

# Development of an Emission Reduction Term for Near-Source Depletion

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## ABSTRACT

Vehicle movement on unpaved surfaces generates significant particulate matter (PM) emissions consisting mostly of fugitive dust. These sources are found in rural areas, on construction sites, at in military training areas. However, localized terrain features, topography, groundcover, wind, and other atmospheric conditions can have significant impact in limiting the portion of PM/dust emissions that are regionally transportable. In particular, recent MRI dust plume profiling tests show that tall vegetation (oak and cedar trees) bordering an emission source captures fugitive dust (PM<sub>10</sub> and PM<sub>2.5</sub>) in the range of 50 percent over a transport distance of 25 m from the source (e.g., unpaved road). These rates significantly exceed the levels represented in standard air plume dispersion models used for regulatory compliance purposes. Accordingly, these compliance models overpredict the PM impacts of military training exercises, typically by a factor of four.

Subsequent to the field tests of tall trees as deposition receptors for fugitive dust, field testing and modeling representation were performed by MRI to assess the effectiveness of tall prairie grass in capturing particulate matter emissions from military training exercises. Field testing was performed in 2005 at Fort Riley, Kansas. The measured PM-10 capture efficiencies on tall grass were in the range of 35 percent over a travel distance of 25 m from the source (training site access road). Once again, the capture efficiencies for the coarse and fine fractions of PM<sub>10</sub> (i.e., particles between 2.5 and 10 microns and particles smaller than 2.5 microns) were in the same range. The types of grasses tested, in addition to the trees previously tested, provide a range of vegetative characteristics that are thought to relate to dust capture efficiency

The desired product of the series of studies described above is a modeling representation of dust capture on vegetation bordering traffic on unpaved surfaces. The modeling representation approximates the observations from on-site testing of dust capture on vegetation in three particle size ranges (PM-30, PM-10 and PM-2.5)<sup>a</sup>. Incorporation of an appropriate particle removal term for pre-processing the emission inventory will improve the accuracy of these models by removing a cause of characteristic over-prediction of the air quality impacts of dust emissions from training activities and other open dust sources.

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• <sup>a</sup> PM-X: Airborne particles with aerodynamic diameters equal to or less than X  $\mu\text{m}$ .

## **INTRODUCTION**

Dust from military training activities is often emitted in close proximity to nearby vegetation that can reduce the plume mass of PM-10 through:

- Deposition on vegetative surfaces by impaction, interception, and diffusion, enhanced by electrostatic attraction and thermophoresis (i.e., migration to leaves cooled by evapotranspiration).
- Enhanced gravitational settling of particles in “stilling zones” where the wind velocity is reduced by the vegetation.

Thus, vegetation that borders a source area offers the potential for significant control of dust

Over the past 30 months under contract to EFDC/CERL, field tests have been conducted by Midwest Research Institute (MRI)<sup>1</sup> to characterize (a) the amount and particle size distribution of PM emissions from unpaved test surfaces used for training exercises, and (b) the mass fraction of PM in two particle size ranges (PM-10 and PM-2.5)—PM-X: airborne particles with aerodynamic diameters equal to or less than X  $\mu\text{m}$ —that is captured by vegetation positioned downwind of the source. To enable this work, a new lightweight plume profiling system that could be deployed in heavily vegetated areas was developed and fabricated in the summer of 2003. The performance of the streamlined plume profiler was tested against the conventional MRI profiler<sup>2</sup> in the fall of 2003. The conventional plume profiler has been used to develop the Environmental Protection Agency (EPA) emission factors for fugitive dust generated by traffic on unpaved surfaces.<sup>3</sup> Vegetative capture of fugitive dust on tall trees bordering training areas at Fort Leonard Wood, Missouri was conducted in the fall of 2003 and the summer of 2004. Testing of the capture of fugitive dust on tall prairie grass was conducted at Ft. Riley, Kansas in July and November of 2005.

