COLUMBIA RIVER GORGE VISIBILITY AND AIR QUALITY STUDY

Working Draft: Existing Knowledge and Additional Recommended Scientific Assessment to Consider

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1 INTRODUCTION

This scientific assessment study plan 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 that strategy. This study plan focuses on the scientific investigation component of the overall work plan. It stands as the technical foundation for work to come. It is dynamic in that specific tasks and costs associated with them will change as monitoring, emission inventory, and modeling methods are adapted based on information gathered over the length of this process – in essence this document should be treated as a working draft that evolves over the period of this assessment.

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.

A peer-review workshop was held March 14-15, 2001 in Cascade Locks, Oregon to solicit comments from experts on a "strawman" scientific assessment study plan. Over 50 national and international air quality scientists attended. This plan has incorporated many helpful suggestions from the reviewers.

The role of scientific assessment as outlined in this study plan is not intended to address the two overall purposes of the Scenic Area Act. The two purposes are: 1) protect and enhance scenic, cultural, recreational and natural resources and, 2) protect and support the economy of existing urban areas in the Scenic Area (consistent with the first purpose). Balancing these two purposes is the role of decision-makers (with input from the public and stakeholders), not scientists. How this balance will be assessed is addressed in other parts of the overall work plan (for instance, a plan for economic analysis of strategy alternatives is included elsewhere in the work plan). The scientific investigation only provides a technical foundation by characterizing air quality, identifying sources that contribute to air quality problems, and by providing tools to assess changes in air quality based on changes in emissions. The goals and objectives are discussed below.

1.1 What air quality issues will this study address?

This study will focus its scope on pollutants that affect visibility and pollutants that lead to the formation of ozone and acid deposition. The pollutants that affect visibility are:

- sulfate (converted from sulfur dioxide)
- nitrate (converted from nitrogen dioxide)
- organic carbon (including volatile organic carbon species)
- elemental carbon

- soil dust.

Because such a small amount of these pollutants can cause significant visibility impairment, reducing these pollutants sufficient to protect visibility will result in significant benefits to many other air quality issues of concern. The pollutants that lead to the formation of ozone (nitrogen oxides and VOC's) and acid deposition (sulfur and nitrogen oxides) are contained in this list of visibility impairing pollutants. Therefore there is a direct link between improving visibility and reducing ozone and acid deposition.

This study will ***not*** address air borne toxic pollution. Toxic air pollutants are being addressed through each states air toxic programs that are already in place.

1.2 Goals and Objectives

This study plan will be incorporated as an appendix to the overall work plan discussed above 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. 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 air quality, visibility and meteorological conditions in the Scenic Area, identify sources affecting air quality and visibility in the Scenic Area, and to develop and evaluate models to be used 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 and 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 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. **Selection of modeling tools that will be recommended for assessment of changes in 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

1.3 Guide to study plan

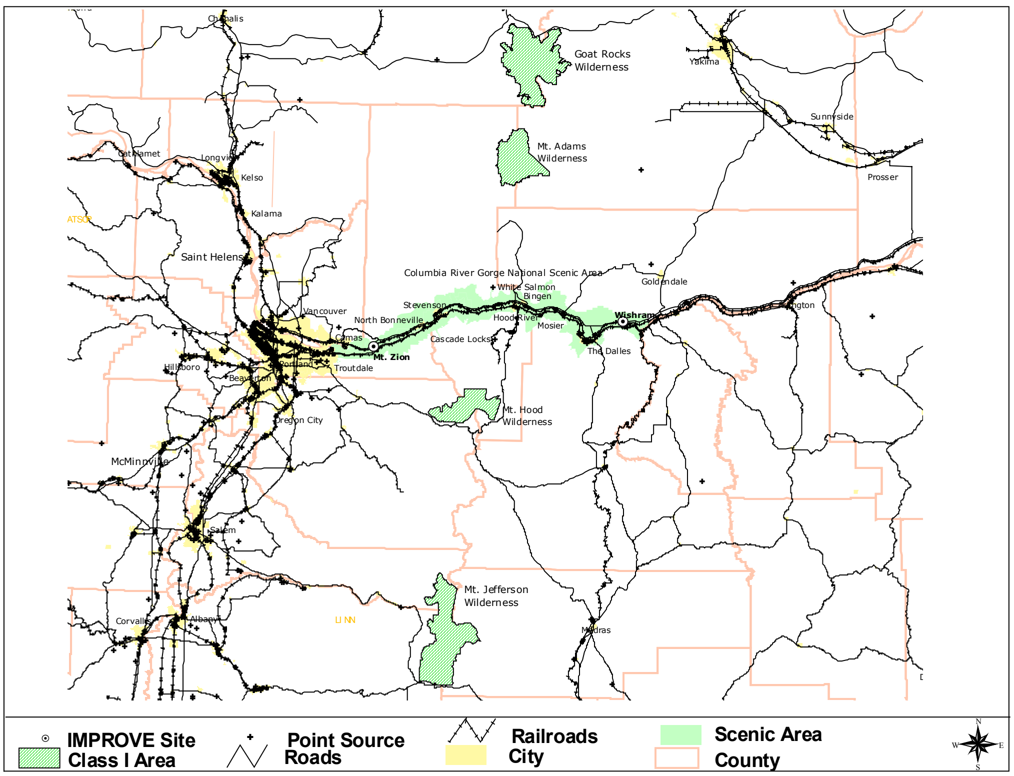
Section 2 summarizes existing knowledge of emissions, meteorology, aerosols and visibility for the area. Section 3 presents a series of hypotheses based on review of existing data, and the additional information needed to help confirm or refute these hypotheses. Alternately, the hypotheses can be considered 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 monitoring, emission inventory and modeling programs are presented. Section 5 describes the proposed study structure. 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 (2001) 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.

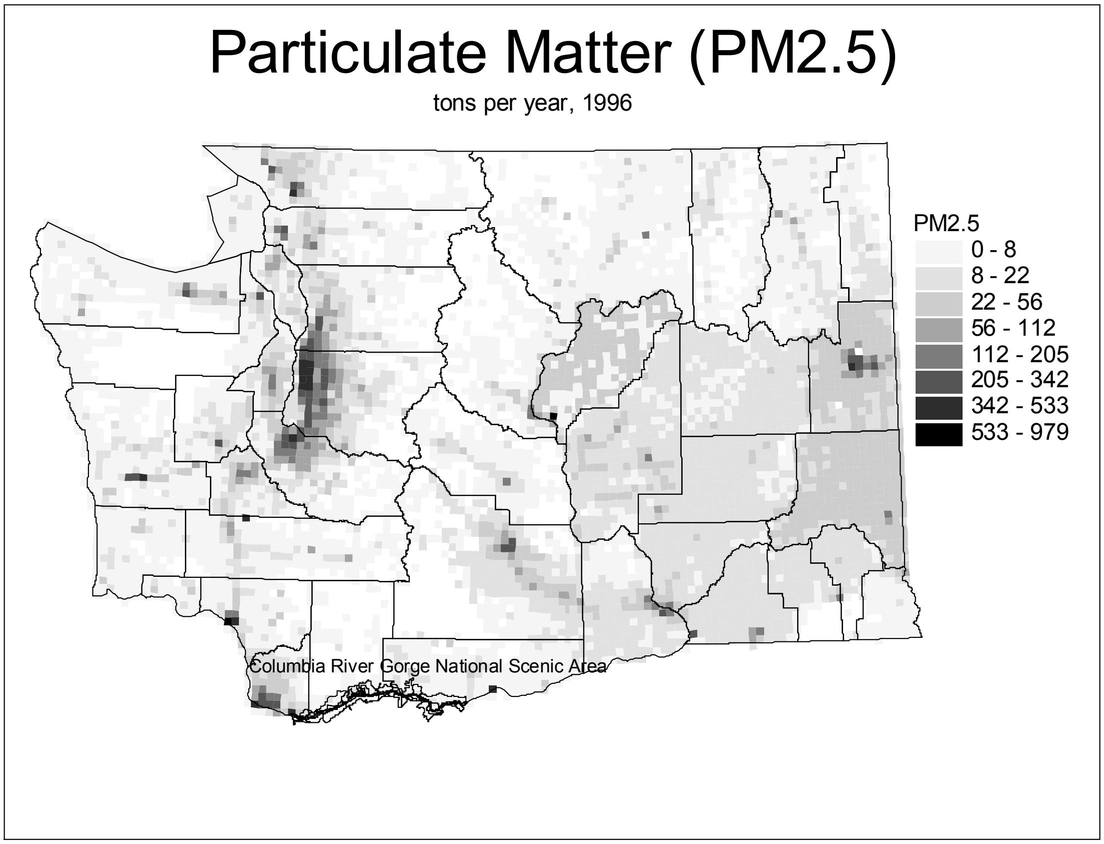


Note that the Portland, Oregon/ Vancouver, Washington urban area (population about 1.8 million) is located immediately to the west of the Scenic Area. The Centralia power plant, with 1996 emissions of 78,000 tons of SO_2, or 47% of the point source SO_2 emissions in EPA Region 10 (Oregon, Washington, Idaho, Alaska) (USEPA, 2001) is located at the north edge of the map, just above Chehalis, about 135 km from the Scenic Area. The Centralia powerplant is scheduled to have 90% controls on one unit by December 2001, and 90% control on the other unit 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 Scenic Area include 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. The Oregon emissions inventories are currently at the county level.

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

Source	OR Statewide Inventory	WA Statewide Inventory
Area Sources		
Agricultural Tilling	no	yes
Agricultural Windblown Dust	no	yes
Ammonia Sources	no	yes, needs detail/update
Asphalt Paving	no	no
Construction Site Emissions	no	no
Consumer and Commercial Products	yes	yes
Dry Cleaning	no	no
Fossil Fuel Combustion	yes	no
Gasoline Stations/ Bulk Stations and Terminals	no	no
Graphic Arts	no	no
Health Services, Hospitals, Sterilization	yes	no
Industrial Wastewater	no	no
Municipal Landfills	yes	no
Open Burning		
Agricultural Burning	yes, needs detail/update	yes, needs detail/update (not in emissions map)
Land Clearing Burning	yes	yes, needs detail/update (not in emissions map)
On-site Incineration	yes	yes, needs detail/update (not in emissions map)
Orchard Heating, Pruning Burning	no	no
Prescribed Burning	yes, needs detail/update	yes
Residential Outdoor Burning	yes, being updated	yes, being updated (not in emissions map)
Paved and Unpaved Road Dust	no	yes
Commercial Pesticides	no	no
Publically Owned Treatment Works	no	no
Residential Wood Combustion	yes, being updated	yes, being updated
Restaurant Emissions	no	no
Structural Fires	yes	no

Surface Cleaning	yes	no
Surface Coating	yes, all categories	yes, some categories
Wildfires	yes, needs detail/update	no
Natural Sources		
Biogenics	work in progress	yes, being updated
Saltwater Associated Emissions	no	no
Nonroad Mobile Sources		
Airport Emissions	work in progress	no
Locomotives	work in progress	work in progress
Other Nonroad Mobile	yes	yes
Ships	yes, being updated	yes, being updated
Onroad Mobile Sources		
Onroad Mobile	yes, needs detail/update	yes
Point Sources		
Point Sources Emissions	yes	yes
Point Sources Stack Parameters	work in progress	yes, for most but not all



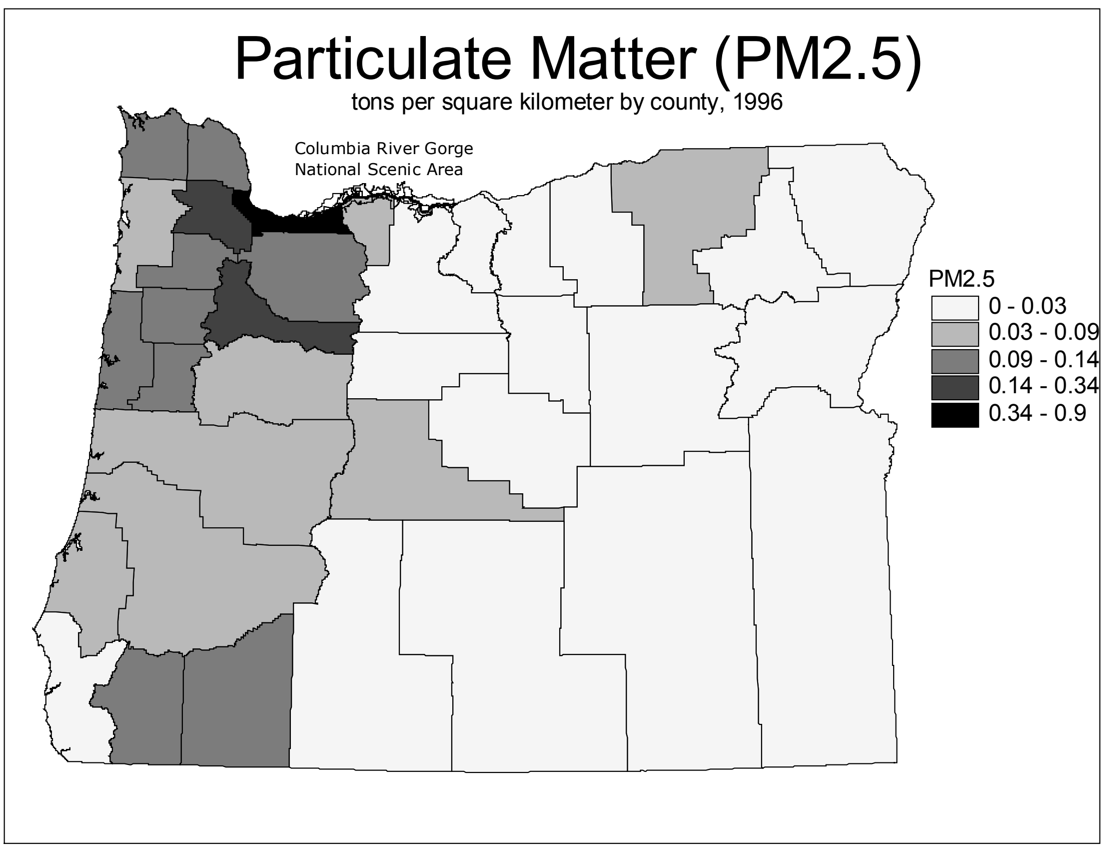


Figure 2.2 $PM_{2.5}$ emissions in Washington and Oregon (Washington DOE and Oregon DEQ).

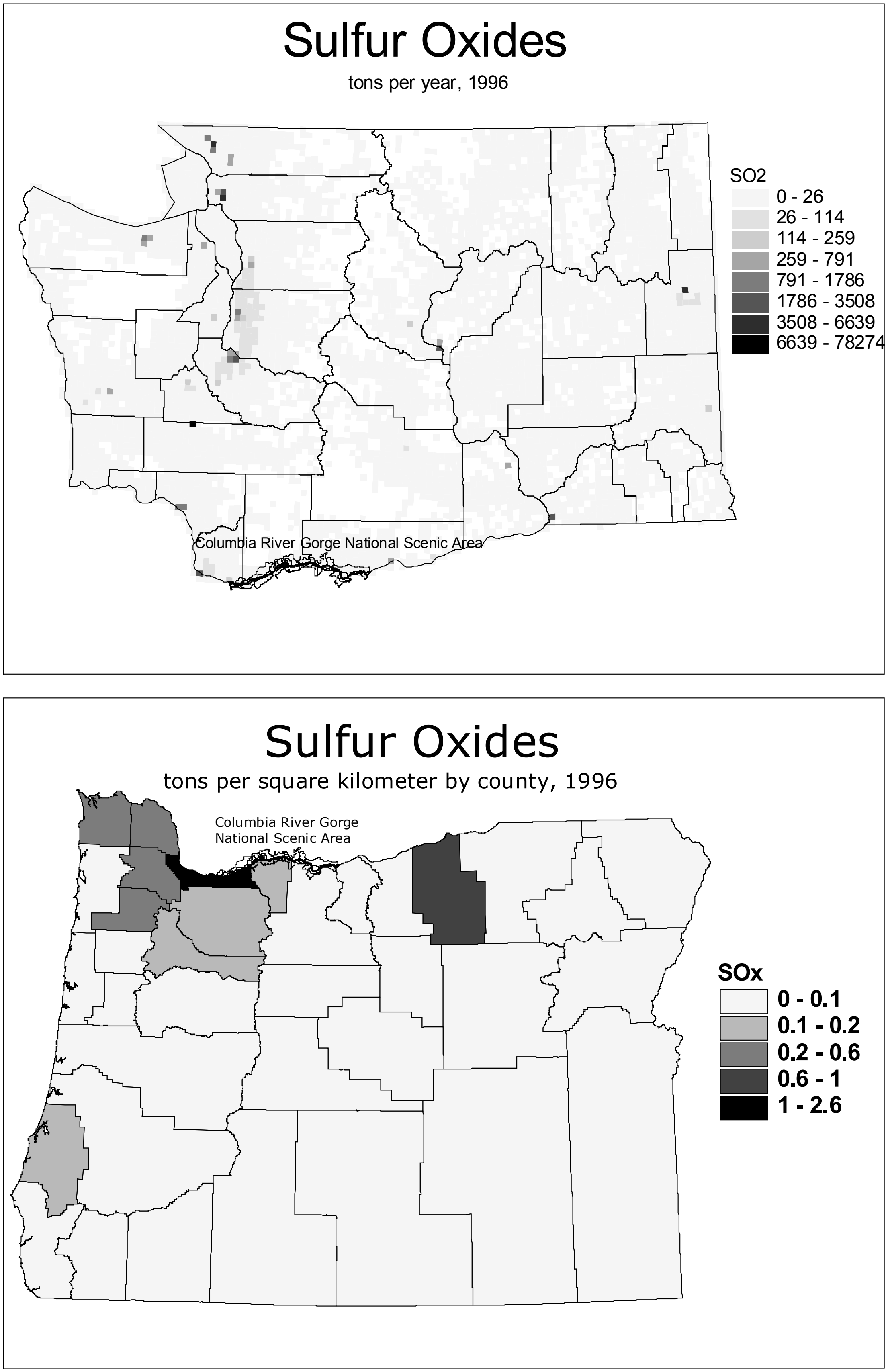
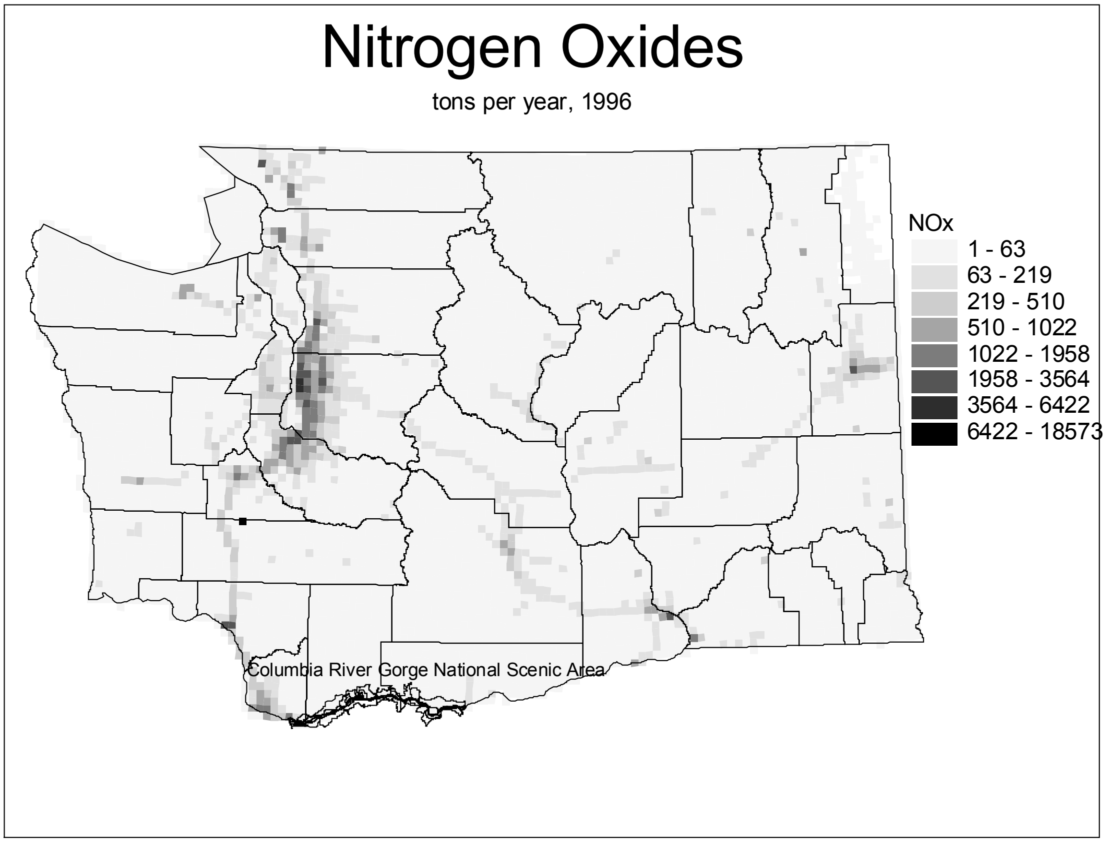


Figure 2-3. SO_X emissions in Washington and Oregon (Washington DOE and Oregon DEQ).



