Columbia River Gorge National Scenic Area

On the Composition and Patterns of Aerosols and Haze Within the Columbia River Gorge

September 1, 1996 – September 31, 1998

Report of Findings

Core Environmental Consulting
Portland Oregon

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State of Washington Department of Ecology

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1. Introduction

The Columbia River Gorge National Scenic Area Management Plan mandates that air quality shall be protected and enhanced consistent with the purposes of the Scenic Area Act and directs the States of Oregon, Washington and the US Forest Service to (1) monitor air pollution and visibility in the Gorge and (2) conduct analysis of monitoring and emissions data to identify all sources, both inside and outside of the Scenic Area that significantly contribute to air pollution. Further, on May 9, 2000 the Commission directed the agencies to develop a work plan to assess visibility degradation within the NSA.

The first step in developing the work plan is a pre-assessment of air pollution and visibility data collected in the Gorge. Continuous aerosol and optical monitoring using IMPROVE protocols began in 1993 when the Wishram site located at the east end of the Gorge was established. In 1996, the Mt. Zion site at the west end of the Gorge was added.

During the period of September 1996 to October 1998, IMPROVE aerosol and extinction data were collected, providing a two-year period of continuous data that is the focus of this report developed by Core Environmental Consulting[1] under contracts from the US Forest Service and State of Washington Department of Ecology. The objective of this analysis is to provide insights into the nature, extent and the possible sources or source-regions that contribute to haze within the Gorge. These insights may be useful in designing enhancements to the monitoring network and/or to future assessment efforts.

2. Methodology

This section briefly describes the monitoring sites, instrumentation and data used in the data assessment. Details of the aerosol and optical monitoring protocols, quality assurance programs and data storage are documented elsewhere[2,3,4]

2.1 Station Descriptions and Instrumentation

Monitoring data from two sites in the Gorge was used in this assessment. The sites are described in Table 1, below: Figure 1 shows the locations of the two sites. During a site survey of December 15, 2000 no emission sources likely to unduly bias the monitoring data were apparent at either site. There is abundant ground cover in the area surrounding both sites to minimize local dust wind entrainment and site exposure at both locations is excellent for meteorological, aerosol and extinction monitoring of the airshed within the Gorge. There is both diesel truck and railway locomotive activity in the general vicinity of the Wishram site but the monitoring location is sufficiently distant from them.

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[1] Core Environmental Consulting 1554 NW Benfield Drive Portland, Oregon 97229. Email:jcore@attglobal.net
[2] IMPROVE Program website http://yampa.cira.colostate.edu/improve/Tools/ReconBext.htm
[3] State of Washington Department of Ecology Air Quality Program Standard Operating Procedures.
[4] US Forest Service Region 6 Air Program; Portland, Oregon

Table 1: Monitoring Site Locations and Instrumentation

Site Name	IMPROVE Abbrev.	Sponsoring Agency	Location	Instrumentation (Sept 96- Oct. 98)
Wishram	CORI	US Forest Service	0.7 mi. west of Wishram, WA at east-end of the Gorge	• OPTEC NGN-2 nephelometer • IMPROVE Aerosol Sampler • 10M tower with WD, WS, RH, air temperature.
Mt. Zion	COGO	Washington DOE	West end of the Gorge on Washington side directly north of Crown Point one mile SSW of Mt Zion. 100 meters north of Washington Hwy 14.	• Radiance M903 nephelometer (heated inlet) • IMPROVE Aerosol Sampler • 10M tower with WD, WS, RH*, air temperature.

- Relative humidity data from the Mt. Zion site was not used in this analysis due to quality assurance issues. Surrogate data from Troutdale, OR airport was used in lieu of the site data.

Note that the principal difference between monitoring instrumentation at these two sites is the integrating nephelometer. The Wishram site used an OPTEC NGN-2 nephelometer operated at ambient temperature (Rayleigh scattering is *excluded* from these measurements) while the Mt. Zion site is equipped with a Radiance M903 nephelometer equipped with a heated inlet to maintain the RH of the air stream below 50% (Rayleigh is *included* in these data).

3. Fine Particle Speciation & Temporal Variations

The fine particle chemical composition as measured by IMPROVE protocols is of critical importance to light extinction in the Columbia Gorge. Table 2 summarizes speciation data (ng/m^3) for the approximately 200 days of data collected at the Wishram and Mt. Zion sites during the study period. Note that the fine particle mass at both sites is largely composed of organic carbon (OC), sulfate, nitrate and elemental carbon with some trace elements associated with soil dust. The average concentrations of these species across the entire study period are quite similar although maximum concentrations of sulfate (4.4 ug/m^3) are highest at Mt. Zion and nitrate (1.7 ug/m^3) is higher at Wishram. Maximum 24-hrour concentrations of OC are 10.3 and 7.2 ug/m^3 for Wishram and Mt. Zion respectively. Tables 2 provides descriptive for the major aerosol components at both sites. Tables 3 and 4 provide frequency distribution statistics for both sites for the major extinction components. Figures 1 and 2 are cumulative frequency distribution histograms for the two sites and are plotted to the same scale to facilitate comparison. Note that Wishram has ten days (4.7%) when nitrate was equal to or greater than 1.5 ug/m^3 while only 2% of the days at Mt. Zion exceeded 1.5 ug/m^3.

Figure 1: Monitoring Site Locations

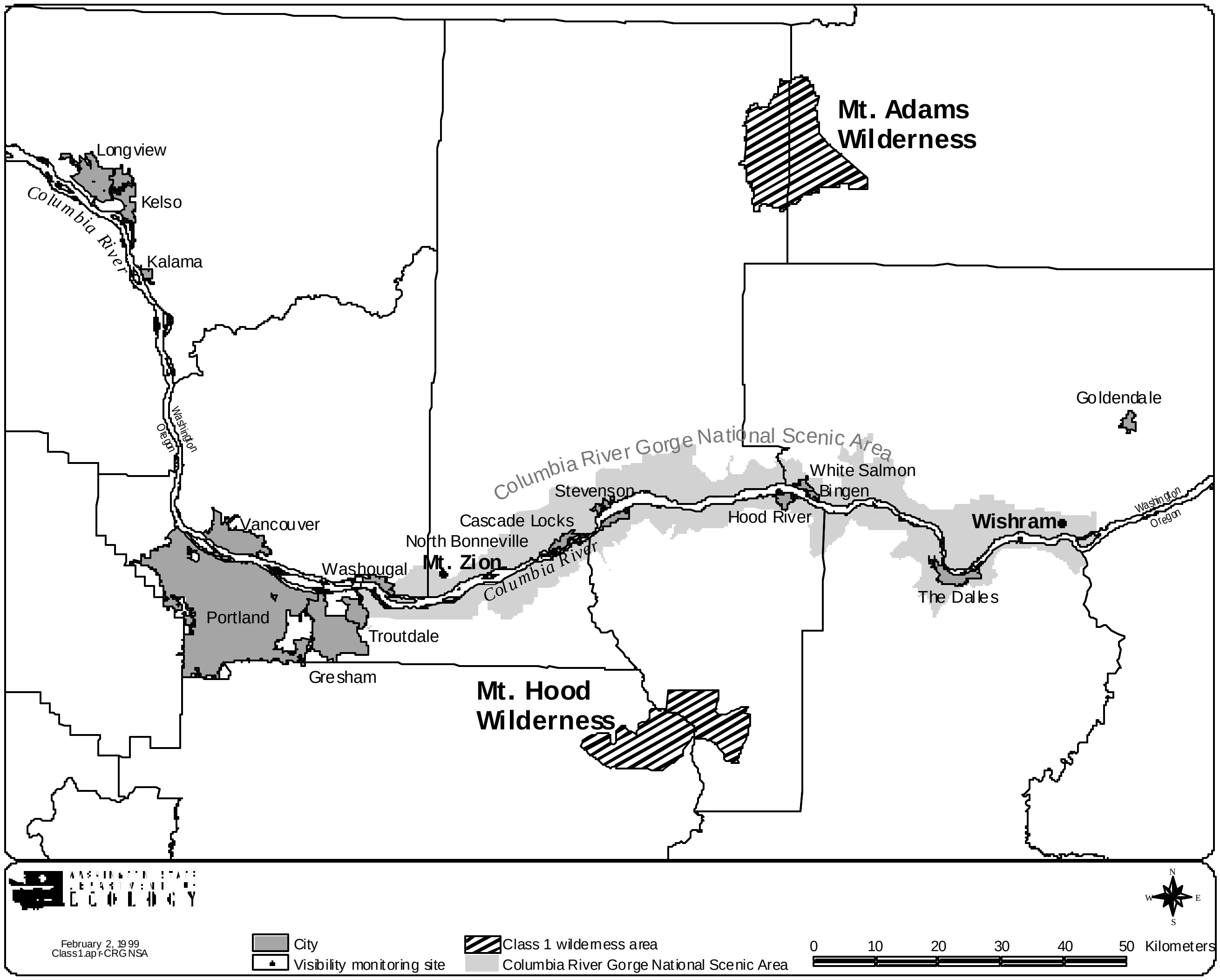

Table 2: Wishram & Mt. Zion Descriptive Statistics (ng/m3) – All Data

Wishram - All Data	AL	BR	CA	FE	K	MF	NA	NO3_	PB	S	SI	SO4	OC	EC
Mean	89	1	33	62	56	6124	172	436	2	354	120	1003	1612	430
Standard Error	10	0	4	6	4	257	13	31	0	16	17	46	78	20
Median	61	1	23	45	42	5401	128	272	2	298	61	824	1330	372
Standard Deviation	144	1	56	84	55	3825	192	462	2	237	253	681	1158	291
Range	1914	5	794	1052	523	28637	1835	3361	15	1413	3441	4311	10085	2936
Minimum	0	0	0	5	14	1083	0	29	0	35	0	93	240	52
Maximum	1914	5	794	1057	536	29720	1835	3389	15	1449	3441	4404	10326	2988
Count	220	221	221	221	221	221	221	217	221	221	221	217	221	221
Mt. Zion - All Data	**AL**	**BR**	**CA**	**FE**	**K**	**MF**	**NA**	**NO3_**	**PB**	**S**	**SI**	**SO4**	**OC**	**EC**
Mean	47	2	28	38	54	5763	221	399	3	389	81	1278	1697	384
Standard Error	9	0	4	5	4	228	22	20	0	20	15	79	69	15
Median	25	1	20	22	42	5224	142	334	2	294	39	939	1458	339
Standard Deviation	128	1	53	66	49	3296	288	285	6	1	221	1146	1005	219
Range	1766	4	746	864	491	22493	2377	1677	58	1710	3082	7000	6861	1391
Minimum	0	0	0	2	8	1019	0	33	0	0	0	56	383	65
Maximum	1766	5	746	865	499	23512	2377	1710	58	1710	3082	7055	7244	1456
Count	212	177	212	212	177	209	177	203	177	212	212	212	210	210

Table 3: Frequency Distribution Analysis of Selected Wishram Aerosol Species

Nitrate				Sulfate				Organic Carbon				Elemental Carbon			
ng/m3	Count	% Obs.	Cum Pct	ng/m3	Count	% Obs.	Cum Pct	ng/m3	Count	% Obs.	Cum Pct	ng/m3	Count	% Obs.	Cum Pct
100	14	6.5%	6.5%	100	1	0.5%	0.5%	250	2	0.9%	0.9%	100	4	1.8%	1.8%
150	21	9.7%	16.1%	150	1	0.5%	0.9%	300	2	0.9%	1.8%	150	13	5.9%	7.7%
200	30	13.8%	30.0%	200	4	1.8%	2.8%	350	3	1.4%	3.2%	200	17	7.7%	15.4%
250	35	16.1%	46.1%	250	4	1.8%	4.6%	400	2	0.9%	4.1%	250	24	10.9%	26.2%
300	18	8.3%	54.4%	300	7	3.2%	7.8%	450	2	0.9%	5.0%	300	25	11.3%	37.6%
350	10	4.6%	59.0%	350	7	3.2%	11.1%	500	4	1.8%	6.8%	350	16	7.2%	44.8%
400	15	6.9%	65.9%	400	5	2.3%	13.4%	550	5	2.3%	9.0%	400	20	9.0%	53.8%
450	14	6.5%	72.4%	450	6	2.8%	16.1%	600	4	1.8%	10.9%	450	22	10.0%	63.8%
500	7	3.2%	75.6%	500	14	6.5%	22.6%	700	13	5.9%	16.7%	500	12	5.4%	69.2%
550	5	2.3%	77.9%	550	10	4.6%	27.2%	800	9	4.1%	20.8%	550	13	5.9%	75.1%
600	7	3.2%	81.1%	600	11	5.1%	32.3%	900	12	5.4%	26.2%	600	10	4.5%	79.6%
700	10	4.6%	85.7%	700	19	8.8%	41.0%	1000	12	5.4%	31.7%	700	19	8.6%	88.2%
800	5	2.3%	88.0%	800	14	6.5%	47.5%	1100	14	6.3%	38.0%	800	14	6.3%	94.6%
900	4	1.8%	89.9%	900	15	6.9%	54.4%	1200	18	8.1%	46.2%	900	2	0.9%	95.5%
1000	3	1.4%	91.2%	1000	16	7.4%	61.8%	1300	7	3.2%	49.3%	1000	3	1.4%	96.8%
1100	2	0.9%	92.2%	1100	8	3.7%	65.4%	1400	9	4.1%	53.4%	1100	3	1.4%	98.2%
1200	3	1.4%	93.5%	1200	10	4.6%	70.0%	1500	9	4.1%	57.5%	1200	0	0.0%	98.2%
1300	4	1.8%	95.4%	1300	9	4.1%	74.2%	2000	37	16.7%	74.2%	1300	2	0.9%	99.1%
1400	0	0.0%	95.4%	1400	9	4.1%	78.3%	3000	32	14.5%	88.7%	1400	0	0.0%	99.1%
1500	3	1.4%	96.8%	1500	5	2.3%	80.6%	4000	19	8.6%	97.3%	1500	1	0.5%	99.5%
2000	3	1.4%	98.2%	2000	20	9.2%	89.9%	6000	4	1.8%	99.1%	2000	0	0.0%	99.5%
2500	2	0.9%	99.1%	2500	16	7.4%	97.2%	8000	1	0.5%	99.5%	2500	0	0.0%	99.5%
3000	1	0.5%	99.5%	3000	3	1.4%	98.6%	10000	0	0.0%	99.5%	3000	1	0.5%	100.0%
4000	1	0.5%	100.0%	4000	2	0.9%	99.5%	12000	1	0.5%	100.0%	4000	0	0.0%	100.0%

Table 4: Frequency Distribution Analysis of Selected Mt. Zion Aerosol Species

Nitrate				Sulfate				Organic Carbon				Elemental Carbon			
ng/m3	Count	% Obs.	Cum Pct	ng/m3	Count	% Obs.	Cum Pct	ng/m3	Count	% Obs.	Cum Pct	ng/m3	Count	% Obs.	Cum Pct
100	10	4.9%	4.9%	100	2	0.9%	0.9%	250	0	0.0%	0.0%	100	6	2.9%	2.9%
150	20	9.9%	14.8%	150	5	2.4%	3.3%	300	0	0.0%	0.0%	150	16	7.6%	10.5%
200	19	9.4%	24.1%	200	7	3.3%	6.6%	350	0	0.0%	0.0%	200	17	8.1%	18.6%
250	22	10.8%	35.0%	250	6	2.8%	9.4%	400	4	1.9%	1.9%	250	22	10.5%	29.0%
300	19	9.4%	44.3%	300	11	5.2%	14.6%	450	1	0.5%	2.4%	300	27	12.9%	41.9%
350	18	8.9%	53.2%	350	3	1.4%	16.0%	500	3	1.4%	3.8%	350	24	11.4%	53.3%
400	18	8.9%	62.1%	400	7	3.3%	19.3%	550	1	0.5%	4.3%	400	17	8.1%	61.4%
450	15	7.4%	69.5%	450	6	2.8%	22.2%	600	7	3.3%	7.6%	450	19	9.0%	70.5%
500	11	5.4%	74.9%	500	11	5.2%	27.4%	700	8	3.8%	11.4%	500	14	6.7%	77.1%
550	12	5.9%	80.8%	550	14	6.6%	34.0%	800	12	5.7%	17.1%	550	6	2.9%	80.0%
600	2	1.0%	81.8%	600	8	3.8%	37.7%	900	5	2.4%	19.5%	600	13	6.2%	86.2%
700	11	5.4%	87.2%	700	10	4.7%	42.5%	1000	9	4.3%	23.8%	700	13	6.2%	92.4%
800	10	4.9%	92.1%	800	9	4.2%	46.7%	1100	9	4.3%	28.1%	800	6	2.9%	95.2%
900	4	2.0%	94.1%	900	6	2.8%	49.5%	1200	14	6.7%	34.8%	900	4	1.9%	97.1%
1000	5	2.5%	96.6%	1000	8	3.8%	53.3%	1300	10	4.8%	39.5%	1000	2	1.0%	98.1%
1100	1	0.5%	97.0%	1100	15	7.1%	60.4%	1400	13	6.2%	45.7%	1100	0	0.0%	98.1%
1200	2	1.0%	98.0%	1200	7	3.3%	63.7%	1500	16	7.6%	53.3%	1200	3	1.4%	99.5%
1300	0	0.0%	98.0%	1300	3	1.4%	65.1%	2000	34	16.2%	69.5%	1300	0	0.0%	99.5%
1400	0	0.0%	98.0%	1400	3	1.4%	66.5%	3000	44	21.0%	90.5%	1400	0	0.0%	99.5%
1500	1	0.5%	98.5%	1500	4	1.9%	68.4%	4000	14	6.7%	97.1%	1500	1	0.5%	100.0%
2000	3	1.5%	100.0%	2000	21	9.9%	78.3%	6000	4	1.9%	99.0%	2000	0	0.0%	100.0%
2500	0	0.0%	100.0%	2500	17	8.0%	86.3%	8000	2	1.0%	100.0%	2500	0	0.0%	100.0%
3000	0	0.0%	100.0%	3000	11	5.2%	91.5%	10000	0	0.0%	100.0%	3000	0	0.0%	100.0%
4000	0	0.0%	100.0%	8000	18	8.5%	100.0%	12000	0	0.0%	100.0%	4000	0	0.0%	100.0%

Sulfate concentrations are higher at Mt. Zion with 13.7% of the days at or above 3 ug/m^3 (29 days) whereas this same sulfate concentration was exceeded only 2.5% of the days (5 days) at Wishram. The organic carbon distribution is nearly the same at both sites. Elemental carbon is also quite similar at both sites with Wishram recording only day when EC concentrations were much higher than those measured at Mt. Zion (2.9 vs 1.4 ug/m^3).

Table 5 is a tabulation of fine mass components at both sites on the same days for cases where fine mass concentrations exceeded 10 ug/m^3. These are the days of highest mass concentration during the study period. The data in Table 5 are shown in Figures 7a and 7b. Note that the relative abundance of the contributing species varies from day to day. Figures 7c and 7d show the degree of specie enrichment (ratio of daily values to site-mean average) on each of these days. On September 24, 1997 when Wishram fine mass reached 18.5 ug/m^3, soil, OC and EC were roughly three times their normal levels. At Mt. Zion on this same day, fine mass reached its highest concentration during the study period (7.5 ug/m^3) when (again) soil, OC and EC concentrations were 3 to 4.5 times higher than their norm. Elevated soil levels from the Asia dust storm of mid-April, 1998 are apparent in the high soils concentrations of April 22nd at both sites.

Table 5: Comparison of Fine Mass Aerosol Components on Common Days (Fine Mass > 10 ug/m^3)

	Wishram (ng/m^3)						Mt. Zion (ng/m^3)					
Date	Soil	EC	OC	SO4	NO3	MF	Soil	EC	OC	SO4	NO3	MF
8/6/97	2083	628	4178	5410	375	15061	1096	622	4209	3782	850	11036
09/10/97	1073	600	5072	2806	418	11759	633	709	4731	3325	1115	11805
09/24/97	1784	1458	9365	1561	595	18465	1564	1106	10141	1302	1111	17518
10/22/97	508	440	5674	2315	580	11098	414	1456	8490	3481	1528	17280
11/05/97	619	642	4282	3888	1932	12950	302	715	5759	2963	1265	11056
11/15/97	190	498	4972	4942	0.0	14828	297	694	5167	4264	2000	12262
04/22/98	2633	871	4600	1946	570	11208	1235	1180	7512	3620	0.0	13950
05/06/98	2074	480	3584	5975	305	13666	1086	832	3686	5588	0.0	12267
07/22/98	1542	874	5305	4142	465	13858	780	938	5632	4321	0.0	13460
08/29/98	1028	621	5209	3331	0.0	12048	765	678	4329	3833	0.0	10626
Average	*1353*	*711*	*5224*	*3632*	*524*	*13494*	*817*	*893*	*5966*	*3648*	*787*	*13126*

3.1 Temporal Variations

Fine particle mass temporal variations are also shown at both sites. There is an overall good correlation between the two datasets (r=0.72), suggesting that fine mass at both sites is predominately influenced by large-scale meteorological events rather than nearby local emissions. Note that fine mass concentrations are generally lowest in the spring months.

3.2 Aerosol Species Covariance

The scatterplots shown in Figure 3a through 3h illustrate the degree of covariance in trace element components of the aerosol. A high degree of correlation between sulfur and elemental carbon would suggest diesel emissions from trucks, rail or barges as a likely influencing source; Fe – S a possible link between soils (predominant Fe source) and sulfate-based fertilizers; K-OC the likely influence of woodsmoke and K– NO3 a soil – nitrate fertilizer association. Significantly, only the K-OC relationship appears worthy of further investigation. The potassium-organic carbon correlation at Wishram and Mt. Zion are 0.65 and 0.67 respectively.

4. Relative Humidity and *f* (RH)

Because relative humidity (RH) affects light extinction, calculation of daily 24-hour humidity and *f* (RH) derived from Tang are necessary. These calculations first required deletion of any hourly RH values greater than 98% and hours with missing values. Hourly RH observations were then averaged for those days with at least 18 hourly averages to derive the RH values in Table 6. Hourly *f*(RH) values were derived using a table lookup function referencing the Tang table using the hourly RH observations. All of the statistical summaries shown in Table 6 were calculated from hourly data. The *f*(RH) average for all data at Mt. Zion site, for example, is the average of 15,700 data points. Daily average RH and *f* (RH) were calculated from the hourly values for each day with 18 or more valid hours of data. These 24-hour averages were then matched to IMPROVE aerosol data sampling days. Troutdale, Oregon RH data was used as a surrogate for Mt. Zion.

Figure 4 shows daily average RH values for both sites for the study period. Note that lower humidity is nearly always observed at the Wishram site located in the high desert of Eastern Oregon as opposed to those recorded at the Troutdale site. Table 6 summarizes seasonal and annual RH and *f* (RH) for the two sites.

Table 6: RH and *f* (RH) Summaries

Averaging Period	Wishram		Mt. Zion	
	***f* (RH)**	**RH**	***f* (RH)**	**RH**
All Data	2.5816	65	3.8184	72
Winter (December – February)	4.1332	80	4.5988	75
Spring (March - May)	2.2284	63	3.7702	72
Summer (June - August)	1.4383	52	2.6686	68
Fall (September -November)	2.7059	69	4.3329	73
Annual 1997	2.4697	65	3.6792	70
Annual 1996 & 98 (Composite)	2.6856	66	3.9493	73

5. Mt. Zion and Wishram Reconstructed Mass

Reconstructed fine mass (RCFM) was calculated according to the IMPROVE protocol:

RCFM=4.125[S} + 1.29 [NO3] + EC + 1.4[OC] + Soil

Where Soil = 2.2[Al] + 2.49[Si] + 1.63[Ca] + 2.42[Fe] + 1.94[Ti]

5.1 Reconstructed Mass Patterns

Figures 5 and 6 use the RCFM estimates to gain insight into the relative abundance of the principal aerosol components on a day-to-day basis for those worst-case days when fine mass is equal to or greater than 10 ug/m^3. At both sites, organic carbon is usually the largest component. On April 28, (Wishram) and April 29, 1998 (Mt. Zion), however, the soil component at both sites dominated the fine particle mass suggesting a region-wide windblown soil episode.

Figures 7a and 7b provide similar information for days on which valid IMPROVE data was obtained at both sites and fine mass exceeded 10 ug/m^3. These ten days provide an opportunity to compare the composition of the fine mass at the two sites: Mt. Zion tends to be more sulfate-dominated while nitrate is a larger component at Wishram on the same day. Again, plots of specie enrichment relative to mean concentrations (figures 7c and 7d) show that for these common days, the Wishram soil component can be three to four-fold higher than average (8/6/97; 9/24/97 4/22/98; 5/6/98). This is less common at Mt. Zion where three-fold increases in the soil component were only seen on 9/24/97 and 4/22/98.

5.2 Reconstructed Mass – Gravimetric Mass Relationships

Figure 8a and 8b are scatterplots of Wishram and Mt. Zion RCFM vs gravimetric measured fine mass for all data points. There is excellent agreement between these two variables along a 1:1 line lending confidence to the RCFM estimates.

