Pahrump Valley, Nevada

PM_{10}
Ten Years of Success

Ten Year Update
Toward Attaining the 24-hour Federal Standard
for Particulate Matter 10 Microns and Smaller

June 2015

Department of Conservation and Natural Resources
Division of Environmental Protection
Bureau of Air Quality Planning

NDEP NEVADA DIVISION OF ENVIRONMENTAL PROTECTION
protecting the future for generations

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Contents

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Executive Summary

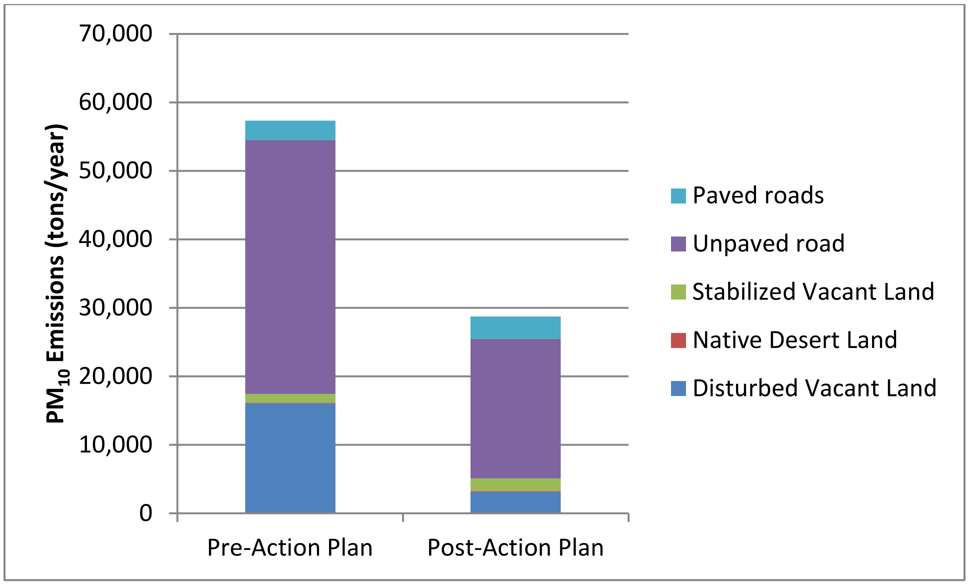
This report summarizes the Nevada Division of Environmental Protection, Bureau of Air Quality Planning's (NDEP-BAQP) research analyzing the success of mitigation measures implemented to reduce particulate matter emissions in the Pahrump Regional Planning District. This report is a culmination of the cooperative efforts by the NDEP-BAQP, the Nye County Board of Commissioners, the Pahrump Town Board, and the U.S. Environmental Protection Agency (USEPA) (collectively, the Parties) to reduce particulate emissions and avoid a nonattainment designation for the area. The final evaluation of this collaborative endeavor demonstrates the effectiveness of the 2003 *Pahrump Valley Clean Air Action Plan Memorandum of Understanding* (MOU)[1] and the subsequent *Clean Air Action Plan* (Action Plan)[2] to address particulate emissions. It describes the analyses and results obtained in reducing the emissions and the atmospheric concentration of particulate matter 10 microns in diameter and smaller (PM_{10}) in the Pahrump Regional Planning District during the period 2003 to 2010. The boundaries of the Town of Pahrump, or Pahrump, and the Pahrump Regional Planning District are essentially the same, and the terms are used interchangeably in this report.

The Town of Pahrump is located in the Pahrump Valley (Nye County) in southern Nevada, approximately 60 miles west of Las Vegas and 60 miles east of Death Valley. The prevalence of large areas of disturbed vacant land and unpaved roads contributed to a significant increase in fugitive dust, or $PM_{10,}$ in the late 1990s and early 2000s. To address this issue and to avoid the area becoming nonattainment for PM_{10}, the NDEP-BAQP developed and implemented the Pahrump MOU and Action Plan in collaboration with the Nye County Board of Commissioners, the Pahrump Town Board, and the U.S. Environmental Protection Agency.

After establishing a base line emission inventory to identify the source(s) of the problem, the Parties identified and implemented control measures, with particular focus on vacant disturbed land and unpaved roads. A second emission inventory was conducted 10 years later to verify the efficacy of these measures in controlling dust emissions and quantifying the improvement in air quality. Undoubtedly, the mitigation efforts to reduce dust from disturbed vacant land and unpaved roads resulted in major dust emission reductions, with approximately a 50 percent decrease in total emissions (Figure A).

[1] *Pahrump Valley Clean Air Action Plan Memorandum of Understanding* (http://ndep.nv.gov/baqp/monitoring/docs/final_mou091503.pdf) (last viewed May 6, 2015)
[2] *Clean Air Action Plan – Pahrump Regional Planning District. Plan to Attain Federal Standards for Particulate Matter 10 Microns and Smaller*. Final Draft, June 30, 2006, http://ndep.nv.gov/baqp/monitoring/docs/caap.pdf .

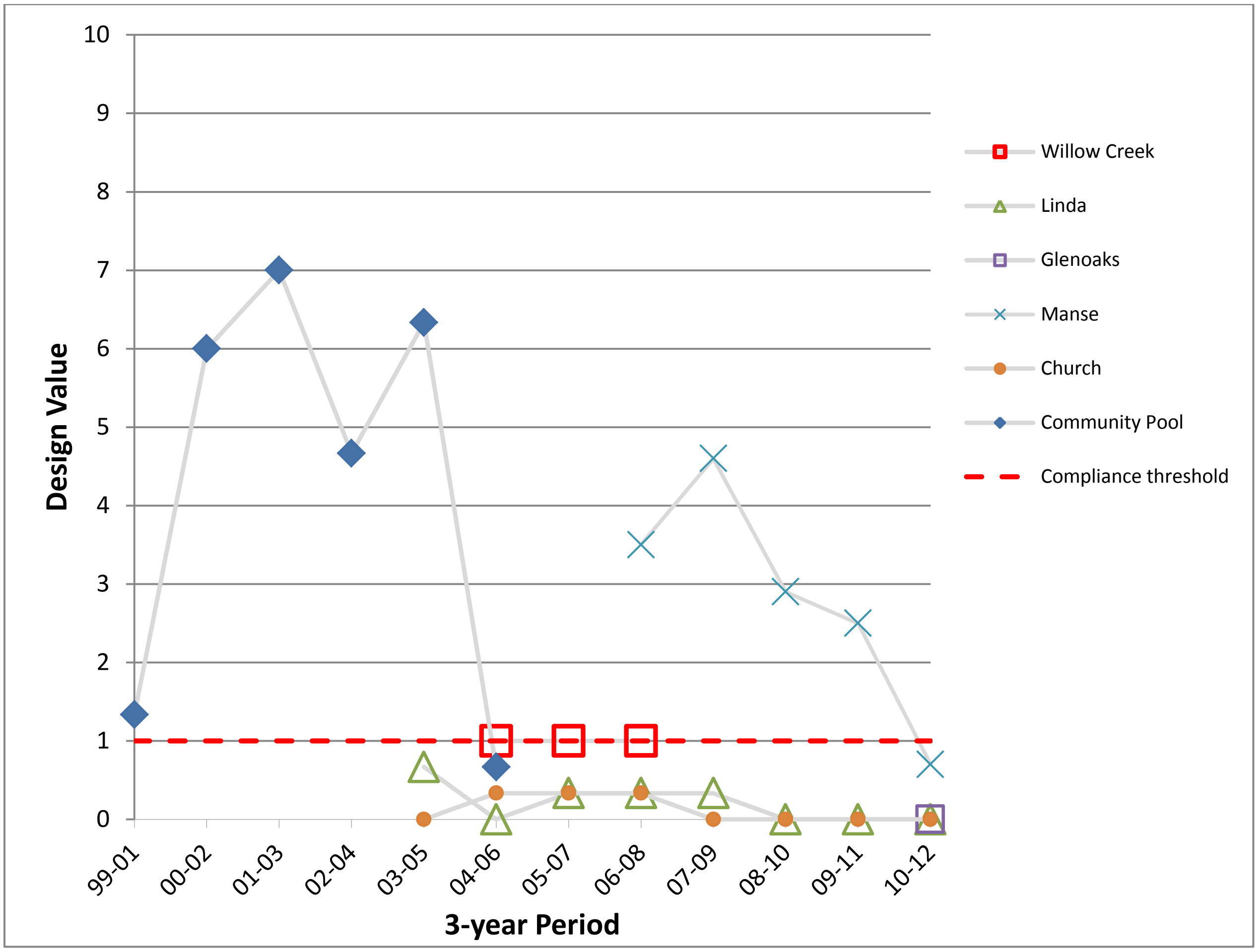
Figure A: PM_{10} emissions from major sources as estimated by the inventories before and after the implementation of the Action Plan (Pre-Action Plan and Post-Action Plan, respectively).



Monitored air quality data demonstrated a significant improvement as well. Even with exceptional events included in the data set[3], the number of violations of the 24-hour PM_{10} national ambient air quality standards (NAAQS) rapidly reached zero after the 3-year period of 2004-2006 at all monitoring sites except one, the Manse monitoring station (Figure B). Even including exceptional events, this site reached attainment in 2010. When exceptional events are excluded from the Manse data, the site demonstrates attainment since it was established in 2006.[4] Further analysis, presented in this report, confirms that there are statistically significant downward trends in ambient PM_{10} concentration within the urban area of Pahrump under low-to-medium wind speeds.

[3] *See* Table 6: Monitored exceedances of the 24-hour PM_{10} NAAQS, between 2001 and 2012, including exceptional events. Data in brackets are either not in USEPA's Air Quality System (AQS) database or represent a partial year of data in the AQS.
[4] *See* Table 7. Expected exceedances, or "design value," of the 24-hour PM_{10} NAAQS in Pahrump, between 2001 and 2012, excluding exceptional events.

Figure B: Expected exceedances or "design value" for each 3-year period as recorded by the monitoring stations in Pahrump, including exceptional events. Compliance with the 24-hour PM_{10} NAAQS is reached when no more than one exceedance per year is observed on a 3-year average basis (the red dashed line marks this threshold). The Linda station was deemed to measure the PM_{10} background level.



1. Introduction

This report is the culmination of the 2003 MOU and the Action Plan and describes the analyses and results obtained in reducing the emissions and the ambient concentration of PM_{10} in Pahrump during the period 2003 to 2010. The MOU and the Action Plan detail the events, the causes and the initiatives that took place to investigate and properly address the substantial degradation in air quality that Pahrump experienced in the late 1990s and early 2000s. The NDEP refers the reader to those documents for a more comprehensive introduction and background on the issue and initiatives related to air quality in Pahrump.

This report is based on data that was available as of mid-2013. It focuses on the data collection and analyses that took place between 2010 and 2013 and evaluates the initial results of the control measures on PM_{10} emissions that were put in place starting from 2004. The main objective of this report is to document the substantial reduction in PM_{10} emissions and improvement in air quality in Pahrump. To facilitate the presentation of the evidence, the term '*pre*-Action Plan' is used to describe measurements, data collection, and analyses that relate to air quality conditions before the implementation of the control measures (circa 2001-2004). Similarly, the term '*post*-Action Plan' is used to describe air quality conditions, data collection, and analyses that relate to more recent years (circa 2007-2011) and were used to assess the positive impact of the control measures adopted in the MOU and Action Plan. This temporal distinction is somewhat artificial as for instance, air quality in Pahrump was continuously monitored during the 2001-2011 period and is ongoing. Likewise, the control measures that were put in place starting from 2004 likely resulted in a gradual, rather than sudden, change in emissions and air quality. Nevertheless, by considering only the 'start' and 'end' point of these continuous changes, differences in emissions and air quality between pre- and post-Action Plan became more detectable by the adopted statistical analyses.

2. Background

In this section, we briefly provide a physical and geographical description of the Pahrump Regional Planning District, historical background on the causes of the substantial increase in atmospheric concentration of coarse particulate matter that occurred during late 1990s and early 2000s, and the initiatives to restore air quality conditions.

2.1 Physical Setting

The unincorporated Town of Pahrump is located in Pahrump Valley (Nye County) in southern Nevada, approximately 60 miles west of Las Vegas and 60 miles east of Death Valley (Figure 1). The Pahrump Valley sits in the rain shadow of the Sierra Nevada Mountains, rarely receiving moisture from Pacific storms. Thus, it experiences an arid climate with approximately five inches of precipitation per year. Average daily maximum temperatures range between 100 degrees Fahrenheit in July and 57 in January; average daily minimum temperatures vary from 57 degrees Fahrenheit in July to 26 degrees in January.

Surface meteorology in the Pahrump Regional Planning District is generally characterized by predominant wind direction from the south-southeast with medium-to-high winds. High winds, however, are common and predominantly from the northwest. In addition to prevailing winds, local topography and temperature also affect valley winds. Daytime wind directions are generally upslope and in an easterly direction. At night, the wind direction is reversed and is downslope towards the valley. Seasonal variations also exist, with major wind events occurring in spring and fall.

From a geological perspective, Pahrump is situated in a large basin (hydrographic area 162, http://ndep.nv.gov/baqp/planmodeling/docs/planningareas.pdf), which has been filled with alluvial sediments from the erosion of the nearby mountains. These fine-grained alluvial sediments were subsequently reworked by eolian processes, forming sand dunes. Some of these dunes are active and others are semi-stabilized with vegetative growth. The climatic, geographical and geological conditions in and nearby the Pahrump Valley are naturally conducive to high surface erosion, dust formation and transport. Dust generation caused by soil destabilization from anthropogenic activities contributes to the deterioration of air quality conditions.

A regional aerial image showing the Pahrump Valley PM_{10} monitoring stations relative to nearby relevant geographic and geologic features is shown in Figure 2. Much of the land cleared for development in Pahrump Valley occurs within Holocene to late Pleistocene geologic units mapped as "fine-grained" or "basin-fill." These units are generally described as loose, friable, and lacking soil development or particle cementation, both of which could serve to inhibit entrainment from high winds, even when not disturbed.

The efforts by the NDEP-BAQP and Nye County authorities over the last ten years have focused on effective, data-validated corrective actions for the abatement and mitigation of anthropogenic dust generation in the Pahrump Regional Planning District.

Figure 1: Pahrump location.

