Clark County
Wind Tunnel Study

Section 5: Addendum to 2004 Wind Tunnel Study - PM_{10} Milestone Achievement Report

Final Report

June 30, 2006

Addendum to 2004 Wind Tunnel Field Study

Comparison of Vacant Lands PM_{10} Emission Factors used in 2001 SIP (1995 and 1998-99 wind tunnel field studies) to 2004 Vacant Lands PM_{10} Emission Factors

For Clark County Dept Air Quality and Environmental Management

PM_{10} SIP Milestone Achievement Report

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Stable Wind Erosion Rates

Stable Wind Erosion rates, averaged over all soil groups, are compared for 2004 and 1995 in Table 1 below.

Table 1. Comparison of Stable PM-10 wind tunnel erosion rates, averaged over all Wind Erodibility Groups, for 2004 and 1995.

ALL WEG Stable - 2004				
wind band (mph)	**geo mean - 1 std.dev flux, ton/acre/hr**	**geo mean flux ton/acre/hr**	**geo mean + 1 std.dev flux, ton/acre/hr**	**sample size, n=**
10-15	6.09E-04	1.73E-03	4.92E-03	77
15-20	5.37E-04	1.60E-03	4.78E-03	91
20-25	8.88E-04	3.07E-03	1.06E-02	97
25-30	5.35E-03	1.04E-02	2.01E-02	11
30-35	2.64E-03	7.97E-03	2.41E-02	102
35-40	4.16E-03	1.24E-02	3.67E-02	33
40-45	3.95E-03	1.12E-02	3.18E-02	41
45-50	3.91E-03	1.28E-02	4.18E-02	2
50-55				
55-60				
60-65				
total data points				454
average, 15-40 mph		7.07E-03		

ALL WEG Stable - 1995				
wind band (mph)	**geo mean - 1 std.dev flux, ton/acre/hr**	**geo mean flux ton/acre/hr**	**geo mean + 1 std.dev flux, ton/acre/hr**	**sample size, n=**
10-15				
15-20	N/A	1.95E-03	N/A	1
20-25	3.16E-04	1.38E-03	6.07E-03	4
25-30	9.46E-04	2.57E-03	7.00E-03	11
30-35	7.81E-04	3.16E-03	1.28E-02	23
35-40	9.17E-04	2.99E-03	9.73E-03	28
40-45	2.08E-03	5.92E-03	1.68E-02	34
45-50	3.02E-03	7.58E-03	1.90E-02	30
50-55	5.94E-03	1.10E-02	2.02E-02	22
55-60	9.03E-03	1.69E-02	3.15E-02	12
60-65	9.99E-03	1.66E-02	2.76E-02	4
total data points				169
average, 15-40 mph		2.41E-03		

Figures 1 and 2 graphically depict the data shown in Table 1. For Stable 2004 flux rates (Figure 1), the emission rates tend to reach a plateau at about 0.0100 ton/acre/hour at the wind speeds greater than 27.5 miles per hour (25-30mph wind band). In contrast, 1995 erosion rates are lower than the 2004 rates, and rise until hitting a 0.0100 ton/acre/hour plateau at 52.5 mph (50-55 mph wind band).

From Table 1, it can be observed that the 2004 estimates were usually computed from much larger data sets than the 1995 data. This is a result of the different field measurement strategy employed in 2004, where fluxes were intentionally measured at lower, pre-set velocity points. The field protocol for the 2004 study was intentionally developed to create larger data sets for the flux measurements, to lower the uncertainty of the estimates of stable wind erosion rates in each wind speed band.

Figure 1. 2004 Stable wind tunnel erosion rates. Data from Table 1.

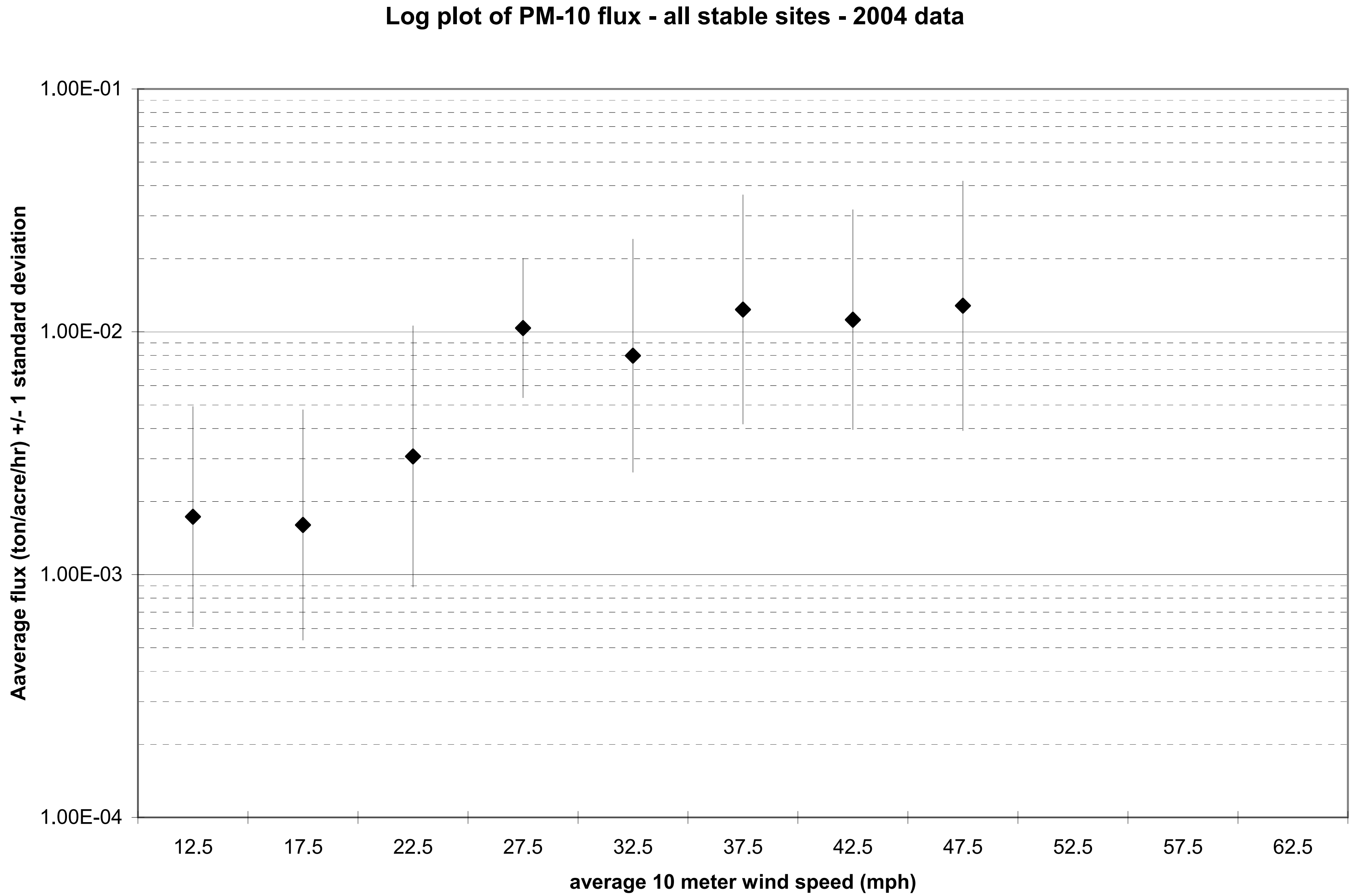
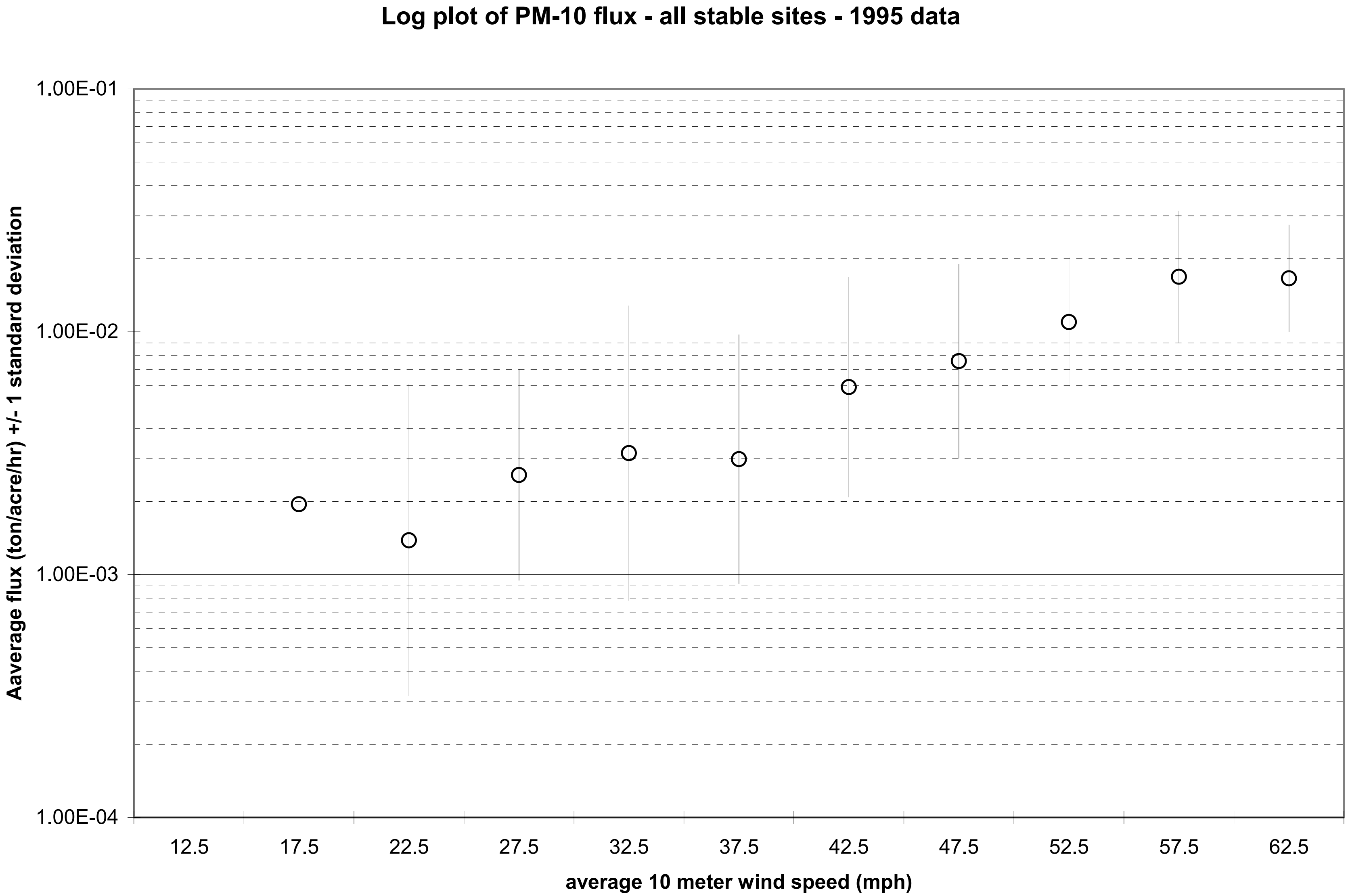