6. Wishram and Mt. Zion Extinction Budgets

The total light extinction coefficient Bext is the sum of the light scattering component, the light absorption component (LAC) and Rayleigh (clean air) scattering (Bray):

Bext = Bscat + Blac +Bray

Following the IMPROVE protocol, extinction budgets (Bext) were calculated from the IMPROVE aerosol data and *f*(RH) estimates in three steps. First, the light scattering component (Bscat) is estimated as (OMC is organic carbon mass or 1.4[OC]):

Bscat = (3)*f*(RH)[Sulfate] + (3)*f*(RH)[Nitrate] + (4)[OMC] + (1)[Soil] +0.6[CM]

Second the light absorption component of extinction was estimated. In this calculation the concentration of light absorbing carbon [LAC] was taken as the concentration of elemental carbon (EC) in the aerosol:

$$B_{lac} = (10)[LAC]$$

Third, Rayleigh scattering (Bray) of 10 Mm-1 was added to make the estimate consistent with nephelometer measurements.

Results from these calculations can then be used to determine the contribution to total extinction from each fine particle mass component under a variety of conditions; to evaluate temporal variation in reconstructed extinction and as a point of comparison to light scattering measurements made by integrating nephelometer. Findings in these areas are discussed below.

6.1 Extinction Frequency Distributions

Table 7 and 8 report the frequency distribution of reconstructed extinction at Wishram and Mt. Zion on IMPROVE sampling days by descriptive categories. These are also shown in Figure 11d. The categories range from natural conditions to severe impairment and should be considered as working definitions for purposes of this report. Table 9 and 10 report the frequency of extinction for each monitoring site

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Table 7: Mt. Zion Frequency of Impairment by Category

Descriptive Category	*Extinction*	*% of Days*
Natural Conditions	=< 20 Mm-1	3.1 %
Noticeable Impairment	20-40 Mm-1	41.6 %
Moderate Impairment	40 – 70 Mm-	43.5 %
Severe Impairment	> 70 Mm-1	11.8 %

Table 8: Wishram Frequency of Impairment by Category

Descriptive Category	*Extinction*	*% of Days*
Natural Conditions	=< 20 Mm-1	1.5 %
Noticeable Impairment	20-40 Mm-1	42.9 %
Moderate Impairment	40 – 70 Mm-	32.9 %
Severe Impairment	> 70 Mm-1	12.8 %

Average percent contribution to extinction (extinction budget) for the Wishram site for Rayleigh, soils, light absorbing carbon, organic carbon mass, sulfate, nitrate and coarse mass are 21%, 1%, 10%, 25%, 23%, 11% and 10% respectively. For the Mt. Zion site these values are 21%, 1%, 8%, 27%, 33% and 10%. These were no coarse mass measurements made at Mt. Zion. Figure 11c illustrates these average extinction budgets.

Table 9: Wishram Reconstructed Extinction Frequency Distributions

Wishram Reconstructed Extinction (Mm-1)			
Bin Mm-1	No. Days.	Pct of Days.	Cum. Pct. Days
20	3	1.5%	1.5%
30	30	15.3%	16.8%
40	54	27.6%	44.4%
50	44	22.4%	66.8%
60	23	11.7%	78.6%
70	17	8.7%	87.2%
80	6	3.1%	90.3%
90	5	2.6%	92.8%
100	5	2.6%	95.4%
120	5	2.6%	97.9%
140	3	1.5%	99.5%

160	1	0.5%	100.0%

Table 10: Mt. Zion Reconstructed Extinction Frequency Distributions

Mt. Zion Reconstructed Extinction (Mm-1)			
Bin Mm-1	No. Days.	Pct of Days.	Cum. Pct. Days
20	5	3.1%	3.1%
30	30	18.6%	21.7%
40	37	23.0%	44.7%
50	27	16.8%	61.5%
60	25	15.5%	77.0%
70	18	11.2%	88.2%
80	4	2.5%	90.7%
90	8	5.0%	95.6%
100	3	1.9%	97.5%
120	3	1.9%	99.4%
140	0	0.0%	99.4%
160	0	0.0%	99.4%
180	1	0.6%	100.0%

6.2 Extinction Budgets on Severely Impaired Days

Figures 9 and 10 report extinction budgets for severely impaired days with 24-hour Bext greater than 70 Mm-1 for Wishram and Mt. Zion, respectively. Figures 11a and 11b illustrate component enrichment relative to mean concentrations for these same days.

- Large nitrate hits are evident at Wishram on the majority of these days. On 1/29/97, nitrate extinction was nearly twelve-fold above average. Nitrate extinction was four-fold or more higher than average on 16 of the 19 days (84%) with severe impairment. Sulfate extinction on severe impairment days is of secondary importance but is commonly found to be 3-5 times higher than average. The remaining components of the extinction budget are of elevated to a much lesser extent.
- Mt. Zion has lower nitrate impacts than Wishram although on 10/22/97, nitrate extinction was six-times higher than average. Sulfate extinction on severe impairment

days is 3-fold or greater than average on 6 of the 17 (35%) severe impairment days during the study.

Data used to plot Figures 9 and 10 are shown below in Tables 11 and 12 below.

6.3 Temporal Variations in Reconstructed Extinction

Daily variations in 24-hour average reconstructed extinction measurements made on the same day at the two sites are shown in Figure 12. Large peaks in extinction at Wishram are apparent on 1/29/97, 4/19/97 and 1/21/98. The largest peak at Mt. Zion occurred on 10/22/97.

Table 11: Wishram Extinction Component on Severe Impact Days (> 70 Mm-1)

Date	Soil	EC	OMC	Sulfate	Nitrate	CM	Bext
10/09/96	2.3	9.6	24.1	10.7	3.5	11.8	72.0
11/02/96	0.6	7.6	33.5	15.5	11.9	2.4	81.6
11/23/96	0.2	4.0	17.1	17.1	23.5	3.5	75.5
11/27/96	0.6	5.9	12.9	68.8	20.8	1.9	120.8
01/04/97	0.7	7.2	17.0	34.3	16.4	2.2	87.8
01/29/97	0.5	7.9	18.5	55.0	50.2	5.0	147.0
04/19/97	0.6	7.1	14.8	47.5	26.4	1.9	108.3
09/27/97	0.2	1.3	52.4	7.2	3.8	7.1	82.0
10/29/97	0.2	2.3	25.0	22.2	14.7	2.2	76.6
11/05/97	0.6	6.4	24.0	43.6	21.7	6.9	113.1
11/12/97	1.2	7.8	36.0	40.6	20.4	5.9	121.9
11/15/97	0.2	5.0	27.8	54.3	0.0	7.3	104.6
12/06/97	0.1	4.5	20.9	40.0	22.2	2.7	100.4
12/10/97	0.4	6.2	17.2	30.5	27.1	3.5	95.0
12/13/97	0.2	5.7	28.0	20.6	27.7	2.2	94.4
12/31/97	0.2	5.1	13.1	69.4	32.8	7.1	137.8
01/14/98	0.5	4.4	16.4	25.9	19.9	1.8	78.9
01/21/98	0.4	6.6	16.4	55.7	22.9	3.4	115.4
01/28/98	0.5	9.4	16.7	24.9	23.7	5.0	90.4
02/11/98	0.6	7.5	12.2	26.2	17.5	1.0	75.0
02/28/98	0.3	5.1	10.1	32.0	23.6	1.5	82.6
03/21/98	1.1	10.4	28.1	25.1	15.6	5.2	95.5
04/28/98	15.8	5.4	20.5	10.7	5.2	31.4	99.0
07/22/98	1.5	8.7	29.7	15.5	1.7	6.5	73.8
09/30/98	1.6	12.9	28.8	16.6	4.5	6.8	81.1

Table 12: Mt. Zion Extinction Components on Severe Impact Days (>70Mm-1)

Date	Soil	EC	OMC	Sulfate	Nitrate	Bext
10/05/96	0.2	5.3	13.7	51.7	8.0	88.9
10/26/96	0.3	3.6	11.6	52.3	7.6	85.3

11/02/96	0.5	4.6	29.0	27.1	13.9	85.1
11/23/96	0.3	3.8	14.1	38.9	4.8	71.9
01/29/97	0.3	5.6	16.9	39.2	17.9	89.9
07/19/97	1.3	4.7	24.1	32.0	5.6	77.7
09/10/97	0.6	7.1	26.5	37.2	12.5	93.9
09/24/97	1.6	11.1	56.8	13.9	11.8	105.1
10/22/97	0.4	14.6	47.5	67.7	29.7	169.9
11/05/97	0.3	7.2	32.3	37.5	16.0	103.3
11/15/97	0.3	6.9	28.9	26.1	12.2	84.5
12/24/97	0.1	5.9	10.2	35.0	20.6	81.8
03/21/98	0.4	6.4	23.7	29.3	8.6	78.5
04/22/98	1.2	11.8	42.1	26.9	0.0	92.0
05/06/98	1.1	8.3	20.6	48.0	0.0	88.0
05/20/98	0.2	6.5	11.5	54.8	13.5	96.5
07/08/98	0.4	5.9	21.6	45.3	5.9	89.1
07/25/98	0.5	6.6	22.7	63.1	0.0	102.9
09/12/98	0.8	7.3	18.9	29.2	8.4	74.6

7. Light Scattering Measurements

As noted in Section 2.1, light scattering measurements were made at the Wishram site with an Optec NGN-2 ambient nephelometer whereas a Radiance M903 nephelometer with heated inlet was used at the Mt. Zion site. Daily average NGN-2 scattering was calculated from hourly data. All hours with RH > 90% and missing values were excluded. A minimum Rayleigh scattering value of 10 Mm-1was substituted for reported values less than 10 Mm-1. As noted below, these two instruments provide a very different response to the same fine particle aerosol mass even if the chemical components of the mass are identical.

7.1 Temporal Variations in Light Scattering

Figure 13a illustrates seasonal variations of scattering at the Wishram site. During the winter months of mid-November to mid-February, extremely high hourly Bscat levels, some exceeding 200 Mm-1, were recorded. On January 29, 1996 nephelometer hourly averages (edited to exclude hours with RH > 90%) peaked at 469 Mm-1 and averaged over a 24-hour period, 275 Mm-1. During the spring and summer months, scattering levels are generally low. Scattering at Mt. Zion, shown in Figure 13b, is much lower than that recorded at Wishram but still exhibits high peaks, some exceeding 70 Mm-1, during the winter months. Note that since the instruments used at the two sites respond differently to the same aerosol mix, only very qualitative comparison of data can be made.

Figures 13c and 13d show the diurnal variations in scattering at Wishram and Mt. Zion for severe impairment periods with 24-hour average extinction exceeding 70 Mm-1. During the period 16 to 19 December 1996, the Wishram hourly scattering data varied from 10 Mm-1 to over 170 Mm-1. These patterns do not exhibit any obvious woodstove-related patterns with lows. Diurnal variations in the Mt. Zion scattering data (Figure 13d) during

October 1997 show late afternoon and evening peaks (10/13; 10/15 and 10/22/97), however, may reflect impacts from wood smoke. This appears consistent with Mt. Zion K-OC covariance (r=0.67) shown in Figure 3g.

7.2 Reconstructed Mass – Scattering Relationships

To better understand the Bscat data from both sites, scatter plots of reconstructed extinction and 24-hour average scattering for matching days were prepared. Figures 14a and 14b show these relationships.

Figure 14a is a plot of Mt. Zion reconstructed extinction vs Bscat for all matching days during the study period. Since light absorption from elemental carbon is excluded from the nephelometer data and given that the air stream is heated, the Radiance data should underestimate reconstructed extinction. A correlation or r=0.82 is found between these two variables. As expected, the Radiance dry scattering data underestimates reconstructed extinction by about one-half (slope 0.55). This is consistent with the known relationship between relative humidity and the light scattering efficiency of the aerosol.

Figure 14b is a similar plot prepared for the Wishram site. One hundred-twenty four days of data where days on which IMPROVE aerosol data were available were matched with 24-hour Bscat data calculated from hourly NGN-2 data edited to exclude hours with RH> 90%. The correlation (r= 0.87) between the two variables is a little better than that found with the Radiance nephelometer and in this case, the NGN-2 nephelometer tends to overestimate the reconstructed extinction (slope = 1.8).

7.3 Light Scattering – Gravimetric Fine Mass Relationships

Figures 15a and 15b are scatter plots of Mt. Zion and Wishram light scattering vs. gravimetric measured fine particle mass. The Mt. Zion Radiance scattering – fine mass relationship for all of the data is consistent with expectations with an good correlation (r=0.83) whereas the Wishram NGN-2 – fine mass scatter plot for all data is less well correlated (r=0.52). Figure 15b suggest that there may be two scattering/mass regimes; (1) where significantly higher scattering to mass ratios occur during winter-time east winds as shown in Table 13 and (2) low scattering/mass conditions which rarely exceed 50 Mm-1. The days shown in Table 13 are among the highest nitrate and sulfate days at Wishram during the study period.

Table 13: Wishram Days with High Bscat/Fine Mass Ratios

Date	Bscat (Mm-1)	MF (ug/m3)	Nitrate (ng/m3)	Sulfate (ng/m3)	OC (ng/m3)	EC (ng/m3)	RH (%)	Ave Air Temp (oF)	24-Hr. Resultant WD
1/29/97	275	16	3389	2794	2354	789	87	30	E
11/5/97	180	13	1498	2499	3059	642	82	52	E
11/15/97	220	14	--	--	3551	498	80	34	E

12/3/97	115	7	1298	2075	1757	455	79	35	E
12/6/97	157	10	1845	3221	2671	449	86	30	E
12/13/97	125	0	2959	2003	3575	571	80	32	E
12/24/97	130	6	1281	1821	1138	353	80	34	NE

8.0 Aerosol Components and Extinction Budgets Stratified by Wind Direction

To understand visibility in the Columbia River Gorge in terms of source regions and pollutant transport, IMPROVE aerosol component data and reconstructed extinction estimates for Wishram and Mt. Zion were stratified by 24-hour resultant wind direction using data provided by the Oregon Department of Environmental Quality. Troutdale winds were used with the Mt. Zion monitoring data. Resultant winds within +- 22^{o} of the eight cardinal wind directions were assigned to descriptive categories, e.g., 68-112^{o} winds as East; 113-157^{o} SE, etc.). Days with 24-hr resultant wind directions within the NE, E or SE categories were combined together into the “easterly” category while those in the SW, W or NW categories were combined into the “westerly” category.

Of the 161 days of data available for the Mt. Zion site, 77 days (47%) fell into the “westerly” category and 56 (35%) into the “easterly” category. The remaining 28 days were northerly or southerly. Similar statistics for the Wishram site are 154 days of data; 111 days (72%) westerly; 40 days (26%) easterly and three northerly days (2%).

8.1 Extinction Stratified by Wind Direction

Figures 16a and 16b show aerosol-reconstructed extinction at the Mt. Zion site at the 80th and 20th percentile of each extinction component for days with easterly and westerly winds. The 80th percentile of the total extinction, sulfate and organic carbon mass are significantly higher under west winds than under east winds while soils, elemental carbon and nitrate are only slightly greater under west winds. Overall extinction is higher on west wind days. On relatively clear days shown in Figure 16b when total extinction is about 30 Mm-1 under west winds, the same sulfate and OMC patterns is evident but the elemental carbon, soils and nitrate components are the same under either wind direction.

For Wishram, total extinction is significantly greater under east winds than under west winds at the 80th percentile level. Extinction is dominated by sulfate and nitrate aerosols both of which are significantly higher at the 80th percentile under east winds. As shown in Figure 16c, extinction from sulfate is about twice that found under west winds. Significantly, east wind nitrate extinction is more than four-times higher than that found under West winds. Impaired days under east winds are significantly poorer than those that occur under west winds. On clear days (Figure 16d), total extinction at the 80th percentile is still significantly higher under east winds. Sulfate and nitrate extinction is also higher under east winds, although to a lesser extent. There is little difference in the elemental carbon, organic carbon, coarse mass or soils extinction as a function of wind direction.

8.2 Aerosol Species Stratified by Wind Direction

Scatterplots of Mt. Zion and Wishram aerosol species relationships were also prepared as a function of wind direction. Figures 17a and 17b show the potassium-organic carbon relationship at Mt. Zion for all data under East and West wind regimes, respectively. Under east winds (winter wind regime), there is a good correlation (r=0.86) but under west winds, the correlation drops to 0.63. For all data at Mt. Zion (Figure 3g), the correlation is 0.67 indicating that during the winter months and under east winds, the Mt. Zion site is likely being impacted by smoke from vegetative burning such as woodstoves, fireplaces, open burning, burning of yard debris, forest land management burning, etc.

Figures 17c and 17d shows the potassium-organic carbon relationship at Wishram during east winds or west winds are identical (r=0.68). Table 14 lists characteristics of selected aerosol components at Wishram during east and west winds. Note that nitrate concentrations are significantly higher (three-fold at the nitrate 80^{th} percentile) under east winds than under west winds.

Table 14: Wishram Aerosol Components (ng/m^3) by Wind Direction

Statistic	Fe	K	NO3_	S	SO4	OC	EC	Wind Dir
Average	70.5	47.5	868.6	430.6	1181.3	1848.3	493.3	East
Maximum	1056.6	197.6	3389.4	1198.2	3221.0	6689.3	1458.3	East
80th Pct	72.0	65.0	1284.3	568.1	1616.7	2196.3	635.3	East
20th Pct	22.5	28.7	325.9	216.8	597.5	1138.1	313.9	East
Average	54.5	52.6	293.3	335.4	967.3	1436.1	374.0	West
Maximum	225.7	293.0	1117.2	1448.6	4404.2	4273.0	1285.3	West
80th Pct	72.8	70.7	408.2	471.9	1362.3	2076.1	514.2	West
20th Pct	24.3	26.3	140.2	162.7	464.9	654.2	206.8	West

9. Summary of Findings

A review of the composition and patterns in fine particles and haze within the Columbia Gorge for the period of September 1, 1996 to September 30, 1998 was conducted to provide insights into the nature and extent of haze within the Columbia River Gorge and to provide guidance for future air quality and visibility studies. Measurements from the Mt. Zion and Wishram sites used in this study included IMPROVE aerosol chemistry data for approximately 200 days at each site as well as approximately 18,000 hours of light scattering, wind direction, wind speed and relative humidity data from each site. IMPROVE protocols were used to calculate reconstructed fine mass and reconstructed extinction. The following is a summary of findings from the study:

1. The principal components responsible for haze in the Columbia River Gorge are nitrates and sulfates aerosols. Nitrate concentrations are highest at Wishram during the winter months under east winds, significantly impairing visibility. Sulfate extinction tends to be higher at Mt. Zion under west winds. Organic and elemental carbon concentrations are

about the same at both sites. Aerosol mass measurements made at the two sites are reasonably well correlated suggesting that both are primarily influenced by large-scale meteorological events rather than by local sources.

2. Evaluation of aerosol specie covariance suggests that wood smoke is a likely wintertime source impacting the Mt. Zion site and, to a lesser extent, Wishram. No apparent relationship between trace elements associated with diesel fuel combustion or sulfate or nitrate-based fertilizers was found.
3. Reconstructed extinction distributions suggest that haze results in noticeable, moderate or and severe impairment of visibility at Mt. Zion 42%, 43% and 12% of the days studied. Comparable statistics for Wishram are 43%, 43% and 13%.
4. On severely impaired days, Wishram sulfate and nitrate extinction can be as much as three to ten-fold higher than average, respectively. At Mt. Zion, the extremes in sulfate and nitrate extinction are not as great ranging from three to six fold greater than average.
5. Light scattering measurements at Mt. Zion are reasonably well correlated with fine mass measurements (r=0.84) and reconstructed extinction (r=0.82). The Radiance nephelometer data at this site tends to underestimate reconstructed extinction by about one-half. The Wishram NGN-2 nephelometer is also well correlated with reconstructed extinction (r=0.87) and fine mass (r=0.83) but overestimates reconstructed extinction. The inconsistency in the two instruments compounds interpretation of the extinction data. A consistent measurement methodology is needed
6. Temporal variations in fine mass, reconstructed extinction and light scattering all indicate seasonal trends with the most frequent and severe impairment occurring during the winter months. These trends are more extreme at Wishram than at Mt. Zion. No obvious, consistent diurnal trends are apparent in the data at either site, discounting local wood burning sources as a significant source.

7. Wind direction does affect extinction levels at both sites. At Mt. Zion on hazy days, the highest extinction occurs under west winds when sulfate and OMC extinction is higher than it is under east winds. At Wishram, much higher extinction occurs under east wind conditions when nitrate and sulfate extinction both increase. Several days during the study period had highly elevated winter season nitrate extinction under east winds.

10. Recommendations

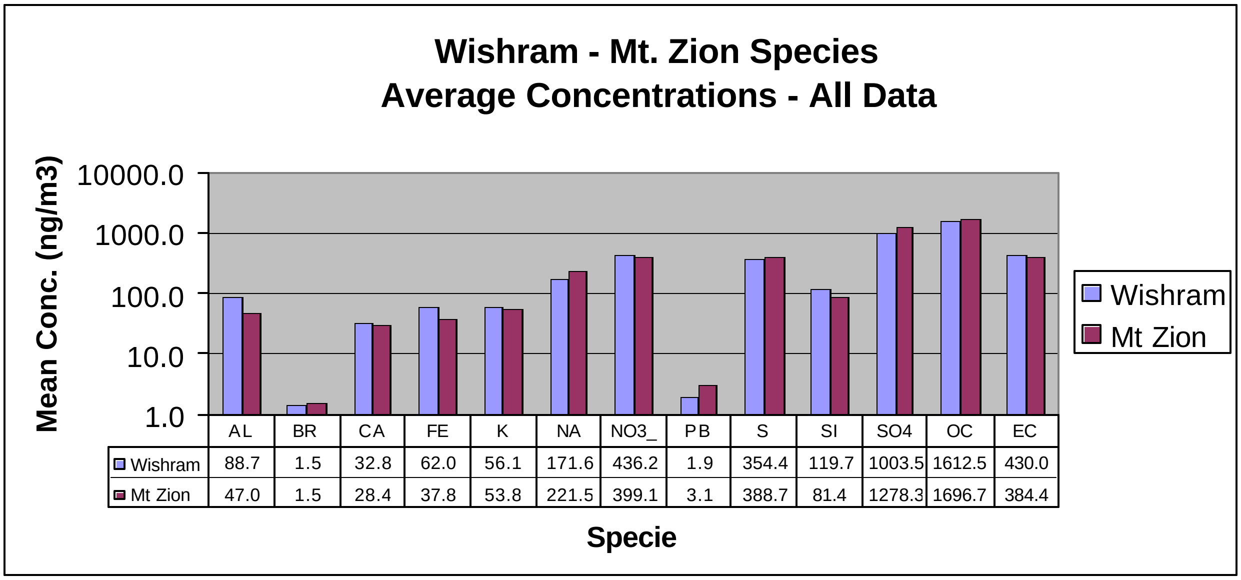
These finding suggest several areas for future program enhancements:

- A consistent method of measuring hourly scattering is needed to improve compatibility in the data and more accurately track hourly extinction within the Gorge;
- Future efforts should focus on identifying sulfate and nitrate precursors as well as ammonia sources east of the Wishram site during the winter months. These efforts should include a spatially resolved emission inventory, back-trajectory modeling of nitrate and sulfate episodes identified in this study and intensified, short-term studies during the winter months at Wishram;
- An inventory of ammonia and NOx emissions east of Wishram is needed both for nitrate and sulfate precursor modeling and may identify ammonia sources that play an important role in the formation of haze within the Gorge;
- A survey of wood burning emissions within the Gorge is needed to identify the magnitude of emissions and location of sources that may be impacting the Mt. Zion site during east winds.

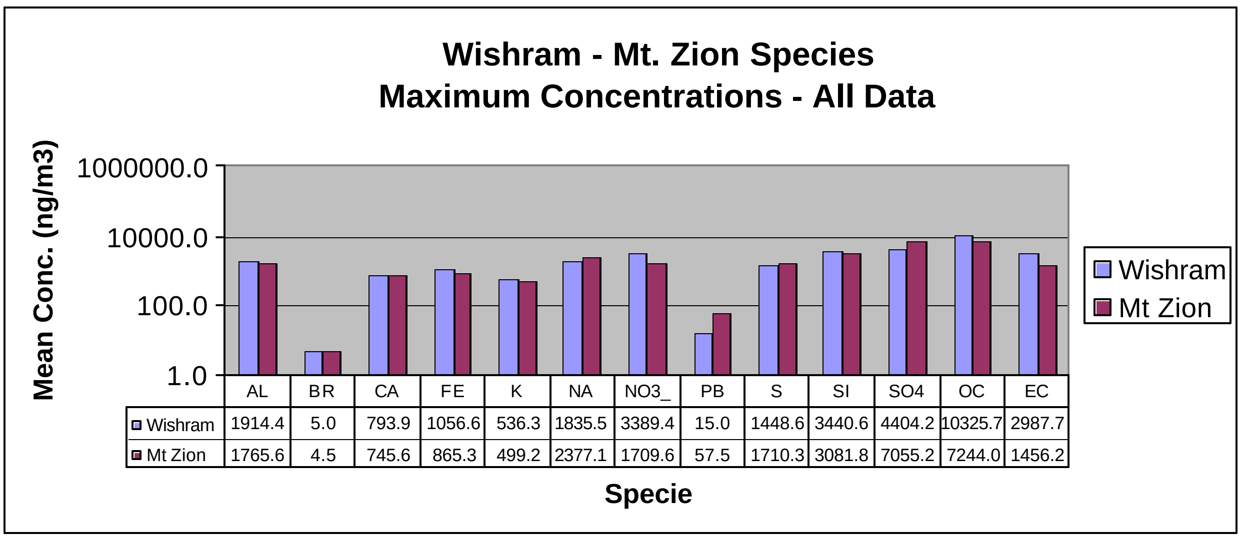
Acknowledgements

This work was supported by USDA Forest Service Region 6 and the State of Washington Department of Ecology. Data and insights provided by B. Bachman and F. VanHaren from these two agencies, respectively, were essential to completing this work. Special thanks also to P. Allen, State of Oregon Department of Environmental Quality for his assistance in processing the meteorological data used in this effort.