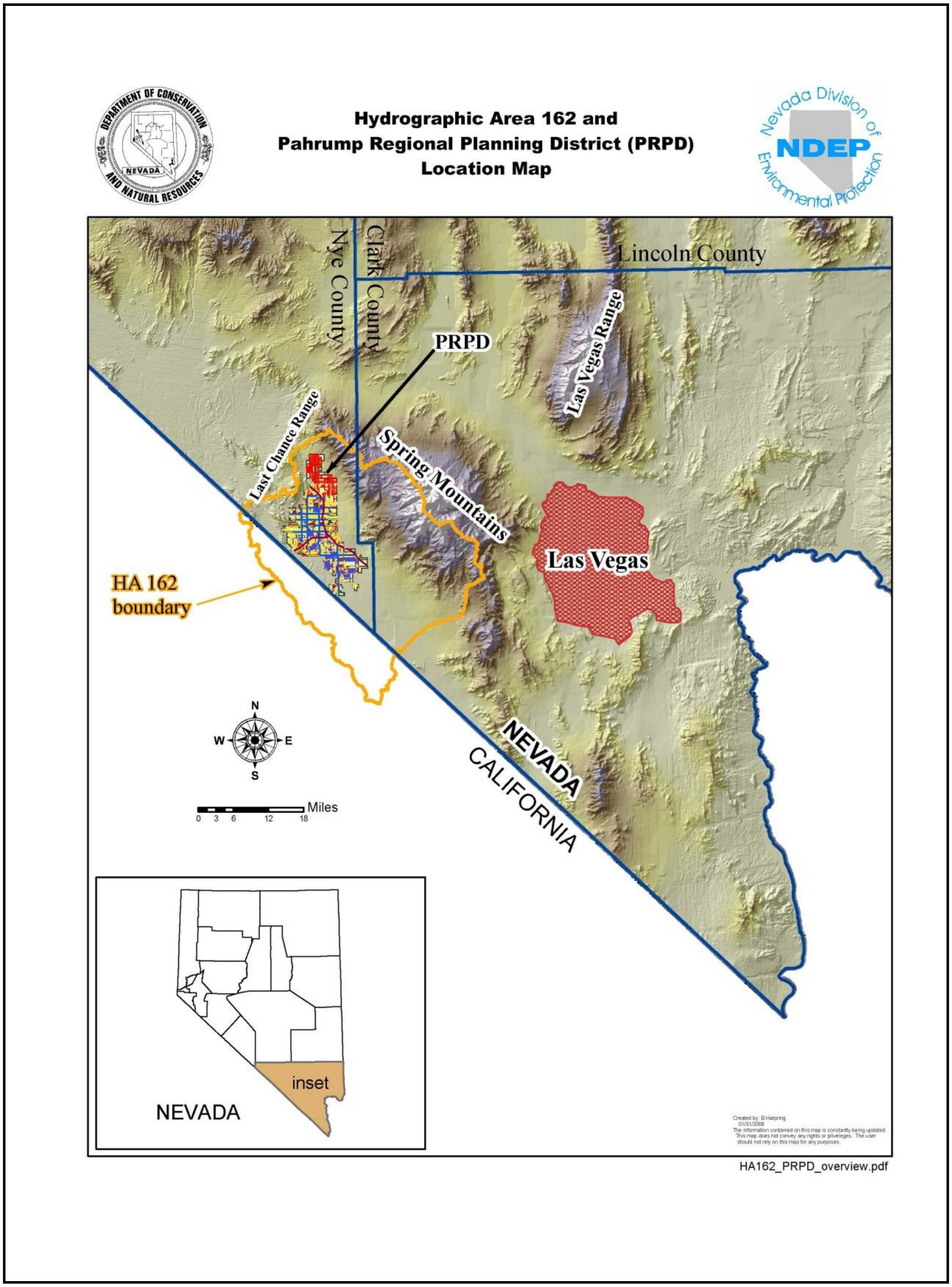
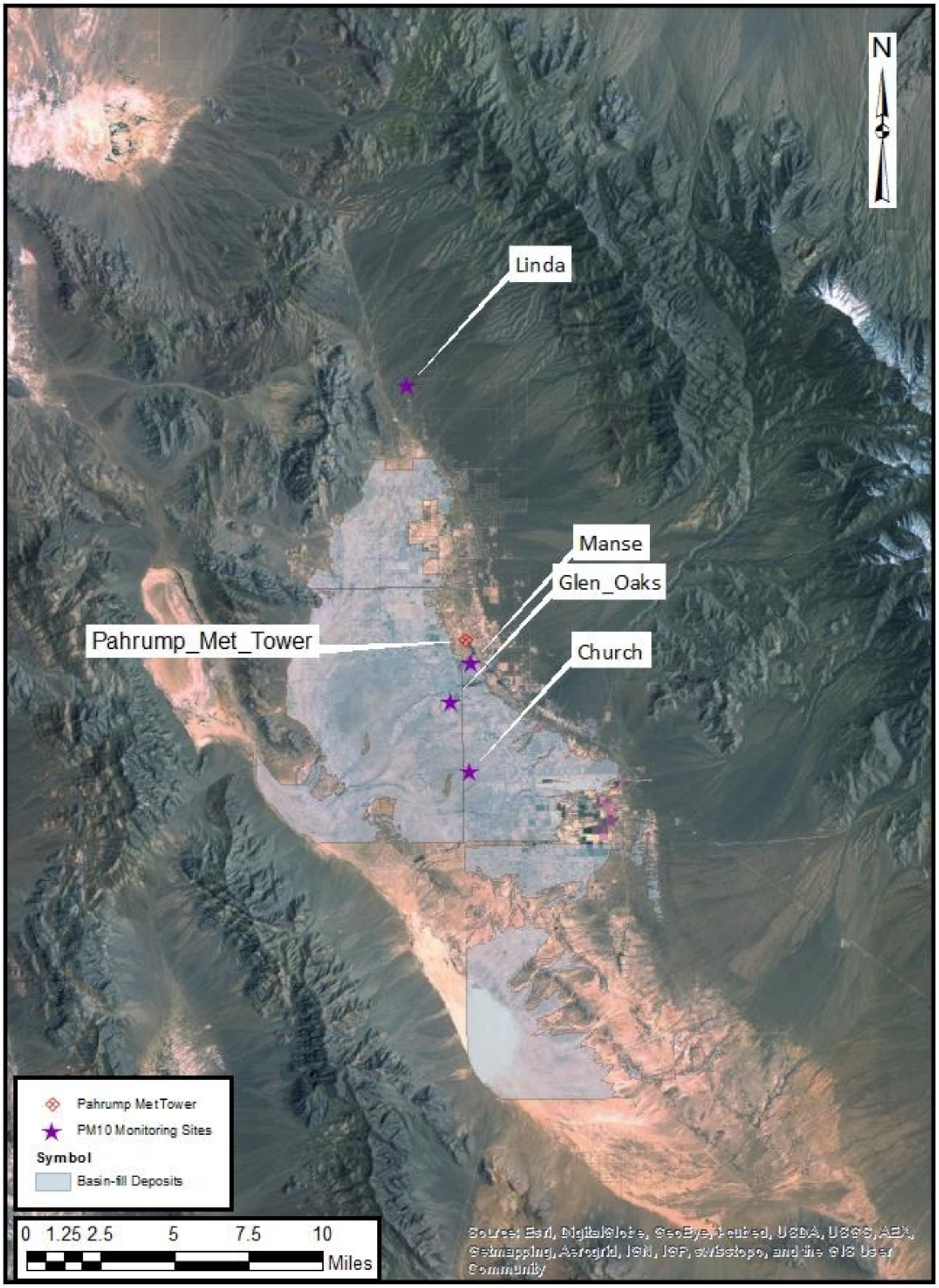


Figure 2: Fine-grained basin-fill deposits in the Pahrump Valley



2.2 History of PM_{10} Issue in Pahrump

The population in Pahrump tripled in a fifteen year period, from 13,060 people in 1994 to 36,441 in 2010[5] (179 percent increase). Much of this rapid growth occurred during the late 1990s, leading to intensive business and residential development. Large parcels of land were cleared of vegetation and scraped and gravel and dirt roads were constructed. Unfortunately, many of the planned residential developments never materialized. The result was large areas of abandoned disturbed vacant lands and miles of gravel and dirt roads.

High winds in the Pahrump Valley, combined with the disturbed vacant land and unpaved roads, resulted in increased dust formation and transport. Citizen complaints about the dust problem in the late 1990s led to the installation of an initial PM_{10} monitor to assess the ambient air quality. This monitor was installed in downtown Pahrump in January 2001 (at the 'pool site', Figure 10) and was managed by the NDEP-BAQP. This site recorded 27 exceedances of the 24-hour PM_{10} NAAQS during the period 2001 to 2004[6] (Table 6).

Section 107(d)(3) of the Clean Air Act, 42 U.S.C. § 7407(d)(3), allows the USEPA to redesignate an area or portion thereof based upon available information. Because the cause of the PM_{10} problem in the Pahrump area was clearly attributed to abandoned lots and unpaved roads, which could be corrected, the USEPA exercised its discretion not to redesignate the area. This discretion allowed for innovation and problem-solving to address the root cause of the problem. Typical industry or mobile source controls for a nonattainment area would have failed to address the real problem of undeveloped lots and unpaved roads. Therefore, rather than formally declare the Pahrump area in violation of the PM_{10} NAAQS (i.e., designate it nonattainment), the USEPA agreed to a different, more collaborative, and ultimately, more effective approach to achieve PM_{10} attainment. This approach was developed and implemented by the NDEP-BAQP, in collaboration with the Nye County Board of Commissioners, the Pahrump Town Board and USEPA and was formally described in the MOU signed by the above agencies in September 2003.

2.3 Memorandum of Understanding

The MOU outlined the duties and responsibilities of the signatory agencies in reducing PM_{10} emissions. It was the first step towards the development and implementation of a PM_{10} emission control plan (i.e., the Action Plan). The MOU approach had two goals: (1) it allowed for deferral of action by the USEPA on a nonattainment designation of the Pahrump area, and (2) it established the basis for a strong engagement and direction from state and local agencies to address PM_{10} emissions. This approach was considered less onerous for all parties involved than the process of a formal nonattainment designation. It was also the most promising and efficient way to achieve rapid air quality improvement in the Pahrump area.

[5] Nevada State Demographer - http://nvdemography.org/ (last viewed December 30, 2014)
[6] The 24-hour PM_{10} NAAQS is defined as the 24-hour average of the monitored values, expressed in $\mu g/m^3$. Compliance with the NAAQS is met when the 24-hour average does not exceed 150 $\mu g/m^3$ more than once per year on average over 3 years (http://www.epa.gov/air/criteria.html) (last viewed December 30, 2014).

3. Clean Air Action Plan

The Action Plan was developed as the strategy for achieving compliance with the 24-hour PM_{10} NAAQS. The Action Plan's first strategic goal was to identify the primary sources of anthropogenic PM_{10} emissions (hereafter referred to as pre-Action Plan emissions). The NDEP-BAQP compiled base year emission inventories, using 2001 to 2003 as the base years. The base year emission inventories identified disturbed vacant lands and unpaved roads as the main contributors to PM_{10} emissions (Table 1, Figure 3). The emission reduction strategies and control measures selected in the Action Plan explicitly targeted these types of sources and focused on areas within the Pahrump Regional Planning District where the most land development was occurring and was expected to occur in the future. Nye County began formal implementation of its dust control program in December 2004. The NDEP-BAQP expanded continuous monitoring of PM_{10} concentrations in the area from one monitoring site to five (Figure 10). The MOU set forth a compliance deadline of December 31, 2009 by which the NAAQS were to be attained, followed by a five-year maintenance period ending on December 31, 2014.

3.1 Pre-Action Plan Emission Inventories

The base year emission inventory was compiled by the NDEP-BAQP to determine the sources of PM_{10} emissions and identify the major source contributors to the high PM_{10} concentrations. The base years used for the emission inventory were 2001 through 2003. All potential sources of PM_{10} emissions were evaluated, including land types, road types, mobile sources, construction activities, residential municipal solid waste burning, and stationary sources.

In January 2003, the NDEP-BAQP conducted a field survey of the Pahrump Regional Planning District to identify the types of roads throughout the valley (paved and unpaved, local, arterial and highway) and to identify land types (native desert, stabilized vacant land, and disturbed vacant land). For each road type, the ArcGIS mapping tool (ArcMap v.10.0, ESRI) was used to calculate the total lengths from data obtained from the Nye County Department of Public Works. A traffic count survey was conducted on the unpaved local roads and was used to calculate an average traffic volume for all local roads in the valley. For arterials and highways, activity data was obtained from the Nevada Department of Transportation. Average activity was used for arterials without direct information. The resulting activity data and AP-42[7] equations were used to calculate fugitive emissions for all road types.

For land types, the NDEP-BAQP combined the field survey data with hydrographic area mapping data from the Nevada Division of Water Resources to estimate total acreages of disturbed lands, native desert, and stabilized vacant land. Emission factor methodologies from the 2001 Clark County PM_{10} SIP[8] were used to calculate wind erosion emissions from the different land types.

Based on these inventories, area and mobile sources (disturbed vacant land and unpaved roads) were found to be the overwhelming causes of the PM_{10} problem in the Pahrump Valley (Table 1 and Figure 3).

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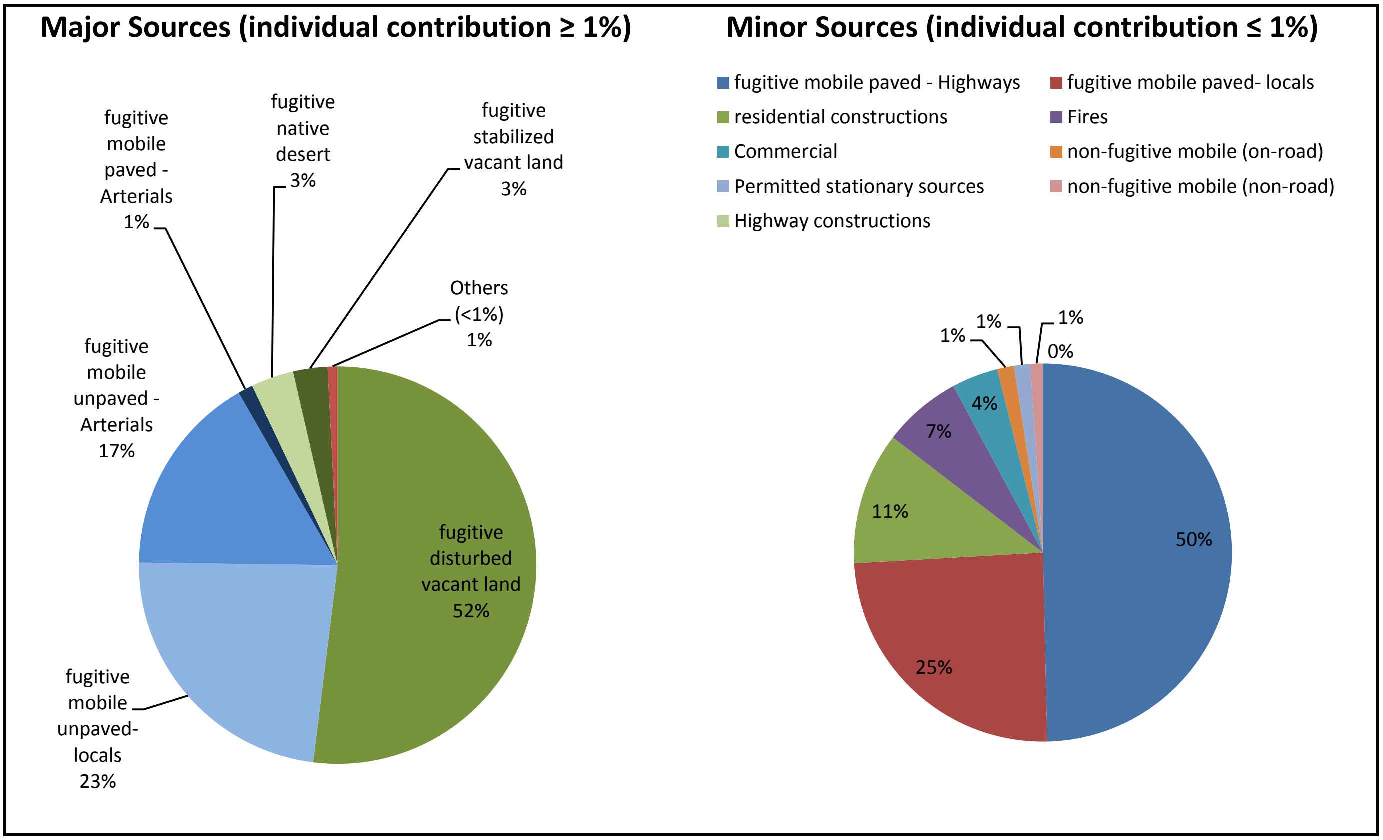
[7] EPA Compilation of Air Pollutant Emission Factors (AP-42), 5th Edition - Chapter 13

[8] PM_{10} State Implementation Plan for Clark County (2001), available at http://www.clarkcountynv.gov/depts/airquality/Pages/StateImplementationPlans.aspx (last viewed December 30, 2014)

Table 1: PM_{10} emissions as recorded by the pre-Action Plan inventory (compiled between 2001 and 2003, *see* also Section 4 for more details). Sources are grouped into major sources (individual contribution greater than 1%) and minor sources (individual contribution less than 1%).

Source	*Emissions (Short Tons/Year)*	*Percentage*
Major sources		
Fugitive disturbed vacant land	60,287	51.97
Fugitive mobile unpaved - local roads	26,947	23.23
Fugitive mobile unpaved - arterial roads	19,148	16.51
Fugitive mobile paved - arterial roads	1,410	1.22
Fugitive native desert	4,027	3.47
Fugitive stabilized vacant land	3,246	2.80
Subtotal	**115,065**	**99.20**
Minor Sources		
Fugitive mobile paved - highways	465	0.40
Fugitive mobile paved - local roads	229	0.20
Residential construction	106	0.09
Fires (municipal solid waste burning)	63	0.05
Commercial	37	0.03
Non-fugitive mobile (on-road)	13	0.01
Permitted stationary sources	13	0.01
Non-fugitive mobile (non-road)	10	0.01
Highway construction	0	0.00
Subtotal	**936**	**0.80**
Total	**116,001**	**100**

Figure 3: Relative contribution of each source type to total PM_{10} emissions (pre-Action Plan inventory, compiled between 2001 and 2003, *see* also Section 4 for more details). Percentages in 'Minor Sources' refer to the relative contribution within the 'Others' source group under Major Sources.



3.2 Control Strategies

The following control measures for reducing emissions of PM_{10} from unpaved roads were evaluated:

- Road paving / chip sealing / graveling
- Watering
- Application of chemical dust suppressants
- Reduction in speed
- Vehicle routing
- Private road dust control
- Prohibiting construction of new unpaved roads
- Road closures

Paving and chip sealing were selected as the best control measures. Paving and chip sealing were projected to achieve 97.5 percent control efficiency. Nye County had a program already in place and agreed to continue this program into the future. According to the Action Plan, chip seal and paving priorities would be established by the emissions inventory and petition from residents. Watering would be used on an as needed basis. In November 2003, an update to the Pahrump Master Plan was approved requiring asphalt paving in all new master planned communities, industrial parks and business parking in the Pahrump Regional Planning District. These requirements were adopted into Nye County Code Section 16.28.280.I.

The following control measures for reducing emissions of PM_{10} from disturbed vacant land were evaluated:

- Limiting vehicle access
- Watering
- Revegetation
- Soil covers
- Dust suppressants
- Windbreaks
- Dust control plans

Existing dust control measures included State regulations, which prohibit emissions of fugitive dust and require a surface area disturbance permit for disturbances greater than five acres (NAC 445B.22037). On a local level, Nye County revised its Master Plan in 2003 and adopted a number of ordinances to control fugitive dust in late 2004 and early 2005. The revised Master Plan required asphalt paving in all new master planned communities, industrial parks and business parking in the Pahrump Regional Planning District. Nye County Ordinance 297 established a comprehensive set of County Dust Control Regulations, regulating unpaved parking lots and storage areas, construction activities, and open areas and vacant lots within the Pahrump Regional Planning District.

To assist in the implementation of fugitive dust control measures, the NDEP-BAQP added a new air quality inspector position with an office in Pahrump. This position became available November 17, 2004 and was filled in early 2005. Under the direction of the Nye County Planning Director, this inspector was to review zoning designations, review and approve dust control plans, conduct inspections, investigate fugitive dust complaints, provide training and handle public outreach and education in the Pahrump area in accordance with the county's Dust Control Ordinance. The inspector would also be responsible for initiating the enforcement process when potential violations of the ordinance were discovered and documented. He would write warning letters and notices of alleged violation, conduct initial enforcement conferences with alleged violators and establish fines and penalties in accordance with the County's Enforcement Policy. If the inspector and the alleged violator could not agree during an enforcement conference as to the facts, corrective actions, or fines/penalties assessed, the case would be referred to the Compliance Review Committee. The Compliance Review Committee is comprised of the Nye County Public Works Director, the Community Planner, and an ex-officio member from the NDEP-BAQP, all of whom are duly trained in application of the County Ordinance, the Dust Control Handbook, Nye County Enforcement Policy, and Nye County Penalty Policy Guidance.

