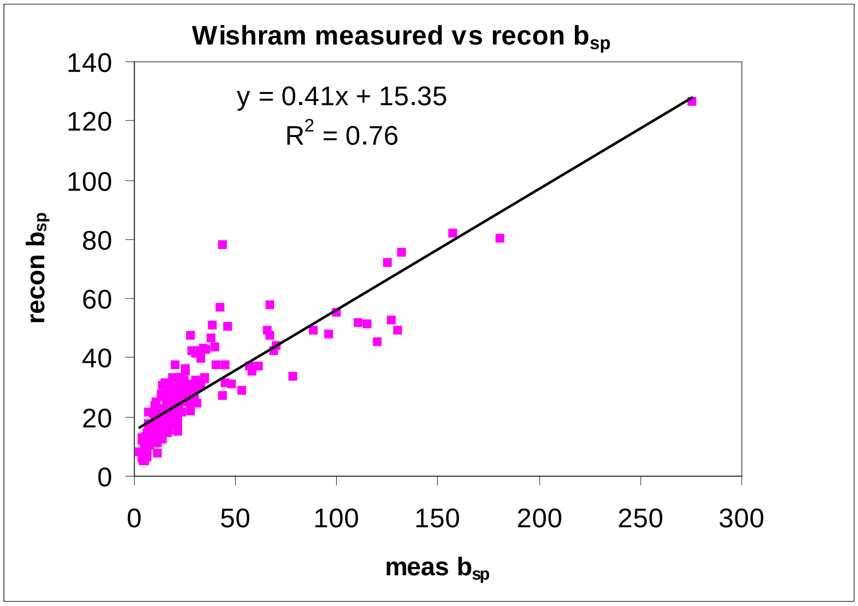


Figure 2-13 Measured versus reconstructed particle light scattering, Wishram – 9/96-9/98.

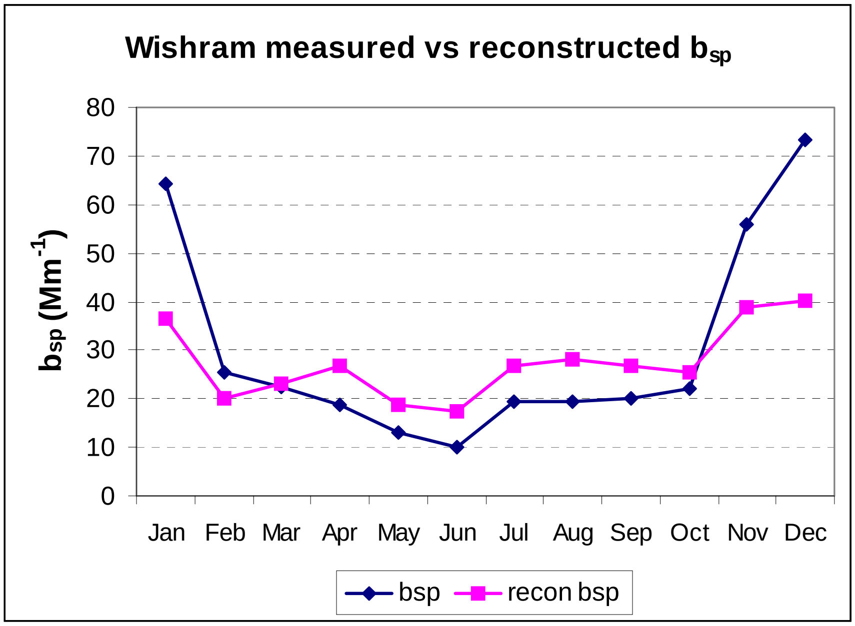


Figure 2-14 Measured and reconstructed particle light scattering by month, Wishram 96/96-9/98.

At lower values of measured scattering, the slope in Figure 2-13 is close to one. However, at higher levels, the measured is much greater than reconstructed. Figure 2-14 shows that measured is lower than reconstructed scattering for the months May-September, but much higher than reconstructed scattering in November –January. Scatterplots of measured and reconstructed scattering by summer and winter (Figure 2-15) show a distinct difference. In summer, the slope of reconstructed to measured is about 0.9, with an intercept of 9 mm^{-1} (clean days have less measured scattering). In winter, the slope is only about 0.4 (with an r^2=0.92) and an intercept of about 12 mm^{-1}. This difference in winter could indicate a problem with the mass measurements, such as too little nitrate due a change in the nitric acid denuders in 1996 (see below); a possibility of water growth of coarse mass (e.g. growth of sulfate or nitrate to >2.5 μm); forms of sulfate with higher scattering efficiency than ammonium sulfate (e.g. sulfuric acid), or substantial scattering by NaCl or other compounds; or a bias low in the RH measurements, leading to lower f(RH) to be applied. The measurements program needs to be designed to address this inconsistency between measured and reconstructed scattering at Wishram in winter.

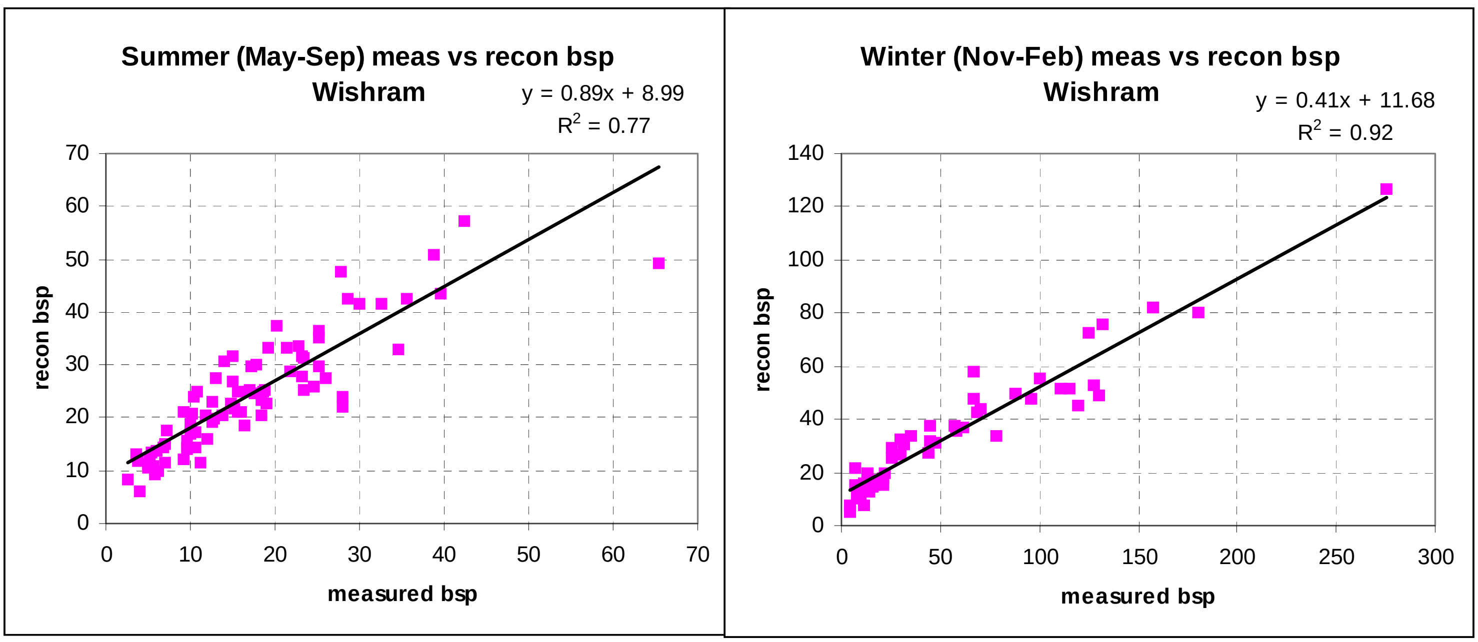
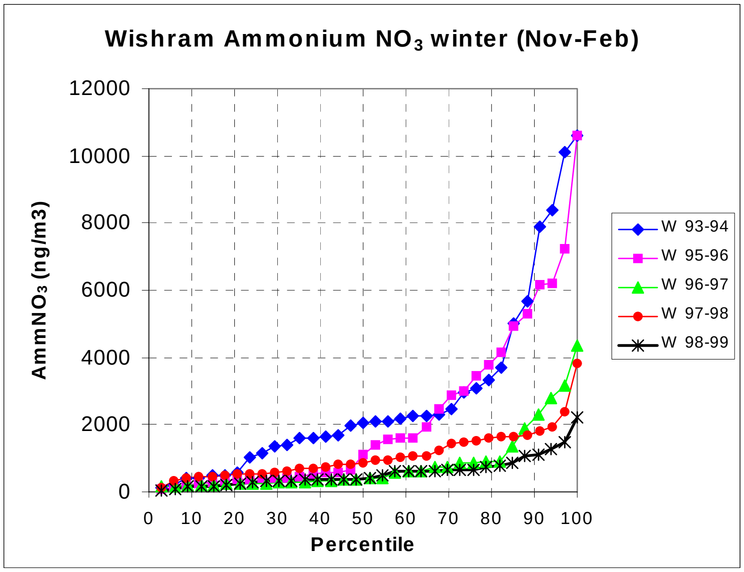
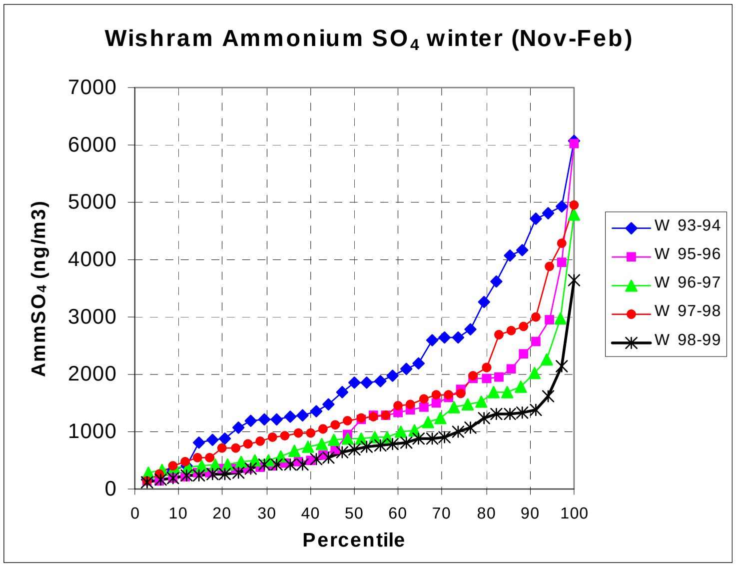


Figure 2-15. Measured versus reconstructed particle light scattering at Wishram, summer (May-September) and winter (November-February) for 9/96-9/98.