Appendix 1: Figures



	AL	BR	CA	FE	K	NA	NO3_	PB	S	SI	SO4	OC	EC
Wishram	88.7	1.5	32.8	62.0	56.1	171.6	436.2	1.9	354.4	119.7	1003.5	1612.5	430.0
Mt Zion	47.0	1.5	28.4	37.8	53.8	221.5	399.1	3.1	388.7	81.4	1278.3	1696.7	384.4



	AL	BR	CA	FE	K	NA	NO3_	PB	S	SI	SO4	OC	EC
Wishram	1914.4	5.0	793.9	1056.6	536.3	1835.5	3389.4	15.0	1448.6	3440.6	4404.2	10325.7	2987.7
Mt Zion	1765.6	4.5	745.6	865.3	499.2	2377.1	1709.6	57.5	1710.3	3081.8	7055.2	7244.0	1456.2

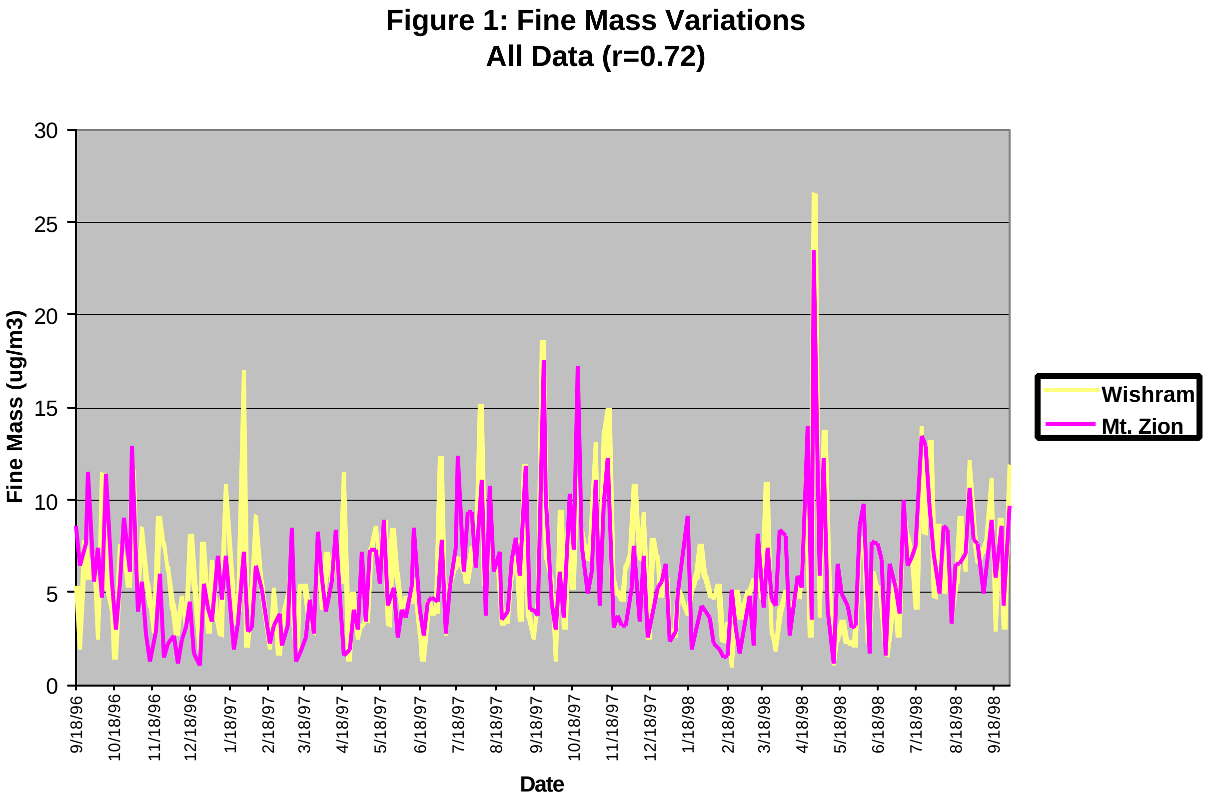
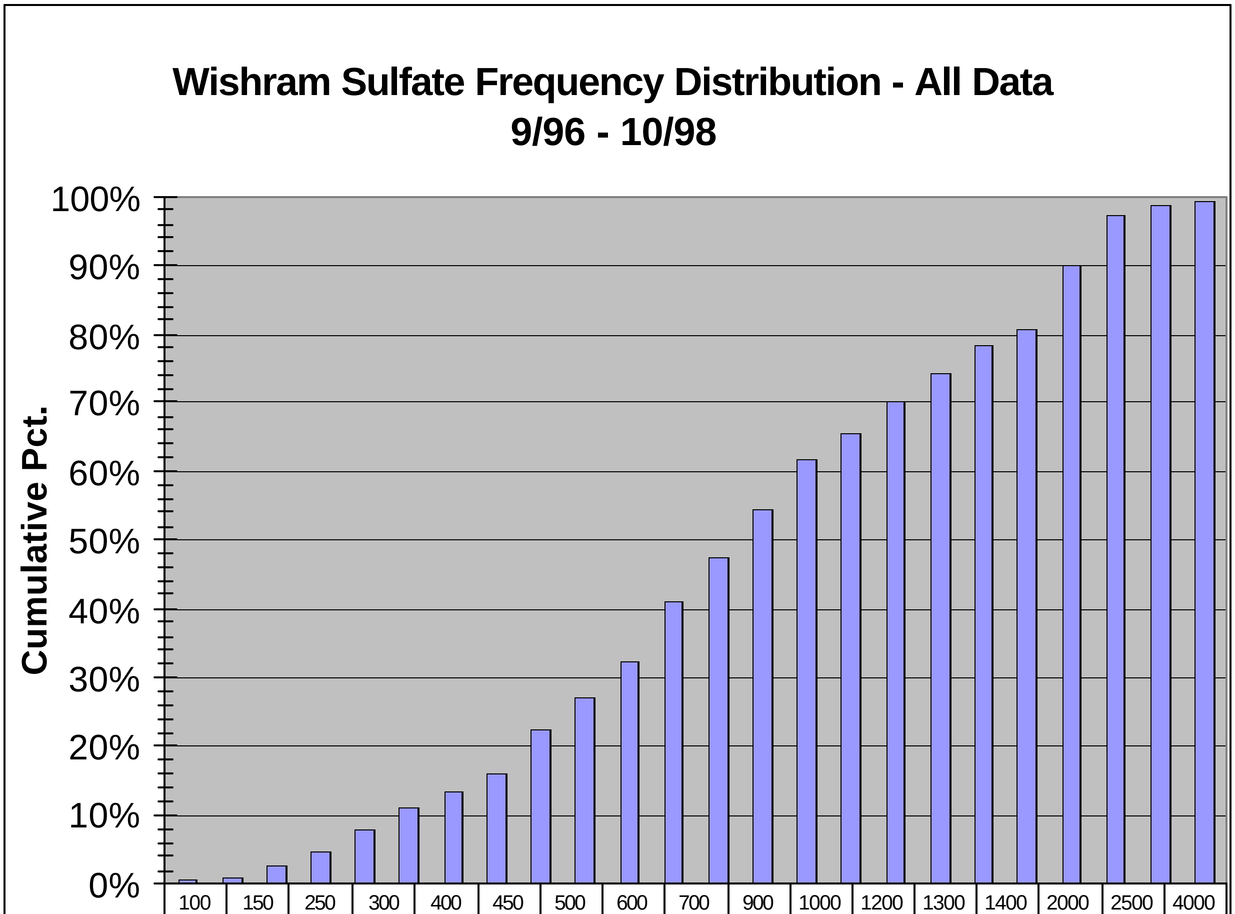


Figure 1: Fine Mass Variations
All Data (r=0.72)
Fine Mass (ug/m3)
30
25
20
15
10
5
0
9/18/96
10/18/96
11/18/96
12/18/96
1/18/97
2/18/97
3/18/97
4/18/97
5/18/97
6/18/97
7/18/97
8/18/97
9/18/97
10/18/97
11/18/97
12/18/97
1/18/98
2/18/98
3/18/98
4/18/98
5/18/98
6/18/98
7/18/98
8/18/98
9/18/98
Date
Wishram
Mt. Zion

Figure 2a-1



	100	150	250	300	400	450	500	600	700	900	1000	1200	1300	1400	2000	2500	4000
Sulfate Freq	0.5%	0.9%	4.6%	7.8%	13.4%	16.1%	22.6%	32.3%	41.0%	54.4%	61.8%	70.0%	74.2%	78.3%	89.9%	97.2%	99.5%

Figure 2a-2

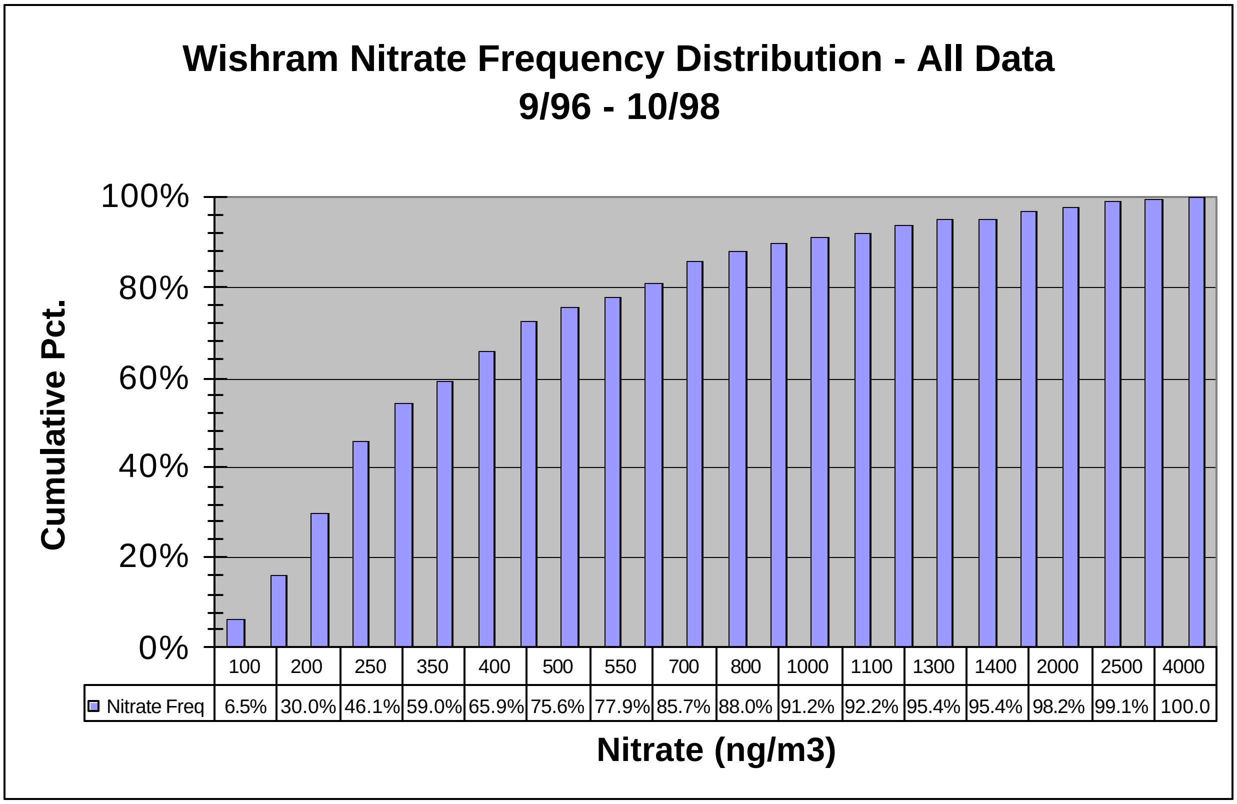

Wishram Nitrate Frequency Distribution - All Data
9/96 - 10/98
Cumulative Pct.
100%
80%
60%
40%
20%
0%
100
200
250
350
400
500
550
700
800
1000
1100
1300
1400
2000
2500
4000
Nitrate Freq
6.5%
30.0%
46.1%
59.0%
65.9%
75.6%
77.9%
85.7%
88.0%
91.2%
92.2%
95.4%
95.4%
98.2%
99.1%
100.0
Nitrate (ng/m3)

Figure 2a-3

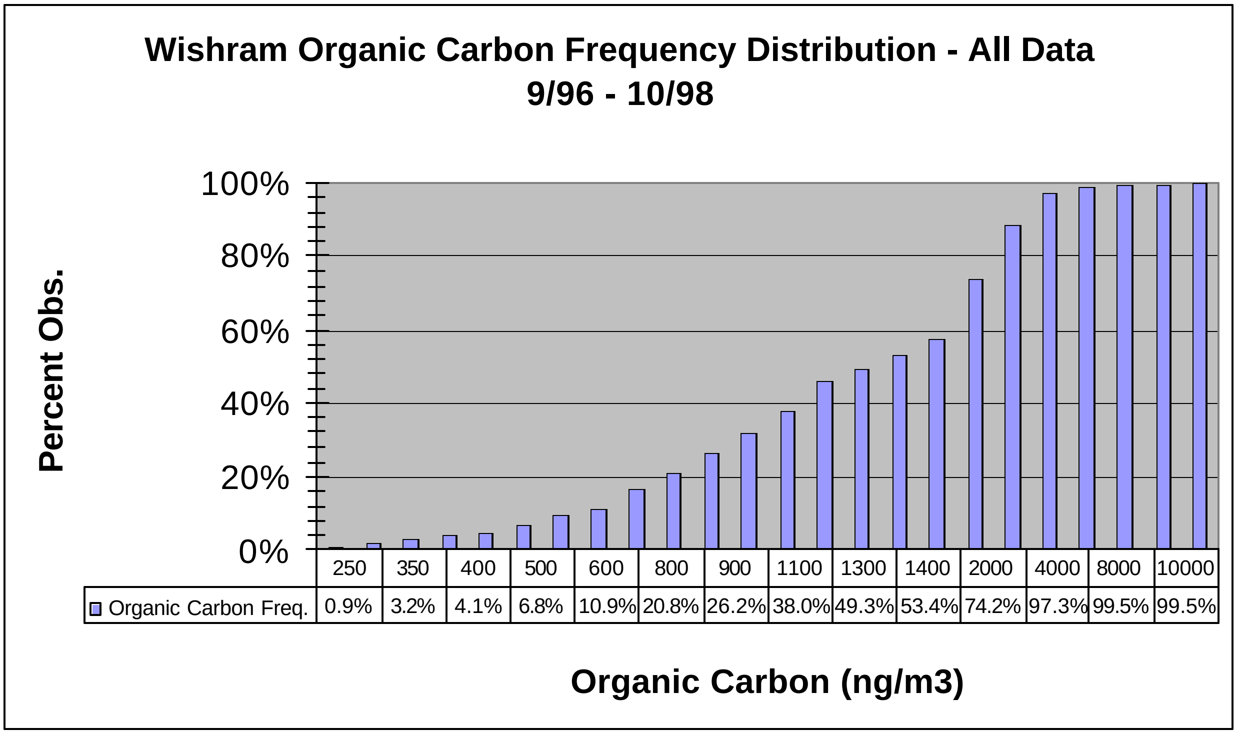

Wishram Organic Carbon Frequency Distribution - All Data
9/96 - 10/98
Percent Obs.
100%
80%
60%
40%
20%
0%
250 350 400 500 600 800 900 1100 1300 1400 2000 4000 8000 10000
Organic Carbon Freq. 0.9% 3.2% 4.1% 6.8% 10.9% 20.8% 26.2% 38.0% 49.3% 53.4% 74.2% 97.3% 99.5% 99.5%
Organic Carbon (ng/m3)

Figure 2a-4

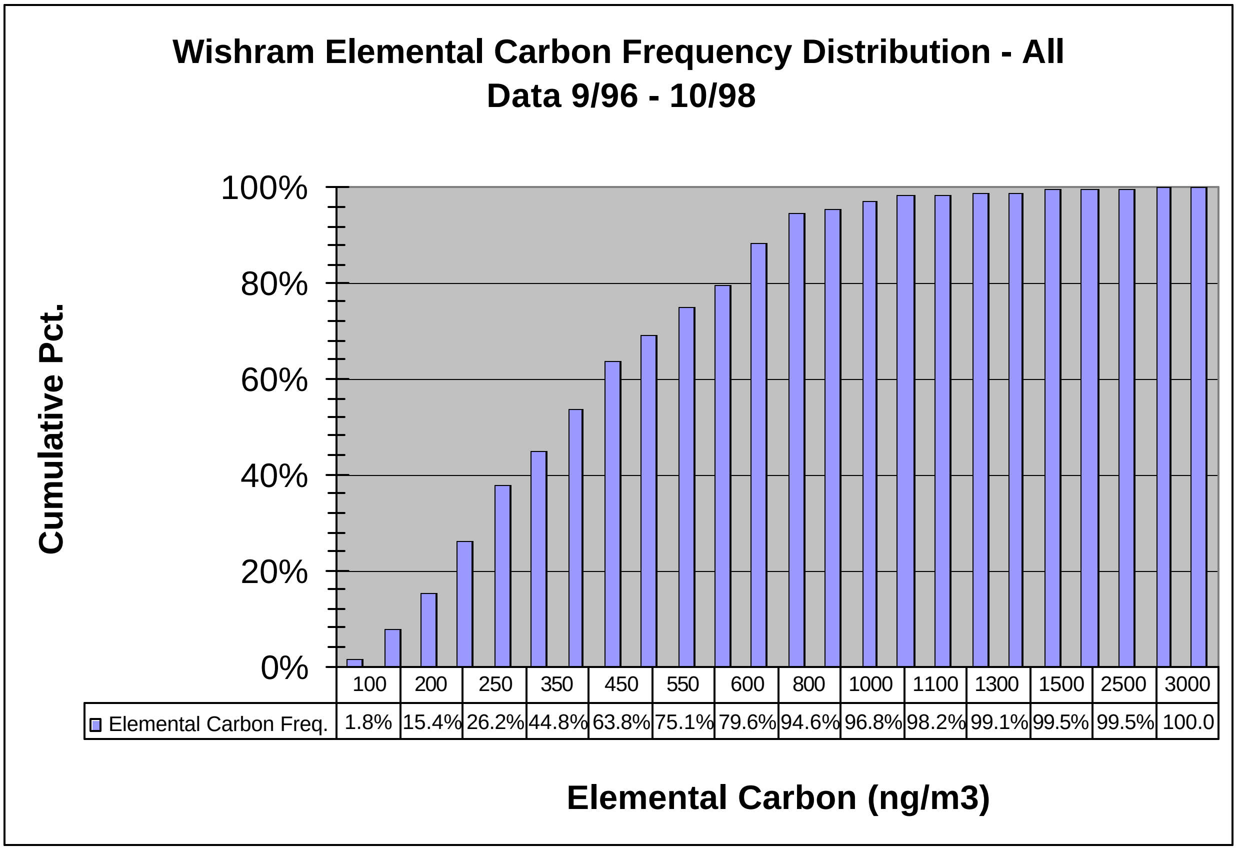

Wishram Elemental Carbon Frequency Distribution - All Data 9/96 - 10/98
Cumulative Pct.
100%
80%
60%
40%
20%
0%
100
200
250
350
450
550
600
800
1000
1100
1300
1500
2500
3000
Elemental Carbon Freq.
1.8%
15.4%
26.2%
44.8%
63.8%
75.1%
79.6%
94.6%
96.8%
98.2%
99.1%
99.5%
99.5%
100.0
Elemental Carbon (ng/m3)

Figure 2b-1

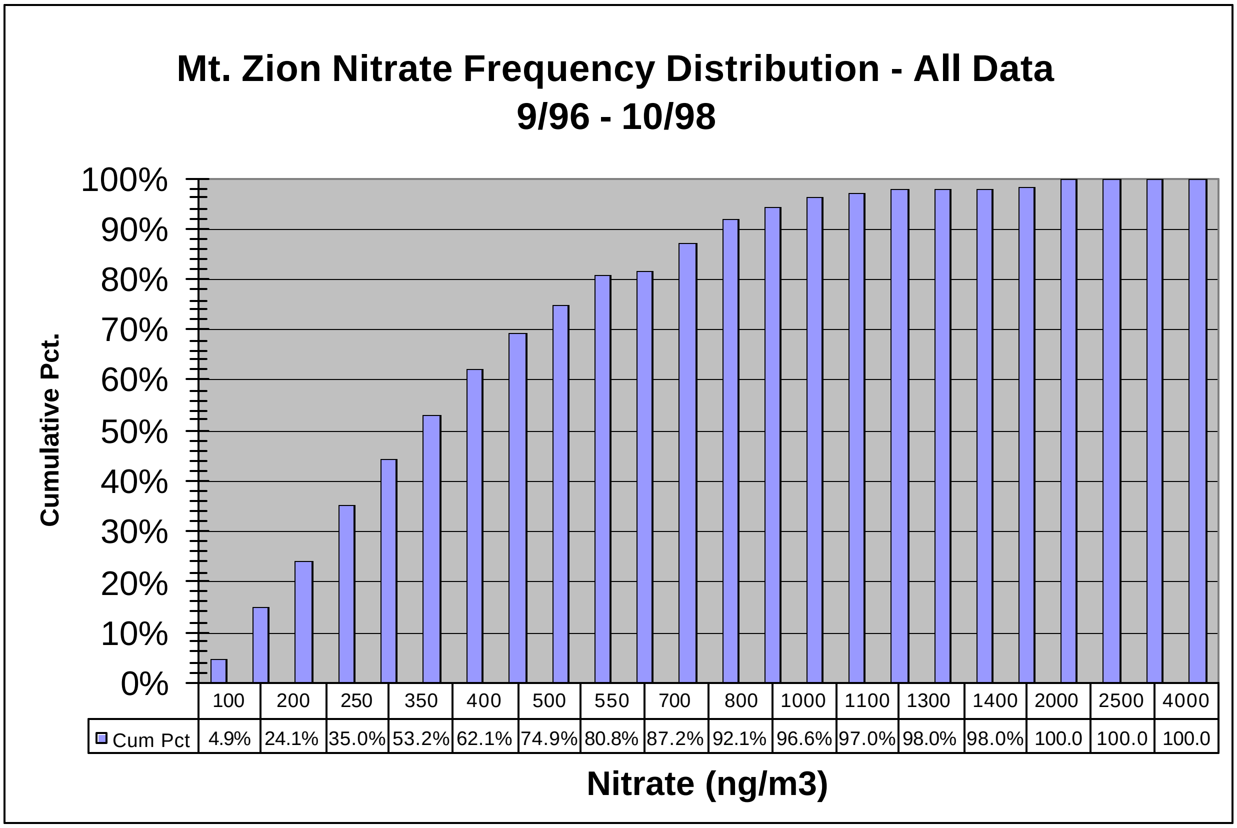

Mt. Zion Nitrate Frequency Distribution - All Data
9/96 - 10/98
Cumulative Pct.
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
100 200 250 350 400 500 550 700 800 1000 1100 1300 1400 2000 2500 4000
Cum Pct 4.9% 24.1% 35.0% 53.2% 62.1% 74.9% 80.8% 87.2% 92.1% 96.6% 97.0% 98.0% 98.0% 100.0 100.0 100.0
Nitrate (ng/m3)