This paper describes a modeling representation of dust capture on vegetation bordering fugitive dust sources involving vehicle traffic on unpaved surfaces. Besides vehicle operations found in military training areas, traffic dust sources are the most prevalent fugitive dust sources in the country as a whole. There are a number of options for modeling representation of dust capture on vegetation, each with advantages and disadvantages. These are reviewed in the sections below.

## **ASSISTING THE U.S. ARMY IN SUSTAINABLE RANGE MANAGEMENT**

The Army is undertaking a new Sustainable Range Management Program to expand (and redesign, if necessary) training lands at military facilities throughout the country. The critical role of training has been reestablished as a fundamental component of our successes in Iraq and the ongoing mission of the military for the foreseeable future. It is essential that restrictions in training activities be minimized, so that this component of military combat readiness is enhanced to the maximum degree possible. Urban encroachment and environmental permit conditions are placing significant limits on the current training activity at Army installations.

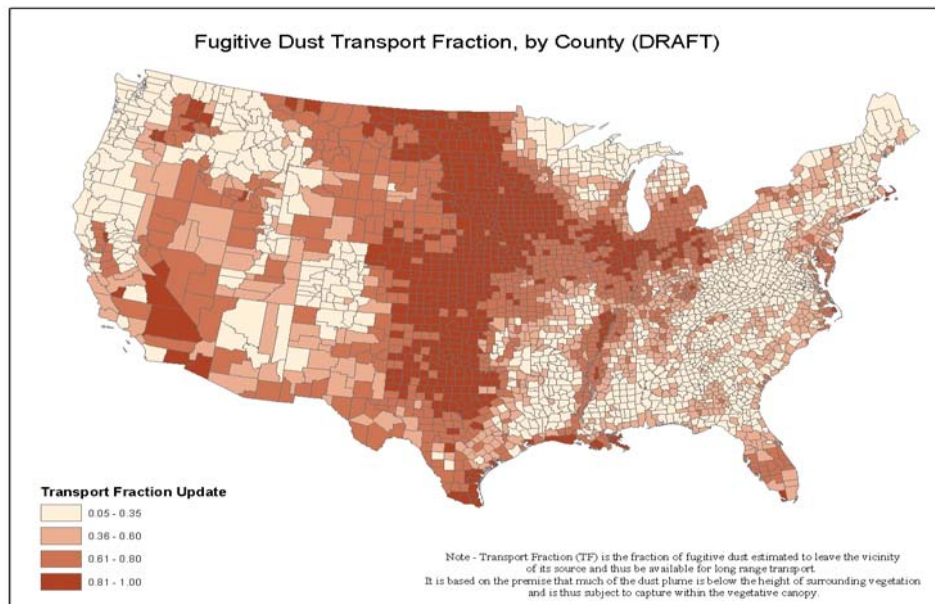
Dust and smoke generated by Army training activities generate significant quantities of PM-10 and PM-2.5 emissions.<sup>4</sup> These emissions, when input to current regulatory dispersion models promulgated by USEPA, often incorrectly predict non-compliance with ambient air quality standards and accompanying violations of permit conditions. Even though monitored values at the property lines of military training installations typically show much smaller than predicted air quality impacts, modeled non-compliance has placed limits on the amount of training that can take place at any point in time.

The field data gathered by MRI to quantify the deposition of PM-10 and PM-2.5 on vegetation around military training facilities, provides a useful input to development of an experimental foundation for development of improved dispersion modeling approaches. Field testing is intended to provide benchmark characterization of the effectiveness of certain major categories of vegetation in the capture of dust generated by vehicular traffic.

## CORRECTING CURRENT REGULATORY DISPERSION MODELS

The problem of overprediction of dust and smoke impacts using regulatory dispersion models is recognized by USEPA’s Office of Air Quality Planning and Standards at Research Triangle Park. This discrepancy of up to a factor of 4 is attributed mostly to inadequate treatment of particle removal mechanisms that apply to dust and smoke.<sup>5</sup> The dominant particle removal mechanisms are believed to be associated with near-source vegetative capture. Over the past three years, MRI has worked with USEPA in studying the theory behind the particle deposition on vegetation. MRI has made use of the Biogenic Emissions Landcover Dataset, which classifies coverage of vegetation in each county into more than 100 categories, while assisting USEPA with the projection of county-level capture efficiencies. (See Figure 1.)