In cases where the Compliance Review Committee is not successful in resolving details of the alleged violation, the matter is scheduled for *de novo* hearing by the Air Quality Hearing Officer. At the hearing, the Hearing Officer will hear the facts of the case and review evidence. Based on the evidence presented by the parties, the Hearing Officer may allow, dismiss, or modify the violation as alleged, order the corrective actions as recommended, and order or dismiss payment of calculated fines/penalty (as recommended or revised, either upward or downward). The adjudicated order of the Compliance Review Committee and/or Hearing Officer may be appealed by the alleged violator to the Nye County

Board of County Commissioners (BOCC). The BOCC may either uphold or remand the Hearing Officer's decision. If the BOCC remands the decision, it is re-heard. If the decision is upheld, the alleged violator is subject to the Hearing Officer's Order. If the alleged violator is dissatisfied with the BOCC decision, he may file for judicial review pursuant to the NRS.

Further, Nye County committed to limiting off-road vehicle use to minimize the emissions from existing disturbed vacant lands. Re-vegetation on a site-specific basis was also selected as a control measure. Additionally, the NDEP-BAQP committed to continue operating the expanded monitoring network through 2014.

4. Post-Action Plan Emission Inventories and Analysis

The pre-Action Plan emission inventory demonstrated that more than 90 percent of the total emissions were generated by either dust entrainment from disturbed vacant land or fugitive dust from unpaved roads. When fugitive dust emissions from paved roads, stabilized vacant land, and native desert are added to the disturbed vacant land and unpaved road emissions, more than 99 percent of total emissions in the pre-Action Plan inventory are encompassed (Table 1 and Figure 3). Therefore, the post-Action Plan inventory focused solely on emissions from land erosion and fugitive emissions caused by mobile sources.

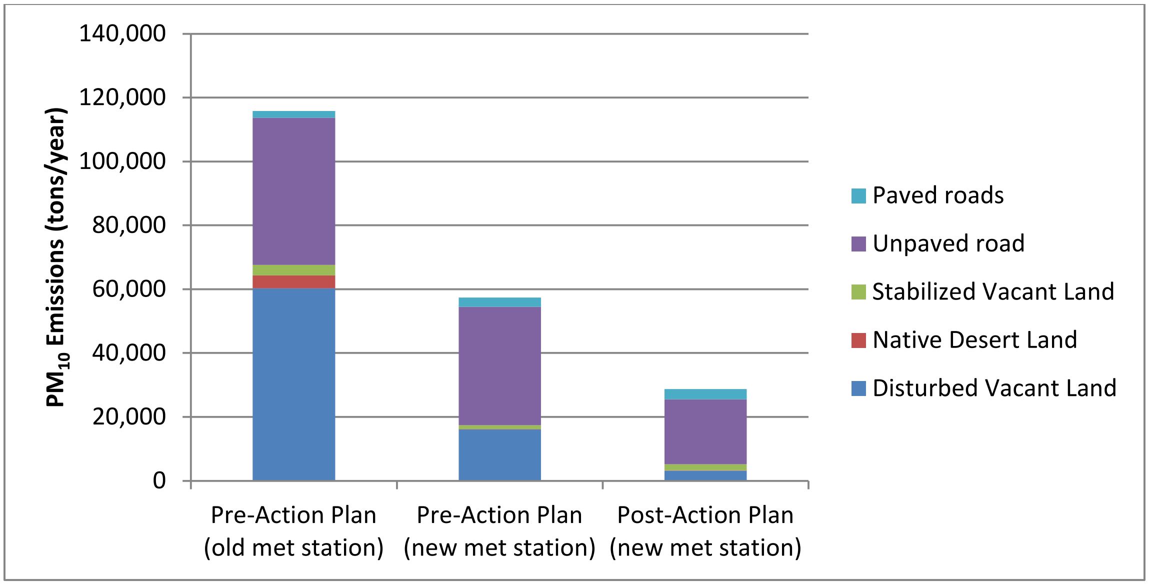
The original Action Plan emission inventory was developed between 2001 and 2003 and used 2001 wind speed observations from the meteorological instrumentation co-located at the pool monitoring station to characterize fugitive emissions from vacant, stabilized and native desert land. In 2004, the 'pool station' meteorological site could no longer be hosted at its existing location. The instrumentation at the 'pool site' was replaced by a better equipped and permanent meteorological station (sited and equipped according to USEPA recommendations and serviced by regular independent audits[9]) on a location about 240 meters north-northwest of the original location. Although the two locations were only a few hundred yards apart, a wind speed frequency analysis demonstrated that the wind speed observations from the new station are not comparable with those from the old 'pool station.' This was unexpected. Wind speeds from the new site yield substantially lower fugitive dust emissions estimates from land than the old site (*see* Appendix A). The very complex urban terrain is most likely the cause for this difference. The presence of buildings and other impervious-to-wind obstacles creates extreme heterogeneous wind speed and direction fields, which are characterized by large variability even across small distances.

As discussed in Appendix A, it is not possible at this stage to determine which one of the two stations' reported wind speed datasets are the closest to the 'average' wind speed in Pahrump (which would yield an average fugitive dust emission estimate), making it difficult to assess the uncertainty on the estimated fugitive dust emissions across the Pahrump area. Nevertheless, the analyses and results presented in this report clearly show a substantial reduction in vacant disturbed area between pre-Action Plan and post-Action Plan conditions, supporting a significant relative decline in fugitive dust emissions from land in the past ten years. Figure 4 shows the PM_{10} emissions as reported in the original Action Plan using the

[9] EPA – Quality Assurance Handbook for Air Pollution Measurement Systems – Volume IV: Meteorological Measurements Version 2.0

old station met data and as estimated in this report by using the same pre-Action Plan inventories, but wind measurements from the new station.

Figure 4: PM_{10} emissions from major sources as reported in the Action Plan and as estimated in this report using the inventories compiled before and after implementation of the Action Plan (pre-Action Plan and post-Action Plan, respectively).



4.1 Fugitive Dust from Land Erosion

Fugitive dust emissions from vacant land are largely driven by shear stress imparted by wind to the surface, which creates entrainment when the fluid forces exceed the effects of the weight of the particle and cohesion between adjacent particles.[10] A critical value of wind shear velocity is required to initiate grain movement. Once the wind shear velocity is reached, an initial spike in emissions typically is observed. Sustained wind above the threshold causes further dust emissions until the entrainment thresholds, which are constrained by surface moisture content, cohesion, vegetation or other non-erodible roughness elements, are no longer met. Different types of land are characterized by different environmental controls on entrainment thresholds. The parameters used to determine dust emissions in the post-Action Plan inventory were the same as those used in the pre-Action Plan inventory (i.e., as determined by the Clark County Wind Tunnel Study[11]). *See* also Appendix A of this document for more details.

[10] Lancaster, et. al. *Field Studies of the Potential for Wind Transport of Plutonium-Contaminated Soils at Sites in Areas 6 and 11, Nevada Test Site* at 3 (July 1995), Desert Research Institute, Publication #45136.

[11] 1) 2001 Clark County SIP - Appendix C, Section I, Estimation of Valley-Wide PM_{10} emissions using UNLV 1995 wind-tunnel measurements, revised vacant land classifications, and GIS-based mapping of vacant lands, available at http://www.clarkcountynv.gov/depts/airquality/Pages/StateImplementationPlans.aspx. (last viewed March 11, 2014).
2) James D.E. et al.- Development of Vacant Land Emission PM-10 factors in the Las Vegas Valley, 10th International Emission Inventory Conference – May 1-3, 2001. http://www.epa.gov/ttnchie1/conference/ei10/fugdust/james.pdf (last viewed March 19th, 2014).

4.1.1. Land Surface Distribution

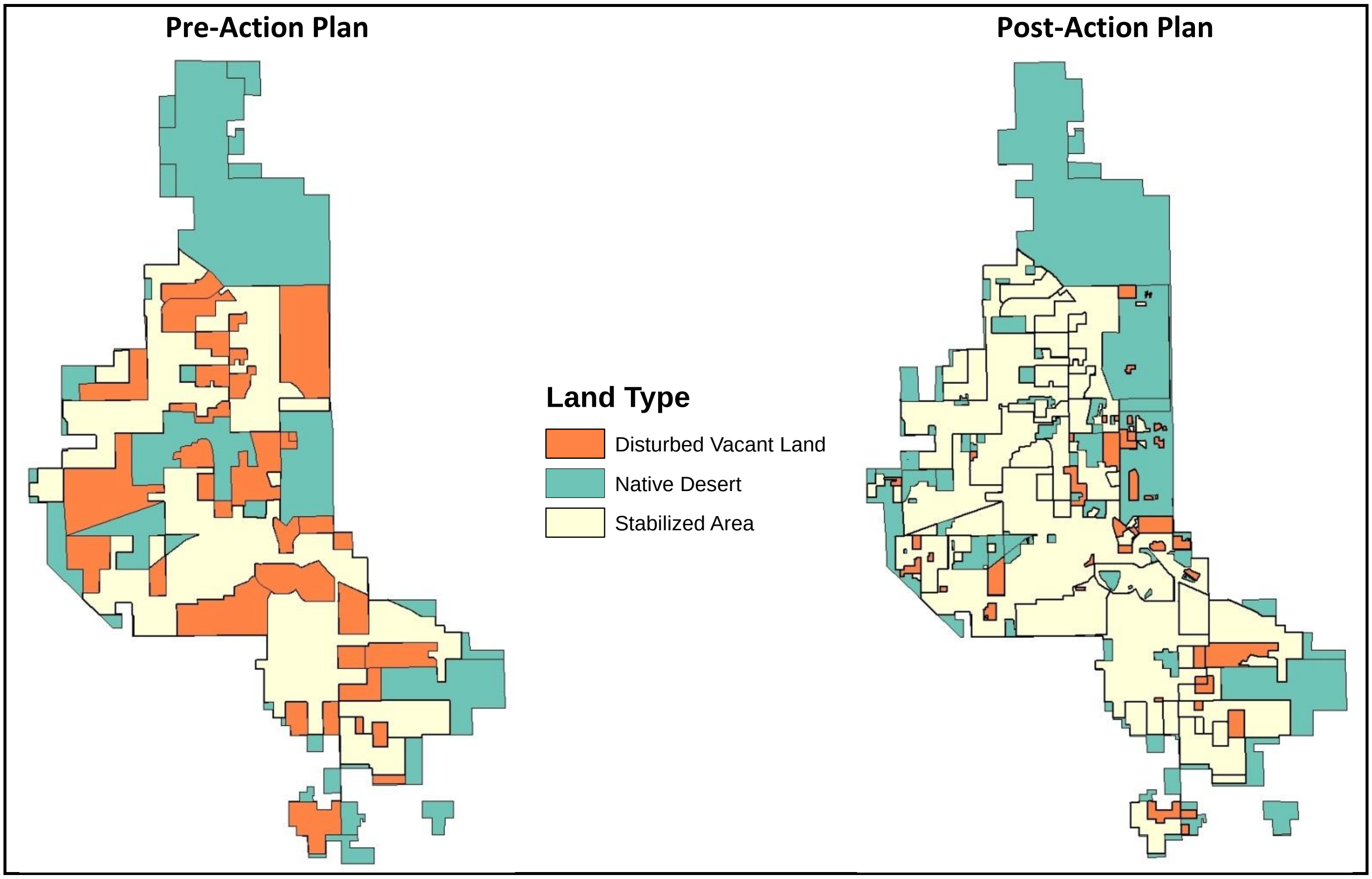
In May 2011, the NDEP-BAQP conducted land surface surveys to update the land surface type (i.e., disturbed vacant, stabilized vacant and native desert), location and extent across the area covered by the Pahrump Regional Planning District. Results were digitized into Geographic Information System (GIS) software (ArcMap v.10.0, ESRI) for further post-processing and analysis. The pre- and post-Action Plan surveys covered essentially the same area. The small difference in total area (less than 2 percent) is mostly attributable to changes of the Pahrump Regional Planning District boundary limits in the 2003 (pre-Action Plan) and 2011 (post-Action Plan) surveys.

As Table 2 shows, the post-Action Plan survey revealed a substantial decline in disturbed vacant land from the pre-Action Plan survey (18,716 acre reduction or about 80 percent of the pre-Action Plan disturbed vacant land). Stabilized vacant land increased by approximately 15,400 acres (about 47 percent of pre-Action Plan stabilized vacant land), while native desert land increased by about 6 percent (Table 2 and Figure 5).

Table 2: Area (acres) as measured for each land type during the pre- and post-Action Plan surveys. Numbers in parentheses describe the relative contribution of each land type.

Year	*Total Area*	*Disturbed Vacant Land*	*Native Desert*	*Stabilized Vacant Land*
2004	86,476	23,281 (26.9%)	30,403 (35.2%)	32,792 (37.9%)
2011	84,957	4,565 (5.4%)	32,230 (37.9%)	48,161 (56.7%)
% Change		-80%	6%	47%

Figure 5: Land type distribution in pre- and post-Action Plan surveys.



4.1.2. Emissions

Wind speed measurements used to estimate wind erosion in the Action Plan were obtained from the 2001 hourly readings at the 'pool station' monitoring site in Pahrump. As discussed in the introduction of Section 4, the old and new sites did not have comparable wind speed profiles and therefore pre-Action Plan estimates of fugitive dust from land (obtained using the 'pool station' data) could not be fairly compared with the post-Action Plan estimates (obtained using the re-located meteorological station). It is important to note that the difference in measured wind speed between the two sites was not related to data quality or equipment operation errors.

In order to overcome this limitation, the results presented in the Action Plan were not used. Instead, the fugitive PM_{10} emissions were recalculated using the wind speed records from the new meteorological station, which meets USEPA criteria. Indeed, recalculated emissions under pre-Action Plan land surface conditions were lower than those presented in the Action Plan (as expected, because of the lower frequency of high winds, *see* Section A.2). This difference in estimated emissions clearly shows the effects of the location factor on meteorological measurements in complex urban terrains. For planning purposes, the higher wind speeds and resulting higher emission estimates of the old 'pool station' site provided a more conservative data set by which corrective action measures were planned and implemented.

In recognizing the different wind speed profiles between the two sites, it is important to assess the relative differences in PM_{10} emissions from vacant, disturbed land between pre- and post-Action Plan conditions. In this context, spatial (i.e., across the Pahrump area) and temporal (through the years) variability in wind speed do not play major roles in PM_{10} emissions. Rather, the change in land type distribution between pre- and post-Action Plan conditions is much more significant to PM_{10} emission levels than spatial and temporal wind speed variability. The two land- and road-type surveys (2003 and 2011) were used to characterize pre-Action Plan and post-Action Plan conditions. Data from the current meteorological station (i.e., from 2004 to 2012) were used to characterize the intra-annual variability in wind speed by assuming that no significant long-term changes in wind speed distribution occurred in this period. For each year, PM_{10} emissions were calculated using both the pre- and post-Action Plan land type distributions. This provided a more robust estimate of the fugitive PM_{10} emissions due to land erosion, the variability of PM_{10} emissions over nine years, and a more precise estimate of the difference in emissions due to the changes in land type. (*See* Appendix A for more details on the calculation methodologies)

Figure 6 shows that total pre-Action Plan fugitive dust emissions were estimated at approximately 17,500 tons per year. Post-Action Plan emissions had significantly reduced to approximately 5,100 tons per year, which is a 70 percent reduction from 2004 emissions. Emissions from disturbed vacant land decreased from about 16,000 tons per year to 3,200 tons per year (80 percent reduction). Emissions from stabilized vacant land increased from 1,300 tons per year to 1,800 tons per year (45 percent increase), most likely as a result of the significant shift in disturbed vacant to stabilized vacant land (Table 2), creating a 47 percent increase in post-Action Plan acreage of stabilized vacant land. Emissions from native desert land did not substantially change (*see* Appendix A).

Figure 6: Total and per-land-type fugitive PM_{10} emissions estimated using the land surface surveys in 2003 and 2011 and 9 years of continuous wind speed measurements. Error bars are the 95% confidence interval of the means.