Figure 2. 1995 Stable wind tunnel erosion rates. Data from Table 1



Computed Ratios of 2004 to 1995 stable erosion rates are shown in Table 2.

Table 2: Computed ratios of 2004 to 1995 Stable wind tunnel erosion rates, using data shown in Table 1.

ALL WEG Stable - ratio of 2004 to 1995 data			
wind band (mph)	**geo mean - 1 std.dev**	**geo mean**	**geo mean + 1 std.dev**
10-15			
15-20		0.82	
20-25	2.81	2.21	1.74
25-30	5.65	4.03	2.87
30-35	3.38	2.52	1.88
35-40	4.54	4.14	3.77
40-45	1.89	1.89	1.89
45-50	1.30	1.69	2.20
50-55			
55-60			
60-65			
average ratio	3.26	2.47	2.39

Geometric mean 2004 stable erosion rates were, on average, a factor of 2.5 higher than 1995 stable erosion rates, with multipliers ranging from 0.82 to 4.14 .

The higher values likely occurred because of differences in sampling methods. In the 2004 study, the wind tunnel was moved three times at each study site, and obtained erosion data at each wind speed from a soil surface that likely had been depleted less than during the 1995 study, where the tunnel was run in place for 10 minutes at each increasing wind speed.

The 2004 field study employed shorter periods (4.0 minute) of steady-state erosion at each velocity compared to the 1995 study (10 minutes), so that the average erosion rate was calculated on a surface that had not been depleted of erodible particles for as long a period as during the 1995 study.

Unstable Erosion Rates

Unstable Wind Erosion rates, averaged over all soil groups, are compared for 2004 and 1995 in Table 3 below.

Table 3. Comparison of Unstable PM-10 wind tunnel erosion rates, averaged over all Wind Erodibilty Groups, for 2004 and 1995.

ALL WEG Unstable - 2004				
wind band (mph)	geo mean - 1 std.dev flux, ton/acre/hr	geo mean flux ton/acre/hr	geo mean + 1 std.dev flux, ton/acre/hr	sample size, n=
10-15	6.29E-04	1.80E-03	5.13E-03	63
15-20	4.66E-04	1.29E-03	3.56E-03	102
20-25	1.71E-03	4.66E-03	1.27E-02	103
25-30	6.83E-03	2.20E-02	7.07E-02	12
30-35	6.79E-03	1.72E-02	4.35E-02	96
35-40	1.19E-02	2.81E-02	6.68E-02	30
40-45	1.29E-02	3.13E-02	7.57E-02	46
45-50	1.10E-02	3.17E-02	9.11E-02	5
50-55				
total data points				457
average 15-40 mph		1.47E-02		

ALL WEG Unstable -1995				
wind band (mph)	geo mean - 1 std.dev flux, ton/acre/hr	geo mean flux ton/acre/hr	geo mean + 1 std.dev flux, ton/acre/hr	sample size, n=
10-15				
15-20	1.50E-03	4.95E-03	1.63E-02	3
20-25	1.23E-03	5.21E-03	2.21E-02	4
25-30	1.18E-03	6.40E-03	3.48E-02	12
30-35	1.21E-03	4.62E-03	1.76E-02	13
35-40	8.96E-04	7.05E-03	5.54E-02	19
40-45	2.37E-03	1.13E-02	5.41E-02	9
45-50	9.71E-04	7.12E-03	5.22E-02	7
50-55	N/A	3.69E-03	N/A	1
total data points				68
average 15-40		5.64E-03		

Figures 3 and 4 graphically depict the data shown in Table 3. For Unstable 2004 flux rates (Figure 3), the emission rates tend to reach a plateau at about 0.020 to 0.0300 ton/acre/hour at the wind speeds greater than 27.5 miles per hour (25-30mph wind band). In contrast, 1995 erosion rates (Figure 4) are lower than the 2004 rates, and tend to fluctuate between 0.005 and 0.010 ton/acre/hour in wind bands ranging from 15-20 mph to 45-50 mph

From Table 3, it can be observed that the 2004 estimates were usually computed from much larger data sets than the 1995 data. As was the case for the stable emissions factors (Table 1), this is a result of the different field measurement strategy employed in 2004, where fluxes were intentionally measured at lower, pre-set velocity points. The field protocol for the 2004 study was intentionally developed to create larger data sets for the flux measurements, to lower the uncertainty of the estimates of unstable wind erosion rates in each wind speed band.

Unstable PM10 emissions rates are likely higher in 2004 than in 1995 because the 2004 surfaces were freshly destabilized with a rake. In contrast, the 1995 unstable surfaces were tested in the "as-found" condition, and unstable surfaces may have been partially re-stabilized through crusting or fine particle depletion.

Figure 3. 2004 Unstable wind tunnel erosion rates. Data from Table 3.