In light of the differences in measured and reconstructed scattering in Wishram for the winters of 1996-1997 and 1997-1998, the frequency distribution of major components was calculated for each of the winters for which aerosol data is available at Wishram. Winter frequency distributions for ammonium nitrate, ammonium sulfate, and organic mass are shown in Figure 2-16. Figure 2-16a shows much lower concentrations of ammonium nitrate after the winter of 1995-1996. The ammonium sulfate and organic mass plots show the the winter of 1993-1994 had high concentrations of these compounds as well, but do not show the same pattern of much lower concentrations after 1995-1996 as ammonium nitrate does. The IMPROVE network changed the method of operating the nitric acid denuders during 1996, treating them with glycerin to make them more effective at removing gaseous nitric acid. This time frame coincides with an apparent reduction in particulate nitrate at Wishram. If the new method is correct, it suggests a significant positive artifact occurred until 1996 (nitrate levels too high). If the older method was more correct, the post- 1996 nitrate values could be too low. This is currently being investigated by the IMPROVE program. Additional measurements in the Columbia River Gorge could help resolve this issue locally.





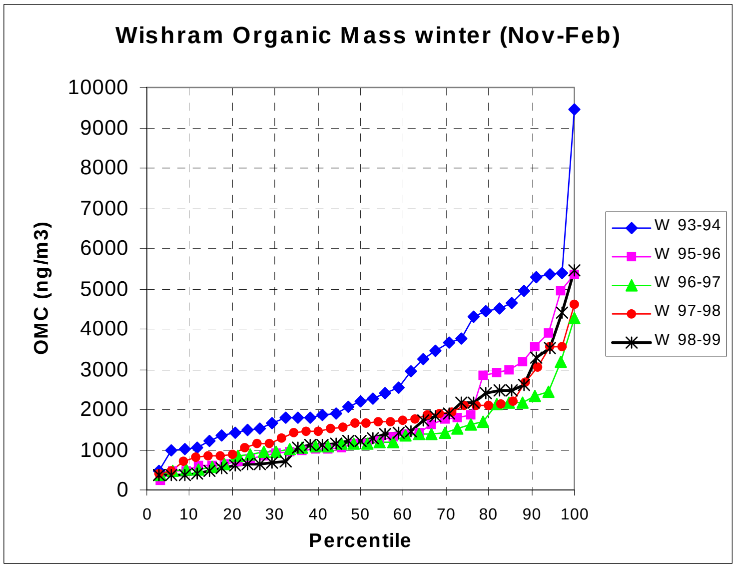


Figure 2-16. Frequency distribution of reconstructed fine ammonium nitrate, ammonium sulfate, and organic mass at Wishram for the winters of 1993-94 through 1998-1999. The winter of 1994-1995 was missing most data.

3. HYPOTHESES TO BE TESTED

In this section, hypotheses are stated as a framework (or a basis) to plan a measurement, data analysis, and modeling program to help answer key questions regarding haze in the Scenic Area. The hypotheses could just as easily be listed as a series of questions. They are used as a guide to designing the study, but not as the sole reason for making proposed measurements or conducting modeling and data analysis activities. Some analyses that must be done, such as closure (mass, optical, etc.) exercises, are not necessarily evident in the list of hypotheses, but will be done.

HYPOTHESIS 1: In the summer and early fall, visibility in the gorge, in particular the west end is significantly impacted by the Portland, Oregon/Vancouver, Washington metropolitan and to a lesser extent other regional sources (Kelso/Longview, Centralia powerplant, Seattle/Tacoma, Vancouver B.C.).

Evidence to support hypothesis 1: The Portland,Oregon/Vancouver Washington Primary Metropolitan Statistical area (PMSA) had an estimated population on July 1, 1999 of 1,845,840 (U.S. Census Bureau). The PMSA is immediately to the west of the Columbia River gorge. There are substantial quantities of particulates and precursor gases in the PMSA which could contribute to haze in the Gorge. During the summer months, lower level winds are consistently channeled into the Gorge from the Portland urban area due to a pressure gradient across the gorge. Temperature gradients between the cool waters of the Pacific Ocean and heated interior areas east of the Cascade Mountains results in a significant west-east pressure gradient. The Columbia River gorge provides a channel through which this pressure gradient can be realized, with the resultant flow from high pressure to the west to lower pressure in the east. These winds effectively bring polluted air from the urban and industrial areas upwind into the gorge.

In addition to the flow from Portland, emissions from areas downriver (and upwind) along and near the Columbia River such as the Longview/Kelso area can be carried into the gorge. Less frequently, emissions from areas north of the Columbia River such as the Centralia power plant and the Puget Sound to Vancouver, British Columbia region can be contributing to the mix due to northwesterly synoptic scale flow around the summertime Pacific High.

More specific evidence of contribution of nearby sources west of the gorge in summer is given by diurnal plots of light scattering at Mt. Zion using a Radiance heated nephelometer. Figure 3-1 shows a regular diurnal pattern in light scattering in the months June- October, with a sharp rise in b_{sp} in late morning, a peak early in the afternoon and then a decline. It is speculated here that the rise in late morning is due to transport of a “blob” of polluted air that had built up during light wind conditions overnight. As the heating of the interior increases the pressure gradient in the late morning, the winds increase and move the blob through the gorge. B_{sp} decreases later in the afternoon due to increased vertical and along-wind dispersion, and more rapid air-flow through the

Portland area itself, limiting the buildup of pollutants that are subsequently transported through the gorge.

Additional information needed: Additional monitoring can help confirm the effects of the Portland area and regional sources upon aerosol concentrations and visibility in the gorge during the summer. If the explanation for the diurnal patterns in light scattering at Mt. Zion is correct, the diurnal peak in the heated nephelometer signal should be delayed with distance downwind in the gorge. It is possible that the peak could be reduced substantially at locations downwind of Mt. Zion due to the pulse arriving during the period of maximum mixing. A nighttime peak should also be noted in the metropolitan area. High time resolution light absorption data from aethalometers may also provide a good marker of the urban area and its associated emissions. High time resolution particulate sulfate and nitrate measurements may also be useful in identifying transport. Finally, 24-hour aerosol sampling and analysis could be useful by considering gradients in aerosol concentrations.

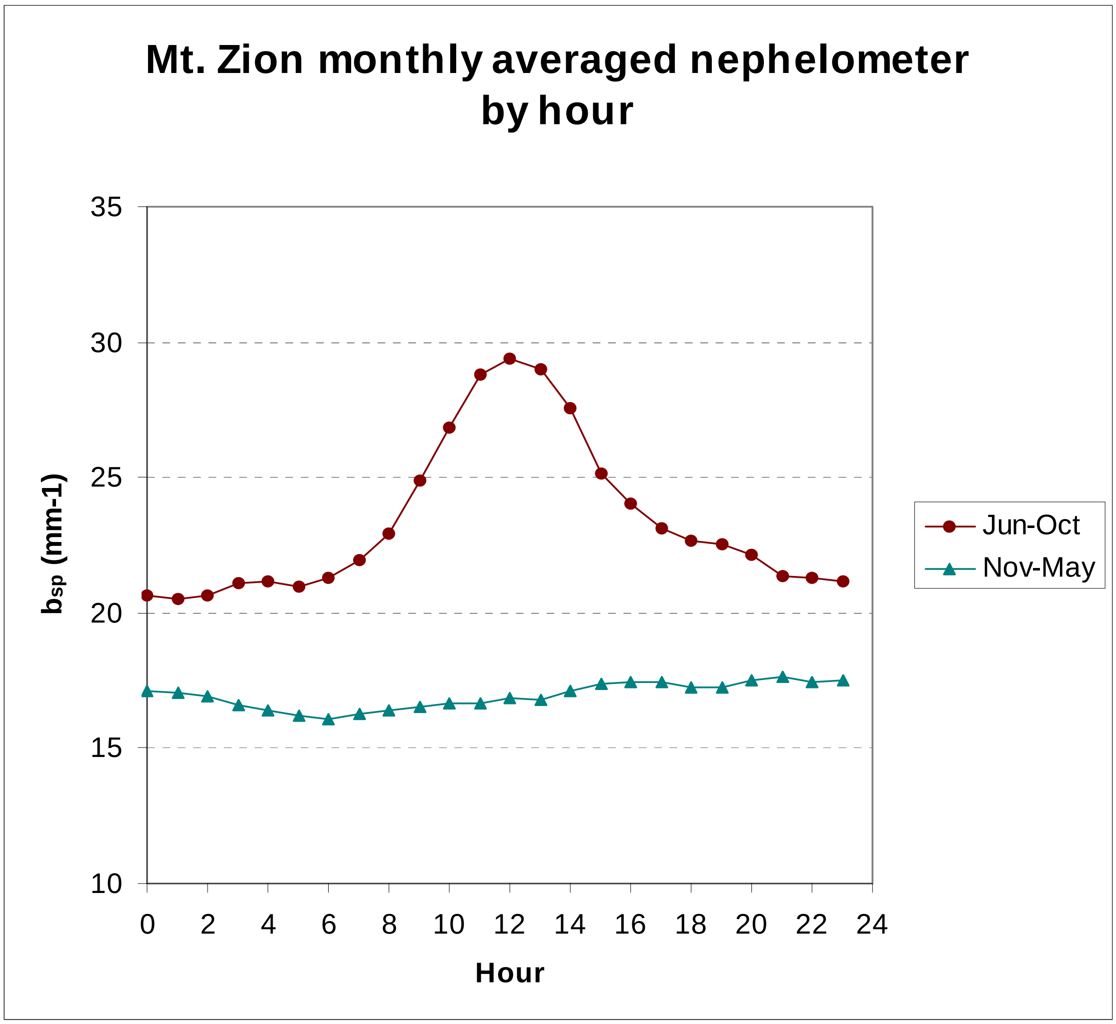


Figure 3-1. Hourly averaged light scattering at Mt. Zion for June-October and November-May. Data for the period 9/96-9/98. Light scattering measured by Radiance Research nephelometer with humidity limited to 50% by heating.