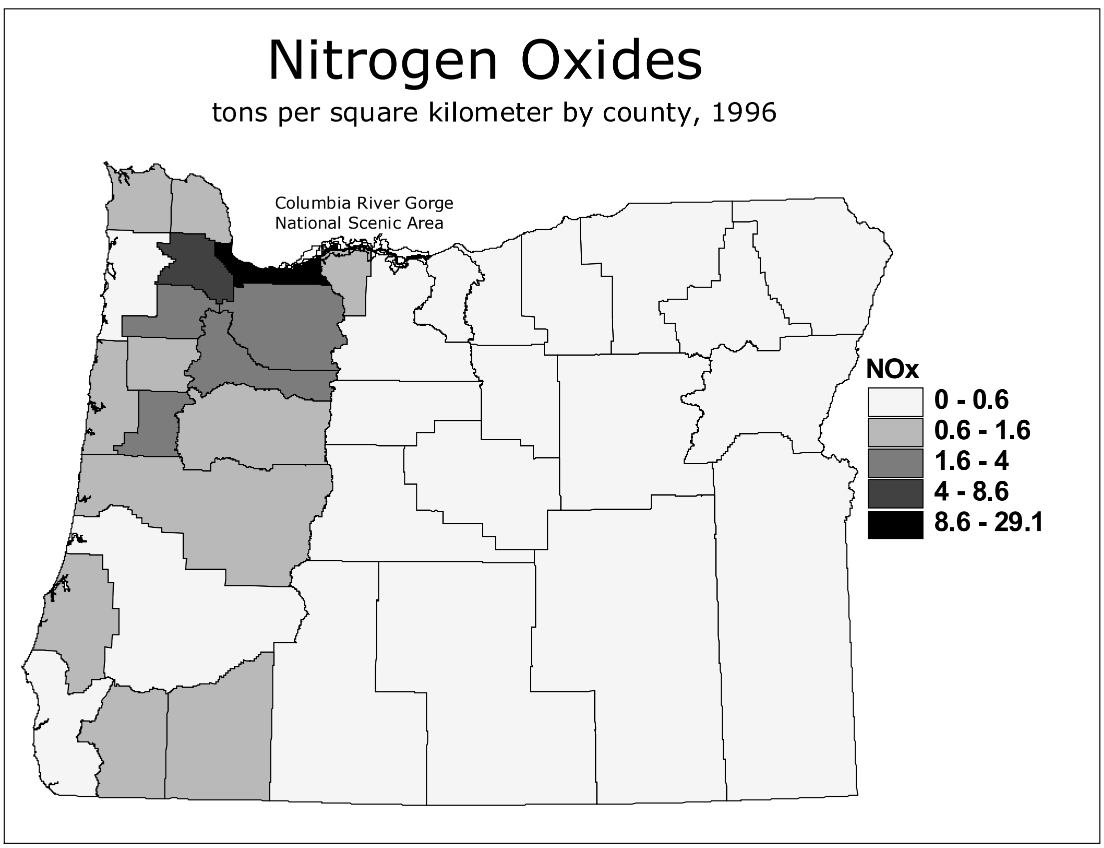
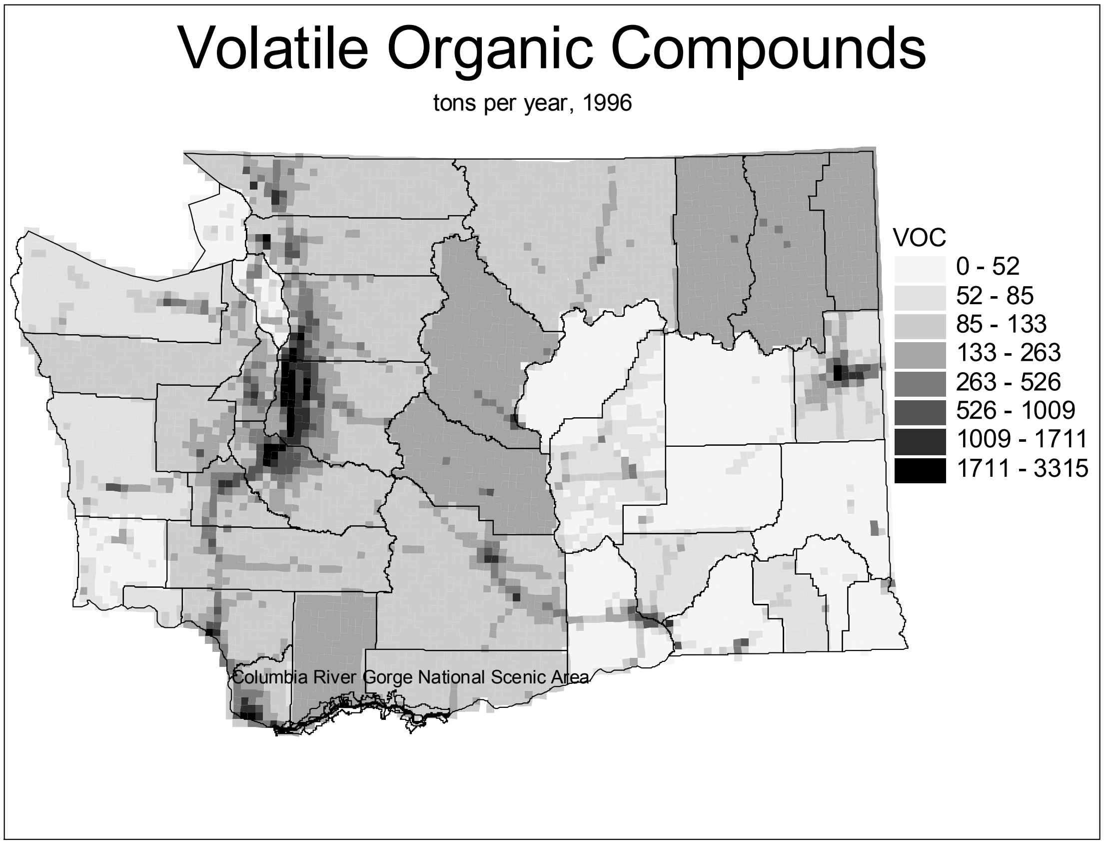


Figure 2-4 NO_X emissions in Washington and Oregon (Washington DOE and Oregon DEQ).



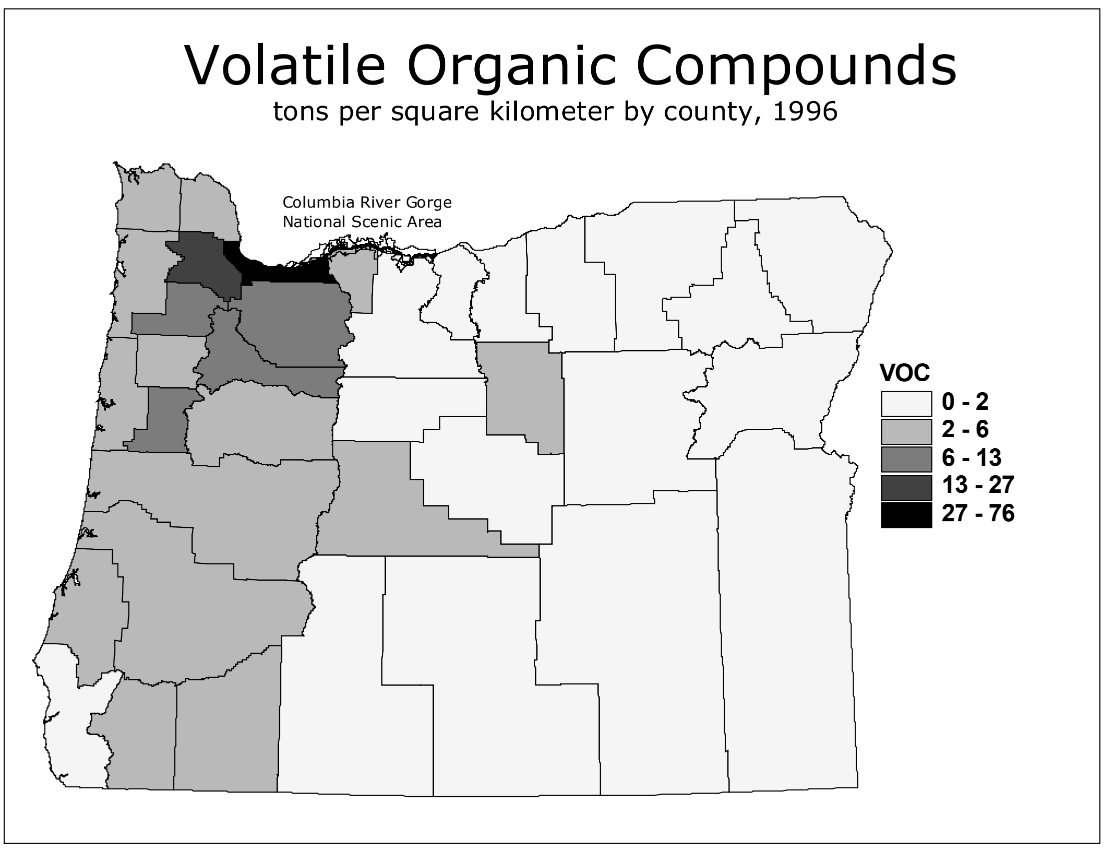


Figure 2-5. VOC emissions in Washington and Oregon (Washington DOE and Oregon DEQ).

2.2 Meteorology and Climatography:

The meteorological parameters of most interest for the study are the 3-dimemsional wind components, including the turbulent intensities, and the 3 dimensional moisture fields. The wind fields determine the transport and dispersion of air pollutants, while the moisture fields affect gas-to-particle conversion, particle growth, and deposition. Available meteorological information in or near the Scenic Area consists mainly of a few surface monitoring sites.

Storms, typically originating in the Gulf of Alaska, affect the region with peak intensity and frequency from November through March. However, the most significant precipitation events are associated with the so called "Pineapple Express". Figure 2.6 shows the annual average precipitation at sites along the Columbia River from the Pacific Ocean (Astoria) to east of the Columbia River Gorge (Boardman).

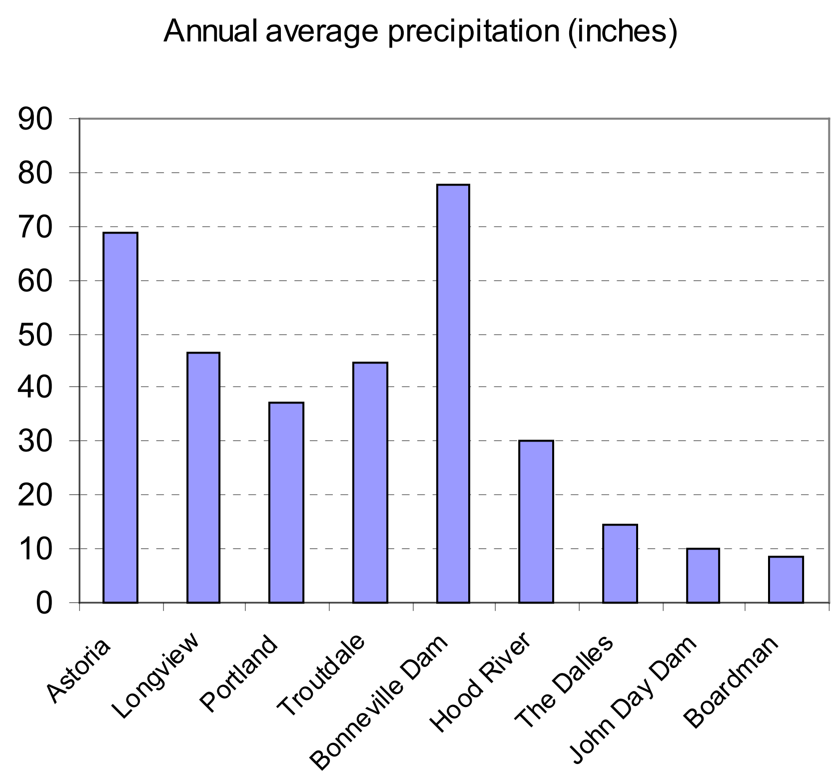


Figure 2.6. Annual average precipitation at sites along the Columbia River from west (left) to east (right). Period of record varies by site. Data obtained from the Western Regional Climate Center.

Precipitation amounts decrease from the coastal site of Astoria to Portland as moisture is wrung out by coastal mountain ranges. East of Portland, the precipitation increases dramatically to the central gorge due to air rising over the Cascade Range. At Hood River, which is east of the crest of the Cascade Range, precipitation is much decreased from the peak to the west. With further distance to the east, precipitation levels continue to decrease and reach a minimum of 7-8 inches annually.

Figure 2-7 shows the monthly average precipitation at sites west of the Columbia River Gorge (Portland), in the central portion of the gorge (Bonneville Dam) and near the eastern end of the gorge (The Dalles).

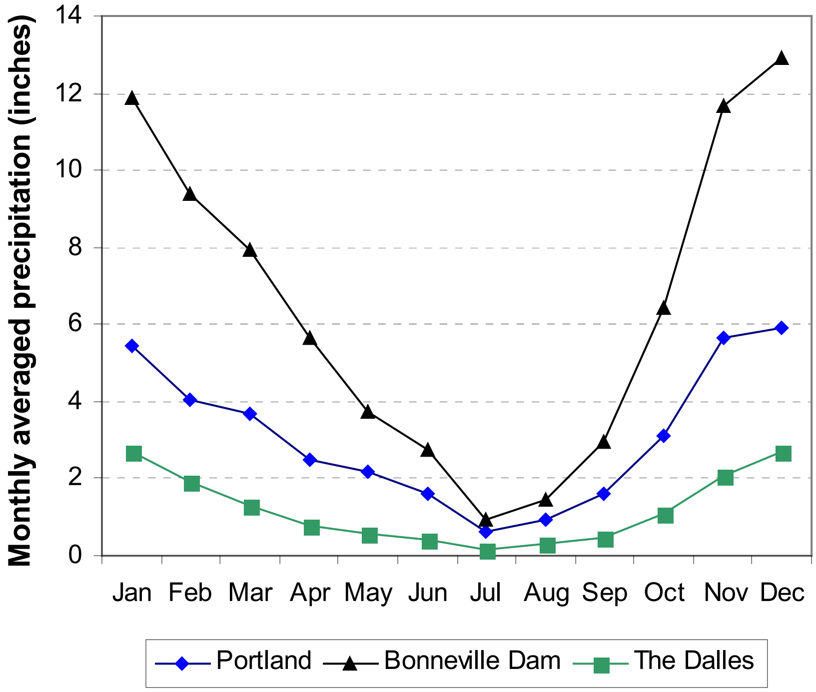
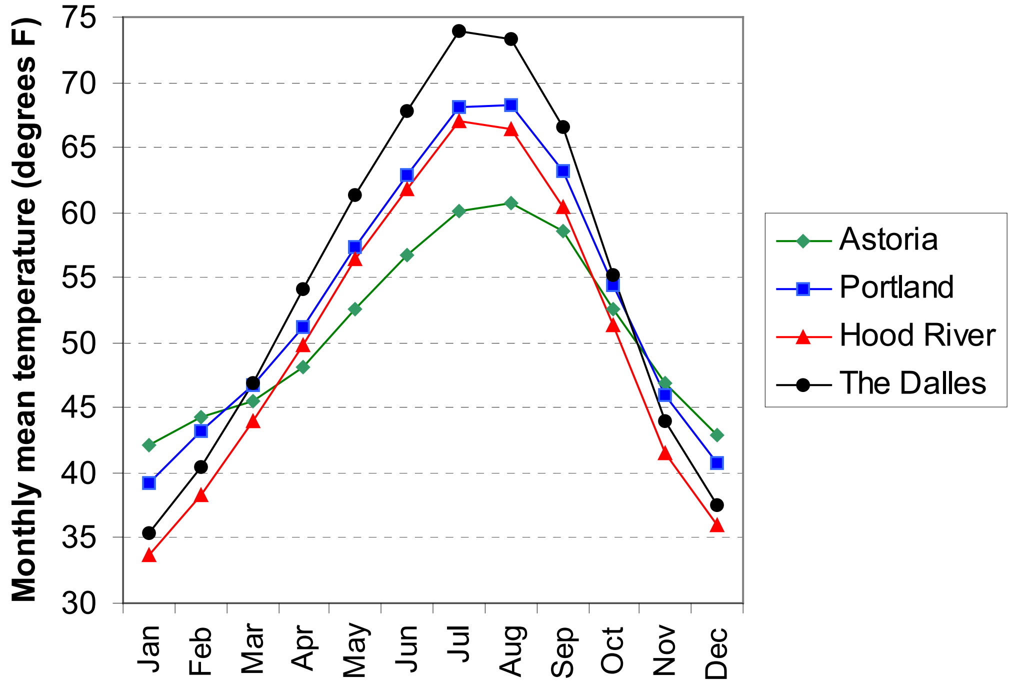


Figure 2.7 Monthly averaged precipitation at Portland, Bonneville Dam, and The Dalles. Data from the Western Regional Climate Center.