**Figure 1.** County level estimates of vegetative capture efficiencies.



At the same time, USEPA is in the process of exploring new modeling treatments that better account for particle removal mechanisms. Consequently, USEPA is seeking field data on dust and smoke dispersion that can be used as the basis for developing algorithms for observed particle removal effects. MRI’s test results on vegetative capture are providing ground truth data for use in this model development process.

## SUMMARY OF TEST RESULTS

The field data collected by MRI under the sponsorship of the Army Construction Engineering Research Laboratory are shown in Table 1. The data indicate that, in areas bordered by tall grass, substantial amounts (up to 40 percent) of PM-10 in the form of fugitive dust generated by military training exercises are captured over short travel distances (10s of meters) through the vegetation. On tall trees, the capture efficiencies may exceed 50 percent. Moreover, particle-size data indicate that vegetation effectively captures both fine (PM-2.5) and the coarse PM-10 emissions (see Table 2).

**Table 1.** PM-10 plume mass loss (light winds).

Type of Vegetation*	PM-10 Plume Loss
Short grass	< 10%
Tall Grass	35-45%
Tall Cedar Trees	45-67%
Short Cedar Trees	29%
Tall Oak Trees	41-50%

\* Plume loss in trees over 20 m travel distance with light winds (2-4 mph).

**Table 2.** PM-2.5/PM-10 ratios.

	Average Ratio of PM-2.5/PM-10	
	5 m from Road	20 m from Road
Without Trees	0.23	0.24
With Trees	0.26 (upwind of trees)	0.19 (downwind of trees)

Figure 2 shows typical PM-10 exposure (mass flux) profiles obtained for tall grass at Ft. Riley. There is a cross-over point in the profiles because of the lofting of the plume at the 25 m (Tower B) distance, as compared to the plume at the 5 m (Tower A) distance.