As areas near, but above the gorge would be expected to be less influenced by the Portland area, nephelometer, aethalometer, and aerosol measurements at these areas can be compared to those within the gorge to estimates the regional versus Portland area influences. This would tend to underestimate the Portland influence somewhat because while much material from Portland/Vancouver is expected to enter the gorge, some material will be transported up slopes on either side of the gorge and up the sidewalls of the gorge itself (mainly the south-facing Washington side). By comparing with measurements further from Portland, a better indication of regional versus local contributions can be made.

The measurements, in particular, those with time resolution of one-hour or less should have collocated wind speed and direction to help define the source-receptor relationships.

At a minimum, measurements should be made upwind of Portland (between Portland and Longview/Kelso), in Portland, and at multiple distances downwind of Portland. Measurements at a clean location near the mouth of the Columbia River could provide an estimate of background levels.

Tetroons could be released from various locations in the Portland/Vancouver area during midday in summer to see if they are transported into the gorge or are transported up slopes on either side of the gorge.

Transport and dispersion models would be helpful to show the potential for contributions from more distant areas such as Seattle and Vancouver, B.C.

HYPOTHESIS 2: Visibility in the gorge, in particular, the east end is significantly impacted by urban and industrial sources in or near the gorge plus regional sources north and east of the gorge in the Columbia River basin in winter

Evidence to support hypothesis 2: Occasionally during winter, high pressure areas set up over the intermountain west, resulting in light winds over the Columbia River basin. Mixing heights are low and low clouds and fog are common in the gorge and Columbia River Basin providing an environment conducive to the formation of secondary aerosol. Pollutants accumulate and drift slowly into the gorge via drainage flows, where local sources add to the pollutant mix, resulting in the potential for significant buildup of pollutants as well as formation of secondary aerosols. Drainage flow would slowly transport pollutants down the Columbia River. Toward the west end of the gorge, the air accelerates, with winds becoming strongest near the exit of the gorge. Automated ASOS visibility measurements indicate widespread reduced visibilities in the area, commonly including the Tri-Cities (Richland-Pasco-Kennwick), The Dalles, Yakima, and Pendleton, and occasionally extending to Spokane. Near and east of the Scenic Area is the Boardman coal-fired powerplant and nearly collocated feedlots. Within the gorge are the towns of The Dalles (estimated population 12,175 and Hood River estimated population 20,400 (population estimates for July 1, 2000 from Portland State University population research center). There are also some small industrial sources in the gorge including aluminum smelters.

Additional information needed: Comparing aerosol and light scattering data along with wind speed and direction from monitoring sites on upwind and downwind side of towns in the gorge would give a good indication of the importance of their contribution to haze in the gorge. Light scattering and aerosol chemistry should be collected. Aethalometers may also be useful in identifying periods of impact from the towns (diesel, wood-burning). A few additional aerosol monitoring sites at rural areas in the Columbia River basin would be useful at determining the spatial consistency of the aerosol. Finally, monitoring sites near, but above the gorge would be useful in testing the hypothesis that substantial aerosol is being channeled down the gorge. Sites should be located both near the Columbia River and away from the river to see if concentrations are higher along the river. Differences in aerosol concentration and light scattering within and above the gorge could give an estimate of the contribution from sources in the gorge and areas within the Columbia River basin whose emissions drain into the gorge. Measurements of fog chemistry could also help determine the role of fog and clouds in secondary aerosol production. Tetroons could be released from various locations in the Columbia River Basin during winter to see if they are transported into the gorge.

Transport and dispersion modeling may be helpful to evaluate the potential for contributions to winter haze from regions north and east of the gorge, such as the Spokane area.

HYPOTHESIS 3: SO_2 and NO_X emissions from the Boardman coal-fired power plant just east and south of the gorge interact with ammonia from adjacent feed lots, in the presence of frequent low clouds and fog in winter to produce significant quantities of ammonium sulfate and ammonium nitrate that then moves into the gorge under drainage and larger scale pressure gradient flows.

Evidence to support hypothesis 3: The Boardman powerplant is a coal-fired unit operated by Portland Gas and Electric and located about 15 Km south of the Columbia River about 100 Km east of the Scenic Area boundary. The powerplant is rated at 560MW and is uncontrolled for sulfur dioxide. 1999 annual emissions included 16,578 tons of SO_2 and 8949 tons of NO_X (Oregon DEQ). There is a feed-lot immediately adjacent to the Boardman plant; a few kilometers away is another feed-lot. These feed-lots have emissions of ammonia that would help in the formation of secondary ammonium nitrate and ammonium sulfate. During winter, fog and low clouds are common. This would be expected to result in enhanced secondary aerosol formation. During these conditions, winds are light; drainage flow and the mesoscale pressure gradient could cause the sulfate and nitrate formed by the interaction of the powerplant and feed-lot emissions to be transported into the Scenic Area. During a site visit to the plant in early January 2001, the top of the stack was in cloud. In the absence of sufficient ammonia, but ample moisture, sulfuric acid and nitric acid aerosol would be formed. These would have the potential to cause ecosystem damage.

Additional information needed: More information is needed to estimate the magnitude of aerosol produced by the Boardman plant and whether the aerosol is transported into the Scenic Area. One method to determine conclusively if pollutants from the Boardman plant are transported into the gorge would be through the use of artificial tracers, such as certain perfluorocarbons. These materials could be released continuously from the plant during winter conditions that are likely to cause transport into the gorge and monitoring for the presence of these tracers in the gorge. This method also would give the dispersion factor of emission from the plant, which could be used to estimate maximum possible impacts from the plant. Measurements of sulfate and nitrate at the tracer locations could be analyzed to see if sulfate and nitrate levels in the presence of tracer is higher than sulfate and nitrate at nearby sites without tracer. The difference would be an estimate of the impact of the power plant. This method called Tracer -Aerosol Gradient Interpretive Technique (TAGIT) by Kuhns, et. al. (1999) has been used for the Project MOHAVE tracer study (Green, 1999) and will likely be used in the Big Bend Regional Aerosol and Visibility Observational (BRAVO) study (Green, et. al, 2000).

In the absence of perfluorocarbon tracers, enhanced meteorological monitoring in the region near the plant in conjunction with meteorological and trajectory modeling could be used to identify periods of likely transport of the emissions into the gorge. Aerosol measurements at various locations surrounding the site could be established to see if gradients exist between the upwind and downwind locations. Coarse PM may need to be monitored as well as fine due to the large amount of water growth associated with the aerosol (See hypothesis 4). It may also be desirable to collect and chemically analyze fog in the area near the plant. It would be worthwhile to investigate whether any endemic tracers are available, such as selenium, that would help determine the presence or absence of emissions from the plant in ambient samples. Also, high-time resolution sulfate and nitrate monitors mounted on aircraft could be used to map out 3-dimensional sulfate and nitrate concentrations in the vicinity of the plant.

Tetroons could also be released to follow air flow from the vicinity of the power plant. They could be set to follow air motion at estimated plume height. If tetroons released from near the plant travel though the gorge, plant emissions would also. These would be released on a forecast basis.

HYPOTHESIS 4: Following the evaporation of fog, sulfur and nitrogen containing aerosol droplets are too large to enter the IMPROVE $PM_{2.5}$ sampler, but are scattering much light, causing an apparent inconsistency between measured and reconstructed scattering in the eastern portion of the gorge (Wishram monitoring site).

Evidence to support hypothesis 4: In winter months, the nephelometer measured scattering is substantially higher than scattering reconstructed from the aerosol data and using the standard IMPROVE equations. Some, but not all of the difference can be explained by the presence of fine sodium and chlorine. NaCl is very hygroscopic and thus quite effective at light scattering in humid conditions. We have no speciated PM_{10} measurements. It seems likely that there is a significant amount of NaCl and $NaNO_3$ in the coarse mode (in the BRAVO study, $NaNO_3$ was mainly coarse). There is commonly fog and low clouds in the Columbia River gorge in winter. After the evaporation of fog, much of the hygroscopic aerosol may be in the coarse mode. Using the standard coarse mass scattering efficiency of 0.6 m^2g^{-1} could significantly underestimate coarse particle scattering under these conditions.

Additional information needed: Aerosol and light scattering measurements need to be made on the same size particles for comparability. Nephelometers with a $PM_{2.5}$ size cut inlet can be compared with the IMPROVE $PM_{2.5}$ speciated data. PM_{10} samples should be collected on the same substrates as are now collecting $PM_{2.5}$ and then fully speciated (elements, ions, OC/EC). Both $PM_{2.5}$ and PM_{10} need to be analyzed for ammonium ion as well to help determine the chemical form of the nitrogen and sulfur containing compounds. PM_{10} cut nephelometers can then be compared to the PM_{10} scattering data. Finally, a nephelometer without a size-selective inlet can be used to determine if any significant scattering by particles >10 μm is being measured. Ambient (unheated) nephelometers should be used to determine the scattering in each size range. Adding heated nephelometers would give an idea of the importance of water growth for each size range. Optical particle counters would give an estimate of the particle size distribution for particles greater than about 0.3 μm in diameter. More sophisticated measurements would include ramping humidity up and down and measuring the particle size distributions and light scattering at each humidity level. Finally, it would be informative to perform chemical analysis of fog water. This should include PH measurements to determine if the fog is acidic or not.

HYPOTHESIS 5: Sources within the gorge are only minor contributors to aerosol and haze in the gorge.

Evidence to support hypothesis 5: Figure 2-8 showed average monthly estimated aerosol major components for the Mt. Zion and Wishram monitoring sites. It is noted that for the months November through February, during which prevailing winds in the gorge are easterly (from east to west), component concentrations are higher at Wishram, which is the upwind site in the gorge. Similarly for the period May through October when the wind are predominately westerly, component concentrations (except fine soil) are higher at the upwind site (Mt. Zion). Thus, an argument can be made that because concentrations decrease downwind within the gorge, sources within the gorge cannot be contributing significantly to the aerosol and haze levels in the gorge. It can also be argued that the Mt. Zion and Wishram sites are affected by nearby sources whose influence would decrease significantly with distance downwind due to dispersion; if not for sources within the gorge, concentrations would decrease even more between the upwind and downwind sites. Scatterplots of aerosol component concentrations showed moderate relationships between the two sites, suggesting a significant regional component to the aerosol. Mt Zion and Wishram ammonium sulfate for summer (May-September) and Winter (November-March) had squared correlation coefficients (r^2) is about 0.5 for each. For OMC and EC, the 2 sites are highly correlated in summer (r^2=0.77 and 0.76, respectively for OMC and EC), but poorly correlated in winter (r^2=0.37 and 0.14 for OMC and EC)(see Figure 2-9). This suggests that regional sources of OC and EC are most important in summer, while local source of OC and EC are important in winter.