Precipitation follows a similar annual cycle at the 3 sites. Precipitation reaches a minimum in July and has modest increase in August and September, followed by a large increase from September to November. Average precipitation is near the peak for the months November through February and then declines each month through July. Even though rainfall amounts decrease substantially in spring, cloud cover is still rather extensive in the western portion of the area through June (67% average at Portland).

Summertime wind patterns are quite consistent within and near the Scenic Area. The Hood River area is famous among wind surfers for its consistent winds in summer. Heating of the areas east of the Cascade Range produces a thermal low pressure in that area, while the area to the west is influenced by the Pacific High and cool ocean waters. This results in a significant decrease in pressure from west to east in the gorge. Figure 2-8 illustrates the differences in monthly mean temperature at Astoria, Portland, Hood River, and The Dalles. The Pacific Ocean site of Astoria is the coolest, with Portland and Hood River about the same temperature in summer. A significant difference in temperature is evident between Hood River and The Dalles. This temperature difference causes a pressure difference between these gorge sites, which results in moderate to strong winds developing in response to the along gorge pressure gradient.

Figure 2-8. Average monthly temperature (degrees F) at Astoria, Portland, Hood River, and The Dalles. Data from the Western Regional Climate Center.



In winter, patterns are less consistent. It is common for high pressure to occur east of the gorge, with lower pressure to the west. This results in acceleration of air flow in the western portion of the gorge. Note that the temperature gradient is reversed in direction in winter, with colder air to the east. The temperature (and probably pressure) gradient is located between Hood River and Portland in the winter. This is also the region with the strongest winds. At Portland International Airport, located along the Columbia River near the mouth of the gorge, flow is nearly always along the river. In summer, the direction is consistently toward the gorge, particularly in the afternoon and evening. In winter, the direction is somewhat less consistent, but predominantly out of the gorge. At the IMPROVE monitoring site at Wishram (east of The Dalles), summer winds are nearly always from the west (upriver). Winter winds at Wishram are variable, typically from the east for a few days, then from the west for a few days.

There is little upper air data available, and none in the gorge. At levels above the gorge, flow would be less confined, although mountains such as Mt. Hood would substantially alter flows near them. There is also little information regarding mixing depths and to what extent other features such as low-level jets affect transport and dispersion. This study plan proposes a considerable amount of enhanced meteorological monitoring and modeling to help understand these flows.

2.3 Visibility and Air Quality

Visibility and Aerosols
Visibility is limited due to the scattering and absorption of light by gases and particles (aerosol). The light extinction coefficient (b_{ext}) is the optical parameter that provides a measure of light absorption and scattering. Scattering of light by air molecules (Rayleigh scattering) is natural and has a magnitude of about 11 per million meters (Mm-1) at sea-level and decreases at higher elevations due to decreased air density. On very clean days Rayleigh scattering can dominate the total light extinction. The compounds of most interest for visibility include the following 5 major components of particles: sulfates, nitrates, organic carbon compounds, elemental carbon, and crustal components. The relative importance of each compound varies from location to location and day to day. For sulfate and nitrate compounds, and probably some organics, during high humidity, growth of the compounds due to uptake of atmospheric water can substantially increase the light scattering caused by these compounds.

Optical and 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:

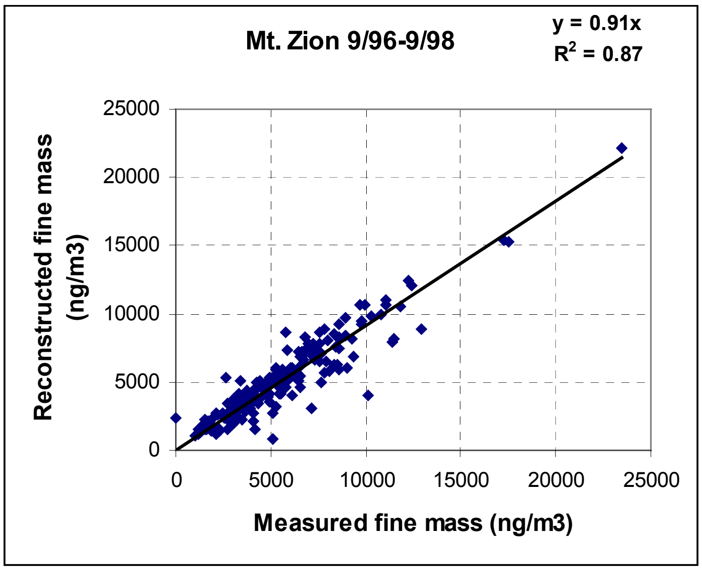
Sulfate assumed to be ammonium sulfate and =4.125*S from particle induced X-ray emission (PIXE) on Teflon filter
Nitrate assumed to be ammonium nitrate and =1.29*$NO3^-$ from ion chromatography on nylon filter
Carbon from Thermal optical reflectance (TOR) on quartz fiber filter
Organic mass = 1.4*Organic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

Reconstructed mass allows for a comparison of assumed forms of chemical combinations of the elements to the total measured mass and tests the assumptions made.

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 2-9. About 90% of the fine mass is accounted for at both sites, and squared correlation coefficients (r^2) are about 0.9.



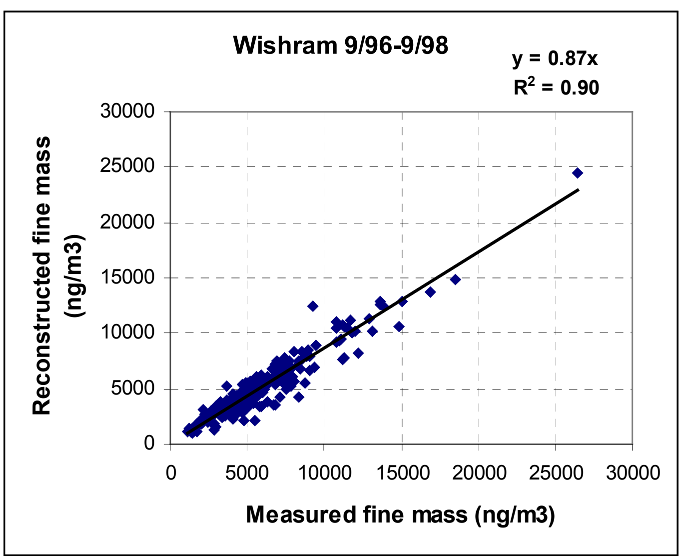


Figure 2-9. Measured versus reconstructed mass, Wishram and Mt. Zion 9/96-9/98.

Averaged reconstructed fine mass was 5.3 μg/m^3 at each site. Annual average reconstructed mass budgets are shown in Figure 2.10. At each site, organic mass is the greatest component, followed by ammonium sulfate, with ammonium nitrate, soil, and elemental carbon much less.

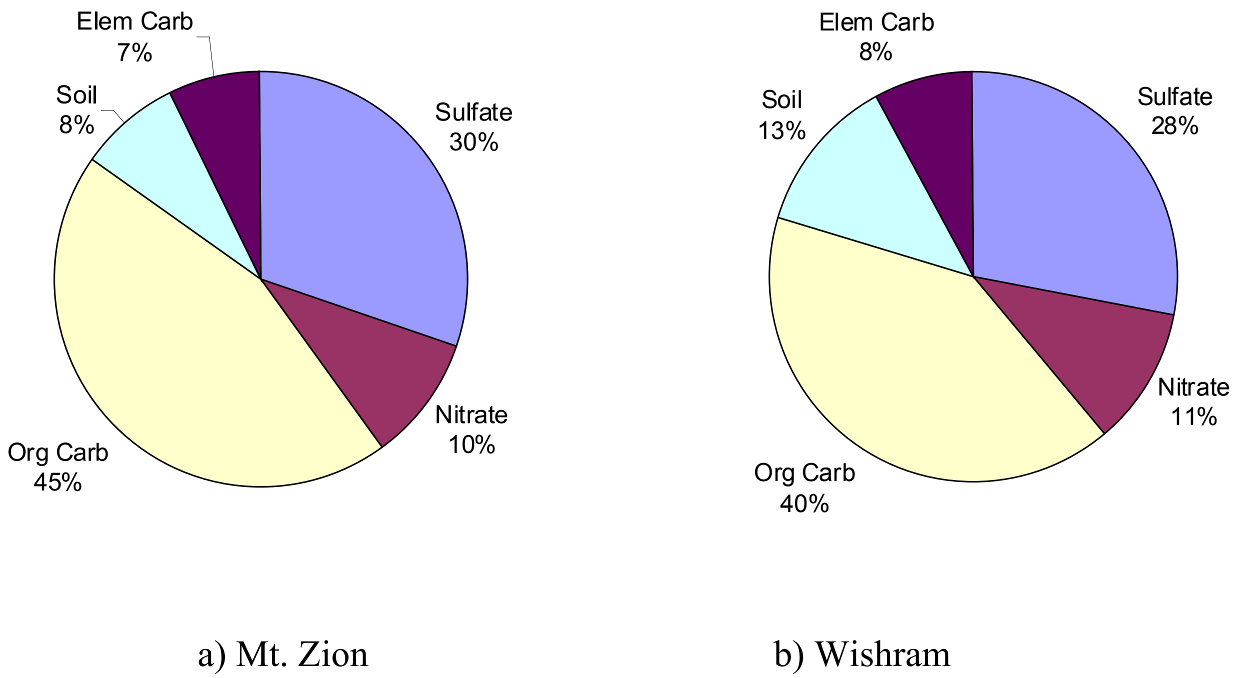
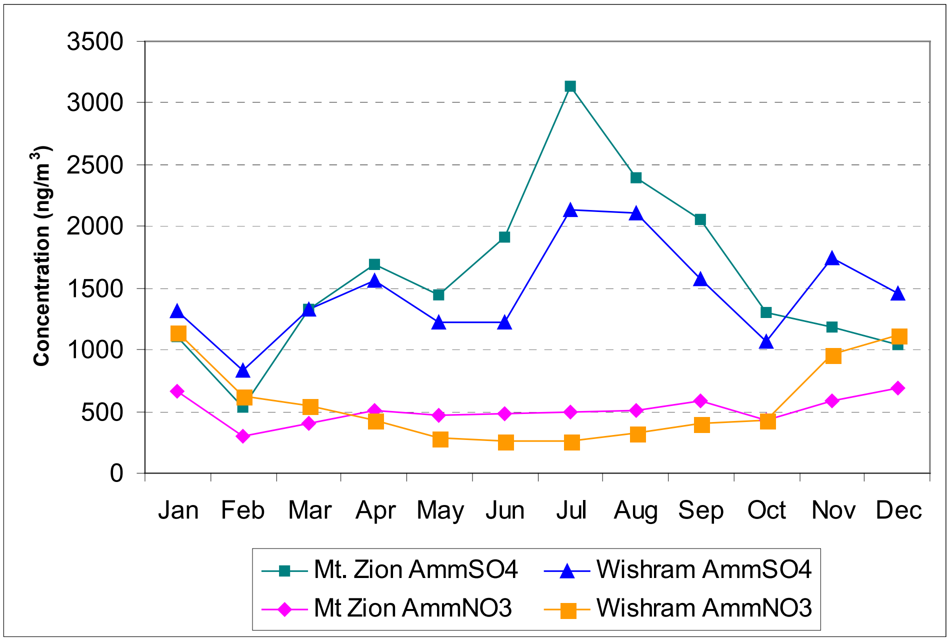


Figure 2-10. Annual average reconstructed mass budget a) Mt. Zion; b) Wishram

Monthly averaged component concentrations for the 9/96-9/98 period are shown in Figure 2-11. 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 mainly from a single day of very high fine soil due to transport of Chinese dust in April 1998. Another episode of Chinese dust affected much of the US in April 2001. It is likely that less noticeable impacts of Chinese dust occur with some regularity in springtime. Cases of significant transport of dust across the Pacific Ocean into the area can be tracked by satellite measurements. 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 more often from the 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 2-12.



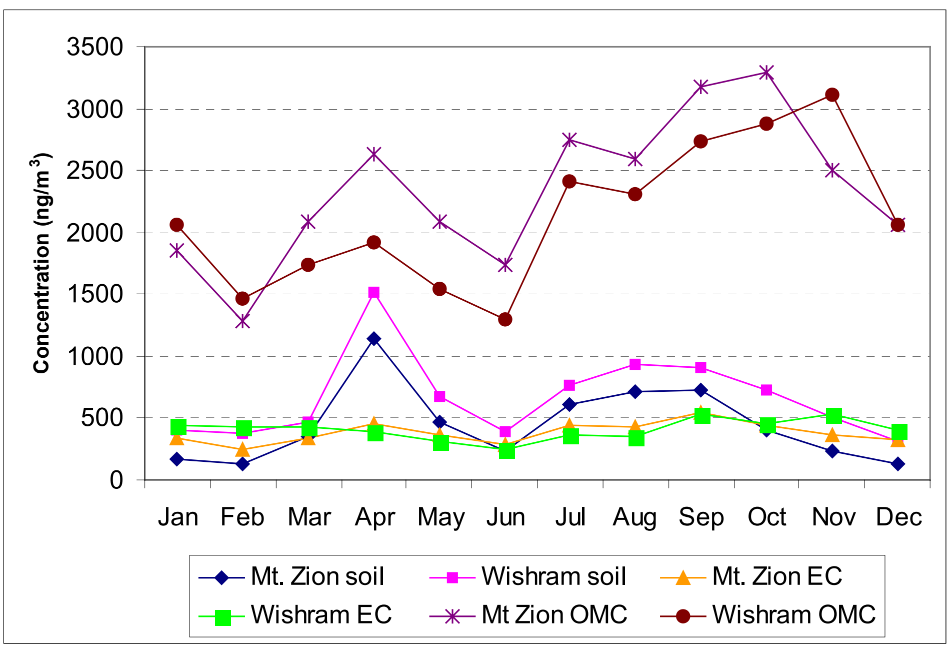


Figure 2.11 Monthly average reconstructed fine mass components Wishram and Mt. Zion, September 1996-September 1998 a) Ammonium sulfate and ammonium nitrate; b) organic mass, elemental carbon, soil.

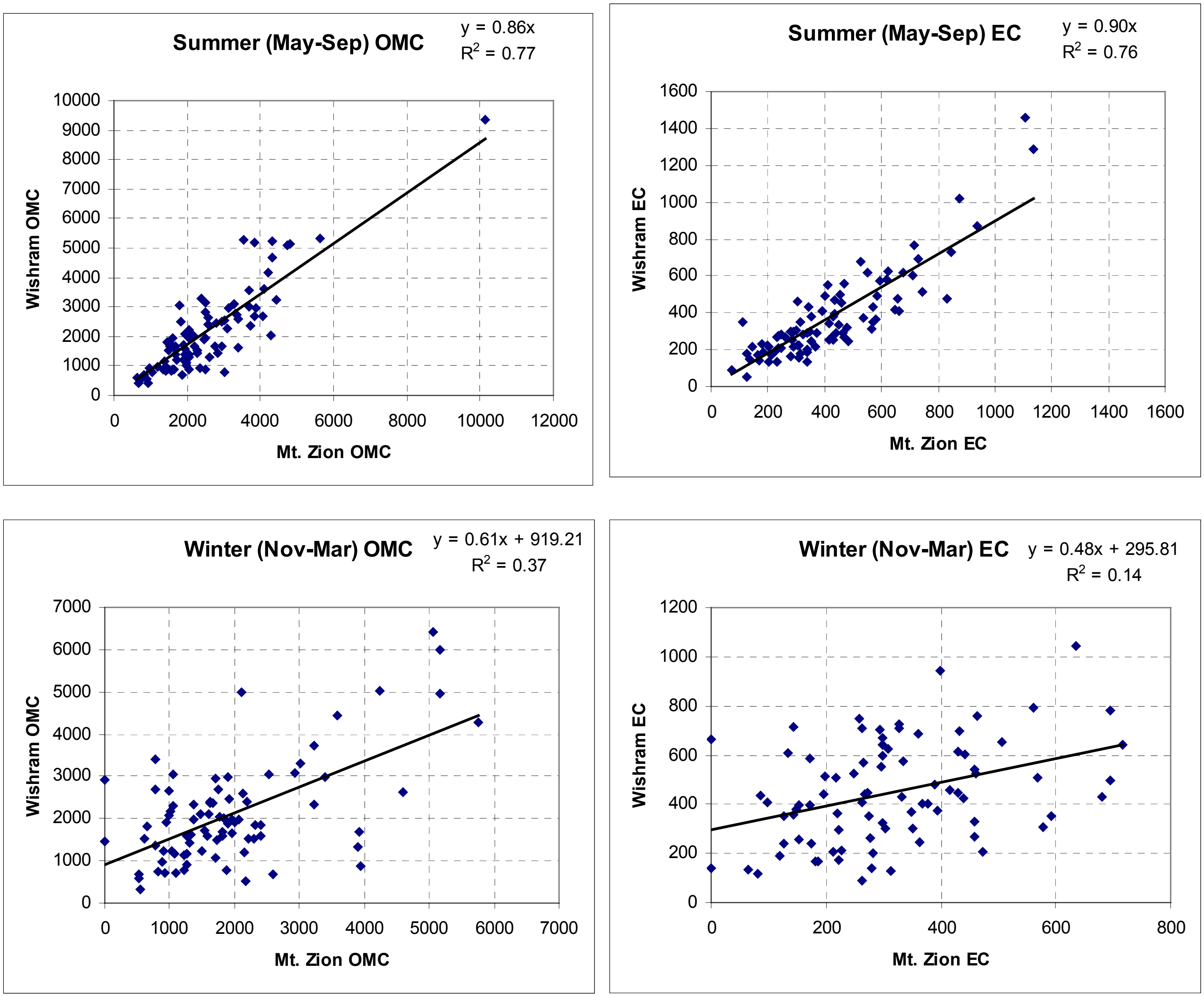


Figure 2-12. Scatterplots of organic mass and elemental carbon for Wishram and Mt. Zion, summer and winter.