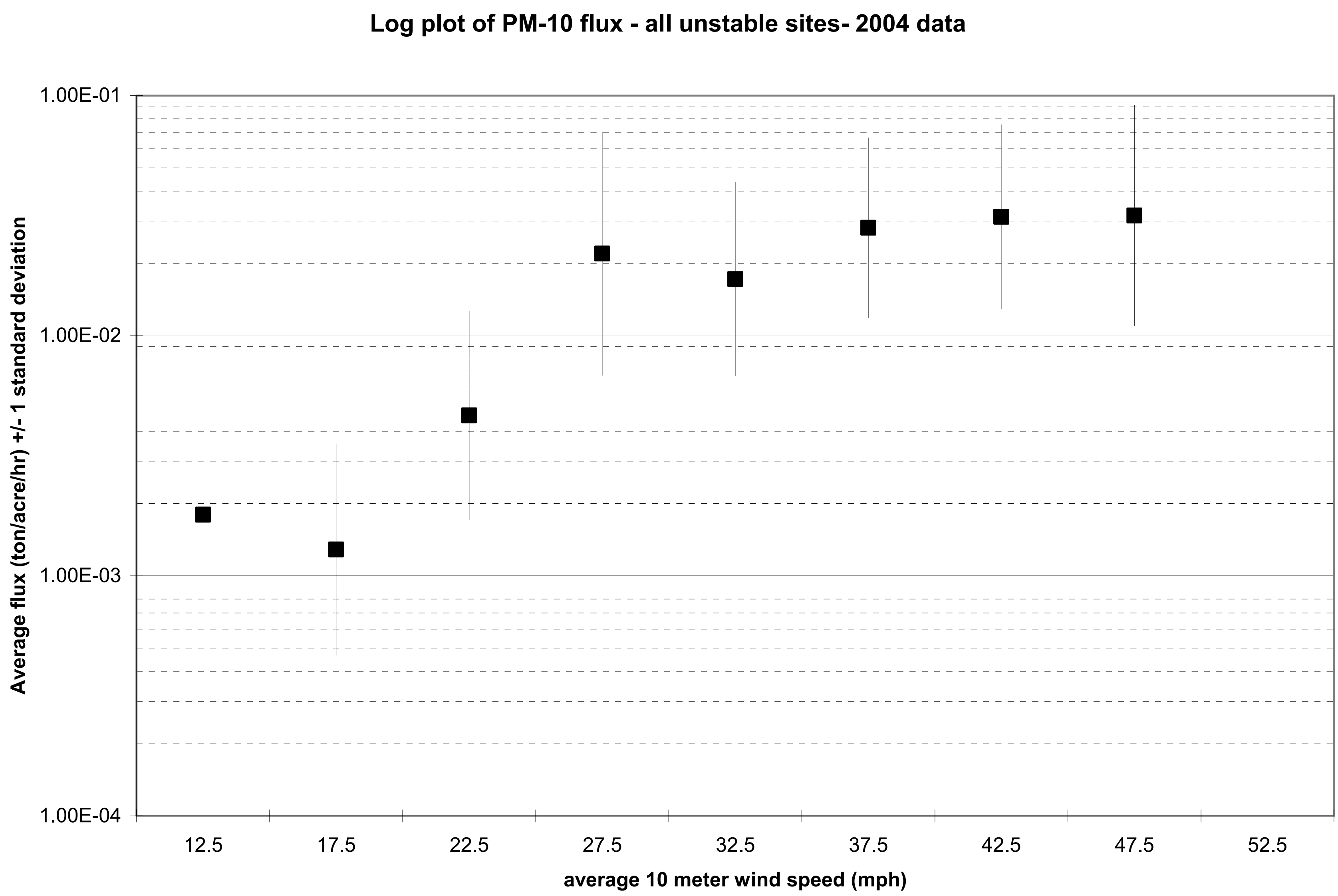
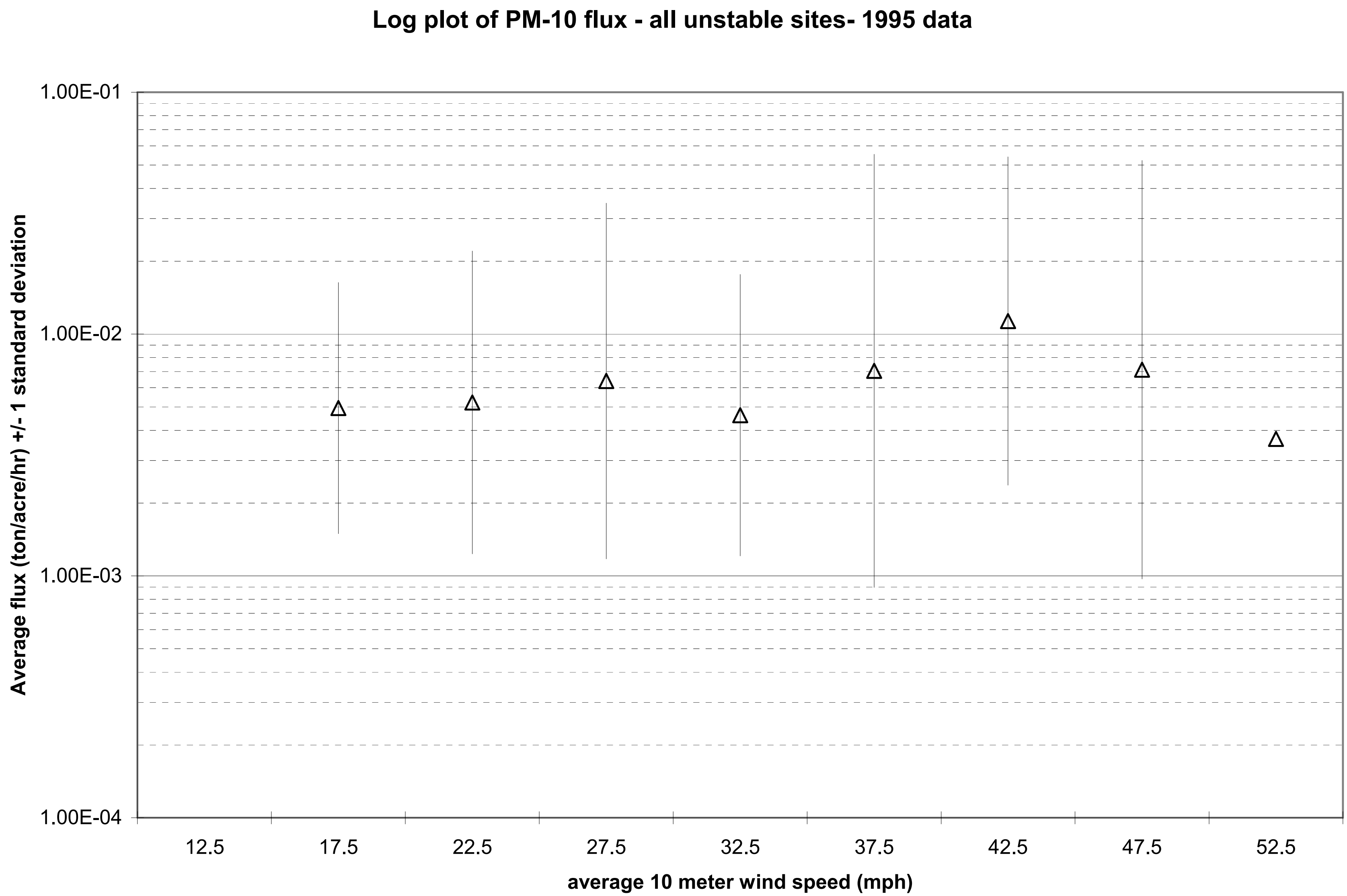


Figure 4. 1995 Unstable wind tunnel erosion rates. Data from Table 3.



Computed Ratios of 2004 erosion rates to 1995 erosion rates are shown in Table 4.

Table 4. Computed Ratios of 2004 to 1995 wind erosion rates, averaged over all Wind Erodibility Groups. Wind bands for which the sample size of either 2004 or 1995 data sets is less than 10 are shown in **<u>bold underlined font</u>** and should be considered unreliable.

ALL WEG Stable - ratio of 2004 to 1995 data			
wind band (mph)	**geo mean - 1 std.dev**	**geo mean**	**geo mean + 1 std.dev**
10-15			
15-20		**<u>0.82</u>**	
20-25	**<u>2.81</u>**	**<u>2.21</u>**	**<u>1.74</u>**
25-30	5.65	4.03	2.87
30-35	3.38	2.52	1.88
35-40	4.54	4.14	3.77
40-45	1.89	1.89	1.89
45-50	**<u>1.30</u>**	**<u>1.69</u>**	**<u>2.20</u>**
50-55			
55-60			
60-65			
average ratio	3.26	2.47	2.39
average ratio -reliable data	3.87	3.14	2.60

ALL WEG Unstable - ratio of 2004 to 1995 data			
wind band (mph)	**geo mean - 1 std.dev**	**geo mean**	**geo mean + 1 std.dev**
10-15			
15-20	**<u>0.31</u>**	**<u>0.26</u>**	**<u>0.22</u>**
20-25	**<u>1.39</u>**	**<u>0.89</u>**	**<u>0.57</u>**
25-30	5.81	3.44	2.03
30-35	5.62	3.72	2.47
35-40	13.24	4.00	1.21
40-45	**<u>5.45</u>**	**<u>2.76</u>**	**<u>1.40</u>**
45-50	**<u>11.33</u>**	**<u>4.45</u>**	**<u>1.75</u>**
50-55			
55-60			
60-65			
average ratio	6.16	2.79	1.38
average ratio reliable data	9.43	3.86	1.84

For reliable data, geometric mean 2004 stable erosion rates were, on average, a factor of 3.14 higher than 1995 unstable erosion rates, with multipliers ranging from 01.89 to 4.03.

Unstable erosion rates from the 2004 study were generally lower than the 1995 erosion rates in the lower wind speed bands (0.26 ratio at 15-20 mph and 0.89 at 20-25 mph), where data were unreliable. Reliable unstable 2004 erosion rates were generally 3.86 x higher than 1995 erosion rates in the 25-40 mph wind bands, with ratios ranging from 3.44 to 4.00.

The higher average unstable ratio values likely occurred for three reasons:

1) <u>Unstable 2004 sites were "fresh" and had not had time to re-crust or be partially depleted.</u>

Unstable sites for the 2004 study were created by disturbing stable soil surfaces with a metal rake, and then measuring the erosion rate immediately, before the surface could restabilize. In the 2004 study, objective methods, based on a sequence of the ball drop test, vegetation coverage, and percent nonerodible rock cover, were used to classify field sites as stable or unstable. Use of these objective methods resulted in classification of 31 of the 32 measured 2004 sites, as found, as "stable". Because of this finding, it was decided to intentionally create unstable surfaces with a metal gravel rake, to obtain a comparison of erosion rates from fresh unstable sites (worst-case scenario) to the same sites in stable conditions.