Additional information needed: A good emissions inventory can help identify sources that may be significant. Major point sources are reasonably well documented, but some sources such as trains and ships, and highway emissions are not well documented. Emission estimates from area sources such as Hood River and The Dalles could be improved upon as well. After review of emissions and other data, additional monitoring could address the hypothesis. Upwind and downwind monitoring of cities within the gorge could give an estimate of their potential effects on gorge visibility. Additional monitoring within the cities would give an estimate of the amount of aerosol or light extinction within the cities caused by local versus transported emissions. Speciated aerosol measurements and light scattering and light absorption would be appropriate measurements. It is recognized that for secondary aerosol, the full effect of emissions may be some distance downwind due to the time required for gas-to-particle conversion.

For trains and highways within the gorge, if the emission inventory indicates that these sources may be significant, high time resolution monitoring with aethalometers and nephelometers very close to these sources can give an idea of their importance, at least for primary particulate emissions.

The effects of significant sources of SO_2 within the gorge, such as aluminum smelters may be difficult to determine from monitoring due to the conversion time typically needed for secondary aerosol formation. During winter conditions with low clouds and fog, conversion may occur sufficiently quickly to be able to detect impacts nearby using speciated aerosol measurements upwind and downwind of the sources.

Modeling emissions from sources within the gorge may be reasonable using a box model.

HYPOTHESIS 6: Smoke from wildfires, prescribed fires, agricultural burning, and home heating occasionally causes significant visibility degradation in the gorge and surrounding areas.

Evidence to support hypothesis 6: Smoke contains substantial quantities of organic aerosol. Wildfires in the Pacific Northwest are most common in the late summer. Prescribed fire (reduced in scope in recent years) typically occurs in spring and late fall. Agricultural burning in the Willamette Valley and Columbia River Basin in autumn and wood burning for winter heating in cities in and near the gorge results in potential impacts from smoke nearly year-round. Occasionally large spikes are seen in organic (and elemental) carbon concentrations. There is no other likely explanation for these spikes other than being due to fire. Core (2001) found moderate correlations between potassium and organic carbon at Wishram and Mt. Zion. The best relationship between K and OC (r^2=0.74) was for Mt. Zion under east wind conditions (winter). This could be due to wood burning for home heating particularly in cities in the gorge such as Hood River and The Dalles, or other vegetative burning. The high correlation between Mt.

Zion and Wishram for summertime OC and EC (r^2=0.76 and r^2=0.77) could be hypothesized to be from burning affecting both sites during the same sampling period.

Additional information needed: It is critical to make measurements that can give us a good estimate of the importance of wood smoke and other major source types to organic carbon. The reconstructed extinction analysis indicates that organic carbon is a substantial contributor to haze in the Scenic Area. Analysis of aerosol organic carbon by GCMS can give estimates of OC from burning, diesel engines, gasoline engines, and meat cooking (Fujita et. al., 1998). The methodology includes Chemical Mass Balance (CMB) modeling based upon the relative abundance of various organic compounds identified in the GCMS analysis.

A substantial amount of organic material is needed for the GCMS analysis. This may necessitate using material from a number of different samples to get a composite for say a week of every day sampling or a month for every third day sampling. Another approach is to collect high-volume samples or multiple collocated samples, combining all samples for a day for one analysis. This sampling and analysis should be done for at least two sites- most likely Wishram and Mt. Zion. In addition, carbon-14 analysis could be done to determine the contemporary versus fossil carbon ratio.

HYPOTHESIS 7: Organic aerosols, a major component of fine mass in the gorge, do not have significant fraction that are hygroscopic. The substantial enhancement of scattering during high humidity conditions is mainly due to water growth of sulfur and nitrogen containing compounds.

Evidence to support hypothesis 7:
Whether or not a significant fraction of the organic aerosol exhibits water growth during high humidity conditions is very important in determining the extinction budget in the gorge. This is because while the concentration of organic compounds is estimated to be on average 40-50% higher than that of sulfur compounds (without water), the water growth of sulfur compounds causes the estimated extinction to be substantially greater. If a significant portion of the organic aerosol grows, then the relative importance of organic aerosol to light extinction could be significantly greater than is assumed in the instance of no water growth. Typically, most organic compounds are considered to be hygrophobic rather than hygroscopic (Malm et al., 2000). Indeed, the presence of organic material may in some cases act to prevent water growth of particles containing sulfur and organics both. Using statistical analysis among light scattering, a systematically varying RH, and aerosol speciation, Malm and Day (2001) concluded that organic compounds in the atmosphere are essentially hygrophobic. Saxena et. al., (1995) using results from TDMA analyses at two sites concluded organic aerosols may enhance or inhibit water growth. Mc Dow et al. (1994) found that wood smoke particles increased in mass by 10% as humidity increased from 40-90%, and found diesel exhaust to increase only 2-3% in mass with the equivalent increase in RH.

Additional information needed: High time resolution aerosol speciation data, along with nephelometer data with systematically controlled RH would allow a statistical approach such as by that by Malm and Day with higher time-resolution. Using a high-time resolution carbon analyzer (about 1 hour), in conjunction with high time resolution sulfate and nitrate analyzers would allow frequent measurements to be used to compare with light scattering as a function of RH. For example, if short-term changes in organic carbon concentration occur without a change in sulfate or nitrate, the scattering efficiency of the added organic carbon can be estimated. These efficiencies can be compared over a range of relative humidities to see if the efficiency increases with higher humidity. Also, use of particle size counters such as optical particle counters and differential mobility analyzers can be utilized in conjunction with the nephelometers and high-time resolution aerosol data to see if the distribution of particle sizes changes with different RH's. Again, the trick is to separate out effects of sulfate and nitrate particle growth.

HYPOTHESIS 8: The existing IMPROVE sites (Wishram and Mt. Zion) are generally representative of the eastern and western portions of the gorge and not unduly influenced by nearby sources. The sites are also generally representative of conditions below the rim of the gorge.

Evidence to support hypothesis 8: This hypothesis is significant in that, as the only sites monitored to date in the gorge, analyses and preliminary conclusions to date depend on the area of representation for these sites. Also, the suitability of using these sites for long-term trend analysis representative of the gorge as a whole depends upon the zone of representation of these sites. The siting of the sites is not in very close proximity to any significant sources. The sites are located 100-200 m above the river, and well below the rim of the gorge. They are not in very close proximity to any highway or railroad, although these sources are located below the sites. Mt. Zion is located relatively close to the Portland/Vancouver area and a pulp mill near the western end of the gorge, but not in very close proximity. Wishram is located approximately 15 Km from The Dalles, but this again is not particularly close. As far as being generally representative of conditions below the rim, there is no data at different elevations above the river. Hypothesis 9 (below) states that due to strong winds, conditions are well mixed below the rim, which would support the contention that the sites are representative of conditions below the rim. However, without vertical soundings, we do not know the depth of the mixing.

Additional information needed: To determine if local sources are significantly affecting the site, additional monitoring on either side of the sites and high-time resolution monitoring at the sites are useful. If aethalometer data (for example) for a site shows spikes on 5-minute data, it is likely that local sources are impacting the site. Also, if local sources are affecting a site significantly, a site some distance downwind should show a considerable reduction in impact due to dispersion. Monitoring should also be done above and below the site to see the vertical scale of representation for the site. Easy to operate, relatively inexpensive high time resolution monitors such as nephelometers on either side and above and below the site could help show the scale of representation of the site. High time resolution aerosol, such as nitrate, sulfate, and carbon, and aethalometer data could indicate what sources may be affecting the site by the temporal variation of each aerosol component. In additional full speciation at locations on either side of the site may be useful to help identify the impacts of certain sources with unique markers as well as giving an idea of the general area of representation for the site.

HYPOTHESIS 9: Air within the gorge is vertically well mixed year-round. In summer, it is typically capped by an inversion which results in the primary transport of outside air into the gorge via the east and west ends with little entering from above.

Evidence to support hypothesis 9: Hypothesis 9 is formulated mainly on theory, rather than observations, because there are no observations available. Adiabatic mixing from turbulence associated with the strong winds in the gorge may be expected to result in well-mixed conditions within the gorge, with a capping inversion above. Additionally, in summer, a subsidence inversion associated with the Pacific High would enhance the stability above the gorge, resulting in little mixing of air from inside and outside of the gorge. Air inside the gorge would be mainly affected by what enters the gorge from the east or west, depending on flow direction. An exception would be air entering from major side canyons, such as the Hood River.

It could be argued that there is significant mixing of air out of the gorge due to heating of the south-facing slopes on the Washington side. Upslope flows would enhance the exit of air from the gorge. It is important to resolve this issue in order to formulate conceptual models of regional source impacts and evaluate numerical transport and dispersion models.

Additional information needed: Upper-air meteorological data is needed to help determine vertical transport and mixing properties in and above the gorge. Radiosondes will give vertical profiles of temperature, dew point, wind speed, wind direction, and pressure. This enables us to see if a capping inversion is present at the top of the high wind layer or elsewhere. A limitation to radiosondes is that they only give information for the times they are released. Also during strong winds, the balloon may travel significantly in the horizontal as well as vertical direction. Radar wind profilers give wind speed and directions averaged over layers about 60 m thick, starting about 100 m above the ground. The instruments are automated, operate 24 hours a day and take little maintenance. RASS used in conjunction with the radar gives vertical profiles of virtual temperature, but typically only up to 1 km or so, which may not be sufficient to see the inversions of interest. For lower level winds, Doppler sodar collocated with the radar gives more resolution to the winds in the lower layers. The dearth of upper-air sounding sites in the area (the closest site is Salem, Oregon) adds to the importance of adding upper air observations.