<u>Reconstructed fine particle extinction</u>

Reconstructed fine particle extinction is a method used to estimate the fractional contribution from each of the major aerosol components (sulfate, nitrate, organic carbon, elemental carbon, and crustal) to visibility impairment. Reconstructed fine particulate light extinction by month is shown in Figure 2-13. 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. The f(RH) is 1 below about 30% RH and then increases gradually at first, but then at an ever increasing rate which is quite rapid above about 90% RH (see Malm *et. al.,* 2000 for the f(RH) growth curve and more detail). 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.

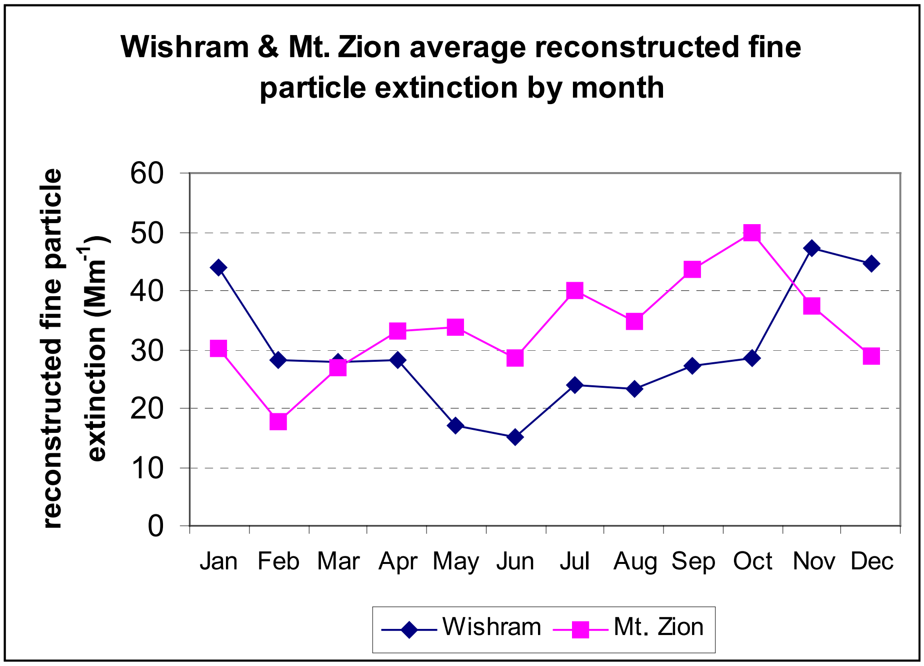


Figure 2-13. Average reconstructed particle extinction by month, Wishram and Mt. Zion 9/96-9/98.

The monthly components of reconstructed extinction for Wishram and Mt Zion are shown in Figures 2-14 and 2-15. 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).

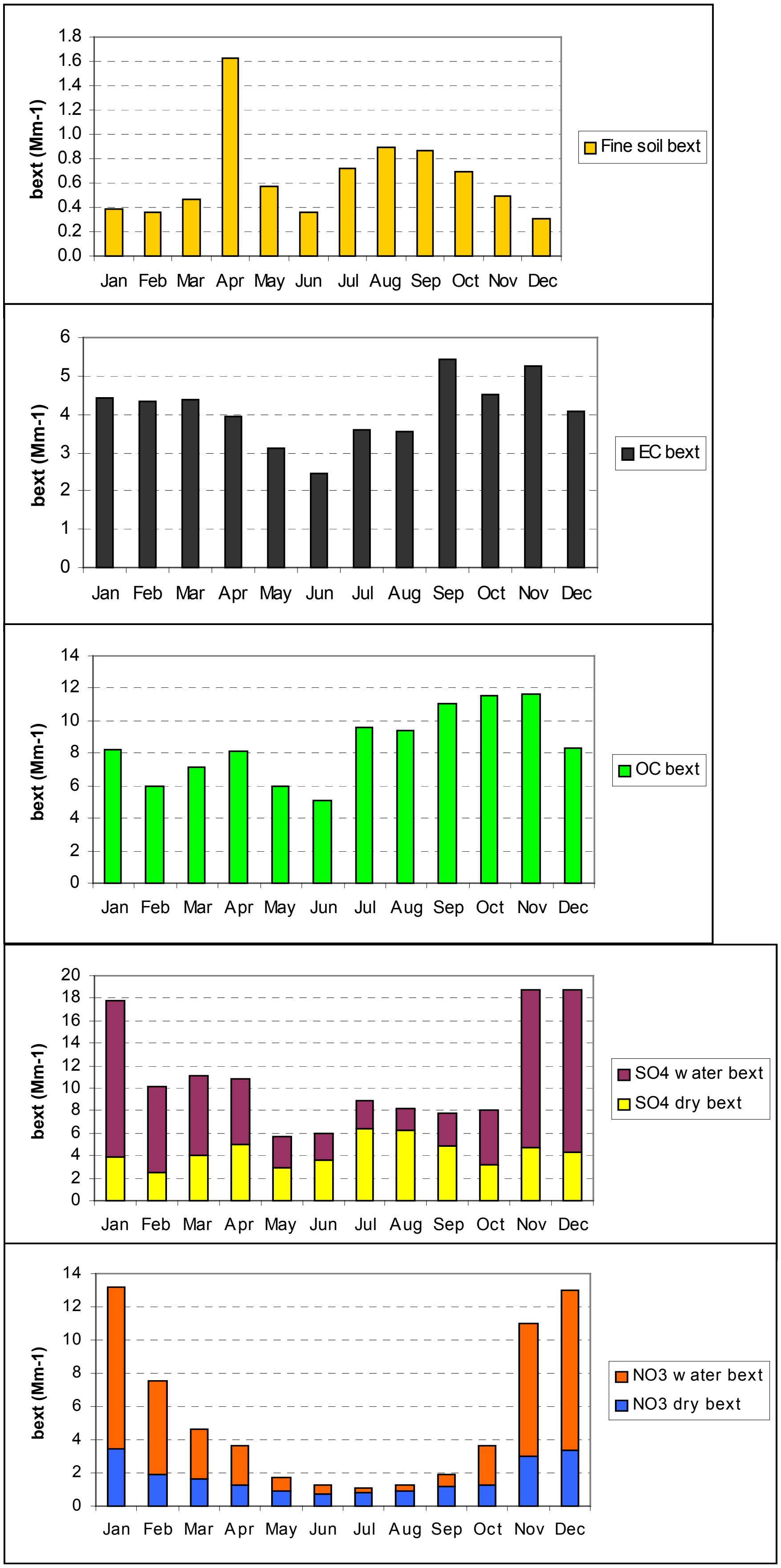


Figure 2-14. Monthly averaged reconstructed particle extinction components, Wishram.

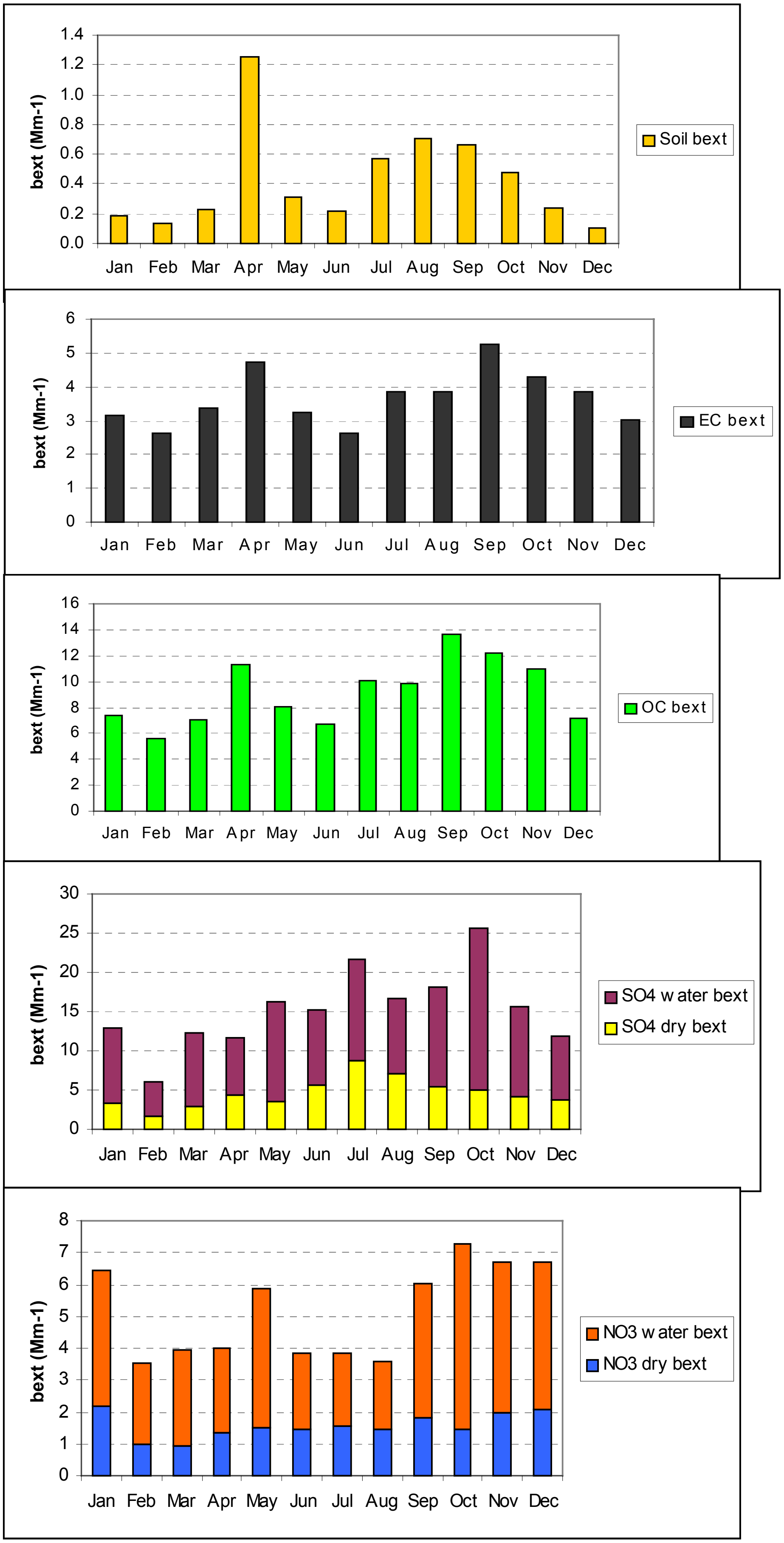


Figure 2-15. Monthly averaged reconstructed particle extinction components, Mt. Zion.

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 2-16. 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 2-17. 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.

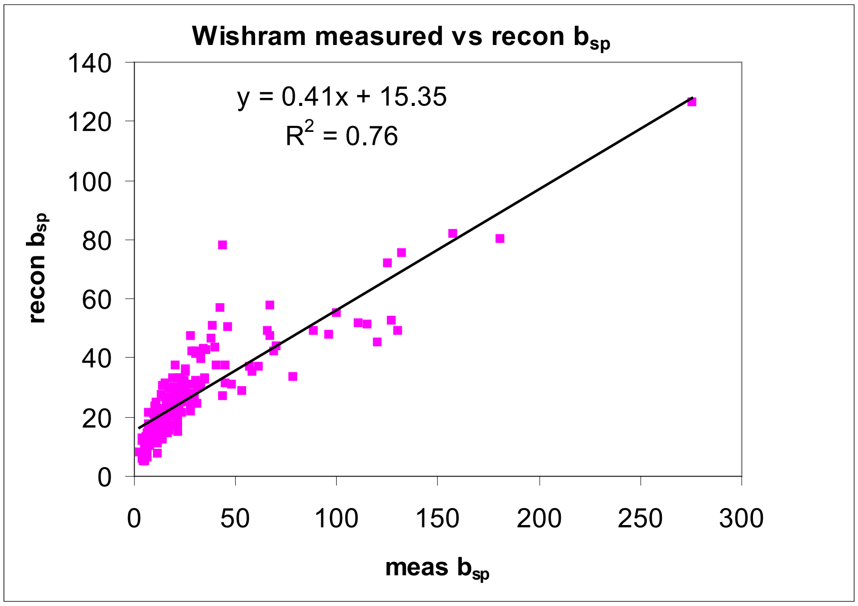


Figure 2-16 Measured versus reconstructed particle light scattering, Wishram – 9/96-9/98.

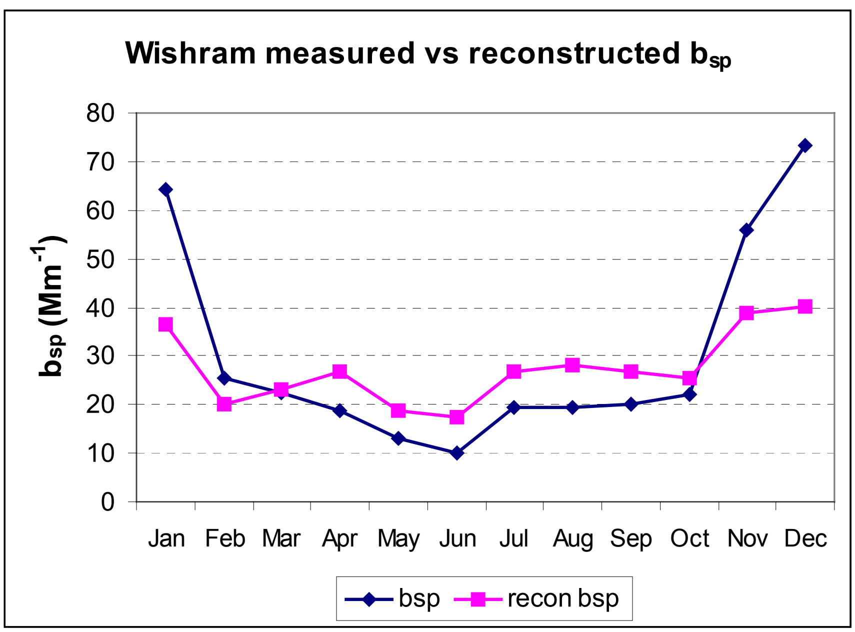


Figure 2-17 Measured and reconstructed particle light scattering by month, Wishram 96/96-9/98.

At lower values of measured scattering, the slope in Figure 2-16 is close to one. However, at higher levels, the measured is much greater than reconstructed. Figure 2-17 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 2-18) 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.

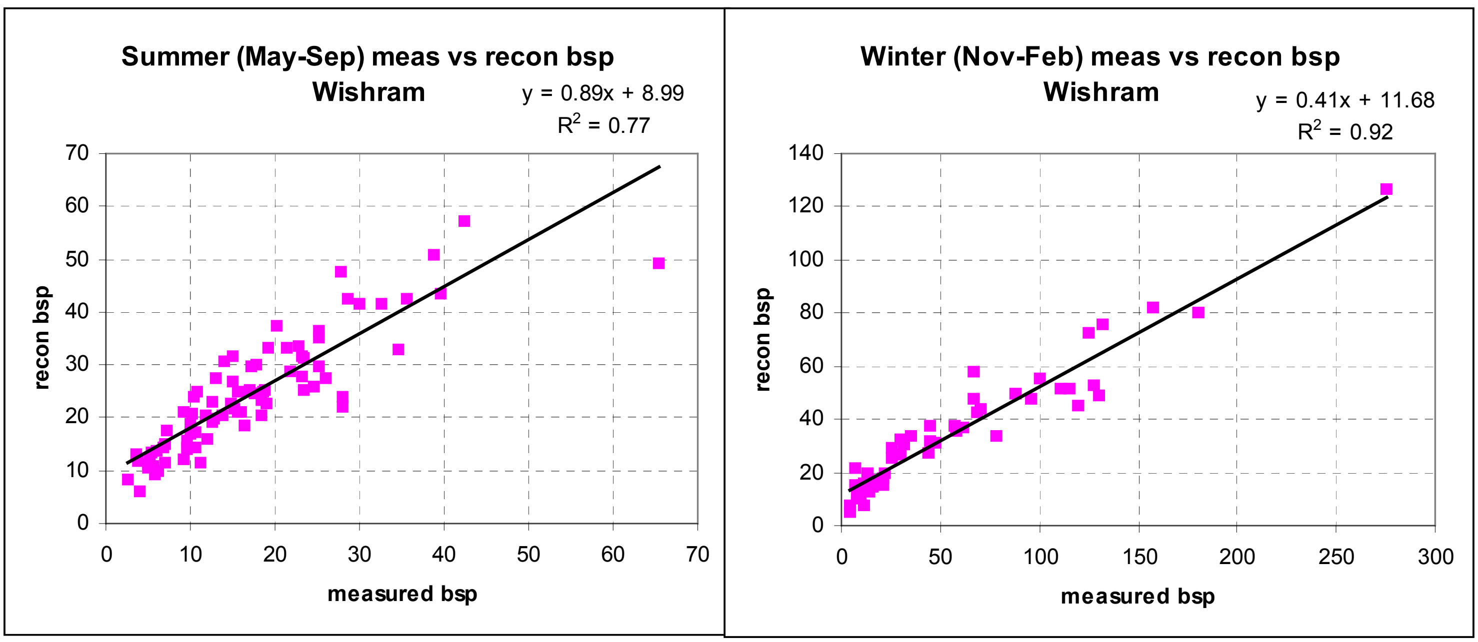
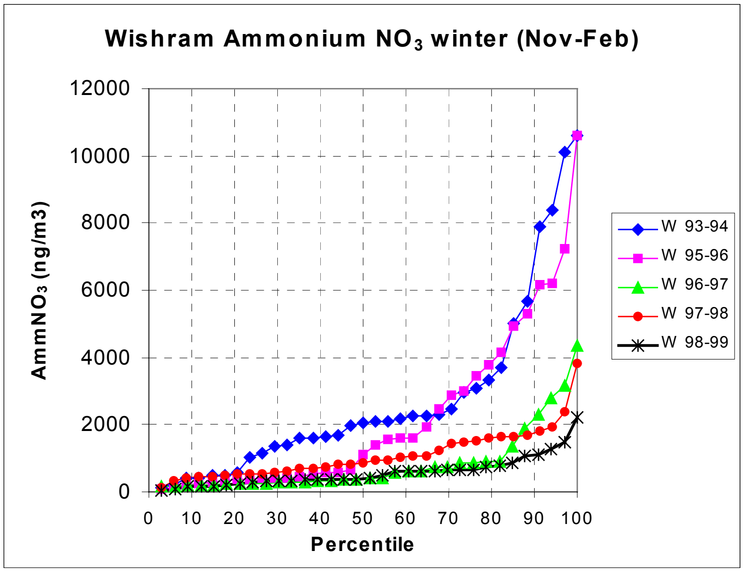
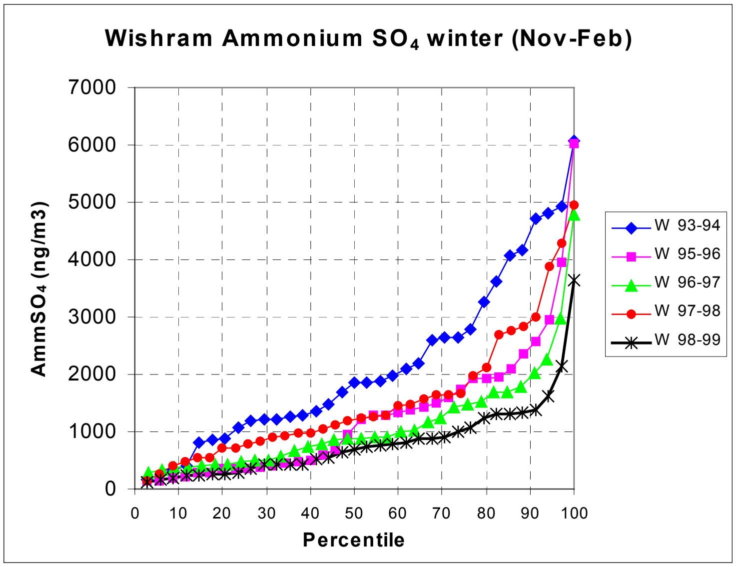


Figure 2-18. Measured versus reconstructed particle light scattering at Wishram, summer (May-September) and winter (November-February) for 9/96-9/98.