Soil surfaces were not intentionally destabilized in the 1995 study. Unstable sites were measured when found in field surveys. The age of the unstable (or recently destabilized) surfaces in the 1995 study was not known. Some of the 1995 sites may have been partially depleted of fine erodible material, or may have been partially re-stabilized. Our 1995 field notes are not sufficiently detailed to allow us to interpret the degree of instability. The 1995 field methods classified sites as stable or unstable by visual inspection of the physical sites (originally classified as "disturbed" or "undisturbed", followed by re-examination of the site photos in 1999-2000 to reclassify sites as "stable" or "unstable"

<u>2) There are more Unstable sites in 2004 than in 1995.</u> The result of the intentional destabilization is that there are 32 intentionally unstable sites in the 2004 study, compared to 29 as-found unstable sites in the 1995 study.

<u>3) There are more unstable measurement per site in 2004 than in 1995.</u>
Only one set of three or four velocity runs at each unstable site in 1995. In the 2004 study, three runs were performed at different locations on each site. Each run consisted of 4 velocity steps. Therefore, each of the 32 sites had three sets of four velocity increments in 2004, compared to one set of three or four velocity increments for 29 sites in 1995.

Because of the lower number of unstable datapoints in the 1995 study, we intentionally planned a change in field methods to create a larger unstable dataset in the 2004 field study. Field measurement methods for the 2004 wind tunnel study were purposely changed to increase the number of unstable wind erosion data points. This was done because of the because of differences in sampling methods. In the 2004 study, the wind tunnel was moved three times at each study site, and obtained erosion data at each wind speed from a soil surface that likely had been depleted less than during the 1995 study, where the tunnel was run in place for 10 minutes at each increasing wind speed.

<u>4) There may have been less PM-10 depletion during each run in the 2004 field study.</u>
The 2004 field study employed shorter periods (4.0 minutes) of steady-state erosion at

each velocity compared to the 1995 study (10 minutes), so that the average erosion rate was calculated on a surface that had not been depleted of erodible particles for as long a period as during the 1995 study. This was done because the 2004 field study used four progressive step increases in erosion velocity during each wind tunnel run, each step of duration 4 minutes, with a total run length of 16 minutes for the four velocity steps.

To conclude, the combination of intentional destabilization at a higher number of sites, with more measurements per site (reasons 2 and 3 above) created a much larger 2004 unstable data set than the 1995 data set. The 1995 data set is thinly populated in some wind speed bands (Table 3) because there were only three runs per site at a smaller number of as-found unstable sites. Additionally, erosion rates are higher in 2004 because the sites were freshly destabilized, as opposed to likely having been partially depleted or re-crusted in 1995.

Change in Erosion rates, Stable to Unstable

Table 5 compares the Unstable/Stable erosion ratios for 2004 and 1995 wind tunnel field study data.

Table 5. Computed Ratios of 2004 Unstable to Stable wind erosion rates and 1995 Unstable to Stable wind erosion rates, averaged over all Wind Erodibility Groups. Computed ratios for which data set sizes are less than 10 are shown in **bold underlined font**

ALL WEG Unstable/Stable ratios - 2004			
wind band (mph)	**geo mean - 1 std.dev flux, ton/acre/hr**	**geo mean flux ton/acre/hr**	**geo mean + 1 std.dev flux, ton/acre/hr**
10-15	1.03	1.04	1.04
15-20	0.87	0.80	0.74
20-25	1.93	1.52	1.20
25-30	1.28	2.12	3.52
30-35	2.57	2.16	1.81
35-40	2.85	2.28	1.82
40-45	3.27	2.79	2.38
45-50	**<u>2.81</u>**	**<u>2.47</u>**	**<u>2.18</u>**
50-55			
55-60			
60-65			
average, 10-25 mph		1.12	
average, 25-50 mph		2.36	

ALL WEG Unstable/Stable ratios- 1995			
wind band (mph)	**geo mean - 1 std.dev flux, ton/acre/hr**	**geo mean flux ton/acre/hr**	**geo mean + 1 std.dev flux, ton/acre/hr**
10-15			
15-20	**<u>N/A</u>**	**<u>2.54</u>**	**<u>N/A</u>**
20-25	**<u>3.90</u>**	**<u>3.77</u>**	**<u>3.63</u>**
25-30	1.24	2.49	4.97
30-35	1.55	1.46	1.38
35-40	0.98	2.36	5.69
40-45	**<u>1.14</u>**	**<u>1.91</u>**	**<u>3.22</u>**
45-50	**<u>0.32</u>**	**<u>0.94</u>**	**<u>2.75</u>**
50-55		**<u>0.34</u>**	
55-60			
60-65			
average, 15-25 mph		3.15	
average, 25-50 mph		1.83	

In 2004, the average ratio of Unstable/Stable erosion rate was 1.12 in the 10-25 mph wind bands, and 2.36 in the 25-50 mph wind bands. The data are flat in the 10-25 mph wind bands, increase between the 20-25 mph and 25-30 mph wind bands, and then plateau again in the 25-50 mph wind bands. This can be distinctly seen in Figure 5.

Compared to 1995, the average Unstable/Stable ratio for 2004 is lower in the10-25 mph wind bands, and higher in the 25-50 mph wind bands.
In 1995, the average ratio of Unstable/Stable erosion rate was 3.15 in the 10-25 mph wind bands, and 1.83 in the 25-50 mph wind bands. The ratio data tend to decrease with increasing wind speed (Figure 6).

Some of the 1995 wind band data are thinly populated (data set sizes less than 10). These “thin” ratios are shown in **bold underlined font** in Table 5. The small dataset sizes may contribute to unreliable estimates of the anticipated increase in wind erosion rate that accompanies destabilization of a soil surface, and an erratic, declining ratio pattern with increasing wind speed (Figure 6)

In contrast, the 2004 data, with much larger data set sizes, show a more consistent pattern of negligible increase in the lower wind bands, and a plateau in the higher wind bands (Figure 6).

Figure 5. Plot of Unstable/Stable flux ratio data for 2004, averaged over all Wind Erodibility Groups. The 47.5 mph data point should be considered unreliable (n < 10).

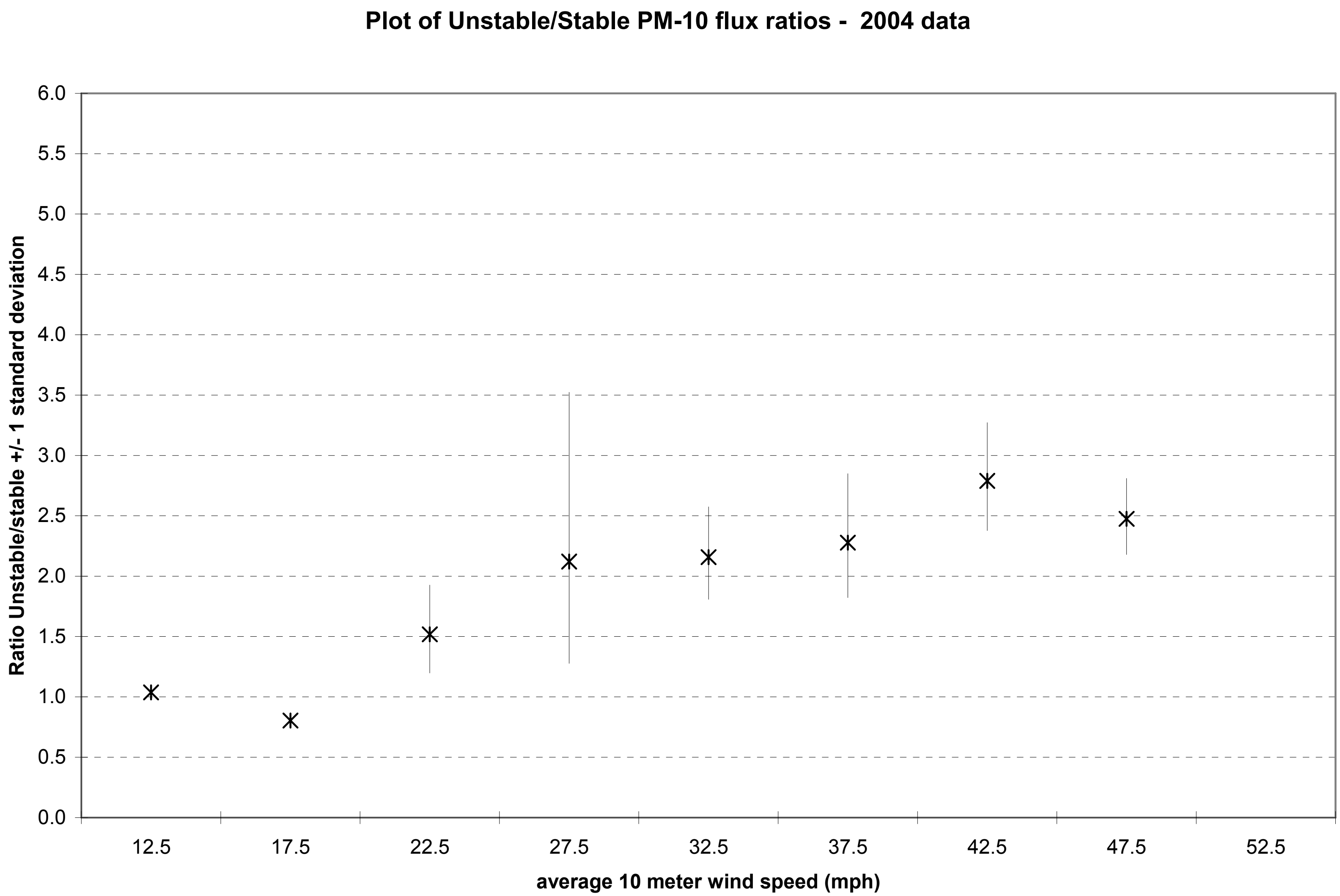


Figure 6. Plot of Unstable/Stable flux ratio data for 1995, averaged over all Wind Erodibility Groups. The 17.5, 22.5, 42.5, 47.5 and 52.5 mph wind band data should be considered to be unreliable (n < 10).