**Figure 2.** Typical PM-10 mass flux profiles for tall grass at distances of 5 m and 25 m from the source.

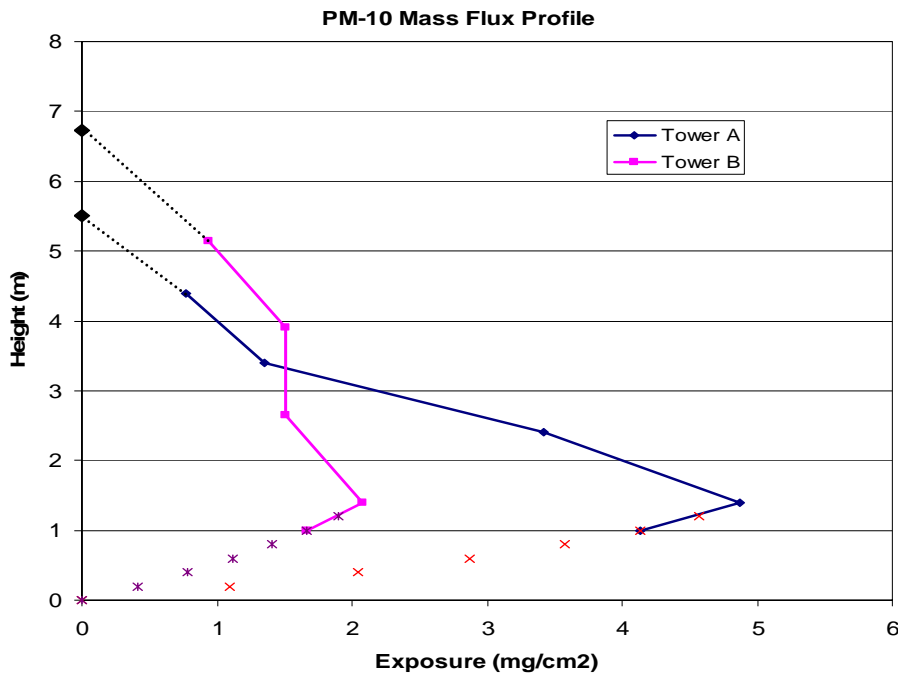
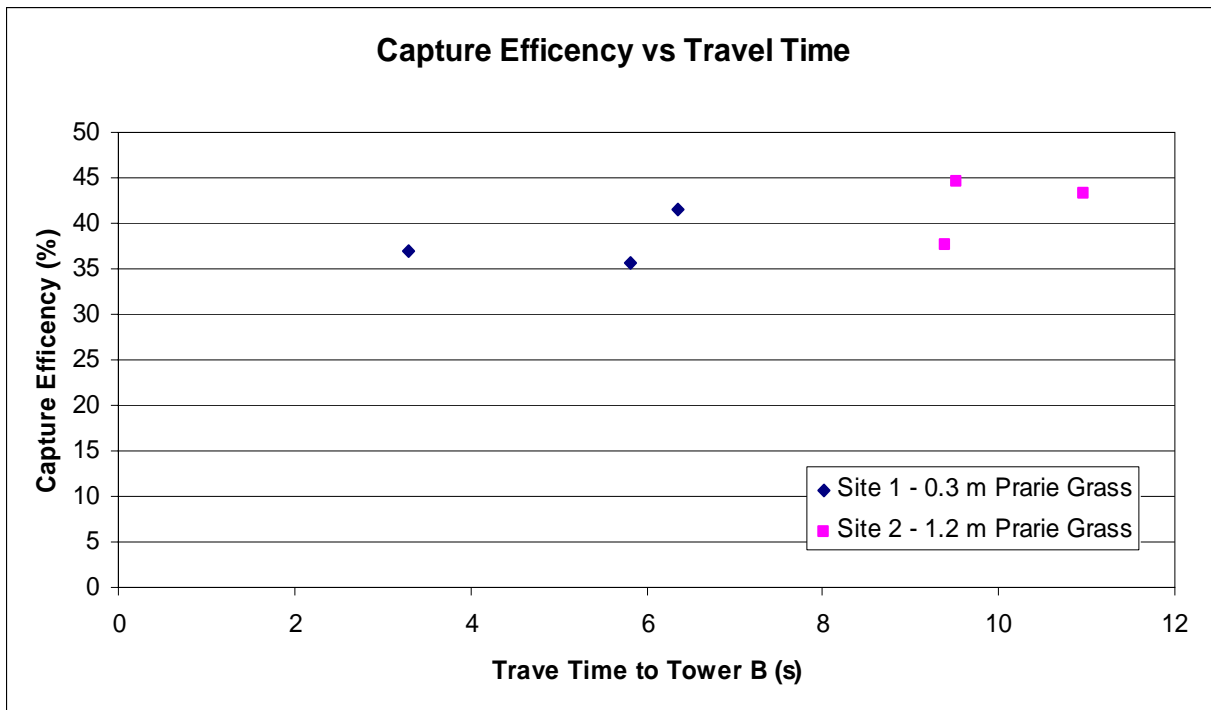


Figure 3 shows the PM-10 capture efficiencies for example tall grass test series from Ft. Riley. Because of differences in wind speed and wind angle in relation to the test road, these results are plotted as a function of travel time based on wind speed at a 3 m height above ground. The capture efficiencies appear to correlate with residence (travel) time across the tall grass.

**Figure 3.** PM-10 capture efficiency vs. travel time across tall grass at Ft. Riley.



The results from tall trees at Fort Leonard Wood, as shown above, are believed to bracket the upper end of the PM-10 capture efficiency over a travel distance of approximately 20 m into the vegetative belt of tall oak trees, for the following reasons. First, the unobstructed winds that carried the road dust into the trees were very light (in the range of 2 to 3 mph at a height of 3 m above ground level). Lower wind speeds provide a longer residence time for a given travel distance as the dust cloud enters the vegetative belt. Second, the height of the oak trees exceeded the dust plume height, so that little if any dust plume mass passed over the trees. Third, the moderate equivalent porosity of the vegetative belt of oak trees (as measured by wind speed reduction at a height of 1.5 m)<sup>1</sup> was ideal for capture of dust particles. If the porosity is too low, high blockage of the wind occurs, and the dust cloud tends to loft as the plume approaches the vegetative belt. Conversely, if the porosity is too high, the leaf area is low and there is less opportunity for deposition of the dust plume on leaf surfaces.