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 2-19. Figure 2-19a 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.





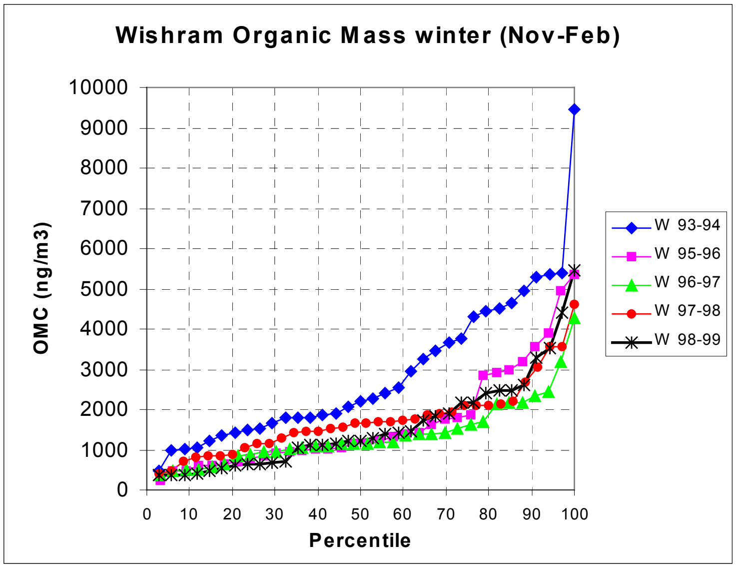


Figure 2-19. Frequency distribution of reconstructed fine ammonium nitrate, ammonium sulfate, and organic mass at Wishram for the winters of 1993-94 through 1998-1999. The winter of 1994-1995 was missing most data.

Long-term Ozone Field Studies
Ozone is measured at only one site (Wishram) in the Scenic Area. Ozone measurements have been recorded at Wishram since 1993. The temporal pattern at Wishram is typical of an urban transport site. Median values fluctuated between 20 and 42 ppb. Since the ozone levels do not typically dip below 20 ppb during the night hours, probably due to insufficient nitrogen oxide (NO) to react with all of the ozone available, the dosages observed at Wishram are generally higher than those observed at urban or urban fringe sites.

Peak one-hour averages occur during the mid-day and evening hours, and correlate well with regional ozone values. During episodic conditions when other sites in the region experience high ozone values, the observations at Wishram are also high. Wishram peak values are slightly higher than analogous sites located in pristine areas or national parks in the northwest (Olympic National Park and Mt. Rainier National Park), but lower than protected areas elsewhere in the west such as Sequoia/ Kings Canyon National Park. Wishram has never exceeded the 125 ppb one-hour ozone standard.

A single exceedance of the eight-hour average standard occurred at Wishram on July 13, 1996. The July 1996 episode resulted in exceedances throughout the region. The site is in attainment of the 8-hr standard since the standard is computed as the average of the 4^{th} highest annual 8-hr average over three years.
Since the ozone levels observed at Wishram have met, and continue to meet the national ambient air quality standards, human health-related effects are not assumed to be an issue in the area that the site is representing. Wishram is considered a regional scale site (representative radius of over 50km). Measurements are not available for the west and central areas of the Scenic Area.

Sites in Portland have exceeded the 8-hr ozone standard 101 times between 1977 and 2000. The probability of Portland sites exceeding the 8-hr standard on any given three years has been calculated to be close to 50%. This value may be slightly high due to potential bias from measurements conducted in the late seventies. EPA standardized instrument calibration procedures in 1980.

Special Ozone Studies
During the summer of 1996 Cooper and Peterson measured the spatial variation in ozone dosages in various transects throughout western Washington including the Columbia River Gorge. They deployed passive ozone samplers along nine river drainages from near sea level to mountain passes and other high altitude sites. They found that weekly average ozone concentrations were highest in the drainages east and southeast of the greater Seattle-Tacoma area (maximum = 55 to 67 ppb) and in the Scenic Area east of Portland (maximum = 59 ppb).

In the case of the Columbia River Gorge transect, ozone dosages were higher with increasing distance eastward in the Gorge with the exception of the western-most site. The western-most site, located 36 km east of Portland, had a higher summer average dosage (32 ppb) than the two sites east of it (23 and 25 ppb) located 48 and 71 km east from Portland. The highest summer average dosage was observed at Wishram (41 ppb). Although the highest weekly dosage was measured at Wishram, it is quite possible that sites west of Wishram might experience higher peaks than Wishram. More availability of NO at sites west of Wishram would lead to the disappearance of ozone at night, and thus resulting in lower weekly averages, but potentially higher daytime peaks, at sites closer to the Portland urban area.

No air pollution modeling studies specific to the Scenic Area have been conducted. However, the western portion of the Scenic Area has been included in the 5-km resolution modeling domain that Washington State University and Department of Ecology have been using since 1996. During the Southwest Washington Ozone study, a very considerable amount of effort was required to obtain an MM5 solution with reduced surface wind speeds and wind directions congruent with observations in the Portland area. The complex terrain of the Scenic Area is a dominant topographical feature that greatly influences the flow patterns in that region. Since then, investigators at University of Washington (Sharp) have produced higher resolution MM5 runs of the gorge. The results they have obtained seem promising, but have not yet been verified with observations mainly due to the sparse or non-existence of meteorological field measurements in the region.

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

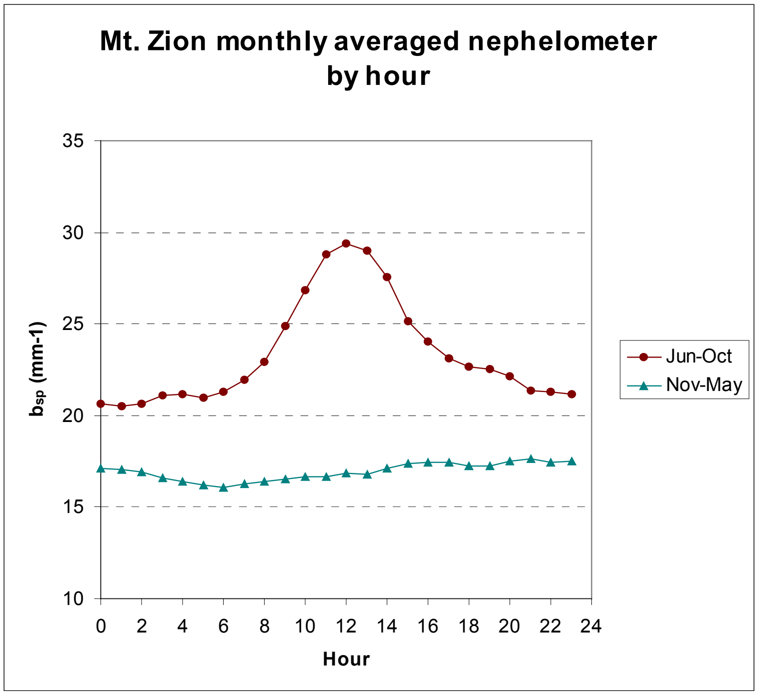


Figure 3-1. Hourly averaged light scattering at Mt. Zion for June-October and November-May. Data for the period 9/96-9/98. Light scattering measured by Radiance Research nephelometer with humidity limited to 50% by heating.

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.

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.

Aircraft measurements of light scattering could also test this hypothesis. Airborne observations could provide additional information on aerosol concentration gradients in relation to boundary-layer and flow structure. By making several passes over the area within the gorge, these measurements could also provide insight into the possible transport of pollutants up the slopes on either side of the gorge. It is suggested that boundary layer growth and the subsequent mixing will act to reduce aerosol concentration further downwind in the gorge. Airborne observations would be able to directly test this hypothesis by making measurements at several altitudes.

Lidar could also be used to characterize aerosol concentration, distribution, and velocity through a cross-section of the gorge. 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-Kennewick), 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.

Aircraft observations could also help mapping out the 3 dimensional structure of aerosols in the area, as described under hypothesis 1. Low clouds and fog could limit aircraft observations in winter, however. Lidar could also be used to characterize the vertical distribution of aerosol and aerosol transport as a function of height in 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.

Air quality modeling using a mesoscale meteorological model such as MM5 along with a chemical transport model could also be used to investigate the effects of the Boardman powerplant on air quality within the NSA. Additional meteorological monitoring using a radar wind profiler near the powerplant would help in providing the initial transport direction for the plume in the modeling analysis.

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 winds in the gorge are frequently 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 using high-resolution meteorological fields and emissions inventory and a chemical transport model could also be used to estimate effects from in-gorge sources. The model results need to be compared with measurements to obtain confidence that the emissions inventory and meteorological fields are well described.

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 Gas Chromatography Mass Spectroscopy (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 Tandem Differential Mobility Analyzer (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. Radio Acoustic Sounding System (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.

The following hypotheses were suggested at the peer-review workshop on the "straw-man" study plan.

HYPOTHESIS 10: Short-term climate variability leads to significant variability in attribution analysis.

Evidence to support hypothesis 10: Weather patterns change significantly due to cycles such as El Nino, La Nina. These changes include changes in frequency of transport from sources to receptors as well as changes in precipitation, and cloud cover that would alter chemical transformation and deposition. Attribution analysis performed for any one-year or for special study periods, e.g. winter and summer intensive studies, must be put into context by comparing with longer term expectations.

Additional information needed: Ideally, the attribution analysis would provide an estimate of impacts for the study period, average impacts, and a range of impacts due to climate variability. The analysis could be qualitative, semi-quantitative, or quantitative. The estimated frequency of specific source-receptor relationships for the study period could be estimated for additional years by considering transport frequency as predicted by models run for multiple years. However, these models are likely to be models such as HYSPLIT using relatively coarse meteorological data. Thus, biases could result. More semi-quantitative estimates could be made by looking a general frequencies of wind directions at long-term monitoring sites. E.g. if easterly winds in the gorge are 50% more frequent during the study year than for a long-term average, then impacts from sources in the eastern portion of the region are greater during the study year than long-term averages, perhaps by 50%. In short, regardless of the methodology applied, it is important to place the study period into perspective regarding probable frequency and magnitude of impacts from specific source areas.

HYPOTHESIS 11: Spatial variability of visibility is significantly affected by ammonia variability. Reductions in SO_2 may lead to increases in NO_3 due to ammonia limitation.

Evidence to support hypothesis 11: There is not evidence in the study area to support or refute hypothesis 11. It is based on an assumption that in the area, or portions of the area, ammonia gas is not present in sufficient quantities for reaction with nitric acid for formation of ammonium nitrate particles. Limitations of ammonia would also lead to less than complete neutralization of sulfate particles, such as sulfuric acid (H_2SO_4) and ammonium bisulfate (NH_4SO_4), which have different light scattering effects than the fully neutralized ammonium sulfate ($(NH_4)_2SO_4$). If SO_2 is reduced, there could be less ammonia used in neutralizing sulfates, thereby freeing up additional ammonia for reacting with nitric acid (HNO_3) to produce particulate nitrate.

Additional information needed: Measurements of ammonia and nitric acid are needed to see if the atmosphere is ammonia limited. Measurements of ammonium ion would also be helpful to help determine the degree of neutralization of sulfate aerosol. These measurements should be used in conjunction with measurements of particulate nitrate and sulfate. Measurements at a few sites throughout the study area would be desired. These measurements could also support emissions inventory and chemical transport model evaluations

HYPOTHESIS 12: Secondary organics from non-fire biogenic emissions is a significant contributor to $PM_{2.5}$ mass.

Evidence to support hypothesis 12: The Pacific Northwest is heavily forested and can be expected to be a significant source of biogenic compounds. Some biogenic compounds undergo chemical reactions that result in the formation of particles.

Additional information needed: Speciated aerosol and gas phase organic analysis should be done to identify certain compounds associated with biogenic emissions. For example, alpha-pinene is emitted from forests typical of the Northwest. The measurements, in conjunction with receptor modeling can help to estimate the biogenic contribution to organic aerosol.

HYPOTHESIS 13: Fugitive dust emissions are overestimated and carbon emissions are underestimated.

Evidence to support hypothesis 13: Reconciliation between modeled concentrations of fugitive dust and measurements consistently show that modeled concentrations are too high. While positive and negative biases occur in inventories of fugitive dust emissions, the net result is to overestimate emissions, particularly transportable emissions (Watson and Chow, 1999). The effects of emission height and deposition are not well understood for ground-level fugitive emissions.

On-road vehicle measurements and CMB source apportionment has shown that motor vehicle emissions of carbon are underestimated, mainly due to underestimation of emissions from high emitting vehicles (Watson et. al, 1998)

Additional information needed: For any modeling of the region that includes fugitive dust, time-resolved inventories that are reflective of meteorological condition and activity level need to be used. The inventories should use the best available methods for estimating transportable emissions rather than total emissions. The results also need to be reconciled with ambient measurements, including crustal contribution to PM_{10}. This implies chemical characterization of PM_{10} as well as $PM_{2.5}$.

HYPOTHESIS 14: Side canyon flows are important from transferring material into and out of the gorge and act as chemical reactors and reservoirs.

Evidence to support hypothesis 14: Particularly in the central and eastern gorge, there are numerous side canyons. Some of these side canyons include rivers that drain significant areas. It is reasonable to expect that these side-canyons would help facilitate transfer of air into and out of the gorge through drainage flow, upslope flows, etc. Air that enters the side canyons from the main gorge could have a longer residence time in the gorge area by being cut-off from the typical moderate wind speeds in the main gorge channel. This additional residence time could provide for enhanced conversion of gas to particles within the gorge area.

The Hood River Valley includes several towns and supports a large orchard industry, including emissions sources such as smudge pots. Additional side canyons contain small towns and associated emissions sources as well.

Additional information needed: Meteorological measurements should be made in side canyons to characterize these flows. This could include surface measurements, particularly for wind speed and direction, and upper air measurements with high resolution, such as sodars or tethersondes. Nephelometers collocated with the surface meteorology sites could give an idea of the visibility effects associated with the side-canyon flows. For areas with significant sources, such as the Hood River Valley, speciated $PM_{2.5}$ monitoring may be appropriate. An aethalometer could identify effects from smudge pots with high time resolution. Gas phase monitoring of precursor compounds in conjunction with $PM_{2.5}$ measurements could help to assess whether enhanced secondary particle formation is occurring in the side-canyons.

HYPOTHESIS 15: Geogenic sources (e.g. volcanoes) are sometimes important contributors to haze in the gorge).

Evidence to support hypothesis 15: Active volcanoes can release large amounts of SO_2 to the atmosphere, which can then form particles and contribute to haze. Popocatepetl in Mexico has been emitting on the order of 5,000-10,000 tons per day of SO_2 over the past few years. At the Miyakejima volcano in Japan, SO_2 emissions have ranged from 20,000 to 130,000 t/d, with an average of 40,000 t/d from mid September 2000 to February 2001. The eruption of Mt. St. Helens, which is very close to the National Scenic Area, in 1980 spewed an estimated 1 millions tons of SO_2 into the atmosphere. Subsequent monitoring by the United States Geological Survey (USGS) indicated continued releases of SO_2 into the atmosphere in the years following the eruption. The USGS stopped monitoring SO_2 from Mt. St. Helens when emissions dropped to below 25 tons per day.

Additional information needed: Activity from active volcanoes needs to be considered for data analysis, emissions inventory and modeling. If volcanoes in the Pacific northwest become more active, the USGS will most likely make estimates of SO_2 using correlation spectroscopy (COSPEC) for total column SO_2 and wind speed data. If needed, COSPEC measurements at Mt. St. Helens or other northwest volcanoes could be made in support of the study. The large emissions from volcanoes such as Miyakijima could have a contribution to sulfate in the Columbia River Gorge. $PM_{2.5}$ speciated measurements should be made along the Pacific Coast at one or more sites to determine background concentrations of components (in particular sulfate) entering the study region. This will help in setting boundary conditions for chemical transport modeling as well as aiding in data analysis. The coastal monitoring site(s) could also identify background levels of soil dust during periods affected by Asian dust storms, such as the April 1998 episode.

HYPOTHESIS 16: Protecting visibility protects other air quality concerns, such as ecosystems, cultural resources, etc.

Evidence to support hypothesis 16: To improve visibility, reductions in emissions of precursor gases such as SO_2, NO_X, and VOC's are important. Reductions in primary organic and elemental carbon and fugitive dust would also help improve visibility. Many of these emissions also may contribute to additional air quality impacts. Acidic aerosols containing sulfur and nitrogen can cause damage to ecosystems and cultural resources. Elemental carbon, or soot, could also impair cultural resources by coating surfaces. NO_X and VOCs contribute to ozone concentrations. Thus, reducing emissions that result in particulate matter will also help reduce other air quality impacts. One potential cause of ecosystem impacts, emissions of air toxics, would not be directly addressed under actions designed for visibility protection.

Additional information needed: More information needs to be gathered to determine the sensitivity of resources to gases and aerosols. At a minimum, aerosol and cloud/fog water acidity should be determined for sensitive areas. Resources should be monitored for evidence of adverse effects. Emissions inventories must include reasonable estimates of toxic compounds.

HYPOTHESIS 17: Ozone concentrations throughout the gorge are currently well below the national ambient air quality standard, and so are below levels of concern from a human health standpoint.