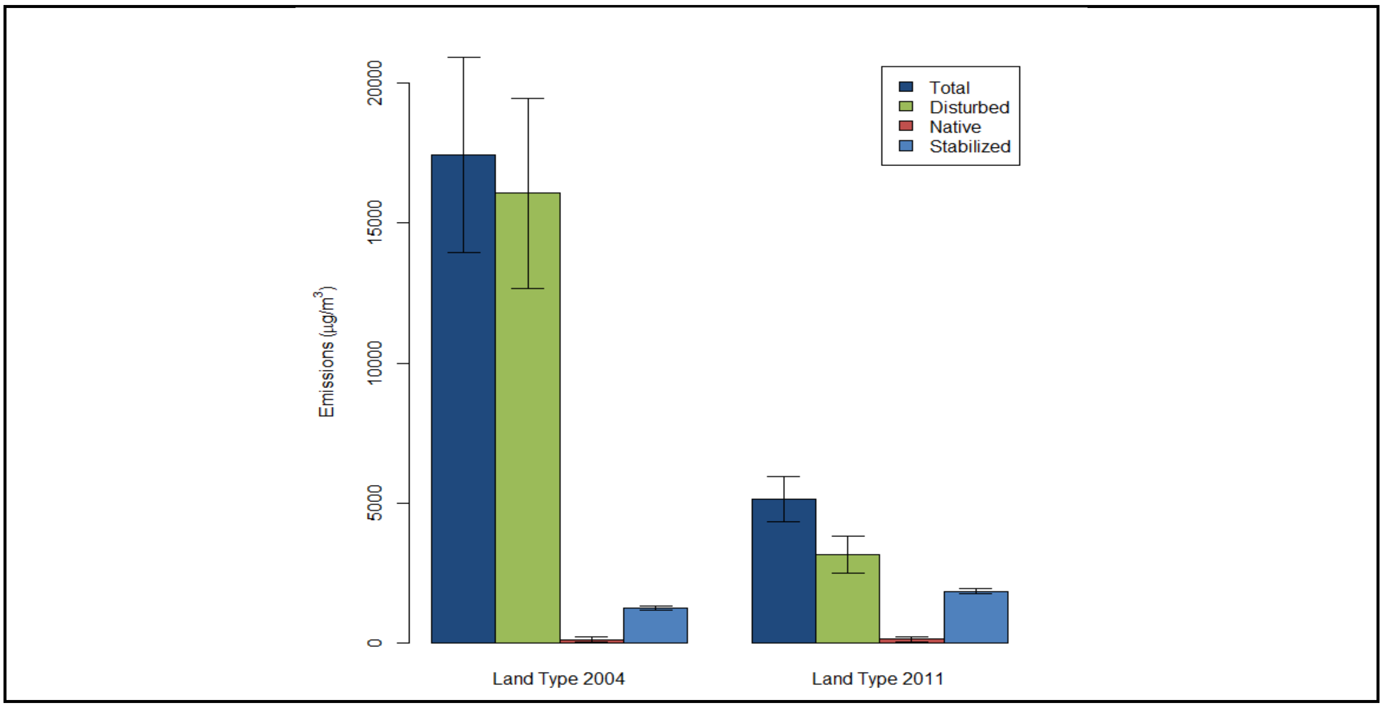
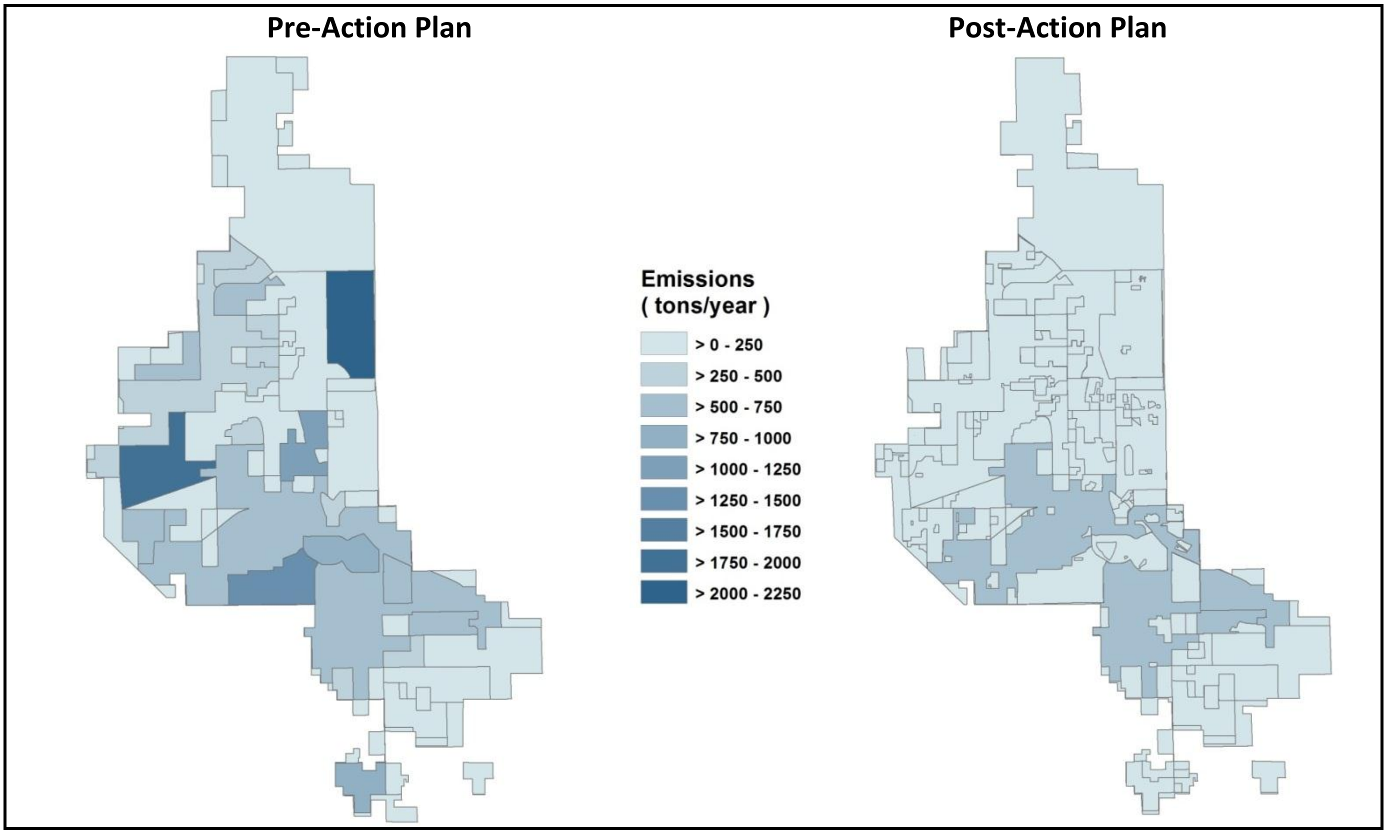


Figure 7 shows pre-Action Plan and post-Action Plan fugitive emissions from land across the Pahrump Regional Planning District. In this map, each surveyed area is represented with its total emission (tons per year).

Figure 7: Annual emissions estimated using pre- and post-Action Plan land types and meteorological data from 2004 to 2011. Emissions are expressed in short tons/year.



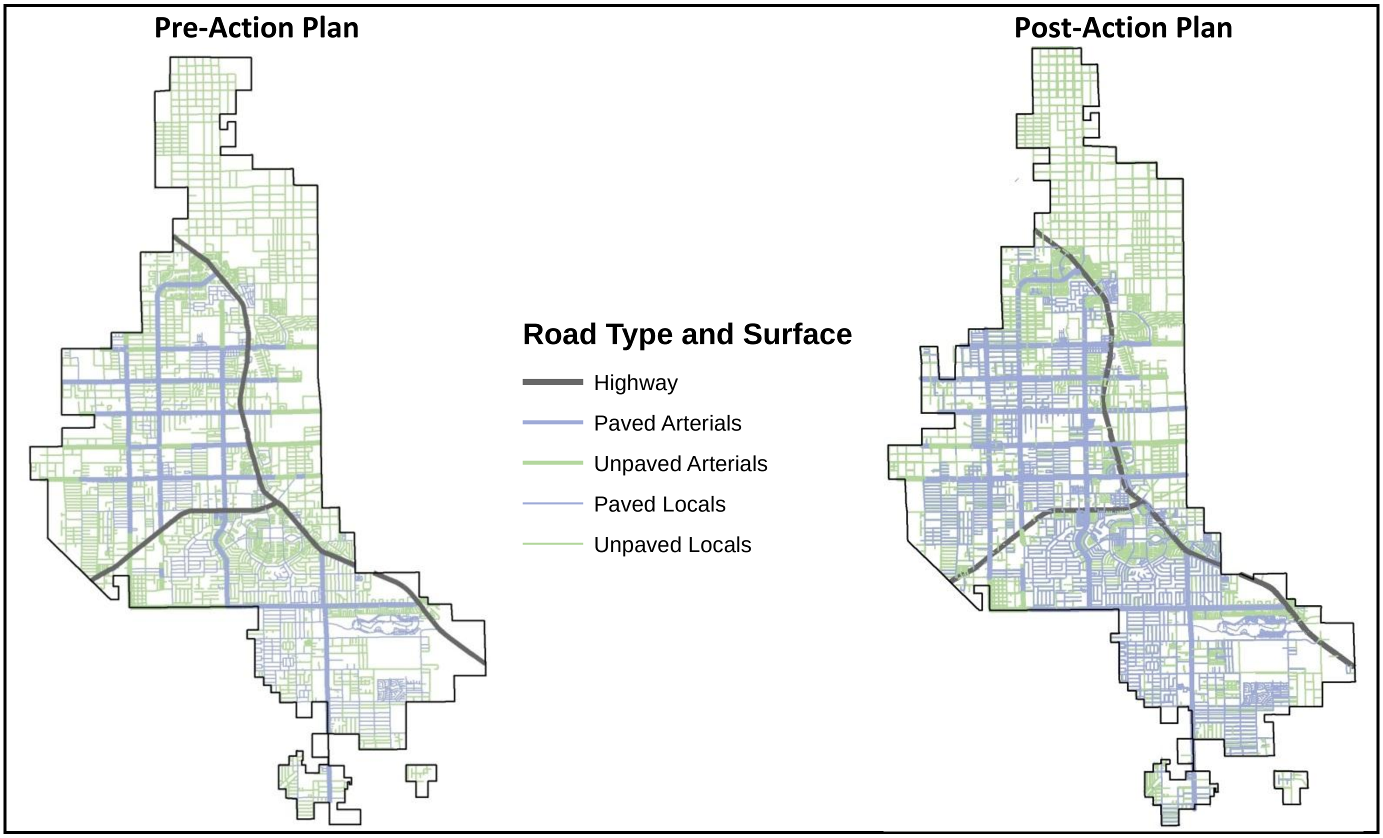
4.2 Fugitive Dust Created by Mobile Sources

Fugitive emissions created by mobile sources were estimated using the available equations in the EPA Compilation of Air Pollutant Emission Factors (AP-42), 5th Edition - Chapter 13. In general, these equations are functions of road conditions and traffic volume, and provide emission factors expressed in pounds of fugitive PM_{10} per units of vehicle-miles traveled (VMT, *see* Appendix A for more details). Because both equations for paved and unpaved roads were modified in recent updates of the AP-42, the emission factors were recalculated and applied to both pre- and post-Action Plan road conditions and traffic. Road types (highway, arterial, local) and surface (paved, unpaved) were originally surveyed in 2003 for the analysis presented in the Action Plan. A second survey was conducted in May 2011 to establish post-Action Plan road type and surface conditions. A traffic data study was conducted at eleven locations in May 2012 to obtain average traffic volume for unpaved local roads over a period of

24-hours[12]. The average traffic volume for this type of road was 46 vehicles per day, a decline from the pre-Action Plan survey of 60 vehicles per day.

Both datasets were digitized and geo-referenced using GIS software (ArcMap v. 10.0, ESRI) for further post-processing and analysis (Figure 8).

Figure 8: Road type and surface as surveyed in 2003 (pre-Action Plan) and 2011 (post-Action Plan)



The total length of the road network in Pahrump changed minimally between pre- and post-Action Plan (i.e., less than 10 percent). No significant changes in the total lengths were recorded in the highway and arterial road networks (less than 2 percent), but the local road network extended 70 miles longer after the Action Plan (increase of about 7 percent). The relative proportion of unpaved roads was reduced from 69 percent pre-Action Plan to 47 percent post-Action Plan, attributed mainly to a substantial reduction in unpaved local roads (about 30 percent reduction, *see* Table 3).

[12] Traffic Data Services, Flagstaff, AZ conducted both traffic data studies in 2004 and 2012 using similar design and methodologies.

Table 3: Length (in miles) for each type of road in 2003 (pre-Action Plan) and 2011 (post-Action Plan).

Road Type	*Pre-Action Plan*			*Post-Action Plan*		
	All	Paved	Unpaved	All	Paved	Unpaved
Highway	24.1	24.1	0	24.0	24.0	0
Arterial	84.2	62.8	21.4	85.6	76.3	9.3
Local	1006.9	254.5	752.4	1080.6	530.8	549.8
Total	1115.2	341.4	773.8	1190.2	631.1	559.1

Annual Average Daily Traffic (AADT, vehicle/day) for highways and arterial roads for post-Action Plan were obtained from the Nevada Department of Transportation. The average AADT for arterials (1,500 vehicles/day for pre-Action Plan and 1,110 vehicles/day for post-Action Plan) was used for arterial roads without direct estimates. Post-Action Plan daily traffic volume for unpaved local roads was obtained through the survey conducted in 2012. The average AADT from this survey (46 vehicles/day) was used for all the local roads that were not directly surveyed. VMT was calculated extrapolating the daily traffic volume to the entire year and length of the roads (*see* Appendix A for details).

In order to assess the effects of the implementation of dust-reduction control measures, four major factors need to be considered:

1. Change in road conditions (e.g., from unpaved to paved)
2. Change in vehicle velocity (e.g., change in speed limits)
3. Change in traffic volume (e.g., more or less cars)
4. Change in road network extent (e.g., more or less roads)

All these four factors can cause changes in fugitive PM_{10} mobile emissions, but only the first two can be directly linked to dust reduction policies. Because not enough information was available to assess actual vehicle velocity, this analysis solely focused on the effect on road conditions, therefore assuming no significant change in vehicle speed between pre- and post-Action Plan. Appendix A provides information on the approach adopted to determine the relative contribution of change in road conditions to the overall changes in fugitive dust emissions.

4.2.1. Fugitive Emissions

Prior to the Action Plan, 93 percent of total PM_{10} emissions created by on-road mobile sources (about 40,000 tons/year) originated from unpaved roads, with unpaved local roads contributing 54 percent of total road emissions. After the Action Plan, total PM_{10} emissions estimates were reduced by 50 percent from pre-Action Plan estimates to approximately 20,000 tons/year. Emission contributions from unpaved arterial roads saw the largest decrease, from approximately 39 percent to 24 percent of total road emissions. Contributions from all unpaved roads were reduced to about 84 percent of total emissions (Table 4).

Table 4: Pre-Action Plan PM_{10} emissions (tons/year) from on-road mobile source disaggregated by road type and surface.

Road Type	*Pre-Action Plan*			*Post-Action Plan*		
	All	Paved	Unpaved	All	Paved	Unpaved
Highway	334	334	0	601	601	0
Arterial	17,544	2,147	15,397	6,878	1,944	4,934
Local	22,025	348	21,677	12,876	733	12,143
Total	39,903	2,829	37,074	20,355	3,278	17,077

The increase in fugitive dust emission between pre- and post-Action Plan caused by new or longer roads (*see* Appendix A) was estimated to be approximately 850 tons per year. Once this contribution is removed, the net reduction in emissions caused by changes in road surface and traffic volume was about 20,400 tons per year, 71 percent of which can be attributed to the Nye County paving/chip sealing program and 29 percent to overall reduction in traffic volume.

Highway fugitive dust emissions almost doubled between pre-Action Plan and post-Action Plan, due to higher traffic volume. Highway traffic increased between pre- and post-Action Plan, whereas arterial and local traffic decreased. Nonetheless, the relative contribution of highway emissions to total emissions remained very low (less than 3 percent). Emissions from arterial roads decreased 10,666 tons per year, approximately 60 percent, between pre-Action Plan and post-Action Plan. Seventy-eight percent of this decrease (about 8,300 tons per year) was attributable to the changes from unpaved to paved arterial road surfaces. A reduction in traffic volume on arterials between pre-Action Plan and post-Action Plan was the secondary cause for the decrease in PM_{10} emissions.

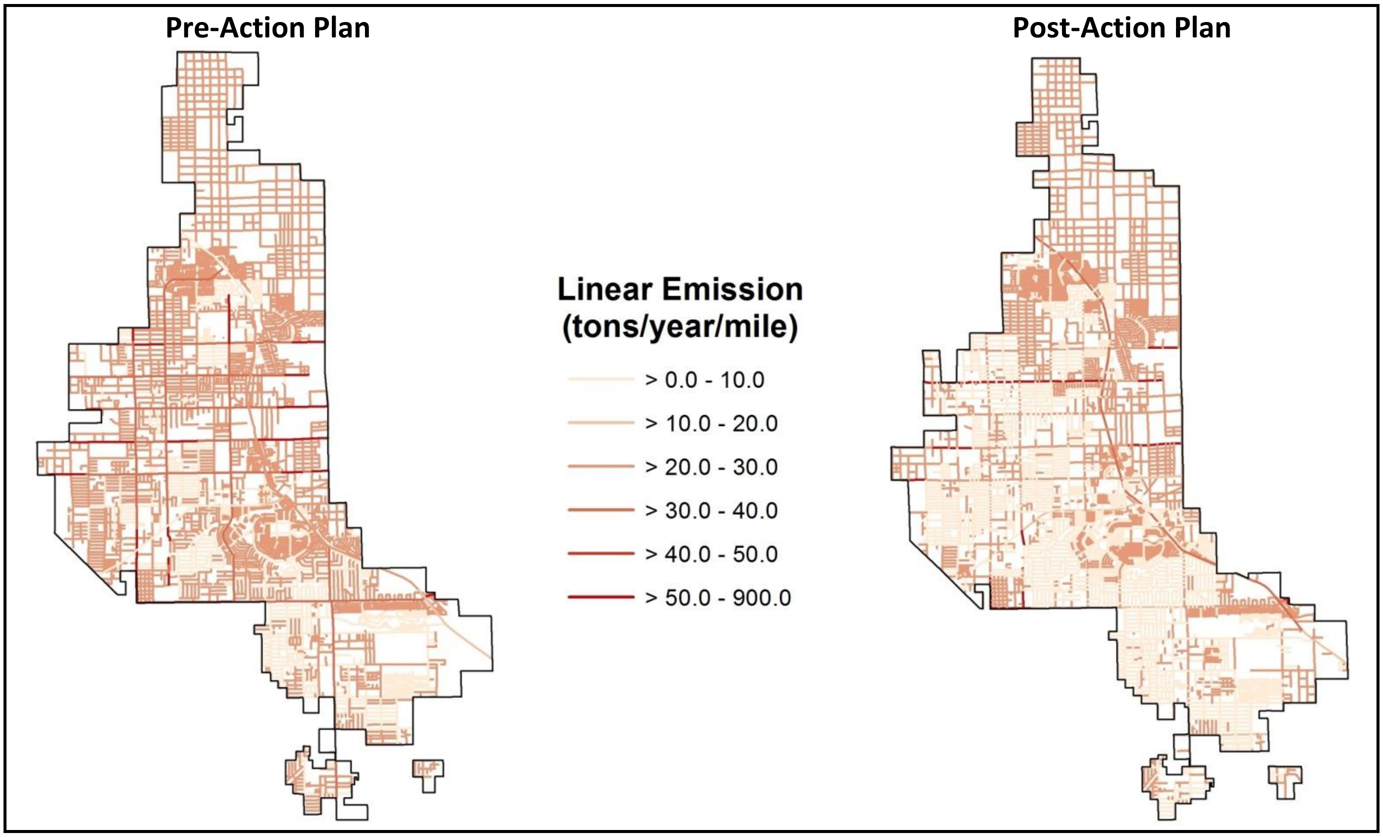
After accounting for emissions attributed to the change in road length pre- and post-Action Plan, the emissions from local roads decreased by about 10,000 tons per year (i.e., 45 percent decrease from pre-Action Plan local road emissions). Sixty-three percent of this reduction was caused by changes in road surface, while the remaining 37 percent was caused by decrease in local traffic volume (Table 5).