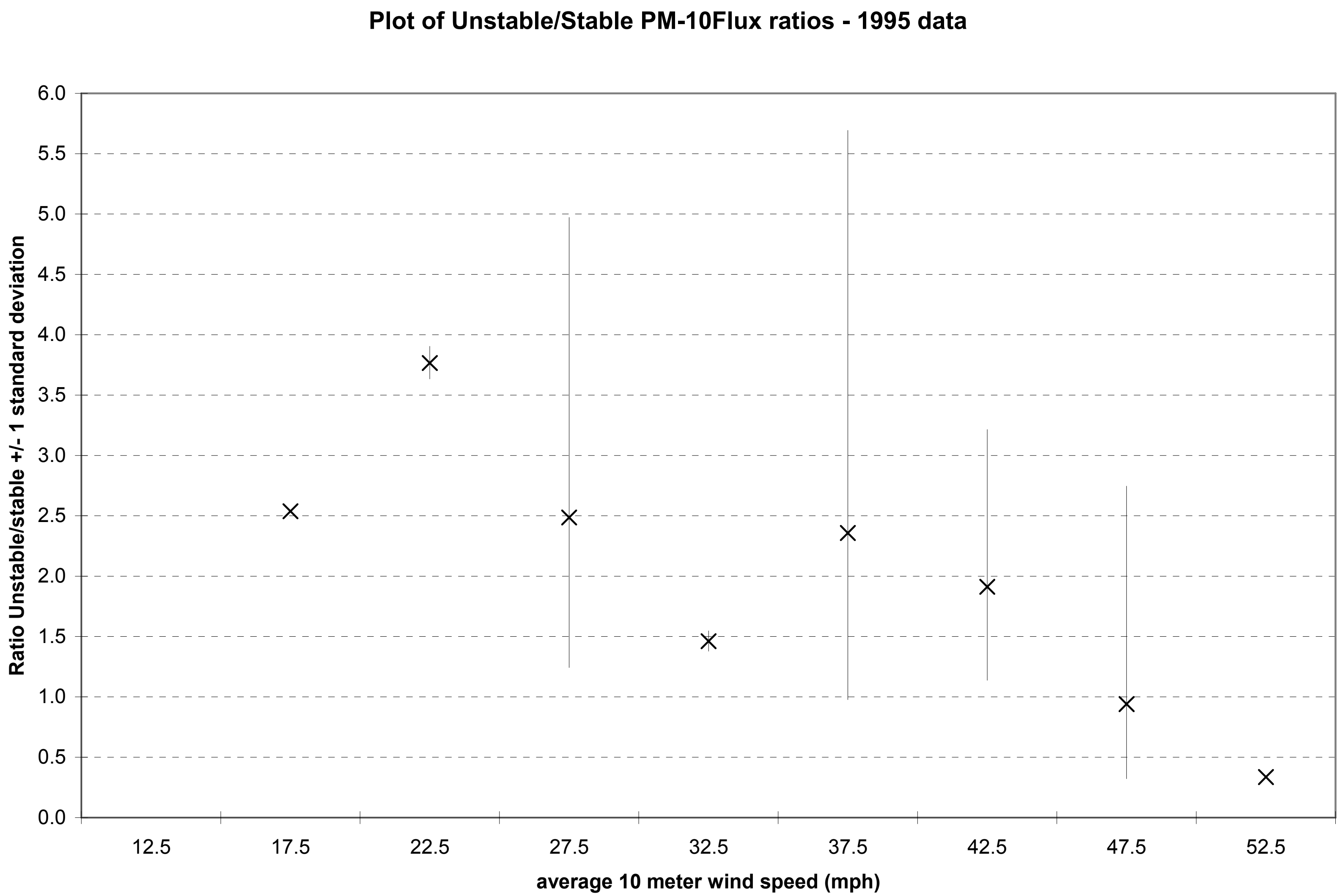


Figure 5 shows two distinct zones for the 2004 data set. The 12.5 (10-15mph) and 17.5 (15-20) mph wind bands show no increase in erosion rate for unstable surfaces compared to stable surfaces. The 20-25 mph is a transitional zone with an unstable wind erosion rate about 1.5x the stable value. The 27.5-37.5 mph wind bands show a plateau where the unstable erosion rate is about 2.2x the stable rate. The 47.5 mph wind band (unreliable) shows an erosion rate comparable to the 27.5-37.5 mph wind bands.

In contrast, Figure 6, shows erratic decline in the Unstable/Stable ratios for the reliable data in the 27.5 to 37.5 mph wind bands, with unstable rates ranging from about 1.5x in the 30-35 mph (plotted as 32.5 mph) wind band to 2.5x in the 25-30 mph (plotted as 27.5 mph) wind band.

Comparison of 2004 Stable land emission factors to 1998-1999 Stabilized Land emission factors.

Table 6 shows stabilized soil surface emission factors developed as part of a 1998-1999 wind tunnel study to evaluate the long-term weathering performance of seven commercially available dust suppressants applied to soil surfaces in Clark County. Reported data available for three wind bands range from 1.1×10^{-4} to 2.7×10^{-4} ton/acre/hour, generally one to one and a half orders of magnitude lower than values reported for stable lands in Table 1.

Table 6. Emission factors for <u>stabilized</u> dust-suppressant-treated soil surfaces. Surfaces are intact. Suppressant weathering ages range from one to five months.

Phase II Results - Intact dust suppressants - Spike corrected				
Wind Band	Geom mean flux	Geom mean flux	Geom mean flux	Number
(mph)	-1 Std. Dev.		+1 Std. Dev.	of runs
	(ton/acre/hr)	(ton/acre/hr)	(ton/acre/hr)	spike corrected
10-15				N/A
15-20	1.00E-04	2.65E-04	7.04E-04	18
20-25	5.24E-05	1.38E-04	3.65E-04	32
25-30	1.92E-05	1.09E-04	6.19E-04	18
30-35	N/A	N/A	N/A	2
35-40	N/A	N/A	N/A	N/A
40-45	N/A	N/A	N/A	N/A
45-50	N/A	N/A	N/A	N/A
50-55	N/A	N/A	N/A	N/A
55-60	N/A	N/A	N/A	N/A
60-65	N/A	N/A	N/A	N/A

Reported data for stabilized soils emission factors, from Table 6, expressed as a ratio to emission factors for all stable wind erodibility groups, from Table 1, are shown in Table 7. Results indicate that recently-applied dust suppressants have emission factors ranging from 0.4% to 18.6% of the values for wind erodibility groups.

Table 7. Ratio of emission factors, stabilized soils to stable soils.

Emission factor ratio of stabilized soils to (all WEG stable soils), as %			
Wind Band	Geom mean flux	Geom mean flux	Geom mean flux
(mph)	-1 Std. Dev.		+1 Std. Dev.
	(ton/acre/hr)	(ton/acre/hr)	(ton/acre/hr)
10-15			
15-20	18.6%	16.5%	14.7%
20-25	5.9%	4.5%	3.4%
25-30	0.4%	1.1%	3.1%
30-35	N/A	N/A	N/A
35-40	N/A	N/A	N/A
40-45	N/A	N/A	N/A
45-50	N/A	N/A	N/A
50-55	N/A	N/A	N/A
55-60	N/A	N/A	N/A
60-65			

Reported data for stabilized soils emission factors, from Table 6, expressed as a ratio to emission factors for all unstable wind erodibility groups, from Table 2, are shown in Table 8. Results indicate that recently-applied dust suppressants have emission factors ranging from 0.3% to 21.5% of the values for wind erodibility groups.

Table 8. Ratio of emission factors, stabilized soils to unstable soils.

Emission factor ratio of stabilized soils to (all WEG unstable soils), as %			
Wind Band	Geom mean flux	Geom mean flux	Geom mean flux
(mph)	-1 Std. Dev.		+1 Std. Dev.
10-15			
15-20	21.5%	20.6%	19.8%
20-25	3.1%	3.0%	2.9%
25-30	0.3%	0.5%	0.9%
30-35	N/A	N/A	N/A
35-40	N/A	N/A	N/A
40-45	N/A	N/A	N/A
45-50	N/A	N/A	N/A
50-55	N/A	N/A	N/A

For the purposes of planning reductions for a State Implementation Plan, if the data in Table 8 were to be expressed as a *percentage reduction* in emissions factors, defined as (100% - tabulated value in Table 8), the reductions would range from 78.5% to 99.7%. Results from Table 8 shown as percentage reductions, are shown in Table 9.