Evidence to support hypothesis 17: The ozone data collected at Wishram over the past seven years has not yet shown a violation of the ozone standard. The 75^{th} percentile of that data set falls below 42 ppb hourly average and the 99^{th} percentile falls below 66 ppb, both far below the 125 ppb one-hour standard. As pointed out in the previous section, only one exceedance (not a violation) of the eight –hour average 85 ppb standard occurred at the site during the regional episode of July 11-14, 1996.

Additional Information needed: Ozone measurements are needed at the west end and the central region of the Scenic Area. Many more exceedances of the 8-hour standard have occurred at the Portland sites; therefore it is possible that hourly ozone peaks at the west end and in the central part of the Scenic Area would be higher than at Wishram. The ozone dosage work conducted by Cooper and Peterson is also suggestive of this.

HYPOTHESIS 18: Ozone concentrations in part of the Scenic Area are above levels known to negatively impact ecosystem resources.

Evidence to support hypothesis 18: The fact that the 8-hr standard is apparently being met at Wishram would indicate that vegetation is being protected since the standard was set both as a primary one (to protect human health) and as a secondary one (to protect public welfare including vegetation.) However, other evidence does not support this indication. Although the 8-hr standard is expected to be more protective of vegetation than the 1-hr standard, it does not directly account for cumulative exposure or maximum concentrations. According to the Federal Land Managers' Air Quality Related Values Workgroup (FLAG), cumulative exposure and peak concentration are important biological parameters. They propose the use of other ozone metrics such as the W126. The W126 is an index that uses a sigmoidal weighted function to weigh each hourly ozone concentration.

Native plant species sensitive to ozone were identified for different regions in the FLAG document and by Brace, Peterson and Bowers in their Guide to Ozone Injury in Vascular Plants of the Pacific Northwest. Several of these ozone–sensitive species are found in the Scenic Area, among them are western serviceberry (Amelanchier alnifolia), salal (Gaultheria shallon), Ponderosa pine, Quaking Aspen (Populus tremuloides).   The Forest Service has documented ozone damage to pine species at Maryhill State Park in the Eastern Gorge.

The FLAG document also points out that ozone can affect entire ecosystems as shown in U.S. EPA research in which plants growing in areas of high exposure to ambient ozone may undergo natural selection for ozone tolerance.

Additional Information needed: Changes in growth and ecosystem form or function are difficult to document.   A field survey of sensitive plant species in the Scenic Area might reveal any damage currently occurring due to ozone. As already suggested, at least two more continuous ambient measurement sites in the Scenic Area are needed. An index such as W126 using any existing and future continuous measurements should be computed so that ozone exposure to vegetation in the Scenic Area can be better evaluated.

HYPOTHESIS 19: Ozone measured within the Scenic Area results primarily from precursor emissions outside the Scenic Area and is tied to regional episodes.

Evidence to support hypothesis 3: The temporal pattern at Wishram is suggestive of a "transport site" as defined by Bohm et al.   Transport sites are characterized by ozone maxima in the late afternoon and early evening. At night the ozone levels typically remain above 20 ppb.

A precursory look at the data shows that ozone concentrations are elevated at Wishram when they are elevated at most other sites in Portland and throughout the region. This fact is not surprising in light of the unique set of meteorological conditions that are needed to generate and sustain a high ozone episode: light winds and high temperatures that typically accompany strong high pressure ridges that can build off the coast in the summertime. Recker (1997) and Steenburg et. al. (1996) have documented these synoptic conditions that lead to ozone episodes in Washington and Oregon.

Additional Information needed: As pointed out earlier, additional ozone monitors are needed to get a better spatial picture of the ozone concentrations throughout the Scenic Area.   At the Technical Foundation Study phase (TFS), with appropriate background and initial data, a Lagrangian model using verified trajectories through the Scenic Area could provide a first look at ozone formation dynamics.

Regional Eulerian photochemical grid modeling is needed during episodic conditions to understand the spatial and temporal distribution of ozone in the gorge as well as its precursors. A modeling exercise of that nature is also needed for understanding the formation of secondary aerosols, and so would be an essential ingredient of an air quality study in the gorge. Process analysis of the proposed grid modeling study will be useful to follow the formation of the ozone plume and establish its main contributors.

HYPOTHESIS 20: Elevated ozone concentrations are correlated with periods of impaired visibility. Reductions in ozone precursors will have a positive benefit on visibility.

Evidence to support hypothesis 20: The following theoretical evidence exists to support hypothesis 20:

i. In the gas phase, oxidation of SO2, the initial step in the formation of sulfate aerosol, occurs predominantly through reaction with the hydroxyl radical (OH). OH production is enhanced during periods of peak ozone formation.
ii. Sulfur oxidation through reaction with ozone in the aqueous phase is rapid.
iii. Ozone and OH aid the formation of secondary organic aerosol by the oxidation of low vapor pressure organic gases.
iv. Stagnant meteorological conditions with low vertical mixing are typical of ozone episodes, and also lead to elevated concentrations of smog-related aerosols and NO2. NO2 is a gas that absorbs light, and, like aerosols, can also cause visibility impairment.

Additional information needed: A statistical analysis of periods of elevated ozone and the corresponding measured light-extinction needs to be conducted. In addition, process analysis of the modeling results to follow the atmospheric chemistry processes that predominate during periods of elevated ozone and impaired visibility in the Scenic Area will help verify hypothesis 20.

4 ELEMENTS OF THE PROPOSED STUDY

There are three components in the study (monitoring, emissions inventory, and modeling). This section outlines the various methods and approaches that are under consideration.

4.1 MONITORING COMPONENT

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 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.

The measurements need to have an uncertainty associated with them. This is necessary for placing confidence in conclusions drawn from the data, for use in receptor modeling, and for evaluation of meteorological and chemical transport modeling. Assigning uncertainty to measurements is best determined by having a period of collocated measurements in the study area, although collocated measurements done in other locations may be adequate. These measurements can give a quantitative value of precision, although accuracy is not directly addressed. At monitoring sites with both high time resolution measurements and longer (e.g. 24 hour) average measurements, the high-time resolution measurements can be averaged to the 24-hour period for comparison. Additional aspects regarding measurement quality are addressed in Section 8- Quality Assurance.

Many of the measurements in the monitoring program will be conducted within the Scenic Area and regions nearby. To the uninitiated this may appear to bias results towards in-Gorge sources. But because the Scenic Area is the receptor of pollutants emanating from various regions near and far, it is very critical to know what is happening inside the Scenic Area to be able to understand what, when and where the pollutants come from.

4.1.1 Optical measurements

<u>Nephelometers</u>

Heated nephelometers or nephelometers used in conjunction with Nafion dryers will be deployed as a sort of high time resolution aerosol monitor, while ambient nephelometers will be used to characterize ambient light scattering. Heated nephelometers may volatilize some aerosol, such as nitrate and volatile organics. It would be preferable to use dry scattering for example, with Nafion driers which would not volatilize aerosol components, if resources allow. Both dry and ambient nephelometers 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.
- Nephelometers mounted in aircraft could give information on vertical mixing of the aerosol and how distributions change with distance downwind in the gorge and by time of day.

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.

Total light extinction

A measure of the total light extinction is desirable as a check on the light scattering and light absorption measurements as well as being a measure directly related to haze. The sum of scattering by gases and particles and absorption by gases and particles should equal the total light extinction. This comparison i.e. optical closure has proved somewhat elusive in the past. The absorption measurements typically have been based upon filter-based measurements which may not directly relate to atmospheric measurements. Photo-acoustic methods (e.g. Moosmuller) are a more direct measurement of absorption than are filter-based measurements and include NO_2 absorption as well (filter measurements do not). Light scattering measurements by nephelometers have scattering angle truncation effects, which mostly results in missing a portion of the coarse particle scattering. Even in near-ambient nephelometers, some modification of the aerosol occurs due to heating of the aerosol by the nephelometer lamp.

Transmissometers measure the total light extinction through a path in the atmosphere from the light source to the receiver, typically a distance of a few kilometers. These measurements are hard to compare directly to nephelometer and various absorption measurements, which are made at essentially one point, as are aerosol measurements. Also, the transmisssometer measurement relies on an accurate calibration of lamp brightness, which varies (in a somewhat predictable manner) over time. Density changes in the atmosphere due to large temperature gradients can cause broadening of the light beam, thereby increasing the measured extinction, even though it is unrelated to aerosol concentration. During periods of fog and low cloud, common to the Scenic Area, transmissometer measurements may be either unavailable or indicating very high extinction (which, while correct, may be of little use). In spite of these limitations, transmissometers could be of potential use in optical closure, if sited such that the transmissometer sight path is representative of the scattering and absorption measurement areas. It would be most useful for periods without low clouds or fog.

Total extinction measurements such as the extinction cell developed by Moosmuller may provide a better method than transmissometers for optical closure. The extinction cell, coupled with photo-acoustic absorption measurements and nephelometers (missing some coarse scattering) could provide a good measure of each component of light extinction. NO_2 measurements would give the required information to calculate its light absorption.

Ground based LIDAR

LIDAR uses the backscatter of light from aerosol to indicate the distribution of aerosol along the beam. By rotating the beam, the aerosol distribution over a volume, as well as the velocity of the aerosol can be determined. This can be very useful in understanding the vertical mixing characteristics in an area and showing whether aerosol is being transported by certain features, such as nocturnal jets, etc. A LIDAR situated in mid-gorge may be most useful in documenting aerosol transport up and down the gorge. LIDAR will work only up to the base of clouds. Under clear conditions to above the gorge, information upon aerosol concentration and transport within and above the gorge, and whether there is coupling can be obtained.

4.1.2 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 (chemical transport) 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. NO_y is of value for use in chemical transport modeling

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, HNO_3, NOy, SO_2, O_3, and speciated organic gases. Useful for air quality modeling, determination of limited species for chemical reactions.

- 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. Particle size measurements could also be taken aboard aircraft to give 3-dimensional structure of particle count and size distribution during periods of particular interest.

- Additional out-of-gorge IMPROVE monitoring sites will continue to routinely collect speciated $PM_{2.5}$ data. This includes site at Mt. Hood, The 3 Sisters Wilderness, Mt. Ranier, Snoqualamie Pass, and other IMPROVE monitoring sites. This data can help specify regional background conditions for the NSA.

4.1.3 Meteorological measurements

Meteorological measurements, especially wind speed and direction are needed to understand source-receptor relationships. Analysis of data from the measurements will help understand flows into and out of the gorge, including along side canyons, and vertical mixing. They are also necessary for input to and evaluation of meteorological models. They are useful for interpretation of other measurements such as light scattering and speciated aerosol.

Proposed measurements 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. Radar wind profilers would be helpful in many places. The number of profilers deployed would be limited by resources and suitable locations for deployment. Desirable locations for profilers include: mid-gorge, western end of gorge, eastern gorge, near Longview, near Boardman, south of Portland.

- Ceilometers. Ceilometers are optical instruments that give the height of cloud bases. Cloud base height is useful for chemical transport modeling by serving as input to or evaluation of the model predicted cloud levels. Chemical transformation processes are quite different if liquid water is present than in the absence of liquid water.

- Solar radiation. Spectrally-resolved solar radiation is useful for calculation of photolysis rate parameters in chemical transport modeling.

4.1.4 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).

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

Table 4.1 Recommended measurements to consider and estimated costs in order of priority.		
Measurement	What it tells us	Cost
Technical Foundation Study		
Ambient nephelometers at Wishram, Mt. Zion – minimum 1 year	Light scattering including water growth effects	\$30K +\$18K/yr
Aethalometers at Wishram, Mt. Zion – minimum 1 year	High time resolution light absorption–impact of local sources? See Portland material moving through?	\$24K/site + \$10K/site/yr \$68K 1 year, 2 sites
Additional heated nephelometers with surface meteorology along Gorge (3 minimum e.g. Cascade Locks, another below Hood River, between Hood River & The Dalles) plus heated nephelometers with surface meteorology at 3 vertical levels in mid-gorge (river, above river, rim)	B_{sp} gradient along gorge/effects of local cities. Vertical mixing/b_{sp} gradients	\$20K+\$15K /yr /site= \$105K 3 sites 1 year
Portable Radar wind profiler and/or tethersonde and ceilometer deployed at key areas – e.g. mouth of gorge, mid-gorge, side canyons, eastern gorge for exploratory measurements + 1 year one site	Basic information on structure of atmospheric flow in gorge – depth of flows, side-canyon importance, etc. Help to design more detailed meteorological measurements	\$100K
$PM_{2.5}$ 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	\$88K+36K/yr
PM_{10} speciation at Wishram, Mt. Zion Include $NH4^{+}$, SO_2 IMPROVE schedule, 1 year	Speciation for comparison with coarse particle scattering-aerosol neutralization	\$30K+ \$70K/yr =\$100K
NH_3, HNO_3 (g), SO_2, Wishram, Mt. Zion one year IMPROVE schedule, 1 day in 6, 4-6 samples per day for NH_3, HNO_3, SO_2. Continuous NOy, O_3	Provide data for air quality modeling Determine if atmosphere is ammonia limited- evaluate emissions inventory	\$200K
Precipitation and Fog water sampling and chemical analysis- Boardman powerplant area, central gorge as possible during 45 day period	Determine potential ecosystem and cultural resources affects	\$80K
Speciated PM2.5 east of Gorge (Columbia Basin) and west of the Gorge (upwind of Portland). IMPROVE 1 day in 3 schedule.	Regional species gradient (transport sites) east and west of Gorge.	\$60K/site, 2 sites, 1 year = \$120K
Scene Monitoring (Camera). Digital Image Acquisition and Time Lapse Video. Two sites, one western and one eastern Scenic Area	Digital scene images to visually illustrate visibility conditions, and time lapse video to capture dynamics of formation and movement of haze.	\$42K first year, \$31K each year thereafter.

One-year expanded measurement program: additional horizontal and vertical gradients in gorge year-round, in-gorge vs. out-of gorge sources		
Additional PM monitoring site collocated with mid-gorge nephelometer site. Speciated $PM_{2.5}$ and PM_{10}, with NH_{4+}, NH_3, SO_2,	Characterize central gorge. Compare with measurements at east and west end of gorge. Some gradient information.	$40K + $80K/yr= $120K 1-year
Gas and particle phase speciated organic aerosol using GCMS. 2 sites, one in six days for 1 year	Identification of key organic species in gas and particle phase. Contribution of biogenics, burning, gasoline, diesel, and meat-cooking to organic carbon with CMB	$160K
Radar wind profiler/SODAR/RASS 1 site, 1 year	Vertical wind/temperature profiles	$100K
Speciated $PM_{2.5}$ 2 nephelometer sites along gorge- IMPROVE schedule, 1 year	Species gradient along gorge/local city effects	$30K+$80K /yr=$110K
DRUM samplers vertical nephelometer sites 1 year, analyze periods of interest	Vertical gradients of species (at least sulfur)	$75K
Speciated $PM_{2.5}$ at nephelometer site at top of gorge, IMPROVE schedule, 1 year	In gorge/above gorge species gradient	$15K+$40K /yr=$55K
2 Additional aethalometers either side of City of Hood River – year round	Help determine presence of emissions from gorge cities, especially winter wood burning	$68K
High –time resolution SO_4, NO_3, EC/OC 1-3 sites (Wishram , Mt. Zion, mid-gorge site) 1 year	Year-round knowledge of chemical species changes in time	$100K/site+ $100K/yr per site= $200-$600K
Summer intensive period studies – effects of Portland/Vancouver Continue measurements as appropriate from TFS and one-year expanded network study and add:		
Nephelometers and surface meteorology upwind (downriver) of Portland (one or more), Portland (3)	Change in light scattering due to Portland urban area	$25K/site 4 sites= $100K
Speciated aerosol upwind of Portland (3)/ Portland (3), along gorge sites (5), top of gorge (1 or more) Daily for 30 days July-August, reporting, meetings	Chemical speciation changes due to Portland urban area – relate to light scattering changes	$140K +$110K/ month (6 new sites)
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 Mt. Zion or central gorge site.	Chemical species change in time – relate to nephelometer data	$140K
DRUM samplers 5 along gorge sites 30 days- analyze periods of interest	High-time res. speciation- Track movement of Portland plume	$50K
Radar wind profilers & sodars 6 sites	Vertical wind profiles	$200K
Organic gas and aerosol speciation, at	Spatial pattern of organic speciation	$100K

additional sites or times if TFS studies warrant		
Extinction cell, photoacoustic absorption, light scattering one site	Extinction budget closure	$70K
Winter Intensive period studies – Boardman plant, CR Basin sources, in-gorge, fog water Continue measurements as appropriate from TFS study and add:		
Nephelometers near and away from river either side- eastern gorge minimum 3 sites	Extent of channeling of emissions eastern gorge	$10K/site assumes have equipment $30K 3 sites
Speciated aerosol near and away from river Eastern gorge/Hood River drainage/CR Basin- 5 sites 45 days, reporting	Species channeled vs. regional	$35K+$33K/ month= $85K 45 days
Speciated aerosol 5 along gorge sites, 1 above gorge site 45 days, reporting	Gradient within gorge, upwind/ downwind of gorge cities	$10K+ $51K/month= $86K 45 days
Radiosondes 4/day for 30 days 2 sites, one mid-gorge, one east end of gorge	Mixed-layer depth, vertical wind (transport) structure	$60K
Precipitation and Fog water sampling and chemical analysis- Boardman powerplant area, central gorge as possible during 45 day period	Potential ecosystem and cultural resources effects	$80K
High –time resolution SO_4, NO_3, EC/OC Wishram	Chemical species change in time – relate to nephelometer data	$50K (assumes instruments available)
Radar wind profilers & sodars 6 sites	Continuous vertical wind structure	$200K
Extinction cell, photoacoustic absorption, light scattering one site	Extinction budget closure	$70K
Organic gas and aerosol speciation, at additional sites if TFS studies warrant	Spatial pattern of organic speciation	$100K
Ceilometers at 2 wind profiler sites	Cloud base height	$25K

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

Supplemental measurements at next funding levels		
NH_3, HNO_3, NOy, O_3 at additional sites if warranted by TFS studies	Provide data for air quality modeling. Spatial pattern of ammonia and limitation	$80K summer, $80K winter
Expanded aerosol monitoring network summer study- 10 additional sites e.g. Mt. Hood, Columbia River mouth, south of Tacoma, south of Portland,	Aerosol gradients for larger area and with more resolution	$175K + $100K /month= $275K

additional above gorge, east of Wishram, top of Mt. Zion, Mt. Ranier- 30-60 days		1-month 10 sites
Expanded aerosol network winter study- 10 additional sites 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	$50K + $100K/ month= $200K 45 days
Small aircraft measurements of light scattering, light absorption, particle size, wind speed and direction, temperature, and humidity	Determine vertical distribution of aerosol and boundary layer depth as function of time of day and location in gorge. Possible information on side-canyon aerosols	$180K summer, $120K, winter
Aerosol Microphysics studies- nephelometer with RH ramped, particle growth with TDMA, SEM analysis	Better understanding of water growth of particles	$100k summer, $100K winter
Additional wind profilers for intensive periods 6 more sites (12 total)		$200K summer, $200K winter
Measurements at highest funding level		
LIDAR- a six week winter study and 6 week summer study- operation on about ½ of days	Gorge cross-section mapping of aerosol, along with wind velocities, as a function of height	$190K
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	$300K
Additional radar wind profilers/sodars, operation for 1 year	Better description of meteorological fields, full annual cycle- useful for model evaluation and input	Additional $200K 6 sites, $400K 12 sites
Tracer studies- e.g. Boardman powerplant winter	Determine if power plant affects gorge- use with chemistry data for estimated impacts (e.g. TAGIT)	$500K
Tetroons from Boardman powerplant area by forecast during 45-60 day period	Potential transport of power plant products into gorge	$50K

4.1.5. Data Analysis/Conceptual Model Development

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.