Figure 2b-2

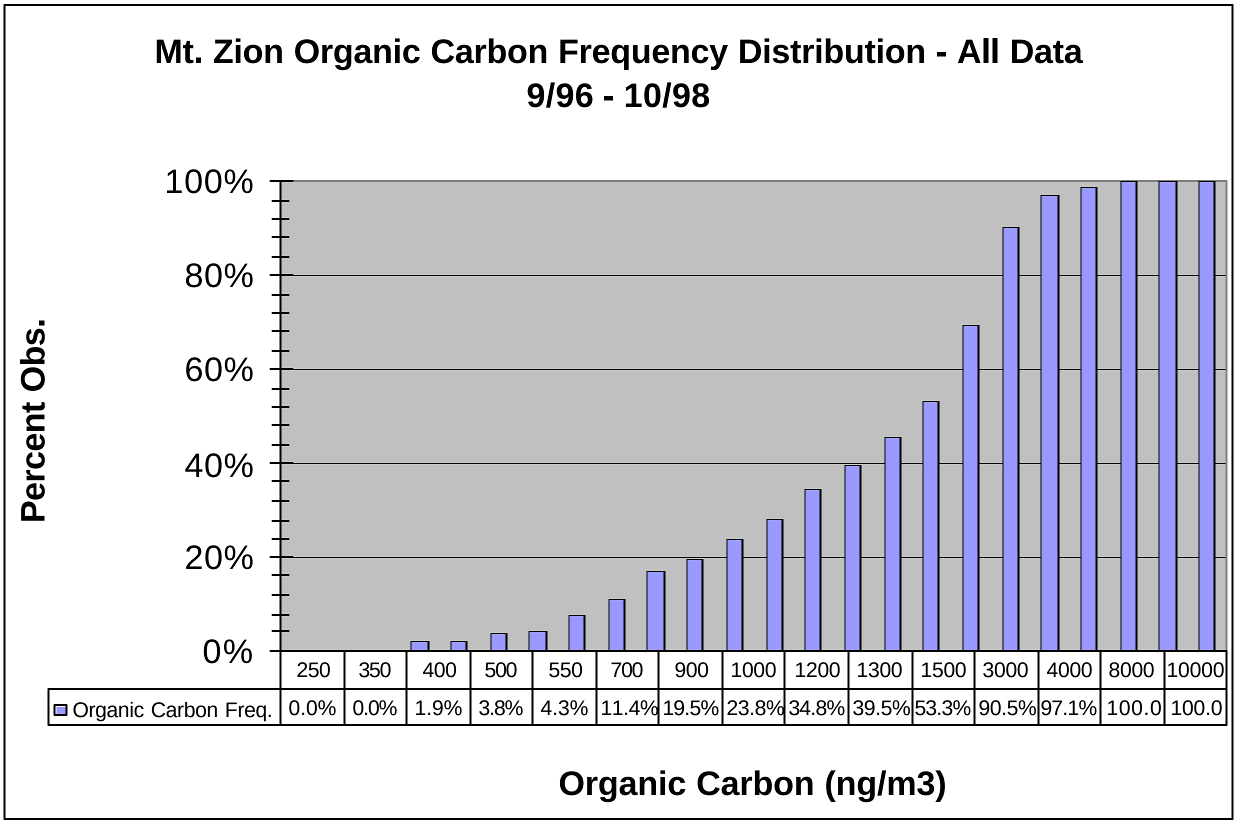

Mt. Zion Organic Carbon Frequency Distribution - All Data
9/96 - 10/98
Percent Obs.
100%
80%
60%
40%
20%
0%
250 350 400 500 550 700 900 1000 1200 1300 1500 3000 4000 8000 10000
Organic Carbon Freq.
0.0% 0.0% 1.9% 3.8% 4.3% 11.4% 19.5% 23.8% 34.8% 39.5% 53.3% 90.5% 97.1% 100.0 100.0
Organic Carbon (ng/m3)

Figure 2b-3

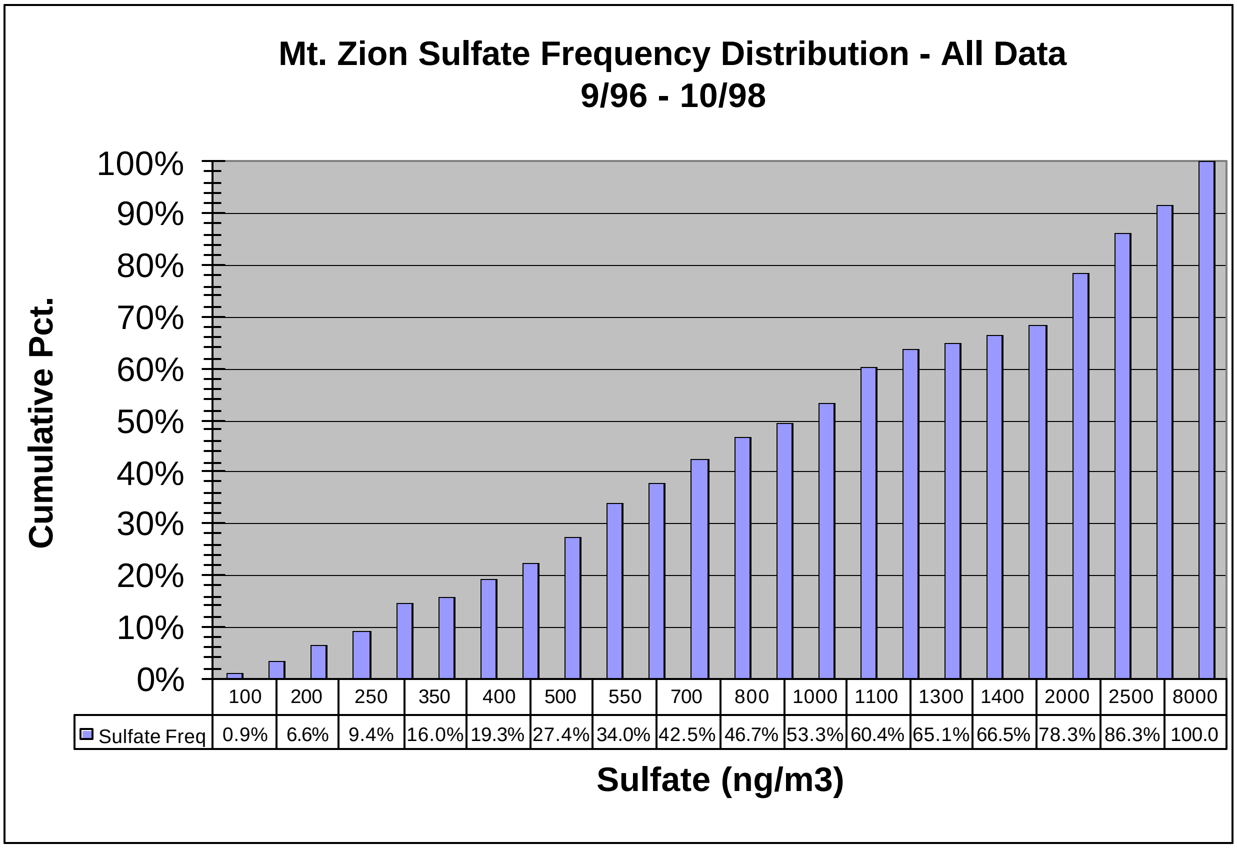
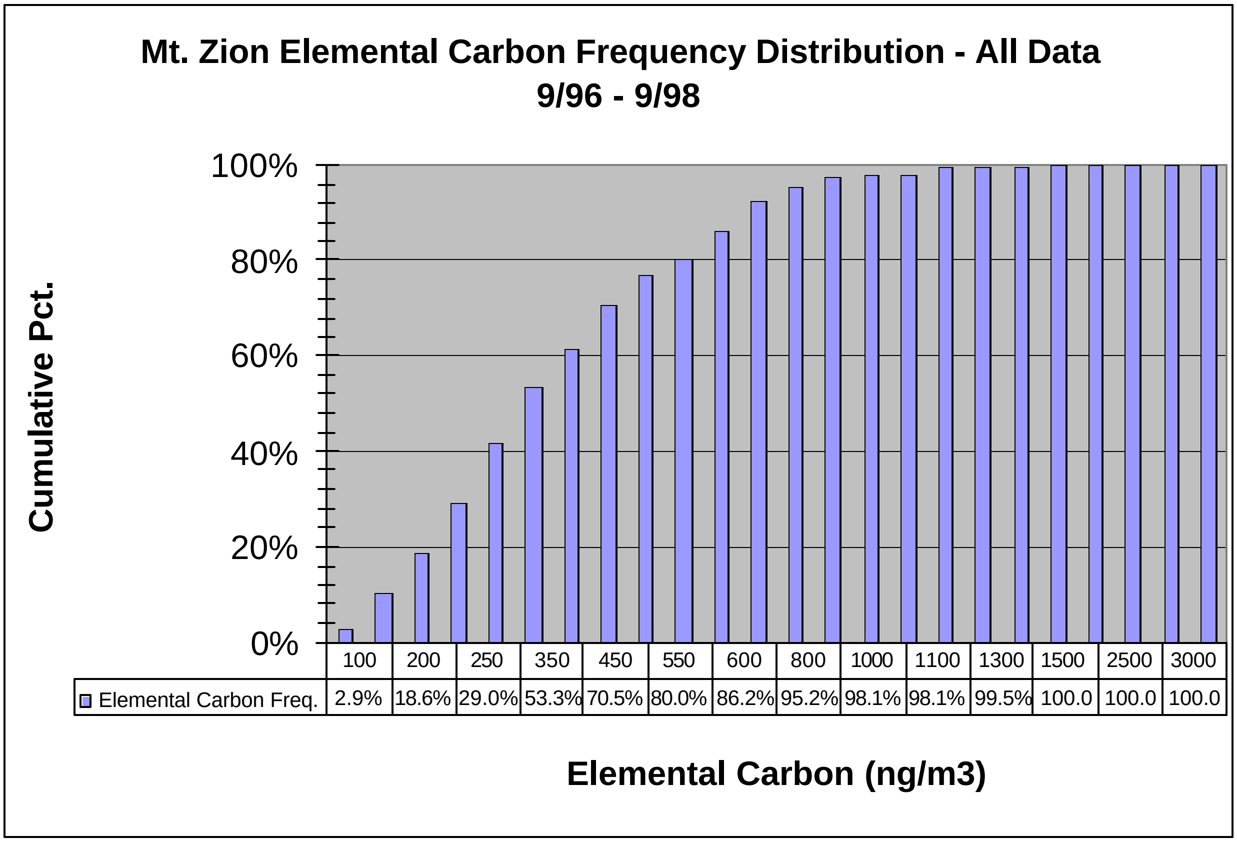

Mt. Zion Sulfate Frequency Distribution - All Data
9/96 - 10/98
Cumulative Pct.
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
100 200 250 350 400 500 550 700 800 1000 1100 1300 1400 2000 2500 8000
Sulfate Freq 0.9% 6.6% 9.4% 16.0% 19.3% 27.4% 34.0% 42.5% 46.7% 53.3% 60.4% 65.1% 66.5% 78.3% 86.3% 100.0
Sulfate (ng/m3)

Figure 2b-4


Mt. Zion Elemental Carbon Frequency Distribution - All Data
9/96 - 9/98
Cumulative Pct.
100%
80%
60%
40%
20%
0%
100 200 250 350 450 550 600 800 1000 1100 1300 1500 2500 3000
Elemental Carbon Freq.
2.9% 18.6% 29.0% 53.3% 70.5% 80.0% 86.2% 95.2% 98.1% 98.1% 99.5% 100.0 100.0 100.0
Elemental Carbon (ng/m3)

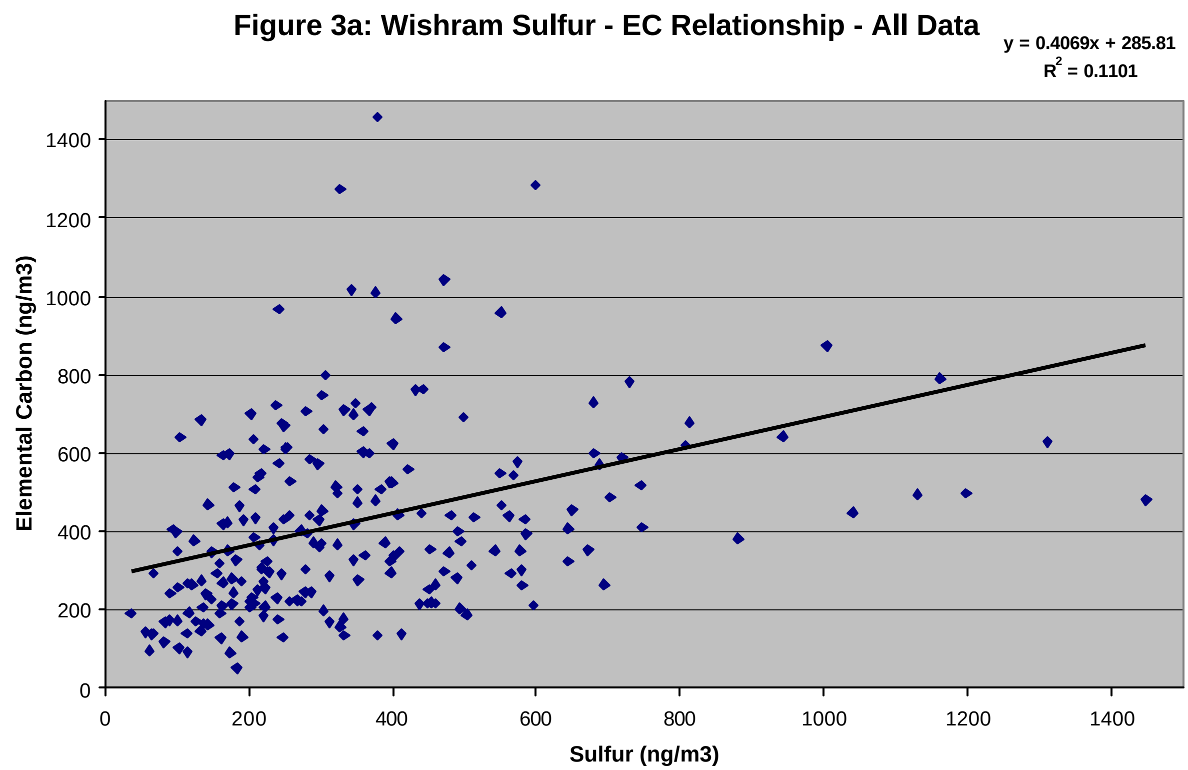


Figure 3a: Wishram Sulfur - EC Relationship - All Data
y = 0.4069x + 285.81
R2 = 0.1101
Elemental Carbon (ng/m3)
Sulfur (ng/m3)
0
200
400
600
800
1000
1200
1400

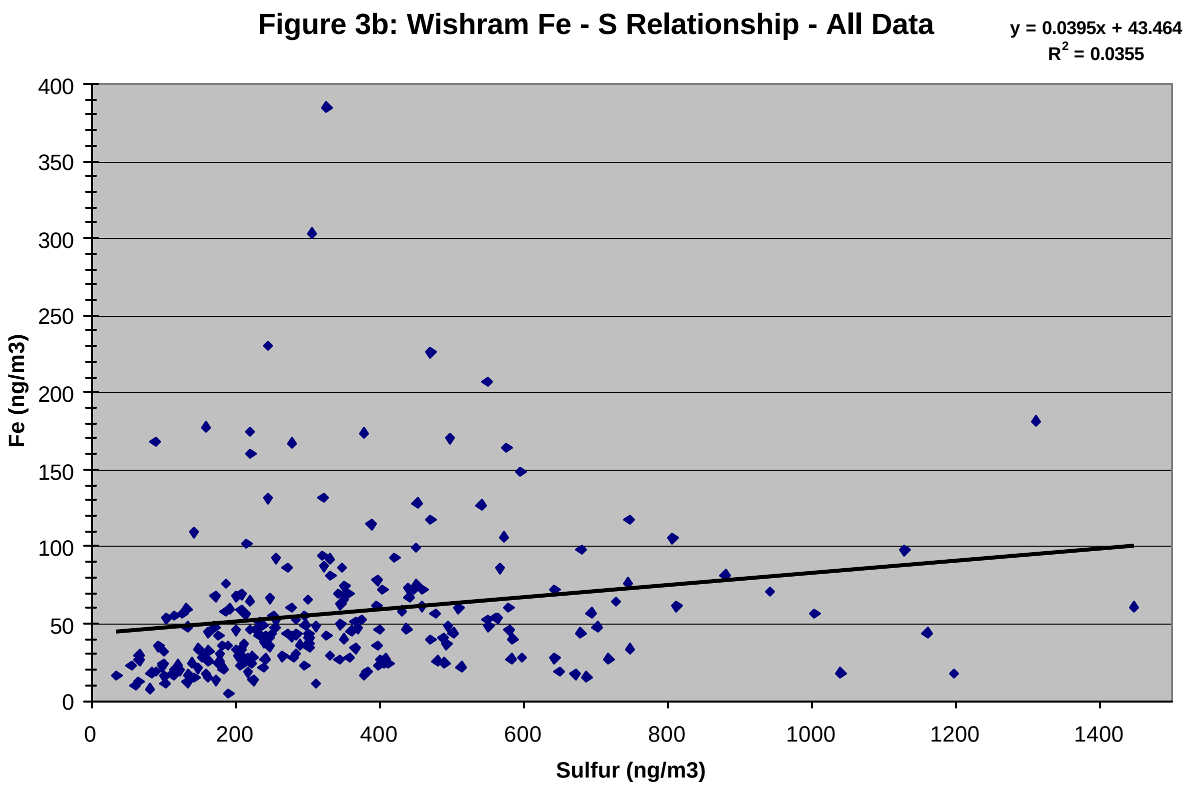


Figure 3b: Wishram Fe - S Relationship - All Data
y = 0.0395x + 43.464
R2 = 0.0355
Fe (ng/m3)
400
350
300
250
200
150
100
50
0
0
200
400
600
800
1000
1200
1400
Sulfur (ng/m3)

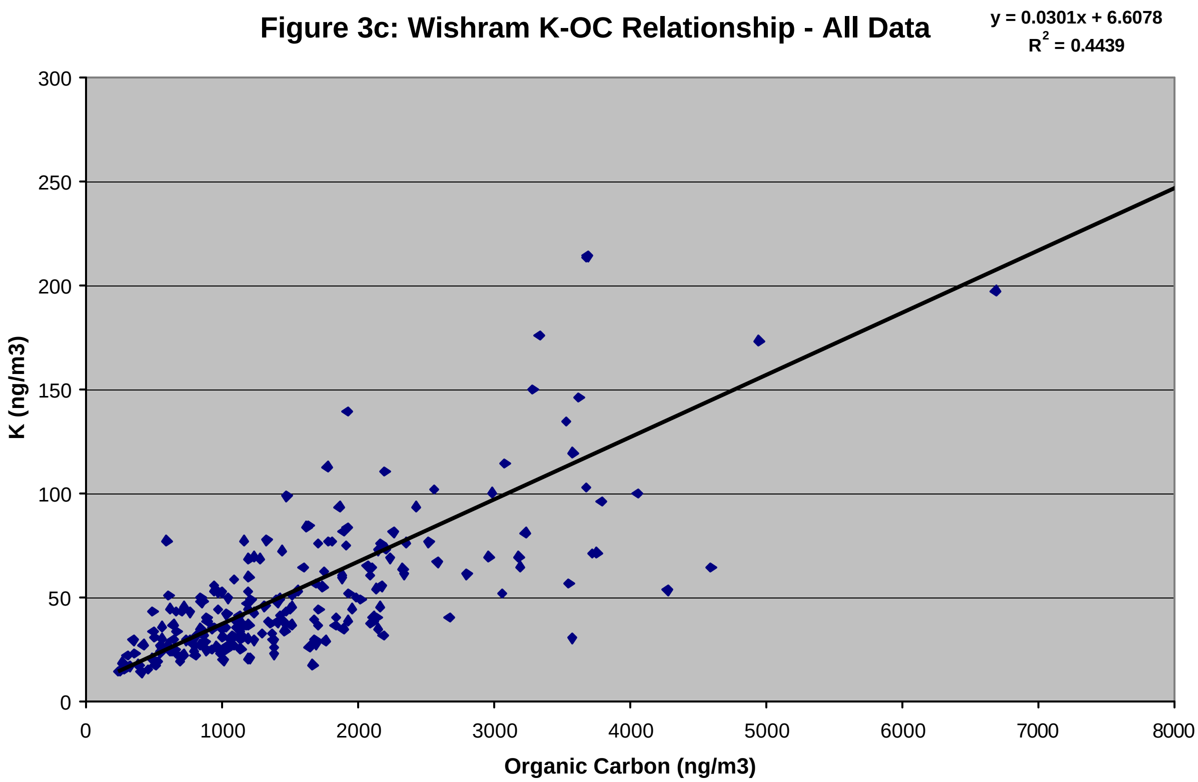


Figure 3c: Wishram K-OC Relationship - All Data
y = 0.0301x + 6.6078
R2 = 0.4439
K (ng/m3)
0
50
100
150
200
250
300
0
1000
2000
3000
4000
5000
6000
7000
8000
Organic Carbon (ng/m3)

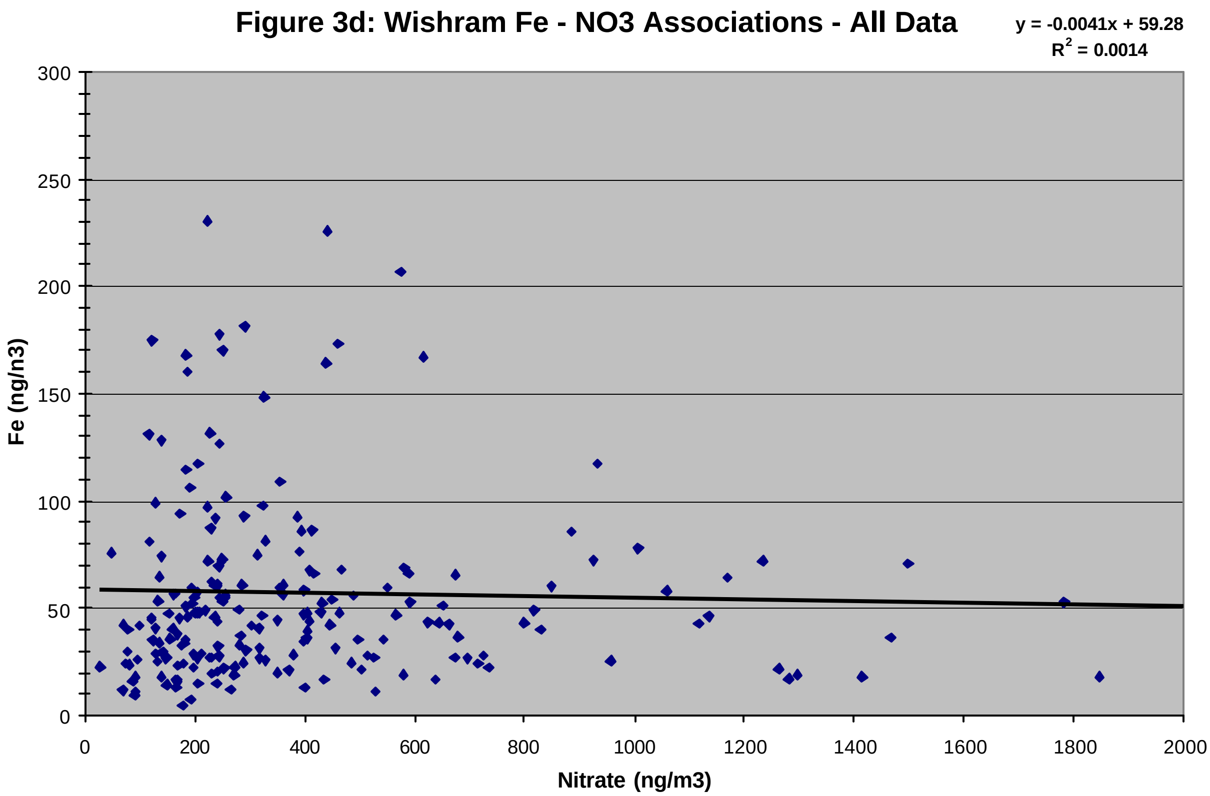
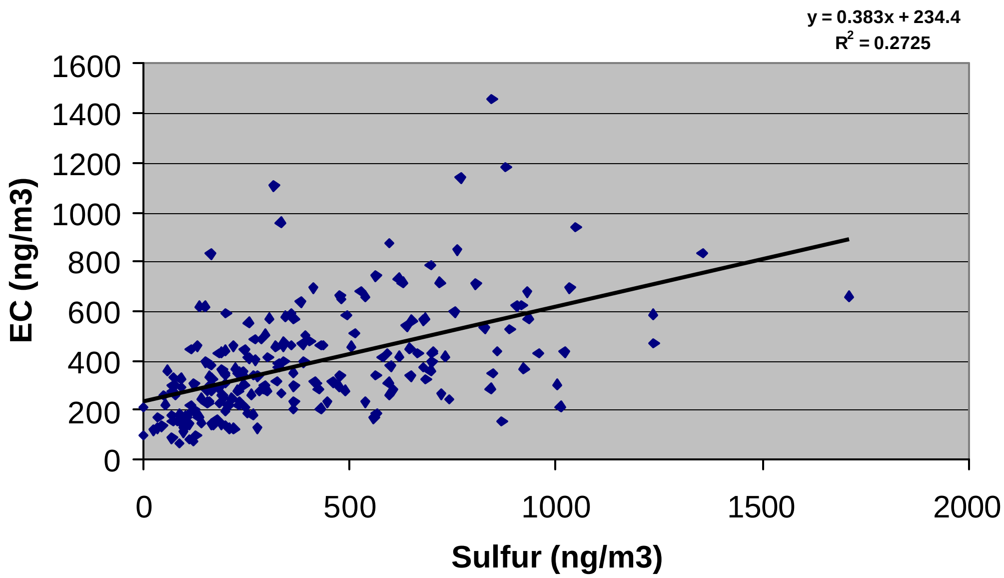


Figure 3d: Wishram Fe - NO3 Associations - All Data
y = -0.0041x + 59.28
R2 = 0.0014
300
250
200
150
100
50
0
Fe (ng/n3)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Nitrate (ng/m3)

