

Letter Report

Yucca Mountain Environmental Monitoring Systems Initiative
**Air Quality Scoping Study for Ash Meadows National
Wildlife Refuge, Nevada**



prepared by

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INTRODUCTION

The Desert Research Institute (DRI) is performing a scoping study as part of the U.S. Department of Energy's Yucca Mountain Environmental Monitoring Systems Initiative (EMSI). The main objective is to obtain baseline air quality information for Yucca Mountain and an area surrounding the Nevada Test Site (NTS).

Air quality and meteorological monitoring and sampling equipment housed in a mobile trailer (shelter) is collecting data at seven sites outside the NTS, including Ash Meadows National Wildlife Refuge, Sarcobatus Flat, Beatty, Rachel, Caliente, Pahrnagat National Wildlife Refuge, and Crater Flat, and at four sites on the NTS. The trailer is stationed at any one site for approximately eight weeks at a time.

Letter reports provide summaries of air quality and meteorological data, on completion of each site's sampling program.

SITE LOCATION AND CHARACTERISTICS

The sampling site (Site #1) is located within the Ash Meadows National Wildlife Refuge (NWR), which is south of the Nevada Test Site and Yucca Mountain, and approximately 30 miles northwest of Pahrump, Nevada. Site #1 is approximately 90 miles northwest of Las Vegas in the Amargosa Valley of southern Nye County, Nevada (Figure 1; Table 1).

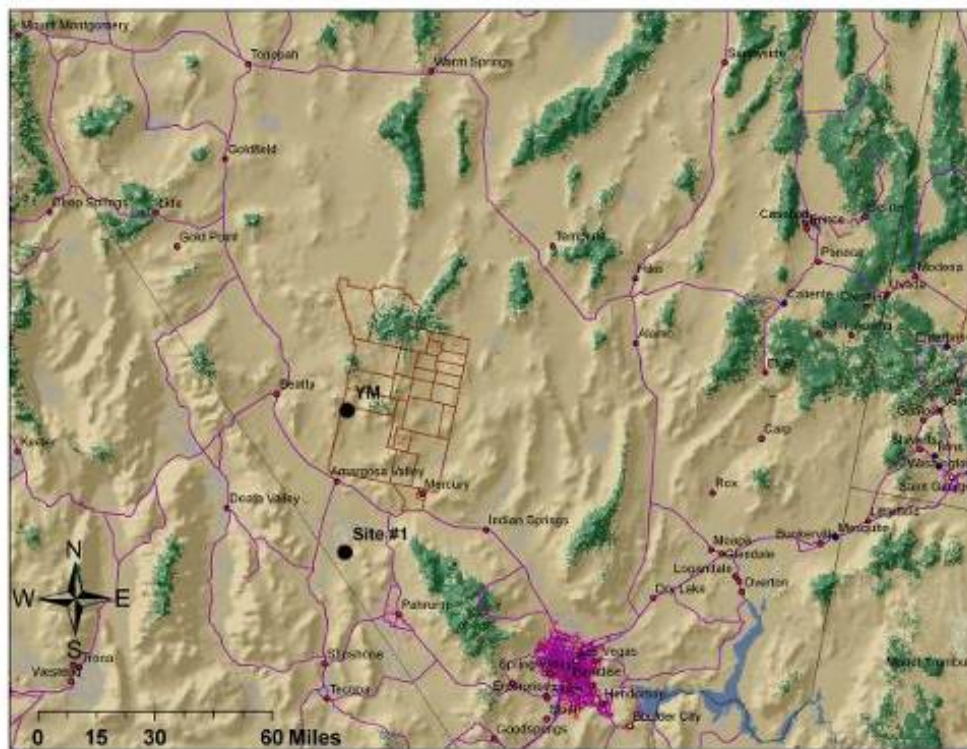


Figure 1. Southern Nevada map showing the location of Site #1 (at Ash Meadows NWR), Nevada Test Site, and Yucca Mountain. The map background is land use and land cover obtained from the 2001 National Land Cover Database.

The refuge covers over 23,000 acres of spring-fed wetlands and alkaline desert uplands and it is managed by the U.S. Fish and Wildlife Service (FWS). It is a unique ecosystem, with the largest concentration of endemic life in the U.S., provides habitat for at least 24 plants and animals, and supports two refugee populations of Devils Hole pupfish.

Table 1. Longitude, latitude, and elevation of the mobile trailer location at Site #1 (Ash Meadows NWR).

Site	Ash Meadows
Latitude	36° 23' 25"
Longitude	116° 17' 27"

Location of the trailer is shown in Figure 2. The mobile trailer was located at an abandoned residential property near the intersection of Ash Meadows Road and Bell Vista Road. Monitoring of PM₁₀, PM_{2.5}, and meteorological conditions was carried out from March 24, 2006, to May 18, 2006.

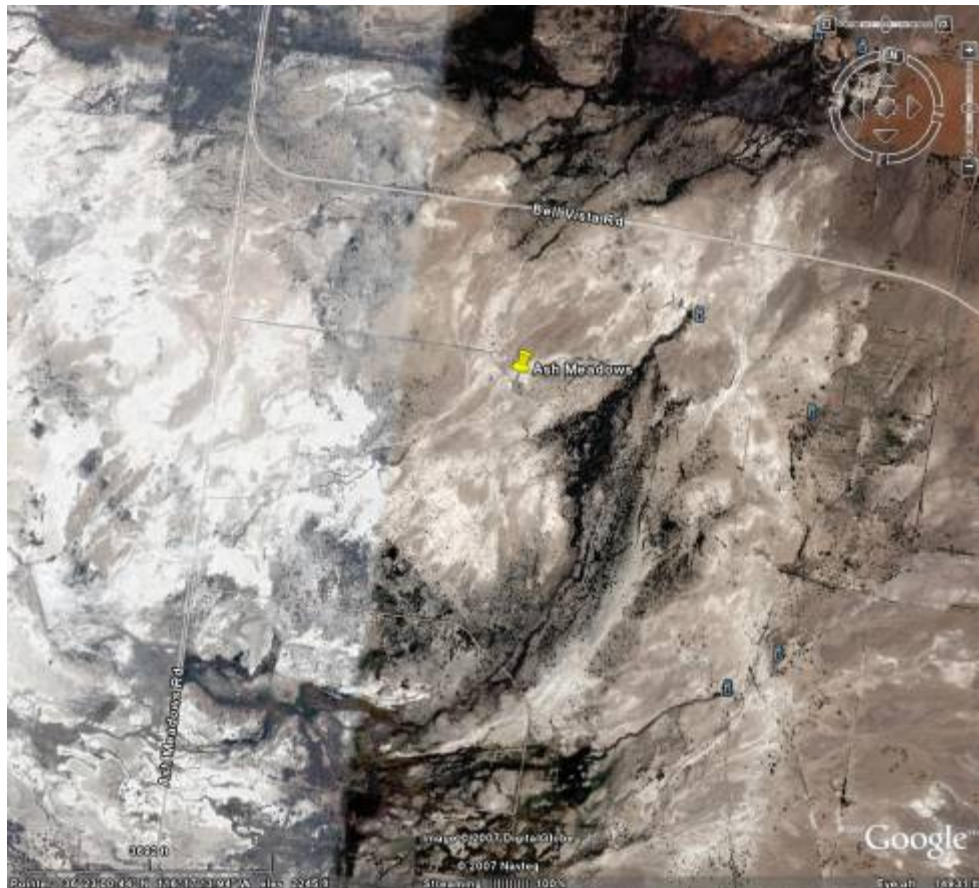


Figure 2. Location of the mobile trailer in Ash Meadows NWR. Image obtained from Google Earth.

AEROSOL SAMPLING AND MONITORING

Filter Sampling

Sampler Description and Procedures

BGI, Inc., PQ100 and PQ200 Ambient PM_{2.5} Federal Reference Method (FRM) samplers were used to collect 24-h integrated PM₁₀ and PM_{2.5} samples. Figure 3 shows the PQ100 and PQ200 in the mobile trailer (left) and the PM₁₀ sampling inlets on the top of the trailer (right). Both PQ100 (Designation No. RFPS-1298-124) and PQ200 (Designation No. RFPS-0498-116) are designed to meet the criteria for collecting 24-h samples of ambient aerosol according to the U.S. National Ambient Air Quality Standards (NAAQS).



Figure 3. Photographs of PQ100 (green/gray box in left photo), PQ200 (white box in left photo) and their sampling inlet (right photo).

Figure 4 shows a schematic drawing of the samplers. Briefly, particles with aerodynamic diameter larger than 10 μm were removed by impaction at the size selective inlet, while the remaining particles remained airborne. For the PM₁₀ fraction, particles were then collected by a filter located downstream of the size selective inlet. For the collection of PM_{2.5}, particles in the range between 2.5 and 10 μm were removed by the Very Sharp Cut Cyclone (VSCC) (U.S. Environmental Protection Agency [EPA] Equivalent Designation No. EQPM-0202-142), then collected by a filter.

For both the PQ100 and PQ200, samples were collected at a volumetric flow rate of 16.67 liters/min. The flow rate is controlled to ± 2 percent precision with a mass flow meter. The actual ambient temperature and barometric pressure, filter temperature and pressure, and anomalies (if any) were recorded (and controlled) by a microprocessor. The sampler was equipped to operate from an internal 12-volt DC battery. The battery was recharged by a battery charger from 120-volt AC. Alternatively, a 32-watt solar panel with an additional external ballast battery was installed to provide power for days without electricity. Two sets of PQ100 and PQ200 samplers were installed in the mobile trailer. PM₁₀ and PM_{2.5} samples were collected on filters in numbered cassettes, labeled TT (for PM₁₀ Teflon), FT (for PM_{2.5} Teflon), TQ (for PM₁₀ Quartz), and FQ (for PM_{2.5} Quartz). Each filter cassette was loaded with a pre-weighed 46.2-mm-diameter PTFE (Teflon) membrane filter (Whatman # 7592-

004) or 47-mm quartz fiber (Pallflex #2500QAT-UP) filter. The Teflon membrane collected particles for measurement of mass by gravimetric analysis, light absorption by densitometry, and elements by x-ray fluorescence spectrometry. Quartz fiber filters were used for measurement of water-soluble ions by atomic absorption spectrometry, ion chromatography, and automated colorimetry, and also for measurement of carbon species by thermal optical reflectance.

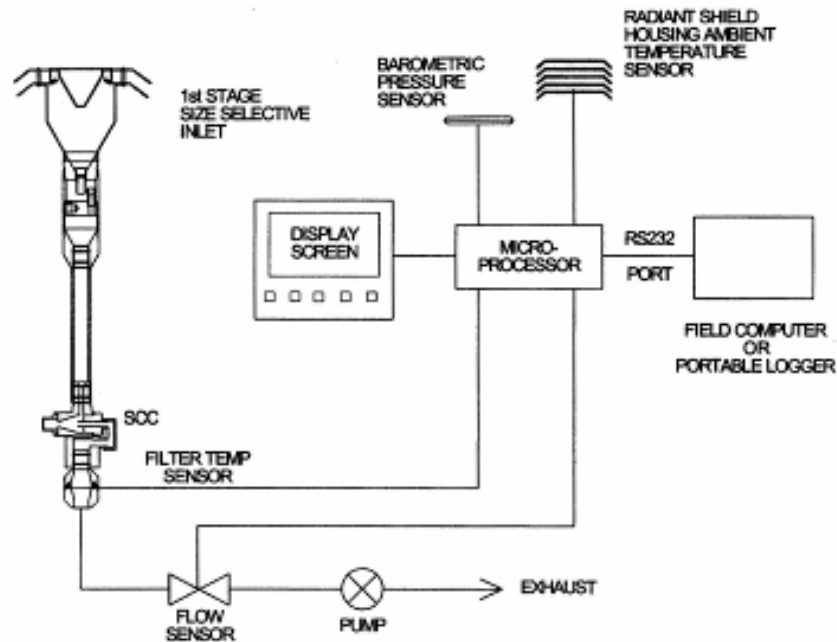


Figure 4. A diagrammatic representation of the BGI PM_{2.5} sampler showing the PM₁₀ size selective impactor head as the first stage followed by a PM_{2.5} very sharp cut cyclone (VSCC). This configuration can be readily modified to a PM₁₀ sampler by removal of the VSCC.