Table 9. Percent reduction of unstable land emissions factors resulting from stabilization by recently applied commercially available dust suppressants.

Percentage unstable EF reduction from dust suppressant stabilization			
Wind Band	Geom mean flux	Geom mean flux	Geom mean flux
(mph)	-1 Std. Dev.		+1 Std. Dev.
10-15			
15-20	78.5%	79.4%	80.2%
20-25	96.9%	97.0%	97.1%
25-30	99.7%	99.5%	99.1%
30-35	N/A	N/A	N/A
35-40	N/A	N/A	N/A
40-45	N/A	N/A	N/A
45-50	N/A	N/A	N/A
50-55	N/A	N/A	N/A

As a simple worst-case rule of thumb, the stabilized land emissions factors could be estimated to be approximately one-fifth (20%) of the emissions from unstable lands. Best case reduction could be estimated to be approximately a 99% reduction of unstable land emissions factors.

Velocity threshold for initiation of erosion, 1995

The following method was used to develop the threshold information in 1995.
1) Close the damper until a spike occurred, record the pitot tube pressure drop corresponding to that threshold, perform the velocity profile measurements at that pressure drop while the tunnel was running, and then continue to close the damper until the desired test velocity for that run was achieved, then hold that velocity for 10 minutes.

The tunnel was run in exactly the same place three or four times, each time for 10 minutes, with each successive velocity being higher than the previous one. The tunnel was therefore eroding a depleted surface each time.

Results for the 1995 wind tunnel study are shown in Table 10 below. The mean velocity for 56 stable sites was 27 mph. The mean for 29 unstable sites was 26.4 mph. The 16th percentile value for stable sites was 21.8 mph. The 16th percentile value for unstable sites was 22.2 mph. Results for unstable sites and stable sites are not significantly different. For its 2001 SIP, Clark County used a threshold of 25 mph for its Natural Events Action plan

Table 10. 1995 Wind tunnel study threshold values for initiation of erosion.

Table D.1 Statistical summary of aerodynamic roughnesses and PM-10 spike velocities
All soils

Unstable (disturbed) sites (new classification) n = 29			
		computed	extrapolated
category	aero roughness (cm)	spike velocity @ 7.6 cm (mph)	spike velocity @ 10 m (mph)
minimum	0.0027	9.6	18.2
mean - 1 std.dev	0.0139	11.3	22.2
mean	0.0514	13.0	26.4
mean + 1 std.dev	0.1898	14.9	31.3
maximum	0.4099	17.3	37.1

Stable (undisturbed) sites (new classification) n = 56			
		computed	extrapolated
category	aero roughness (cm)	spike velocity @ 7.6 cm (mph)	spike velocity @ 10 m (mph)
minimum	0.0001	6.7	12.4
mean - 1 std.dev	0.0124	10.9	21.8
mean	0.0712	12.7	27.0
mean + 1 std.dev	0.4106	14.7	33.4
maximum	0.4899	19.1	39.1

The data show that a 16th percentile ((mean – 1 standard deviation, so that 84% of the data exceeded these values) velocity threshold, extrapolated to a measurement at 10 meters from the velocity profiles observed in the wind tunnel, was 22.2 mph for sites rated as unstable, and 21.8 mph for sites rated as stable. A value of 20 mph was used in the Valley-wide estimates prepared by UNLV for Clark County in 2000 and 2001.

Velocity threshold for initiation of erosion, 2004

Compared to the 1995 field study, wind tunnel threshold measurement techniques were changed during the 2004 field study.

In 1995, the tunnel bypass damper was placed in the open position, flow was initiated in the tunnel, and the damper was then closed until a PM-10 concentration signal (or "spike") exceeding 1 mg/m^3 was observed on the TSI Dust-Trak® . The damper was held in this position and the tunnel velocity profile was performed. Once the aerodynamic roughness was calculated, the pitot tube tunnel center-line pressure drop associated with the spike was converted to a wind velocity at 10 meters. This velocity was interpreted as the threshold for initiation of PM-10 erosion. TSI PM-10 data were not recorded during the profiling run and the duration of the profiling run was variable. The tunnel was then operated in the same place for three or four 10 minute runs. Each run was at a constant velocity, and the three velocities were at progressively higher speeds.

In the 2004 study, the tunnel bypass damper was placed in the open position, flow was initiated, and the velocity profile was performed with the damper in the open position. Once pitot tube profiling was completed, the tunnel continued to run with the damper in the wide open position until five minutes were completed. TSI PM-10 data were recorded during the profiling run. The aerodynamic roughness was used to estimate the 10-meter velocity corresponding to the wide open damper position. The tunnel was then operated for four or five progressively increasing velocity steps. The steps were created by moving the damper until each pre-determined pitot tube center line pressure drop was observed and then holding the damper at each position usually for 4.0 minutes.

Because of this change in field technique, velocities for initiation of a 1 mg/m^3 PM-10 “spike” are not available in the 2004 data set. Many of the 2004 profiling data sets obtained at the wide-open damper position do show a “spike” at the wide open damper position.

Net PM-10 erosion rate data from the 2004 field study were extracted from the 2004 flux calculation database for both stable and unstable field sites, and were statistically analyzed to see if one could calculate a threshold velocity below which there was little or no observed PM-10 flux. Two techniques were used to analyze the 2004 data for velocity thresholds:

1) Extract all wide open damper velocity and PM-10 flux data for stable and unstable cases (regardless of Wind Erodibility Group) and calculate means and standard deviations for fluxes obtained in several velocity ranges

2) Extract all stable and unstable data (regardless of Wind Erodibility Group) and plot the data to see if they show a definite trend towards low or zero flux at a specific velocity.

Results for Method 1) are shown in Table 11.

Table 11 – 2004 stable profile run data. Average velocities for several low PM-10 flux ranges

Stable

Flux range ton/acre/hour	Mean velocity	Standard deviation	Sample size
< 10-5	15.6	1.6	12
> 10-5 and < 10-4	15.3	0.7	3
> 10-4 and < 10-3	15.3	2.7	22
> 10-3 and < 10-2	15.4	1.8	59

Unstable

Flux range ton/acre/hour	Mean velocity	Standard deviation	Sample size
< 10-5	15.8	2.5	11
> 10-5 and < 10-4	16.3	0.4	2
> 10-4 and < 10-3	15.7	2.3	28
> 10-3 and < 10-2	16.1	2.4	54

Examination of the data in Table 11 shows that there is no observable trend towards lower velocities in the lower profiling flux ranges. A threshold for initiation can't be established from this method.

Results for Method 2) are shown in Figures 7 and 8.

Figure 7, a log-scale plot of all stable flux data (n = 465) shows that there are measurable PM-10 fluxes (12 zero values are omitted) to the lowest velocities observed in the wind tunnel study. The minimum velocity in the stable data set is 10.3 mph. No flux data are available for velocities below this value. As a worst-case scenario, it is recommended that stable flux data from the 10-15 mph wind band be used for hourly average winds less than 10 mph.

Figure 8, a log-scale plot of all non-zero unstable flux data (n = 460) also shows that there are measurable PM-10 fluxes (11 zero values are omitted) to the lowest velocities observed in the wind tunnel study. The minimum velocity in the unstable data set is 11.4 mph. No flux data are available for velocities below this value. As a worst-case scenario, it is recommended that unstable flux data from the 10-15 mph wind band be used for all hourly average winds less than 10 mph.

Figure 7. Logarithmic plot of all non-zero 2004 Stable flux data against 10-meter wind speed (n=465). Zero flux values (n=12) are omitted