Once the data have been analyzed, the conceptual model of the physical and chemical processes governing air quality in the Scenic Area will be developed.

4.2 EMISSIONS COMPONENT

A good emissions inventory is necessary to understand air quality, perform source attribution and evaluate alternative emissions scenarios. An emissions inventory including SO_2, NO_X, NH_3, speciated VOC, and speciated primary PM is needed. This includes emissions from all potential source types affecting the gorge – industry, mobile sources (e.g. vehicles, ships, trains, air craft), area sources (e.g. woodstoves, outdoor burning, solvent use, agriculture), and biogenics (e.g. natural emissions from vegetation). Proper spatial and temporal distribution of the emissions is also necessary. Temporal resolution is normally hourly, and spatial resolution depends on analysis requirements. In chemical transport models, emissions typically require the same spatial resolution as the meteorological data. Efforts are underway, as described below, to produce a "state of the science" inventory for the Pacific Northwest; however, verification with measurements will be necessary to evaluate how "good" the inventory really is.

Oregon and Washington have been involved in emissions inventory preparation for many years. Inventories have been prepared in response to federal and state requirements for point source reporting, State Implementation Plans (SIPs) for visibility and individual criteria air pollutants, and various special studies. The states have a history of cooperation, though coordinated inventory efforts have been fairly limited in scope. With the increased emphasis on regional issues such as ozone and haze, Idaho, Oregon and Washington initiated the formation of the Northwest Regional Technical Center (NWRTC). The NWRTC is tasked with the comprehensive analysis of transport, dispersion, and chemical transformation of airborne emissions throughout the Pacific Northwest, and will be instrumental in the development of Regional Haze SIPs. As part of the initial demonstration, the three states are meeting regularly to coordinate emissions inventory efforts for two haze episodes that occurred in July 1996. The inventory resulting from the demonstration project will be used as a basis for this proposed study.

The states began the inventory process by discussing a comprehensive list of source categories that could potentially contribute to visibility impairment. Staff identified the sources believed to be the most significant contributors and assigned a lead from one of the states to each category. The leads are in the process of researching their source categories and will make recommendations to the group addressing the pollutants, methodology, data sources, temporal/spatial resolution, and spatial surrogate. Sources are listed in the table below.

During discussion, the states found common inventory deficiencies. They requested and received special funding to inventory several of the source categories identified (woodstoves, residential outdoor burning, commercial marine vessels, railroads, and biogenics). In addition to the regional inventory projects funded, Oregon received special funding to obtain stack parameters for point sources, inventory aircraft, research ammonia emission factors, and other work if resources allowed. Results from the funded work are expected during the summer of 2001.

NWRTC Emissions Inventory Source Categories and Pollutants

Category	Include?	Pollutants
Major Point Sources	Yes	criteria
Onroad Mobile Sources	Yes	criteria, NH_3
Locomotives	Yes	criteria
Ships	Yes	criteria
Aircraft	state's discretion	criteria
Recreational Boats	Yes	criteria
Other Nonroad Mobile	Yes	criteria
Residential Wood Combustion	Yes	criteria
Restaurants	further research	criteria
Agricultural Burning	Yes	criteria
Prescribed Burning	Yes	criteria
Other Open Burning	Yes	criteria
Wildfires	further research	criteria
Agricultural Tilling	further research	criteria
Windblown Dust	further research	criteria
Paved Road Dust	Yes	criteria
Unpaved Road Dust	Yes	criteria
Surface Coating	Yes	criteria
Surface Cleaning	Yes	criteria
Commercial/Consumer Products	Yes	criteria
Biogenics	Yes	criteria
Livestock NH_3	Yes	NH_3
Fertilizer Application	Yes	NH_3
Soil NH_3	Yes	NH_3

Through the NWRTC, the emissions will be prepared for air quality modeling using the Sparse Matrix Operator Kernel Emissions (SMOKE) emissions processor. Spatial surrogates are being obtained and will be assigned to 12-km grids using GIS methods and incorporated into SMOKE along with temporal and chemical speciation profiles. The NWRTC is carefully looking into the most recent research that the Western Regional Air Partnership (WRAP) has produced on fugitive dust sources, and will incorporate their recommendations into the emissions inventory.

It is worth noting that staff from the three states participate regularly in the Emissions Forum of the WRAP. WRAP is a Regional Planning Organization formed to address the federal regional haze rules, and is made up of government, tribes, industry, and environmental groups throughout the western US. Technology transfer is part of the WRAP process, and the state modeling inventories are expected to benefit from the knowledge gained by WRAP.

The inventory process and resulting NWRTC inventory will be modified and enhanced to meet the needs of the TFS study. This may involve adapting the inventory for a different episode, and could involve processing the data using a finer spatial resolution. Because the spatial surrogates will be obtained in GIS formats, finer grid resolution will be possible. Adapting the inventory to a different episode could require generating new emission rates for sources that vary with meteorology (onroad mobile, biogenic, etc.). It could also involve obtaining growth factors to project activity to other years.

Effects of control measures upon ambient concentrations of particulate nitrate can also be tested using the Simulating Composition of Atmospheric Particles at Equilibrium (SCAPE) model (Kim et al., 1993a, 1993b) along with the proposed NH_3, NH_4^+, $NO3^-$, HNO_3, and SO_4 measurements. The model apportions nitric acid/nitrate and ammonia/ammonium between gas and particle phases. If the agreement with the measurements is satisfactory, the model can then be applied to evaluate effects of applying controls to ammonia and/or total nitrate (gaseous + particulate) upon ambient particulate concentrations. Another chemical model is needed to assess the effects of NO_X controls on total nitrate.

After the TFS effort, it is likely that more inventory work will be needed. More comprehensive source category coverage and spatial definition may be necessary. This could involve special source surveys. Inventory verification involving additional grid modeling for comparisons to measurements may be necessary. Additional work may also 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.

4.3 MODELING COMPONENT

As discussed above, there are two main objectives to the modeling component of the study:

1) to help understand current sources contributing to air pollution within the gorge thus supporting or modifying the conceptual model.
2) to provide a modeling methodology for future use in quantitatively estimating air quality changes resulting from different emissions scenarios.

Models can be used to help us understand some of the processes suggested by the analysis of the air quality and meteorological monitored data. When a quantitative model can reasonably agree with the processes suggested by the conceptual model, the certainty of our conclusions about both models is increased. The ultimate goal is a complete modeling system (emissions, meteorological fields, air quality model) that can accurately explain the measurements and thus can, with some confidence, predict the future given a variety of emissions scenarios.

For the first objective, a model is used that will tell us how much of an impact we can attribute to a source or type of sources. There are several types of attribution models. Some work in a forward manner from emission sources to receptors (locations in the

Scenic Area). These models work by taking a known mix of emissions, transporting them by and through meteorological conditions, chemically transforming the pollutants, and finally depositing the resulting chemical species in the air or on the ground in the receptor location. Other models work in the reverse. For these models, the sample at the end point (for example, from an IMPROVE or other monitoring site) is analyzed for its chemical constituents, and an attempt is made to match that composition with what we know about the make up of a source category's emissions. Essentially, each source category has a unique "finger print" that suggests that the source was responsible for all or part of the impact. Used alone, however, reverse attribution models in general can only identify types of sources (e.g. pulp mills versus diesel vehicles versus coal fired boilers) rather than specific individual sources.

For the second objective, a model is used to predict future air quality using meteorological measurements, source specific pollutant emissions data, and calculated or assumed boundary conditions to calculate the transport, dispersion, deposition and chemical transformation of pollutants in the atmosphere. These predictive models can be used to predict future air quality impacts from a variety of emission scenarios.

It is possible that the same modeling system could be used for both objectives.

Because haze, ozone, and secondary particle formation operate on a regional scale, a regional scale modeling system is required. This eliminates the use of simple straight-line Gaussian plume models like the Industrial Source Complex (ISC) and AERMOD.

Most regional modeling systems have three components: an emissions model, a meteorological model, and an air quality model. Each component is briefly described below.

4.3.1 Emissions Modeling

An emissions processor is necessary for converting emissions inventory data into formatted emission files for the grid-type dispersion models. This process is described above in the emissions inventory component. Finer resolutions may be required for the finer resolution (4, 1.33-km and potentially 0.4-km) grid structure. These activities would include GIS mapping of county level emissions to the grid, meteorological adjustments to the emissions, inclusion of any day-specific emissions (e.g., CEM data), temporal (e.g., day-of-week and diurnal) adjustments, and speciation into the species in the chemical mechanism being used.

Limitations in emissions inventories will also affect modeling adequacy. Sources of SO_2 should be reasonably well quantified. NO_X emissions estimates may also be reasonably good. Higher uncertainties may be associated with the ammonia, particulate and VOC inventories. Measurement, data analysis, and receptor modeling components of the study may be sufficient to characterize impacts from some of the sources contributing to these inventories.

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.

4.3.2 Meteorological Modeling

Most regional scale air quality modeling systems require time-varying three-dimensional wind fields in order to simulate the complex spatial and temporal wind flows over modeling domain (several hundreds of kilometers in size). These wind fields are typically generated using meteorological models used in weather forecasting. An example of such a model is the Fifth-Generation NCAR / Penn State Mesoscale Model (MM5) model. Currently, it is reasonable to run these models using a relatively coarse (12 km) resolution grid over the entire Pacific Northwest (e.g., Oregon, Washington and Idaho). However, because the terrain within the Scenic Area is complex, narrow and deep, a 12-kilometer grid spacing would not resolve much of the terrain within the Scenic Area. The use of such a coarse grid would smooth out much of the terrain features within the Gorge. A much finer grid resolution (perhaps less than 1 km) is need to adequately resolve the terrain so that the wind flow within the Gorge may be correctly simulated. In this modeling study, the modeling domain would likely need a nested grid structure such as:

- 36-km grid covering the western U.S.
- 12-km grid covering Washington, Oregon, and western Idaho;
- 4-km grid covering southern Washington, northern Oregon, and potentially extending into most western Idaho;
- 1.33-km grid covering the Columbia River Gorge region;
- 0.44-km grid, if necessary, covering the Gorge area.

Three-dimensional grid modeling at the 36/12/4/1.33/(0.44)-km scales listed above are quite time and resource intensive, with most of the resources used in the finest grid areas. Therefore, it is expected that only a few episodes could realistically be evaluated. If adequate modeling results can be obtained using coarser resolution (e.g., a 36/12/4-km grid) and/or using reduced form modules (RFM), then much longer periods could be modeled.

Example Meteorological Models:

- The Fifth-Generation NCAR / Penn State Mesoscale Model (MM5) model is a prognostic mesoscale meteorological model that uses finite-difference approximations to the solution of the governing partial differential equations for thermodynamics, momentum, and moisture. This model is currently in operation across the United States. In the Pacific Northwest, the MM5 modeling is typically run at 4- and 12-km resolution. MM5 (and its predecessor MM4) has been invested in by the environmental science community for two decades as driver for regional scale environmental models.

- The Weather Research and Forecasting Model (WRF) is a candidate model for replacing the MM5 and ETA meteorological models. It is being designed to better represent the physical and dynamical processes that occur at the 1-10km spatial scale. An early version of the model is available now; it is expected to be fully operational by 2003-2004. WRF is being developed by in a collaborative effort by NCAR, Forecast Systems Laboratory of NOAA, University of Oklahoma CAPS (Center for Analysis and Prediction of Storms), National Centers for Environmental Prediction, and the USAF Air Force Weather Agency (**http://www.wrf-model.org/**).

- The CALMET diagnostic wind model has also been used and there has been some success using coarse MM5 output with CALMET. CALMET is the meteorological pre-processor for the CALPUFF modeling system developed by Earth Tech (**http://www.src.com/calpuff/calpuff1.htm**). However, the complex flow fields within the Gorge, including upslope/downslope flows due to slope heating/cooling, can not be accurately simulated with a diagnostic wind model so a prognostic meteorological model must be utilized.

- The Regional Atmospheric Modeling system (RAMS) is a multipurpose, numerical prediction model designed to simulate atmospheric circulations spanning in scale from the hemisphere down to large eddy simulations (LES) of the planetary boundary layer. Its most frequent applications are to simulate atmospheric phenomena on the mesoscale (horizontal scales from 2 km to 2000 km) for purposes ranging from operational weather forecasting to air quality regulatory applications to support of basic research. RAMS was developed by Colorado State University (http://www.aster.com/rams.shtml).

4.3.2 Air Quality Modeling

There are three main types of air quality models, each with their own advantages and disadvantages:

Receptor Models. Receptor models are based on observed particulate matter (PM) concentrations and apportion the measured PM based on emission source profiles or PM precursors. The most common receptor model is the Chemical Mass Balance (CMB) model that uses source signatures (fingerprints) and PM and other trace element observations to allocate the observed PM concentrations to generic source categories. The receptor model could then be used with a back-trajectory wind fields to identify areas and source categories likely contributing ambient concentrations at aerosol sites for given sampling periods.

> Advantages: Once the measurements are collected, receptor models can be applied cost effectively to understand the general source types that contributed to the observed PM concentrations. Once the observed PM is apportioned to the general source categories, future-year PM estimates are obtained by performing linear or proportional rollback of the PM component attributed to a specific

source category by the change in emissions in that source category from the base-year to future-year scenario.

Disadvantages: Receptor models only provide contributions due to general source categories, such as gasoline combustion, diesel combustion, coal-fired power plants, vegetative burning, etc. It will not differentiate between subcategories within these major source categories (e.g., on-road mobile and non-road gasoline sources; heavy duty trucks, construction/agricultural equipment, and locomotive diesel sources; wood stoves, agricultural, prescribed, and wildfire vegetative burning; specific coal-fired power plants, etc.). In addition, receptor models can only differentiate general geographic source regions from which sources contribute to the PM concentrations at receptor sites, and can not treat secondary PM species, such as sulfate, nitrate, and secondary organic aerosols.

Example Receptor Models:

- The Chemical Mass Balance (CMB) receptor model uses the chemical composition of ambient pollution samples to estimate the contributions of different source types to the measured pollutant concentrations. The CMB model has been most widely used for suspended particulate matter, but it is equally applicable to gaseous species. The chemical composition of each source-type's emissions (source profile) must also be known to use the model. The model is available on the EPA SCRAM internet site (http://www.epa.gov/ttn/scram/)

Dispersion Models. Dispersion models simulate the transport, dispersion, and deposition of pollutants by following an air parcel as it moves downwind from the emission sources to receptors of interest. The CALPUFF model is such a dispersion model that also has a simplified treatment of ammonium sulfate and ammonium nitrate that is formed in the atmosphere (secondary PM). Dispersion models are typically first applied to a PM episode and the model estimates are compared against the observed PM in a model performance evaluation. Once the dispersion model is accepted as reproducing the observed PM sufficiently well, the model can be used to estimate future-year PM levels for alternative emission growth and control scenarios.

Advantages: Dispersion models can provide estimates of the contribution of primary PM emissions to PM concentrations by source category and source type. Under simple chemistry conditions, some dispersion models can also provide estimates of certain secondary PM species (e.g., sulfates and nitrates). For modeling small sets of sources and receptors dispersion models can be cost-effective.

Disadvantages: Dispersion models assume a coherent air parcel, an assumption that breaks down in areas of complex flow fields. Thus, the validity of dispersion models breaks down at longer downwind distances or when three-dimensional flow processes are present (e.g., complex terrain, land/sea breezes, lake breezes, frontal systems, etc.) Treatment of secondarily formed PM in dispersion models is highly simplified and not valid under many circumstances, especially those involving photochemical oxidants. Computer run times of dispersion models is directly dependent on the number of sources and receptors specified, thus their cost-effectiveness is compromised when analyzing the impacts of many sources.

Example Dispersion Models:

- CALPUFF is a multi-layer, multi-species non-steady-state puff dispersion model that simulates the effects of time- and space-varying meteorological conditions on pollutant transport, transformation and removal. CALPUFF can be applied on scales of hundreds of meters to hundreds of kilometers. It includes algorithms for subgrid scale effects (such as terrain impingement), as well as, longer range effects (such as pollutant removal due to wet scavenging and dry deposition, chemical transformation, and visibility effects of particulate matter concentrations). The CALPUFF modeling system developed by Earth Tech (http://www.src.com/calpuff/calpuff1.htm) and is the current recommended model for evaluating the long-range transport (> 50 kilometers) impacts from point sources. The CALPUFF model has also been run in a "backward" dispersion mode. This method is intended to demonstrate which geographic areas have contributed air to a receptor site during a given time period and estimates associated dispersion factors from each contributing grid cell. This general methodology has been in use for several years (e.g. Uliasz, 1996) and is currently available for use in NOAA's HYSPLIT model (http://www.arl.noaa.gov/ready/hysplit4.html). The utility of this approach depends upon the quality of the meteorological fields used.

- The Inorganic and Secondary Organic PARTicles (ISOPART) model is a Lagrangian aerosol model. Carbon chemistry within the ISOPART model is based on the Carbon Bond IV mechanism. The model chemistry has been extended to quantify the biogenic contribution to organic aerosol mass based on explicit chemistry (where reaction rates and pathways are known) and using smog chamber data to estimate aerosol yields. The model, when used with high quality meteorological fields, may help to better understand the relative contribution of primary versus secondary organic aerosol, a major contributor to fine particulate matter in the Scenic Area. The results can also be compared to CMB results using the speciated organic aerosol data.