Figure 3e: Mt. Zion Sulfur - EC Relationship - All Data



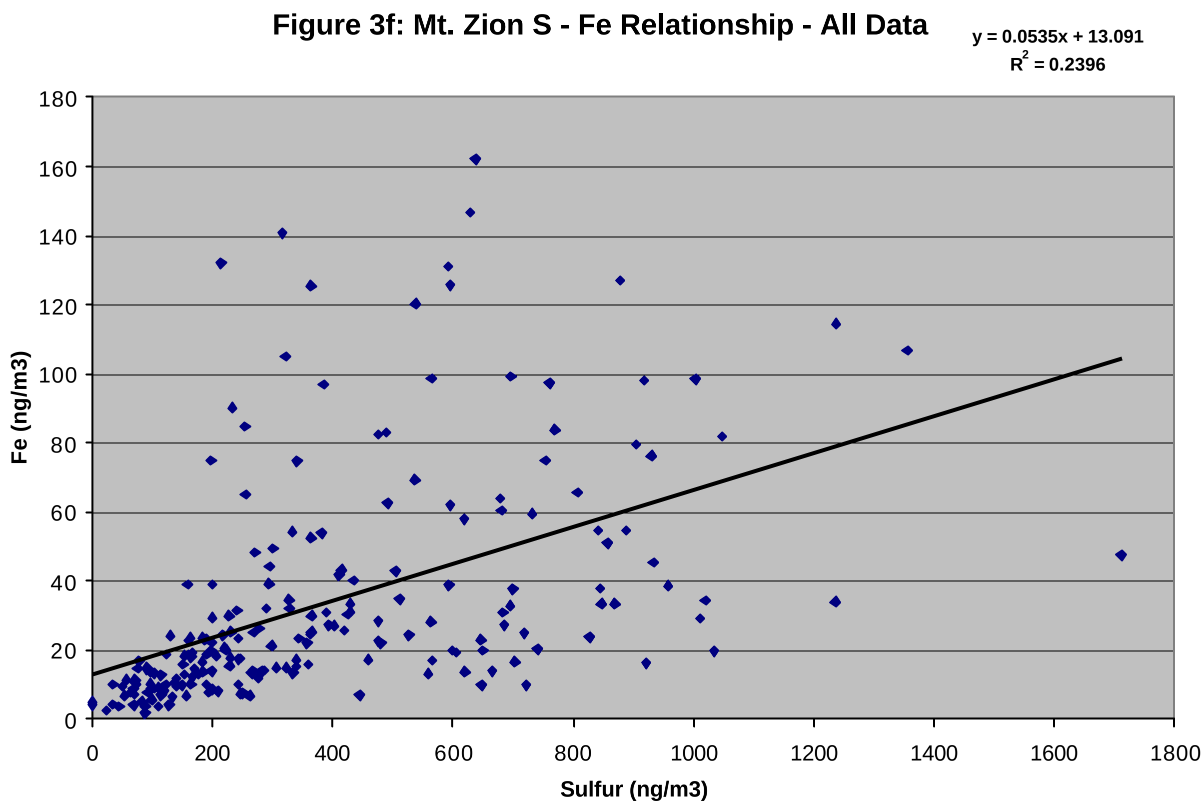


Figure 3f: Mt. Zion S - Fe Relationship - All Data
y = 0.0535x + 13.091
R2 = 0.2396
180
160
140
120
100
80
60
40
20
0
Fe (ng/m3)
0
200
400
600
800
1000
1200
1400
1600
1800
Sulfur (ng/m3)

Figure 3g: Mt. Zion K - OC Relationship - All Data

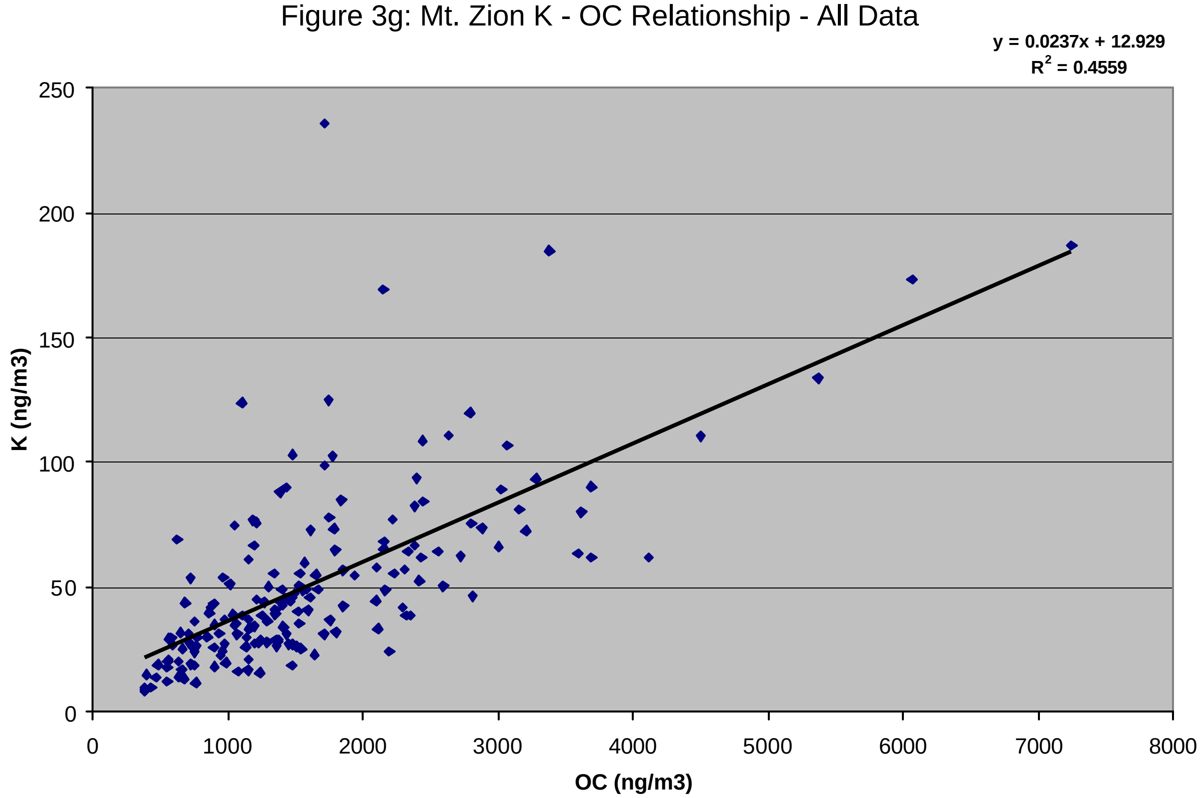
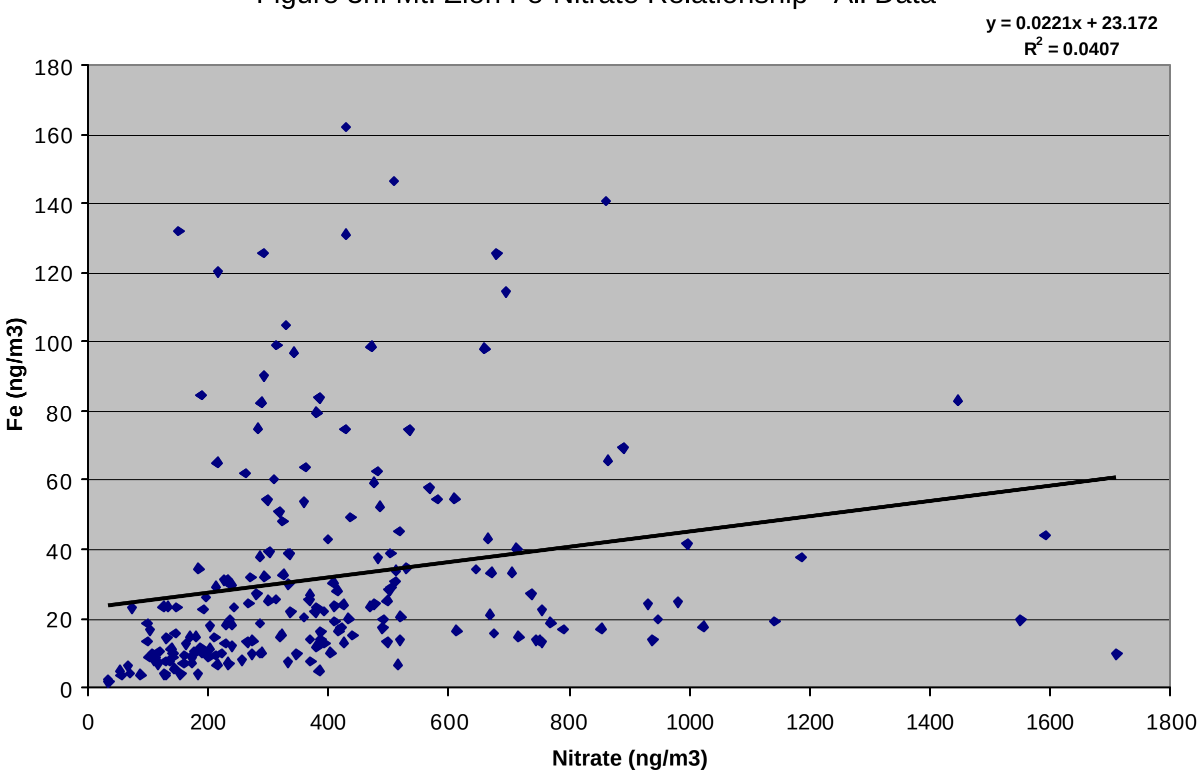


Figure 3h: Mt. Zion Fe-Nitrate Relationship - All Data



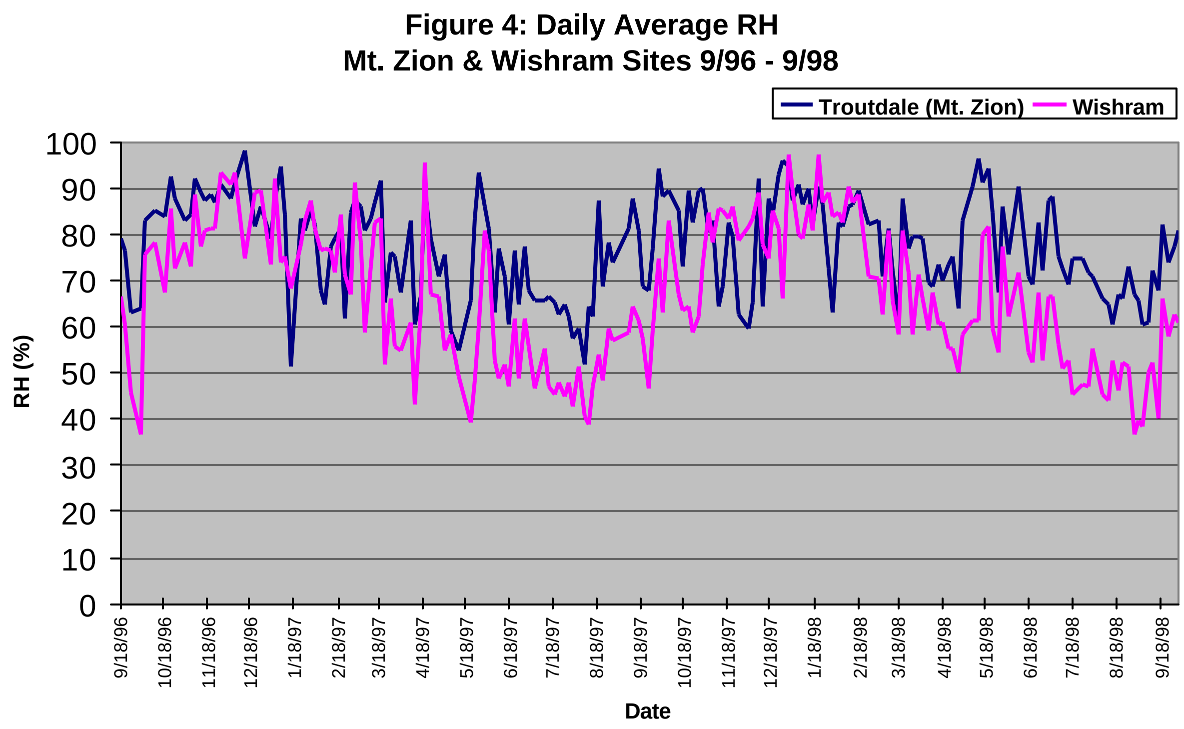


Figure 4: Daily Average RH
Mt. Zion & Wishram Sites 9/96 - 9/98
Troutdale (Mt. Zion)
Wishram
RH (%)
100
90
80
70
60
50
40
30
20
10
0
9/18/96
10/18/96
11/18/96
12/18/96
1/18/97
2/18/97
3/18/97
4/18/97
5/18/97
6/18/97
7/18/97
8/18/97
9/18/97
10/18/97
11/18/97
12/18/97
1/18/98
2/18/98
3/18/98
4/18/98
5/18/98
6/18/98
7/18/98
8/18/98
9/18/98
Date

Figure 5: Wishram RCFM
Days > 10 ug/m3

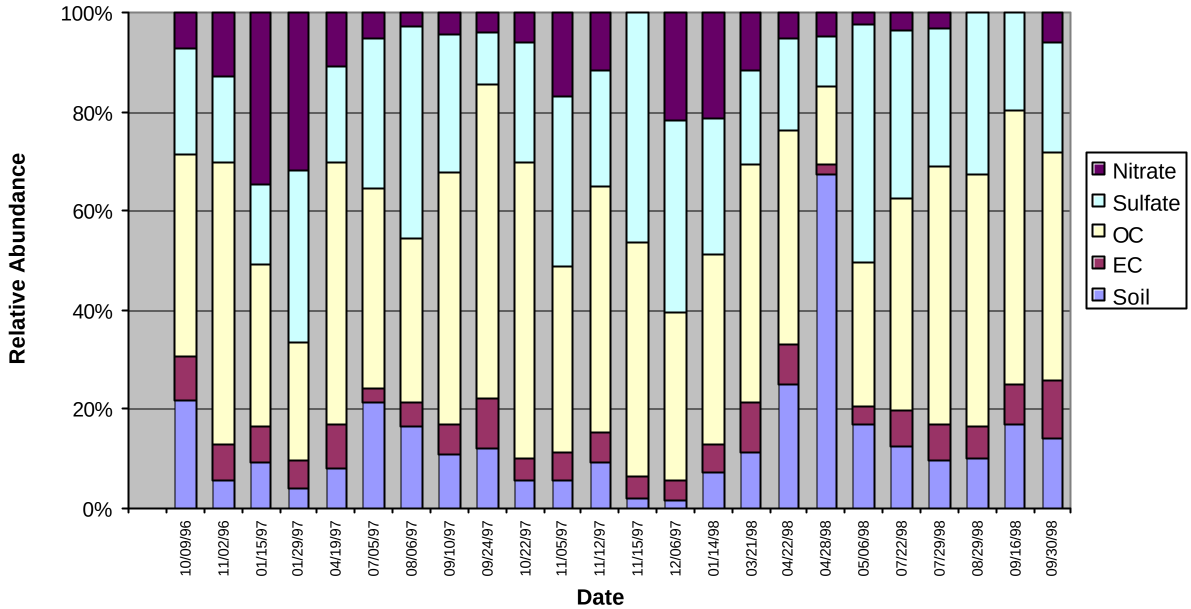


Figure 6: Mt. Zion RCFM
Days > 10 ug/m3

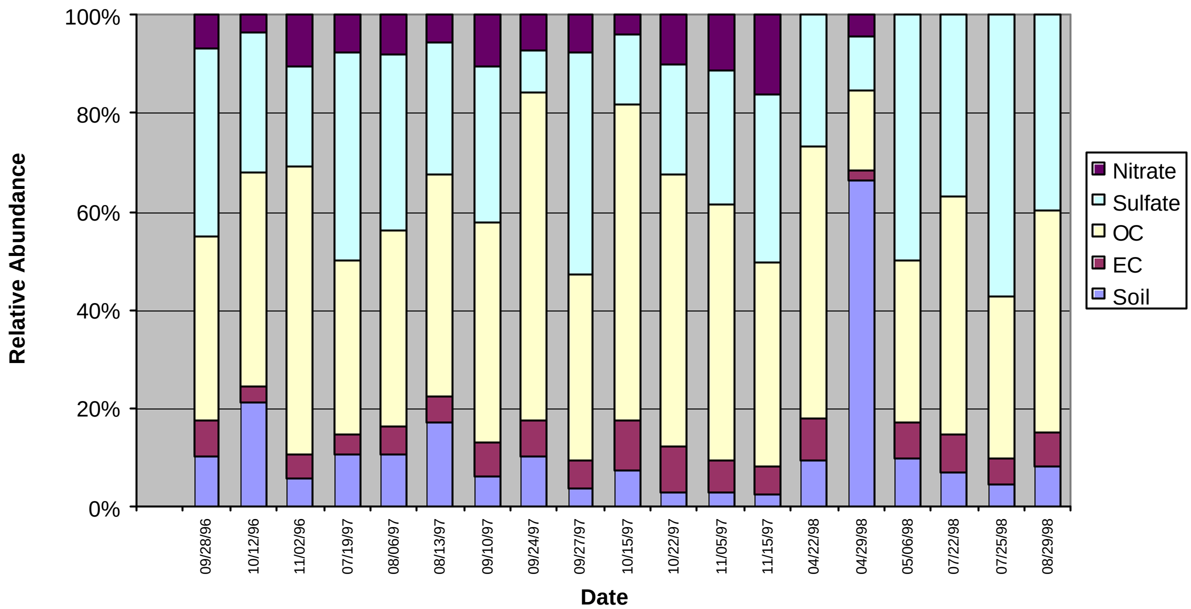
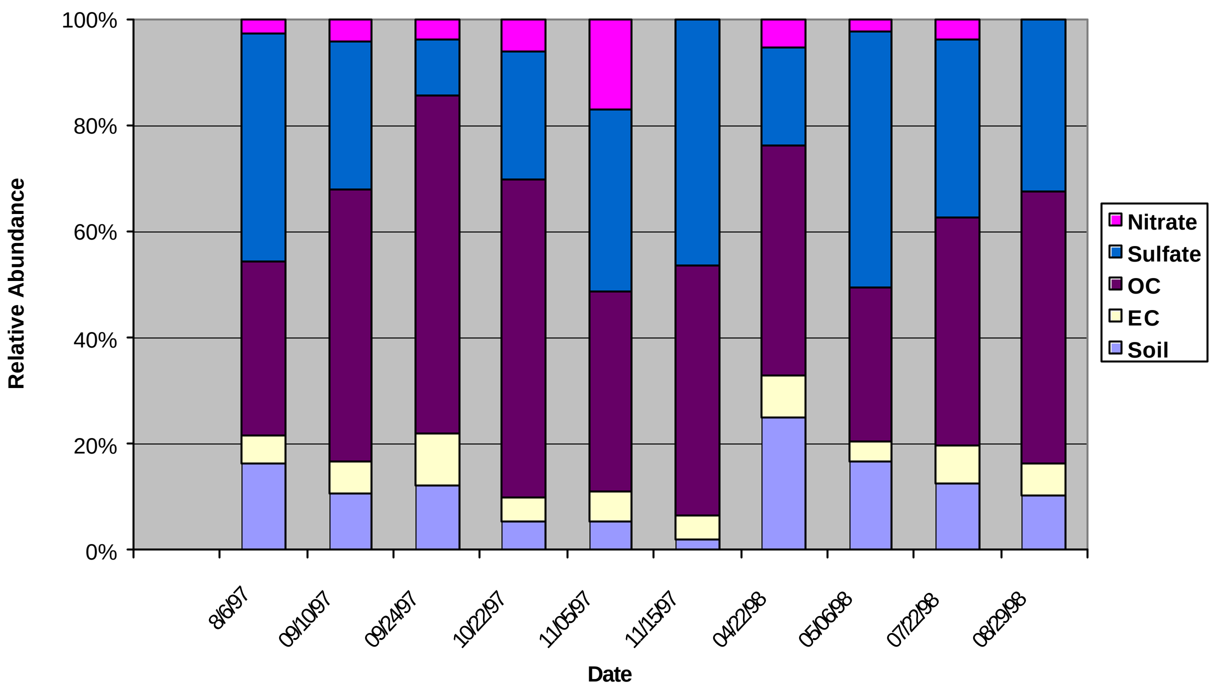


Figure 7a: Wishram Aerosol Components
Common Days > 10 ug/m3



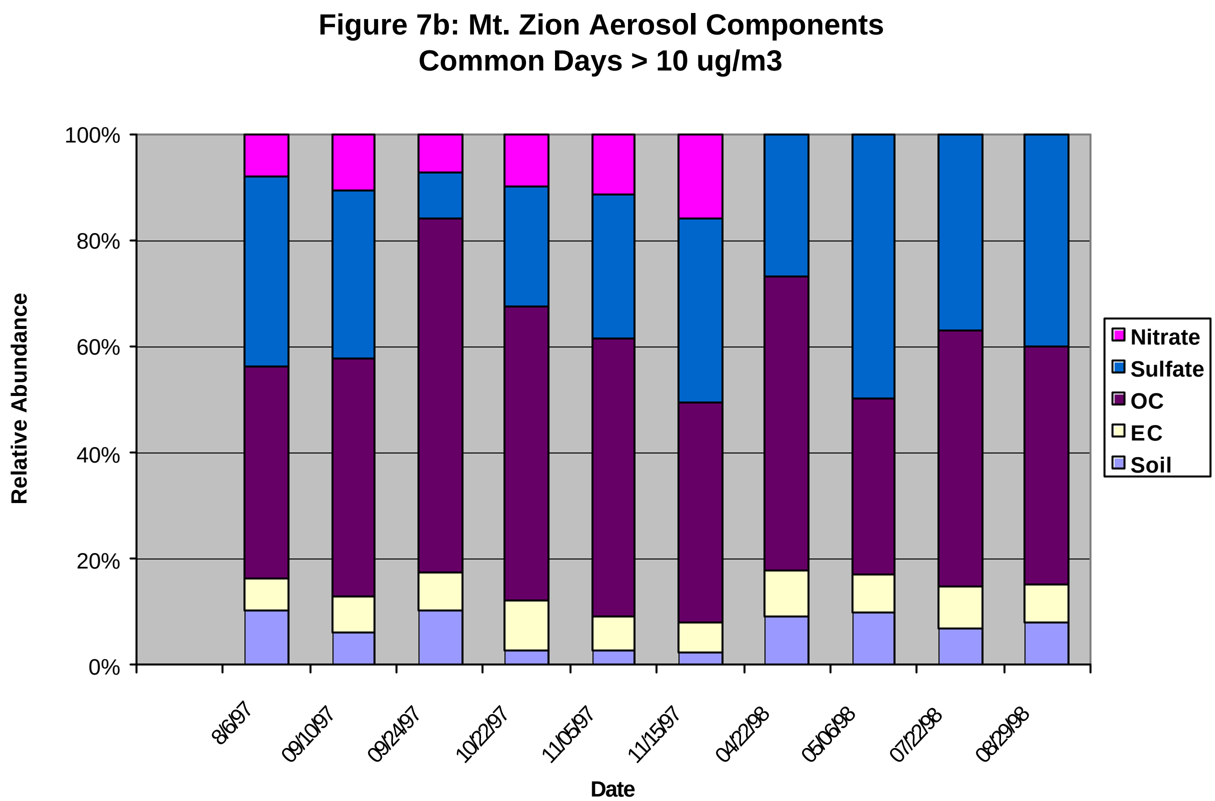


Figure 7b: Mt. Zion Aerosol Components
Common Days > 10 ug/m3
100%
80%
60%
40%
20%
0%
Relative Abundance
8/6/97
09/10/97
09/24/97
10/22/97
11/05/97
11/15/97
04/22/98
05/06/98
07/22/98
08/29/98
Date
Nitrate
Sulfate
OC
EC
Soil

Figure 7c: Wishram Species Enrichment
(Days > 10 ug/m3)

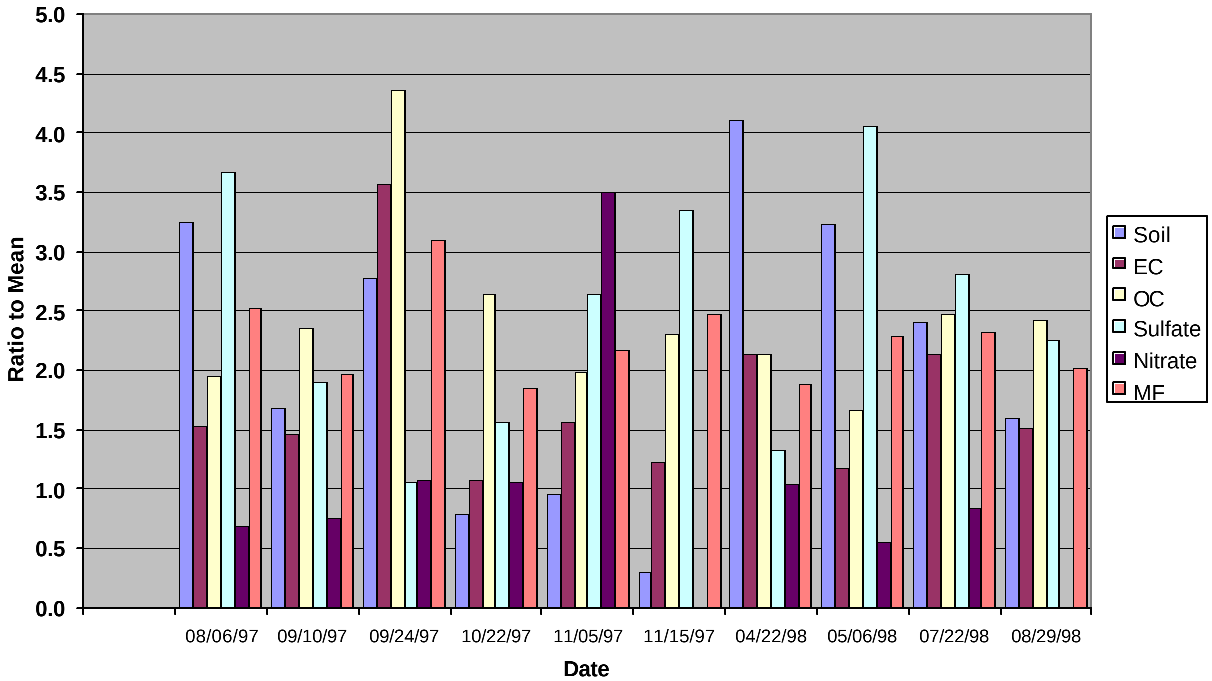


Figure 7d: Mt. Zion Species Enrichment (Days > 10 ug/m3)