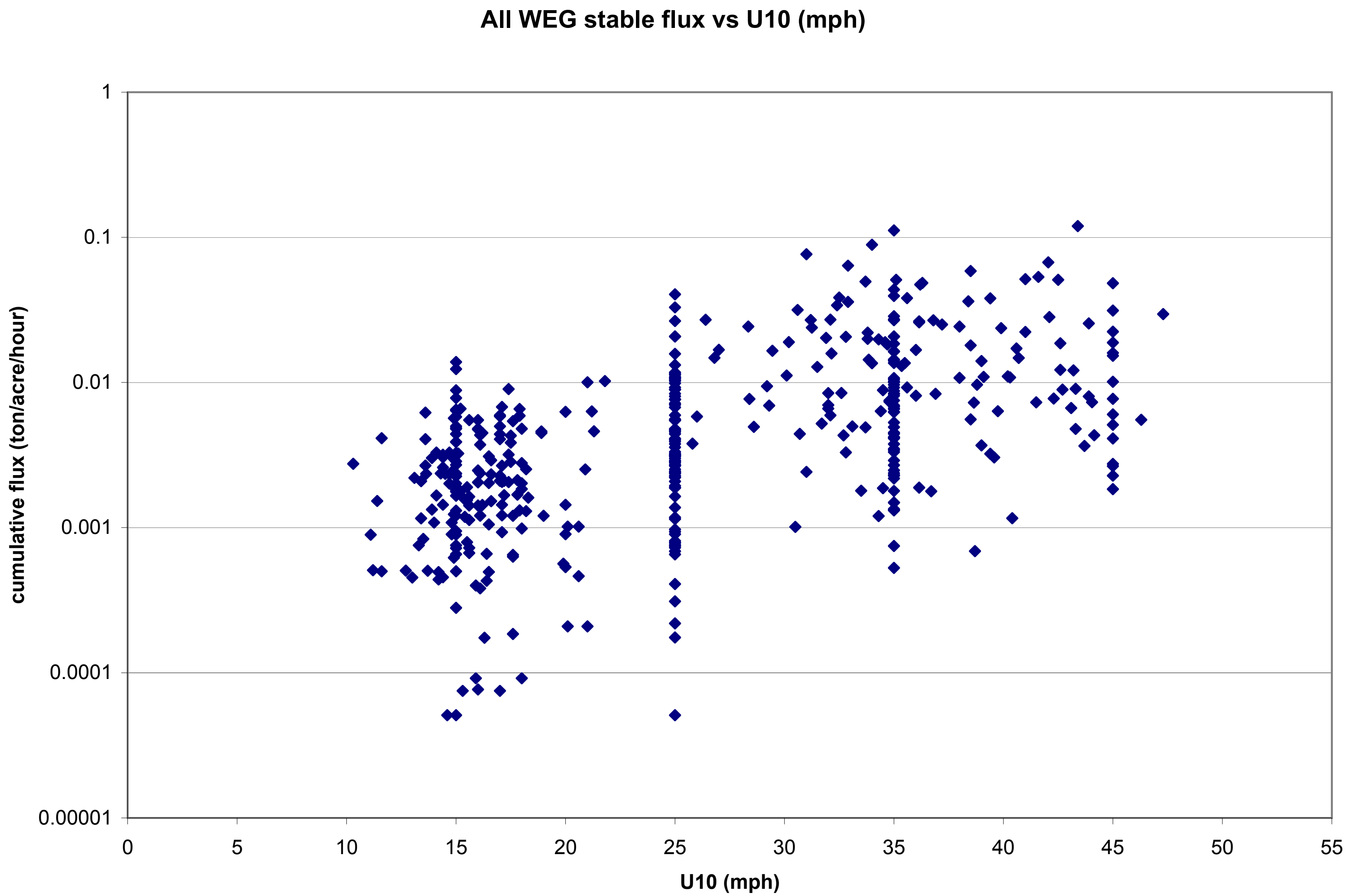
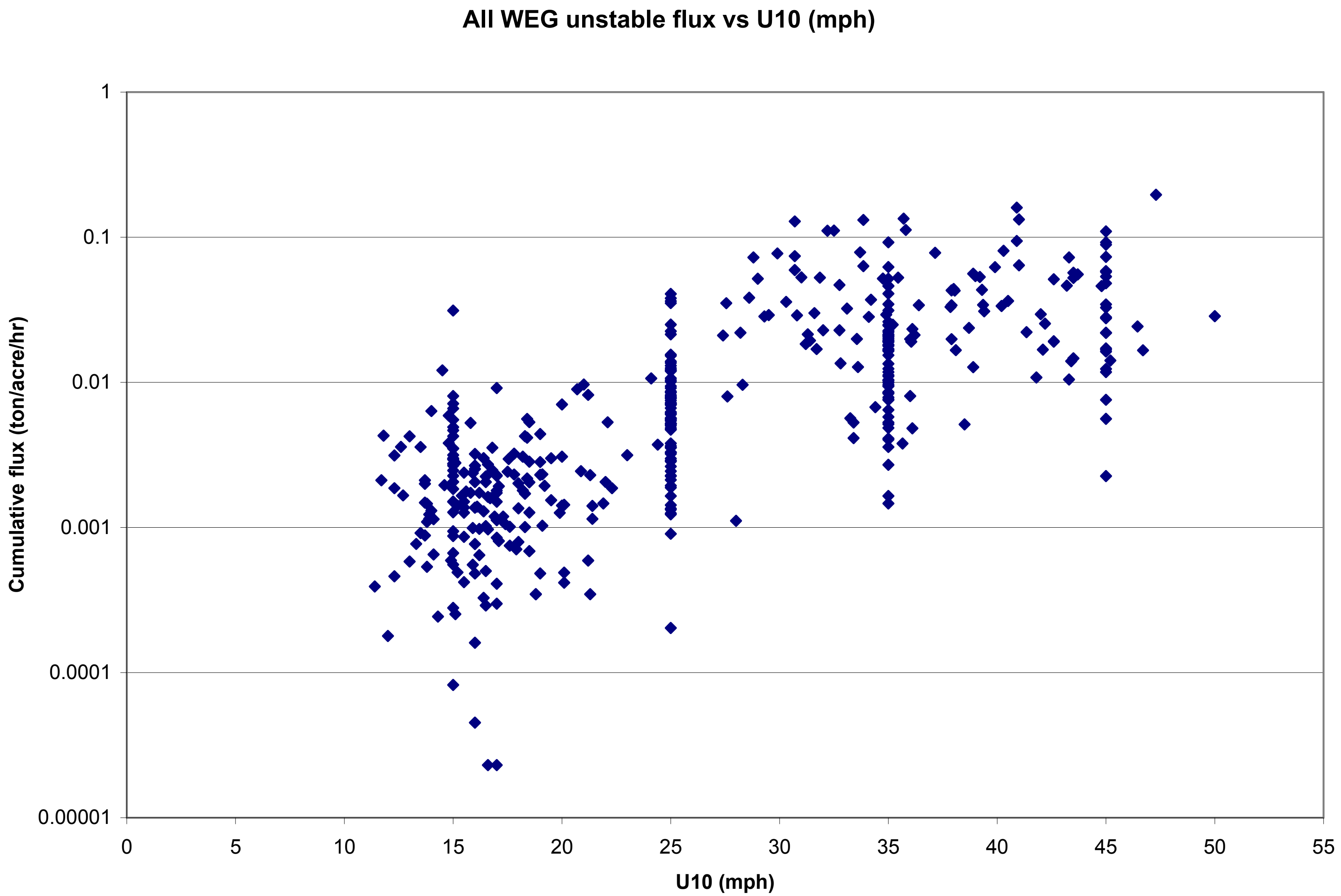


Figure 8. Logarithmic plot of all non-zero 2004 Unstable flux data against 10-meter wind speed (n=460). Zero flux values (n= 11) are omitted.



Threshold velocities for Natural Events Action plan

Data from the 2004 wind tunnel study were examined to determine a 10-meter velocity threshold for significant non-linear increases in PM-10 flux. Two approaches were used 1) Raw flux data from all wind tunnel sites were plotted on a linear scale and examined for a nonlinear increase in erosion rate. The plots are shown in Figures 9 and 10.

2) Processed logarithmic mean and standard deviation flux data, already plotted in Figures 1 (stable) and 3 (unstable), were examined for a “slope break” to see if a transition from lower to higher PM-10 flux rates could be established.

Results for Method 1) are plotted in Figures 9 and 10.

Figure 9 for Stable surfaces shows that:
a) below 25 mph, the majority of Stable PM-10 fluxes, with four exceptions, are below 0.010 ton/acre/hour.
b) the Stable PM-10 flux distribution broadens to values well above 0.010 ton/acre/hour at velocities above 25 mph.

Figure 10 for Unstable surfaces shows the same pattern as the figure for Stable fluxes:
a) below 25 mph, the majority of Unstable PM-10 fluxes, with four exceptions, are below 0.010 ton/acre/hour.
b) the Unstable PM-10 flux distribution broadens to values well above 0.010 ton/acre/hour at velocities above 25 mph.

Figure 9-10 data indicate that a non-linear increase in PM-10 flux begins to occur once 10-meter velocities exceed 25 miles per hour.

Results for Method 2, plotted in Figures 1 and 3, show a slope “break” occurs in the 20-25 mph (22.5 mph plotting point) wind band. PM-10 flux rates for velocities above the 20-25 mph wind band are about one order of magnitude higher than PM-10 flux rates for velocities below the 20-25 mph wind band.