Operation, calibration, and maintenance of PQ100 and PQ200 are described in standard operation procedure (SOP) “BGI PQ100 PM₁₀ and PQ200 PM_{2.5} REFERENCE SAMPLERS FOR THE YUCCA MOUNTAIN AIR QUALITY PROGRAM.” Flow calibration and leak tests were performed during the installation day (March 24, 2006). The leak check was performed according to the manufacturer’s operational instruction manual only for PQ200; no procedure exists for the PQ100. The flow rate was calibrated using a BGI Tri-Cal flow meter. The sampler was then placed in calibration or “run” mode and a one-point calibration verification or one-point flow-rate verification was performed. Aerosol samples were collected on a 1-in-6-day schedule. Audits of the flow and leak tests were done onsite at the beginning and end of the monitoring campaign. Teflon and quartz filters were prepared and assembled in their filter holders in the Desert Research Institute’s (DRI) Environmental Analysis Facility (EAF) in Reno and shipped to DRI’s facilities in Las Vegas. The filters were kept at -4°C and transported to the field in a cryo-cooler. Exposed filters were also stored at -4°C in Las Vegas. Upon completion of the monitoring period at the site, all filters were shipped to the EAF in Reno.

Gravimetry

Table 2 shows mass concentrations (and uncertainty) for filters collected at Ash Meadows. PM₁₀ mass concentrations varied from 2.04 µg/m³ to 13.23 µg/m³, while PM_{2.5} mass concentrations ranged from 0.71 µg/m³ to 5.75 µg/m³. Higher PM₁₀ and PM_{2.5} concentrations were measured toward the end of the monitoring campaign (4/29/06 to 5/17/06; Figure 5). In all cases, 24-h PM₁₀ and PM_{2.5} levels were substantially lower than the daily and annual NAAQS as recently revised by EPA (24-h PM₁₀: 150 µg/m³, 24-h PM_{2.5}: 35 µg/m³; Annual PM_{2.5}: 15 µg/m³) (Figure 5). Fine particles (PM_{2.5}) accounted for approximately 40 percent of PM₁₀ (PM_{2.5}/PM₁₀ ratio of 0.41) (Figure 6). This value was indicative of the predominant input of coarse particle sources (e.g., dust), with considerable input of anthropogenic sources (e.g., combustion, vehicle emissions) from a nearby mine facility (located southeast of the site) or occasional transport from the city of Pahrump.

Table 2. Collection day, filter number, mass, and uncertainty determined by gravimetric analysis and associated flags of samples at Site #1 (Ash Meadows NWR).

Date	No	Type	Mass (µg/m ³)	Uncertainty (µg/m ³)	Flags
3/30/2006	005	PM ₁₀	2.4542	0.4042	
		PM _{2.5}	1.4988	0.3926	
4/05/2006	006	PM ₁₀	2.0383	0.3983	
		PM _{2.5}	0.7077	0.3870	
4/11/2006	007	PM ₁₀	5.5324	0.4741	
		PM _{2.5}	2.2065	0.4009	
4/17/2006	009	PM ₁₀	2.7038	0.4081	f5: Teflon membrane separated from support ring.
		PM _{2.5}	1.8318	0.3961	
4/21/2006	010	PM ₁₀	0.7072	0.3867	f5: Teflon membrane separated from support ring
		PM _{2.5}	0.0000	0.3854	v: Invalid (void) analysis result.
4/29/2006	011	PM ₁₀	9.4842	0.6109	
		PM _{2.5}	4.2465	0.4400	
5/05/2006	012	PM ₁₀	12.4376	0.7315	
		PM _{2.5}	5.4908	0.4729	
5/11/2006	014	PM ₁₀	13.2280	0.7653	f5: Teflon membrane separated from support ring.
		PM _{2.5}	5.7452	0.4807	
5/17/2006	015	PM ₁₀	12.8643	0.7498	
		PM _{2.5}	3.9550	0.4332	

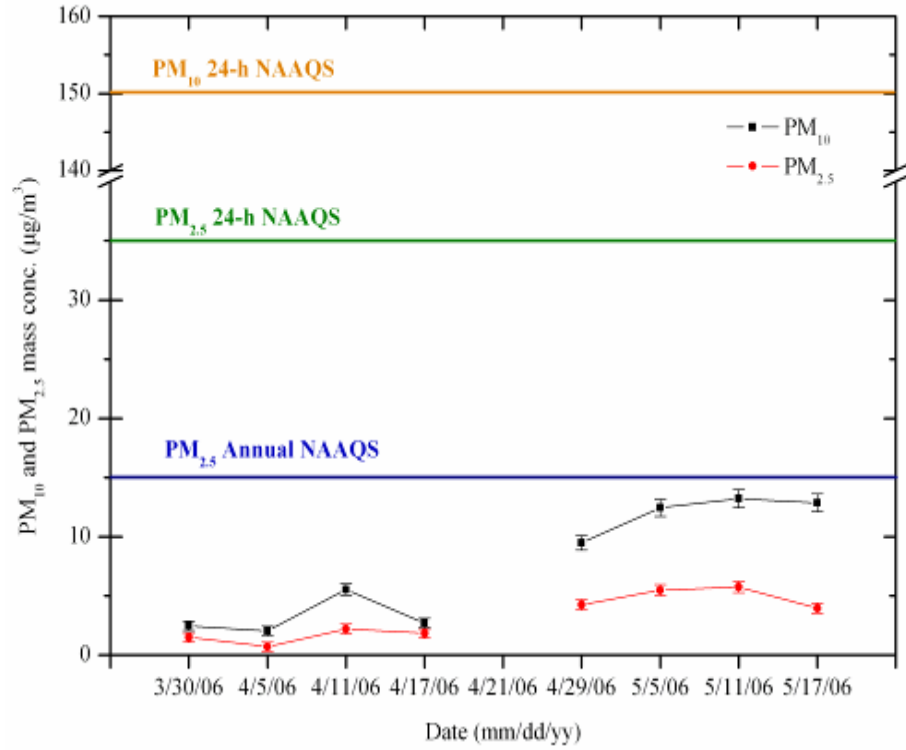


Figure 5. Time series of PM₁₀ and PM_{2.5} mass concentrations (mean \pm uncertainty) at Site #1 (Ash Meadows).

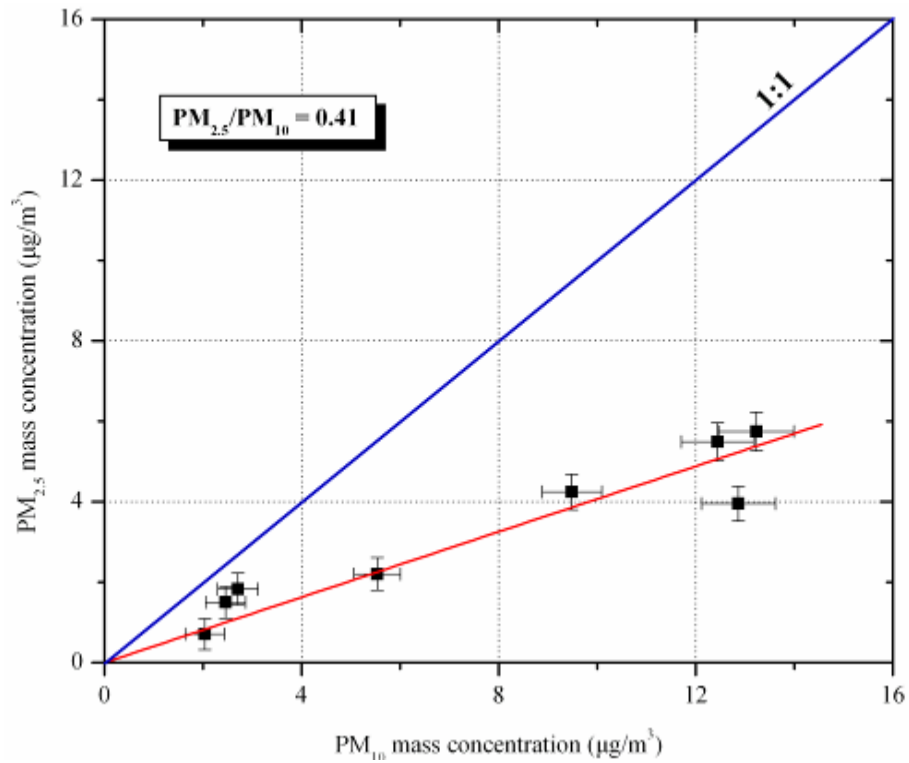


Figure 6. Relationship between mean (\pm uncertainty) daily PM_{2.5} and PM₁₀ at Ash Meadows.

Chemical Analysis

Table 3 shows the chemical content of PM₁₀ and PM_{2.5} samples collected on 4/11/2006 and 5/05/2006. Chemical analysis included elements (from sodium to uranium) by x-ray fluorescence spectrometry, major anions (sulfate, nitrate, and chloride) by ion chromatography, major cations (sodium, potassium) by atomic absorption, particulate ammonium by colorimetry, and elemental and organic carbon by thermal optical reflectance (TOR).

Table 3. Results of the chemical analysis for selected filters from Ash Meadows. Chemical components with concentration higher than two times the uncertainty are in bold, while those with concentrations lower than two times the uncertainty are in italics. Concentrations are in $\mu\text{g}/\text{m}^3$.