Table 5: Contribution of changes in road conditions and traffic volume to change in total fugitive dust emissions. The contribution of new or longer roads is not included in this table (*see* Appendix A). A positive number indicates an increase in emissions between pre- and post-Action Plan, likewise a negative number indicates a reduction in emissions. All values are expressed in tons/year.

Road Type	*Effect*	*All*	*Paved*	*Unpaved*
Highway	Change in surface type and traffic	267	267	0
	Change in surface type only	16	16	0
	Change in traffic only	251	251	0
Arterial	Change in surface type and traffic	-10,666	-203	-10,463
	Change in surface type only	-8,268	461	-8,729
	Change in traffic only	-2,398	-664	-1,734
Local	Change in surface type and traffic	-9,993	347	-10,340
	Change in surface type only	-6,305	340	-6,645
	Change in traffic only	-3,688	7	-3,695
All types	Change in surface type and traffic	-20,392	411	-20,803
	Change in surface type only	-14,557	817	-15,374
	Change in traffic only	-5,835	-406	-5,429

Figure 9 shows the change in mobile source fugitive dust emissions from pre- to post-Action Plan across the Pahrump Regional Planning District. Where a considerable amount of local roads were paved as a consequence of dust reduction policies of the Action Plan (Figure 8), emissions decreased substantially.

Figure 9: PM_{10} linear emissions from on-road mobile sources (tons/year/mile) in pre- and post-Action Plan



5. Monitoring Data

This section discusses the results of analyses aimed to investigate the PM_{10} levels, changes and trends as measured by the monitoring stations located in Pahrump during the period 2004 to 2011. Figure 10 shows the location of the PM_{10} monitoring stations in Pahrump. The 2004 to 2011 time period was selected because it spans the period during which the dust-reduction policies described in the Action Plan were implemented, and because it provides a sufficiently long time-series to statistically detect changes or trends.

Table 6 presents the monitoring data from each of the stations in Pahrump from 2001 to 2012. Of all of the PM_{10} stations that recorded data between 2001 and 2012, only three had enough years of data to allow trend analyses. These stations are:

- **Linda** station, located on the north side of Pahrump, outside the urban development. Because of its location, this station is assumed to monitor the background concentration of PM_{10}. Data are available from 2004 to 2012.
- **Manse** station, approximately located in the center of the urban development of Pahrump. Data are available from 2005 to 2012.
- **Church** station, located within the urban development of Pahrump, but south of the Manse Station. Data are available from 2004 to 2012.

Figure 10: Location of the five PM_{10} monitoring stations and one meteorological (Met) station in Pahrump. Green and red dots mark active and inactive stations, respectively. The Pahrump Regional Planning District border is outlined by white lines.

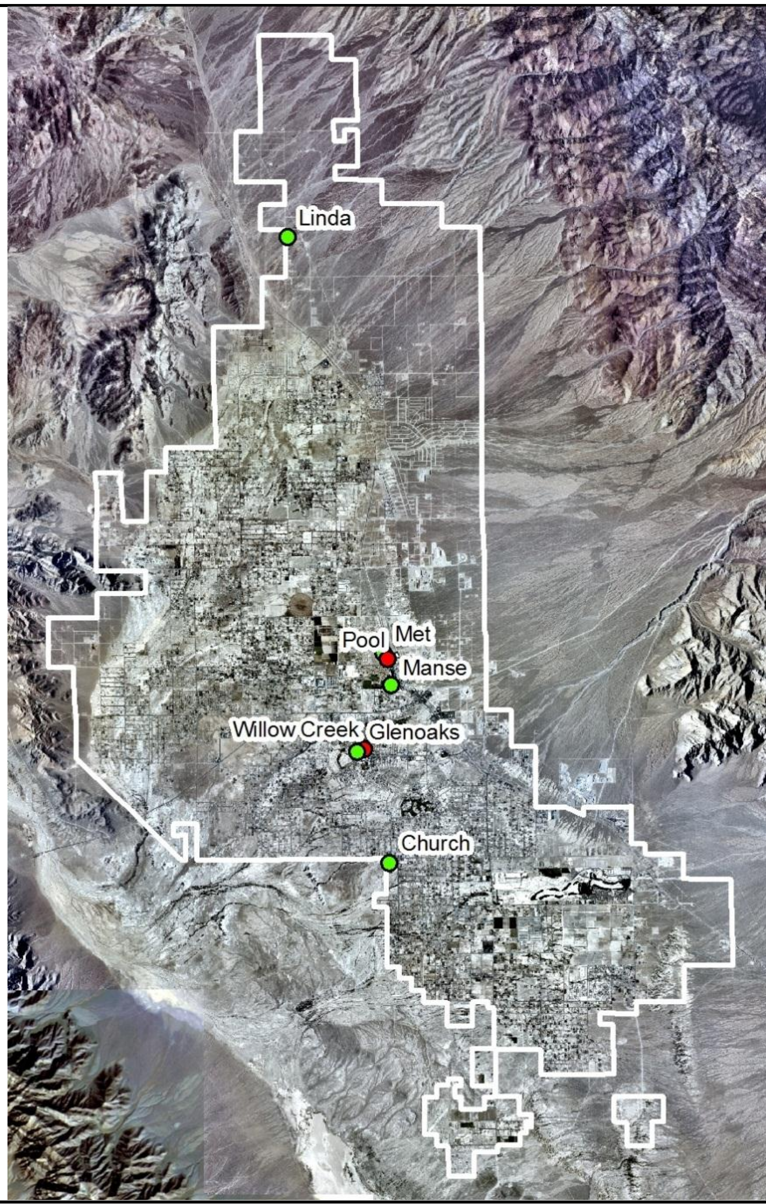


Table 6: Monitored exceedances of the 24-hour PM_{10} NAAQS, between 2001 and 2012, including exceptional events. Data in brackets are either not in USEPA's Air Quality System (AQS) database or represent a partial year of data in the AQS.

Year	*Community Pool*	*Willow Creek*	*Linda*	*Glenoaks*	*Manse*	*Church*
2001	[4]	----	----	----	----	----
2002	[13]	----	----	----	----	----
2003	[7]	----	[2]	----	----	----
2004	[3]	2	0	----	----	[0]
2005	----	0	0	----	----	0
2006	----	1	0	----	3	1
2007	----	2	1	----	5	0
2008	----	0	0	----	2	0
2009	----	----	0	----	5	0
2010	----	----	0	0	0	0
2011	----	----	0	0	1	0
2012	----	----	0	0	1	0

Table 7 shows design values (expected exceedances in USEPA terminology) for PM_{10} in Pahrump from 1999 through 2012. Events for which the NDEP-BAQP has submitted a demonstration that the event was an exceptional occurrence have been excluded from the calculations.[13] Compliance with the 24-hour PM_{10} NAAQS is met when the expected number of exceedances per year, averaged over a three year period, is less than or equal to one. The data show that Pahrump has been meeting the standard since the 2003-2005 design value period.

Table 7: Expected exceedances[14], or "design value," of the 24-hour PM_{10} NAAQS in Pahrump, between 2001 and 2012, excluding exceptional events. Values in italic parentheses have not been calculated according to USEPA method, but are rather a simple average of the three years of data. Values in red underscore represent violations of the NAAQS.

3-Year Period	*Expected Exceedances or "Design Value" Excluding Exceptional Events*					
	Community Pool	*Willow Creek*	*Linda*	*Glenoaks*	*Manse*	*Church*
99-01	---	---	---	---	---	---
00-02	---	---	---	---	---	---
01-03	*(8.0)*	---	---	---	---	---
02-04	*(7.7)*	---	---	---	---	---
03-05	---	---	*(0.7)*	---	---	*(0.0)*
04-06	---	*(0.7)*	*(0.0)*	---	---	*(0.0)*
05-07	---	*(0.0)*	*(0.0)*	---	---	*(0.0)*
06-08	---	0.0	0.0	---	0.0	0.0
07-09	---	---	0.0	---	0.0	0.0
08-10	---	---	0.0	---	0.0	0.0
09-11	---	---	0.0	---	0.3	0.0
10-12	---	---	0.0	0.0	0.7	0.0

[13] The NDEP has submitted exceptional events demonstration packages to USEPA for all exceedances at all sites (Willow Creek, Linda, Manse and Church) from 2006 through 2009, and is awaiting USEPA concurrence.
[14] Exceedance means a daily value that is above the level of the 24-hour NAAQS after rounding to the nearest 10 µg/m^3.

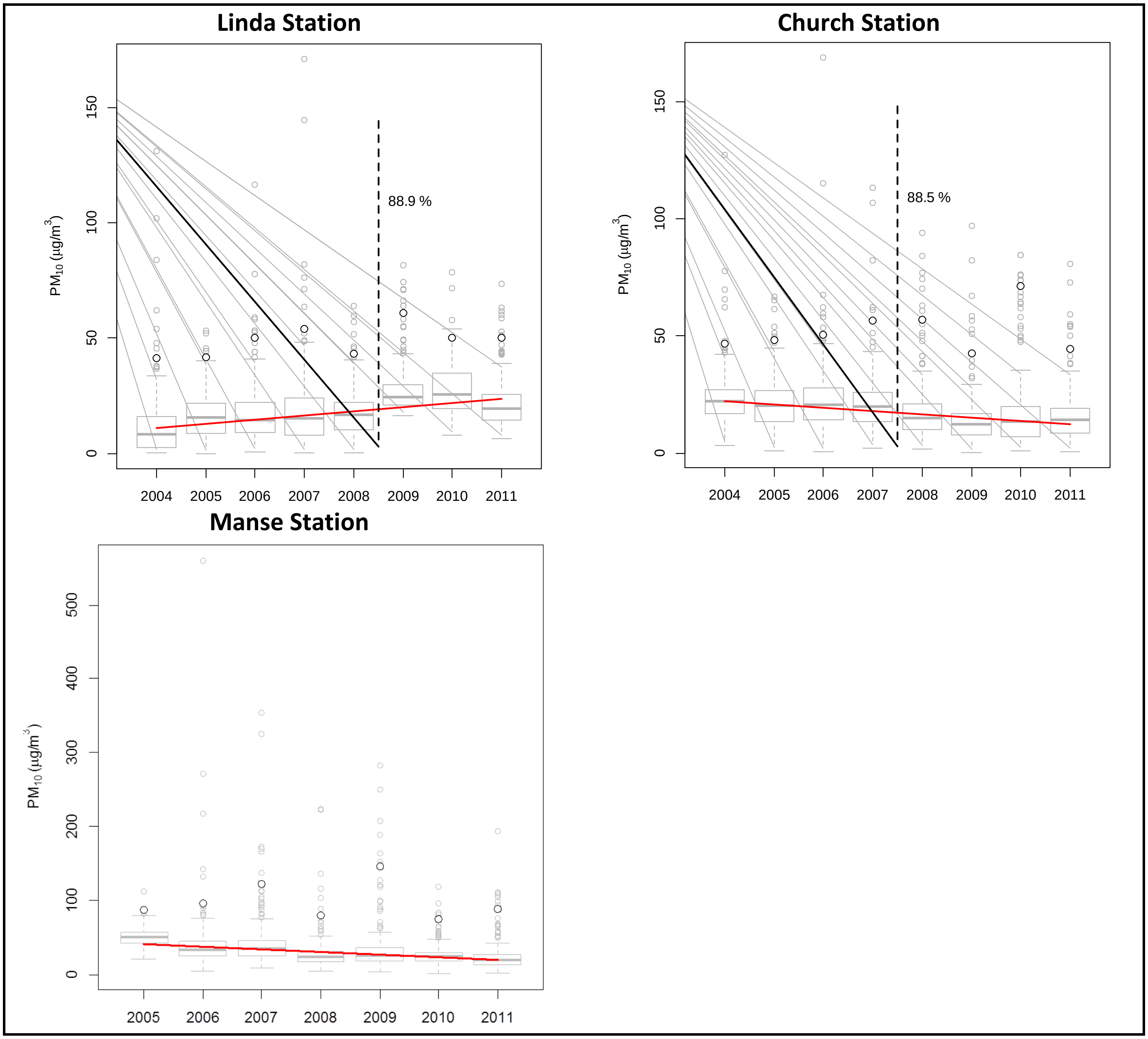
The NDEP-BAQP investigated potential changes in PM_{10} monitored concentrations using two different approaches. The first approach provides statistical evidence for a gradual and linear change in concentrations over the period of time considered (i.e., trend analysis); the second approach provides evidence for a sharp change in concentration at any point in time across the period considered (i.e., change-point analysis, *see* Appendix B for more details). For this analysis, daily averages of PM_{10} concentration were used. Besides the data filtering as a consequence of standard quality control on the data (e.g., sensor malfunctioning, data transfer problems, etc.), no further filtering was performed on the datasets. For instance, no data points were removed in coincidence with exceptional events such as wild and prescribed fires, or large gathering events.

For each year, the median, mean, 98^{th} percentile, and maximum of the daily average distribution were tested for trends and sudden changes. The annual distributions of PM_{10} daily averages are characterized by a prominent skewness, as, for instance, exceptional events and high winds increase the likelihood of high PM_{10} concentrations. Because of this skewed distribution, the median is a more reliable measure of central tendency than the other statistics. In this section, only the results from the median-based analysis are shown, even though results did not substantially differ if the other statistics were used instead (*see* Appendix B).

All stations' datasets were characterized by significant linear trends. Manse station recorded a negative trend (i.e., decrease in concentration) in its annual median of about -3.7 $\mu g/m^3$ per year. The annual median concentration decreases at the Church station as well, though with a slower pace (-1.4 $\mu g/m^3$ per year). Linda station recorded a significant increase in annual median PM_{10} concentration of 1.8 $\mu g/m^3$ per year. (Figure 11)

Among all the stations, the Church station showed significant evidence (close to 90 percent of confidence) of a sharp decline in median concentration occurring between 2007 and 2008 (i.e., the years from 2004 to 2007 had a median significantly higher than the years from 2008 to 2011). The Linda station showed significant evidence of a sharp increase in median concentration occurring between 2008 and 2009. The negative trends recorded by the urban monitoring stations (Church and Manse) suggest an improvement in PM_{10} conditions at local scale (i.e., within the urban area of Pahrump). The positive trend recorded by the Linda station may instead suggest deterioration in PM_{10} conditions on a regional scale (e.g., background level). However, this trend seems to be mainly driven by a significant increase in PM_{10} concentrations in 2009 and 2010, with the concentration in 2011 returning to a lower level. In fact, given the distinct results from Linda station, further analysis was conducted by including PM_{10} observations from the years 2012 and 2013. The inclusion of these years confirmed that after 2010, concentrations at Linda station returned to levels comparable to those pre-2009 and equally important, no significant PM_{10} trend is now detectable at this station (see Appendix D).

Figure 11: Trend and change-point analysis for annual daily average distributions for each of the three monitoring stations considered across the 2004-2011 period. Each year's distribution is shown using a boxplot-style representation. The gray box identifies the 25th and 75th percentiles (bottom and top, respectively); the whiskers include points that are 1.5 times the interquartile range (i.e., difference between 75th and 25th percentile) from the 75th percentile (top whisker) and 1.5 times the interquartile range from the 25th percentile (bottom whisker); horizontal tick gray line within the box is the median; black empty circle is the 98th percentile. The results from the trend and change-point analyses are shown only if the corresponding p-value ≤ 0.1 (*see* Section C.1 for the definition of p-value) or the confidence in the sharp change ≥ 85% (*see* Appendix A for more details). In this case, a solid red line describes the trend and a dashed vertical line describes the point when the sharp change occurred (black if the confidence is ≥85% and red if ≥90%).



6. Wind and Dust Emissions

Wind is one of the main factors affecting PM_{10} levels in the atmosphere. In a very simplified manner, the stronger the wind, the more dust will be transferred into the air and transported for longer distances, while less will be deposited back to the ground surface. This is even more important in an area like Pahrump, where the pre-Action Plan emission inventory showed that a very large fraction of PM_{10} emissions originated from disturbed vacant land.