Near-surface wind and temperature measurements on the slopes of the gorge, particularly south-facing slopes would be useful to consider if significant material is exiting the gorge this way. Nephelometers collocated with the meteorological measurements would also show (as air begins to flow upslope) if the aerosol exiting the gorge has higher concentrations than the air above. Significant differences in nephelometer readings or aerosol concentrations within and out of the gorge would indicate limited mixing above and below the gorge.

The additional meteorological measurements could also be used to evaluate and refine meteorological models, which could then be used as input to a dispersion model to help understand the 3 dimensional flow fields and mixing of air within and above the gorge.

Table 3-1 shows the recommended measurements, along with identification of which hypotheses are supported by the measurement. In Chapter 4, more detailed information is given regarding the recommended monitoring program, including suggested order of priority of measurements.

Table 3-1 Summary of]Measurements needed to support testing of each hypothesis

Measurements S=summer W=winter Y=year-round	Hypothesis 1 Portland	Hypothesis 2 Columbia River Basin	Hypothesis 3 Boardman powerplant	Hypothesis 4 Water growth >2.5	Hypothesis 5 In-gorge sources minor	Hypothesis 6 Smoke	Hypothesis 7 Organics not hygroscopic	Hypothesis 8 Existing sites representative	Hypothesis 9 Capping inversion above gorge
Nephs Upwind of Portland, Portland	S				S				
Nephs bottom, middle, top of gorge	S	W						S,W	S,W
Nephs near, away from river east of gorge		W			W				
Nephs along gorge east-west	S	W			S,W			S,W	
Ambient (unheated nephs)	S	W	W	W	S,W,Y		S,W,Y		
Nephs either side of towns, sources		W			S,W				
PM10 & PM2.5 nephs IMPROVE site				W	S,W,Y				
Ramped RH w/nephs				W			S,W		
Aethalometers Wishram, Mt. Zion	S							S,W	
Aethalometers either side of gorge cities		W			S,W				
DRUM aerosol IMPROVE sites + above gorge	S	W		W					
Speciated Aerosol upwind of Portland, Portland	S								

Measurements S=summer W=winter Y=year-round	Hypothesis 1 Portland	Hypothesis 2 Columbia River Basin	Hypothesis 3 Boardman powerplant	Hypothesis 4 Water growth >2.5	Hypothesis 5 In-gorge sources minor	Hypothesis 6 Smoke	Hypothesis 7 Organics not hygroscopic	Hypothesis 8 Existing sites representative	Hypothesis 9 Capping inversion above gorge
Speciated aerosol along gorge	S	W	W		S,W			S,W	
Speciated aerosol CR Basin		W			W				
Speciated aerosol above, middle, bottom gorge	S	W						S,W	S,W
PM10 & PM2.5 speciation IMPROVE site					S,W.Y				
GCMS organic analysis	S	W				S,W,Y	S,W		
High-time res. SO4, NO3, EC/OC IMPROVE site	S	W			S,W		S,W	S,W	
Fog water chemistry		W		W			W		
OPC/TDMA							S,W		
Surface met with all nephs	S	W			S,W				S,W
Radar wind profilers/RASS/ SODARS	S	W	W						S,W
Radiosondes	S	W	W						S,W
Tetroons	S	W	W						
Tracers			W						
Source sampling	S	W	W		S,W,Y			S,W	

4. PROPOSED MONITORING PROGRAM

This proposal envisions four monitoring study components: a 12-month expanded network; a 1-2 month summer intensive study; a 1-2 month winter intensive study; and long-term trends monitoring. The long-term trends proposal would likely entail continuation of some of the year-round monitoring, but cannot be planned without information developed by the other three study components. The 12-month expanded program and two seasonal intensive studies are described below.

In this section a list of measurements is presented. They correspond to the measurements described to support (or refute) the hypotheses, but are organized by instrument/measurement type. In the subsequent section the order of priority for the measurements is given along with the information is added with each measurement and the cost. In some cases, additional measurements of the same type are called for at additional sites (e.g. more aerosol gradient sites)

The measurements need to be designed to meet expected needs of quantitative source attribution models as well as in the development of conceptual models. This includes measurements to use for model input as well as for model evaluation.

4.1 Optical measurements

Nephelometers

Heated nephelometers will be deployed as a sort of high time resolution aerosol monitor, while ambient nephelometers will be used to characterize ambient light scattering. Both will help characterize the spatial and temporal patterns in the Scenic Area. These will be used in conjunction with meteorological data (especially wind speed and direction).

- Ambient nephelometers will give a measure of total light scattering including the effects of water growth. Comparison with collocated heated nephelometers will give an estimate of the importance of water growth. Ambient nephelometers are necessary only at sites where a complete extinction budget is needed (e.g. Mt. Zion and Wishram). At these sites PM_{10} cut and $PM_{2.5}$ cut ambient nephelometers should be used in addition to open-air nephelometers in order to evaluate fine and coarse particle scattering and compare to PM_{10} and $PM_{2.5}$ chemical speciation.
- Nephelometers placed along the gorge will be used to identify effects of sources or source areas propagating through the gorge (e.g. the Portland urban plume) and to consider the effects of in-gorge sources (cities) by the differences in upwind and downwind light scattering (all year).
- Nephelometers placed at different vertical heights will give some understanding of the vertical distribution of aerosol in the gorge and how it changes on a diurnal or seasonal patterns or with different synoptic weather conditions. It will help answer questions of whether material is mixed out of

the gorge during the day or due to turbulence or whether material in the gorge stays confined to the gorge (all year). A location in mid-gorge e.g. Cascade Locks is preferred.

- Nephelometers placed in the Portland/Vancouver urban area and upwind of Portland can give an idea of the increase in light scattering across the Portland area and presumably due to the urban area (mainly summer).
- Nephelometers placed at some distance (10-20 km away from the gorge on either side of an along river monitoring site east of the gorge can give an idea of whether material is being channeled narrowly along the river, or is spread out horizontally (winter).
- RH controlled nephelometers with RH ramped up and down to see effect of water growth. These are most effective when used with high-time resolution aerosol speciation data.

Aethalometers

Aethalometers measure light absorption through a filter tape. The measurements are typically reported as mass concentration of black carbon, but can also be interpreted as ambient light absorption. The measurements have time resolution of 5 minutes or more depending upon ambient levels; thus they are useful in determining whether local sources such as diesel emissions are affecting the site. They may also help identify impacts from urban areas, which have elevated light absorption. Aethalometers placed at the Mt. Zion and Wishram IMPROVE sites would identify any impacts from local sources and add to the characterization of the aerosol and optical properties of the sites. An aethalometer at Mt. Zion may indicate arrival of air from the Portland urban area. An additional aethalometer at a nephelometer and surface meteorology site between The Dalles and Hood River could help give an indication of impact from these towns.

4.2 Aerosol and Gaseous Measurements

As light scattering and light absorption by aerosols is the main cause of visibility impairment, aerosol measurements are critical to understanding haze, including the source types and source areas responsible. A wide-variety of aerosol measurements are proposed, covering time-scale of minutes to a day and from chemical speciation of most elements to identification of individual compounds and organic aerosol speciation. As with nephelometers, aerosol measurements can be used to determine gradients in the horizontal and vertical, with high time resolution for some measurements. The added benefit of speciated aerosol measurements over nephelometers is identification of which chemical components are changing in time or space. However, high time resolution aerosol speciation is more costly and difficult than high time resolution light scattering from nephelometers. High time resolution aerosol in conjunction with nephelometer data can be very effective for assessing the causes of haze.

Gaseous measurements can help especially for the air quality models. SO_2 in conjunction with SO_4 measurements give a measure of the fraction of gas-to-particle conversion; VOC measurements can help in the evaluation of the air quality models especially for secondary organic aerosol from biogenic emissions. Ammonia (NH_3) is useful to help evaluate the emissions inventory and to determine availability of ammonia for full neutralization of SO_4 and NO_3 aerosol.

Aerosol and gas measurements proposed include:

- $PM_{2.5}$ and PM_{10} monitoring at Wishram and Mt. Zion with full chemical speciation. Currently PM_{10} is only done on Teflon and is not analyzed for chemical species. The monitoring should be done for one-year on the IMPROVE schedule and daily for intensive studies. The analysis should also include NH_4 and SO_2, which are not currently done. These measurements are needed for calculation of the extinction budget.

- Deployment of DRUM size-resolved impactors at a minimum of Mt. Zion and Wishram, and one site outside the gorge representative of regional conditions. These can give 1-hour time resolution speciated aerosol in 3 or 8 size ranges. Sites need to be visited once per six weeks. Inexpensive sampling can be done for long periods of time and analyzed later for exceptional events. These measurements, in conjunction with nephelometer data and meteorological data will help in the identification of which sources impact a site at a given time. The site above the gorge will give the regional background. By comparison with the sites in the gorge, the regional versus transport through the gorge difference can be obtained for each element. This could be quite useful for studying the effects of Portland in the summer, for example. They also give information on size of aerosol needed for Mie-theory calculations and will give additional information regarding the water growth of aerosols.

- Organic speciation using GCMS at a minimum of Mt. Zion, Wishram, and one site above the gorge. This, in conjunction with Chemical Mass Balance modeling (CMB) will allow us to apportion organic aerosol to key source types (burning, diesel, gasoline vehicles, and meat cooking).

- Speciated aerosol at a few locations along the gorge, best if situated with nephelometers and surface meteorology sites. This will allow us to see how chemical component concentrations change with distance downwind in the gorge. If the ratio of the mix changes, then certain compounds must be added due to sources or chemical transformation (e.g. SO_2 to SO_4) (or selectively removed, which is less likely). This will help tell what sources in the gorge are contributing.

- Speciated aerosol at river-level-mid gorge and top of gorge at a site in mid-gorge e.g. Cascade Locks. Useful in conjunction with collocated nepehlometers and surface meteorology to evaluate vertical mixing in-gorge.

- Speciated aerosol in Portland (at least 3 sites) and upwind (minimum 1 site) in summer (minimum). Along with nephelometers, gives estimate of contribution of Portland to gorge aerosol. Also, may provide source signature for Portland, if significantly different from upwind sites.

- Speciated aerosol at multiple sites in Columbia River basin in winter. Gives information on spatial consistency of aerosol in Columbia River basin, which is often upwind of gorge in winter. Could help identify contributions from significant sources.