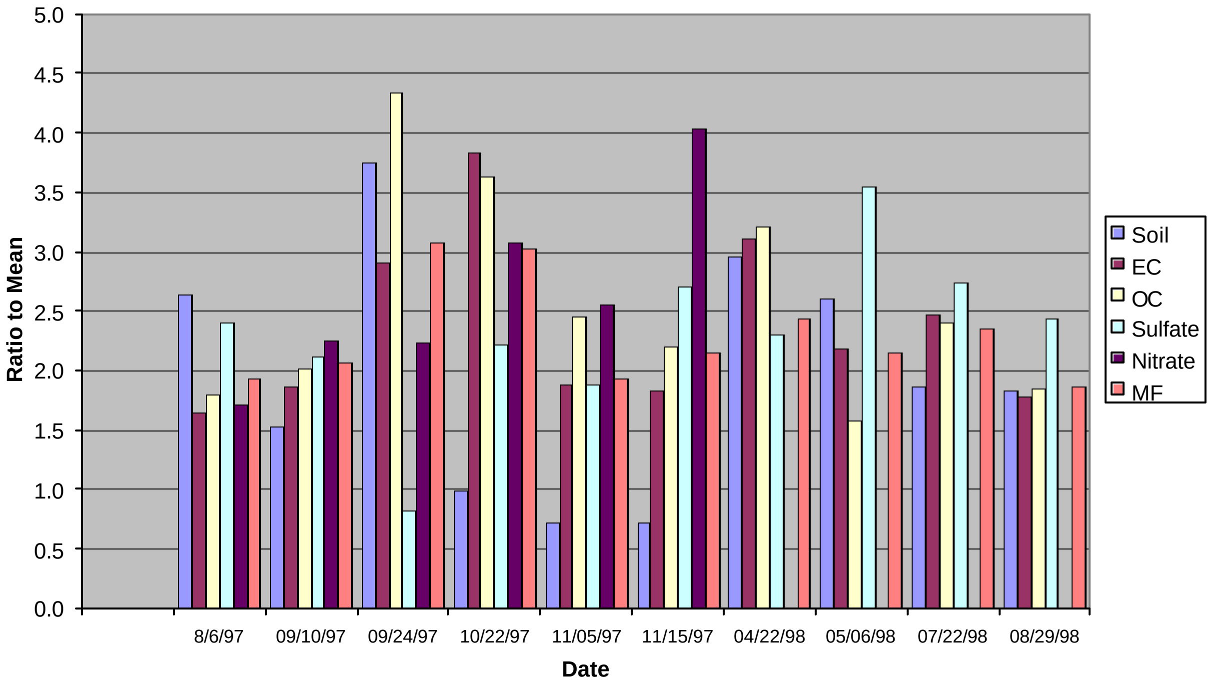


Figure 8a: Wishram RCFM - Measured Mass
All Data

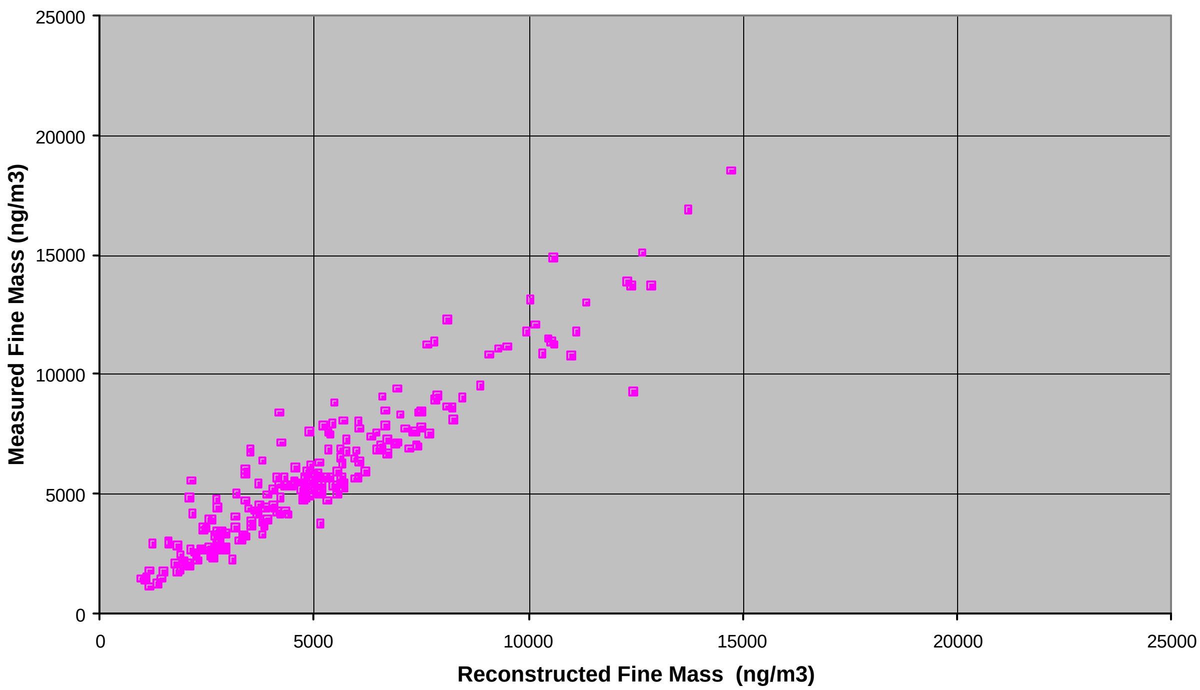
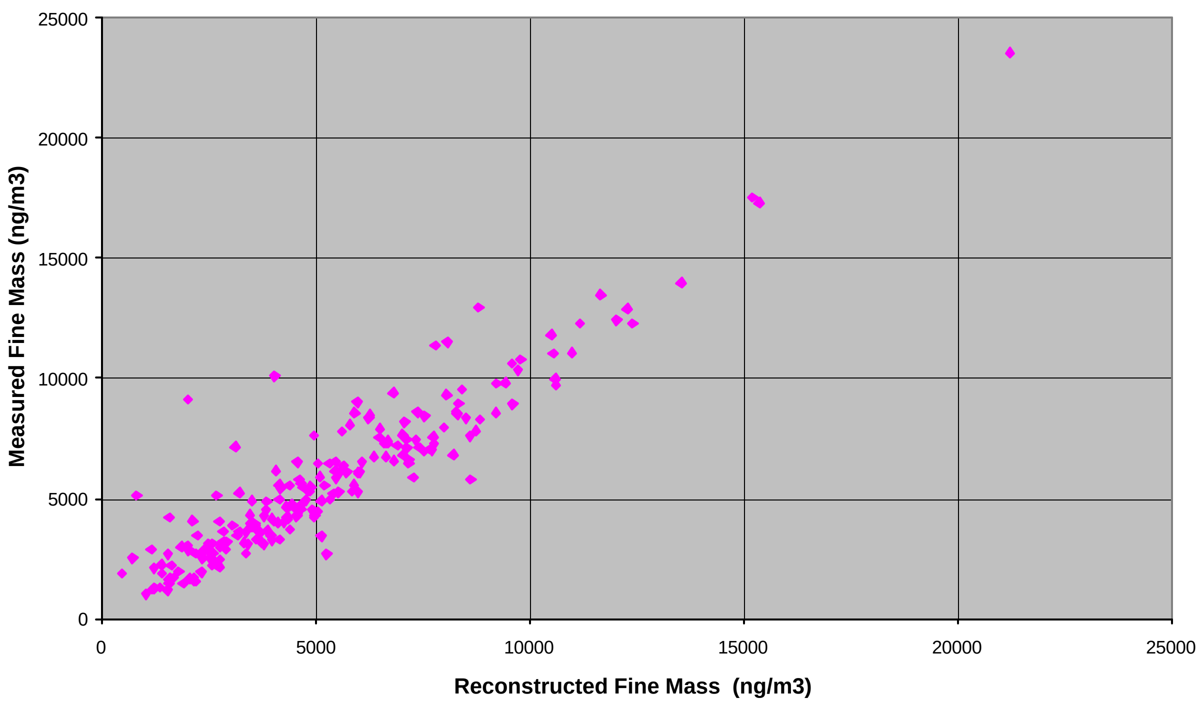


Figure 8b: Mt. Zion RCFM - Measured Mass
All Data



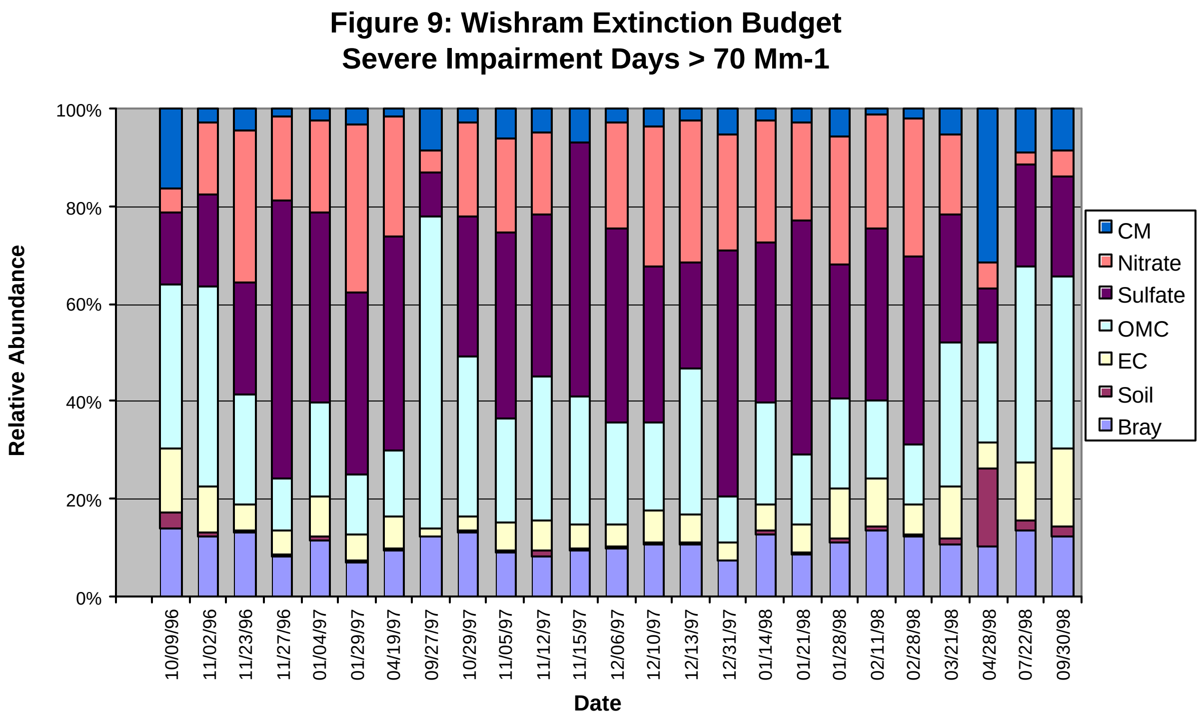


Figure 9: Wishram Extinction Budget
Severe Impairment Days > 70 Mm-1
Relative Abundance
100%
80%
60%
40%
20%
0%
10/09/96
11/02/96
11/23/96
11/27/96
01/04/97
01/29/97
04/19/97
09/27/97
10/29/97
11/05/97
11/12/97
11/15/97
12/06/97
12/10/97
12/13/97
12/31/97
01/14/98
01/21/98
01/28/98
02/11/98
02/28/98
03/21/98
04/28/98
07/22/98
09/30/98
Date
CM
Nitrate
Sulfate
OMC
EC
Soil
Bray

Figure 10: Mt. Zion Extinction Budget
Severe Impairment Days > 70 Mm-1

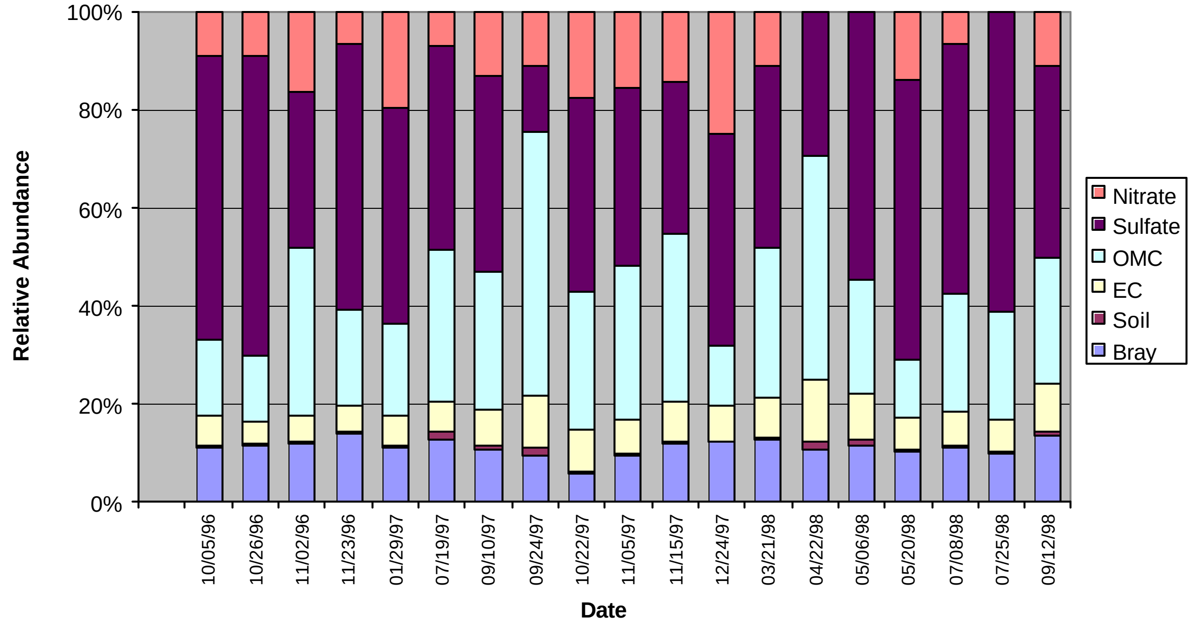


Figure 11a: Wishram Extinction Species Enrichment
Severe Impairment Days > 100 Mm-1

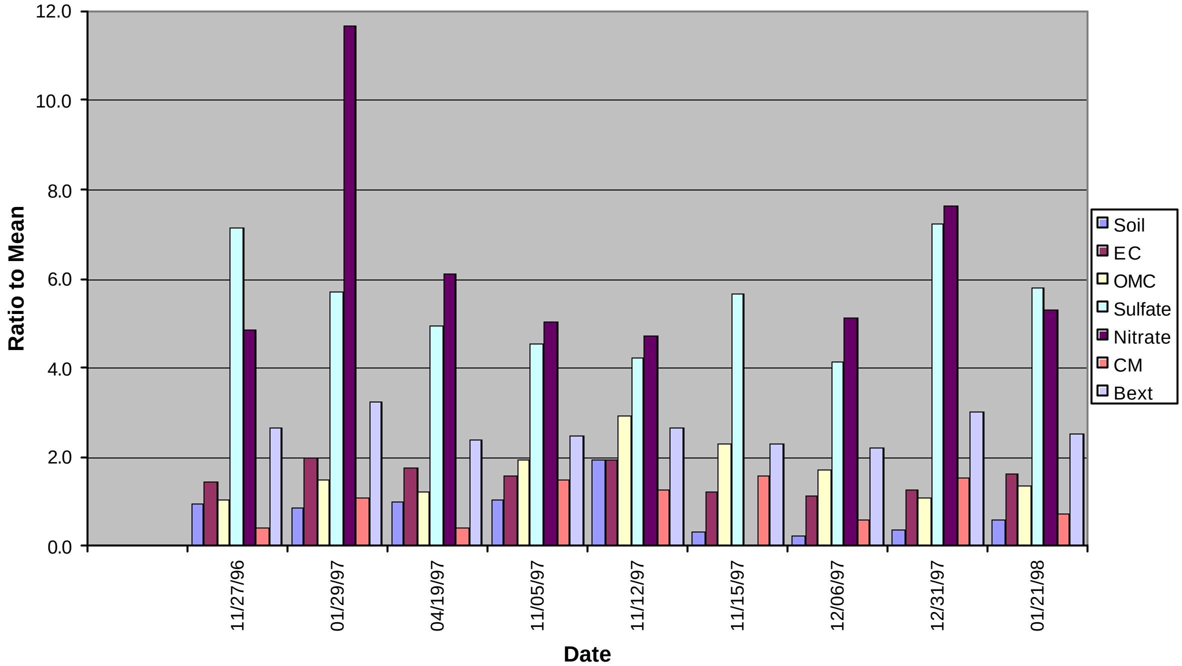


Figure 11b: Mt. Zion Extinction Species Enrichment
Severe Impairment Days > 70 Mm-1

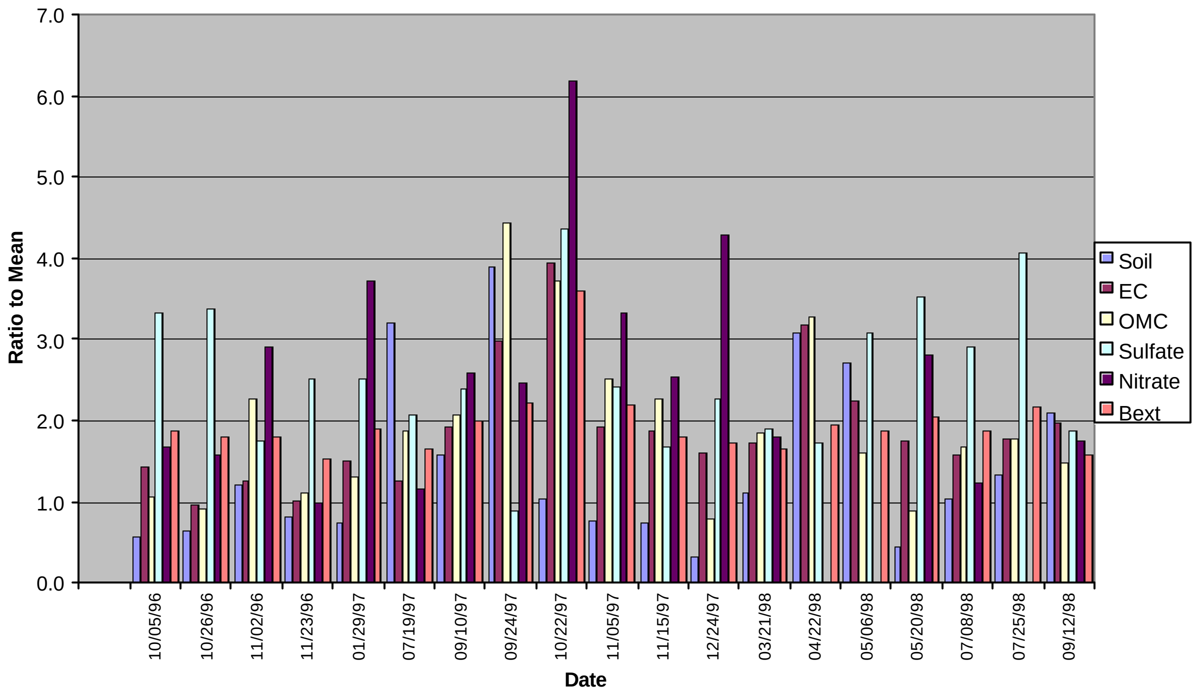


Figure 11c: Comparison of Extinction Components By Site
All Data Sept. 1, 1996 - Sept. 31, 1998
(Note: No Coarse Mass Extinction at Mt. Zion)

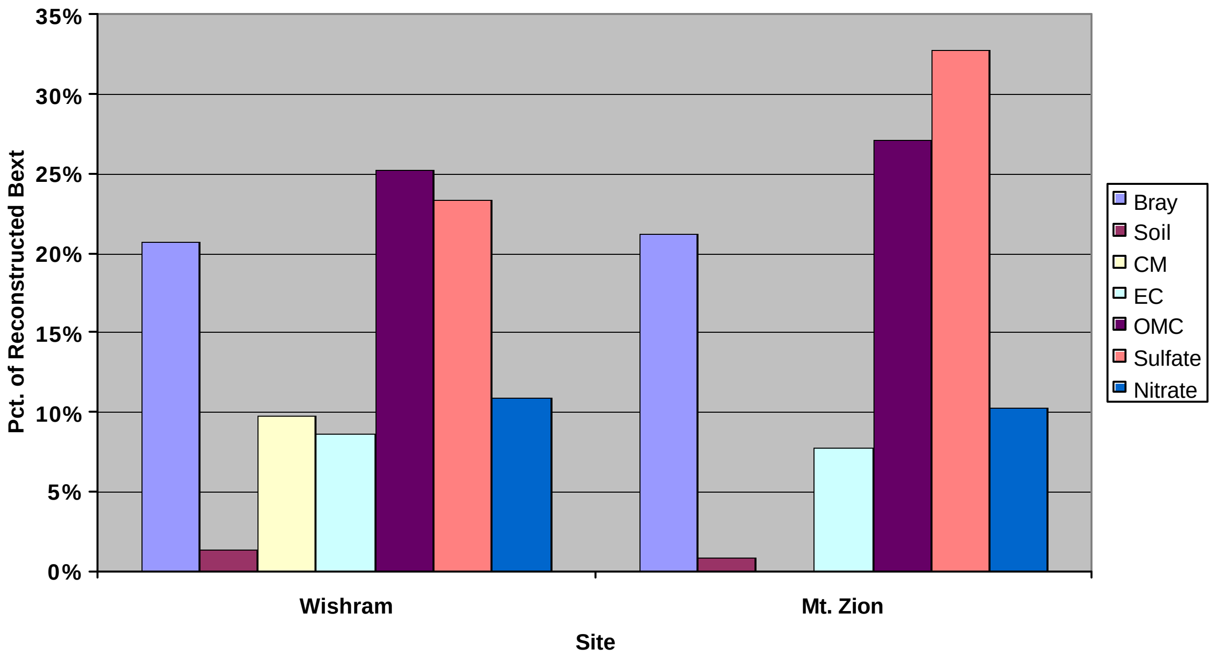


Figure 11d: Frequency of Impairment
From Reconstructed Extinction Estimates
All Days Sept. 1, 1996 - Sept. 31, 1998