In order to better understand the effect of wind intensity on PM_{10} concentrations in Pahrump, the analysis presented in the previous section was repeated but with the recorded PM_{10} concentrations further disaggregated into four wind speed classes (as measured by the meteorological station) according to the quartile distribution of the aggregated datasets from 2004 to 2011 (i.e., 25^{th}, 50^{th}, and 75^{th} percentiles equal to 1.69, 2.46, and 3.69 meters per second (m/s) respectively) (Figure 12, Figure 13 and Figure 14). In this section, only the results obtained using the annual median of the daily PM_{10} concentration distribution are shown (*see* Section Appendix A for more details).

Figure 12: Manse Station. Trend and change-point analysis for annual daily average PM_{10} distributions disaggregated by wind speed quartiles. Each year distribution is shown using a boxplot-style representation. The gray box identifies the 25th and 75th percentiles (bottom and top, respectively); the whiskers include points that are 1.5 times the interquartile range (i.e., difference between 75th and 25th percentile) from the 75th percentile (top whisker) and 1.5 times the interquartile range from the 25th percentile (bottom whisker); The horizontal tick gray line within the box is the median; the black open circle is the 98th percentile. The results from the trend and change-point analyses are shown only if the corresponding p-value ≤ 0.1 (*see* Section C.1 for the definition of p-value) or the confidence in the sharp change ≥ 85% (*see* Appendix A for more details). In this case, a solid red line describes the trend and a dashed vertical line describes the point when the sharp change occurred (black if the confidence is ≥85% and red if ≥90%).

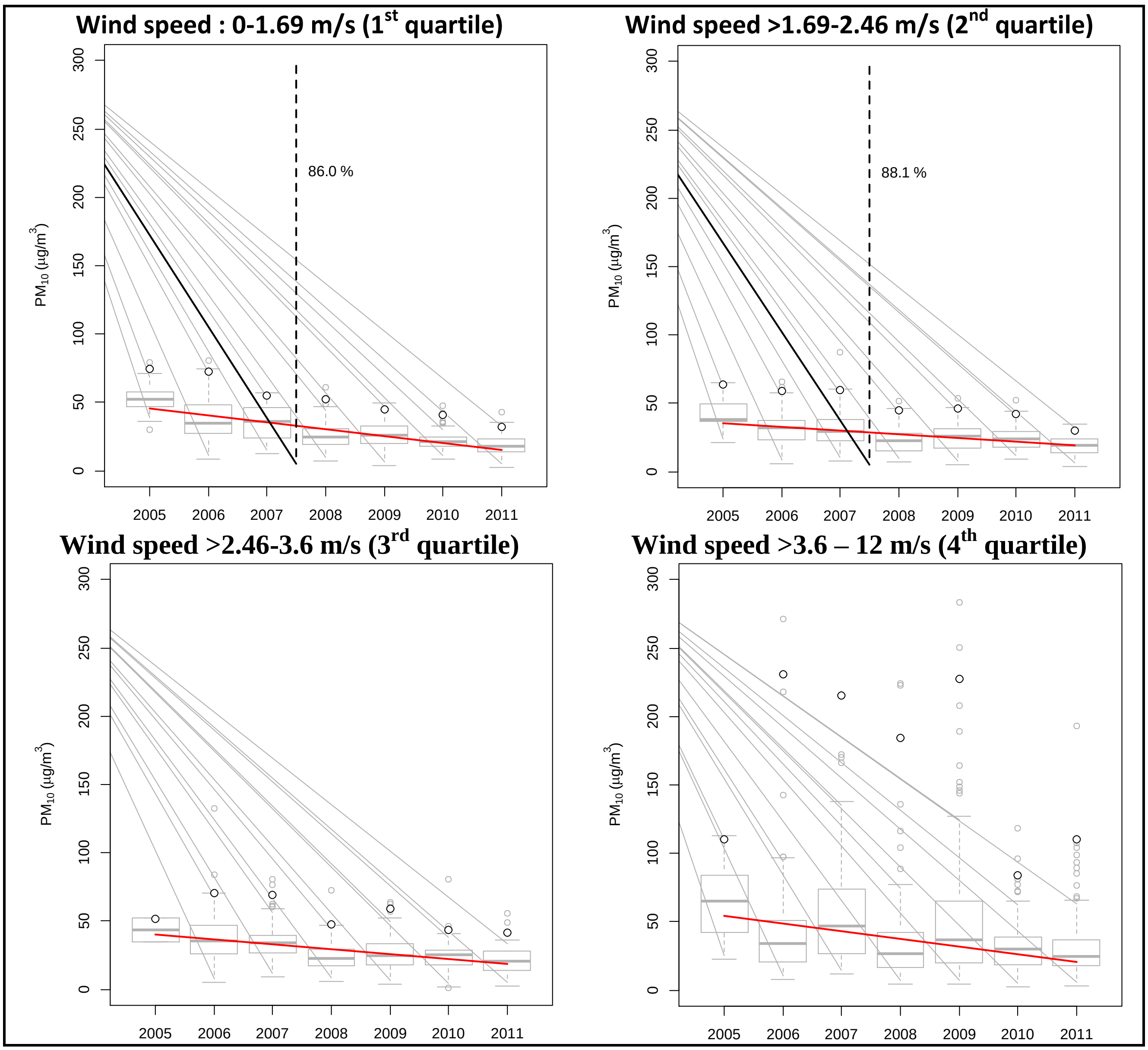


Figure 13: Church Station

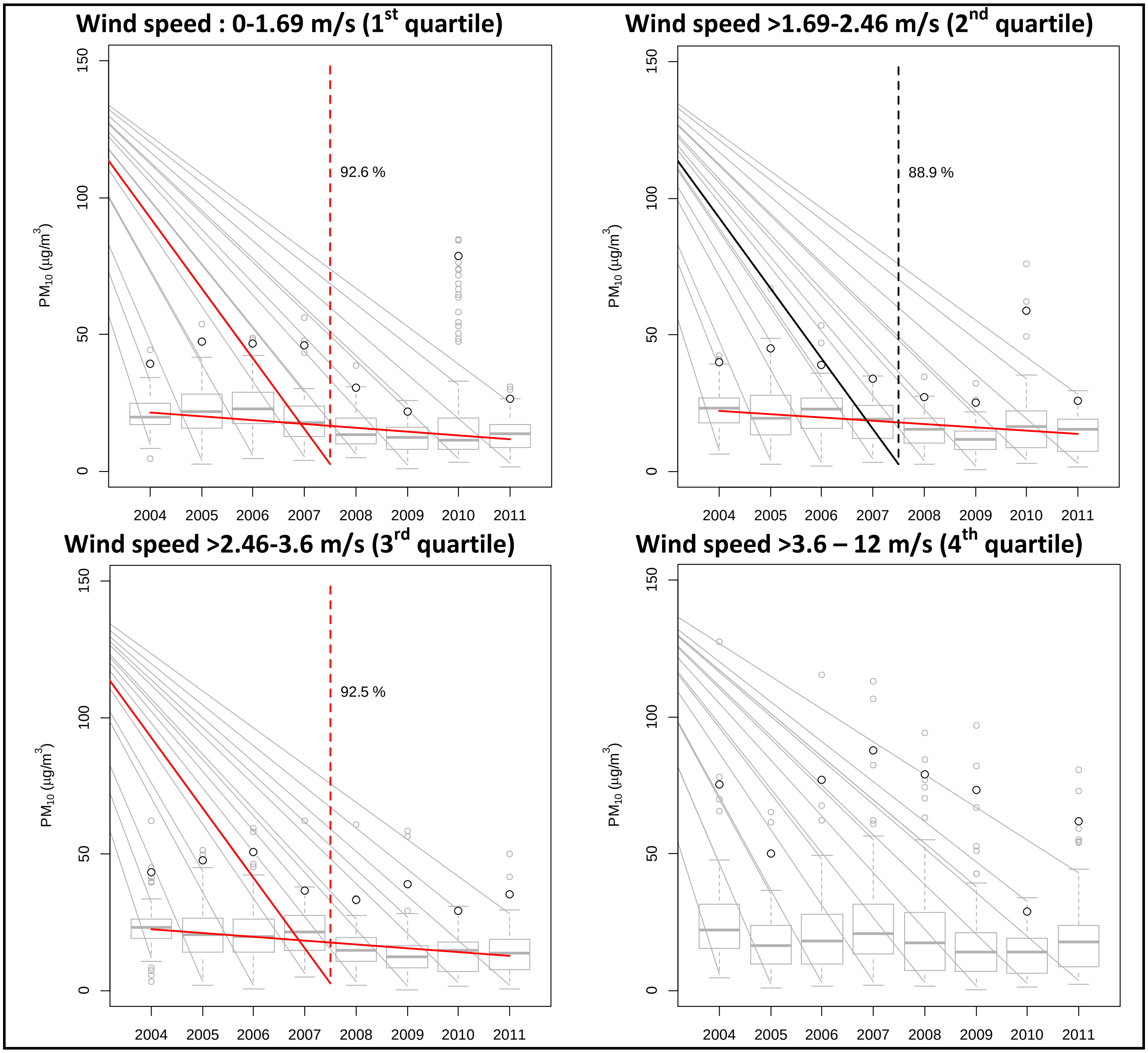
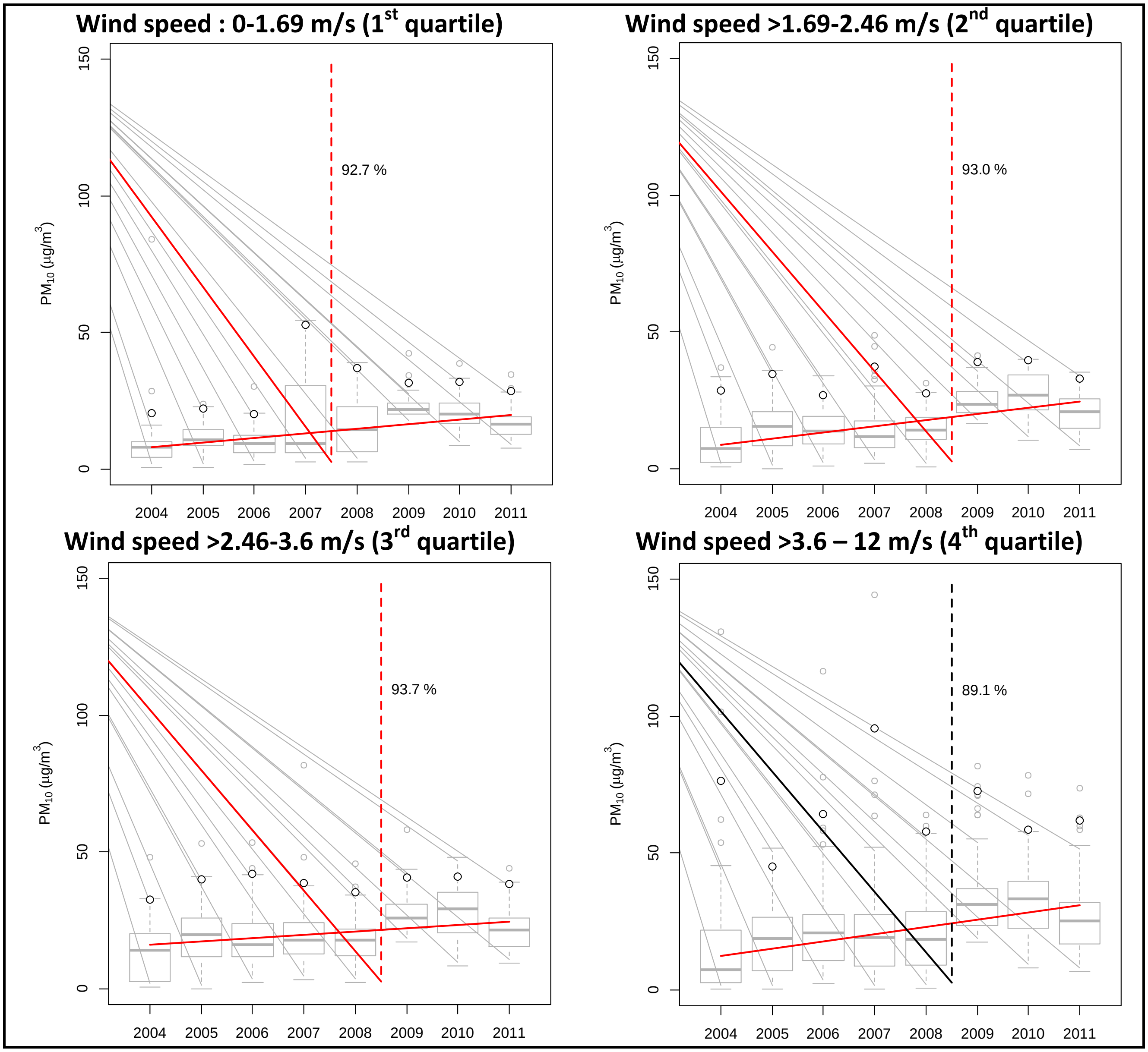


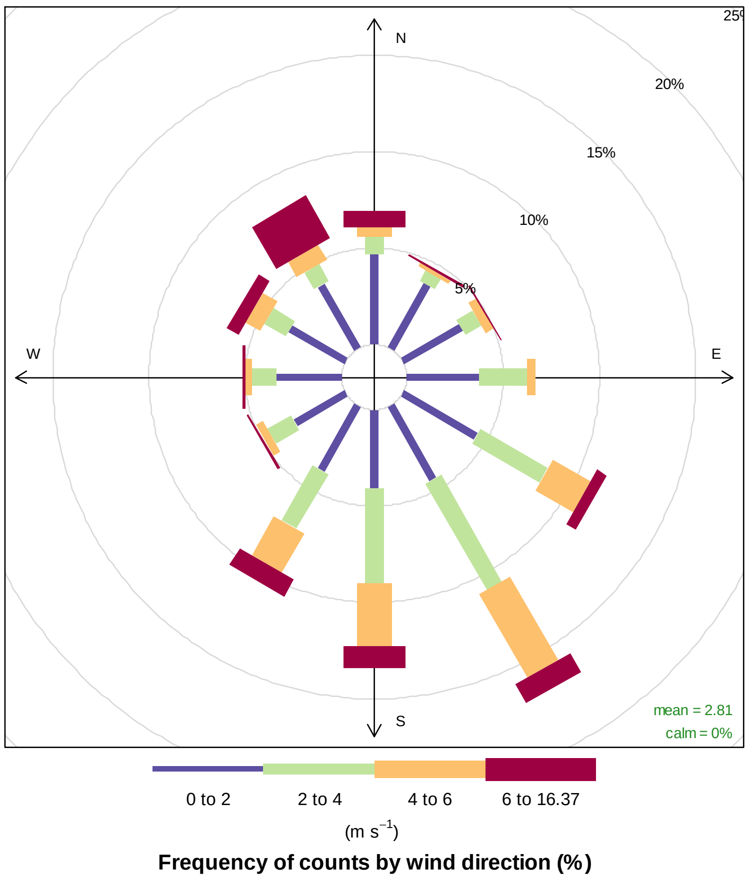
Figure 14: Linda Station



Results in each wind speed class are somewhat similar to the results obtained with aggregated data (*see* previous section), but differences emerge at high wind speeds. Data from the Manse station show a declining trend in PM_{10} concentrations for all wind classes. Evidence of a sharp decline is confirmed (with a confidence ≥ 86 percent) for low-to-medium wind speeds. Data from the Church station shows a declining trend in PM_{10} in the first three wind speed classes (i.e., up to 3.6 m/s). No trend is detected in the class with the highest wind speeds. Similarly, sharp changes in the decline of PM_{10} concentration are detected between 2007 and 2008 (confidence ≥90 percent) in all wind classes but the highest. The Linda station was somewhat different. The analysis of the data from the Linda station substantially confirmed what was already found with the aggregated dataset, with increasing trends in PM_{10} concentration in all wind speed classes and evidence for a sharp change between 2008 and 2009, but a potential decrease after 2010 (*see* Appendix D).

Figure 15 shows the wind-rose as calculated using aggregated hourly values of wind speed and direction recorded by the meteorological station from 2004 to 2011. The predominant wind direction is from south southeast, which is characterized by medium-to-high wind speeds (i.e., 2 to 6 m/s or approximately 4 to 13 mph). However, high winds (i.e., stronger than 6 m/s or 13 mph) are predominantly from the northwest.