- High-time resolution SO_4, NO_3, EC/OC at Mt. Zion in summer and Wishram winter (minimum). Can help evaluate local versus regional scale of impacts, of sites, possibly identification of specific sources impacting sites, and could help with refining scattering efficiency and water growth factors when used with other instruments (e.g. wet/dry nephelometers or RH ramped nephelometers).

- Measurements of additional gas-phase compounds, especially NH_3, SO_2, and speciated organic gases. Useful for air quality modeling.

- Fog water sampling and chemical analysis during winter. Use to evaluate acidity of fog for possible ecosystem and cultural resource damage. May also be useful to help understand aerosol properties and visibility effects when fog evaporates.

- Condensation particle counter, optical particle sizer, differential mobility analyzer. Deploy during summer and winter intensive studies. Determine particle size (needed for theoretical scattering calculations). Used with high-time resolution chemistry help to understand aerosol water growth. Large concentration of condensation nuclei indicates a nearby source.

4.3 Meteorological measurements

Meteorological measurements, especially wind speed and direction are needed to understand source-receptor relationships. They are also necessary for input to and evaluation of meteorological models. They most useful when used in conjunction with other measurements such as light scattering and speciated aerosol.

Proposed measurement include:

- Surface meteorology: wind speed, direction, temperature, relative humidity at main aerosol monitoring sites and all nephelometer sites. Wind speed and direction will help confirm the sources which may be contributing to the measured light scattering or aerosol concentrations. RH is needed for estimated water growth used for reconstructed scattering calculations. Temperature at different vertical levels in the gorge can give an idea of stability and vertical mixing of aerosol. Surface meteorological data can also be used for input to or evaluation of meteorological models.

- Radiosondes: Radiosondes give vertical profiles of horizontal wind speed and direction, temperature, relative humidity, and atmospheric pressure. Radiosondes released within the gorge will give us information regarding the transport of material within the gorge. The temperature structure will indicate if capping inversions are present that prevent mixing with material above the gorge. Also vertical profiles of wind speed will help in estimated the speed of transport of material through the gorge. The radiosondes will also be helpful in evaluating meteorological models. Radiosondes should be released during typical summer and winter conditions and 3 or more times per day to help capture diurnal cycles in wind and thermal structure.

- Radar wind profilers with RASS and Sodar. Radar wind profilers typically give hourly averaged winds at intervals of 60 meters from about 100 m AGL to 5000 m (or so) AGL. These operate continuously with little maintenance. As with radiosondes, they help understand vertical variations in the horizontal wind; they also give the vertical velocity component of wind. Radio acoustic sounding system (RASS) used in conjunction with the radar wind profilers give vertical profiles of virtual temperature to about 1000 m. Similar to the radiosonde temperature data, information regarding vertical stability below about 1000 m can be obtained. Sodars collocated with the radar wind profiler can give higher resolution wind data (horizontal and vertical) at low levels and is used to supplement the radar wind profilers in the lower layers of the atmosphere. As well as helping to understand flow patterns and pollutant transport, he measurements can be used as input to meteorological models and to evaluate the performance of the models. A radar wind profiler in mid-gorge would probably be of most use.

4.4 Tracers

These measurements would track transport or transport and dispersion from emissions sources or source areas. They are also valuable in evaluating transport and dispersion models.

- Tetroons. Tetroons are constant pressure balloons that are tracked by radio. These follow airflow and give an indication of where pollutants may travel. A tetroon released and set to flow at the height of a power plant stack may track the centerline of the emissions from the plant. Release of multiple tetroons at a location could give an estimate of horozontal dispersion. However, as the tetroons are confined to a set pressure (height), dispersion from vertical shear of the horizontal wind would not be properly realized. Still, it should give a reasonable indication of whether emissions from a location where the tetroons are released would travel into the gorge. A prime candidate area for tetroon releases would be near the Boardman coal-fired powerplant in winter. Also, potential release sites would be in around the Portland area during summer to see how many are transported into the Columbia River Gorge. Potential conflicts with aircraft would have to be addressed.

- Perfluorocarbon tracers. Perfluorocarbon tracers (PFT's) are chemical compounds that have very low atmospheric background (generally <1 part per quadrillion). A release and ambient monitoring of these compounds gives the transport and dispersion properties of the air into which it is released. They do not account for wet or dry deposition, or chemical conversion that will affect gas and particles in the atmosphere. When used successfully, they can be very effective at documenting the transport of emissions in to an area of interest as well as giving the dispersion factor. These are very useful for evaluating transport and dispersion models as well. PFT's could be injected into the stack of the Boardman powerplant in winter and monitored in the National Scenic Area to see if the emissions from the plant are entering the gorge. Consideration of aerosol concentrations gradients between where the plant emissions are noted by tracer concentrations above background, and locations with no elevated tracer levels gives a quantitative estimate of sulfate and nitrate due to the power plant (TAGIT model).

4.5 Emissions

For evaluation of alternative emissions scenarios, in addition to having accurate meteorological fields and chemical modeling, it is necessary to have a good emissions inventory. An emissions inventory for SO_2, NO_X, NH_3, primary organic aerosol, and soot, are needed minimally. This includes emissions from all potential source types affecting the gorge – industry, gasoline and diesel motor vehicle, trains, ships, area sources (cities and towns), etc. and a proper spatial and temporal distribution of the emissions. After a review of emissions inventories available, it is likely that more inventorying will be needed. This may involve source sampling to help quantify certain emissions.

Additional source characterization may be appropriate to establish source profiles for certain sources for use in Chemical Mass Balance (CMB) modeling. A review of source types present in the area and the availability of appropriate source profiles for these sources should be made. Source sampling could then be done to generate source profiles for potentially significant source types without appropriate existing profiles.

Even without using emissions in air quality models, in some cases, the inventory may make it apparent as to which sources are or are not likely to be important, based upon their size, proximity to a monitoring site, and wind direction.

In Table 4-1, the recommended measurements are presented in order of priority.

Table 4.1 Recommended measurements and estimated costs in order of priority.		
Measurement	What it tells us	Cost
More complete characterization of existing sites		
Ambient nephelometers at Wishram, Mt. Zion – minimum 1 year	Light scattering including water growth effects	
$PM_{2.5}$ cut and PM_{10} cut ambient nephelometers at Wishram, Mt. Zion – 1 year	Fine and coarse particle scattering, comparison with $PM_{2.5}$ and PM_{10} speciation data	
PM_{10} speciation at Wishram, Mt. Zion Include $NH4^+$, SO_2 IMPROVE schedule, 1 year- analyze at least ½ + special interest	Speciation for comparison with coarse particle scattering	
Aethalometers at Wishram, Mt. Zion – minimum 1 year	High time resolution light absorption– impact of local sources? See Portland material moving through?	
Horizontal and vertical gradients in gorge year-round, in-gorge vs out-of gorge sources		
Additional heated nephelometers with surface meteorology along Gorge (3 minimum e.g. Cascade Locks, another below Hood River, between Hood River & The Dalles)	B_{sp} gradient along gorge/effects of local cities	
Heated nephelometers at 3 levels in mid-gorge- river, above river, rim	Vertical mixing/b_{sp} gradients	
Speciated $PM_{2.5}$ 3 nephelometer sites along gorge- IMPROVE schedule, 1 year, analyze ½ + special interest	Species gradient along gorge/local city effects	
DRUM samplers vertical nephelometer sites 1 year, analyze periods of interest	Vertical gradients of species (at least sulfur)	
Speciated $PM_{2.5}$ at nephelometer site at top of gorge, IMPROVE schedule, 1 year, analyze ½ + special interest	In gorge/above gorge species gradient	
Speciated organic aerosol using GCMS Wishram, Mt. Zion, 1 site above gorge. IMPROVE schedule one-year, monthly composite analyses?	Contribution of burning, gasoline, diesel, and meat-cooking to organic carbon with CMB	
Summer intensive period studies – effects of Portland/Vancouver		
Nephelometers upwind (downriver) of Portland (one or more), Portland (3)	Change in light scattering due to Portland urban area	
Speciated aerosol upwind of Portland (1 or more)/ Portland (3), along gorge sites (5), top of gorge (1 or more) Daily for 30 days July-August	Chemical speciation changes due to Portland urban area – relate to light scattering changes	
Radiosondes 4/day for 30 days 2 sites, one mid-gorge, one mouth of gorge (e.g. PDX)	Vertical profiles of stability and wind (mixing, transport speed)	$60K
High –time resolution SO_4, NO_3, EC/OC	Chemical species change in time –	

Mt. Zion or central gorge site.	relate to nephelometer data	
DRUM samplers 5 along gorge sites 30 days- analyze periods of interest	High-time res. speciation- Track movement of Portland plume	
Radar wind profilers & sodars 2 sites	Vertical wind profiles	
NH_3, SO_2, NO_X –Mt. Zion	Aerosol neutralization, sulfur gas/particle split, emission inventory and model evaluation	
Winter Intensive period studies – Boardman plant, CR Basin sources, in-gorge, fog water		
Nephelometers near and away from river either side- eastern gorge minimum 3 sites	Extent of channeling of emissions eastern gorge	
Speciated aerosol near and away from river Eastern gorge- minimum 3 sites 45 days	Species channeled vs regional	
Speciated aerosol 5 along gorge sites, 1 above gorge site 45 days	Gradient within gorge, upwind/ downwind of gorge cities	
Radiosondes 4/day for 30 days 2 sites, one mid-gorge, one east end of gorge	Mixed-layer depth, vertical wind (transport) structure	
Fog water sampling and chemical analysis- Boardman powerplant area, central gorge as possible during 45 day period	Potential ecosystem affects	
High –time resolution SO_4, NO_3, EC/OC Wishram	Chemical species change in time – relate to nephelometer data	
Radar wind profilers & sodars 2 sites	Continuous vertical wind structure	
NH_3, SO_2, NO_X -Wishram	Aerosol neutralization, sulfur gas/particle split, emission inventory and model evaluation	
Tetroons from Boardman powerplant area By forecast during 45-60 day period	Potential transport of power plant products into gorge	

Presented next are measurements that would strengthen the above studies and would be done with a higher level of funding.