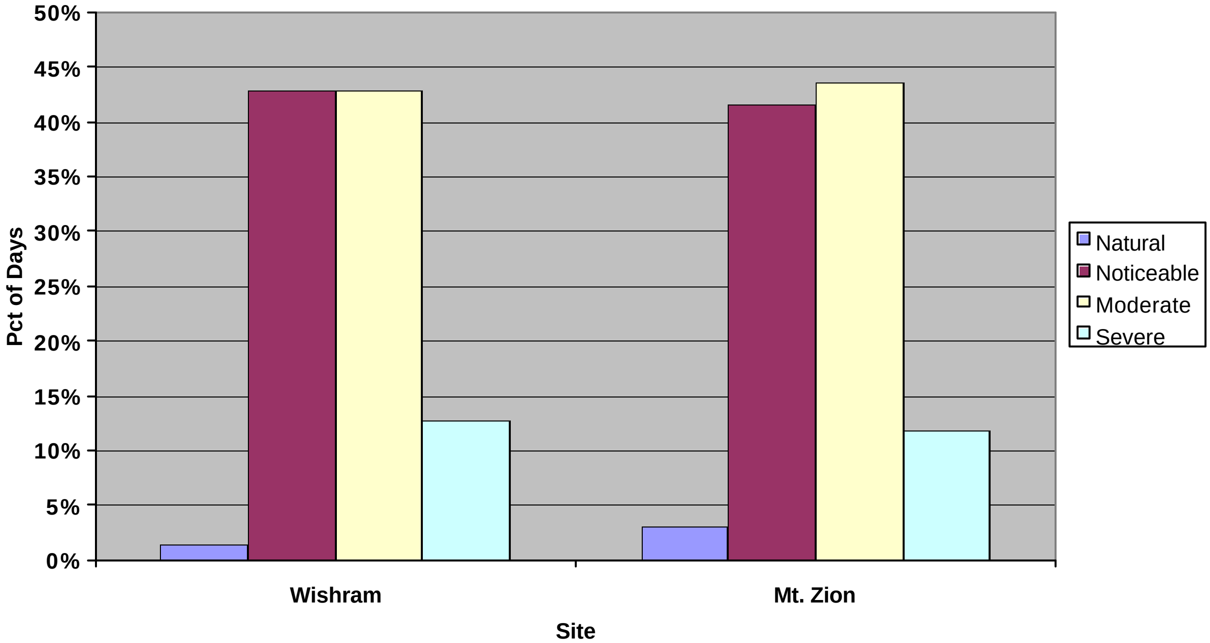


Figure 12: Temporal Variation in Extinction
All Data

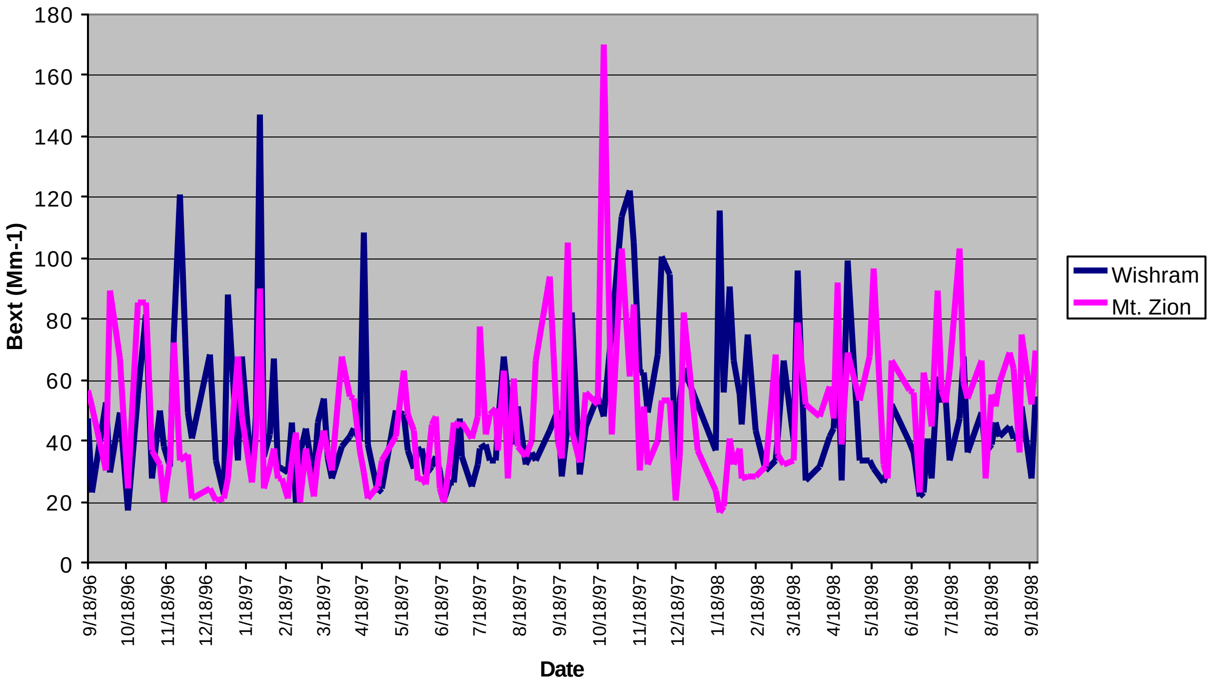


Figure 13a: Wishram Nephelometer Light Scattering
All Data 9/96 - 10/98

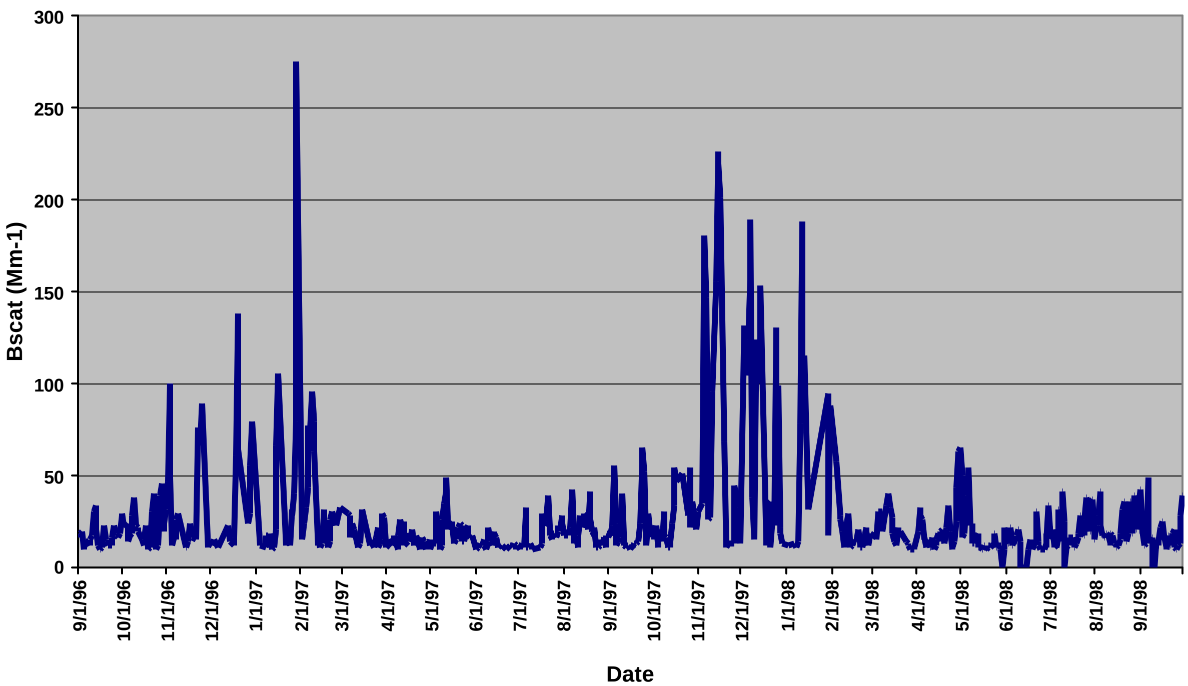
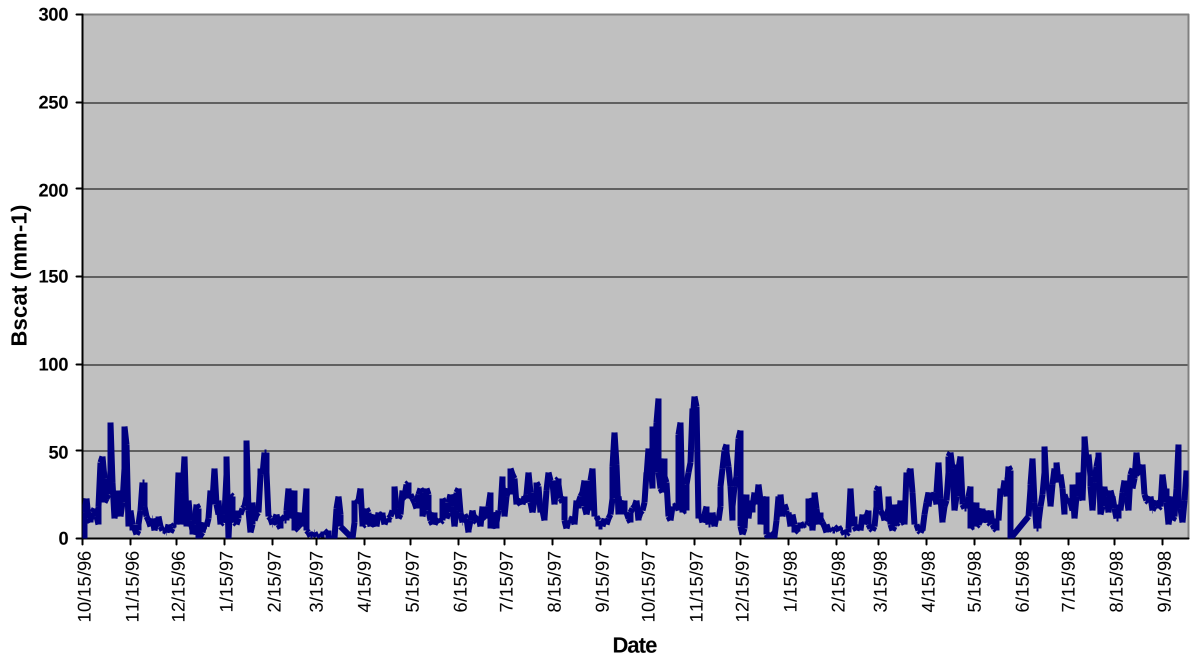


Figure 13b: Mt. Zion Nephelometer Dry Light Scattering
All Data 9/96 - 10/98

(Note: Plotted to same scale as Fig. 13a for Wishram)



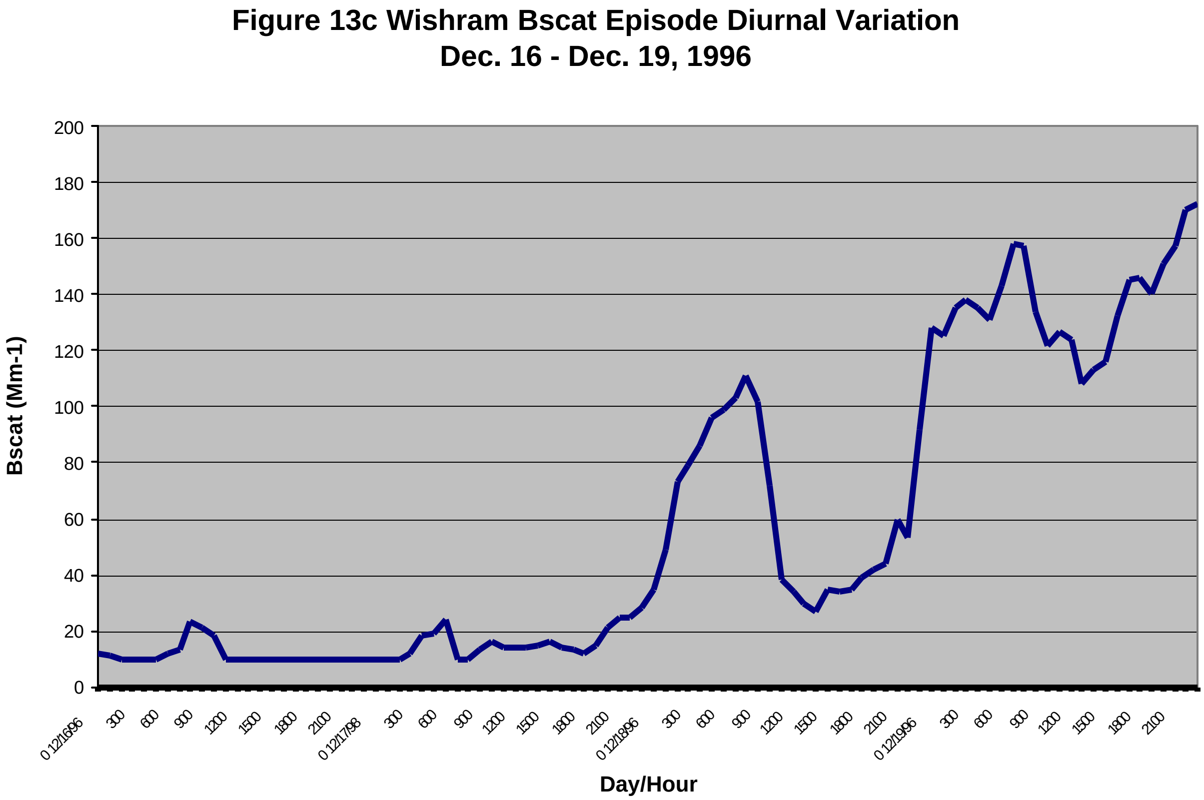


Figure 13c Wishram Bscat Episode Diurnal Variation
Dec. 16 - Dec. 19, 1996
Bscat (Mm-1)
200
180
160
140
120
100
80
60
40
20
0
Day/Hour

Figure 13d: Mt Zion Fall Season Diurnal Variations
Severe Impairment Days
< 70 Mm-1 24 Hour Average

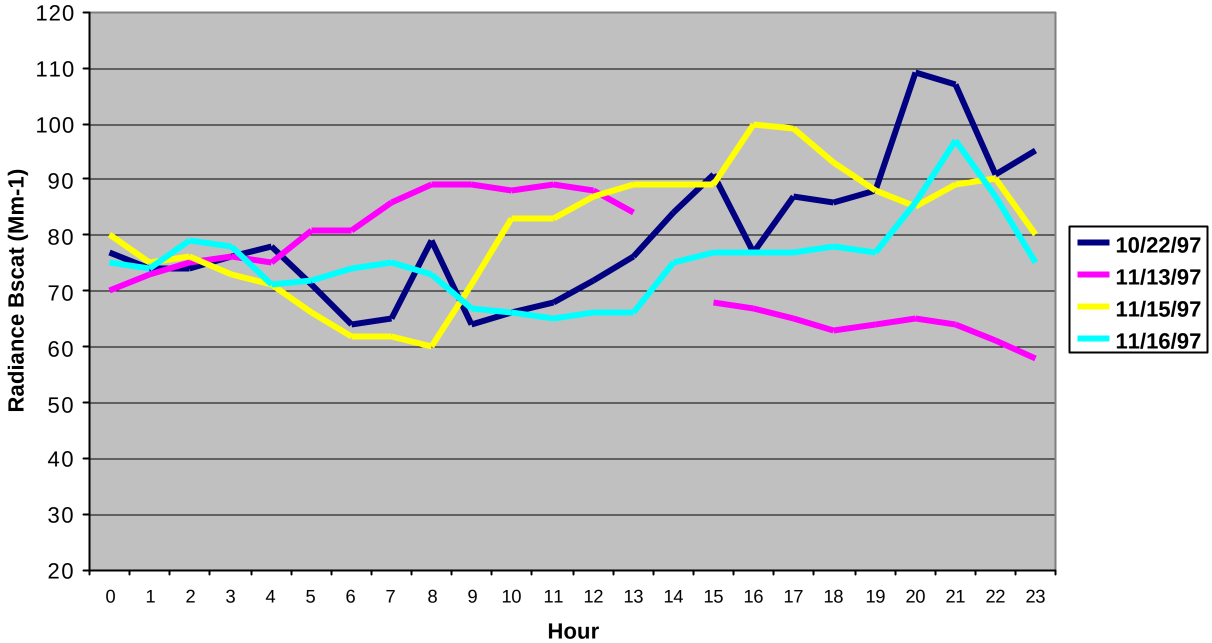


Figure 14a: Mt. Zion Reconstructed Extinction Vs Bscat
All Matching Days 9/96-9/98

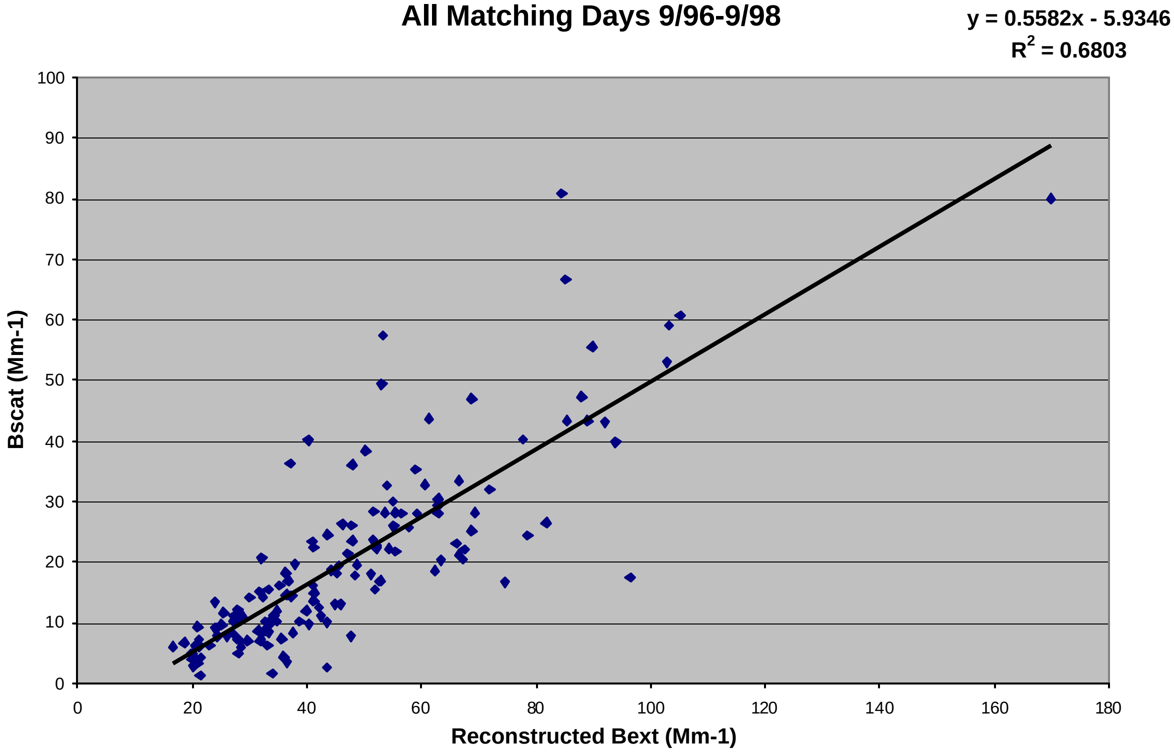


Figure 14b: Wishram Reconstructed Extinction Vs NGN-2 Bscat
All Matching Days 9/96 - 9/98

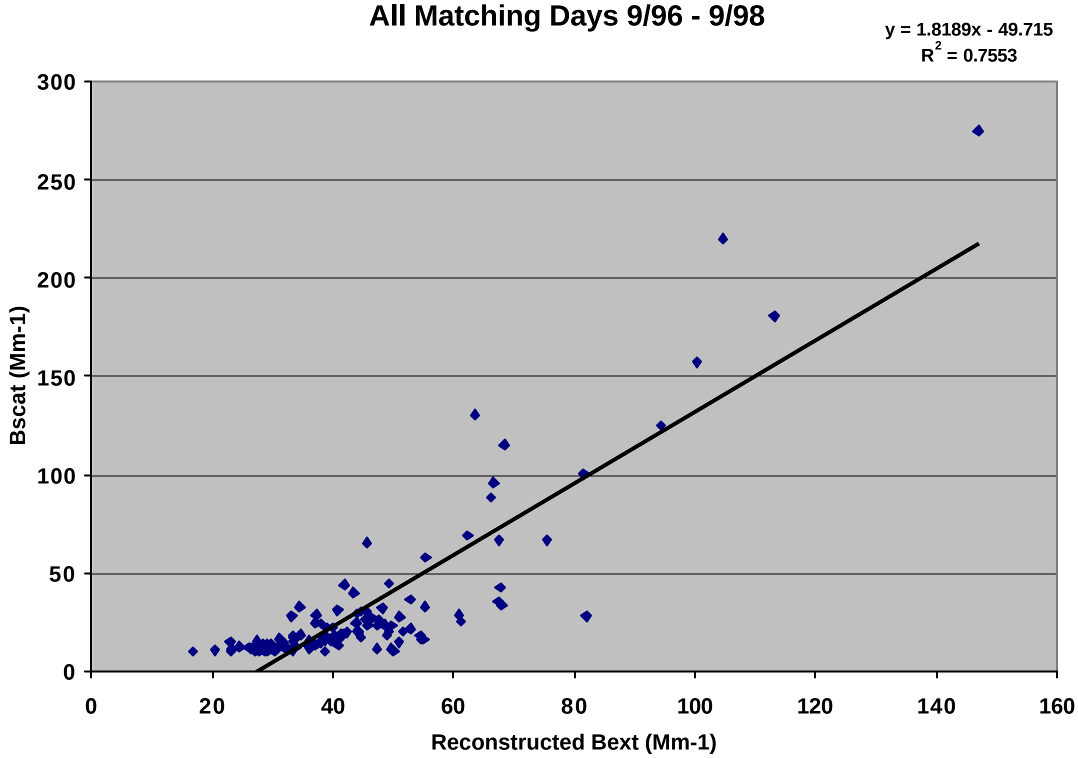
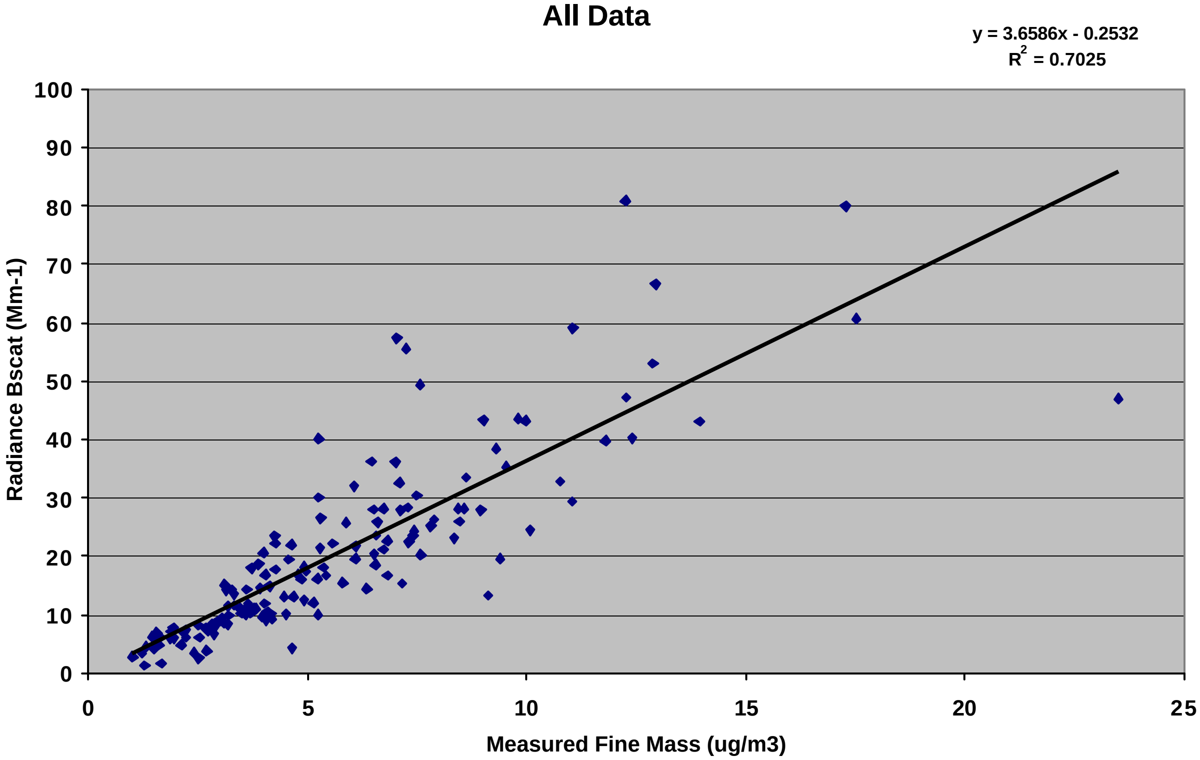


Figure 15a: Mt. Zion Radiance Bscat Vs Measured Fine Mass
All Data



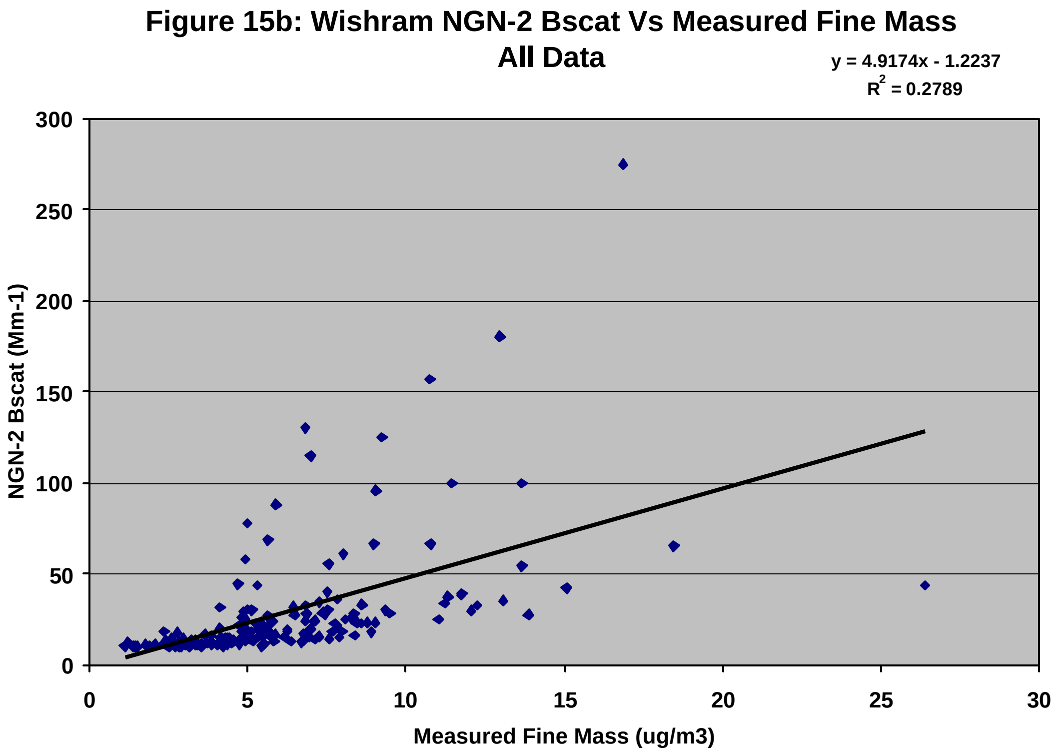


Figure 15b: Wishram NGN-2 Bscat Vs Measured Fine Mass
All Data
y = 4.9174x - 1.2237
R2 = 0.2789
300
250
200
150
100
50
0
NGN-2 Bscat (Mm-1)
0
5
10
15
20
25
30
Measured Fine Mass (ug/m3)