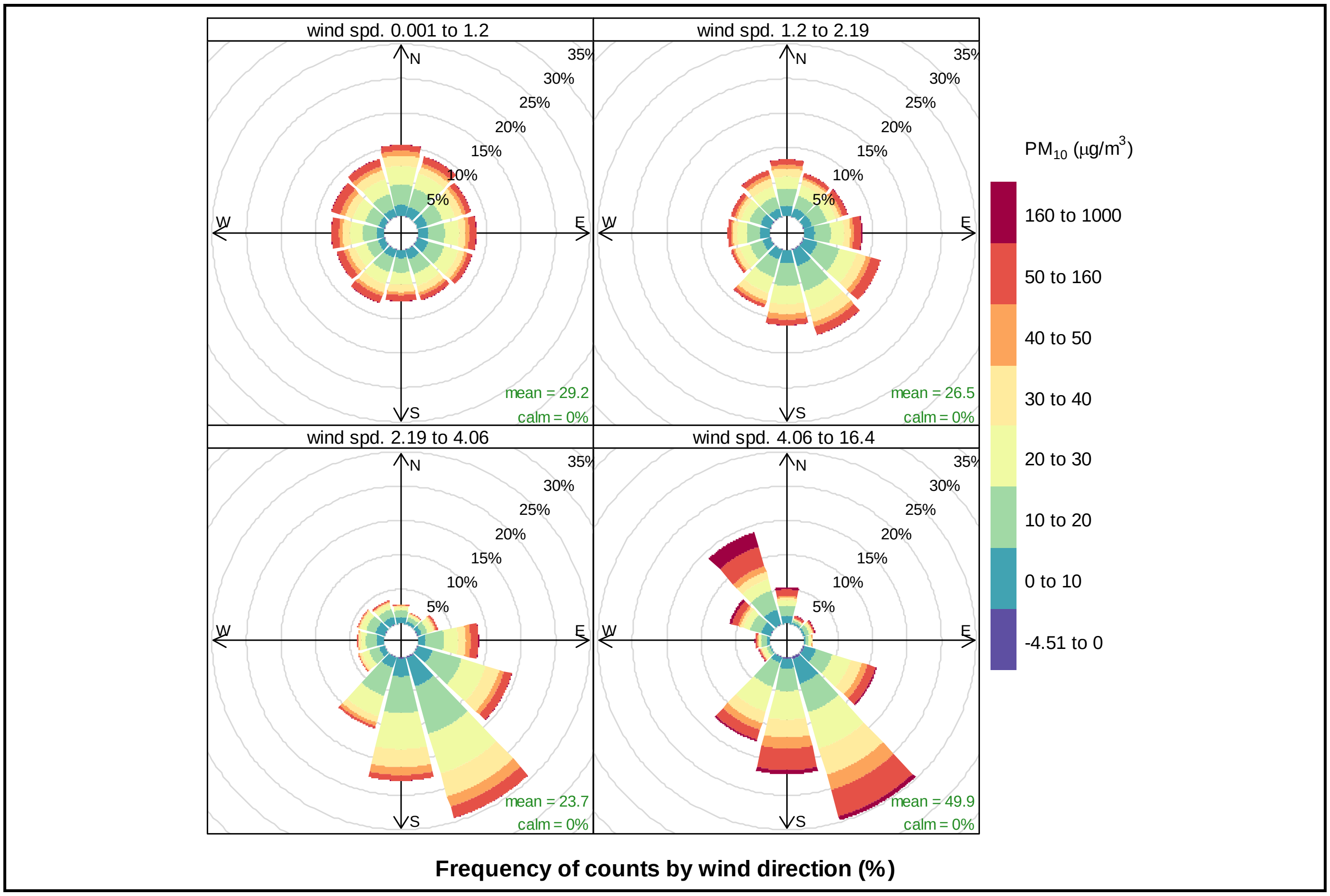
Figure 15: Wind-rose calculated using hourly values of wind speed and direction recorded by the meteorological station in Pahrump from 2004 to 2011.



A pollution-rose links together wind direction and observed concentration of pollutant (PM_{10} in this case). If wind records are further disaggregated by wind speed, useful indications of the potential origin of pollutant sources can be derived. Such analysis was performed using hourly records of wind speed and direction, and hourly PM_{10} concentrations from all three monitor stations. In this section, only the results from the Manse station are shown (Figure 16), as the other two stations did not substantially differ in their behavior (*see* Appendix B for details on the approach and more results).

At low wind speeds (e.g., less than 1.2 m/s or approximately 3 mph) there is no preferential wind direction and recorded PM_{10} concentration, suggesting that nearby sources are equally affecting the measurements. As wind speed increases (from 1.2 m/s, or 3 mph, up to about 4 m/s or 9 mph), a clear directionality in the wind begins to appear (as shown in the aggregated wind-rose as well, Figure 15). Predominant winds are coming now from the south southeast; however, no specific direction shows substantial differences in PM_{10} concentrations, which remain below the very high concentrations recorded by the monitor (e.g., below 160 µg/m^3). At high wind speeds (i.e., higher than 4.06 m/s or 9 mph), although the prevalent wind direction is still from the south southeast, there is now a significant northwesterly component. High concentrations are associated with the northwesterly direction, suggesting a potential high source of PM_{10} in the northwest.

Figure 16: Pollution-rose for Manse station. Hourly PM_{10} concentrations from 2005 to 2011 were further disaggregated into wind speed classes (in meters per second, corresponding to the quartiles of the aggregate distribution). Each pollution-rose shows the distribution of the recorded PM_{10} concentrations for each wind direction (30° angle step). Mean is the mean PM_{10} concentration for that particular wind speed class. Wind speed was not filtered for calms in this analysis; hence the 'calm' percentage is always 0 percent.



7. Conclusions

The results presented in this report clearly show significant reductions of PM_{10} emissions in the Pahrump Regional Planning District during the period 2001 to 2010. Emissions from the main sources of PM_{10} (disturbed vacant land and unpaved roads) substantially decreased as a result of the controls put in place by the MOU and Action Plan. The reduction in disturbed vacant land of about 80 percent (in favor of stabilized land) yielded an estimated reduction in PM_{10} emissions of approximately 70 percent (*see* Section Fugitive Dust from Land Erosion). The paving of a large portion of local and arterial roads yielded a reduction in emissions of about 40 percent (*see* Section 4.2).

The monitoring data demonstrate substantial improvement in air quality during the same period. Pahrump reached the goal of the MOU and Action Plan, attaining the 24-hour PM_{10} NAAQS well before December 31, 2009. Table 7 presents the design values for the 24-hour PM_{10} data between 2001 and 2012 with exceptional events removed.[15] The design value has been below the NAAQS since 2005. Further confirmation of the air quality improvement comes from the trend analysis performed on the monitoring data for the 2004-2011 period (*see* Section Monitoring Data). For the two stations that measure PM_{10} concentrations within the Pahrump urban area, significant downward trends in PM_{10} concentrations were found for low to moderate wind speed.

The data and the analyses presented in this report unequivocally demonstrate that air quality in the Pahrump Regional Planning District has substantially improved to a level below the national standards. Particulate matter emissions due to anthropogenic activities have declined substantially. This is due to the synergic collaboration among local, state and federal agencies, which together were able to identify the primary emission sources and implement mitigation measures to reduce emissions. As a result, the agencies were able to achieve significant improvements in air quality in a much shorter timeframe through an informal process than if the area had been designated nonattainment. Working together, the agencies were able to swiftly and significantly improve air quality in the Pahrump Regional Planning District.

[15] See supra n.13.

Appendix A: PM_{10} Fugitive Emissions from Vacant Land

A.1 Emissions Factors

Fugitive PM_{10} emissions from vacant land were estimated using the same approach described in the Action Plan. Emission factor methodologies from the Clark County Wind Tunnel Study[11]were used to calculate wind erosion emissions from vacant land (disturbed and stabilized) and native desert. Fugitive dust emissions from vacant land are largely driven by shear stress imparted by wind to the surface, which creates entrainment when the fluid forces exceed the effects of the weight of the particle and cohesion between adjacent particles.[16] A critical value of wind shear velocity is required to initiate grain movement. Once the wind shear velocity is reached, an initial spike in emissions typically is observed. Sustained wind above the threshold causes further dust emissions until the entrainment thresholds, which are constrained by surface moisture content, cohesion, vegetation or other non-erodible roughness elements, are no longer met. Different types of land are characterized by different environmental controls on entrainment thresholds.

Disturbed Vacant Land

The methodology derived from the Clark County Wind Tunnel Study uses simplifying assumptions of wind speed and dust reservoir. It assumes that an initial wind speed threshold of 20 mph is required to initiate the erosion process, and an emission spike is associated with the first hour of wind above the threshold. The dust reservoir is assumed to be infinite, but each day is assumed to represent a single wind event with no recharge of the reservoir. Therefore, emissions after the initial spike continue until the wind speed falls below the threshold or the day ends.

Wind Speed Category (mph)	*Spike emission factor (ton/acre)*	*Sustained wind emission factor (ton/acre/hour)*
20.0-24.9	0.000816	0.00521
25.0-29.9	0.00194	0.00640
30.0-34.9	0.00141	0.00462
35.0-39.9	0.00380	0.00705

Native Desert

The initial wind speed threshold is assumed to be 25 mph. The dust reservoir is assumed to deplete in the first hour, with no recharge until the next calendar day.

Wind Speed Category (mph)	*Spike emission factor (ton/acre)*	*Sustained wind emission factor (ton/acre/hour)*
25.0-29.9	0.000490	0.00257
30.0-34.9	0.000588	0.00316
35.0-39.9	0.000924	0.00299

[16] Lancaster, et. al. *Field Studies of the Potential for Wind Transport of Plutonium-Contaminated Soils at Sites in Areas 6 and 11, Nevada Test Site* at 3 (July 1995), Desert Research Institute, Publication #45136.

Stabilized Vacant Land

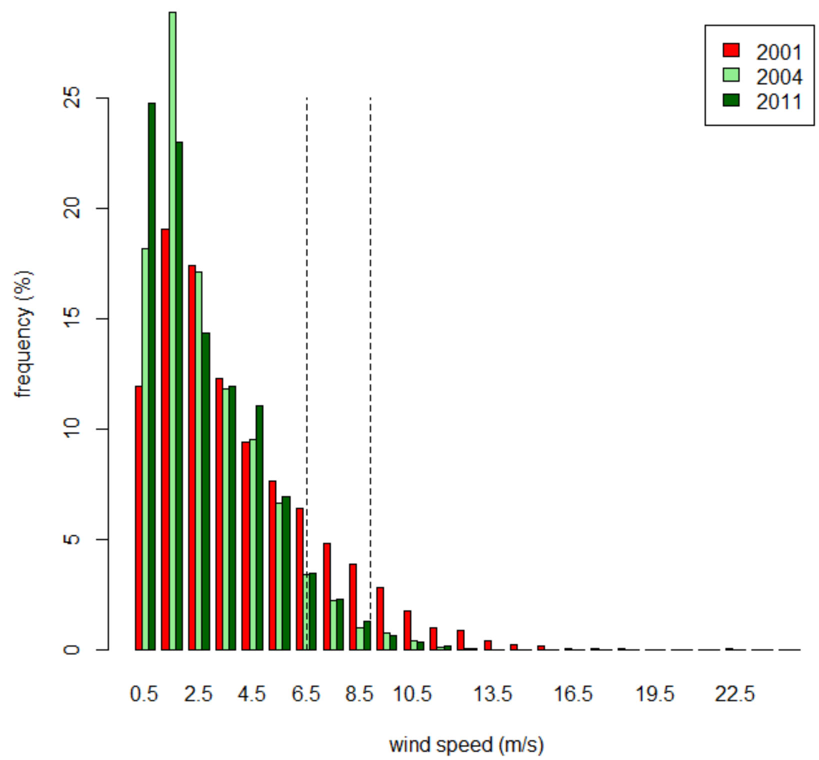
The initial wind speed threshold is 15 mph. As for the native desert land, the dust reservoir is assumed to be depleted in the first hour of sustained wind; however, there is no emission spike in this hour.

Wind Speed Category (mph)	*Spike emission factor (ton/acre/hour)*	*Sustained wind emission factor (ton/acre/hour)*
15.0-19.9	0	0.00042
20.0-24.9	0	0.00034
25.0-39.9	0	0.00019

A.2 Wind Speed Data

Wind speed data used in the Pahrump Action Plan were obtained from the 2001 readings of the anemometer co-located with the pool monitoring station in Pahrump. The meteorological data from this station were discontinued in 2004 because a better equipped and permanent meteorological station (sited and equipped according to EPA recommendation and serviced by regular independent audits) was built on a location at about 240 meters north-northwest of the original location. A brief analysis of wind speed distribution from both stations revealed that readings are not comparable for the purpose of this analysis. Wind speed measurements at the 'pool station' (data from 2001) are characterized by the presence of higher and more frequent wind speeds than the measurements at the current meteorological station. This difference is critical because high wind speeds are assumed to drive erosion and dust formation from land surfaces. Because of this difference between meteorological stations, only records from the current meteorological station in Pahrump were used in this analysis.

Figure 17: Frequency distributions of wind speeds at the 'pool station' (2001) and current meteorological station (2004 and 2011) in Pahrump. The vertical dashed lines approximately mark wind speed of 20 and 25 mph. Overall, the 'pool station' is characterized by higher and more frequent wind speed than the current meteorological station. Because of this, wind speed records from the two stations were deemed not comparable.



A.3 Emissions

Data from the current meteorological station (i.e., from 2004 to 2012) were used to characterize the intra-annual variability in wind speed by assuming that no significant long-term changes in wind speed distribution occurred in this period. For each year, PM_{10} emissions were calculated using both the pre- and post-Action Plan land surface distributions. This provided a more robust estimate of the fugitive PM_{10} emissions due to land erosion, their variability over nine years, and a more precise estimate of the difference in emissions due to the changes in land surfaces. Table 8 reports the estimated annual emissions from 2004 to 2011, using the relocated meteorological station, and the emissions estimated using the 2001 data from the original 'Pool' station. For each year, emissions were calculated using both pre- and post-Action Plan land surface surveys.

Table 8: Annual PM_{10} emissions as estimated using annual wind speed datasets from the meteorological station in Pahrump and land surface distribution in 2004 and 2011. The results from the analysis presented in the Pahrump Action Plan (using met data from the 'pool station' are shown as reference).

Meteorology	*Emissions as per Land Surface 2004 (tons/year)*				*Emissions as per Land Surface 2011 (tons/year)*			
	total	disturbed	desert	stabilized	total	disturbed	desert	stabilized
Pool Station 2001 (Action Plan)	67,545	60,263	4,029	3,253	20,866	11,818	4,271	4,778
Met Station 2004	15,427	13,955	186	1,286	4,823	2,737	197	1,889
Met Station 2005	10,427	9,377	0	1,050	3,381	1,839	0	1,542
Met Station 2006	16,219	14,907	0	1,312	4,851	2,923	0	1,927
Met Station 2007	26,363	24,796	207	1,361	7,081	4,862	219	1,999
Met Station 2008	22,679	21,149	279	1,252	6,281	4,147	296	1,838
Met Station 2009	18,748	17,198	186	1,364	5,572	3,373	197	2,003
Met Station 2010	15,799	14,529	93	1,178	4,677	2,849	99	1,729
Met Station 2011	13,843	12,595	0	1,249	4,304	2,470	0	1,834
Mean from Met Station ± Standard Deviation	17,438 ± 3,505	16,063 ± 3,398	119 ±77	1,256 ±72	5,121 ±805	3,150 ±666	126 ±81	1,845 ±106

Appendix B: PM_{10} Fugitive Emissions from Mobile Sources

B.1 Emissions Factors

Emission factors for fugitive emissions from mobile sources were estimated using the currently recommended equations in the EPA Compilation of Air Pollutant Emission Factors (AP-42), 5th Edition, Chapter 13: Miscellaneous Sources (Nov. 2006).

For unpaved roads, the emission factors (lb/VMT) were calculated as

$$E = \frac{k \left(\frac{s}{12}\right)^{1.0} \cdot \left(\frac{S}{30}\right)^{0.5}}{\left(\frac{M}{0.5}\right)^{0.2}} - C$$

Where

- E: size-specific emission factor (lb/VMT)
- k : empirical constant, used as a particle size multiplier and to obtain units of lb/VMT, set to 0.0022 for all types of roads.
- s: surface material silt content (%), set to 16% for both arterial and local roads as from the Pahrump Action Plan 2006
- S: mean vehicle speed (mph), set to 25 mph for both arterial and local roads
- M: surface material moisture content (%), set to 0.2 % as from the Pahrump Action Plan.
- C: emission factor for 1980's vehicle fleet exhaust, brake wear and tire wear (lb/VMT), set to 0.00047 lb/VMT as from the AP-42, 5th Edition.

For paved roads, the emissions factors (lb/VMT) were calculated as

$$E = k(sL)^{0.91} \cdot W^{1.02}$$

Where

- E: size-specific emission factor (lb/VMT)
- k : empirical constant, used as a particle size multiplier and to obtain units of lb/VMT, set to 0.0022 for all types of roads
- sL: road surface silt loading (g/m2), set to 1.34 for highways and 24.7 for both arterial and local roads (Pahrump Action Plan).
- W: average weight (tons) of the vehicles traveling the roads, set to 3 tons as for Pahrump Action Plan 2006.

B.2 Road Length

Road type and surface were originally surveyed in 2003 for the Action Plan and a second survey was conducted in 2011 to mark differences between the years. Both datasets were digitized and geo-referenced using GIS software (ArcMap v. 10.0, ESRI), providing the length for each road.

The total length of the road network in the Pahrump Town Boundary did not substantially change between 2003 and 2011 (less than 10%). No significant changes in the total length were recorded in the highway and arterial types (less than 2%), but local roads extended 70 miles longer in 2011 (increase of about 7%). The relative proportion of paved roads to unpaved roads changed substantially between 2003 and 2011. In 2003, 69% of all road mileage was unpaved; in 2011, that percentage had decreased to only 47% of the total mileage being unpaved.

Table 9: length (in miles) for each type of road in 2003 (pre-Action Plan) and 2011 (post-Action Plan).

Road Type	*2004*			*2011*		
	All	Paved	Unpaved	All	Paved	Unpaved
Highway	24.1	24.1	0	24.0	24.0	0
Arterial	84.2	62.8	21.4	85.6	76.3	9.3
Local	1006.9	254.5	752.4	1080.6	530.8	549.8
Total	1115.2	341.4	773.8	1190.2	631.1	559.1

AADT for highways and arterial roads for 2011 were obtained from Nevada Department of Transportation. The average AADT for arterials (1,500 vehicles/day for pre-Action Plan and 1,110 vehicles/day for post-Action Plan) was used for arterial roads that did not have direct estimates. Daily traffic volume for local roads was obtained through a survey conducted in 2011. The average AADT from this survey (46 vehicles/day) was used for all the local roads that did not have direct observations. VMT were calculated extrapolating the observed daily traffic volume to the entire year and by using the length (in miles) of each road surveyed in Pahrump. VMT from the Action Plan were used to re-calculate emissions from 2003 on-road mobile sources.