DATE	4/11/2006				5/5/2006			
SIZE	PM ₁₀		PM _{2.5}		PM ₁₀		PM _{2.5}	
	Conc.	Uncer.	Conc.	Uncer.	Conc.	Uncer.	Conc.	Uncer.
Chloride, Cl ⁻	<i>0.0207</i>	<i>0.0295</i>	<i>0.0246</i>	<i>0.0295</i>	<i>0.0252</i>	<i>0.0295</i>	<i>0.0059</i>	<i>0.0294</i>
Nitrate, NO ₃ ⁻	0.286	0.03	0.1504	0.0296	0.4952	0.0311	0.2090	0.0297
Sulfate, SO ₄ ²⁻	0.6645	0.0324	0.5558	0.0316	1.4729	0.0422	1.3385	0.0403
Ammonium, NH ₄ ⁺	0.1535	0.0301	0.1616	0.0302	0.4350	0.0338	0.4488	0.0341
Sodium, Na ⁺	0.0969	0.0027	0.0392	0.0020	0.1342	0.0033	0.0598	0.0022
Potassium, K ⁺	0.0156	0.0031	0.0124	0.0030	0.0505	0.0038	0.0293	0.0033
OC1	1.1804	0.183	1.4658	0.2267	2.1633	0.3338	2.6691	0.4116
OC2	0.8505	0.1691	0.7976	0.1597	1.2743	0.2457	1.4248	0.2731
OC3	0.3598	0.1652	0.4493	0.1693	0.7844	0.1884	0.7932	0.1889
OC4	0.1517	0.0642	0.2692	0.0862	0.3947	0.1139	0.4073	0.1168
Pyrolyzed OC-TT	0.1030	0.0424	0.1818	0.0521	0.5629	0.1191	0.4909	0.1054
Pyrolyzed OC-Op	<i>0.0097</i>	<i>0.0371</i>	<i>0</i>	<i>0.0370</i>	0.4037	0.0838	0.2993	0.0669
Total OC	2.5497	0.351	2.9797	0.3905	5.0181	0.5907	5.5913	0.6492
EC1	0.0615	0.0305	0.0993	0.0343	0.4037	0.0865	0.3388	0.0742
EC2	0.0451	0.0356	0.1231	0.0410	0.2211	0.0523	0.192	0.0486
EC3	<i>0</i>	<i>0.0116</i>	<i>0</i>	<i>0.0116</i>	<i>0</i>	<i>0.0116</i>	<i>0</i>	<i>0.0116</i>
Total EC	0.0970	0.0540	0.2224	0.0843	0.2211	0.084	0.2315	0.0869
Total Carbon	2.6467	0.2817	3.2021	0.3059	5.2392	0.4088	5.8229	0.441
Sodium, Na	<i>0.1181</i>	<i>0.1510</i>	<i>0.0436</i>	<i>0.1501</i>	<i>0.0941</i>	<i>0.1507</i>	<i>0.0338</i>	<i>0.1498</i>
Magnesium, Mg	<i>0.0807</i>	<i>0.0449</i>	<i>0.0204</i>	<i>0.0446</i>	0.2473	0.046	0.0861	0.045
Aluminum, Al	0.1949	0.0188	0.1136	0.0183	0.5643	0.0229	0.1895	0.0188
Silicon, Si	0.3928	0.0174	0.1867	0.0152	1.2719	0.0322	0.4928	0.0188
Phosphorous, P	<i>0.0085</i>	<i>0.0045</i>	<i>0.0085</i>	<i>0.0045</i>	0.0256	0.0046	0.0178	0.0046
Sulfur, S	0.2488	0.0209	0.2343	0.0208	0.5937	0.0238	0.5609	0.0235
Chlorine, Cl	<i>0.0051</i>	<i>0.0037</i>	<i>0</i>	<i>0.0037</i>	<i>0.0095</i>	<i>0.0037</i>	<i>0.0007</i>	<i>0.0037</i>
Potassium, K	0.0686	0.0024	0.0309	0.002	0.2205	0.0049	0.0789	0.0025
Calcium, Ca	0.2166	0.0053	0.0608	0.0031	0.6228	0.013	0.147	0.0042
Scandium, Sc	<i>0.0023</i>	<i>0.0074</i>	<i>0</i>	<i>0.0074</i>	<i>0</i>	<i>0.0074</i>	<i>0</i>	<i>0.0074</i>
Titanium, Ti	0.0140	0.0013	0.0047	0.0013	0.0385	0.0015	0.0111	0.0013
Vanadium, V	<i>0.0002</i>	<i>0.0003</i>	<i>0.0002</i>	<i>0.0003</i>	0.0007	0.0003	0.0002	0.0003
Chromium, Cr	<i>0.0011</i>	<i>0.0015</i>	<i>0</i>	<i>0.0015</i>	<i>0.0016</i>	<i>0.0015</i>	<i>0.0007</i>	<i>0.0015</i>
Manganese, Mn	<i>0.0023</i>	<i>0.0032</i>	<i>0.0028</i>	<i>0.0032</i>	0.0116	0.0032	0.0028	0.0032

Table 3. Results of the chemical analysis for selected filters from Ash Meadows. Chemical components with concentration higher than two times the uncertainty are in bold, while those with concentrations lower than two times the uncertainty are in italics. Concentrations are in $\mu\text{g}/\text{m}^3$ (continued).

DATE SIZE	4/11/2006				5/5/2006			
	PM ₁₀		PM _{2.5}		PM ₁₀		PM _{2.5}	
	Conc.	Uncer.	Conc.	Uncer.	Conc.	Uncer.	Conc.	Uncer.
Iron, Fe	0.1276	0.0042	0.0536	0.0034	0.3873	0.0086	0.1207	0.0041
Cobalt, Co	0	0.0003	0	0.0003	0	0.0003	0	0.0003
Nickel, Ni	0	0.0008	0	0.0008	0	0.0008	0.0005	0.0008
Copper, Cu	0	0.0017	0	0.0017	0	0.0017	0	0.0017
Zinc, Zn	0.0010	0.0015	0	0.0015	0.0034	0.0015	0.0127	0.0015
Gallium, Ga	0.0010	0.0049	0	0.0049	0.0010	0.0049	0.0015	0.0049
Arsenic, As	0	0.0006	0	0.0006	0.0020	0.0006	0	0.0006
Selenium, Se	0	0.0011	0	0.0011	0	0.0011	0	0.0011
Bromine, Br	0	0.0021	0	0.0021	0.0003	0.0021	0.0003	0.0021
Rubidium, Rh	0	0.001	0.0007	0.0011	0	0.001	0.0007	0.0011
Strontium, Sr	0.0020	0.0025	0.0025	0.0025	0.0059	0.0025	0.0005	0.0025
Yttrium, Y	0.0007	0.0015	0.0007	0.0015	0.0007	0.0015	0	0.0015
Zirconium, Zr	0	0.0039	0.0008	0.0039	0	0.0039	0	0.0039
Niobium, Nb	0	0.0025	0.0007	0.0025	0	0.0025	0	0.0025
Molybdenum, Mo	0.0003	0.0025	0	0.0025	0	0.0025	0	0.0025
Palladium, Pd	0.0054	0.0059	0	0.0059	0	0.0059	0	0.0059
Silver, Ag	0	0.0056	0.0007	0.0056	0.0016	0.0056	0	0.0056
Cadmium, Cd	0.0008	0.0044	0	0.0044	0.0033	0.0044	0	0.0044
Indium, In	0.0023	0.0049	0	0.0049	0	0.0049	0	0.0048
Tin, Sn	0.0003	0.0053	0.0082	0.0053	0	0.0053	0.0018	0.0053
Antimony, Sb	0	0.008	0.0016	0.008	0.0051	0.008	0.0007	0.008
Cesium, Cs	0	0.0023	0	0.0023	0	0.0023	0	0.0023
Barium, Ba	0	0.0025	0	0.0025	0.0007	0.0025	0	0.0025
Lanthanum, La	0.0003	0.0017	0.0003	0.0017	0	0.0017	0	0.0017
Cerium, Ce	0	0.0016	0.0003	0.0016	0	0.0016	0	0.0016
Samarium, Sa	0.0015	0.0033	0	0.0033	0	0.0033	0	0.0033
Europium, Eu	0	0.0051	0	0.0051	0	0.0051	0	0.0051
Terbium, Tb	0	0.0037	0	0.0037	0	0.0038	0	0.0037
Hafnium, Hf	0.0096	0.0152	0	0.0151	0	0.0152	0	0.0152
Tantalum, Ta	0.0039	0.01	0.0015	0.01	0.0044	0.01	0	0.0099
Tungsten, W	0.0113	0.0164	0.0015	0.0164	0.0108	0.0164	0.0025	0.0164
Iridium, Ir	0	0.0046	0.0029	0.0046	0	0.0046	0	0.0046
Gold, Au	0	0.0075	0	0.0075	0	0.0075	0	0.0075
Mercury, Hg	0	0.0037	0	0.0037	0	0.0037	0	0.0037
Thallium, Th	0	0.0025	0	0.0025	0	0.0025	0	0.0025
Lead, Pb	0.0013	0.0036	0	0.0036	0	0.0036	0	0.0036
Uranium, U	0	0.0063	0	0.0063	0	0.0063	0	0.0063

OC = organic carbon
EC = elemental carbon
OP = optical pyrolysis
TT = transmittance

With respect to the chemical composition of PM₁₀ and PM_{2.5}, the following patterns are observed:

- Sulfur (S) was mostly in the form of sulfate (SO₄²⁻) with sulfate-to-sulfur ratio of 2.37 to 2.67. Sulfate and ammonium (NH₄⁺) were entirely associated with fine particles, while only about 50 percent of nitrate (NO₃⁻) was measured in PM_{2.5}. Ammonium-to-sulfate molar ratios varied from 1.21 to 1.78, suggesting that sulfate aerosols were mostly in the form of ammonium bisulfate, (NH₄)HSO₄ (Malm *et al.*, 2002). Nitrates appeared to be partially neutralized by ammonium in the fine particle mode, while coarse particle nitrates may be the product of the reactions of nitric acid with soil dust elements such as calcium (Ca) during collection (Lefer and Talbot, 2001).
- Carbonaceous aerosol was predominantly in fine particles. For PM_{2.5}, organic carbon (OC) concentrations accounted for more than 90 percent of particle mass. This may be attributed to the positive bias of OC concentrations caused by the absorption of low vapor pressure organic compounds on the quartz filter. Overestimation also may explain the relatively low EC/OC ratio values (between 0.03 and 0.07), which were approximately 10 times lower than those determined for atmospheric aerosol.
- Soluble potassium (K⁺) accounted for 22 percent of total potassium in PM₁₀ and 40 percent of total potassium in PM_{2.5}. Soluble potassium is a tracer of biomass burning, which suggested the impact of emissions from local and/or regional fire (prescribed or wildfire) events. This was further supported by estimates of nonsoil potassium K_{non-soil} (K_{total} - (0.26 x [Al])) that were comparable to measured water-soluble K⁺.
- Ratios of Al/Si (0.44 to 0.49), K/Fe (0.53 to 0.56) and Ca/Al (1.10 to 1.11) were comparable to those determined for samples collected at the Interagency Monitoring of Protected Visibility Environments (IMPROVE) sites in the western United States (Al/Si: 0.31 to 0.43, K/Fe: 0.67 to 0.78, Al/Ca: 1.4 to 1.7) when soil dust was the major component of particulate matter (Kavouras *et al.*, 2005).

The IMPROVE mass estimation scheme is adopted to reconstruct aerosol mass into five major types: sulfate, nitrate, organic, light-absorbing carbon, and soil. For this scheme, sulfate and nitrate are assumed to be in the forms of ammonium sulfate [(NH₄)₂SO₄] and ammonium nitrate [NH₄NO₃], respectively (Malm *et al.*, 2004). Organic mass concentration [OMC] was estimated as [OMC] = 1.4 x [OC], where [OC] is the organic carbon concentration. The 1.4 factor was used to correct for other elements (mainly hydrogen and oxygen) associated with the composition of organic compounds (White and Roberts, 1977). Soil mass concentration [SOIL] was estimated as the sum of the elements present in the soil as oxides (Al₂O₃, SiO₂, CaO, K₂O, FeO, Fe₂O₃, and TiO₂) as follows: [SOIL] = 2.2 x [Al] + 2.49 [Si] + 1.63 x [Ca] + 2.42 x [Fe] + 1.94 x [Ti]. Therefore, the reconstructed aerosol mass was estimated as follows:

$$[\text{Aerosol Mass}] = (128/96) \times [\text{SO}_4] + (80/62) \times [\text{NO}_3] + \text{EC} + [\text{OMC}] + [\text{SOIL}]$$

Figure 7 shows the concentrations of ammonium sulfate, ammonium nitrate, organic carbon mass, elemental carbon, and soil for PM₁₀ and PM_{2.5} collected on 4/11/2006 and 5/5/2006 in Ash Meadows. Considering the positive bias for organic carbon measurements, carbonaceous aerosol (OMC and EC) appeared to account for 44 to 52 percent of PM₁₀ and 65 to 69 percent of PM_{2.5}. Soil represented 30 to 40 percent of PM₁₀ and about 15 percent of PM_{2.5} mass, while sulfate contributed about 12 percent for both PM₁₀ and PM_{2.5} fractions (Figure 7). The difference between PM₁₀ and PM_{2.5} mass concentrations for the two days (April 11, 2006 and May 5, 2006) may be attributed mainly to higher concentrations of soil and organic carbon.