The next series of tests planned for Fort Leonard Wood will be performed in the same driver training area where the earlier results were obtained. If wind directions are appropriate, the same specific test sites will be used again. Tests will be performed under higher wind conditions to test the hypothesis that higher winds produce a lower capture efficiencies for a given travel distance into a vegetative belt of a certain kind of trees.

These test results from Fort Leonard Wood appear to be consistent with those obtained under the prior program that showed an average of about 50 percent capture of PM-10 on tall cedar trees over a 20-m travel distance. Moreover, the capture efficiency was found to be insensitive to particle size. The prior testing occurred at MRI's Deramus Field Station in Grandview, Missouri. Cedar trees were cut down from nearby farmland, and an array of cedar trees was set up in the center of the circular unpaved test track at the Deramus Field Station. The height of the cedar trees was sufficient so that virtually all of

the dust plume mass passed into the tree belt. The wind speeds were in the range of 5 mph, but the leaf area index of the cedar trees was much higher than for the oak trees tested at Fort Leonard Wood.

The combined duplicate tests of dust plume transport across an open field in the center of the test track at MRI's Deramus Field Station show negligible plume loss. In other words, the difference in plume mass at the two test distances from the unpaved road was less than the repeatability of the plume profiling method.

## MODELING REPRESENTATIONS

One of the main purposes of this study is to develop modeling representations of dust capture on vegetation bordering military training areas. This will improve the accuracy of these models by removing a source of characteristic overprediction of the air quality impacts of dust emissions from training activities. This section presents the rationale for a modeling representation of dust capture on vegetation that matches the observations from on-site testing of this phenomenon.

Originally, the approach focused on developing a new algorithm for vegetative capture that can be incorporated into regulatory dispersion models in the plume rather than grid format (ISC/AERMOD). The required features included the following:

- Needs to be Direction-Specific Depletion (similarity to direction-specific building dimensions for building downwash in ISC)
- Depletion Term May Vary over Season of Year
- Approach Already Being Taken by EPA in Upgrading SMOKE (Grid Model)

However, it became clear that an attractive option would take the form of a source reduction term that reduces the emissions based on the type and coverage of vegetation bordering the source. The advantages and disadvantages of each approach are summarized in Table 3.

Option 1 is consistent with the approach taken to represent vegetative capture in grid models. As illustrated in Figure 1 above, default source reduction factors have been developed for every county in the country, based on the prevalence and types of vegetation found. The calculated emissions at the source are multiplied by a "transportability factor" that accounts for the fraction of the emissions that penetrate the near-source vegetative barrier and move into upper transport zones with a potential for regional impact. The data collected in support of assessing military training activities provide the opportunity to go further beyond the "limiting case" analyses that were used in developing the default transportability factors for county by county application.

Under Option 2, any modifications to EPA plume dispersion models must follow a standard protocol. Elements of the protocol include generation of reliable field data on the plume dispersion process, proposal of algorithms to represent the data in modeling components, and response to public comments on the proposed modifications before the model revisions are finalized.

**Table 3.** Options for modeling representation of dust capture on vegetation.

**Option 1: Use of Mitigation Term for Near-Source Deposition Phenomena**

Advantages—

- 1) Source reduction approach does not require any changes to EPA’s workhorse air dispersion models, including ISC and AERMOD
- 2) Near-source deposition zone (50 to 100m) lies within transport distance not normally associated with reliable model predictions.
- 3) Vegetation is placed in the same category as other dust control measures.