Figure 9. Linear plot of Stable PM-10 flux against 10-meter wind speed. All Wind Erodibility groups. n = 477

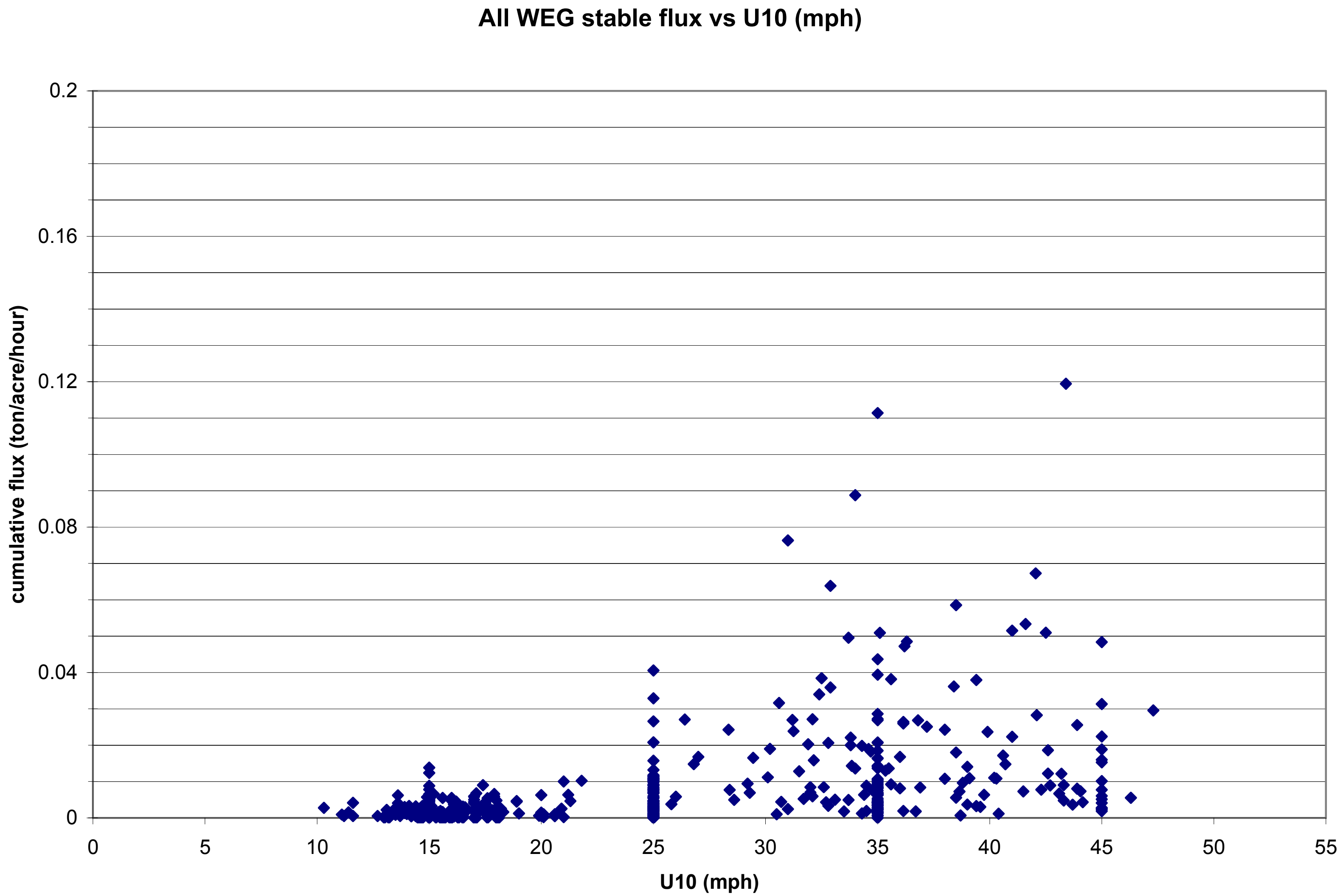
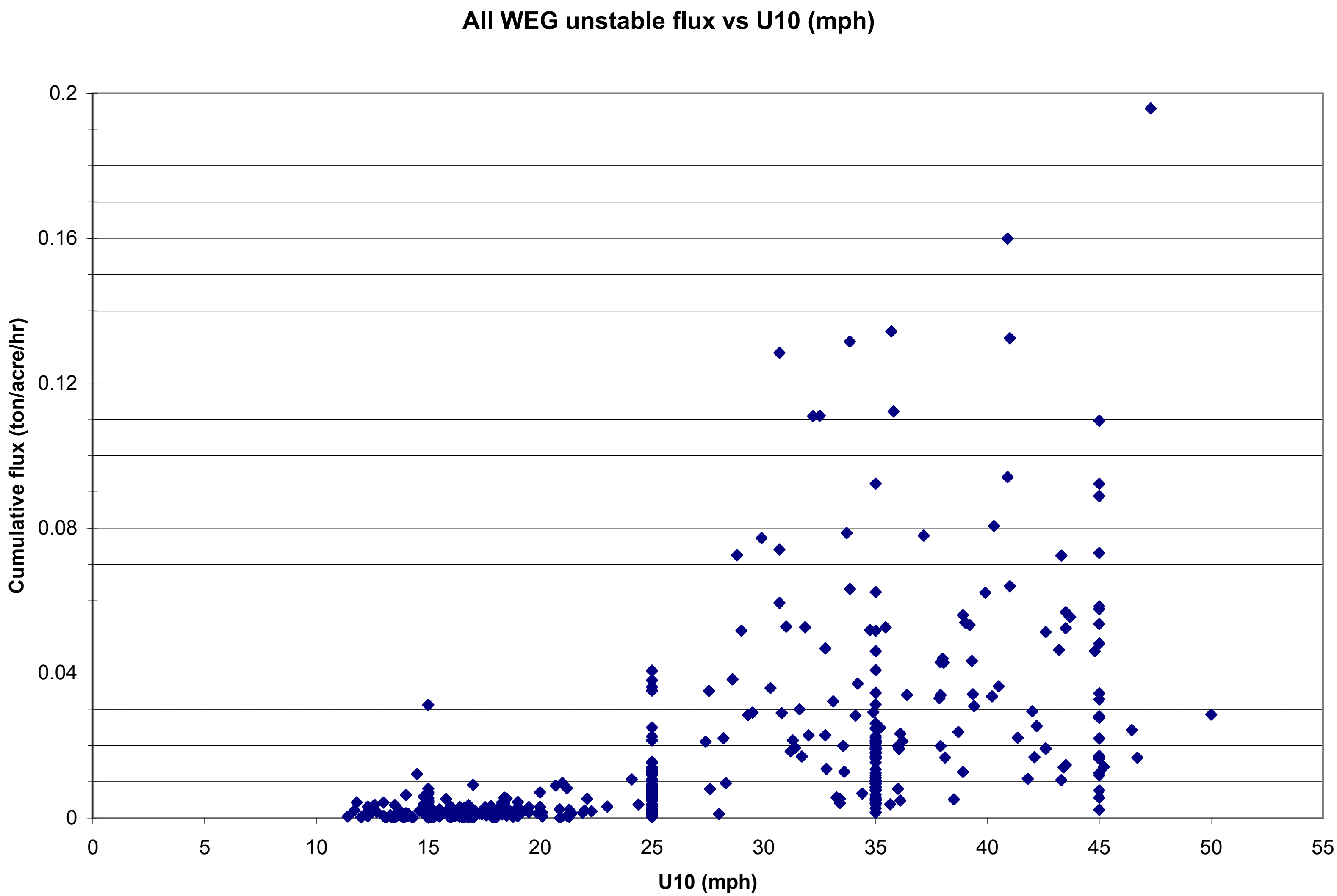


Figure 10. Linear plot of Unstable PM-10 flux against 10-meter wind speed. All Wind Erodibility groups. n = 471



Impacts of changes from 1995 to 2004 for SIP purposes

1) Comparing absolute flux rates 2004 to 1995.

- a) From Table 2, Stable 2004 fluxes were
  - i) 18% lower in the 15-20 mph wind band (1995 data unreliable in this band), and
  - ii) ranged from 1.7X to 4.0X higher in the 20-25 mph and higher wind bands,
- b) From Table 4, Unstable 2004 fluxes were
  - i) 74% lower in the 15-20 mph wind band (1995 data unreliable) and 11% lower in the 20-25 mph wind band
  - ii) ranged from 2.8X to 4.4X higher in the 20-25 mph and higher wind bands.

2) Comparing unstable to stable flux rates.

From Table 5, for modeling impacts of converting Unstable land to Stable land

- a) compared to 1995, the 2004 data are much more reliable than the 1995 data because of larger sample size.
- b) the 2004 show a
  - i) no increase in flux compared to stable lands below the 20-25 mph (22.5 mph plotting point) wind band
  - ii) a transitional increase where unstable fluxes are 1.5X higher than stable in the 22.5 mph wind band, and
  - iii) a consistent Unstable/Stable ratio of about in the 2.2 to 2.7 range above a threshold of 22.5 mph (20-25 mph wind band),

The Unstable/Stable ratios for the 1995 data set are unreliable at the low and high ends of the wind-band ranges, but, in the middle wind bands (27.5 to 37.5 mph) where reliable data are available, they range from 2.5 to 1.5, and do not show a consistent pattern.

3) Thresholds for Initiation of PM-10 erosion. The 1995 data showed a distinct threshold for initiation of erosion of about 20-22 mph (Table 10). The 2004 data do not show a threshold for initiation of PM-10 erosion, and exhibit measurable fluxes at 10-meter velocities as low as 10-11 mph (Figures 7 and 8) Although some sites showed zero net flux in the 10-15 mph wind band, other field sites did exhibit measurable fluxes in the 10-15 mph wind ban. The difference in result is a consequence of a change in field measurement technique in 2004.

4) Natural Events Action Plan threshold. The 2004 data, analyzed by two methods show that non-linear increases in PM-10 flux generally begin occur at 10-meter velocities exceeding 25 mph. It is recommended that the 25 mph threshold for a natural event be used for planning purposes.

5) Effects of applying dust suppression to Unstable lands. Mean stabilized land PM-10 emission factors range from 1.1×10^{-4} to 2.6×10^{-4} ton/acre/hr (Table 6). The 2004 unstable

land PM-10 flux can be reduced by 78.5%-99.7% by application of dust suppressants (Table 9).