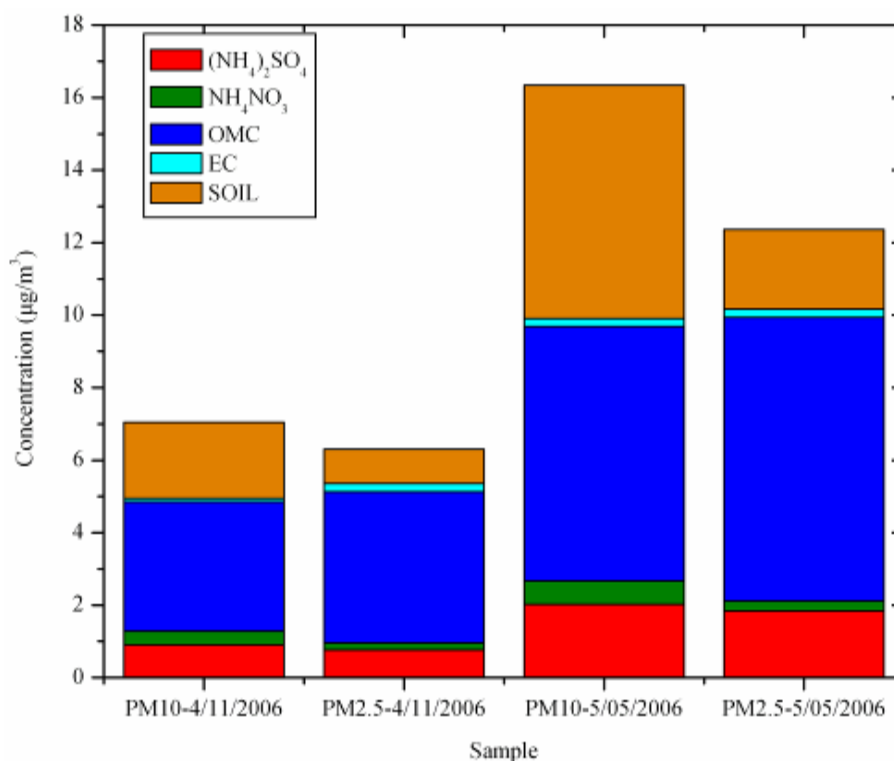


Figure 7. Reconstructed mass for PM₁₀ and PM_{2.5} based on chemical composition.

Aerosol Monitoring

Monitor Description and Procedures

The TEOM Series 1400 Ambient Particulate Monitor from Thermo Scientific and the DUSTTRAK™ Aerosol Monitor from TSI were used to continuously measure PM₁₀ and PM_{2.5} mass concentrations (Figure 8). The TEOM Series 1400 monitors the ambient particulate mass concentration of PM₁₀ (EPA certification EQPM-1090-079) (or PM_{2.5}) in real time by direct measurement of particulate mass collected on a filter attached to an oscillating inertial mass transducer. The mass transducer in the sensor unit has a tapered ceramic tube (element) that is fixed at the downstream end and a Teflon-coated glass fiber filter on the free end. The oscillating frequency of the tube changes proportionally as ambient air is drawn through the filter and the particulate loading thereon increases. The flow rate

through the filter sample is set at a nominal 3.0 l/min. A bypass (auxiliary) flow provides an additional 13.67 l/min for a total flow rate of 16.67 l/min. An internal datalogger stores mass values, time, and some meteorological data. To eliminate bias caused by humidity, the filter is heated to 50°C. Operation, calibration and maintenance of the TEOM is described in SOP “RUPPRECHT & PATASHNICK (R&P), SERIES 1400A TAPERED ELEMENT OSCILLATING MICROBALANCE (TEOM).” Flow calibration and leak tests were performed on the day of installation (March 24, 2006). Data were downloaded during site visits. Regular checks of time, filter loading, by-pass filter, and flow rates were accomplished during site visits.



Figure 8. Left photograph: The front panels of PM₁₀ (right on the left photograph) and PM_{2.5} (left on the left photograph) of TEOM. Right photograph: The measurement units of TEOM and DUSTTRAK on top of them.

The DUSTTRAK™ Aerosol Monitor is a portable, battery operated laser photometer. The monitor provides measurements of particle mass based on 90° light scattering. Atmospheric aerosol passes through a size selective inlet (either PM₁₀ or PM_{2.5}) and is directed to an optics chamber at a flow rate of 1.7 l/min. The light source is a laser diode that emits light at a wavelength of 780 nm. The aerosol sample is drawn into the sensing chamber where it is illuminated with a narrow beam of laser light. Light scattered by aerosol particles is collected by a set of lenses and focused onto the photodetector. The detector signal is proportional to the amount of scattered light, which is proportional to the mass concentration of the aerosol. Voltage is read by the processor and multiplied by an internal calibration constant to yield mass concentration. The calibration constant is pre-set by the manufacturer for scattering characteristics of the respirable mass of ISO 12103-1, Al test dust. Local variations in aerosol particle size distribution and composition relative to this standard may result in differences in the actual response factor of the instrument. The operation, calibration, and maintenance of TSI is described in SOP “TSI INCORPORATED MODEL 8520 DUSTTRAK AEROSOL MONITOR FOR THE YUCCA MOUNTAIN AIR QUALITY PROGRAM.”

Both PM₁₀ and PM_{2.5} DUSTTRAK inlets were attached on a wide “Y” connector, which was connected to one end of a second “Y” (Figure 9). A funnel was connected to the other end of the second “Y” to achieve fast exchange of ambient air into the sampling line.

Flow calibration and zero-tests were performed on the day of installation (March 24, 2006) and subsequent site visits. Deviations in flow were predominantly due to failure of the pump diaphragm. In those cases, the instrument was replaced. Deviations of the zero check were corrected by performing zero calibration according to the manufacturer's operational instruction manual.

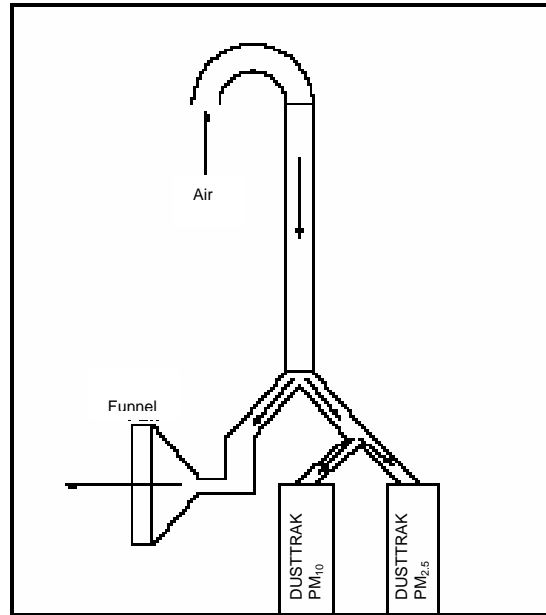


Figure 9. Sampling inlet for DUSTTRAK.

Continuous Measurements of PM₁₀ and PM_{2.5}

Trends and correlations of particle mass were examined using hourly TEOM data integrated for 24 hours (from 0:00 to 23:00 PST). Statistics for 24-h particle mass are presented in Table 4. Twenty-four-h PM₁₀ levels ranged from 4.1 to 72.3 $\mu\text{g}/\text{m}^3$ with a mean of 15.1 ($\sigma=10.2$) $\mu\text{g}/\text{m}^3$, while PM_{2.5} concentrations varied from 0.1 to 8.9 $\mu\text{g}/\text{m}^3$ with a mean of 3.9 ($\sigma=2.4$) $\mu\text{g}/\text{m}^3$. Similarly shaped temporal trends were found for PM₁₀ and PM_{2.5}. With the exception of two high PM₁₀ episodes during the first two weeks of the monitoring period, concentration levels and day-to-day variation of PM₁₀ (and PM_{2.5}) can be described by cycles of two to three days of increased concentrations followed by a concentration decrease for a couple of days (Figure 10). A rather consistent relationship between PM fractions was observed, with PM_{2.5} accounting for about one-third of PM₁₀ (PM_{2.5}/PM₁₀ ratio of 0.31) (Figure 11). While differences in particle mass for weekdays/weekends were not statistically significant, somewhat higher PM₁₀ levels were measured on Tuesdays (Day #2) (Figure 12).

Table 4. Statistics for 24-h PM₁₀ and PM_{2.5} TEOM mass concentrations.

	Mean	Median	Minimum	Maximum	Std. Deviation
PM ₁₀	15.1	14.1	4.1	72.3	10.2
PM _{2.5}	3.9	3.5	0.1	8.9	2.4

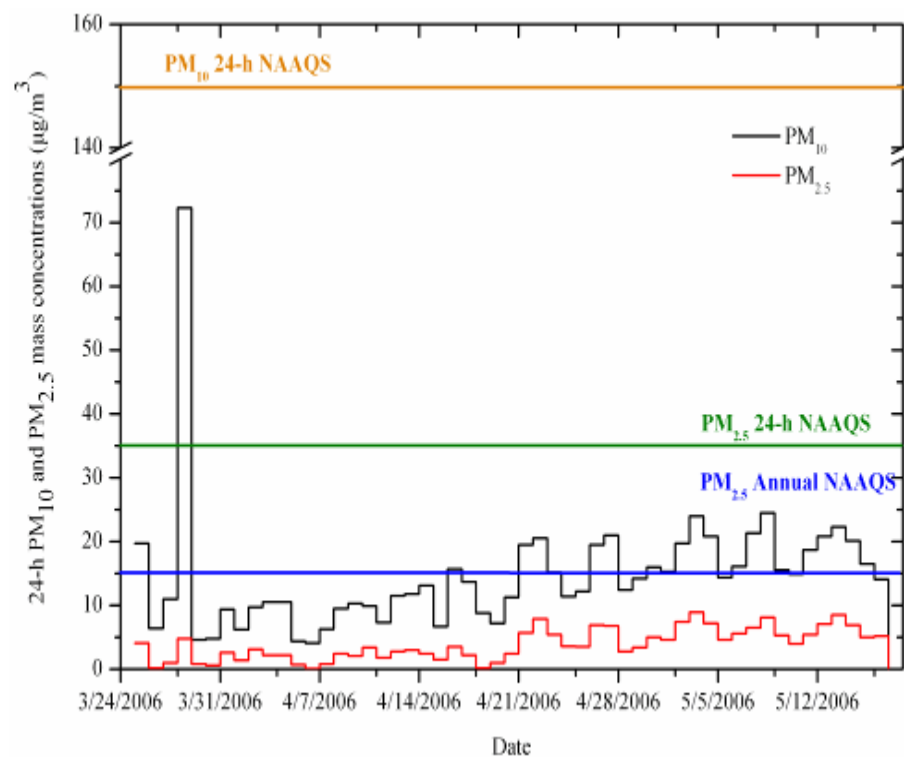


Figure 10. Mean 24-h PM_{10} and $PM_{2.5}$ mass concentrations measured by TEOM at Site #1 (Ash Meadows).