B.3 Relative Contribution of Different Factors Affecting Fugitive Dust Emission

In order to assess the effects of the implementation of the dust reduction policy, four major factors need to be considered:

1. Change in road conditions (e.g., from unpaved to paved)
2. Change in vehicle velocity (e.g., change in speed limits)
3. Change in traffic volume (e.g., more or less cars)
4. Change in road network extent (e.g., more or less roads)

While all of these four factors can cause changes in fugitive PM_{10} mobile emissions, only the first two can be directly linked to dust reduction policies. Because not enough information was available to assess actual vehicle velocity, this analysis solely focused on the effect on road conditions, assuming no change in vehicle speed pre-Action Plan and post-Action Plan.

The contribution of the other three major factors (i.e., road conditions, traffic volume and road network length) was estimated by using the following scenarios:

1. Estimate of PM_{10} emissions from fugitive mobile sources for road conditions (*Rc*) and traffic volume (*Tv*) as surveyed pre-Action Plan (hereafter, *RcTvPre).*
2. Estimate of PM_{10} emissions from fugitive mobile sources for road conditions and traffic volume as surveyed post-Action Plan (hereafter, *RcTvPost*).

3. Estimate of PM_{10} emissions from fugitive mobile sources for traffic volume as surveyed pre-Action Plan but for road conditions as surveyed post-Action Plan (thereafter, *RcPostTvPre*).

The difference in emission between *RcTvPost* and *RcTvPre* is attributable to changes in road conditions, traffic, and road length.

$$RcTvPost - RcTcPre = f(road\ conditions, traffic, road\ extent)$$

The difference between *RcPostTvPre* and *RcTvPre* is attributable to changes in road conditions and road extent.

$$RcPostTvPre - RcTvPre = f(road\ conditions, road\ extent)$$

Finally, the difference between *RcPostTvPre* and *RcTvPost* is only attributable to changes in traffic.

$$RcPostTvPre - RcTvPost = f(\ traffic)$$

The change in emissions between pre-Action Plan and post-Action Plan due to road length was estimated by assuming that the only changes occurred at local road level. This is a fair assumption, considering that the difference in highway-arterial combined miles between 2011 and 2003 was about 1%. Between 2003 and 2011, a total of about 73 miles were added to the local road network of Pahrump. By using the paved to unpaved ratio for local roads in 2011 (i.e. about 50% paved vs. unpaved), the 2011 AADT (46 vehicle/day), and the emission factors from the above described emission factor equations, the total contribution of the new roads resulted in 844 tons/year (806 tons/year from new unpaved local roads and 38 tons/years from new paved local roads).

Once the contribution of change in road length to change in emissions between pre- and post-Action Plan is determined, it is possible to estimate the contribution of the change in road conditions and traffic.

Appendix C: PM10 Concentration Trend and Wind Speed/Direction Analyses

C.1 PM_{10} Concentration Analysis Trend

Potential changes in PM_{10} monitored concentrations were investigated using two different approaches:

Mann-Kendall

This analysis provides statistical evidence for a gradual and linear change in concentrations over the period of time considered (i.e., trend analysis). This analysis is considered more robust than the standard linear regression, as it is less sensitive to outliers. A p-value of 0.1 was used in this analysis as a threshold for rejecting the null hypothesis that there is no linear trend. The p-value provides an estimate of how the analyzed data *'support'* the null hypothesis. Low p-values (i.e., close to zero) may indicate that the actual data do not support the null hypothesis, leading to its rejection. Likewise, high p-values (i.e. close to one) may indicate that the data support the null hypothesis, which should not be rejected. The choice of the p-value threshold is somewhat arbitrary, but it is customary to use values of 0.05 (or lower) for critical applications (i.e., medical fields) and 0.1 for less critical applications.

Sen's Slope

This analysis estimates the slope of the linear trend. As for the Mann-Kendall approach, the Sen's slope is considered more robust to outliers.

Change-Point

This analysis identifies the presence of significant changes in the time-series. A significant change is defined as a positive or negative 'step' that causes the mean of the data points before to be significantly different from the mean of the data points following the change. As for the previous two statistical techniques, it is possible to associate a confidence level to the identified change. Low confidence may indicate that the change did not actually occur; likewise, high confidence may indicate that the change actually occurred. The calculation of the confidence level does not have an analytical form, but rather is performed by a stochastic process (i.e., Monte Carlo simulation). In other words, the confidence level is not determined precisely but has an associated uncertainty. For this reason, even if in this analysis a confidence threshold of 90% was adopted to determine the existence of a change-point, results that have a confidence level of 85% or higher were presented as well. While the change-point analysis will always return a potential point of change, it is through the assessment of its confidence level that reliable conclusions can be drawn.

For each year, the median, mean, 98^{th} percentile, and maximum of the daily average distribution were tested for trends and change-point. The annual distributions of PM_{10} daily averages are characterized by a prominent skewedness, as for instance, exceptional events and high winds increase the likelihood of high PM_{10} concentrations.

Table 10: Results from the trend and change-point analyses. Annual median, maximum, mean, and 98th percentile of the daily PM_{10} daily average distribution were tested from trend and point of change. The reported time of change is the year after the change was determined. Trend slopes and change-point times are reported regardless of their confidence as a reference. However, in order to derive sensible conclusions, it is very important to always associate trend and change-point with their confidence levels.

Station	*Statistics*	*Median*	*Max*	*Mean*	*98th percentile*
Linda	p-value on trend	0.02	0.54	0.01	0.11
	trend (µg m^3 $year^{-1}$)	1.8	-6.0	1.6	1.4
	Change-point confidence	0.90	0.34	0.89	0.36
	Change-point time	2009	2008	2009	2006
Manse	p-value on trend	0.04	0.55	0.02	1.00
	trend (µg m^3 $year^{-1}$)	-3.7	-40.1	-4.7	-1.5
	Change-point confidence	0.82	0.60	0.85	0.36
	Change-point time	2006	2010	2008	2010
Church	p-value on trend	0.02	0.17	0.02	0.54
	trend (µg m^3 $year^{-1}$)	-1.4	-6.9	1.2	1.8
	Change-point confidence	0.88	0.33	0.93	0.00
	Change-point time	2008	2008	2008	2010

To better understand the effect of wind intensity on PM_{10} concentrations in Pahrump, the trend and change-point analyses were repeated but with the recorded PM_{10} concentrations further disaggregated in four wind speed classes (as measured by the meteorological station) according to the quartile distribution of the aggregated datasets from 2004 to 2011 (i.e., 25th, 50th, and 75th percentiles equal to 1.69, 2.46, and 3.69 m/s respectively).

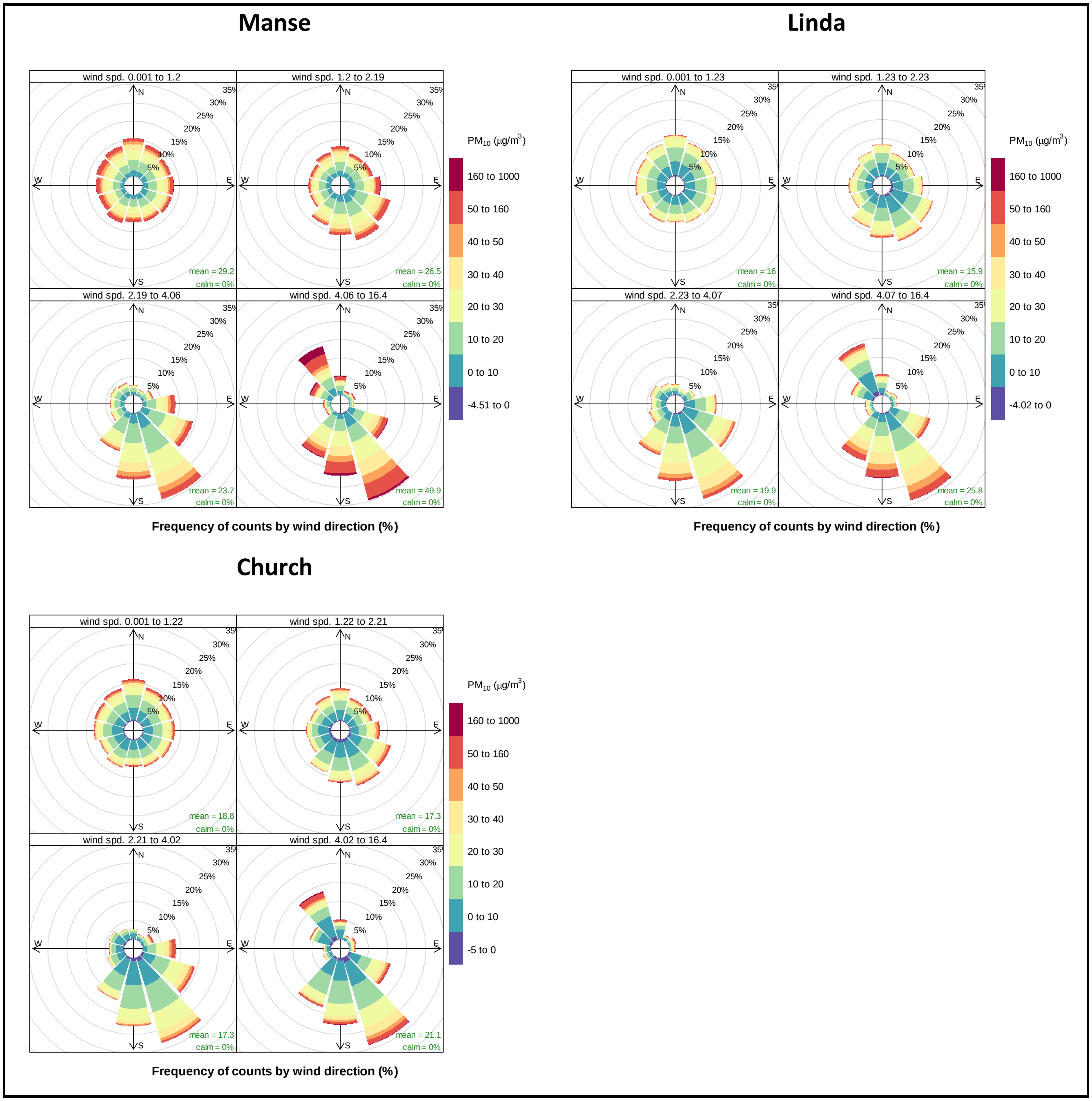
Table 11: Results from the trend and change-point analyses. Annual median, maximum, mean, and 98th percentile of the daily PM_{10} daily average distribution, disaggregated by wind speed classes, were tested from trend and point of change. The reported time of change is the year after the change was determined to have happened. Trend slopes and change-point times are reported regardless of their confidence as a reference. However, in order to derive sensible conclusions, it is very important to always associate trend and change-point with their confidence levels. It is important to note the different meaning of the p-value and the confidence in change-point. Simply stated, the lower the p-value, the higher the likelihood that the trend is real. The change-point confidence reports the confidence on the fact that the change actually occurred; the higher the value, the higher the possibility that the change occurred.

Station	*Wind speed class (m/s)*	*Statistics*	*Median*	*Max*	*Mean*	*98th percentile*
Linda	>0-1.69	Trend (p-value on trend)	1.7 (0.04)	-2.6 (0.71)	1.7 (0.06)	1.4 (0.54)
		Change time (confidence)	2008 (0.88)	2005 (0.08)	2007 (0.87)	2007 (0.91)
	>1.69-2.4	Trend (p-value on trend)	2.2 (0.06)	-0.8 (0.71)	1.8 (0.06)	1.0 (0.27)
		Change time (confidence)	2009 (0.91)	2008 (0.09)	2009 (0.88)	2009 (0.47)
	>2.46 – 3.6	Trend (p-value on trend)	1.2 (0.04)	-0.6 (0.71)	1.2 (0.06)	0.2 (0.71)
		Change time (confidence)	2009 (0.93)	2008 (0.00)	2009 (0.94)	2005 (0.26)
	> 3.6 – 12	Trend (p-value on trend)	2.6 (0.06)	-6.0 (0.54)	2.5 (0.04)	-0.44 (0.90)
		Change time (confidence)	2009 (0.92)	2008 (0.36)	2009 (0.93)	2007 (0.00)
Manse	>0-1.69	Trend (p-value on trend)	-4.6 (0.02)	-6.2 (0.02)	-4.4 (0.01)	-7.0 (<0.01)
		Change time (confidence)	2008 (0.88)	2007 (0.62)	2008 (0.89)	2007 (0.88)
	>1.69-2.46	Trend (p-value on trend)	-2.8 (0.02)	-4.5 (0.13)	-3.0 (0.02)	-4.9 (0.02)
		Change time (confidence)	2008 (0.87)	2008 (0.85)	2008 (0.78)	2008 (0.83)
	>2.46 – 3.6	Trend (p-value on trend)	-3.7 (0.04)	-5.6 (0.55)	-3.5 (0.01)	-2.1 (0.07)
		Change time (confidence)	2008 (0.87)	2006 (0.58)	2008 (0.82)	2010 (0.56)
	> 3.6 – 12	Trend (p-value on trend)	-5.7 (0.07)	-40.1 (0.55)	-4.1 (0.07)	-18.7 (0.55)
		Change time (confidence)	2006 (0.67)	2010 (0.61)	2010 (0.59)	2010 (0.86)
Church	>0-1.69	Trend (p-value on trend)	-1.4 (0.06)	-2.2 (0.71)	-1.4 (0.17)	-1.6 (0.39)
		Change time (confidence)	2008 (0.93)	2011 (0.01)	2007 (0.71)	2010 (0.00)
	>1.69-2.46	Trend (p-value on trend)	-1.2 (0.04)	-1.9 (0.17)	-1.3 (0.02)	-2.3 (0.17)
		Change time (confidence)	2008 (0.94)	2011 (0.24))	2008 (0.93)	2011 (0.28)
	>2.46 – 3.6	Trend (p-value on trend)	-1.4 (0.02)	-1.6 (0.17)	-1.5 (0.06)	-2.2 (0.11)
		Change time (confidence)	2008 (0.92)	2010 (0.79)	2008 (0.93)	2007 (0.88)
	> 3.6 – 12	Trend (p-value on trend)	-0.6 (0.11)	-8.1 (0.17)	-1.0 (0.17)	-2.5 (0.53)
		Change time (confidence)	2009 (0.46)	2010 (0.28)	2009 (0.57)	2010 (0.59)

C.2 Pollution-Rose

The pollution roses presented here describe the frequency of hourly PM_{10} concentrations across different wind directions. In order to analyze the potential effect of wind speed on these distributions, data points were also disaggregated in four classes of wind speed (corresponding to the quartiles of hourly wind speed, i.e., 1.2, 2.19, and 4.6 m/s for 25th, 50th, and 75th percentile, respectively).

Figure 18: Pollution-rose[17] for Manse, Linda, and Church stations. Hourly PM_{10} concentrations from 2005 to 2011 were further disaggregated into wind speed classes (in meters per second, corresponding to the quartiles of the aggregate distribution). Each pollution-rose shows the distribution of the recorded PM_{10} concentrations for each wind direction (30° angle step). Mean is the mean PM_{10} concentration for that particular wind speed class. Wind speed was not filtered for calms in this analysis; hence the 'calm' percentage is always 0%.



[17] Pollution-rose graphs were made using the 'openair' package (version 0.7, http://www.openair-project.org/) for R (version 2.15.2, http://www.r-project.org/).

Appendix D: PM_{10} Trend at Linda Station with the Addition of 2012 and 2013 Observations.

Linda station showed a distinct positive trend in PM_{10} concentrations from 2004 to 2011 (Figure 11 Figure 14). However, this trend seemed mainly driven by increases in concentrations during the years 2009 and 2010, with concentrations in 2011 seemingly returning to pre-2010 levels. In order to identify which trend better describes the observation at Linda station, the same analysis presented in Figure 11 was repeated, but with the addition of PM_{10} observations taken in 2012 and 2013. The results demonstrate that when these years are added, there is no significant trend in PM_{10} concentrations at Linda station. The change-point analysis shifts from 2008-2009 to 2007-2008 with the addition of the years 2012 and 2013. This is expected, as the effect of the high mean concentrations in 2009 and 2010 and gradual decline in the following years creates a difference in mean concentration between the 2004-2007 and 2008-2013 periods. At this time, the reason for the increase in concentration in years 2009 and 2010 is not clear. The NDEP and Nye County continue to monitor the station to gain a better understanding of the reasons for both the increase and subsequent decrease. In 2014, the NDEP installed a camera to understand the events driving the monitoring data at this station. The air monitoring data is currently reported in near real-time to the NDEP for careful observation. Finally, the NDEP spoke with Nye County officials about the issues, and they committed to observing the area to better understand the monitoring data.

Figure 19: Trend and change-point analysis for annual daily average distributions for Linda station across the 2004-2013 period. Each year's distribution is shown using a boxplot-style representation. The gray box identifies the 25th and 75th percentiles (bottom and top, respectively); the whiskers include points that are 1.5 times the interquartile range (i.e., difference between 75th and 25th percentile) from the 75th percentile (top whisker) and 1.5 times the interquartile range from the 25th percentile (bottom whisker); horizontal tick gray line within the box is the median; black empty circle is the 98th percentile. The results from the trend and change-point analyses are shown only if the corresponding p-value ≤ 0.1 (*see* Section C.1 for the definition of p-value) or the confidence in the sharp change ≥ 85% (*see* Appendix A for more details). In this case, a solid red line describes the trend and a dashed vertical line describes the point when the sharp change occurred (black if the confidence is ≥85% and red if ≥90%).