Figure 16a: Mt. Zion Extinction By Wind Direction On Impaired Days (80th Percentile)

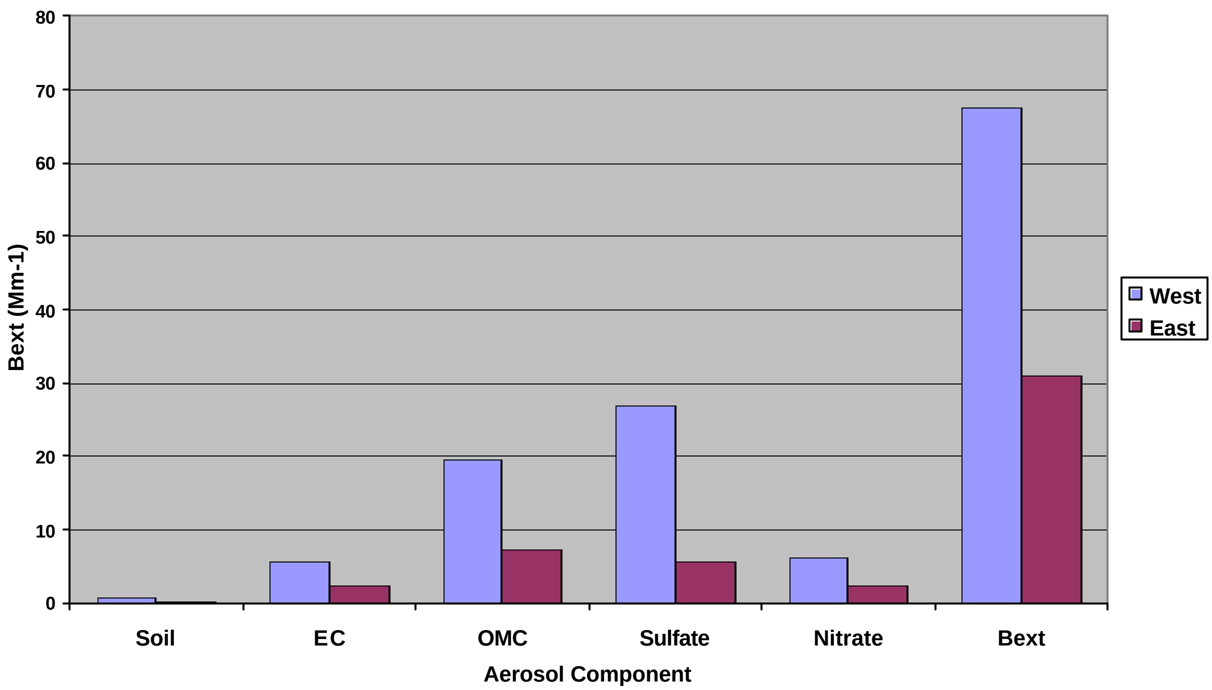


Figure 16b: Mt. Zion Extinction by Wind Direction
On Clear Days (20th Percentile)

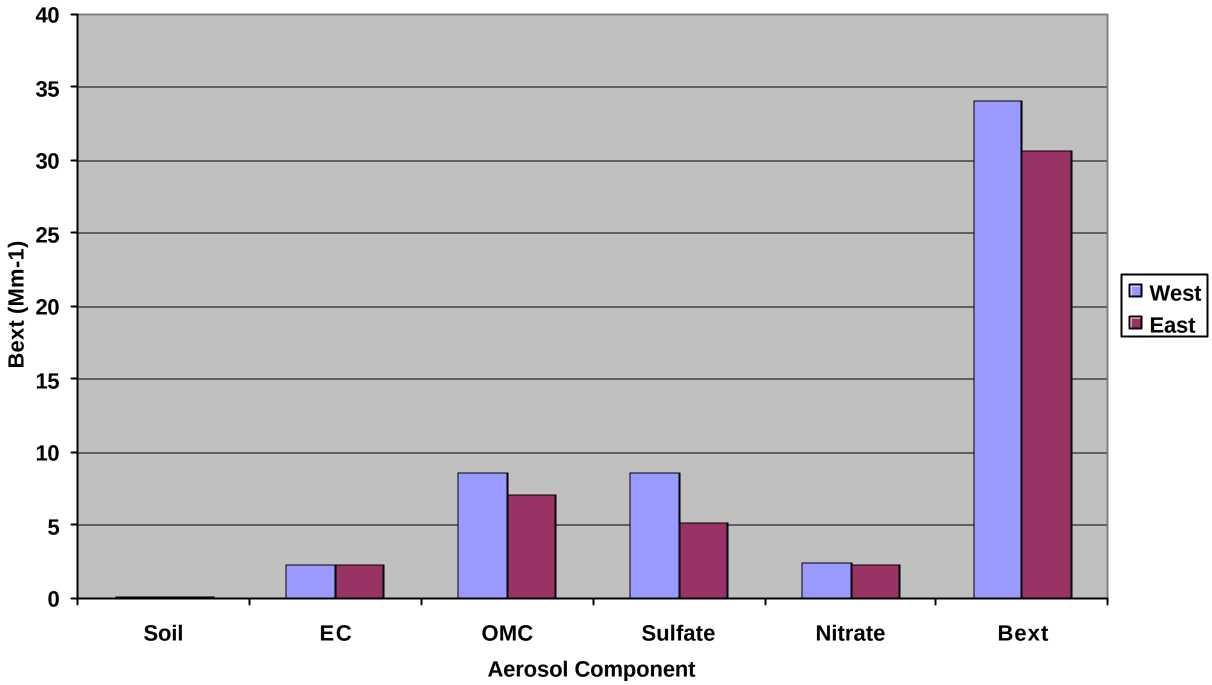
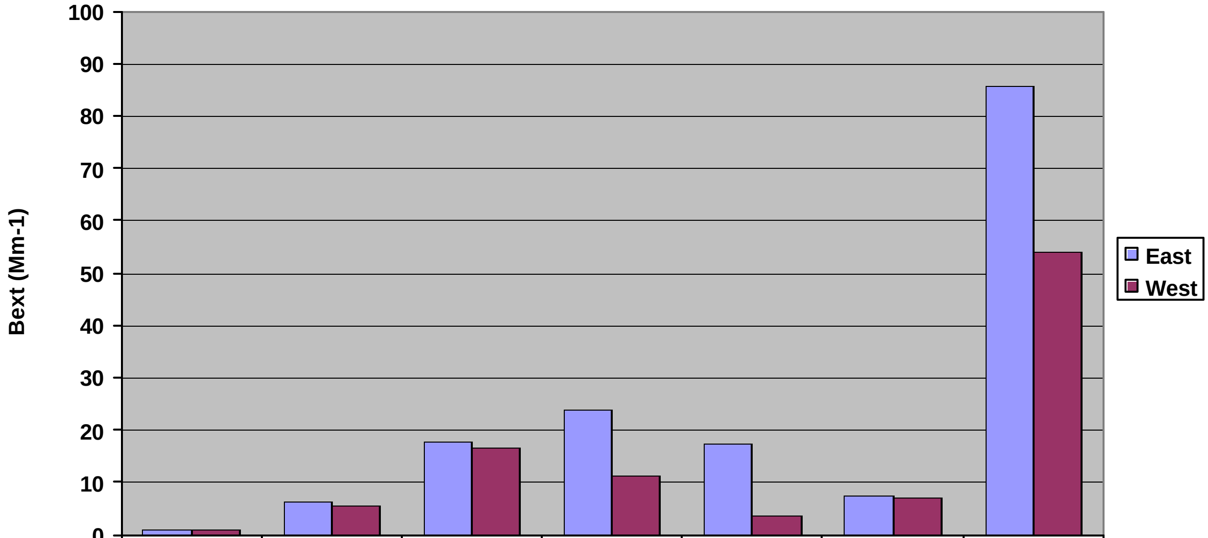


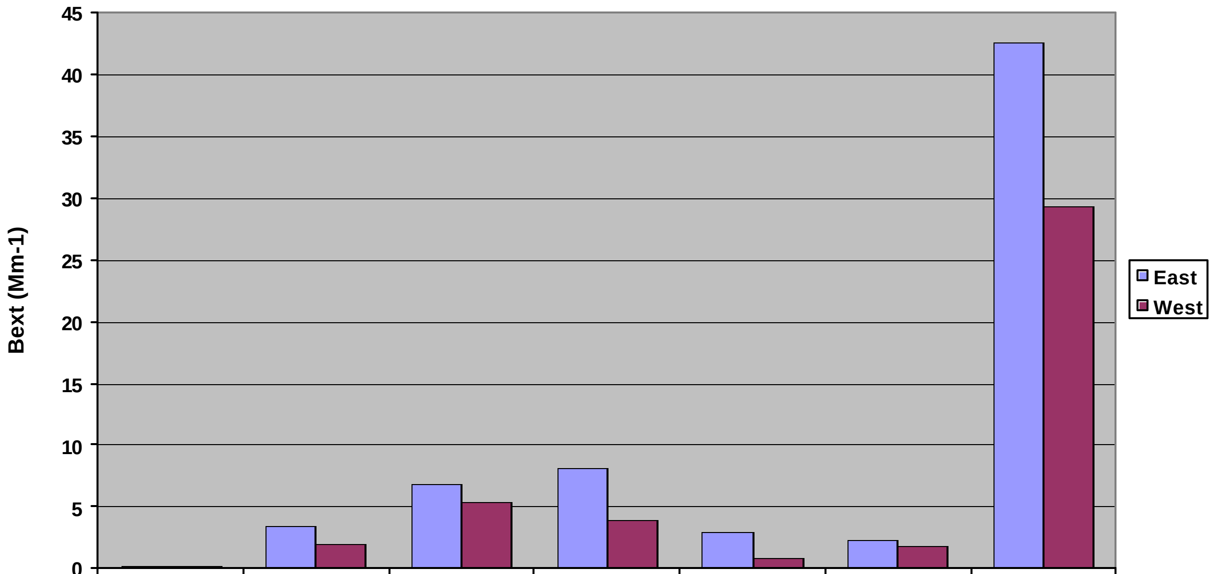
Figure 16c: Wishram Extinction By Wind Direction On Impaired Days (80th Percentile)



	Soil	EC	OMC	Sulfate	Nitrate	CM	Bext
East	0.8	6.5	17.8	24.0	17.6	7.4	85.8
West	0.8	5.6	16.5	11.4	3.8	7.0	54.0

Aerosol Component

Figure 16d: Wishram Extinction By Wind Direction
On Clear Days (20th Percentile)



	Soil	EC	OMC	Sulfate	Nitrate	CM	Bext
East	0.3	3.4	6.8	8.2	3.0	2.3	42.6
West	0.2	2.0	5.4	3.9	0.8	1.9	29.3

Aerosol Component

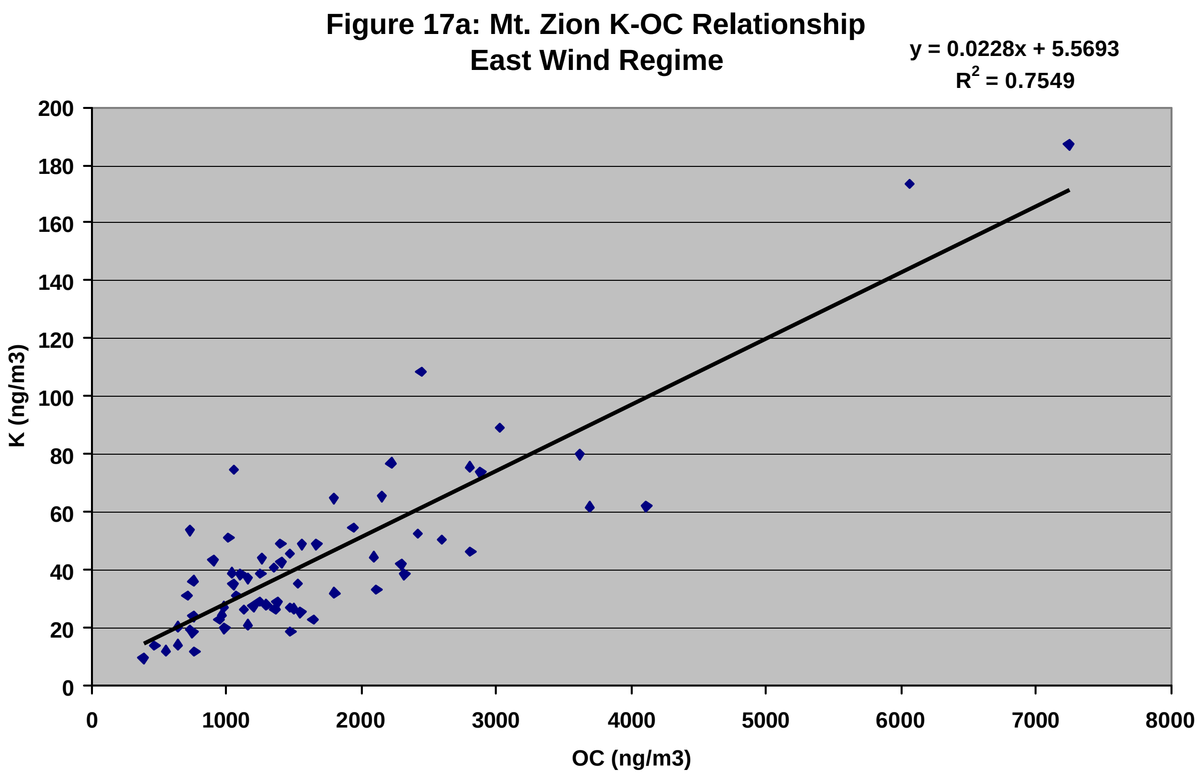
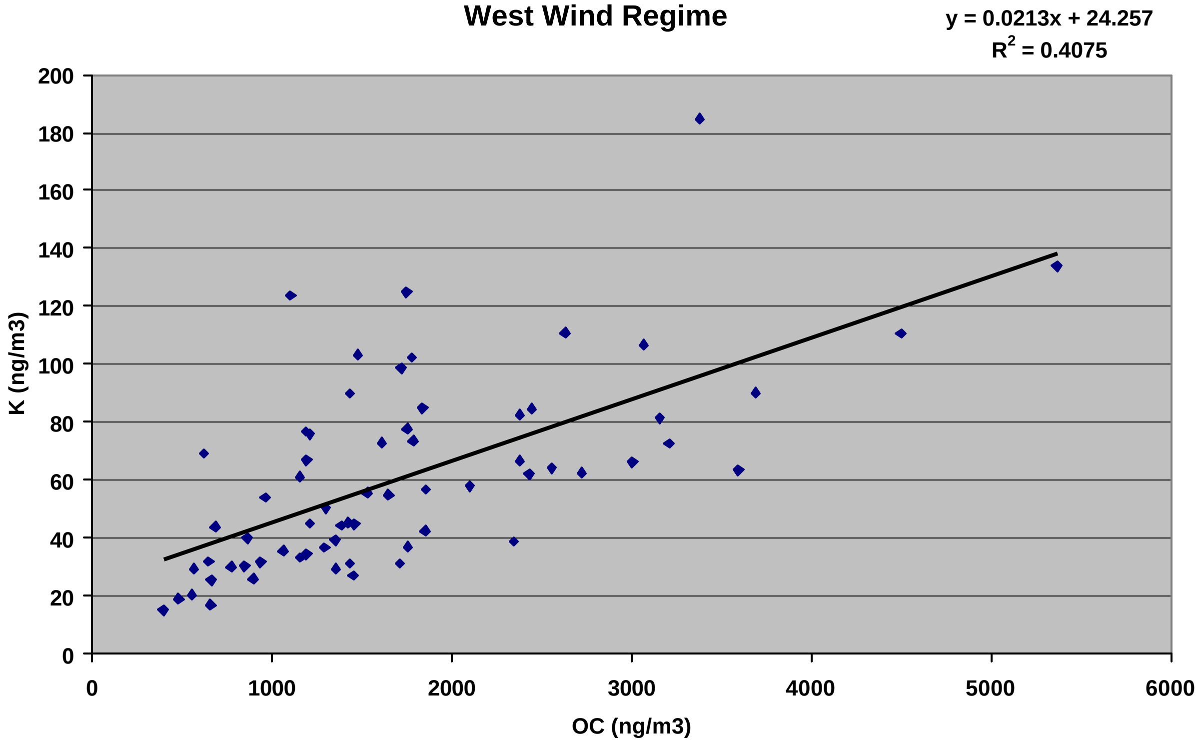


Figure 17a: Mt. Zion K-OC Relationship
East Wind Regime
y = 0.0228x + 5.5693
R2 = 0.7549
K (ng/m3)
OC (ng/m3)
0
20
40
60
80
100
120
140
160
180
200
0
1000
2000
3000
4000
5000
6000
7000
8000

Figure 17b: Mt. Zion K-OC Relationship
West Wind Regime



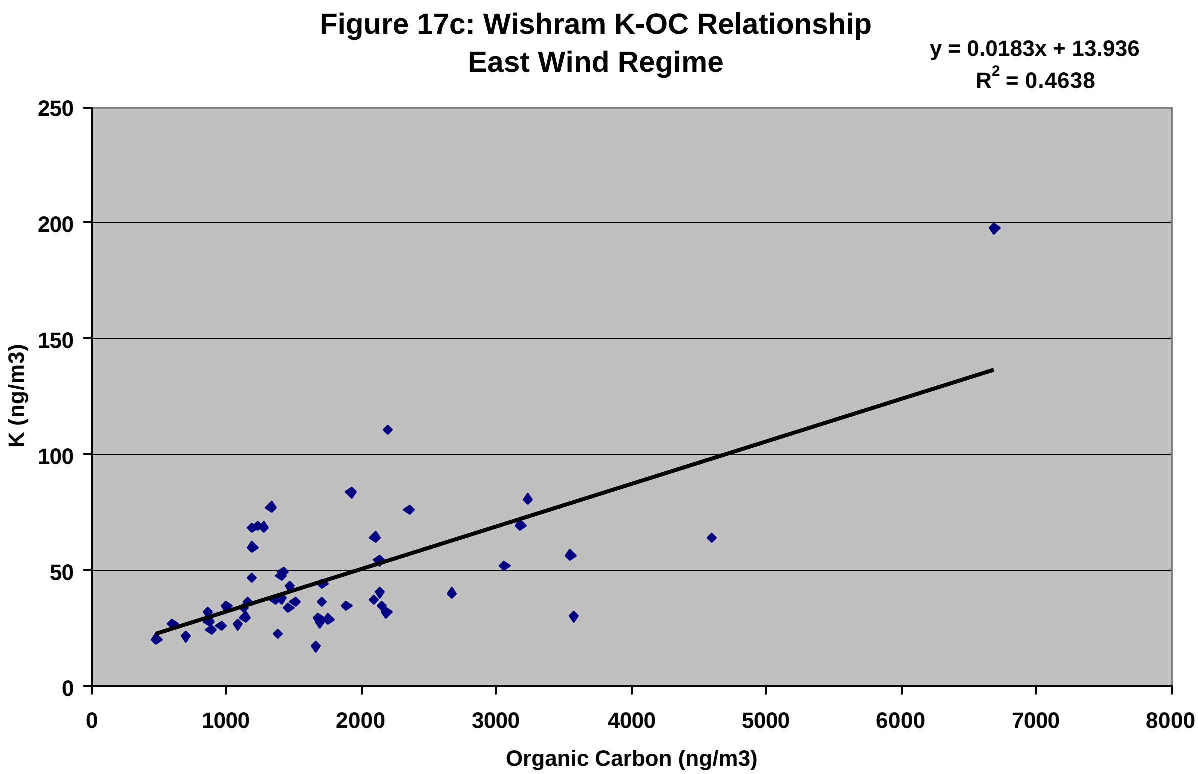


Figure 17c: Wishram K-OC Relationship
East Wind Regime
y = 0.0183x + 13.936
R2 = 0.4638
K (ng/m3)
250
200
150
100
50
0
0
1000
2000
3000
4000
5000
6000
7000
8000
Organic Carbon (ng/m3)

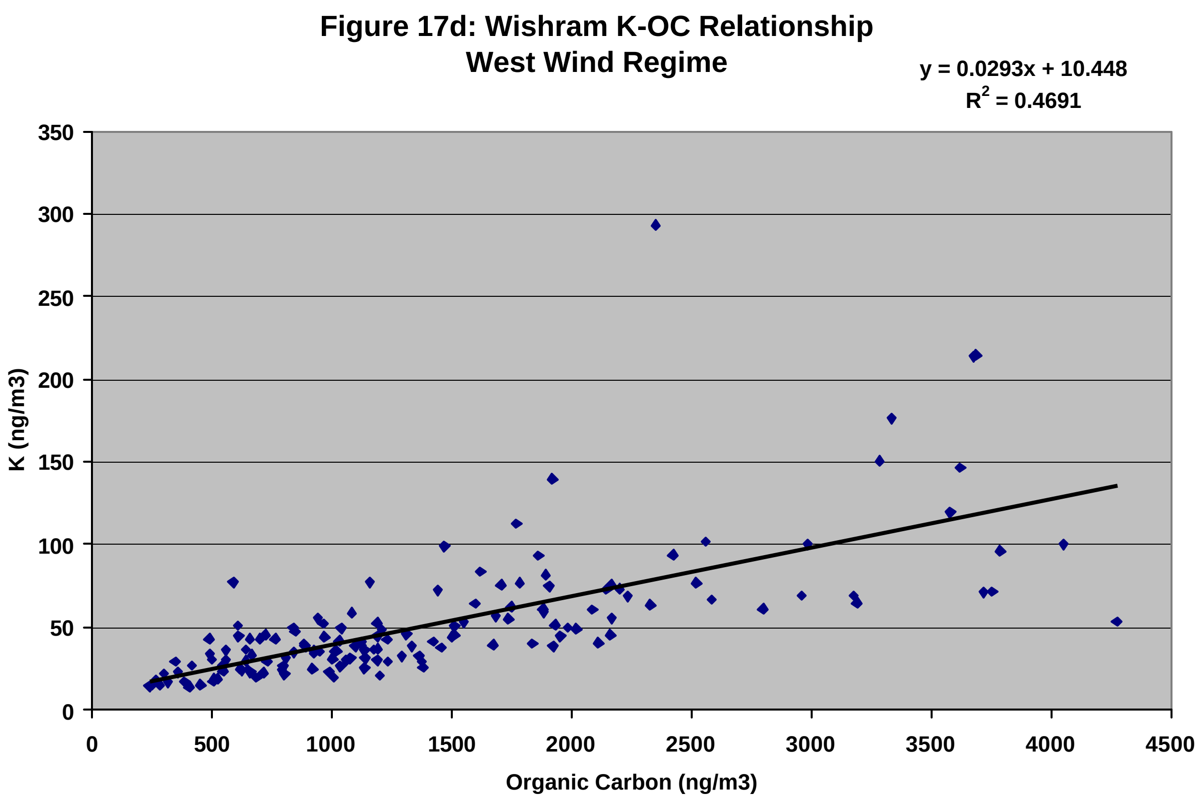
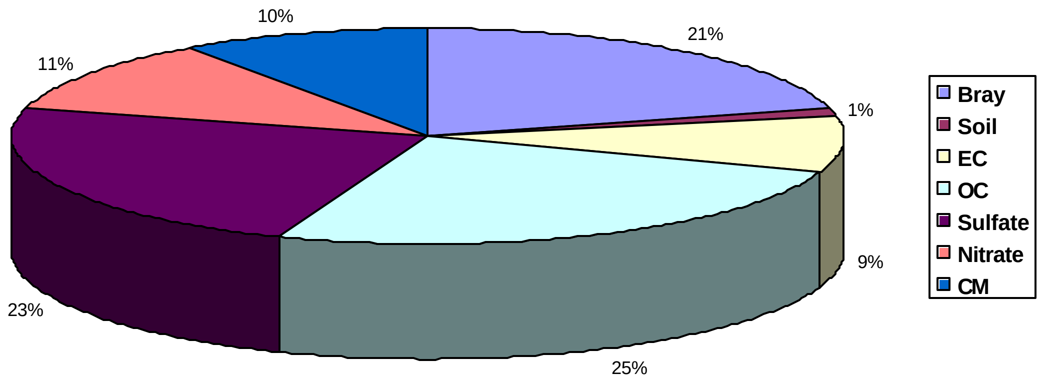


Figure 17d: Wishram K-OC Relationship
West Wind Regime
y = 0.0293x + 10.448
R^2 = 0.4691
K (ng/m3)
0
50
100
150
200
250
300
350
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Organic Carbon (ng/m3)

Wishram Extinction Contributions
All Data Sept 1, 1996 - Sept. 31, 1998



Mt Zion Extinction Contributions
All Data Sept. 1, 1996 - Sept. 31, 1998
(Note: No Coarse Mass Data at Mt. Zion)