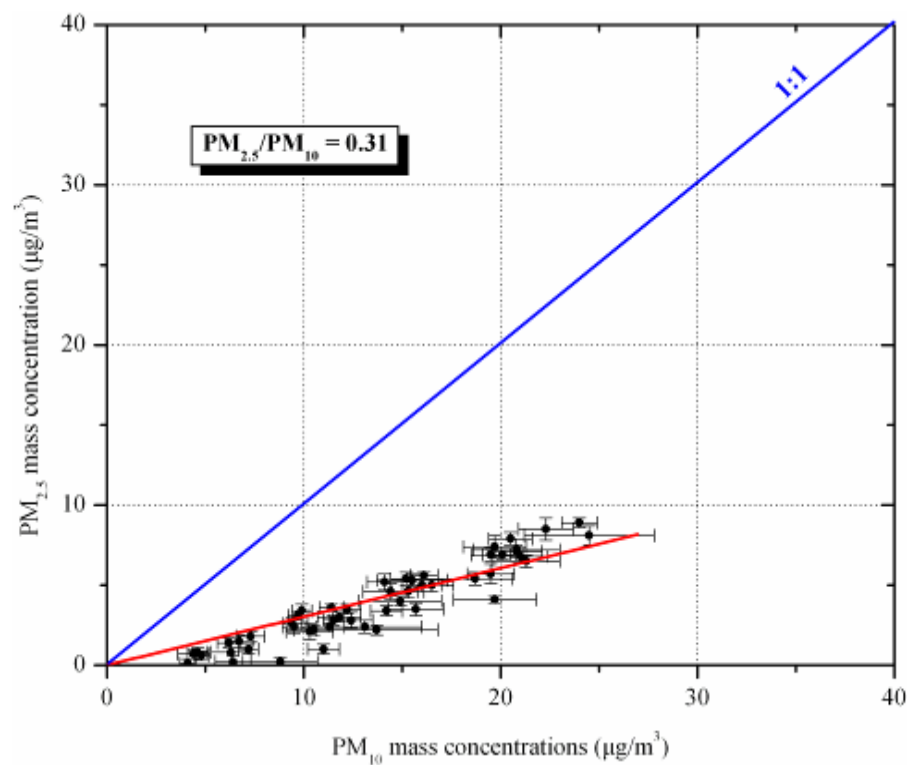


Figure 11. $PM_{2.5}/PM_{10}$ mass ratios at Site #1 (Ash Meadows NWR). Error bars represent the standard error of the mean.

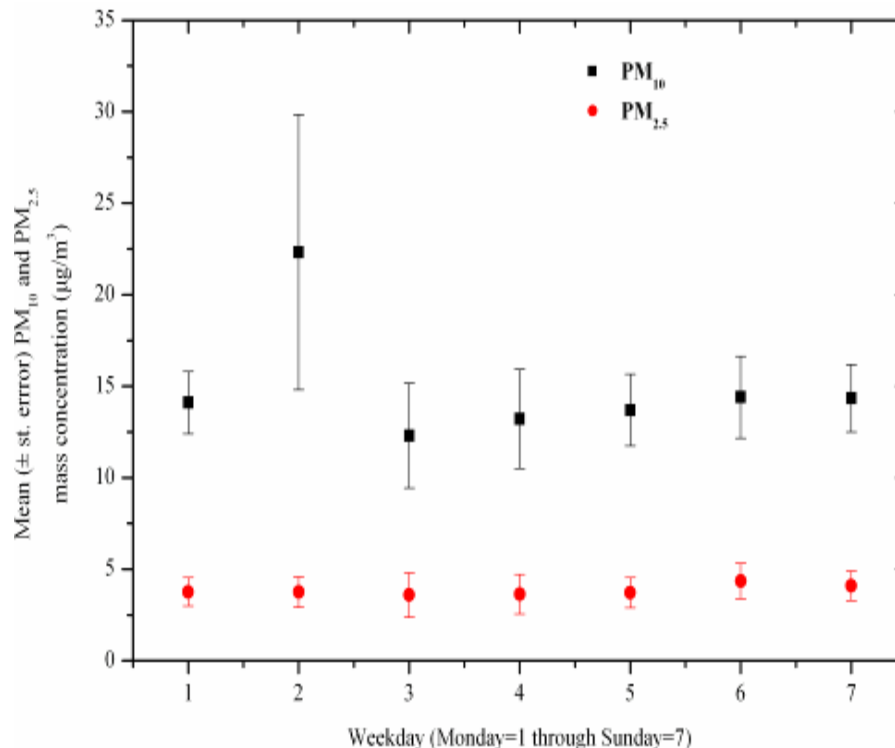


Figure 12. Variation of mean (\pm st.error) PM_{10} and $PM_{2.5}$ ($\mu\text{g}/\text{m}^3$) in weekdays and weekends at Site #1 (Ash Meadows) (Monday=1, Tuesday=2, Wednesday=3, Thursday=4, Friday=5, Saturday=6, Sunday=7).

Variations of daily PM_{10} and $PM_{2.5}$ measured with DUSTTRAK and TEOM are presented in Figure 13 and Figure 14. The time series plots for PM_{10} particle mass concentrations measured by TEOM and DUSTTRAK are similar in shape, but lower by about $10 \mu\text{g}/\text{m}^3$ on average for the DUSTTRAK (Figure 13). As a result, a slope of 0.60441 and an intercept of $-2.44127 \mu\text{g}/\text{m}^3$ is estimated (Figure 15). As for $PM_{2.5}$, both TEOM and DUSTTRAK are comparable for the first two to three weeks where $PM_{2.5}$ levels were lower than $6 \mu\text{g}/\text{m}^3$. For the remaining period, $PM_{2.5}$ mass concentrations measured by DUSTTRAK were as high as two times those measured by TEOM (Figure 14). In fact, the slope between TEOM and DUSTTRAK $PM_{2.5}$ was 1.64844, with a rather low intercept of $0.24485 \mu\text{g}/\text{m}^3$. These differences between TEOM and DUSTTRAK for PM_{10} and $PM_{2.5}$ were associated with limitations of the measurement principle. For example, the ability to measure coarse particles (particles with aerodynamic diameter between 2.5 and $10 \mu\text{m}$) by light scattering is quite limited. This also was supported by the relatively high intercept for PM_{10} , which indicated a rather constant underestimation of PM_{10} by DUSTTRAK. As a result, in Ash Meadows where coarse particles constitute more than 60 percent of PM_{10} , deviations were expected to be considerable. On the contrary, light scattering provides more reliable measurements of particle mass in the accumulation mode, while the heated element in the TEOM measurement unit may result in losses of volatile species such as nitric acid and low vapor organic compounds, and therefore, underestimating $PM_{2.5}$ mass concentrations.

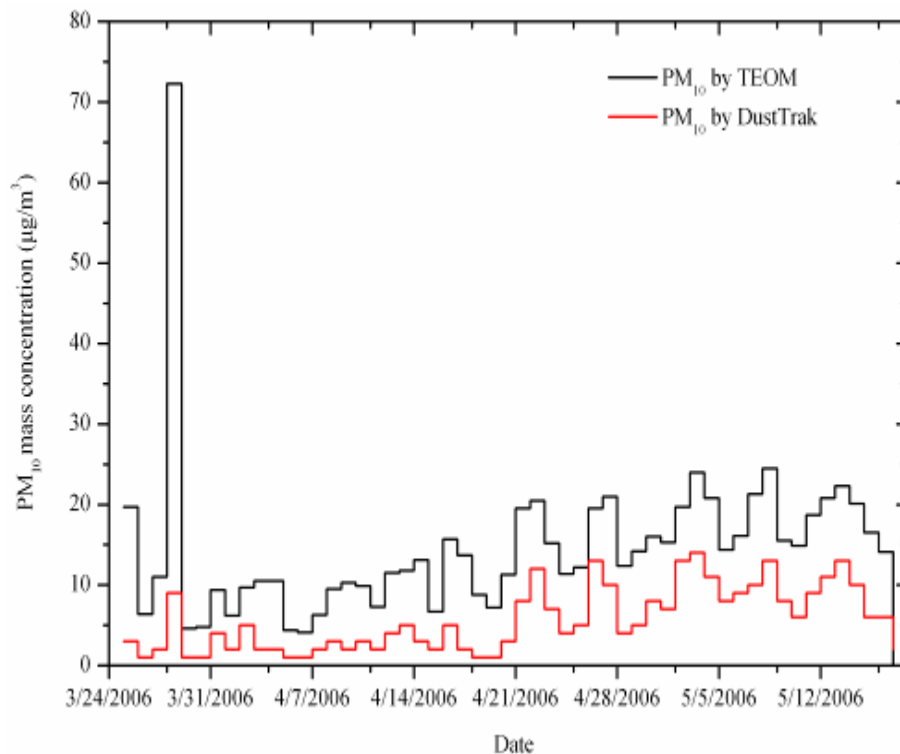


Figure 13. PM₁₀ mass (µg/m³) measured with DUSTTRAK and TEOM at Site #1 (Ash Meadows NWR).

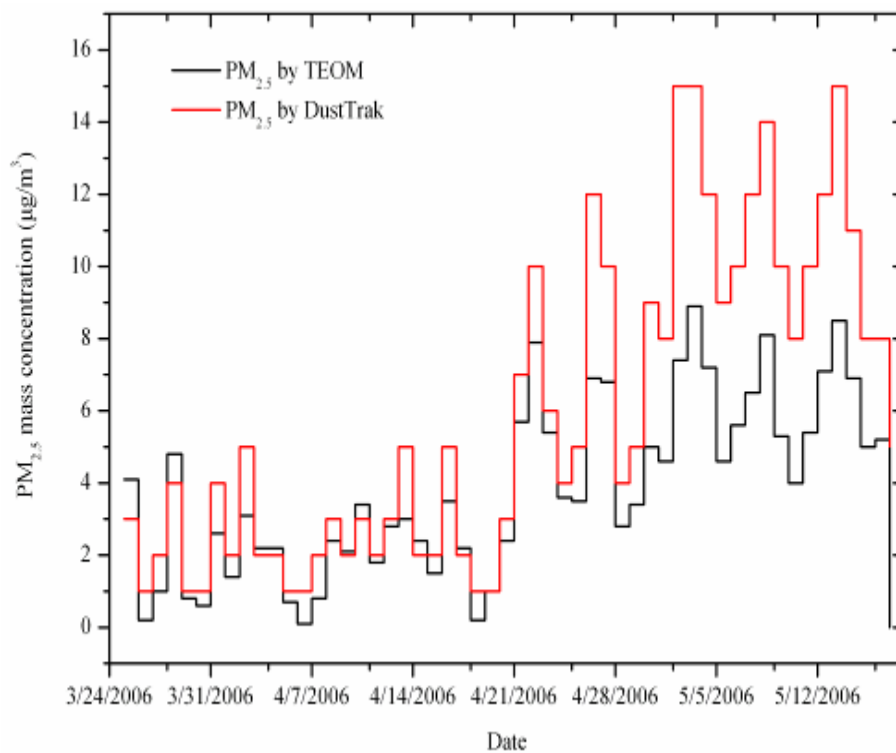


Figure 14. PM_{2.5} mass (µg/m³) measured with DUSTTRAK and TEOM at Site #1 (Ash Meadows NWR).

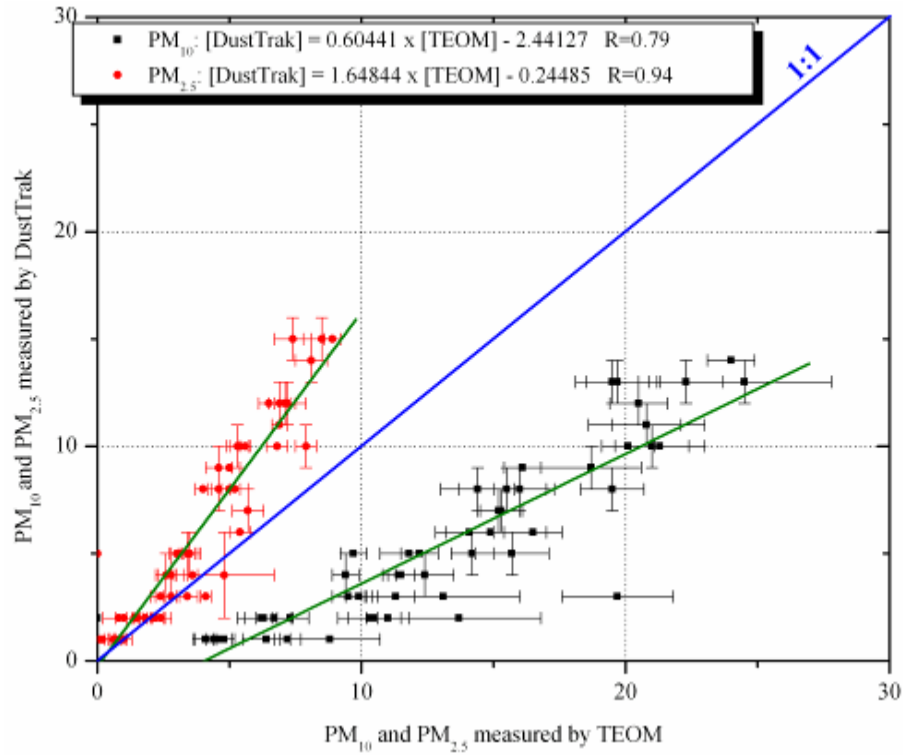


Figure 15. Comparison of 24-h PM_{10} and $PM_{2.5}$ mass concentrations measured by TEOM and DUSTTRAK. Error bars represent the standard error of the mean.