Disadvantages—

- 1) Near-source concentrations will be grossly under-predicted.
- 2) A separate model is needed to produce source reduction factors.
  - a) Source reduction model must characterize deposition structures (similar to building downwash)
    - i) Vegetative type, density, and height
    - ii) Location in relation to source
  - b) Reduction model must incorporate dependence on wind direction, unless vegetation that borders source is sufficiently uniform
- 3) May cause confusion over permit fees.

**Option 2: Improved Deposition Algorithms within Dispersion Models**

Advantages—

- 1) Will correctly represent the actual emissions from a source
- 2) Will correctly represent short-distance deposition and dispersion phenomena
- 3) New deposition algorithms may be able to use a resistance formulation in which the deposition velocity is the sum of the resistances to pollutant transfer within the surface layer of the atmosphere, across the laminar sublayer and onto the surface, plus a gravitational settling term (similar to Atmospheric Dispersion Modeling System (ADMS))
- 4) Is consistent with current model algorithms that deal with other particle removal terms (e.g., wet deposition, gravitational settling and dry deposition, downwash)
- 5) More realistic treatment of particle concentrations at short distances, up to 200 m from source
- 6) Mechanism for EPA review and approval exists, including (1) statistical performance measures recommended by the American Meteorological Society and (2) peer scientific reviews.

Disadvantages—

- 1) Requires implementation in EPA’s dispersion models
- 2) Review process for EPA model changes likely to involve lengthy review period, in comparison with that required for emission factor adjustments

A proposed EPA-military workshop should lead to needed improvements in air dispersion models for fugitive dust plumes. It can accomplish this through:

- 1) Better joint understanding of how vegetative capture affects the dispersion and depletion of airborne fugitive dust as it travels downwind
- 2) Coordinated planning of a testing and data validation program to support new algorithms that accurately predict vegetative capture
- 3) Development and implementation of vegetative capture terms to be integrated into both new and existing dispersion models

By incorporating vegetative capture into available plume dispersion models, we can remove much of the over-prediction of the impacts of emissions from a wide variety of fugitive dust sources, including military training activities

## SUMMARY AND CONCLUSIONS

The primary field testing program to measure the capture of unpaved road dust on vegetation adjacent to training areas was conducted at Fort Leonard Wood, Missouri. Oak trees prevail at Fort Leonard Wood, but in certain areas, there are clusters of cedar trees, which are the most common conifer in the state of Missouri.

The MRI data are consistent with the widely observed discrepancies between the actual, measured ambient impact of fugitive dust and the high predictions (nominally represented by a factor of 4) by available atmospheric dispersion models. Such models do not incorporate terms for enhanced deposition of dust particles within trees and other types of groundcover in the path of plume transport. EPA has already undertaken steps to incorporate vegetative capture into grid models for PM (e.g., SMOKE). However, no such activities are under way to incorporate vegetative capture into plume models that can be applied to the localized impact assessment of fugitive dust sources.

The modeling representation for vegetative capture of dust, as developed in this study, effectively brackets the observed test results within the spectrum of possible capture efficiencies. Moreover, it can be used as the basis for a new deposition algorithm for incorporation into regulatory dispersion models.

It is believed that the promising results already obtained, when combined with the expansion of data, will be effective in adding strength to the findings of this study on the magnitude of vegetative capture, based on a breadth and expected consistency of results. Utilization of these data in developing more realistic particle deposition algorithms for dispersion models should add reliability to regulatory modeling by removing the widely observed overprediction of the impacts of military training exercises. Improvements in the realism of EPA's atmospheric dispersion models will add substantially to cost-effectiveness of managing existing training lands and of planning any necessary expansion of ranges to accommodate increased levels of training activity for the future.

Cost-effective range management requires reliable predictive models for determining environmental impacts. Clearly, the tendency of available plume models to substantially over-predict the air-quality impacts of dust sources places an unnecessary restriction on the frequency, duration, and level of activity of certain training exercises. Thus, it is in the best interest of the military planners and the taxpayers who fund them to provide predictive tools that are accurate and reliable.



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## KEY WORDS

Fugitive Dust; Near-Source Depletion; Emission Reduction; Receptor Vegetation