Supplemental measurements at higher funding levels		
Expanded aerosol monitoring network summer study- e.g. Mt. Hood, Columbia River mouth, south of Tacoma, south of Portland, additional above gorge, east of Wishram, top of Mt. Zion, Mt. Ranier- 30-60 days	Aerosol gradients for larger area and with more resolution	
Expanded aerosol network winter study- e.g. along Hood River drainage, Portland, few sites Columbia River Basin, above gorge- 45-60 days	Aerosol gradients for larger area and with more resolution	
Aerosol Microphysics studies- nephelometer with RH ramped, particle growth with TDMA, SEM analysis	Better understanding of water growth of particles	

High –time resolution SO_4, NO_3, EC/OC Wishram and Mt. Zion 1 year	Year-round knowledge of chemical species changes in time	
Source sampling and chemical analysis for selected sources- e.g. paper mill, aluminum smelter, Boardman powerplant	Used to identify presence of particular sources/ receptor modeling	
Additional radar wind profilers/sodars, operation for 1 year	Better description of meteorological fields, full annual cycle- useful for model evaluation and input	
2 Additional aethalometers either side of City of Hood River – year round	Help determine presence of emissions from gorge cities, especially winter wood burning	
Tracer studies- e.g. Boardman powerplant winter	Determine if power plant affects gorge- use with chemistry data for estimated impacts (e.g. TAGIT)	

5. PROPOSED DATA ANALYSIS AND MODELING PROGRAM

Note to workshop participants: Sufficient time was not available to fully describe the data analysis and modeling plan. Workshop participants are encouraged to help further define these components, particularly the modeling program and measurements needed to support the modeling.

Much can be learned from the review of data collected from the monitoring program. This includes the consideration of horizontal and vertical gradients in quantities such as light scattering, light absorption, and aerosol composition, and how these changes relate to meteorological conditions such as wind speed and direction, mixing, etc. The high-time resolution of one-hour or less proposed for some of the measurements, in conjunction with meteorological data and emissions information, will be illuminating as to the transport and mixing of visibility reducing aerosols affecting the Scenic Area. These analyses will be of considerable value in the formulation of conceptual models of the way in which emissions, meteorology, and visibility-reducing aerosol are related in this region. These analyses will also be quite useful for aiding the selection, further development, and evaluation of quantitative models of source apportionment.

Many of the ways in which these measurements will be used for data analysis were described in the hypotheses and measurements sections of this plan. Another way to organize a discussion of data analysis is by the types of analysis.

Descriptive analysis includes a summarization of the data collected. Several purposes are served by descriptive analysis including data quality assurance and validation, data familiarity, and a means of testing the plausibility of some aspects of prospective conceptual models. An example of descriptive data analysis is summarizing temporal and spatial patterns of aerosol concentration.

Association analyses are similar to descriptive analyses except that more than one parameter is considered at a time. Like descriptive analysis, association analysis is an important step in data quality assurance and validation, promotes data familiarity, and is a means to test conceptual models. In addition association analysis allows precision (and other quality descriptors) to be directly determined from collocated measurement, permits assessment of aerosol and optical closure at some of the more complete monitoring sites, and may reveal insightful relationships concerning the conditions associated with and causes of haze. They also test our assumptions of the reconstructed mass, scattering, etc. Examples of relevant closure exercises are presented below:

- Fine mass ($PM_{2.5}$) and PM_{10} closure – compare the sum major of measured species combined with the mass of the assumed common oxides with the gravimetric fine and PM_{10} mass; should also include ion balance
- Optical closure – compare the sum of the measured light scattering and light absorption with the total measured light extinction; and

- Scattering, absorption, and extinction budgets – compare the sum of the calculated scattering and extinction for the major aerosol components (component concentration multiplied by a scattering or extinction efficiency that may be a function of relative humidity) with the measured total light scattering or extinction. For size-selective measurements of scattering, absorption, or extinction (e.g. nephelometers with $PM_{2.5}$ inlets), compare with reconstructed scattering, absorption, or extinction from $PM_{2.5}$ aerosol component concentrations.

In order to know how applicable special study results are to other periods of times (other times of the year and other years), the representativeness of the study period must be determined. The approach used to determine representativeness of the study period starts by comparing meteorological and air quality data during the study period with similar data for other times during the year and for the same period of time in previous years. Significant changes in emissions also need to taken into account when considering representativeness. Simple statistical tests and comparisons of frequency distribution plots for the study period and other periods show the degree of similarity of the study period is to those other period for each parameter.

Attribution analyses are quantitative assessments of the contributions by important sources. Attribution methods are typically divided into two broad categories: predictive air quality models and receptor models. Air quality models use meteorological measurements, pollutant emissions data, and calculated or assumed boundary conditions to calculate the transport, dispersion, deposition and chemical transformation of pollutants emitted into the atmosphere at specific known emission source locations. Receptor models rely on the ambient air quality measurements made at monitoring site and the characteristics of the likely emission sources to infer the contribution of those sources.

The proposed measurements program would allow for a considerable amount of information to be obtained regarding source types and area responsible for haze in the Columbia River Gorge. Gradients in light scattering and aerosol components, speciation of organic aerosols, high time resolution measurements, combined with meteorological measurements will be quite helpful in defining source-receptor relationships and developing conceptual models regarding the causes of haze in the gorge. The measurements will also be useful for running Chemical Mass Balance, especially for the organic carbon sources. Determining source-receptor relationships for secondary compounds of interest (mainly sulfate and nitrate) is more problematic.

One of the main goals of the study is the development and application of models that can be used to accurately assess changes in air quality and visibility within the Scenic Area due to changes in emissions. Before listing the steps needed to be taken to achieve this goal, it is useful to first point out some of the challenges that must be overcome en route.

Receptor modeling might be quite useful for some compounds such as organic aerosol. However, for secondary compounds, classic receptor models such as CMB cannot be used; some hybrid models may be useful for this purpose, but some critical assumptions are often necessary. While in some cases, receptor modeling may identify individual unique sources, more typically it identifies source types. Other information, such as transport direction, etc. must still be used to separate effects out by individual source or source area. The general assumptions required for CMB are given by Watson (1984).

It is desirable, to include all the physical process explicitly in a model, such as is the goal of source-oriented models such as Eulerian grid models. As a class, they (with the necessary input data) have the potential to provide a complete tool for air quality impact assessment. They explicitly include an emissions inventory, 3-dimensional meteorological fields needed to transport, disperse, chemically transform, and deposit emissions throughout the region of interest.

The modeling relies on an accurate knowledge of emissions of primary and precursor compounds, an adequate representation of the meteorological fields (wind speed and direction, turbulence, moisture, precipitation, etc.), and accurate treatment of chemical reactions. In highly complex terrain such as the Columbia River Gorge, proper representation of the transport and dispersion properties of the flow is at the limits of the current state of meteorological modeling (Green and Tombach, 2000). Pitchford et. al. (2000) demonstrated with perfluorocarbon tracer data that winter –time average concentrations of tracers released within the Colorado River Canyon were greater within the Canyon at distances hundreds of kilometers downwind then they were at nearby locations above the canyon rim. Modeling invariably smoothes out the terrain features, which may lead to less confinement of the flow than is actually occurring. In order to have a potential for success, the model terrain must be able to realize the gorge as a continuous passage, near sea-level and with the approximately correct height and width. Unless the model terrain meets these requirements, it is inappropriate to attempt modeling of emissions entering, moving through, or exiting the gorge. Thus, high spatial resolution will be required.

Limitations in emissions inventories will also affect modeling adequacy. Biogenic emissions in particular have a high level of uncertainty. Ammonia emissions are also likely to have considerable uncertainty. Emissions from burning (wildfires, prescribed fires, home heating are also highly uncertain, but the measurement, data analysis, and receptor modeling components of the study may be sufficient to characterize impacts from these sources. Sources of SO_2 should be reasonably well quantified. NO_X emissions estimates may also be reasonably good.

The ultimate goal of the modeling will be to have a complete system (emissions, meteorological fields, air quality model) that can accurately explain the past and thus can, with some confidence, predict the future given a variety of emissions scenarios. A sequence of events could lead to attaining this goal:

- Use high-spatial resolution mesoscale meteorological modeling (e.g. MM5) for periods of special interest in the gorge that have enhanced meteorological and air quality data (e.g. summer and winter intensive study periods).). Horizontal grid spacing would probably need to be less than 1 Km in and near the gorge to resolve the topography sufficiently well.

- Withhold some of the additional meteorological data (surface and upper air) to evaluate the performance of the model. Make model modifications as appropriate. If model is performing well, it may help to define flow features, mixing, etc. within the gorge and assist in the formulation of the conceptual models.
- Run back-trajectories or dispersion models backwards in time to identify areas likely contributing ambient concentrations at aerosol sites for given sampling periods. Compare with results from data analysis and receptor modeling.
- Evaluate transport and dispersion with tracer studies, if resources permit.
- After compiling an acceptable emissions inventory, perform limited air quality simulations for portions of the intensive studies. Lagrangian models such as ISOPART could be tried first. More complicated Eulerian grid models such as CMAQ could also be tried. Evaluate models against aerosol data.
- Perform reconciliation among the receptor and source models and data analysis. Do the models agree? Are the results consistent with conceptual models developed with the measurement data?
- If the modeling system has been determined to acceptably reproduce the study period data, apply to periods for which the model has not been run. If adequate performance is achieved, the modeling system should be able to give a good evaluation of the expected changes in concentrations given various emissions scenarios.
- Apply modeling system to the various emissions scenarios.

In the short-term, use of existing MM-5 fields at 12 km horizontal grid spacing may be useful as a screening tool for estimating potential impacts (background or boundary conditions) from sources somewhat distant from the gorge, such as the Seattle/Tacoma area and Vancouver, B.C. However, the transport of these emissions into the gorge cannot be accurately predicted with this resolution.

After the formulation of conceptual models is completed, the main task of selecting which models are appropriate for achieving study goals can be determined. The information leading to the development of the conceptual models will enable us to know what physical processes are most important for the models to accurately simulate.

The measurements made in support of conceptual model development will also be useful for input to and evaluation of quantitative models for evaluating changes in air quality due to changes in emissions.

6. DATA MANAGEMENT

The number and variety of measurements in large collaborative efforts generate volumes of data that must be stored in an organized, easily accessible format. A single organization must be responsible for assembling and maintaining the study database.

Data from the proposed study can be grouped roughly into one of four categories.

I. Automated pseudo-continuous samples (Analysis occurs at the time of sample procurement): This category encompasses data from instruments that are self-contained sample procurement and measurement devices. Typically, measurements are made at regular intervals that range from several minutes to one or two hours. Examples include surface meteorology, continuous measurement of airborne species (SO_2, SO_4^{2-}), and nephelometers.