Comparison of Filter to Continuous Results

Figure 16 and Figure 17 show the relationships between PM_{10} and $PM_{2.5}$ measured by TEOM/DUSTTRAK and FRM filter-based methods. Temporal correlations between PM_{10} and $PM_{2.5}$ measurements by TEOM, DUSTTRAK, and filter methods were good, with correlation coefficients from 0.80 to 0.98. As previously, PM_{10} mass concentrations measured by DUSTTRAK were lower than those measured by filters (slope of 0.68026 and intercept of $0.65198 \mu\text{g}/\text{m}^3$). Interestingly, while the slope between TEOM and filter PM_{10} measurements was near unity (slope: 0.92111), a relatively high intercept ($4.77236 \mu\text{g}/\text{m}^3$) was estimated.

As for $PM_{2.5}$, TEOM and filter-based methods showed an acceptable agreement (slope of 0.87578, intercept $0.00154 \mu\text{g}/\text{m}^3$). On the other hand, the differences between $PM_{2.5}$ mass measured by DUSTTRAK and filters increased proportionally for higher $PM_{2.5}$ concentrations at a rate of 1.78137 (slope). Considering that increases in $PM_{2.5}$ mass were associated with higher concentrations of organic carbon mass (Figure 7), these patterns indicated that volatilization losses (if any) for the filter method and TEOM (which utilized a filter in a heated compartment) were comparable, but they increased for higher $PM_{2.5}$ concentrations. Since the DUSTTRAK measures light scattering of aerosol at ambient conditions, volatile components are included.

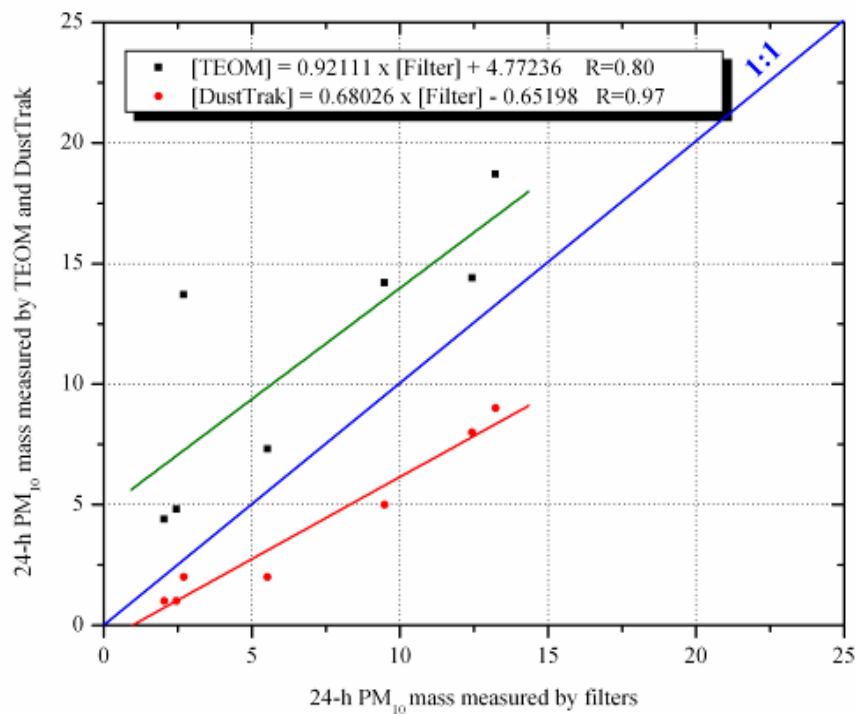


Figure 16. Relationships between PM_{10} concentrations ($\mu g/m^3$) measured by TEOM, DUSTTRAK, and filter-based methods.

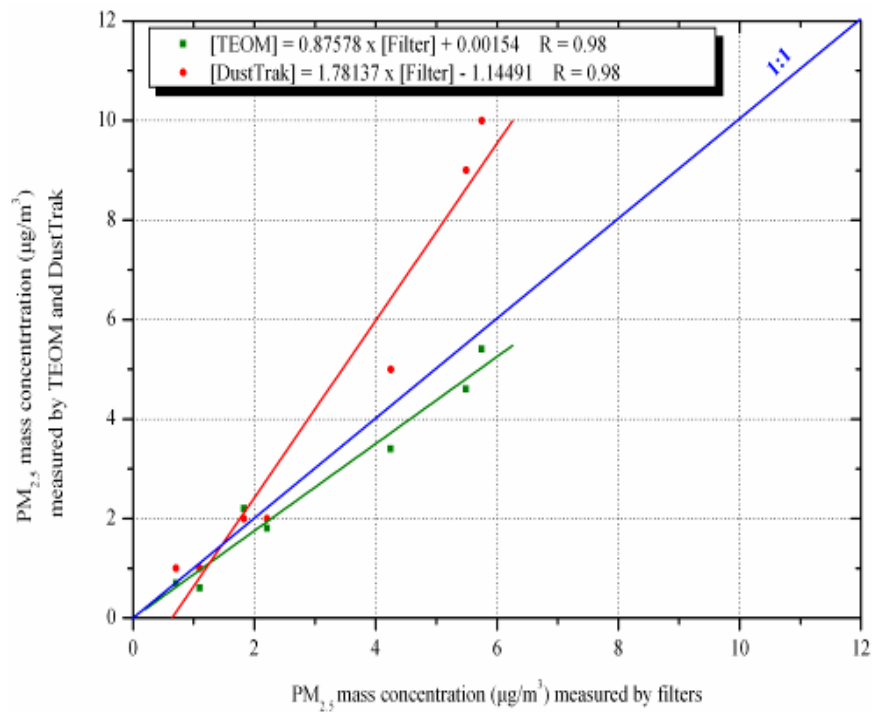


Figure 17. Relationships between $PM_{2.5}$ concentrations ($\mu g/m^3$) measured by TEOM, DUSTTRAK, and filter-based methods.

METEOROLOGY

Variations of hourly data for meteorological parameters are presented in Figure 18 through Figure 22. Descriptive statistics of hourly data also are presented in Table 5. Solar radiation progressively increased up to 87.1 watts/m² and only a few days (approximately 10 days) were covered by clouds (Figure 18). Ambient temperature varied from 35.5 to 99.7 °F with a mean temperature of 67.6 °F for the monitoring period (Table 5), which was associated with a decrease in relative humidity (Figure 19). During the monitoring period, only five rain events occurred (Figure 20), with a total precipitation of 20.83 mm.

Table 5. Descriptive statistics of 1-hour meteorological data.

	Mean	Minimum	Maximum	Sum
Solar Radiation (watts/m ²)	24.2	0.0	87.1	
Wind speed (miles/h)	9.6	0.7	29.6	
Temperature (°F)	67.6	35.5	99.7	
Relative humidity (%)	29	7	99	
Precipitation (mm)				20.83

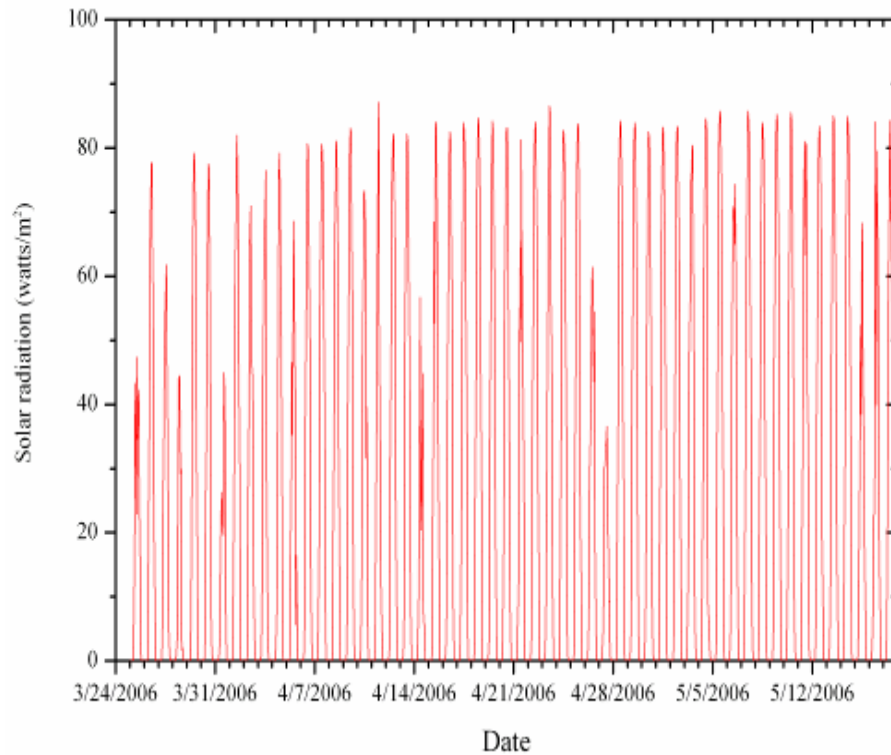


Figure 18. Solar radiation (in watts/m²) at Site #1 (Ash Meadows NWR).

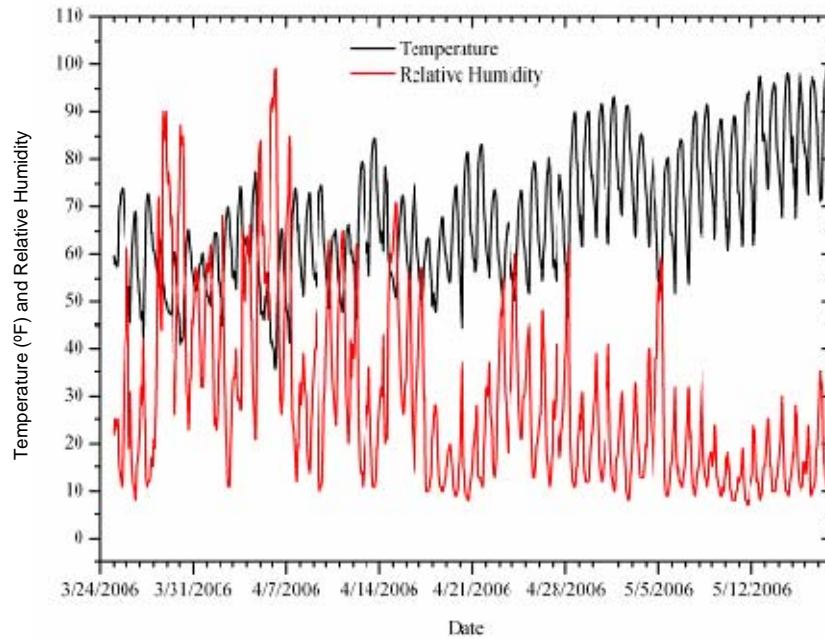


Figure 19. Temperature (in °F) and relative humidity at Site #1 (Ash Meadows NWR).