Three-Dimensional Chemical Transport Models. Three-dimensional (3D) chemical transport models (CTMs) are photochemical grid models that are usually driven by 3D meteorological fields generated by a meteorological model (e.g., MM5) and can simulate 3D transport and dispersion of pollutants. They require gridded speciated emissions inventories of primary PM and secondary PM precursors for all sources. 3D CTMs can treat both regional as well as local issues. However, they can only resolve processes down to the grid resolution used so that typically grid nesting is used when analyzing multiscale issues. CTMs can use state-of-science chemistry and other algorithms, but some can also use more simplified and numerically efficient approaches. Like dispersion models, CTMs are set up and evaluated for a base year and then once the model has been judged to be performing adequately, they can be used to assess future-year PM and visibility for a variety of emission growth and control options.

> Advantages: Potentially can provides the most scientifically accurate and credible estimate of PM in the Gorge from all sources in and out of the Gorge. Can treat complex nonlinear chemistry, three-dimensional transport and dispersion, and emissions from all point, area, mobile, and biogenic sources.
> Disadvantages: Requires extensive data and computer resources to operate. Model run times can be quite large. The resolution of the estimated impact is limited to the resolution used in the grid model.

Example Chemical Transport Models:

- EPA Models–3 Community Multiscale Air Quality (CMAQ) Modeling System Chemical Transport Model (CTM) has a number of different modules and mechanisms for treating the chemical and physical processes of importance. (http://www.epa.gov/asmdnerl/models3/) The CMAQ modeling system has been designed to approach air quality as a whole by including state-of-the-science capabilities for modeling multiple air quality issues, including tropospheric ozone, fine particles, toxics, acid deposition, and visibility degradation. In this way, the development of CMAQ involves the scientific expertise from each of these areas and combines the capabilities to enable a community modeling practice. CMAQ was also designed to have multi-scale capabilities so that separate models were not needed for urban and regional scale air quality modeling. CMAQ CTM (CCTM) includes the following process modules: horizontal and vertical advection with mass conservation adjustments, horizontal and vertical diffusion, Gas-phase chemical reaction solver, aqueous-phase reactions and cloud mixing, aerosol dynamics and size distributions, plume chemistry effects, aerosol deposition velocity estimation, and photolytic rate computation. CMAQ CTM is currently being used in the Western Regional Air Partnership (WRAP) regional haze study (described below).

- The Comprehensive Air quality Model with extensions (CAMx) is a publicly available computer modeling system for the integrated assessment of photochemical and particulate air pollution. CAMx includes four versions of the Carbon Bond IV (CBM-IV) chemical mechanism and the 1997 version of the SAPRC chemical mechanism. The SAPRC97 mechanism was added as an alternate mechanism because it is chemically up-to-date and has been tested extensively against environmental chamber data. The current version of CAMx contains a treatment of secondary organic aerosol and an empirical aerosol thermodynamic module for treating PM10. The incorporation of full-science sectional aerosol thermodynamics, SOA, and aqueous chemistry modules is planned in the near future to address PM, visibility, and acid deposition issues. CAMx has been developed by Environ Corp (http://www.camx.com/)

- Multiscale Air Quality Simulation Platform (MAQSIP) is the air quality component of EDSS. MAQSIP is a fully modularized three-dimensional system with various options for representing the physical and chemical processes describing regional- and urban-scale atmospheric pollution. The governing model equations for tracer continuity are formulated in generalized coordinates, thereby providing the capability of interfacing the model with a variety of meteorological drivers. The model employs flexible horizontal grid resolution with multiple multi-level nested grids with options for one-way and two-way nesting procedures. In the vertical, the capability to use non-uniform grids is provided. Current applications have used horizontal grid resolutions from 18-80 km for regional applications and 2-6 km for urban scale simulations, and up to 30 layers to discretize the vertical domain. The aerosol module of MAQSIP is based on EPA's Regional Particulate Model (RPM). The model uses an enhanced version of the RADM2 mechanism to simulate the production of fine particulate matter (PM) and PM precursor species. It includes the response of aerosol size distribution to primary emissions, atmospheric transport, chemistry and dynamics. (http://envpro.ncsc.org/products/maqsip/)

5 PROPOSED STUDY STRUCTURE

5.1 Phased Approach Concept

This program envisions several monitoring, modeling and emission inventory study components that will be conducted over three scientific study phases. The three phases are:

1. The first phase is the technical foundation study (TFS) that must be conducted to provide guidance and a foundation for future technical work. The focus of the TFS is to characterize the physical, meteorological and chemical processes governing air quality and visibility within the Scenic Area. The results of the TFS will guide the final development and recommendation of phase 2 study options. Options for phase 2 will be developed after the TFS is completed.

   The completion of phase 1 is anticipated to occur 18 to 24 months from date of funding.

2. The second phase is primarily for verification of the conceptual model, identification of contributing sources and source areas, and final development, testing, validation and selection of an air quality predictive model to be used later by decision-makers for strategy development. This phase will likely contain a 1 year expanded study plus one to two month summer and winter intensives. It is envisioned that this phase will contain several options that relate to the degree of confidence and level of certainty desired or needed to support development of an equitable, efficient and successful strategy.

   The overall objective of phase 2 is to accurately describe the physical and chemical processes in the 3-dimensional study domain. Therefore, the major objective of the phase 2 study design is to elucidate these processes, on a year round and seasonal basis, with sufficient confidence to serve as a foundation for developing air quality strategies.

   An initial range of potential study components for phase 2 has been investigated and is discussed in detail in this study plan. However, as discussed above, final development and recommendation of phase 2 study options will await the completion of the phase 1 TFS. Preliminary estimates of the cost range for the second phase is two to eight million dollars depending on the results of the TFS and the sophistication needed to develop strategy alternatives.

   Completion of phase 2 is anticipated to occur 24 to 36 months after completion of phase 1.

3. The final phase is continuous long-term trends monitoring to track the progress of any implemented strategy. Progress towards the air quality goal will be checked at periodic intervals (~ every 3 to 5 years). If the agreed upon rate of progress is not

achieved, then the air quality strategy will be revisited and modified if necessary. To ascertain why the strategy is not achieving reasonable progress and to develop new or modified strategies intensified modeling and monitoring may be necessary. Phase 3 is ongoing. The number and location of long term monitoring sites cannot be determined until completion of the phase 1 TFS.

5.2 Rationale for elements of the Technical Foundation study

As discussed above, the focus of the TFS is to characterize the physical, meteorological and chemical processes governing air quality and visibility in the Scenic Area. It is necessary to provide information about these processes because such knowledge will affect what will be proposed for phase 2. Such information serves as a guide to further study very much the same way that early data analysis guided and helped formulate the initial hypotheses discussed in section 3.

Specifically, the TFS accomplishes several things:

- Will make gaseous, particulate and visibility measurements to help define the role of various pollutants in air quality and visibility impairment and to resolve potential discrepancies between measured and reconstructed haze levels.
- Will make meteorological measurements within the Scenic Area to define meteorological features currently not well understood (e.g., wind flow over the rim, through the gorge and side canyons).
- Will develop an initial concept (conceptual model) of the physical and chemical processes governing air quality in the Scenic Area.
- Will refine emission inventories in areas and times that are important to the physical and chemical processes and important for supporting modeling work.
- Will conduct survey level source attribution modeling to give us an initial idea of *potential* source regions and *potential* source types responsible for air pollution in the Scenic Area.
- Will evaluate the strengths and weaknesses of predictive model candidates.
- Will identify the key processes that must be emphasized to obtain adequate predictive modeling capabilities.
- Will identify modeling and measurement approaches for use in phase 2.
- Will *not* result in the final selection of a model capable of predicting air quality under various emission management scenarios.
- Will *not* identify specific sources that contribute to air pollution in the Scenic Area.
- Will *not* provide sufficient information from which to develop air quality strategies.

The following table lists all the components (monitoring, modeling, emission inventory, etc.) that are proposed for the TFS.

Table 5.2, The Technical Foundation Study at a glance

Measurement or task	What it tells us	Cost (in thousands of dollars)
a. Ambient monitoring: Characterization of air quality and chemical processes		
Ambient nephelometers at Wishram, Mt. Zion - minimum 1 year	Light scattering including water growth effects	$48
Aethalometers at Wishram, Mt. Zion - minimum 1 year	High time resolution light absorption-impact of local sources, determine if sites are representative. See Portland material moving through.	$68
Additional heated nephelometers with surface meteorology horizontally along Gorge (3 minimum e.g. Cascade Locks, another below Hood River, between Hood River & The Dalles) and heated nephelometers with surface meteorology at 3 vertical levels (river level, above river and rim of Gorge)	Horizontal Bsp gradient along gorge, see material moving through gorge, determine if sites are representative. Vertical mixing/bsp gradients	$105
PM10 speciation at Wishram, Mt. Zion. Include NH4+, SO2 IMPROVE schedule, 1 year	Speciation for comparison with coarse particle scattering-aerosol neutralization. Supports modeling (inputs, evaluate, validate, reconcile, etc.).	$100
PM2.5/PM10 cut ambient nephelometers at Wishram, Mt. Zion - 1 year	Fine and coarse particle scattering, comparison with PM2.5 and PM10 speciation data, helps with extinction budget closure	$124
NH3, HNO3 (g), SO2, Noy at two sites (Mt. Zion and Wishram) for one year IMPROVE schedule, 1 day in 6, 4-6 samples per day for NH3, HNO3, SO2. Continuous Noy and low level CO. Add O3 at Mt. Zion	Determine if atmosphere is ammonia limited-evaluate emissions inventory. Supports modeling (inputs, evaluate, validate, reconcile, etc.)	$200
Scene Monitoring (Camera). Digital Image Acquisition and Time Lapse Video. Two sites, one western and one eastern Scenic Area	Digital scene images to visually illustrate visibility conditions, and time lapse video to capture dynamics of formation and movement of haze.	$42
b. Meteorology: Characterization of physical processes		
Portable Radar wind profiler and/or tethersonde and ceilometer deployed at key areas - e.g. mouth of gorge, mid-gorge, side canyons, eastern gorge for exploratory measurements.	Basic information on structure of atmospheric flow in gorge - depth of flows, side-canyon importance, etc. Help to design more detailed meteorological measurements. Supports modeling (inputs, evaluate, validate, reconcile, etc.)	$100
Radar wind profiler/SODAR/RASS 1 site, 1 year	Vertical wind/temperature profiles. Same as T5 but year round @ 1 site. Supports modeling (inputs, evaluate, validate, reconcile, etc.)	$100
c. West of Gorge Sources: Characterization of Emissions		
Speciated PM2.5 west of Gorge (upwind of Portland). IMPROVE 1 day in 3 schedule.	Regional species gradient (transport site.)	$60
d. East of Gorge Sources: Characterization of Emissions		
Speciated PM2.5 east of Gorge (Columbia Basin). IMPROVE 1 day in 3 schedule.	Regional species gradient (transport site).	$60
Precipitation and Fog water sampling and chemical analysis- Boardman powerplant area, central gorge as possible during 45 day period	Determine potential ecosystem and cultural resources affects	$80
e. Emissions Inventory		
Complete NW RTC Demo Proj inventory, and grid at 5 km resolution	Supports modeling (inputs, evaluate, validate, reconcile, etc.)	$50
f. Modeling Studies		
Initial CMB modeling	Help identify general source categories and regions	$25

Initial ISOPART modeling	Help identify chemical processes and evaluate EI	$25
Calpuff "footprint" modeling using MM5 data	Help identigy potential source regions	$25
Limited high-resolution CMAQ + SCAPE (chemical modeling)	Assess NH3 limitation issue. Define phys. processes within Gorge.	$125
Review of applicable 3-D modeling practices	Documents pro's and con's of various modeling approaches. Candidate models will be identified for overall modeling system	$10
g. Data QA, Data Analysis, Data Management		
QA, analyze, and manage monitoring data to better understand physical/chemical conceptual model		$125
h. Project Management and Reporting		
Project management and reporting		$75
	Total cost of TFS	**$1,547**
	already funded	**-$450**
	Net funding needed for TFS	**$1,097**

5.3 Development of Phase 2

Knowledge about the physical, meteorological and chemical processes learned during the TFS study will guide the final development and recommendation of phase 2 study options. After completing the TFS, this study plan will be revisited and a range of options will be developed and presented to the public, stakeholders and the Gorge Commission. The range of options will reflect different levels of certainty that the resulting information provided under each option will allow us to identify sources that contribute to air pollution in the Scenic Area and therefore allow decision makers to develop an efficient, equitable and successful strategy. The range of options will also reflect how well the predictive model can simulate measured phenomena and thus conclude how well it will predict future air quality under various emission management scenarios.

As one might expect, to increase our certainty in the study results increasingly sophisticated measurements and modeling are necessary. Increasing sophistication equates to increasing costs of the study. By presenting the options with clear descriptions of what each option allows us to know and the relative degree of certainty we have in the results will allow decision-makers to balance the cost of the study with the desired degree of certainty and to also balance the costs with competing needs. Although the Technical Team and their advisors will recommend a preferred option, it will ultimately be the role of the public, stakeholders, agency decision-makers and the Gorge Commission to select the final option to be used.

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. Scanning Electron Microscopy (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 database 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 SUGGESTIONS ON STUDY MANAGEMENT STRUCTURE

The purpose of this section is to suggest a technical management structure that the author has found to be useful based on his experience in past studies. Because the exact management structure of the overall strategy development process has not been decided and is still under discussion, this section should be viewed as suggestions only to be considered if a technical management sub-structure is deemed to be appropriate for this process.

As discussed in section 5.1, a phased approach to technical studies is being recommended. The first phase is a technical foundation study. Components of the technical foundation study have been developed and are presented in this report for stakeholders, the public, other technical experts and the Gorge commission to review during a public review period scheduled for June and July 2001. Based on input from this public review, the technical foundation study will be revised if necessary and submitted to the Gorge Commission.

If it is decided that the development of air quality strategy alternatives be conducted by an advisory committee it is likely such an advisory committee would not be made up of members with the expertise to develop the components of the technical studies needed to support strategy development. In such a case it would be desirable to form a technical sub-committee who could advise the advisory committee on technical issues.

Following completion of the technical foundation study, a technical sub-committee should be responsible for developing a set of options for phase 2. Based on input from a technical sub-committee, the advisory committee would then be responsible for selecting and forwarding to the Gorge Commission phase 2 technical study option(s). The technical sub-committee should also be responsible for reporting on study progress, ensuring the technical aspects of the study support policy needs and goals, assuring allocation of resources to support the study are efficiently used, and for making modifications to the study as necessary.

9 BUDGET

The estimated budget for each study phase is listed below.
The amount listed for each phase is incremental amounts over previous phases. For example, for the summer and winter high-level studies, the amount listed is additional funding beyond that for the low-level studies.

Phase 1: The first phase is the technical foundation study (TFS) that must be conducted to provide guidance and a foundation for future technical work. The focus of the TFS is to characterize the physical, meteorological and chemical processes governing air quality and visibility within the Scenic Area. The results of the TFS will guide the final development and recommendation of phase 2 study options. Options for phase 2 will be developed after the TFS is completed.

Estimated Cost of Phase 1 (TFS)

Ambient monitoring - $887,000	
Meteorological monitoring - $200,000	
Emission inventory refinement - $50,000	
Model evaluation and survey modeling - $210,000	
Data - QA, analysis & management - $125,000	
Project management - $75,000	
Total:	$1,547,000
Already funded:	$450,000
Estimated net additional funding needed for Phase 1:	**$1,097,000**

Phase 2: The second phase is primarily for verification of the conceptual model, identification of contributing sources and source areas, and final development, testing, validation and selection of an air quality predictive model to be used later by decision makers for strategy development. It is envisioned that this phase will contain several options that relate to the degree of confidence and level of certainty desired or needed to support development of an equitable, efficient and successful strategy.

The overall objective of phase 2 is to accurately describe the physical and chemical processes in the 3-dimensional study domain. Therefore, the major objective of the phase 2 study design is to elucidate these processes, on a year round and seasonal basis, with sufficient confidence to serve as a foundation for developing air quality strategies.

An initial range of potential study components for phase 2 has been investigated and is discussed in detail in section 4 of this report. However, as discussed above, final development and recommendation of phase 2 study options will await the completion of the phase 1 TFS. Preliminary estimates of the cost range for the second phase is two to eight million dollars depending on the results of the TFS and the sophistication needed to develop strategy alternatives.

Estimated cost of potential phase 2 study components

One-year Expanded Study - Estimated total: $1,300,000

Summer Intensive Study, low-level - Estimated total: $1,400,000

Winter Intensive Study, low-level - Estimated total: $1,300,000

Summer Intensive Study, high-level - Estimated total: $1,200,000

Winter Intensive study, high-level - Estimated total: $1,000,000

Highest level (summer, winter, year-round) - Estimated total: $1,700,000

Phase 3: The final phase is continuous long-term trends monitoring to track the progress of any implemented strategy. Progress towards the air quality goal will be checked at periodic intervals (~ every 3 to 5 years). If the agreed upon rate of progress is not achieved, then the air quality strategy will be revisited and modified if necessary. To ascertain why the strategy is not achieving reasonable progress and to develop new or modified strategies intensified modeling and monitoring may be necessary. Phase 3 is ongoing. The number and location of long term monitoring sites cannot be determined until completion of the phase 1 TFS.

10 REFERENCES:

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11 LIST OF ACRONYMS

BRAVO	Big Bend Regional Aerosol and Visibility (Study)
CCTM	CMAQ Chemical Transport Model
CMAQ	Community Multiscale Air Quality
CMB	Chemical Mass Balance
COSPEC	Correlation Spectrometer
DEQ	Department of Environmental Quality (State of Oregon)
DOE	Department of Ecology (State of Washington)
DRUM	Davis Rotating drum Unit for Monitoring
EC	Elemental Carbon
EI	Emission Inventory
F(RH)	Relative humidity growth function
GCMS	Gas Chromatograph- Mass Spectrometer
HYSPLIT	HYbrid Single-Particle Lagrangian Integrated Trajectory Model
IMPROVE	Interagency Monitoring of Protected Visual Environments
ISOPART	Inorganic and Secondary Organic PARTicle model
LIDAR	Light Detection and Ranging
LQL	Lower Quantifiable Limit
MM5	Mesoscale Model version 5
NSA	Columbia River Gorge National Scenic Area
NWRTC	Northwest Regional Technical Center
OC	Organic Carbon
OMC	Organic Mass Carbon method
PFT	Perfluorocarbon Tracer
QC	Quality Control
RASS	Radio Acoustic Sounding System
RH	Relative Humidity
SEM	Scanning Electron Microscopy
SIP	State Implementation Plan
SMOKE	Sparse Matrix Operator Kernel Emissions
SODAR	Sound Detection and Ranging
TDMA	Tandem Differential Mobility Analyzer
TFS	Technical Foundation Study
TOR	Thermal-Optical Reflectance
VOC	Volatile Organic Compound
WRAP	Western Regional Air Partnership
WRF	Weather Research and Forecast model