II. Time-averaged samples (analysis occurs post-sample procurement): This category contains samplers that utilize a substrate such as a filter that requires chemical analysis in the lab. Generally the durations of the measurements are between one hour and one day. Examples include measurement of PM_{10} and $PM_{2.5}$ on filters, and speciated chemical analysis of aerosols.

III. Upper Air data: This category is different from the previous two because measurements can be at irregular intervals and because the same parameter(s) is measured at multiple altitudes at the same site.

IV. Size and Chemically Speciated Aerosol Data: This category includes analysis methods that break down particle measurements both by particle size and by chemical composition. SEM analysis of polycarbonate filters is an example of this type of measurement.

Importing Data into the Database

Data received by the data manager from the various groups that are collaborating in the study has to be imported into a master database. The primary objective of the data management portion of the study is to provide an efficient and simple way to extract desired data from a well-documented, accurate, and uncomplicated database. This requires that a thorough account be kept of all data that end up in the database. The first step in this process is ensuring that data providers and the data manager are in agreement on a consistent, well-documented format for the raw data files. Important factors include measurement units, time reporting conventions, site mnemonics/codes, mnemonics and codes for the parameters that are measured, and data flagging conventions.

Once the conventions for reporting data are firmly in place, computer codes, written in programs such as Microsoft Visual Basic and Visual C++ will be used to import data into the database and convert measurement units, sampling times, measurement locations and so forth into the standard formats of the database. In addition, during the data import process Level 1b validation is applied to each data set; it is expected that Level 1a validation is performed by the data provider.

Data Validation

Mueller (1980), Mueller et al., (1983) and Watson et al. (1983, 1989, 1995) define a three-level data validation process that should be mandatory in any environmental measurement study. Data records are designated as having passed these levels by entries in the VAL column of each data file. Data providers are asked to report data only after Level 1A validation has been performed. These levels, and the validation codes that designate them, are defined as follows:

- **Level 0 (0)**: These data are obtained directly from the data loggers that acquire data in the field. Averaging times represent the minimum intervals recorded by the data logger, which do not necessarily correspond to the averaging periods specified for the data base files. Level 0 data have not been edited for instrument downtime, nor have procedural adjustments for baseline and span changes been applied. Level 0 data are not contained in the database, although they are consulted on a regular basis to ascertain instrument functionality and to identify potential episodes prior to receipt of Level 1A data.

- **Level 1A (1A)**: These data have passed several validation tests applied by the network operator that are specific to the network. These tests are applied prior to submission of data to the data manager. The general features of Level 1A are: 1) removal of data values and replacement with -99 when monitoring instruments did not function within procedural tolerances; 2) flagging measurements when significant deviations from measurement assumptions have occurred; 3) verifying computer file entries against data sheets; 4) replacement of data from a backup data acquisition system in the event of failure of the primary system; 5) adjustment of measurement values for quantifiable baseline and span or interference biases; and 6) identification, investigation, and flagging of data that are beyond reasonable bounds or that are unrepresentative of the variable being measured (e.g. high light scattering associated with adverse weather).

- **Level 1B (1B)**: After data are received by the data manager, converted, and incorporated into the database, validation at level 1B is performed. This is accomplished by software which flags the following: 1) data which are less than a specified lower bound; 2) data which are greater than a specified upper bound; 3) data which change by greater than a specified amount from one measurement period to the next; and 4) data values which do not change over a specified period, i.e., flat data. The intent is that these tests will catch data which are obviously nonphysical, and such data will be invalidated and flagged. Data supplied by project participants which fail these tests may result in a request for data re-submittal.

- **Level 2 (2)**: Level 2 data validation takes place after data from various measurement methods have been assembled in the master database. Level 2 validation is the first step in data analysis. Level 2 tests involve the testing of measurement assumptions (e.g. internal nephelometer temperatures do not significantly exceed ambient temperatures), comparisons of collocated measurements (e.g. filter and continuous sulfate and absorption), and internal consistency tests (e.g. the sum of measured aerosol species does not exceed measured mass concentrations).

- **Level 3 (3)**: Level 3 is applied during the reconciliation process, when the results from different modeling and data analysis approaches are compared with each other and with measurements. The first assumption upon finding a measurement which is inconsistent with physical expectations is that the unusual value is due to a measurement error. If, upon tracing the path of the measurement, nothing unusual is found, the value can be assumed to be a valid result of an environmental cause. The Level 3 designation is applied only to those variables that have undergone this re-examination after the completion of data analysis and modeling. Level 3 validation continues for as long as the data base is maintained.

A higher validation level assigned to a data record indicates that those data have gone through, and passed, a greater level of scrutiny than data at a lower level. The validation tests passed by Level 1B data are stringent by the standards of most air quality and meteorological networks, and few changes are made in elevating the status of a data record from Level 1B to Level 2. Since some analyses are applied to episodes rather than to all samples, some data records in a file will achieve Level 2 designation while the remaining records will remain at Level 1B. Only a few data records will be designated as Level 3 to identify that they have undergone additional investigation. Data designated as Levels 2 or 3 validations are not necessarily "better" than data designated at Level 1B. The level only signifies that they have undergone additional scrutiny as a result of the tests described above.

Database Architecture

There are two different designs for the database, a master database, and a user database. The master database includes information that is superfluous for the day-to-day user, but important for the data manager. Examples of such information are: the line numbers in the original data files that are associated with each data point, the units used by the data provider before conversion to standard units, and the dates that data were imported into the database. While much of the information related to the data points that appear in the master database does not appear in the user version of the database, some fields such as data validity flags and sample analysis method descriptions are included for completeness.

Within the master database, all data are stored in tables with consistent structures. Within the data tables there exists one record for every measurement that results in a datum.

7. QUALITY ASSURANCE

A well-defined program to assure the quality of data collected in a monitoring program is essential to the credibility of its results. Each of the monitoring components (e.g. aerosol sampling, laboratory analysis, & upper air meteorology) has written protocols that describe how the method is done. These protocols also identify the quality control procedures used to avoid problems with the data and to document their quality. An independent quality assurance audit program is used to check how well the protocols, especially the quality control procedures, are being followed.

The major emphasis of independent quality assurance is upon verifying the adequacy of the participants' measurement procedures and quality control procedures, and upon identifying problems and making them known to project management. Although routine audits play a major role, emphasis is also placed upon the efforts of senior scientists in examining methods and procedures in depth. This approach has been adopted because fatal flaws in experiments often emerge not from incorrect application of procedures by operators at individual sites or laboratories, but rather from incomplete procedures, inadequately tested methods, deficient quality control tests, or insufficient follow-up of problems.

At the beginning of the study, auditors should review study design documents to ensure that all measurements are being planned to produce data with known precision and accuracy. The auditors should focus on verifying that adequate communications exist between measurement and data analysis groups to ensure that measurements will meet data analysis requirements for precision, accuracy, detection limits, and temporal resolution. Quality control components of the measurements include: determination of baseline or background concentrations and their variability; tests for sampler contamination; adequate measurements of aerosol and tracer sampler volume and time; blank, replicate, and collocated samples; assessment of lower quantifiable limits (LQL), and determination of measurement uncertainty at or near the LQL; regular calibrations traceable to standard reference materials; procedures for collecting QC test data and for calculating and reporting precision and accuracy; periodic QC summary reports by each participant; documented data validation procedures; and verification of comparability among groups performing similar measurements.

Field performance and system audits should be conducted at each of the monitoring sites. Measurement systems to be audited at many sites include aerosol sampling, meteorological instruments, and nephelometers. Performance audits will include flow rate checks of the aerosol samplers and checks of the settings on the nephelometers. System audits will evaluate the adequacy of project components such as Standard Operating Procedures, measurement documentation, operator training, quality control checks, and sample chain of custody.

System and performance audits of additional special measurements should be done. Nephelometers should be challenged with SUVA gas and high-sensitivity sulfur dioxide monitors and continuous particulate sulfate monitors should both be challenged with an independent SO_2 audit standard gas. Flow rates should be audited on aerosol instruments designed to measure aerosol composition and particle size distribution. System audits should be conducted on the radar profiler/RASS systems. The profiler/RASS audits will focus on the orientation of the profiler modules and on the operational status of the instrument.

Field system audits will be conducted at any tracer release sites. The audits will focus on the ability of the tracer release system to control the tracer emission rates and to quantify the rates accurately and precisely. The audits will also evaluate the adequacy of project components such as Standard Operating Procedures, measurement documentation, operator training, and quality control checks.

Laboratory system audits should be conducted at laboratories performing chemical analyses. These system audits evaluate the adequacy of project components such as Standard Operating Procedures, measurement documentation, quality control checks, operator training, and sample chain of custody.

A system audit should be conducted on-site at the central data management center. The audit will evaluate the adequacy of project components such as communications between the study participants and the data manager, calculation procedures, handling of quality control test data, data archiving procedures, data base security, and data validation procedures. It will also include a spot check of data flow, in which a few selected data points will be subjected to manual calculation at all steps from field generation to final form in the validated data base.

8. STUDY MANAGEMENT STRUCTURE

The overall study management should be overseen by a steering committee. This committee would make decisions related to program administration such as allocation of resources and deciding upon which activities should be funded. The steering committee is also responsible for raising the needed funding. The steering committee would also be responsible for coordination with the appropriate policy committees or organizations. The steering committee should arrange for the services of a technical expert to serve as the technical manager of the study. It is anticipated that the technical manager would need to commit ¼ to ½ time to the study, depending upon the complexity of the study and the precise duties of the technical manager. More time would be needed during critical periods, such as leading up to the beginning of field studies and during intensive field studies, while relatively little time may be required while waiting for data to come in from data collectors, etc.

The technical manager should have the responsibility and authority for decision-making regarding all technical aspects of the study. Other technical study participants provide input and recommendations to be considered by the technical manager. The technical manager is responsible for conduct of a study that is scientifically sound and provides necessary technical information to support policy decisions. The steering committee should ensure the technical aspects of the study support policy needs. The scientific assessment also be not be influenced by desired policy results. Thus, the steering committee serves to help insure the scientific integrity of the study by keeping a buffer between policy and scientific investigation.

9. BUDGET: TO BE COMPLETED

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