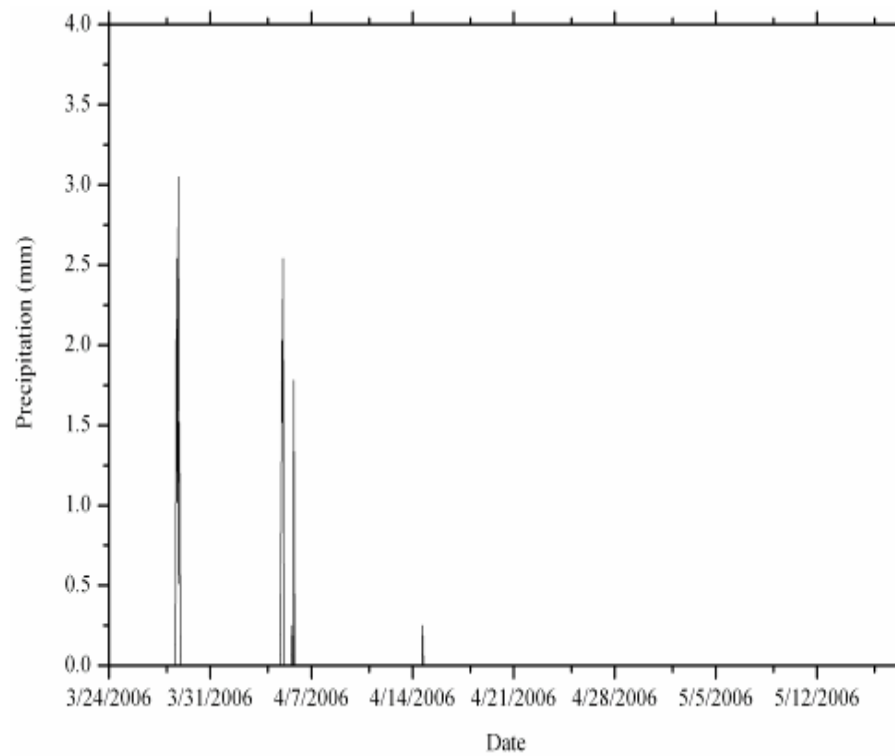


Figure 20. Total precipitation (in mm) at Site #1 (Ash Meadows NWR).

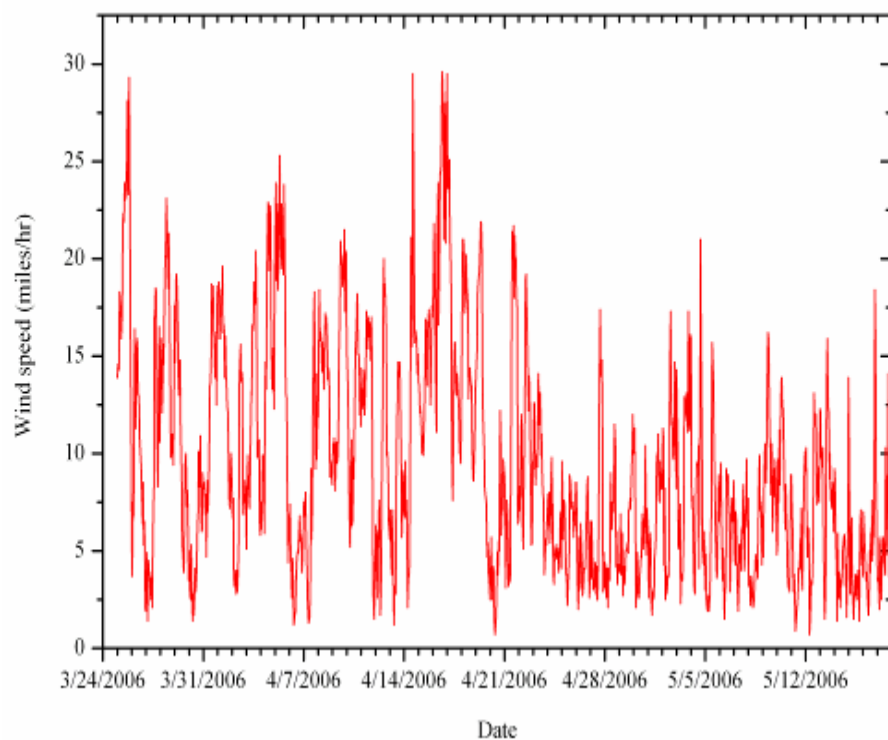


Figure 21. Wind speed (in miles/hr) at Site #1 (Ash Meadows NWR).

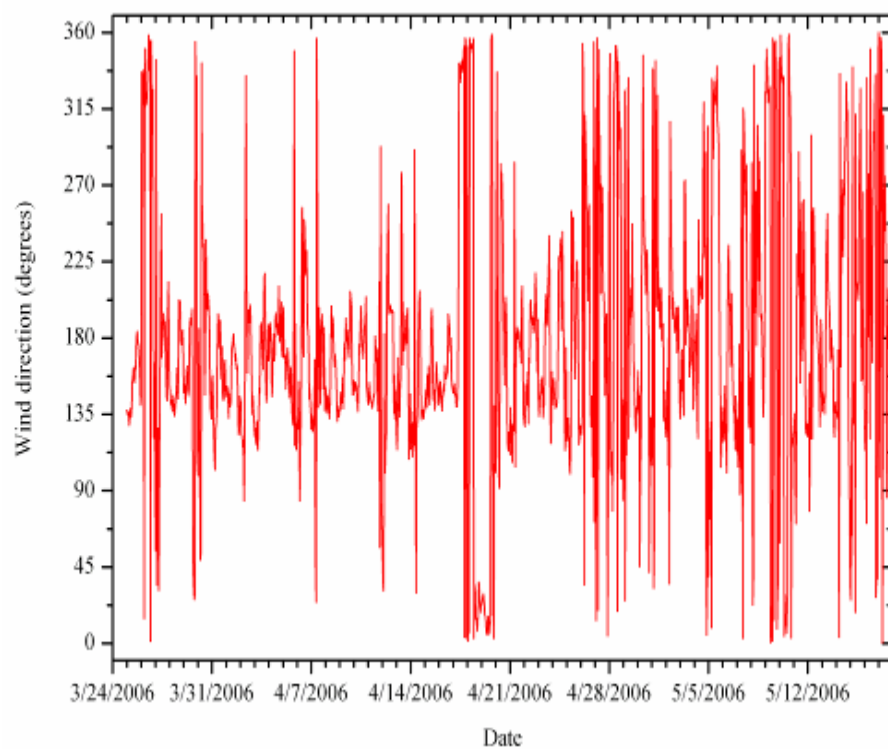


Figure 22. Wind direction at Site #1 (Ash Meadows NWR).

The monitoring period can be divided in two distinct periods based on wind conditions: from March 24 to April 16, 2007, and from April 19 to May 18, 2007 (Figure 21 and Figure 22). During the first period, the prevailing wind direction was from the south-southeast with wind speeds as high as 30 miles/hour. The second period was characterized by frequent changes of wind direction with moderate-to-low wind speeds (lower than 20 miles/hour). To obtain information on prevailing winds, polar plots of wind conditions are given (Figure 23). The classification of wind conditions was retrieved from the Federal Meteorological Handbook (Table6).

Table 6. Wind condition classifications.

Miles/hour	Specification
<1	Calm; smoke rises vertically.
1 to 5	Direction of wind shown by smoke drift not by wind vanes. Wind felt on face; leaves rustle; vanes moved by wind.
5 to 9	Leaves and small twigs in constant motion; wind extends light flag.
9 to 14	Raises dust, loose paper; small branches moved.
14 to 23	Small trees in leaf begin to sway; crested wavelets form on inland waters. Large branches in motion; whistling heard in overhead wires; umbrellas used with difficulty.
23 to 35	Whole trees in motion; inconvenience felt walking against wind. Breaks twigs off trees; impedes progress.
35 to 48	Slight structural damage occurs. Trees uprooted; considerable damage occurs.
>48	Widespread damage.

(retrieved from Federal Meteorological Handbook; Chapter 5. Wind;
<http://www.nws.noaa.gov/oso/oso1/oso12/fmh1/fmh1ch5.htm#chp5link>)

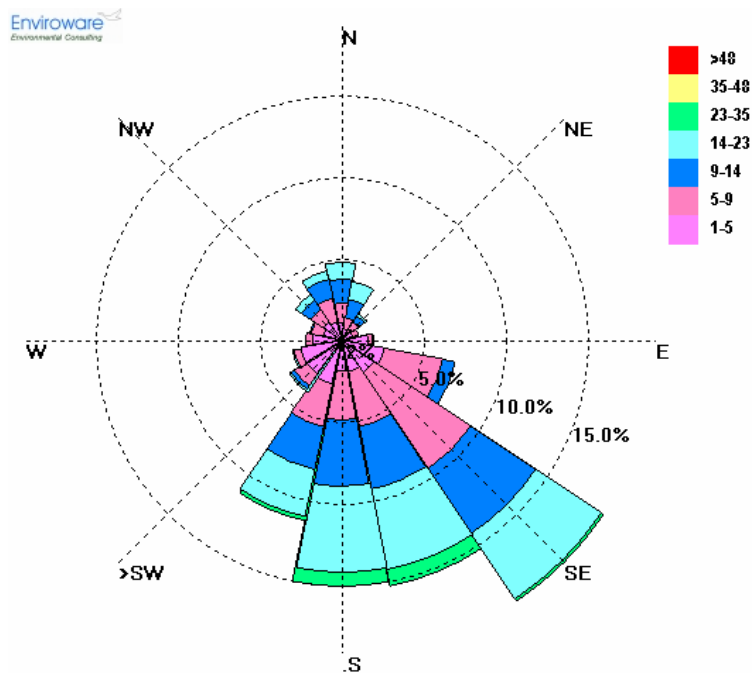


Figure 23. Wind direction and speed at Ash Meadows NWR.

For the entire monitoring period, the prevailing wind direction was southeast and south-southeast, with mean wind speed of 12 miles/hour (Figure 23). More than 5% of southeast/south-southeast winds were associated with wind speeds higher than 14 miles/hour, which has been defined as the threshold for windblown dust emissions. Only a small fraction (less than 5%) of the wind was from the north-northwest sectors, and sometimes associated with high wind speeds. By comparing polar plots of wind speed and location of the monitoring site with respect to the nearest city of Pahrump, it is unlikely that anthropogenic activities from there contributed to air quality in the Ash Meadows NWR.

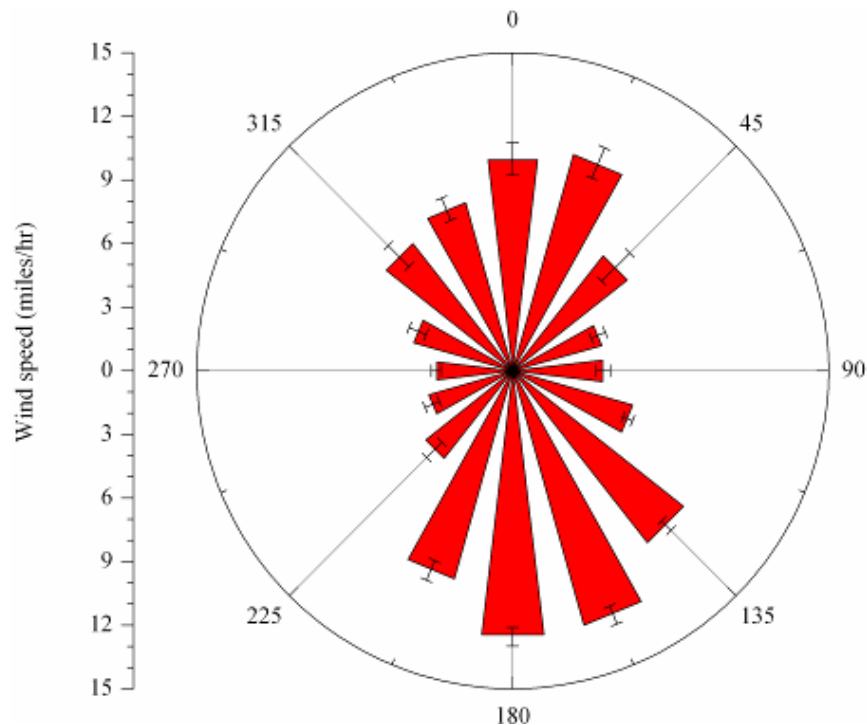


Figure 24. Average wind speed for each wind direction sector. Error bars represent the standard error of the mean.

Associations of Meteorology with Aerosol Measurements

The trends and correlations of PM mass with meteorological condition are shown for hourly TEOM data. A bimodal pattern is observed for both fractions of particle mass (Figure 25). The first mode is associated with comparatively higher particle mass concentration in early morning (5:00 to 6:00) followed by a gradual decrease. A second, less pronounced, mode can be observed in late afternoon (18:00 to 20:00), especially for the fine fraction. Poor association between particle mass and wind speed may be explained by nonwind emissions of particle mass (e.g., nearby mine) in the early morning and changes in wind direction (for example, southern winds; Figure 26 and Figure 27). In general, higher PM₁₀ concentrations were measured when winds were blowing from the west and southeast, while for PM_{2.5}, high concentrations also were measured for northeast winds. These patterns provided indications of the possible sources of coarse and fine particle in and around the Ash Meadows NWR. These include resuspension of road dust and vehicular emissions from nearby unpaved Bell Vista Road and Ash Meadows Road (see Figure 2), which are the two major roads in the refuge.

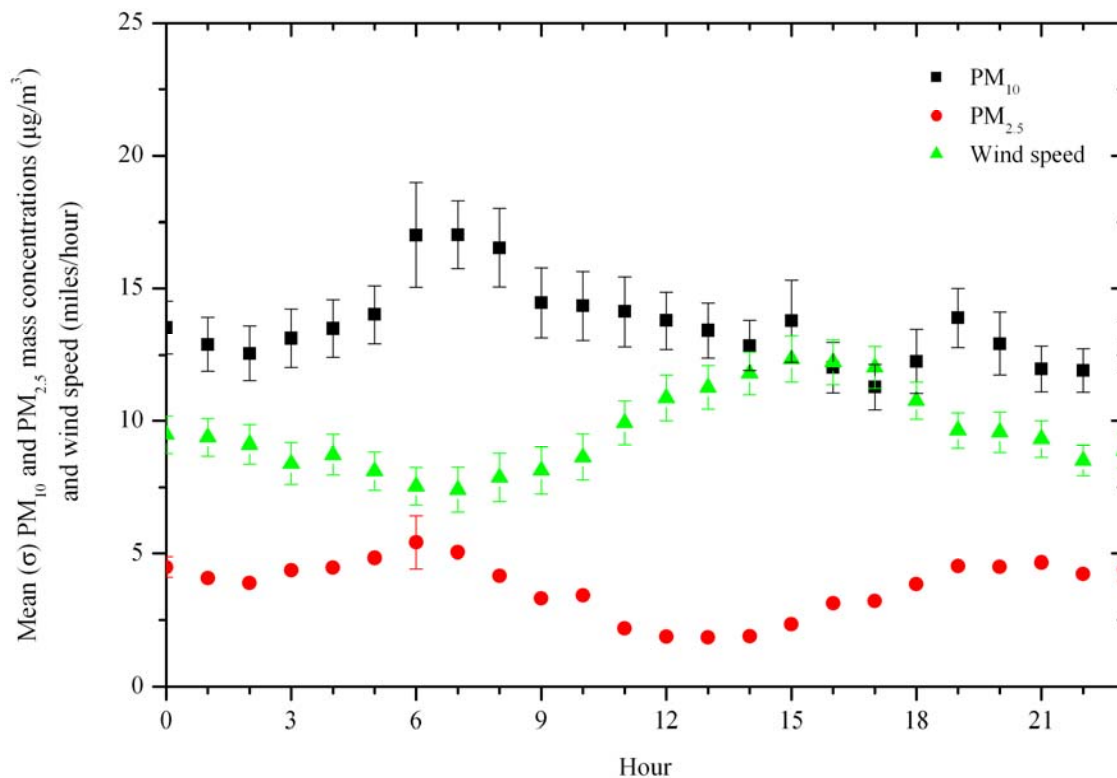


Figure 25. Hourly variation of PM₁₀ and PM_{2.5} mass concentrations (µg/m³) as well as wind speed (miles/hour) at Site #1 (Ash Meadows NWR). Error bars represent the standard error of the mean.

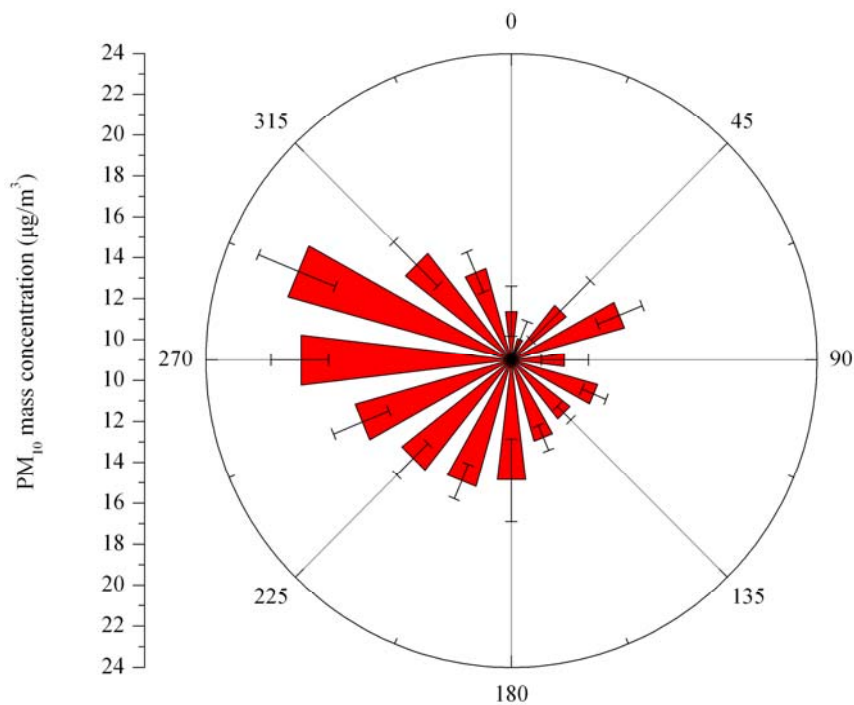


Figure 26. Mean (± st.error) of PM₁₀ mass concentrations (µg/m³) for different wind direction sectors at Site #1 (Ash Meadows NWR).

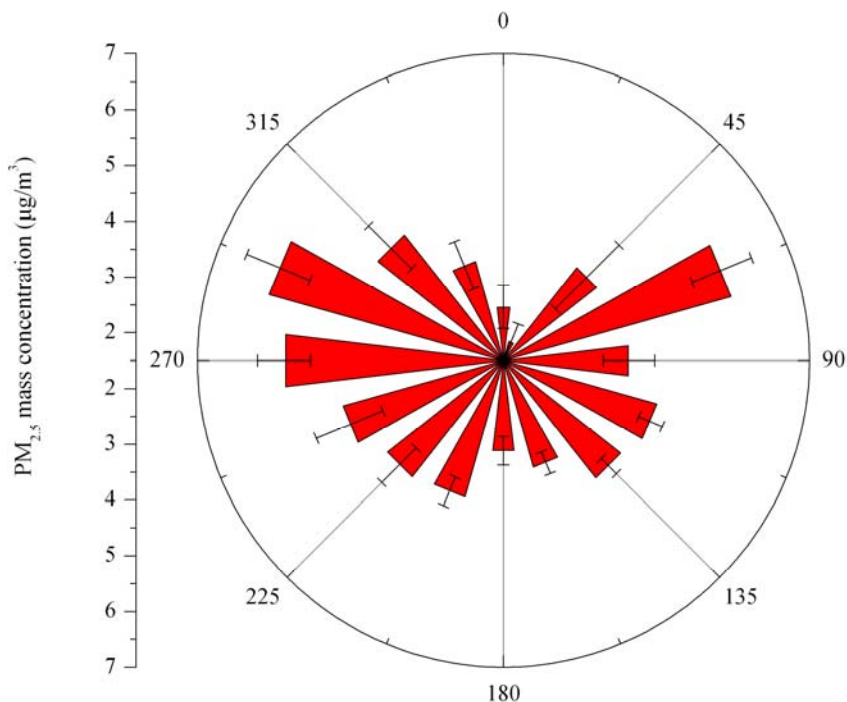


Figure 27. Mean (\pm st.error) of $\text{PM}_{2.5}$ mass concentrations ($\mu\text{g}/\text{m}^3$) for different wind direction sectors at Site #1 (Ash Meadows NWR).

CONCLUSIONS

PM_{10} and $\text{PM}_{2.5}$ mass concentrations and meteorological conditions were continuously monitored from March 24 to May 18, 2006, in the Ash Meadows National Wildlife Refuge with continuous (TEOM and DUSTTRAK) monitors. At the same time, integrated samples of PM_{10} and $\text{PM}_{2.5}$ were collected using FRM samplers on a 1-to-6-day schedule. Two sets of filters were analyzed for major anions (sulfate, nitrate, chloride) and cations (sodium and potassium), elements (from sodium to uranium), and elemental and organic carbon. The comparison of PM_{10} and $\text{PM}_{2.5}$ mass concentrations obtained by continuous monitors and filters showed that differences are associated with the limitations of the measurement technique for each instrument. For example, while light scattering (the measurement technique for DUSTTRAK) is not influenced by volatilization losses and is accurate for fine particles, it performs poorly for coarse particles, resulting in underestimation of PM_{10} mass. On the other hand, TEOM and filter-based methods are subject to both positive (absorption) and/or negative (volatilization) artifacts that may occur during sampling, resulting in either over- or underestimation of $\text{PM}_{2.5}$ mass.

Mean 24-h concentrations of PM_{10} and $\text{PM}_{2.5}$ mass were 15.1 and $3.9 \mu\text{g}/\text{m}^3$, which are significantly lower than the 24-h and annual NAAQS standards (24-h PM_{10} : $150 \mu\text{g}/\text{m}^3$, 24-h $\text{PM}_{2.5}$: $35 \mu\text{g}/\text{m}^3$; Annual $\text{PM}_{2.5}$: $15 \mu\text{g}/\text{m}^3$). Two distinct patterns were observed during the entire monitoring period. The first pattern (March 24 to April 18, 2006) is described by moderate to relatively strong winds from the south, which are associated with low PM_{10} (less than $10 \mu\text{g}/\text{m}^3$) and $\text{PM}_{2.5}$ (less than $5 \mu\text{g}/\text{m}^3$) mass concentrations. During this period, a high PM_{10} episode ($\sim 72 \mu\text{g}/\text{m}^3$) was observed. The second pattern was observed from April 19 to

the end of the monitoring period, with frequent changes of wind direction and relatively low wind speed. This circulation may be indicative of the local topography and the development of stagnant conditions. PM₁₀ and PM_{2.5} concentrations increased significantly (almost by a factor of two) as compared to those measured during March 24 to April 18, 2006. The chemical composition of both PM₁₀ and PM_{2.5} samples indicated that organic carbon is the major component of both fractions, while soil contributes approximately 30 to 40 percent of PM₁₀ mass. Sulfate and nitrate account for about 15 percent. Increases in PM₁₀ and PM_{2.5} mass concentrations are associated higher concentrations of soil and organic mass, respectively. However, the importance of organic carbon mass may be overestimated, especially for fine particles, because of the absorption of low-vapor-pressure organic gases by the quartz filter during sampling.

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